

ANTECEDENTES RECOPIADOS POR EL MMA**1. EFECTOS EN SERES VIVOS**

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2. ANTECEDENTE TÉCNICO

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POSIBLES EFECTOS DE LAS ONDAS ELECTROMAGNÉTICAS UTILIZADAS EN LA TELEFONÍA INALÁMBRICA SOBRE LOS SERES VIVOS

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SUMMARY.—*Possible effects of the electromagnetic waves used in the wireless telephony on wildlife.* A bibliographical revision of the possible effects of the waves used in the wireless telephony on animals is presented and its impact on wild birds is analyzed. After exposing the technical characteristics and the legal situation of this new technology, the scientific discoveries that could have interest for the study of their effects on the wild fauna are revised. Basing us on the current scientific knowledge the foregone possible consequences for the birds is commented, keeping in mind the deterioration of some ecosystems that they occupy. It is recommended to consider the electromagnetic contamination in the microwaves range like a possible factor of decline of some populations in risk, especially of the urban birds, subjected at more radiation levels. Effects on birds in rural and protected areas that have phone masts near cannot be rejected. Keeping in mind that birds are excellent bioindicators, we stick out the importance of carrying out studies that value the effects of this new type of contamination and some methodologies that could be useful for this purpose are presented.

Key words: bioelectromagnetism, bioindicators, electromagnetic contamination, microwaves, non thermal effects, radiofrecuencias, phone masts, wild birds.

RESUMEN.—*Posibles efectos de las ondas electromagnéticas utilizadas en la telefonía inalámbrica sobre los seres vivos.* Se presenta una revisión bibliográfica sobre los efectos de las ondas utilizadas en la telefonía inalámbrica en los seres vivos y se analiza su posible impacto sobre las aves silvestres. Tras exponer las características técnicas y la situación legal de esta nueva tecnología se revisan los hallazgos científicos que pudieran tener interés para el estudio de sus efectos sobre la fauna silvestre. Basándonos en los conocimientos científicos actuales se comentan las posibles consecuencias para las aves, teniendo en cuenta el deterioro reciente de algunos ecosistemas que ocupan. Se recomienda considerar la contaminación electromagnética en el rango de las microondas como un posible factor de declive de algunas poblaciones de riesgo, especialmente de las aves urbanas, expuestas a mayores niveles de radiación. Tampoco pueden descartarse efectos sobre las aves en áreas rurales o protegidas que cuentan con instalaciones próximas. Teniendo en cuenta que las aves pueden ser excelentes bioindicadores, se resalta la importancia de realizar estudios que valoren los efectos de este nuevo tipo de contaminación y se proponen algunas metodologías que se podrán emplear.

Palabras clave: Antenas de telefonía, aves silvestres, bioelectromagnetismo, bioindicadores, contaminación electromagnética, efectos no térmicos, microondas, radiofrecuencias.

INTRODUCCIÓN

El hombre ha utilizado con frecuencia a los seres vivos para detectar posibles alteraciones en los ecosistemas y en su propia esfera vital. Desde los líquenes, muy sensibles a la contaminación por acumular las sustancias tóxicas en sus tejidos, hasta las aves que viven en jardines y edificios, una amplia gama de organismos han servido como indicadores de la salubridad del hábitat humano.

Características físicas y tecnológicas de la telefonía móvil

Las radiaciones electromagnéticas transmiten pequeños paquetes de energía denominados fotones (Aguilar, 2001). Las radiofrecuencias ocupan el rango entre 10 MHz. y 300 GHz. de frecuencia. Las antenas de telefonía móvil lanzan ondas electromagnéticas con una frecuencia portadora de 900 MHz. para el sistema analógico y de 900 MHz. y 1800 MHz. para el

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sistema digital, generalmente conocidas como microondas (rango aproximado entre 1GHz. y 300 GHz.), pulsadas en frecuencias de audio. Las microondas llevan la información sonora por medio de ráfagas o pulsos de corta duración con pequeñas modulaciones de su frecuencia, que se transfieren entre los teléfonos móviles y las estaciones base.

Una antena de un teléfono móvil irradia en todas las direcciones, mientras la antena de una estación base produce una emisión direccional en forma de lóbulo. Además se forman varios lóbulos secundarios, de menor potencia, que se dirigen hacia los lados y la parte de atrás, en las proximidades de la antena. Las estaciones base de telefonía ordinariamente disponen de tres sectores, con tres antenas, que cubren un ángulo de 120 grados cada una (Santini *et al.*, 2000; Hyland, 2000, 2001; Navarro *et al.*, 2003). La frecuencia utilizada en la corriente alterna de uso doméstico (50-60 Hz.) crea un campo electromagnético, inducido y estático (efecto indeseado) que no se proyecta en el espacio, se desvanece a pocos decímetros de la fuente y desaparece cuando la fuente de energía se desconecta (electrodomésticos de uso cotidiano, cables y transformadores). Por el contrario las antenas de telefonía emiten radiaciones de microondas que viajan alejándose de la fuente, continúan existiendo aunque la fuente se desconecte (Aguilar, 2001) y pueden llegar hasta treinta kilómetros de distancia.

Para una dirección concreta con respecto a la antena, la densidad de potencia en un punto varía de forma inversamente proporcional al cuadrado de la distancia a la fuente emisora. A una distancia de 50 metros de una antena de telefonía la densidad de potencia es de unos 10 $\mu\text{W}/\text{cm}^2$ (Santini *et al.*, 2000), mientras a distancias de 100 metros a nivel del suelo se puede medir todavía por encima de 1 $\mu\text{W}/\text{cm}^2$ (*obs. pers.*). Entre 150 y 200 metros, la densidad de potencia del lóbulo principal cerca del suelo es típicamente de unas décimas de $\mu\text{W}/\text{cm}^2$ (Hyland, 2000). Por encima de 0,1 $\mu\text{W}/\text{cm}^2$ se han sugerido efectos biológicos. La densidad de potencia supera ampliamente este valor en las zonas situadas a menos de 300 metros de las antenas (Haumann *et al.*, 2002).

Las variables utilizadas para medir estas radiaciones son la Densidad de Potencia (medida en Vatios por metro cuadrado: W/m^2 , o en $\mu\text{W}/\text{cm}^2$), que expresa la potencia radiante que

incide perpendicularmente a una superficie, dividida por el área de la superficie. La Intensidad de Campo Eléctrico en un punto (medido en Voltios por metro: V/m), que es una cantidad vectorial proporcional a la fuerza ejercida sobre una partícula cargada, depende de su posición en el espacio. También se utiliza la Intensidad Resistencia de Campo Magnético, medida en amperios por metro (A/m), y la Densidad del Flujo Magnético, medida en Teslas (T). Para medir los efectos de las emisiones electromagnéticas sobre los tejidos se utiliza la Tasa o Índice de Adsorción Específica, más conocida como SAR (Specific Energy Absorption Rate), que se define como el índice en que la energía es absorbida por unidad de masa de tejido corporal y se mide en Vatios por kilogramo (W/kg). La unidad SAR se ha estandarizado a partir del calentamiento que se produce en un modelo artificial (una masa de plástico esférica llena de una solución salina) inanimado y homogéneo, carente de las propiedades que caracterizan a los seres vivos.

Previamente al despliegue de la telefonía inalámbrica, las emisiones ondulatorias existentes en el rango de las radiofrecuencias tenían su origen en las antenas de radio y televisión, normalmente instaladas a gran altura o alejadas de los núcleos de población. Desde la segunda mitad de los años 90 del pasado siglo se ha realizado el despliegue de la red de estaciones base de telefonía, que ha incrementado en varios órdenes de magnitud la contaminación electromagnética, especialmente en las ciudades, pero también en el campo, cerca de los núcleos rurales y las infraestructuras viarias (*obs. pers.*). Actualmente se están investigando nuevos tipos de antenas para reducir la potencia necesaria para establecer la comunicación (Cooper & Goldberg, 1996; Cooper, 2003).

Mecanismos de actuación sobre los sistemas biológicos

Uno de los efectos más conocidos de las microondas es su capacidad para poner en resonancia las moléculas de agua (dipolos) y otros componentes de los alimentos, provocando una elevación de su temperatura. El grado de calentamiento resultante depende de la intensidad de la radiación y del tiempo de exposición. Para potencias radiantes por encima de 500 $\mu\text{W}/\text{cm}^2$

se producen efectos medibles de calentamiento de los tejidos (hornos microondas), mientras por debajo de ese nivel los efectos se denominan «no térmicos».

La respuesta de un sistema biológico a un campo electromagnético depende de las propiedades intrínsecas del sistema, de las características del campo externo incidente (especialmente de su potencia radiante y su frecuencia), y del medio en el cual se produce el fenómeno (Lin, 1994). Los animales son complejos electroquímicos muy sensibles, que se comunican con su medio a través de impulsos eléctricos. En ellos existen corrientes iónicas y diferencias de potencial eléctrico a través de las membranas celulares y de los fluidos corporales, tanto intra como extracelulares (Heredia-Rojas *et al.*, 2003). Los campos electromagnéticos generados en las estructuras biológicas, están caracterizados por determinadas frecuencias específicas, que pueden verse interferidas por la radiación electromagnética incidente, provocando una inducción y modificando su respuesta (Smith, 1989; Hyland, 2000, 2001). Algunos órganos o sistemas como el cerebro, el corazón y el sistema nervioso, son especialmente sensibles a estas inducciones. Por ejemplo, varios autores han notificado que la baja frecuencia de los pulsos del sistema GSM interfiere con las ondas cerebrales provocando ondas delta, patológicas en personas despiertas (Kramarenko, 2003; Marino *et al.*, 2003).

Los sistemas ondulatorios tienen propiedades, como la frecuencia, que puede afectar por el efecto de resonancia a la capacidad de un organismo vivo para absorber la energía de un campo electromagnético irradiante (Hyland, 2000). Las estructuras biológicas pueden entrar en resonancia con frecuencias concretas, cuando su tamaño se aproxima a la mitad de la longitud de la onda incidente. La radiación de microondas pulsantes de baja intensidad, como las empleadas en la telefonía inalámbrica, puede ejercer influencias en los organismos vivos, porque las longitudes de onda de los sistemas celulares de telefonía (12 a 37 cm.) caen en el rango de tamaño de las estructuras biológicas y por tanto, son capaces de provocar respuestas. La energía absorbida puede ser suficiente para provocar sutiles cambios conformacionales de la arquitectura molecular, provocando alteraciones bioquímicas por alteración de la actividad enzimática (Daniells *et al.*, 1998). Existen

«ventanas de frecuencia» en las que los campos electromagnéticos pueden inducir efectos biológicos (Adey, 1981). Incluso algunos efectos pueden manifestarse a una frecuencia concreta exclusivamente en un rango de intensidades, o después de una cierta duración de la irradiación (Hyland, 1998).

Los seres vivos están expuestos a niveles variables de campos electromagnéticos de radiofrecuencias, según la distancia de las antenas emisoras, la presencia de reemisores pasivos capaces de reflejar las ondas (estructuras metálicas) o de amortiguarlas (edificios), el número de comunicaciones de la estación y su posición con relación a la orientación de la antena (Santini *et al.*, 2000). Hay que tener en cuenta además las características técnicas de la antena, su potencia y ganancia, su altura respecto al suelo, la orientación de haz emisor principal (anchura vertical y horizontal), la localización de los lóbulos secundarios, la altura a la que se encuentra el ser vivo y la topografía local.

Existen normativas internas específicas muy estrictas para los trabajadores que realizan las labores de mantenimiento de las antenas de telefonía, que no pueden permanecer más de seis minutos en las proximidades de una antena en funcionamiento. En las áreas de uso público la influencia térmica de la radiación (calentamiento de los tejidos) por las microondas puede ser descartada, pero no ocurre lo mismo con los efectos no térmicos. La libertad de movimiento de las aves y su costumbre de posarse en las cercanías e incluso sobre las propias estaciones base les hace potencialmente vulnerables a efectos tanto térmicos como no térmicos.

Las microondas tienen el potencial para inducir reacciones adversas para la salud de las personas (Hyland, 2000, 2001; Santini *et al.*, 2002, 2003a, 2003b; Navarro *et al.*, 2003) y para la fauna que vive en las proximidades de las antenas emisoras (Balmori, 2003). Los organismos pequeños son especialmente sensibles, tanto por aproximarse su tamaño a la frecuencia de resonancia, como por el menor espesor de su cráneo, que facilita una mayor penetración de la radiación en el cerebro (Santini, 2000; Hyland, 2001; Maisch, 2003; Balmori, 2003). No se conoce todavía con certeza qué aspecto de la radiación electromagnética es el más importante a la hora de provocar un efecto sobre la salud de un ser vivo en la naturaleza, si el nivel medio de exposición diario,

las exposiciones por encima de cierto valor umbral, o simplemente las variaciones de los campos a los que se le somete (Bardasano & Elorrieta, 2000). Para niveles de potencia por debajo de los recomendados en la conferencia de Salzburgo ($0,1 \mu\text{W}/\text{cm}^2$) todavía no se han notificado efectos adversos para la salud. Al alejarnos a más de 300 metros de distancia de las antenas emisoras disminuyen o desaparecen la mayoría de los síntomas notificados en personas (Santini, 2003b).

Situación legal

La Unión Europea en su Recomendación 1999/519/CE (DOCE, 1999), adoptó los niveles de referencia propuestos por la Comisión Internacional para la Protección de las Radiaciones no Ionizantes (ICNIRP) (límite de exposición aceptado para los seres vivos), que son de $450 \mu\text{W}/\text{cm}^2$ para el sistema GSM (900 MHz.) y de $900 \mu\text{W}/\text{cm}^2$ para el DCS (1800 MHz.) (ICNIRP, 1998). La norma vigente en España (Real Decreto Ministerio Presidencia 1066/2001) (BOE, 2001), adoptó los criterios de la Recomendación Europea.

A pesar de la evidencia experimental de la existencia de respuestas biológicas a niveles inferiores, las restricciones propuestas por el ICNIRP (1998) protegen exclusivamente de los efectos térmicos a corto plazo. Por esta razón algunos países han adoptado sus propios niveles de referencia, acogiendo al «Principio de Precaución». Italia, en un decreto de 1998, adoptó un límite de potencia de exposición de $10 \mu\text{W}/\text{cm}^2$ para GSM (900 MHz.) igual que Hungría, Bulgaria y Polonia. China tiene un límite de $6,6 \mu\text{W}/\text{cm}^2$. Rusia, Suiza, Luxemburgo y Valonia (Bélgica) de $2,4 \mu\text{W}/\text{cm}^2$. Salzburgo (Austria) de $0,1 \mu\text{W}/\text{cm}^2$ y Nueva Gales del Sur (Nueva Zelanda) de $0,001 \mu\text{W}/\text{cm}^2$ (Santini, 2000; Balmori, 2003).

Es importante mencionar aquí que con niveles de $0,1 \text{pW}/\text{cm}^2$ se consigue oficialmente una comunicación exitosa, apta para los requerimientos de cobertura del sistema (Haumann *et al.*, 2002). Esto quiere decir que con niveles de densidad de potencia (de exposición) 4.500 millones de veces más bajos que los autorizados en la actualidad en España, existe suficiente cobertura para que un teléfono móvil funcione.

REVISIÓN DE LOS EFECTOS DE LAS MICROONDAS SOBRE LOS SERES VIVOS.

Desde hace más de 30 años, existe una evidencia creciente de la existencia de efectos biológicos sobre los seres vivos por debajo de los niveles legales (efectos a niveles de potencia en los que no tiene lugar un calentamiento de los tejidos). En el campo de investigación del bioelectromagnetismo, los experimentos se realizan con animales o tejidos vivos, que se someten a las radiaciones emitidas por un teléfono móvil u otra fuente de radiación de microondas durante un cierto tiempo, tomando nota de los posibles efectos. Al finalizar la exposición a las radiaciones se realizan necropsias y análisis de tejidos, células o moléculas. Aunque se ha investigado con una gran variedad de seres vivos, los resultados encontrados en vertebrados tienen especial interés para poder valorar los efectos previsible sobre las aves.

Existen trabajos que no han encontrado efectos observables en los seres vivos, pero otros muchos estudios alertan del peligro de este tipo de radiación, ya que puede interferir con el sistema nervioso y alterar numerosos procesos biológicos (Hyland, 2000, 2001). Existen estudios que muestran cómo los animales expuestos padecen un deterioro de su salud en la vejez de las antenas emisoras (*e.g.* Marks *et al.*, 1995) y algunos de los efectos no térmicos de las microondas sobre las aves se conocen desde hace más de 35 años (Tanner, 1966; Tanner *et al.*, 1967).

En invertebrados sometidos a microondas se ha notificado un incremento de la síntesis de las llamadas «proteínas del estrés», que se sintetizan generalmente cuando las células están expuestas a condiciones ambientales adversas. Este efecto de los campos electromagnéticos ha sido denominado shock no térmico y se obtuvo por exposición de nematodos durante la noche a niveles de radiación inferiores a los autorizados legalmente en España ($\text{SAR} = 0,001 \text{W}/\text{Kg}$.) (De Pomerai *et al.*, 2000) y por exposición de *Drosophyla* durante 10 días a la radiación de un teléfono móvil ($\text{SAR}=1,4 \text{W}/\text{Kg}$) (Weisbrot *et al.*, 2003). Por esta razón los autores sugieren que los límites legales de exposición de los seres vivos deben ser reconsiderados. Otros trabajos no encuentran inducción de proteínas del estrés exponiendo células durante 2 horas a 2.450 MHz. ($\text{SAR} = 25 \text{W}/\text{Kg}$) y a 27

MHz. (SAR = 100 W/Kg; Cleary *et al.*, 1997). La oscilación de la conformación tridimensional de las enzimas, en organismos vivos sometidos a esta radiación, puede afectar a la velocidad de los procesos bioquímicos. Por ejemplo, se ha descrito un incremento de la actividad de la Ornitina Descarboxilasa (Paulraj *et al.*, 1999), tras exponer ratas a una frecuencia de 112 MHz., modulada a 16 Hz., con una potencia de 1 mW/cm² (SAR = 0,75 W/kg.) durante 35 días.

Las ondas electromagnéticas del rango de las radiofrecuencias pueden afectar a la comunicación intercelular y al funcionamiento de los canales de calcio (Dutta *et al.*, 1989) produciendo, por ejemplo, un aumento del flujo de calcio en el cerebro de las ratas expuestas a una frecuencia de 112 MHz., modulada a 16 Hz. con una potencia de 1 mW/cm² (SAR = 0,75 W/kg.) durante 35 días (Paulraj *et al.*, 1999). Otros autores no obtuvieron efectos relevantes sobre la variación en la concentración de calcio intracelular en células cardíacas expuestas a portadoras de 900, 1.300 y 1.800 moduladas a 217 Hz., con un SAR de 1mW/kg., durante 500 segundos (Wolke *et al.*, 1996). También se han descrito interferencias con los procesos inmunitarios en ratones expuestos a frecuencias de microondas en el rango de 8,15-18 GHz. con una densidad de potencia de 1 microW/cm² (Novoselova & Fesenko, 1998). Se han notificado daños en los cromosomas y aneuploidía en linfocitos humanos expuestos a señales emitidas por teléfonos celulares (Mashevich *et al.*, 2003). Algunos autores no han encontrado efectos en linfocitos (Antonopoulos *et al.*, 1997) ni en células de mamíferos expuestas a una radiación de 2.450 MHz. de frecuencia (SAR = 0,7-1,9 W/kg.) durante 2, 4 y 24 horas (Malyapa *et al.*, 1997). Otros trabajos han encontrado efectos genéticos de la microondas sobre hámsters sometidos a radiación de microondas, con una frecuencia de 7,7 GHz y 0,5 mW/cm² de potencia, durante 15, 30 y 60 minutos (Garaj-Vrhovac *et al.*, 1991). El significativo incremento de los micronúcleos en los eritrocitos del ganado que pasta cerca de los transmisores se ha interpretado como un indicio del efecto genotóxico de su exposición (Balode, 1996). También se han observado micronúcleos y una alteración de la división mitótica en trabajadores expuestos a microondas (Garaj-Vrhovac, 1999).

Existe amplia disparidad a la hora de presentar las radiofrecuencias usadas en telefonía móvil como agentes causales de la aparición de tumores. Mientras unos estudios han notificado un aumento del riesgo de padecer tumores cerebrales por los usuarios de teléfonos móviles (Hardell *et al.*, 2002), otros autores no encuentran efectos de las radiofrecuencias en la promoción tumoral (Higashikubo *et al.*, 1999). Se han observado cambios en la proliferación celular como un efecto de la exposición a la señal del sistema GSM a 960 MHz. (Velizarov *et al.*, 1999). Se ha notificado una disminución de la supervivencia de niños con leucemia cerca de antenas de televisión (Hocking & Gordon, 2000), y una reducción significativa del riesgo de leucemia al aumentar la distancia a antenas de televisión (Hocking *et al.*, 1996) o de radio (Michelozzi *et al.*, 1998). En la actualidad los investigadores se decantan por la opinión de que los campos electromagnéticos podrían actuar más bien como promotores que como iniciadores del cáncer; favoreciendo su desarrollo más que induciéndolo directamente (Heredia-Rojas *et al.*, 2003). Recientemente (junio, 2001), el comité de expertos convocado por la Agencia Internacional de Investigación del Cáncer incluyó los campos electromagnéticos de muy baja frecuencia (los de uso cotidiano de 50-60 Hz.) en la Clasificación de Sustancias Carcinogénicas dentro de la categoría de «posible carcinógeno en humanos» (grupo 2B).

Los campos electromagnéticos de alta frecuencia pueden alterar los sistemas nervioso y endocrino. Se han observado efectos de las microondas emitidas por los teléfonos celulares sobre el sistema nervioso (Khudnitskii *et al.*, 1999; Petrides, 2000) y sobre la función cognitiva (Kolvisto *et al.*, 2000), así como sobre el sueño (Mann & Roschke, 1996) y la respuesta eléctrica cerebral (EEG) (Eulitz *et al.*, 1998; Marino *et al.*, 2003). Estas ondas pueden provocar cefaleas y otras alteraciones del sistema nervioso en humanos (Altpeter *et al.*, 1995). Los conejos que se expusieron a una radiación de microondas de 1,5 GHz. de frecuencia con una potencia de 0,3 mW/cm² mostraron efectos en el hipocampo, pero no en el resto del cerebro estudiado (Grigoriev *et al.*, 1995a). Otros autores no encontraron efectos en el sistema nervioso central (Urban *et al.*, 1998), ni alteraciones del electroencefalograma (EEG) o el sueño (Roschke & Mann, 1997).

Radiaciones de microondas de 1,5 GHz. de frecuencia, con pulsos de 16 ms. de duración y 0,3 mW/cm² de potencia, en sesiones de 30 minutos al día durante un mes, produjeron desadaptación, ansiedad y alarma en conejos (Grigoriev *et al.*, 1995b). Los animales de granja, expuestos a la radiación de antenas próximas, mostraron problemas de salud y conspicuos comportamientos aberrantes, que desaparecieron al alejarse de las antenas (Löscher & Käs, 1998). Se ha notificado un déficit de atención junto con trastornos de la función motora, la memoria y el tiempo de reacción en niños que vivieron en las proximidades de una estación de radar (Kolodynski & Kolodynska, 1996) y se ha advertido sobre los posibles riesgos que puede tener la radiación de los teléfonos celulares en el aprendizaje en humanos (Mann & Roschke, 1996), aunque otros estudios no han encontrado efectos en el aprendizaje de las ratas (Sienkiewicz *et al.*, 2000).

La glándula pineal responde a la exposición a determinados campos electromagnéticos con una reducción de la síntesis de melatonina (Olcese, 1990). El descenso de la melatonina puede alterar los ritmos circadianos y favorecer la aparición de depresiones y procesos tumorales (Bardasano & Elorrieta, 2000). Algunos trabajos notifican una disminución de la producción de melatonina en las personas que utilizan teléfonos móviles (Burch *et al.*, 1997). Mientras que otros estudios no encuentran efectos sobre los niveles de melatonina en mamíferos expuestos a las radiaciones utilizadas en telefonía móvil (Vollrath *et al.*, 1997).

Existen estudios que muestran un incremento de la presión arterial y cambios en el ritmo cardíaco de personas laboralmente expuestas a radiofrecuencias (Szmigielski *et al.*, 1998). Aunque otros autores no encuentran efectos en el ritmo cardíaco de personas expuestas a teléfonos celulares mientras duermen (Mann *et al.*, 1998). Algunos trabajos concluyen que los campos electromagnéticos emitidos por las antenas y los teléfonos móviles pueden favorecer la permeabilidad de la barrera hematoencefálica y permitir la entrada de sustancias perjudiciales al cerebro, que dañan las neuronas de las ratas (Salford *et al.*, 2003). Pero otros no encuentran efectos sobre esta barrera fisiológica (Tsurita *et al.*, 2000). También se ha señalado la posibilidad de que los dolores de cabeza, relatados por usuarios de teléfonos móviles,

puedan estar relacionados con este efecto (Frey, 1998).

Se han notificado efectos sobre el sistema urogenital, observándose cambios histológicos y un reducido desarrollo de los túbulos en los testículos de ratas, cuando fueron mantenidas en gran proximidad de teléfonos móviles funcionando (Dasdag *et al.*, 1999). Los mismos autores no encuentran efectos en un estudio posterior (Dasdag *et al.*, 2003). Un estudio griego realizado cerca de un grupo de antenas de radio y televisión (Magras & Xenos, 1997), muestra un progresivo decrecimiento en el número de nacimientos de roedores. Los ratones expuestos a una potencia de 0.168 µW/cm² se volvieron estériles tras cinco generaciones, mientras los expuestos a 1.053 µW/cm² alcanzaron la esterilidad después de tres generaciones. Los niveles de radiación de este estudio actualmente se superan en España en los alrededores de las antenas de telefonía y afectan a una gran superficie territorial, tanto en los núcleos de población como en el campo (*obs. pers.*), por lo que podrían afectar a la reproducción de algunas aves silvestres (Balmori, 2003). Se ha obtenido un aumento de la velocidad del ciclo larvario en nematodos expuestos a radiaciones de 750 MHz. de frecuencia, a una densidad de potencia de 0,5 W/m² (De Pomerai *et al.*, 1999). Otros estudios no encuentran efectos sobre los embriones de rata expuestas durante 36 horas a radiofrecuencias en un rango de entre 60 y 600 V/m de intensidad de campo (Klug *et al.*, 1997).

La enfermedad de las radiofrecuencias o «síndrome de microondas» es una realidad médica, bastante desconocida, provocada por la exposición a estas ondas (Johnson-Liakouris, 1998; Navarro *et al.*, 2003). Abarca un conjunto de síntomas comunes (dolor de cabeza, fatiga, irritabilidad, pérdida de apetito, trastornos del sueño, depresión, etc.), que se han notificado en estudios epidemiológicos realizados sobre personas que viven en las proximidades de las estaciones base de telefonía. Su aparición aumenta de forma estadísticamente significativa al disminuir la distancia a la fuente emisora (Santini *et al.*, 2001, 2002, 2003a, 2003b) y su severidad está directamente relacionada con la densidad de potencia medida en cada domicilio (Navarro *et al.*, 2003). Estos mismos síntomas se han notificado también en usuarios de teléfonos móviles (Frey,

1998). En un estudio encargado por el gobierno holandés, para valorar el impacto de las antenas de la tercera generación de móviles (UMTS) sobre la salud de las personas (Zwamborn *et al.*, 2003), se encontraron efectos significativos sobre las funciones cognitivas y el bienestar a niveles muy bajos (1 V/m) de Intensidad de Campo.

INVESTIGACIONES REALIZADAS CON AVES

Un estudio realizado exponiendo aves durante 206 días a campos de microondas de 7,06 GHz de frecuencia con potencias entre 0,14 y 1440 $\mu\text{W}/\text{cm}^2$ encontró efectos beneficiosos en la producción de huevos pero se duplicó su mortalidad (Tanner & Romero-Sierra, 1974). Para diferentes frecuencias e intensidades de microondas se obtuvieron efectos reductores de la tasa de crecimiento en pollos y ratas expuestas, además de un descenso de la producción de huevos en gallinas, aumento de la fertilidad, y deterioro de la calidad de la cáscara de los huevos (Krueger *et al.*, 1975). Varios autores han notificado un incremento significativo de la mortalidad embrionaria de pollos expuestos a la radiación de teléfonos móviles en funcionamiento (Farrel *et al.*, 1997; Youbicier-Simo *et al.*, 1998; Grigoriev, 2003) que podría estar afectando a las aves silvestres que viven en las áreas más contaminadas por microondas.

Las radiaciones de un teléfono móvil (900 MHz. moduladas a 217 Hz.) indujeron una respuesta en varios tipos de neuronas del Sistema Nervioso Central de las aves (Beasond & Semm, 2002). Desconocemos todavía si el síndrome de las microondas antes mencionado se manifiesta en las aves, pero en un experimento realizado con gallinas expuestas a una frecuencia de 7,06 GHz., con una potencia entre 0,19 y 360 $\mu\text{W}/\text{cm}^2$ durante 206 días, surgieron problemas de salud y un notorio deterioro del plumaje, mientras las necropsias mostraron leucosis y tumores del sistema nervioso central (Tanner & Romero-Sierra, 1982). Por su parte, Kondra *et al.* (1970) encontraron un incremento en la frecuencia de ovulación de gallinas expuestas a 6 GHz. entre 0,02 y 400 pW/cm^2 de potencia durante periodos entre 56 y 476 días. En trabajos recientes efectuados midiendo los niveles de campo electromagnético en el rango

de las radiofrecuencias, se han observado algunos efectos a corto y largo plazo sobre las aves silvestres urbanas en zonas con elevados niveles de contaminación electromagnética (Balmori, 2003).

POSIBLES EXPLICACIONES DE LOS RESULTADOS CONTRADICTORIOS. DIFICULTADES METODOLÓGICAS DE LOS EXPERIMENTOS Y DE SU INTERPRETACIÓN.

Los experimentos que estudian los efectos de las radiaciones electromagnéticas en los seres vivos son complejos ya que existe un elevado número de variables que se deben controlar. La dificultad de su control dificulta las «condiciones idénticas» necesarias para la replicación. Estas diferencias en los diseños experimentales podrían estar provocando resultados contradictorios (Tanner & Romero-Sierra, 1982).

Las radiaciones de microondas parecen provocar efectos diferentes, e incluso contrarios, dependiendo de planteamientos metodológicos como la frecuencia, potencia, modulación, pulsos, tiempo de exposición, etc. (Grigoriev, 1996; Daniells *et al.*, 1998; Nikolaevich *et al.*, 2001). Experimentalmente se ha detectado, en algunos casos, una dependencia bifásica de los efectos biológicos (efectos biológicos opuestos a baja y a alta intensidad; Nikolaevich *et al.*, 2001). Particularmente dañinas parecen ser las radiaciones con frecuencias coherentes con los procesos biológicos (que tengan gran similitud oscilatoria, por ejemplo, con las ondas cerebrales), ya que pueden confundir la comunicación interna del propio ser vivo. Éste efecto únicamente se podrá detectar en estudios «in vivo». Los estudios de carácter morfológico realizados «in vitro» difícilmente encontrarán modificaciones significativas, ya que las alteraciones inducidas son funcionales y están basadas en el intercambio de cargas y no afectan normalmente a la estructura.

Pequeños campos electromagnéticos provocan cambios químicos, fisiológicos y conductuales solo en algunas ventanas de frecuencia concretas (Adey, 1981). Cada estructura (cráneo, órganos, células, moléculas), puede entrar en resonancia con algunas frecuencias cuando su tamaño se aproxima a la mitad de la longitud de la onda incidente. Algunos estudios han demostrado los diferentes efectos de las microon-

das dependiendo de que su longitud de onda se encuentre en el rango de los milímetros, de los decímetros o de los metros (Kemerov *et al.*, 1999, Nikolaevich *et al.*, 2001).

Las ondas pulsadas (en ráfagas), así como determinadas modulaciones de baja frecuencia, han mostrado una gran actividad biológica (Grigoriev, 1996; Hyland, 2001; Nikolaevich *et al.*, 2001). Las relaciones dosis-respuesta (de los efectos no térmicos), no son sencillas de establecer ya que presentan una relación no lineal (Monteagudo, 1997; Hyland, 2001; Marino *et al.*, 2003) y además los efectos acumulativos dependen de la duración de la exposición (Adey, 1996).

En los estudios sobre los efectos de las radiaciones de telefonía sobre las aves es necesario tener en cuenta la suma de las radiaciones de microondas a las que están expuestas en la vida real, ya que las fuentes de radiación con diferentes frecuencias e intensidades, procedentes de varias antenas, pueden superponerse en un mismo punto. La gran movilidad de las aves, la variación de los tiempos de exposición y las propiedades físicas de las ondas radiantes como la resonancia, las reflexiones o la atenuación por ciertas estructuras, pueden complicar el estudio de sus efectos. Además, la Intensidad de Campo Eléctrico en un punto concreto varía continuamente entre ciertos niveles (*obs. pers.*), dependiendo del número de comunicaciones que soporta la antena, del horario e incluso de la meteorología. Es probable que cada especie e incluso cada individuo, muestre diferente susceptibilidad a las radiaciones, ya que la vulnerabilidad depende de su predisposición genética, y del estado fisiológico y neurológico del ser vivo irradiado (Hyland, 2001; Fedrowitz *et al.*, 2004).

En cuanto al protocolo para efectuar las mediciones, los técnicos todavía no se han puesto de acuerdo, especialmente en lo relativo a la utilización de antenas isotrópicas (que integran las emisiones que se reciben en un punto procedentes de todas las direcciones del espacio) o direccionales (que se orientan hacia la fuente emisora, proporcionando mediciones más concretas de los niveles que se reciben en un determinado lugar, procedentes de un emisor puntual). Ambos métodos ofrecen resultados muy dispares en las mediciones realizadas en el campo a diferentes distancias de las antenas (*obs. pers.*).

POSIBLES EFECTOS SOBRE LAS AVES

La revisión bibliográfica precedente muestra que las radiaciones de microondas pulsadas de telefonía pueden producir efectos especialmente sobre los sistemas nervioso, cardiovascular, inmunitario y reproductor:

- Daños en el sistema nervioso por alteración del electroencefalograma, la modificación de la respuesta neuronal o la permeabilización de la barrera hematoencefálica.
- Alteración de los ritmos circadianos (sueño-vigilia) por interferencias con la glándula pineal y desajustes hormonales.
- Cambios en el ritmo cardíaco y la presión sanguínea.
- Deterioro de la salud y de la inmunidad hacia agentes patógenos, debilidad, agotamiento, deterioro del plumaje y problemas de crecimiento.
- Problemas en la construcción del nido o alteración de la fertilidad, el volumen de puesta, el desarrollo embrionario, el porcentaje de eclosiones o la supervivencia de los pollos.
- Efectos genéticos como malformaciones, problemas de locomoción, albinismos y melanismos parciales, o promoción de tumores.

Las microondas pueden estar afectando negativamente a las poblaciones de aves, en los lugares con elevada contaminación electromagnética. Las aves por poseer sistemas magnéticos de navegación tienen capacidad para percibir los campos magnéticos (Liboff & Jenrow, 2000). Por esta razón podrían evitar activamente estas zonas (Balmori, 2003). Las especies más vulnerables es previsible que sean las que tienen la costumbre de alimentarse, cantar, dormir o instalar el nido en lugares elevados o desprotegidos, como tejados, antenas o cables.

Varios millones de pájaros de 230 especies mueren anualmente por colisiones con las torres de telecomunicaciones en Estados Unidos durante la migración (Shire *et al.*, 2000). Todavía no se conoce la causa concreta de los accidentes, aunque se sabe que se producen especialmente durante las noches de niebla o mal tiempo. Las aves manejan varios sistemas de

orientación: las estrellas, el sol, el conocimiento de la orografía y el campo magnético terrestre (Liboff & Jenrow, 2000). La iluminación de las torres de telecomunicación podría atraer a las aves en la oscuridad, pero también es posible que los accidentes se produzcan en circunstancias de poca visibilidad por una alteración de alguno de los sistemas de navegación (percepción del campo magnético terrestre) por las radiaciones electromagnéticas de las antenas. Se hace necesaria más investigación en este aspecto.

En las áreas más contaminadas por las radiaciones electromagnéticas (radio aproximado de 300-500 metros de una antena, en la dirección de emisión del lóbulo principal), se produce un deterioro del hábitat óptimo para la permanencia de las aves, que puede ocasionar el abandono de las áreas de cría o los dormitorios (Balmori, 2003). Teniendo en cuenta los efectos acumulativos de estas radiaciones (Adey, 1996), el tiempo de permanencia es de gran importancia para valorar los efectos producidos sobre las aves. La contaminación electromagnética no es exclusiva de los núcleos urbanos, puesto que las infraestructuras viarias, montañas o los promontorios en la costa albergan con frecuencia emisores, instalados con el fin de cubrir una gran superficie territorial. Los efectos de las antenas sobre el hábitat de las aves son difíciles de cuantificar, pero podrían ocasionar su deterioro, generando áreas de silencio sin machos cantores ni parejas reproductoras. El impacto sobre el ecosistema podría acentuarse por el efecto de las radiaciones sobre las poblaciones de invertebrados presa y sobre las plantas que reducirían el alimento disponible para las aves (Balmori, 2003).

PROPUESTA DE INVESTIGACIONES

Las aves pueden cumplir un buen papel como bioindicadoras. Su cráneo más delgado, su libertad de movimientos y la utilización de lugares con altos niveles de radiación electromagnética les confiere especial vulnerabilidad. Como futuras líneas de investigación sugerimos realizar seguimientos a largo plazo del éxito de cría, de los dormitorios y de la utilización del hábitat por especies cuyo comportamiento les puede hacer más vulnerables a las ondas.

Para demostrar el efecto concluyente de las radiaciones de telefonía móvil sobre las aves es necesario abordar investigaciones en los que se incluya un grupo control (no expuesto) y otro experimental. Este planteamiento metodológico es complicado en la actualidad, teniendo en cuenta la casi absoluta ubicuidad de estas radiaciones. Los trabajos que intenten correlacionar la evolución numérica o presencia de aves con los resultados de las mediciones de los campos electromagnéticos de radiofrecuencias también pueden ser de gran interés. La investigación de las poblaciones de parques urbanos y de territorios circundantes a instalaciones de telefonía en el campo puede ser prioritaria. Un radio de un kilómetro cuadrado y el trazado de circunferencias concéntricas a distancias intermedias pueden ser útiles para investigar resultados diferenciales entre áreas, dependiendo de su proximidad y de los correspondientes niveles de radiación electromagnética. En estos estudios se deberá tener en cuenta la dirección del lóbulo principal de radiación. También puede ser de gran interés la realización de estudios con aves en cautividad sometidas a microondas en laboratorio.

CONSIDERACIONES FINALES

La contaminación electromagnética por microondas debería ser considerada un agente potencial del descenso de algunas poblaciones de aves. En el Reino Unido, donde la legislación es especialmente permisiva en este aspecto (los niveles permitidos de microondas son 20 veces superiores a los de España), se ha producido en los últimos años un declive acusado de varias especies de aves urbanas (Raven *et al.*, 2003). Su coincidencia en el tiempo con el despliegue de la telefonía móvil no tiene porque ser necesariamente una relación causa-efecto, pero la posible relación de ambas circunstancias debería ser investigada. A pesar de que este tipo de contaminación es considerado por algunos expertos como el más novedoso y grave en la actualidad (Hyland, 2001), todavía no se han desarrollado sistemas de inspección y control que eviten sus efectos perniciosos sobre los seres vivos.

Algunos de los mecanismos biológicos de actuación de las radiaciones de microondas todavía son desconocidos, aunque varios efectos

sobre los seres vivos, por debajo de los niveles autorizados actualmente, han sido suficientemente documentados. La industria de telefonía podría estar aprovechando la complejidad de los procesos biológicos y físicos implicados, para tratar de crear un ambiente de inocuidad, negando de forma reiterada la existencia de efectos perjudiciales sobre los seres vivos. Por esta razón los informes relacionados con animales son de especial valor, ya que en este caso no puede alegarse que sus efectos son psicosomáticos (Hyland, 2000).

No deberían existir zonas de uso continuado a la altura de las antenas ni en el interior del haz emisor en un radio de varios centenares de metros. La restricción del acceso a la fauna presenta especial complejidad, razón por la que la reducción de la potencia de emisión de las antenas se presenta como la única solución viable y efectiva para prevenir sus efectos. Muchos investigadores postulan la necesidad de una reducción drástica de los niveles emitidos sobre las personas y los ecosistemas, que es técnicamente viable aunque más costosa para la industria (Hyland, 2001; Haumann *et al.*, 2002). Mientras avanzan las investigaciones, los niveles de exposición de los seres vivos no deberían superar $0,1 \mu\text{W}/\text{cm}^2$ de densidad de potencia, como se ha recomendado en numerosos congresos internacionales y publicaciones. También puede representar un avance la investigación sobre sistemas emisor/receptor de potencias más reducidas que las actuales (Cooper & Golburg, 1996; Cooper, 2003)

La controversia es frecuente cuando desde el mundo científico se reconocen efectos sobre la salud y el medio ambiente que pueden ocasionar grandes pérdidas económicas. El bioelectromagnetismo se encuentra en la frontera entre varias disciplinas alejadas históricamente. Algunos autores sostienen que estamos asistiendo a un cambio de paradigma en biología (Adey, 2003), que rompe con la tradición impuesta desde la física tradicional y las ingenierías que proponían básicamente que las radiaciones no ionizantes no son peligrosas para la vida. Ante el panorama descrito aquí, las investigaciones y seguimientos de la fauna y de otros seres vivos que habitan cerca de las antenas y el apoyo a las mismas por las autoridades medioambientales y sanitarias nos parecen pertinentes.

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INDICE

EDITORIAL

- ¿Y ahora, la salud?** 185
LOS EDITORES

ARTÍCULOS ORIGINALES

SALUD AMBIENTAL

- Efectos de la radiación electromagnética no ionizante sobre la salud y el caso específico de los efectos en la salud humana de la telefonía celular** 187
ANDREI TCHERNITCHIN, LEONARDO GAETE, VERENA ROMERO, MOISÉS PINILLA

SALUD MENTAL

- Trastornos por déficit de atención: consideraciones desde la psicología para un diagnóstico comprensivo integral** 218
ANDREA MOYANO, PAULA TORRES, MARIA JOSE EYHERAMENDY, PAULA BARRERA

SALUD INFANTIL

- Programa Nacional de infecciones respiratorias agudas y síndrome bronquial** 225
GUIDO GIRARDI BRIÈME

EVOLUCIÓN DE LA SALUD PÚBLICA

- Algo importante para celebrar el bicentenario** 234
DR. FERNANDO MONCKEBERG

CRÓNICA

- Pensando en la salud de la humanidad y del ambiente: observación de los últimos eventos significativos relacionados con la energía** 236
DR. CARLOS MONTOYA AGUILAR

ÍNDICE ANUAL Vol. 51	239
INFORMACIÓN PARA LOS AUTORES	245

All titles and abstracts are given in Spanish and English.

Las opiniones expresadas en los artículos son de responsabilidad de los autores.

EDITORIAL

¿Y ahora, la salud?

El vigoroso debate nacional acerca del lucro, la inequidad, la gratuidad y la ineffectividad de la educación en Chile, sumado al paralelismo con los hechos que ocurren en el sector de la salud, ha llevado al Ejecutivo a lanzar diversas propuestas que persiguen conformar una respuesta pertinente a este sector.

El lucro y la inequidad quedaron de manifiesto al anunciarse casi simultáneamente la alzas de precios de los "planes" de las Isapres y sus cuantiosas utilidades. La prensa destaca sobre todo la decisión del Tribunal Constitucional en contra de las diferencias de precios entre usuarios de distinta edad y sexo, diferencias basadas en tablas de riesgo. El gobierno y la opinión pública reaccionan en particular frente a esta crítica.

Sin embargo, el problema es más de fondo: las Isapres son empresas comerciales y como tales su objetivo natural es general utilidades para sus dueños. Este objetivo hace que los precios que cobran sean tan altos como el mercado lo permita, y que a ello contribuyan los gastos de administración y publicidad, el pago por acto a los proveedores, y la desinformación del público ante la multiplicidad de "planes" ofrecidos. La naturaleza individual de los contratos entre las personas y las Isapres lleva a la desigualdad de los servicios entre los cotizantes y a la inequidad con respecto al resto de la población. No puede ser de otra manera, dado que un seguro privado debe, por naturaleza, cuadrar las entradas con los gastos en cada cuenta individual; y un factor determinante de los gastos es el riesgo de enfermar de cada persona.

En suma, la realidad de las Isapres es la que debe ser. Con una excepción fundamental: en Chile, a diferencia de los demás países, la ley establece que la cotización obligatoria correspondiente a la seguridad SOCIAL en salud, sea utilizada para pagar las primas de un seguro administrado privadamente y cuyas utilidades son apropiadas privadamente. Esto le crea al Ministerio de Salud el desafío de mejorar la situación por la cual reclaman los cotizantes y que objeta el TC. Para el Ministerio y los parlamentarios no hay solución dentro del régimen actual. La única solución coherente sería salir de este régimen: "privatizar las Isapres", es decir, que los interesados paguen las primas desde su bolsillo, por planes integrales o complementarios, y que las empresas pasen a ser fiscalizadas por la Superintendencia de Valores y Seguros como cualquier otra organización de este rubro.

Se habla de desmunicipalizar la educación. En el caso de la salud había, desde antes de 1990, suficientes argumentos contra la administración edilicia, argumentos que no se tuvieron en cuenta al dictar el Estatuto de la Atención Primaria (APS). Por ejemplo: la multiplicación de aparatos administrativos, uno por cada una de las 350 comunas; la gran inequidad de ingresos propios entre municipios ricos y pobres; la inconexión con los hospitales, conducente a ineficacia de resultados en el estado de salud poblacional; la discontinuidad asociada a los períodos electorales; la baja resolutivez de las acciones. La carga del trabajo de administrar establecimientos perjudica el ejercicio de las funciones que sí corresponden a las alcaldías en materia de salud: la higiene y el saneamiento ambiental; la coordinación de los distintos sectores locales para promover y proteger la salud; el estímulo a la participación comunitaria, y la información a las organizaciones sociales.

Con todo, debe reconocerse el esfuerzo de los equipos de conducción de la atención primaria y la valiosa experiencia que algunos han adquirido en 30 años. Ellos están contribuyendo inteligentemente, en la muchos casos, a la integración de los médicos del actual "Programa Ministerial de Formación de Especialistas para la APS". Esta integración del "especialista en formación" en los equipos multiprofesionales aumenta la resolutivez de

los Consultorios urbanos y tiende a cerrar la brecha entre estos y los hospitales. En el caso de la salud, el primer problema a resolver, antes de desmunicipalizar a fardo cerrado, es la automatización de las agendas y la rigidez de normas y metas, todo lo cual tiende a ser impuesto uniformemente desde el nivel central. Recientemente hemos sabido de una comuna pequeña en la cual la aplicación forzada de la estrategia de sectorización ha llevado a dividir al pequeño equipo local en tal forma que la única matrona quedó en un "sector" y la única enfermera, en el otro. Es en el nivel ministerial que corresponde efectuar en primer lugar y con urgencia una reingeniería basada en un mejor conocimiento de la realidad local, en el fomento de la relación médico-paciente y equipo-comunidad y en el cuidado de la programación y gestión clínica en beneficio de las personas, con respeto al uso del tiempo de las mismas.

La tercera gran área a considerar, también destacada desde 1990, es la dualidad del sistema de atención, que resulta en la fragmentación de los recursos de la Seguridad Social para la salud, con una distribución inequitativa. Así se daña la solidaridad que está en la base de las políticas que han tenido éxito en Chile y en otros países, base que reside en el principio de que la atención integral, equitativa, efectiva y eficiente de la salud es un bien y un derecho social universal y una responsabilidad del Estado. Una consecuencia de ese daño es la desprotección financiera de los hogares, reflejada en la alta proporción de gastos de bolsillo en salud para la mayoría de la población. Y la adopción, por el sector público, de la práctica de pagar por acto a los establecimientos estatales es otro factor de alto riesgo financiero, administrativo, técnico y moral; también lo es el uso de incentivos monetarios con preferencia respecto a la planificación y ejecución consciente y participativa en cada servicio y establecimiento, centrada en las personas y no en las patologías e intervenciones específicas.

Los médicos, por formación, estamos por llamar al pan, pan, y al vino, vino. Nos parece que el Sr. Ministro de Salud está en una línea similar. En realidad, no hemos visto buenos resultados de la política de acuerdos para el corto plazo, de las "leyes cortas" y de la resignación ante intereses que no contribuyen al avance real en la salud y el bienestar de la población. Desearíamos que las políticas fueran diseñadas en forma participativa e informada, para el largo plazo y con fundamento en los principios de Efectividad, Equidad, Solidaridad, Eficiencia y Dignidad de las personas.

Los Editores

Efectos de la radiación electromagnética no ionizante sobre la salud y el caso específico de los efectos en la salud humana de la telefonía celular

Health Effects of Non-Ionizing Electromagnetic Radiation, and the Specific Case of the Effects of Mobile Telephony

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Moisés Pinilla³, Verena Romero⁴,

Resumen

Los efectos en salud de la radiación electromagnética ionizante son bien conocidos; sin embargo hay menos reconocimiento de los efectos en salud causados por exposición a radiación electromagnética no ionizante. La primera parte del presente trabajo se refiere a los efectos en salud de las radiaciones electromagnéticas no ionizantes, independiente de su origen, puesto que no hay diferencias apreciables entre los efectos producidos por los diversos tipos de radiación electromagnética no ionizante y por lo tanto, son también válidas para aquellas emitidas por la telefonía celular. Se describe una asociación estadísticamente significativa de varias enfermedades a radiación electromagnética de frecuencia baja (ELF) proveniente de tendidos o transformadores de alta tensión, radiación electromagnética ELF del tendido eléctrico domiciliario y de artefactos electrodomésticos, exposición ocupacional a radiación electromagnética principalmente ELF, y radiación electromagnética de radiofrecuencia (RF) proveniente de antenas de transmisión de televisión. A continuación se analizan los efectos ya demostrados de la telefonía celular (los teléfonos y sus antenas repetidoras). Luego se analizan los grados de certeza de un estudio del Estado de California (USA) para relacionar las diversas enfermedades causadas por radiación electromagnética no ionizante. Este estudio confirmó la alta o mediana probabilidad de una relación causa-efecto de la radiación electromagnética con las siguientes enfermedades: leucemia en adultos y niños, cáncer cerebral en adultos y niños, cáncer de mama femenino y masculino, abortos espontáneos, suicidio, enfermedad de Alzheimer, esclerosis lateral amiotrófica y enfermedades cardiovasculares incluyendo infarto del miocardio. Se describen cuales son estas enfermedades de acuerdo al origen de estas radiaciones y se analizan cuales pueden ser los mecanismos biológicos que determinan la génesis de éstas. Se resumen los trabajos científicos realizados en la URSS y luego en Rusia sobre efectos de radiación electromagnética derivada de la telefonía celular, que originó las normas de ese país y más tarde en Europa Occidental y las decisiones de la OMS respecto de la carcinogenicidad de esta radiación, y se recuentan algunas de las proposiciones realizadas por el actual Gobierno de Rusia en esta materia, y las normas actuales de algunos países. Finalmente se hacen algunas proposiciones para la futura legislación y su regulación en Chile.

Palabras clave: Radiación electromagnética no ionizante, efectos en salud, campos electromagnéticos, telefonía móvil, antenas repetidoras, proposiciones legislación, límites máximos de EMF, comparación de normas de EMF.

Abstract

The health effects of ionizing electromagnetic radiation are well known; nevertheless there exist less recognition on the health effects of exposure to non-ionizing electromagnetic radiation. The first part of the present report refers to health effects of non-ionizing electromagnetic radiation, independently of its origin, since there are not important differences among effects

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caused by the different kind of non-ionizing radiations, therefore, they are valid for those emitted by the mobile telephony. A statistically significant association is described among various diseases and extremely low frequency electromagnetic radiation (ELF) from high tension electric conductors or transformers, intradomestic electric lines or electrodomestic appliances, occupational exposure to electromagnetic fields, mainly ELF, and radiofrequency (RF) electromagnetic radiation from television transmission. Already demonstrated effects of mobile telephony (cellular telephones and their antennas). The degrees of certainty from a study of the State of California (USA) is analyzed to relate various diseases caused by non-ionizing radiation. This study confirmed high or moderate probability of a cause-effect relationship for adult and child leukemia, brain cancer in adults and children, female and male breast cancer, spontaneous abortions, suicide, Alzheimer disease, amyotrophic lateral sclerosis and cardiovascular diseases including myocardial infarction. Various diseases are related to the different origin of the radiation, and the biological mechanisms involved in disease generation are analyzed. Research performed in the USSR and afterwards in Russia on health effects of mobile telephony are summarized, these investigations originated the regulation in this country and afterwards in West Europe, and influenced the decisions of WHO on its carcinogenicity. Some of the protection measures and regulations taken by the current Russian Government are reported, as well as current regulations in some countries. Finally, some propositions are made for future legislation and regulation in Chile.

Keywords: Non-ionizing electromagnetic radiation, health effects, electromagnetic fields, mobile telephony, cell telephony antennas, legislation propositions, maximum EMF limits, EMF norms comparison.

INTRODUCCIÓN

El desarrollo tecnológico ha causado una exposición cada vez mayor de los seres humanos a radiaciones electromagnéticas de diverso tipo. Los efectos de la denominada radiación ionizante sobre los seres vivos son bastante bien conocidos y reconocidos, y los métodos para prevenir estos efectos han sido reglamentados en la mayoría de los países. No obstante, los efectos sobre la salud de radiación electromagnética de menor energía, considerada como "no ionizante", han sido menos estudiados y poco reconocidos por autoridades de salud de numerosos países; en consecuencia, existe reglamentación insuficiente respecto de las medidas destinadas a disminuir o evitar los posibles efectos adversos sobre la salud. El presente trabajo, que es una puesta al día de informes dados a conocer con anterioridad (1, 2), analiza los efectos adversos sobre la salud de algunas radiaciones electromagnéticas no ionizantes para permitir evaluar el riesgo al cual se someten las personas expuestas a ellas, y contribuir a una mejor legislación, reglamentación y normas que permitan disminuir sus efectos sobre salud humana. Indudablemente, la nueva legislación, reglamentación y normas deberán permanecer abiertas, sometidas a las nuevas evidencias científicas que estudios actuales y futuros vayan descubriendo, con el fin de minimizar cualquier riesgo para la salud.

EFFECTOS SOBRE LA SALUD DE LA RADIACIÓN ELECTROMAGNÉTICA "NO IONIZANTE"

Efectos de la radiación electromagnética de baja frecuencia (extremely low frequency, ELF) de redes o transformadores de alta tensión

Olsen et al. (3,4) demostraron una asociación importante entre los tres tumores infantiles combinados: leucemia, tumores del sistema nervioso central o linfomas malignos, y exposición a campos magnéticos de instalaciones de alto voltaje, en residentes cercanos a estas instalaciones. También demostraron una asociación probable con la enfermedad de Hodgkin. Feychting et al. (5) demostraron una asociación entre leucemia infantil y tendidos eléctricos de alta tensión. A niveles superiores a 0,2 μT (microTesla)⁵, el riesgo relativo (RR) fue estimado en 2,7, con un intervalo de confianza (IC) 95%=1,0–6,3; a niveles superiores a 0,3 μT el RR era 3,8 (IC 95%=1,4 a 9,3); la probabilidad para la tendencia, $p=0,005$.

Li et al. (6) realizaron un estudio que consideraba la intensidad de la exposición a campos electromagnéticos y la distancia entre de la fuente de exposición a éstos

5 Tesla es la unidad de medida de la intensidad de un campo magnético; ésta actúa con la fuerza de 1 newton sobre un conductor situado en el vacío, de 1 metro de longitud, recorrido por una corriente de 1 amperio de intensidad y orientado en dirección normal al campo. Un tesla representa una densidad de flujo de 1 weber por metro cuadrado.

y el hábitat de los sujetos expuestos. Estos autores demostraron, en Taiwan, que el riesgo de leucemia en personas expuestas a radiación electromagnética mayor que $0,2 \mu\text{T}$, provenientes de líneas de alta tensión, en relación a los expuestos a menos que $0,1 \mu\text{T}$, presenta un $\text{RR}=1,4$ ($\text{IC } 95\%=1,0-1,9$). Al comparar distancia entre la fuente de exposición y el hábitat de los sujetos expuestos, para distancias menores de 50 m, comparados con distancias mayores de 100 m, encontraron un aumento del $\text{RR}=2,0$ ($\text{IC } 95\%=1,4-2,9$).

A partir de estudios realizados en la década de los 80 que demostraron una relación entre la intensidad del campo magnético y el riesgo de leucemia infantil, y después de revisar más de dos décadas de investigación científica en esta área, científicos del NIEHS (National Institute of Environmental Health Sciences, de Estados Unidos de Norteamérica) concluyeron que la tendencia generalizada de los resultados de dichos estudios sugiere una débil asociación entre el aumento de la exposición a campos electromagnéticos y el aumento de riesgo de leucemia infantil (7).

Efecto de radiación electromagnética ELF de redes eléctricas domiciliarias y electrodomésticos

Un metaanálisis que resume 11 estudios sobre el efecto de radiación electromagnética de 50 o 60 Hz sobre el desarrollo de algunos cánceres dio resultados diferentes de acuerdo al método usado para evaluar la exposición (8). En efecto, el código de cable eléctrico que caracteriza la corriente eléctrica domiciliar estaba relacionado con el total de cánceres, las distancias desde la habitación al tendido eléctrico de alta tensión estaba asociado solo a leucemia, y las mediciones locales de radiación electromagnética no mostraron correlaciones estadísticamente significativas.

Wertheimer et al. (9) encontraron una asociación entre las conexiones a tierra vía tuberías metálicas domiciliarias y cáncer infantil, con un $\text{RR}=1,72$ ($\text{IC}=1,03-2,88$) para niños que habitaban hogares con tuberías de agua conductoras de electricidad, $\text{RR}=3,0$ ($\text{IC}=1,33-6,76$) para niños que habitaban en forma estable dichos hogares, y un $\text{RR}=4,0$ ($\text{IC}=1,6-10,0$) cuando las mediciones de orientación de las radiaciones magnéticas era menor de 55° de la inclinación horizontal.

Dockerty (10) ha descrito una asociación entre el uso de diversos electrodomésticos y el cáncer, especialmente infantil. Para la frazada eléctrica, por ejemplo, el riesgo de leucemia infantil era de 2,2 ($\text{IC } 95\% = 0,7-6,4$); para cáncer del sistema nervioso central el $\text{RR}=1,6$ ($\text{IC}=0,4-7,1$) y otros tumores malignos sólidos, $\text{RR}=2,4$ ($\text{IC}=1,0-6,1$). El riesgo de leucemia aumenta a la más alta categoría cuando se compara el campo magnético en los dormitorios ($> \text{ ó } = 0,2 \mu\text{T}$ comparado con $< 0,1 \mu\text{T}$), con un RR ajustado de 15,5 ($\text{IC}=1,1-224$).

Bates (11) también presentó evidencia epidemiológica de la correlación entre la exposición a campos electromagnéticos débiles de 50 Hz de origen habitacional y el cáncer. Esta correlación es estadísticamente significativa para la exposición a campos de origen domiciliario en niños con significancia estadística aún mayor para cánceres del sistema nervioso central, especialmente cerebrales, en niños.

Milham y Ossiander publican en 2001 una revisión sobre la evidencia histórica que sugiere que la electrificación domiciliar determinó un peak de leucemia infantil (12).

Estudios experimentales de los efectos biológicos de la radiación electromagnética ELF de baja intensidad

Diversos estudios han demostrado efectos en parámetros biológicos de radiación electromagnética ELF que causen alteraciones graves en salud. Por ejemplo, Wolf et al. (13) han demostrado que aumentan la proliferación celular y daño al DNA y un posible papel en mecanismos redox. Winker et al. (14) han reportado daño cromosómico en fibroblastos humanos en cultivo por exposición intermitente a campos ELF.

Efecto de exposición ocupacional a radiación electromagnética, principalmente ELF

La información presentada más abajo se refiere principalmente a exposición ocupacional a radiación ELF, pero en muchos de los estudios epidemiológicos no se han separado de las radiaciones RF, puesto que en muchas actividades laborales estudiadas, se observa exposición a ambas. En consecuencia, se analizarán en conjunto.

La sospecha que la mortalidad por leucemia puede estar asociada a exposición ocupacional a campos eléctricos o magnéticos fue por primera vez anunciada en una publicación científica por Milham en 1982 (15), quien estudió a trabajadores eléctricos de sexo masculino y expresó que "Los hallazgos sugieren que campos eléctricos y magnéticos pueden causar leucemia". Este estudio pionero causó el inicio de una serie de estudios posteriores sobre los efectos de campos eléctricos y magnéticos en salud, especialmente para frecuencias de 50 y 60 Hz.

Estudios posteriores han evidenciado epidemiológicamente la correlación entre la exposición a campos electromagnéticos débiles de 50 Hz de origen ocupacional y el cáncer (11). Esta correlación es estadísticamente fuerte para cánceres del sistema nervioso central, especialmente cerebrales, en trabajadores eléctricos y más débil para la asociación de leucemia y melanoma en trabajadores eléctricos.

Loomis *et al.* (16) han descrito que la mortalidad por cáncer de mama es mayor en trabajadoras eléctricas de sexo femenino que en otras trabajadoras (RR=1,38; IC 95%=1,04-1,82). Los riesgos relativos para ocupaciones eléctricas específicas eran: RR=1,73 (IC 95%=0,92-3,25) para ingenieros eléctricos, RR=1,28 (IC 95%=0,79-2,07) para personal técnico eléctrico, y 2,17 (IC 95%=1,17-4,02) para instaladoras y reparadoras de teléfonos y para trabajadoras en líneas telefónicas. Sin embargo, los autores no han detectado ningún aumento de incidencia de cáncer de mama en otras 7 ocupaciones en mujeres, entre ellas las operadoras telefónicas, digitadoras, programadoras y operadoras de computadoras, aún cuando estas actividades también involucran exposiciones elevadas a campos electromagnéticos.

Caplan *et al.* (17) han analizado once estudios ocupacionales relacionados con cáncer de mama en la mujer y han observado riesgos relativos en las siguientes condiciones: 1,98 en mujeres postmenopáusicas con historia ocupacional afectada por campos electromagnéticos; 2,17 en mujeres instaladoras y reparadoras de teléfono, 1,65 en analistas y programadores; 1,40 en operadoras de radio y telégrafo; 1,27 en operadoras telefónicas en otro estudio.

Kliukiene *et al.* (18) encontraron una correlación entre la exposición ocupacional a radiación electromagnética de 50 a 60 Hz e incidencia de cáncer de mama, con un RR

de 1,08 y de 1,14 (intervalos de confianza IC 95%=1,04-1,12 y 1,10-1,19) para la población que considera todas las mujeres expuestas a niveles mayores que los considerados como *background* (0,1 μ T) acumulados durante su vida laboral de 1000 - 1999 horas y a más de 2000 horas, respectivamente, comparadas con aquellas expuestas a dicho nivel por menos de 900 h respectivamente. El RR era de 1,21 y de 1,20 (IC = 1,11-1,29), cuando se consideraron sólo mujeres menores de 50 años. En este último grupo, los RR eran 0,87 para trabajadoras agrícolas, 0,85 para trabajadoras no especializadas, 0,95 para trabajadoras especializadas, 1,14 para funcionarias de oficina y de 1,32 para funcionarias con educación universitaria. Este estudio involucró una cohorte total de 21.483.769 personas/año bajo riesgo y 22.543 casos observados de cáncer de mama.

Demers *et al.* (19) han descrito un elevado riesgo para desarrollar cáncer de mama masculino en trabajadores relacionados con campos electromagnéticos, RR=1,8, IC=1,0-3,7; riesgo que se eleva entre los electricistas, instaladores de líneas de teléfonos y trabajadores de plantas eléctricas (RR=6,0, IC 95%=1,7-21) y en trabajadores y comunicadores de radio (RR=2,9, IC 95%=0,8-10).

Guénel *et al.* (20) describen un riesgo relativo de 1,64 (IC 95%=1,20-2,24) de leucemia en personas ocupacionalmente expuestas a campos electromagnéticos en forma continua.

Un amplio estudio poblacional del Registro de Cáncer de Noruega muestra una asociación entre trabajo eléctrico y riesgo de leucemia (21), y describe una asociación del cáncer de mama a la exposición acumulada expresada en μ T/años.

Armstrong *et al.* (22) describe para trabajadores de artefactos eléctricos de Quebec y de Francia una asociación entre exposición a campos electromagnéticos pulsátiles y cáncer pulmonar.

En un estudio basado en 170.000 trabajadores de la Compañía de Gas y de Electricidad de Francia entre 1978 y 1989 (23) se ha demostrado la asociación de exposición ocupacional a campos electromagnéticos ELF con la incidencia de tumores cerebrales y el cáncer de colon. El RR de la exposición superior al percentil 90, para tumores cerebrales, era 3,08 (IC 95%=1,08-8,74), y aumentaba a

3,69 (IC=1,10-12,73) si se permitía un periodo de latencia de 5 años antes del diagnóstico.

También se ha encontrado una correlación entre radiación electromagnética de baja frecuencia con cáncer testicular no-seminoma, y se ha sugerido que la acción hormonal puede estar involucrada en el desarrollo de estas neoplasias (24).

En un estudio basado en 1.596.959 hombres y 806.278 mujeres en Suecia (25), se ha investigado la incidencia de diversos tipos de cáncer entre 1971 y 1984, correlacionándolos a la exposición ocupacional a campos magnéticos y electromagnéticos; tomando como base valores determinados por una matriz de exposiciones calculada a partir de medidas para diversas actividades laborales, y datos de censos realizados en ese país. En este estudio, se ha descrito, en hombres, un aumento del riesgo de cáncer testicular en trabajadores jóvenes, y en mujeres, una clara asociación con cáncer endometrial (uterino). Además se han descrito asociaciones entre la exposición y los siguientes tipos de cáncer en hombres: cáncer de colon, de vías biliares, hígado, laringe y pulmón, riñón, órganos urinarios, melanoma, cáncer de piel no-melanoma y astrocitomas III-IV. En este mismo estudio, se han descrito en mujeres asociaciones con cáncer pulmonar, de mama, melanoma y leucemia linfocítica crónica. Se ha sugerido una interacción del campo electromagnético con los sistemas inmune y endocrino, los que interfieren aumentando el riesgo de cáncer en sujetos expuestos.

Savitz y col. (26) han descrito en trabajadores relacionados con electrodomésticos que el riesgo de cáncer cerebral aumenta por un factor de riesgo de 1,94 por μT año de exposición a campo magnético durante los 2 a 10 años previos. La mortalidad aumenta en 2,6 veces en el grupo de exposición más alta.

Efectos de radiación electromagnética de radiofrecuencia (RF) de antenas de transmisión de televisión

Dolk *et al.* (27) encontraron que en adultos residentes en una zona situada a una distancia menor que 2 km de una antena transmisora de señales de televisión, el riesgo de leucemia estaba aumentada 1,83 veces (IC 95%=1,22-2,74) en relación a quienes residen a mayor distancia.

Estos hallazgos eran consistentes en los períodos entre 1974-1980 y entre 1981-1986.

Hocking *et al.* (28) estudiaron la asociación entre el incremento de la incidencia y mortalidad por leucemia en proximidades de antenas de transmisión de televisión en Australia. La densidad energética era de $8,0 \mu\text{W}/\text{cm}^2$ cerca de las antenas, $0,2 \mu\text{W}/\text{cm}^2$ a una distancia radial de 4 km, y de $0,02 \mu\text{W}/\text{cm}^2$ a 12 km. Para todas las edades, la incidencia para leucemia estaba aumentada en 1,24 veces (IC 95%=1,09-1,40). Considerando solo los niños, la incidencia de leucemia estaba aumentada en 1,58 veces (IC 95% = 1,07-2,34) y la mortalidad aumentada en 2,32 veces (IC 95%=1,35-4,01). El RR para morbilidad para leucemia linfocítica infantil era 1,55 (IC 95%=1,00-2,41), y para mortalidad 2,74 (IC 95%=1,42-5,27). No se han detectado aumentos de incidencia o mortalidad por cáncer cerebral.

Efectos de la radiación electromagnética de teléfonos móviles y de las antenas repetidoras

Los teléfonos móviles emiten radiaciones electromagnéticas de altas frecuencias para la transmisión de voz y datos hacia las antenas repetidoras, sin embargo, también generan ondas electromagnéticas de bajas frecuencias, asociadas a la funcionalidad del aparato telefónico mismo.

Dado lo anterior, es necesario, abordar el tema de los impactos a la salud, en sus dos componentes:

- a. Efectos de la exposición a los aparatos telefónicos móviles, durante el tiempo de la llamada
- b. Efectos de la exposición a radiación RF proveniente de teléfonos móviles en niños
- c. Efectos de la exposición a las antenas repetidoras, de manera permanente.

a. Efectos de la exposición a los aparatos telefónicos móviles durante el tiempo de la llamada

Estos efectos han sido menos estudiados que los anteriores, sin embargo ya existe un número creciente de personas que describen una serie de sintomatologías, posibles de medir clínicamente, por las cuales se demostraría un deterioro funcional durante el tiempo de exposición a altas dosis de

radiaciones electromagnéticas de altas frecuencias (tanto de los aparatos móviles, como de las antenas repetidoras). Adicionalmente, existen personas aparentemente asintomáticas, donde estos efectos pueden estar alterando, paulatinamente, diversos mecanismos de comunicación intra e extracelular, tejidos y órganos por mecanismos bioeléctricos y bioquímicos, cuyos efectos diferidos demoran más de 10 o a veces 20 años en manifestarse. Por la demora en producirse estos potenciales efectos diferidos, es prematuro buscarlos y encontrar efectos evidentes. Aún cuando ya se han demostrado algunos de estos efectos diferidos, también es posible hacer extrapolaciones de los efectos causados por ondas electromagnéticas de emisores de televisión, que sí producen efectos evidentes, y del efecto de ondas de muy baja intensidad y de baja frecuencia (50 Hz) de tendidos eléctricos domiciliarios o equipos electrodomésticos, para los cuales sí se han demostrado efectos diferidos sobre la salud (*vide supra*) dado que los seres humanos han estado expuestos por muchos más años a éstos.

Taurisano *et al.* (29) han demostrado elevación de temperaturas superficial y profunda en tejidos de la cabeza expuestos localmente a radiación electromagnética de 900 MHz proveniente de teléfonos celulares, indicando que el efecto térmico puede alcanzar al tejido cerebral, con sus consiguientes efectos adversos para la salud.

Se ha medido experimentalmente los efectos de la radiación electromagnética similar a la de algunos equipos telefónicos celulares, de 900 MHz, con frecuencias de repetición de 217 Hz y el ancho de pulso de 0,6 milisegundos. La exposición de animales de experimentación (ratones) a este tipo de radiación causa en éstos un riesgo relativo de 2,4 en relación a animales controles para desarrollar linfomas (30).

Los primeros estudios que se han realizado han sugerido, de una manera no concluyente, una mayor frecuencia de tumores cerebrales en usuarios de teléfonos celulares (31). Muscat (32) demostró **aumento significativo de tumores neuroepiteliales cerebrales en el hemisferio cerebral del lado de uso del teléfono celular**, en comparación con hemisferio cerebral contralateral. Más tarde, otros autores han demostrado, ya de manera más concluyente, que existe un importante aumento del riesgo de desarrollar un neurinoma acústico (33) en el lado del uso del teléfono celular, por 10 o más años, riesgo relativo 3,9, (1,6-

9,5); han demostrado además la asociación del uso del teléfono celular con otros tumores malignos (34), incluido el linfoma no-Hodgkin (35).

Se ha demostrado que la exposición *in vitro* de leucocitos humanos a radiación electromagnética de frecuencias usadas en telefonía celular causa un efecto genotóxico (aneuploidía del cromosoma 17) a intensidades que no producen efecto térmico, apoyando la hipótesis que los efectos que se producen ocurren por mecanismos no térmicos (36). Posteriormente, un estudio realizado en voluntarios sanos de los efectos de radiación electromagnética a intensidades no térmicas del Sistema Global de Comunicaciones por Telefonía Móvil (GSM), comparando diferentes frecuencias (37) ha demostrado alteraciones en la conformación de la cromatina de linfocitos humanos, que indican efectos genotóxicos y efectos de stress. Dicho estudio ha demostrado un efecto en la proteína 1 receptora supresora de tumores p53 de manera similar a un choque térmico, y que dicho efecto era variable dependiendo de la frecuencia del *carrier*. Lo anterior puede ser uno de los mecanismos que favorecen el desarrollo del cáncer causado por exposición crónica a radiación electromagnética de la telefonía GSM.

Se ha demostrado también que los campos electromagnéticos emitidos por teléfonos celulares alteran los electroencefalogramas, principalmente durante actividades que involucren memoria (38). Esto muestra efectos sobre la función del sistema nervioso central. De igual manera, se ha demostrado que durante el uso de los teléfonos celulares, hay un cambio en la temperatura de tejidos vecinos, vasodilatación en ellos, y un aumento del contenido nasal de óxido nítrico (NO) por la cavidad nasal del lado del teléfono, pero no en la cavidad nasal contralateral (39).

Se han detectado efectos biológicos tales como un aumento de la permeabilidad de la membrana de eritrocitos humanos con densidades atérmicas de radiación electromagnética de 2450 MHz (40).

Se ha demostrado igualmente que la radiación electromagnética de la telefonía celular GSM (Global System for Mobile Communication) altera en mamíferos la barrera hematoencefálica, causando filtración de albúmina desde los vasos sanguíneos al tejido cerebral,

y que ésta sería la causa del daño neuronal en la corteza cerebral, hipocampo y ganglios basales (41), se realizaron estudios funcionales del sistema nervioso en humanos.

Hinrikus *et al.* (42) demostraron en voluntarios sanos que (a) la exposición a microondas de 450 MHz, modulada a frecuencias entre 7 y 1000 Hz, altera las señales electroencefalográficas, aumentando principalmente los potenciales electroencefalográficos α ; (b) los efectos causados por exposición a microondas varía de acuerdo a la frecuencia moduladora, lo cual significa que depende de ésta y es independiente de un efecto térmico, y (c) la sensibilidad a microondas varía de persona a persona y causa efectos en la eficiencia en la memoria visual y en el procesamiento de esta información.

b. Efectos de la exposición a radiación RF proveniente de teléfonos móviles en niños.

En los niños, y en especial en los de corta edad, el efecto de la radiación RF causa más daño, especialmente cerebral, que en los adultos. Eso se debe a que el espesor del cráneo, es decir, la distancia que debe atravesar la radiación desde el teléfono hasta el cerebro, es significativamente menor en niños que en adultos, y en especial durante los primeros años de su vida. También el cerebro está en desarrollo, por lo tanto, los efectos adversos en salud se producen en niños son más pronunciados graves que en adultos.

Hay estudios han demostrado que la absorción de la radiación por tejido cerebral es mucho mayor en niños que en adultos (43).

Otros estudios han demostrado mayores secuelas de exposición a RF provenientes de la telefonía móvil en niños que en adultos, y que estas secuelas son proporcionales al tiempo de exposición y a las horas de uso de dichos artefactos. Por ejemplo, un estudio realizado por el grupo del Dr. Grigoriev (44) ha demostrado una mayor frecuencia de secuelas en memoria, atención y de otros parámetros neurocognitivos susceptibles de ser cuantificados por el uso de esos teléfonos: aumento de trastornos de la percepción fonética, reducción de la eficiencia en el trabajo, reducción de los indicadores de capacidad de atención y memoria lógica, y un aumento de indicadores de fatiga. En este estudio se ha realizado durante 4 años el seguimiento de 196 niños de 7-12 años de edad que

eran usuarios de dispositivos móviles de comunicación, y se observó un constante empeoramiento de estos parámetros a partir de los valores inicialmente mejores, que permanecían de mejor calidad en comparación a niños controles no expuestos. Los autores de dicho estudio han advertido que las posibles consecuencias a corto y largo plazo para la sociedad de exponer a los niños a la radiación de microondas de los dispositivos de comunicación celular debe ser reconocida responsablemente a nivel mundial (44).

Resultados de investigaciones similares a los anteriores han motivado las recomendaciones del Gobierno de Rusia en cuanto a sugerir evitar en lo posible el uso del teléfono celular por niños (y también, mujeres embarazadas), y evitar acciones o propaganda comercial que incentiven el uso del teléfono por niños, tales como diseños infantiles de los dispositivos y juegos infantiles incluidos en dichos dispositivos, que incentivan el uso del uso del teléfono móvil durante la edad infantil (*vide infra*).

c. Efectos de la exposición a las antenas repetidoras, de manera permanente.

En cuanto a la **radiación electromagnética proveniente de antenas repetidoras de telefonía celular**, es necesario mencionar que es la misma que aquella emitida por los teléfonos móviles, según las frecuencias de operación de cada modelo de aparatos.

Si se efectúan mediciones de radiaciones de altas frecuencias en diversos puntos de una ciudad, incluso dentro de espacios interiores de un mismo recinto, se observará que los valores de las potencias varían drásticamente para una misma frecuencia. Esto sucede porque la radiación electromagnética emitida por antenas retransmisoras de teléfonos móviles es transmitida de manera no uniforme en ambientes urbanos. La no uniformidad se debe al patrón de emisión desde las diversas formas y características de las antenas que emiten, principalmente, en forma direccionada, y a reflexiones en diversas superficies y/o condiciones ambientales. Esta no uniformidad en el tiempo y el espacio, ha sido obviada en los estándares, donde sólo se refieren a intensidades promedio y no a los posibles picos de alta intensidad que pueden encontrarse en algunas áreas.

Es importante considerar que, al contrario de lo que normalmente se comunica, la intensidad no es inversamente proporcional al cuadrado de la distancia de la **fente de emisión**, sino que inversamente proporcional al cuadrado de la distancia de la **fente virtual** para cada uno de los planos direccionales (vertical, horizontal, oblicuos, etc), que puede encontrarse a distancias bastante mayores que la fuente de emisión. En otras palabras, si la densidad electromagnética es de 100 mW/m² a un metro de la fuente emisión, la densidad a 10 metros de distancia no es 1 mW/m², como suele calcularse e informarse, sino que puede ser de 30 o aún 90 mW/m², por ejemplo. Esto se debe a la existencia de placas reflectoras que actúan como lentes ópticas convergentes para dirigir las emisiones en las direcciones que se requieren para la transmisión de las señales cuidando la eficiencia energética del procedimiento. Este argumento fue presentado por uno de los autores del presente trabajo (ANT) y aceptado por el Instituto Nacional de Normalización INN de Chile en su norma sobre radiación electromagnética no ionizante en relación a antenas repetidoras. Sin embargo, aún cuando las normas vigentes no sean excedidas, existe el riesgo de que ciertas personas sean afectadas por los microcambios de temperatura que generarían deterioros a la salud. Más aún, es imprescindible considerar la existencia de efectos no térmicos, producidos con intensidades mucho más bajas de radiación no-ionizante, cuyos efectos crónicos o diferidos sólo podrán ser detectados por estudios epidemiológicos en el largo plazo (45). Sin embargo, se pueden diseñar estudios epidemiológicos para la población sensible a las frecuencias que las afectan, por ejemplo: grupos de personas con implantes metálicos o con alguna condición de salud que los hace más vulnerables que al resto de la población, para detectar los límites de exposición máximos que ellas pueden tolerar, principalmente, por radiación permanente de las antenas repetidoras en su entorno.

No obstante, estudios epidemiológicos ya han permitido demostrar efectos en salud de la distancia de residencia con antenas repetidoras de telefonía móvil. Eger *et al.* (46) demostraron que la proporción del desarrollo de nuevos cánceres fue significativamente más alta en aquellos pacientes que habían vivido en los diez años anteriores, hasta una distancia de 400 m de una antena transmisora, que había estado operando desde 1993, comparado con los pacientes que

vivían mucho más lejos; observaron además que los pacientes se enfermaron, en promedio, ocho años más tarde.

Dode *et al.* (47) investigaron la relación entre las muertes por neoplasia y la cercanía a las antenas repetidoras, en Belo Horizonte, Brasil. Entre 1996 y 2006, 7191 muertes por neoplasia ocurrieron en un área a 500 m de las antenas repetidoras (tasa de mortalidad: 34,76 por 10.000 hab). Fuera de esta zona, se ha observado una menor mortalidad por neoplasia. La mayor incidencia acumulada fue de 583 por 100.000 en la región Centro-Sul y la menor incidencia fue de 205 por 100.000 en la región de Barreiro. Durante el monitoreo ambiental, el mayor campo eléctrico medido acumulada fue de 12,4 V/m, y el más pequeño fue de 0,4 V/m. El poder de mayor densidad fue 40,78 µW/cm² y el menor - 0,04 µW/cm².

Wolf *et al.* (48) demostraron epidemiológicamente un aumento en 4,15 veces de la incidencia de cáncer en habitantes de Netanya, Israel, residentes a menos de 350 m de una antena repetidora de telefonía móvil, en comparación a residentes a mayor distancia (p<0,0001).

Santini *et al.* (49) realizaron estudios en 270 hombres y 260 mujeres que vivían o no, en la vecindad de antenas de teléfonos celulares. Se aplicó chi square y la corrección de Yates para comparar la frecuencia de ocurrencia de 16 síntomas no específicos, donde se encontró que las personas de mayor edad eran significativamente más sensibles (p<0,05) y que la posición frontal a las antenas es la peor posición para algunos síntomas estudiados, especialmente hasta un radio de 100 m a las antenas. No hubo diferencias significativas relacionadas al tiempo de exposición (desde 1 a 5 años), excepto para la irritabilidad, que creció significativamente después de 5 años de exposición. Otros factores electromagnéticos (transformadores eléctricos, transmisores de radio y TV, entre otros) tuvieron efectos en la frecuencia de algunos síntomas reportados.

La primera parte del estudio de Santini *et al.* (50) fue realizado, también, en 270 hombres y 260 mujeres que vivían o no en la vecindad de antenas de telefonía celular, consultando por 18 síntomas no específicos.

La comparación de la frecuencia de los síntomas (con chi square y corrección de Yates) en relación a la distancia a las antenas y sexo, mostró un significativo incremento ($p < 0,05$) comparado con las personas que vivían en un radio mayor a 300 m o no expuestos a la estación base: hasta 300 m para cansancio, hasta 200 m para cefaleas, perturbación del sueño, malestares generales, entre otros, hasta 100 m para irritabilidad, depresión, pérdida de memoria, mareos, disminución de líbido, entre otros. Las mujeres, significativamente, más que los hombres ($p < 0,05$) reportaron cefaleas, náuseas, pérdida de apetito, perturbación del sueño, malestar general y perturbaciones visuales. Este fue el primer estudio que demostró que la distancia mínima de ubicación de antenas debe ser mayor a 300 m de lugares habitables.

También se ha demostrado que la radiación electromagnética RF, en densidades de campo considerablemente menores que las guías de ICNIRP, pueden influenciar algunos marcadores psicobiológicos del stress, tales como elevación de niveles cortisol y alfa-amilasa en la saliva (51).

Algunos resultados experimentales, bajo condiciones atómicas, con animales expuestos a radiaciones continuas por períodos de tiempo controlados, son los siguientes:

Esmekaya *et al.* (52) demostró que al exponer ratas Wistar a radiación modulada de 900 MHz (SAR 1,2 W/Kg) por 20 min, por tres semanas, los indicadores de malonodialdehído y de óxido nítrico se elevaron significativamente en hígado, pulmones, testículos y tejido cardíaco, en el grupo expuesto comparado con el grupo control ($p < 0,05$). Por el contrario, los niveles de glutatión decrecieron considerablemente en ratas expuestas ($p < 0,05$). Los autores concluyen que la radiación de modulación pulsada causa daño oxidativo en el hígado, pulmón, testículos y tejido cardíaco por peroxidación lipídica, incremento de óxido nítrico y por supresión de mecanismos de defensa antioxidantes.

En otro estudio se expuso a ratas Wistar de sexo masculino, de 10-12 semanas de edad, a RF emitida por teléfono móvil activo GMS (0.9/1.8 GHz), de forma continua, una hora por día durante 28 días. Los controles

fueron expuestos a un teléfono móvil sin batería en el mismo período. La cantidad de semen entre los dos grupos no tuvo mayor variabilidad y su temperatura facial no se alteró significativamente, sin embargo, la movilidad de los espermios del grupo irradiado disminuyó considerablemente, concluyéndose que este tipo de radiaciones afectan negativamente la calidad del semen y puede deteriorar la fertilidad masculina (53)

En otro estudio (54) se demostró, en la rata, que la exposición microondas crónica (15 minutos por día, durante 8 días) del Sistema Global para Comunicaciones Móviles (GSM), en 1800 MHz, a tasa de absorción específica (SAR) de 2,4 W/kg, redujo la actividad excitatoria sináptica y el número de sinapsis excitadoras en cultivo de neuronas de hipocampo.

Grigoriev (55) demostró que al irradiar embriones de pollo en las frecuencias y potencias de los teléfonos móviles GSM durante el desarrollo embrionario por 21 días, la tasa de mortalidad en el período de incubación aumentó a 75%, siendo 16% en el grupo control.

Lai *et al.* (56) describieron que la exposición de ratas por dos horas continuas de radiaciones de 2450 Mhz (SAR 1,2 W/kg), causó un aumento de roturas de cadenas de DNA en células cerebrales, lo cual fue observado de inmediato y también, hasta cuatro horas después de la exposición. Por otro lado, Kesary *et al.* (57) demostraron actividad mitogénica en células cerebrales de rata expuestas *in vivo* a radiación electromagnética de 2,45 GHz. En otro estudio, Camisi *et al.* (58) demostraron especies reactivas de oxígeno y fragmentación de DNA en un cultivo celular de astrocitos sometidos a campos electromagnéticos de intensidades bajas.

Por último, se ha descrito una nueva entidad patológica, la **hipersensibilidad a radiación electromagnética**, en la cual la exposición a diversos tipos de radiación electromagnética (proveniente de artefactos eléctricos, telefonía celular, terminales de video de computadores personales) que afecta a un porcentaje no menor (pero indeterminado) de personas causando variados síntomas como cefaleas intensas, pérdida de la capacidad de concentración, depresión psicológica, entre otras, y que causan frecuente deterioro en su actividad ocupacional (59). Además, en personas

con hipersensibilidad a radiación electromagnética, sus efectos se manifiestan con mayor intensidad afectando los focos *53BP1* y γ -*H2AX* en linfocitos humanos de personas electro-sensibles (37).

GRADOS DE CERTEZA DE LA RELACIÓN CAUSA-EFECTO DE LOS PRINCIPALES EFECTOS SOBRE LA SALUD CAUSADOS POR EXPOSICIÓN A RADIACIONES “NO IONIZANTES”, SEGÚN RESULTADOS DEL PROGRAMA DE CAMPOS ELECTROMAGNÉTICOS DE CALIFORNIA (60)

Se conoce que los campos electromagnéticos están relacionados con una mayor incidencia de diversas formas de cáncer, entre éstas, leucemia, tumores cerebrales, cáncer de mama. No obstante, se han descrito otras enfermedades que parecen tener relación con la radiación electromagnética, tales como esclerosis lateral amiotrófica, enfermedad de Alzheimer, asma bronquial, enfermedades alérgicas, aumento de incidencia de abortos, dermatitis por monitor de televisor o computador, electrosensibilidad, alteraciones neuroconductuales, cardíacas y endocrinas, etc.

A continuación se presenta un listado de las diversas enfermedades en cuya etiopatogenia puede intervenir la radiación electromagnética, clasificadas de acuerdo a la certeza que se tiene respecto del papel etiológico de dichas radiaciones de acuerdo al estudio realizado en el Programa de Campos Electromagnéticos de California, bajo el patrocinio de las autoridades administrativas y de salud del Estado de California (60). En ese programa, además de clasificar las probabilidades de causa-efecto para las radiaciones electromagnéticas y diversas patologías mediante las pautas de la IARC (International Agency of Research on Cancer), estableció las “pautas-guía de California”, de acuerdo a las cuales tres revisores expertos calificaron la información existente de acuerdo a grado de confianza de los análisis estadísticos de los trabajos publicados, y establecieron un criterio para definir si existía una relación causa-efecto para cada patología, y la probabilidad de la ocurrencia de esa relación causa-efecto.

Radiación electromagnética como etiología muy improbable (2 a 10% de probabilidad que exista una relación causa-efecto):

- Alteraciones reproductivas o de desarrollo (excluyendo abortos)
- malformaciones congénitas
- bajo peso al nacimiento
- Radiación electromagnética como carcinógeno universal (todos los cánceres)

Radiación electromagnética como factor etiológico posible (10 a 50% de probabilidades de existencia de relación causa-efecto)

- Enfermedad de Alzheimer
- Cáncer de mama masculino
- Cáncer cerebral en niños
- Problemas cardíacos, incluyendo infarto del miocardio
- Suicidio

Radiación electromagnética como factor etiológico probable (más de 50% de probabilidades de existencia de relación causa-efecto)

- Leucemia en niños
- Cáncer cerebral en adultos
- Aborto espontáneo
- Esclerosis lateral amiotrófica (enfermedad de Lou Gehring)

Radiación electromagnética posible o probable (desacuerdo entre evaluadores científicos)

- Cáncer de mama femenino
- Leucemia en adultos

Cáncer

Más arriba se han descrito los principales estudios que sugieren que la exposición a radiación electromagnética, tanto ELF como de radiofrecuencia, aumenta el riesgo para desarrollar diversos tipos de tumores: leucemias y linfomas, cáncer de mama masculino y femenino, tumores cerebrales, cáncer de testículo, endometrio y colon, entre otros. La certeza de esta afirmación es variable de acuerdo al tipo de tumor y órgano del que se origina (60). Por ejemplo, se le ha asignado alta certeza (certeza mayor de un 50%) para la asociación de estas radiaciones con leucemia en niños y cáncer cerebral en adultos, mediana o baja certeza (entre un

10 y un 50%) para cáncer de mama masculino y para cáncer cerebral en niños, y muy baja o nula certeza para la clasificación de la radiación electromagnética como un carcinógeno universal (todos los cánceres) (certeza menor de un 10%). Una certeza del 50% significa que existen 50% de posibilidades que la asociación entre ese cáncer y la radiación electromagnética exista realmente y el 50% complementario de posibilidades que la aparente asociación fuera causada por azar en forma independiente a las radiaciones electromagnéticas

Leucemia en adultos

Kheifets ha hecho estudios metaanalíticos que han mostrado que la exposición a radiación electromagnética está asociada a un aumento de incidencia de leucemia en adultos (61), esta evidencia está basada en 43 estudios, de los cuales 23 tienen un RR sobre 1,0 y 20 sobre 1,2; el resumen metaanalítico de estos datos es 1,2 (IC 95%=1,12-1,24). La probabilidad de la asociación era entre un 10 y un 50% (60).

Leucemia infantil

Un metaanálisis realizado por Wartenberg (62) muestra un riesgo relativo de 1,4 (IC 95%=1,0-2,0). La probabilidad de la asociación era mayor que un 50% (60).

Cáncer cerebral en adultos

De los 29 estudios revisados por Kheifets en su metaanálisis (63), 23 tenían un RR superior a 1,0 ($p=0,004$), y 15 estaban sobre 1,2 ($p=0,14$); el $RR=1,2$ (IC 95%=1,1-1,3). La probabilidad de la asociación como causa-efecto era mayor que un 50% (60).

Cáncer cerebral infantil

La probabilidad de la asociación era entre un 10 y un 50% (60).

Cáncer de mama

Para el cáncer de mama femenino, debido a desacuerdo entre evaluadores del Programa de Campos Electromagnéticos de California, se ha establecido una probabilidad entre un 10 y un 90% para la asociación con exposición a radiación electromagnética; para cáncer de

mama masculino, la probabilidad de asociación era entre un 10 y un 50% (60).

Abortos espontáneos

Se ha demostrado que la exposición a radiación electromagnética, tanto ELF como la proveniente de terminales de video, incrementa en forma importante la incidencia de abortos espontáneos, principalmente al inicio del embarazo. Estudios recientes han permitido estimar, para el Estado de California, que el 40% de los 60.000 abortos espontáneos que ocurren al año, es decir, 24.000 abortos, son causados por radiaciones electromagnéticas (64-66)

Efectos neuroconductuales

Se ha demostrado la potenciación del efecto del fármaco sicoactivo clorodiazepóxido bajo la exposición de radiaciones electromagnéticas de baja intensidad (2450 MHz, pulsos de 2 μ segundos, 550 pulsos/segundo, 10 W/m²) (67). Se han demostrado también alteraciones neuroconductuales en animales de experimentación sometidos a una prueba de laberinto y a aprendizaje espacial (68, 69). También se han detectado alteraciones bioquímicas bajo el efecto de radiación electromagnética de 61 GHz, la que induce la liberación de opioides cerebrales (70). Todo lo anterior indica que este tipo de radiaciones, por distintos mecanismos propuestos, causan un efecto a distinto nivel en el funcionamiento del sistema nervioso central. Esto concuerda con las descripciones del aumento de la tasa de suicidios en trabajadores de líneas eléctricas ($RR=2,0$, IC 95%=1,1-3,8) y en operadores de plantas eléctricas ($RR=2,7$, IC 95%=1,3-55,5) (71). También se ha demostrado una correlación dependiente de la dosis con la exposición acumulativa, expresada en microtesla/año, con 0,05 a 0,11 μ T, el $RR=1,6$ (IC 95%=1,0-2,7), y con exposiciones $>0,12 \mu$ T, el $RR=1,7$ (IC 95%=1,0-2,9) (72).

Esclerosis lateral amiotrófica (enfermedad de Lou Gehring)

Diversos autores han demostrado correlación entre la exposición a radiación electromagnética y esta enfermedad (73, 74). Ahlbom (75) ha calculado los riesgos metaanalíticos a partir de estudios previamente publicados relacionando exposición a campos magnéticos

u ocupaciones eléctricas, y encontró un RR=1,5 (I.C. 95% 1,2-1,7), y en dos estudios de cohorte que asignaron exposiciones electromagnéticas según matriz de exposiciones por ocupación, un RR de 2,7 (I.C. 1,4-5,0).

Enfermedad de Alzheimer

Sobel *et al.*, en dos estudios, demostraron una asociación entre exposición ocupacional a campos electromagnéticos y enfermedad de Alzheimer, con RR = 3,0 y 3,9 respectivamente, con IC 95% = 1,6-5,4 y 1,5 y 10,6 (76, 77). Considerando que esta asociación fue significativa sólo en dos estudios y en varios otros la diferencia estadísticamente significativa no fue detectada, de acuerdo a las guías desarrolladas para el Programa de Campos Electromagnéticos de California (60) ha considerado con menor certeza a los campos electromagnéticos como causales de enfermedad de Alzheimer que como determinantes de esclerosis lateral amiotrófica; considerando por ejemplo, que otros factores confundentes tales como shocks eléctricos o corrientes eléctricas de contacto pudieron haber, alternativamente, influido en el desarrollo de la enfermedad de Alzheimer. El rol de la exposición reciente a radiación electromagnética en la enfermedad de Alzheimer se ve apoyada por el estudio de Feychting *et al.*, en donde, en un estudio comparativo dentro de una población de mellizos y gemelos en Suecia se vio que la ocupación reciente con exposiciones ocupacionales mayores de 0,2 μ T (RR=2.4, IC95%=0.8-6.9, y RR=2.7, IC95%=0.9-7.8), pero no la más antigua u ocupación original (RR=0,8, IC 95%=0,3-2,3), estaba estadísticamente relacionada con la enfermedad de Alzheimer, y que la exposición ocupacional reciente estaba relacionada con la demencia (RR=3.3, IC95%=1.3-8.6, y RR=3.8, IC95%=1.4-10.2) (78).

Enfermedad cardiovascular

Sastre demostró que la exposición a 200 mG causa una disminución en la variabilidad de la frecuencia cardíaca en la especie humana (79). Se ha asociado una disminución de la variabilidad en la frecuencia cardíaca un mayor riesgo para la ocurrencia de eventos cardiovasculares (80). En general, una disminución de la variabilidad biológica en respuesta a diversos estímulos refleja una alteración de los mecanismos de regulación homeostática que pueden prevenir el desarrollo de eventos biomédicos tales como

infarto de miocardio; estas alteraciones de los mecanismos homeostáticos suelen ocurrir cuando el individuo está sometido a agentes externos que sobrepasan el límite de la regulación homeostática en respuesta a dichos estímulos (81). En base a estos antecedentes, Savitz *et al.* (82) investigaron, por separado, las muertes causadas por arritmia, infarto agudo del miocardio, arteriosclerosis y enfermedad coronaria crónica en 138.905 trabajadores empleados en 5 empresas de electrodomésticos, y ha seguido su mortalidad entre 1950 a 1986. En este estudio, se ha calculado la exposición acumulativa a campos magnéticos basado en 2841 mediciones de campo magnético, y se ha establecido una correlación entre exposición acumulativa en μ T-años y muertes por arritmia y por infarto agudo de miocardio (subgrupo considerado como vulnerable a la interferencia con el control autonómico de la frecuencia cardíaca), pero no hubo correlación con las otras causas de muerte por causas cardíacas. Los riesgos relativos para exposiciones a 0 a <0,6, 0,6 a <1,2, 1,2 a <2,0, 2,0 a <3,4, y >4,3. μ T-años era de RR=1,00 (IC 95%=1,0-1,0), RR=1,14 (IC 95%=1,04-1,26), RR=1,19 (IC 95%=1,08-1,31), RR=1,35 (IC 95%=1,22-1,48) y RR=1,62 (IC 95%=1,45-1,82) respectivamente (82).

MECANISMOS PROPUESTOS PARA LOS EFECTOS BIOLÓGICOS DE RADIACIONES “NO IONIZANTES”

Los mecanismos propuestos son:

- Efectos térmicos.
- Efectos no térmicos
 - * melatonina
 - * ferritina
 - * ornitín descarboxilasa y poliaminas relacionadas
 - * alteraciones en la membrana celular
 - * aumento de permeabilidad de la barrera hematoencefálica
 - * proteínas de choque térmico (HSP)
 - * cambios endocrinos
 - * mastocitos e histamina
 - * mutagenicidad
 - * imprinting

Efectos térmicos

Las radiaciones electromagnéticas de radiofrecuencia, dependiendo de su intensidad, producen una elevación

térmica de los tejidos. La mayoría de las normas internacionales consideran que los mecanismos implicados en los efectos biológicos principales involucran un efecto térmico, y se basan en los efectos térmicos inducidos por estas radiaciones. Una elevación de la temperatura puede afectar el funcionamiento de diversos sistemas biológicos y si es más pronunciada, causar un daño irreversible. No obstante, aún las elevaciones moderadas inducen la síntesis, por parte de las células afectadas, de proteínas de choque térmico (HSP), las cuales por un lado protegen a las células contra las altas temperaturas y otras condiciones de stress físico o químico, pero también protegen a las células neoplásicas de la acción de agentes farmacológicos terapéuticos usados en el tratamiento del cáncer y pueden proteger a la célula cancerosa contra su destrucción por el sistema inmunológico. Además, como las HSP intervienen en la modulación de la acción de diversas hormonas, pueden afectar la acción de éstas provocando alteraciones de diverso tipo e incluso favoreciendo el desarrollo de cánceres hormono-dependientes (*vide infra*).

Los tejidos que más se alteran son los que tienen un mayor porcentaje de agua en ellos (sistema nervioso central, globo ocular), lo cual se manifiesta frecuentemente como cefaleas, insomnio, y otras alteraciones bajo el efecto de exposición a este tipo de radiaciones. En órganos con poca o nula circulación sanguínea (globo ocular) el daño puede ser mayor puesto que la pérdida de calor es más lenta.

Uno de los efectos que es considerado, por algunos autores, como térmico, es el aumento de permeabilidad de la barrera hematoencefálica. Esto permite el paso de diversas moléculas desde la sangre al cerebro, entre ellas, moléculas tóxicas que normalmente son detenidas por esta barrera (83).

Efectos no térmicos

Existen efectos que se producen bajo intensidades mucho menores que aquellas que producen efectos térmicos. Se considera que la absorción de energía bajo 0,08 W/kg para la población general y bajo 0,4 W/kg para los trabajadores no estaría produciendo efectos térmicos. Sin embargo, bajo esos niveles se pueden estar produciendo efectos por mecanismos microtérmicos, por inhibición de la secreción de la hormona melatonina por igual mecanismo que

el de la luz, por interacción con los mecanismos de repolarización de neuronas, alteración en la estructura y función de diversas enzimas, alteración de canales iónicos, u otros cambios a través de variados mecanismos, que serán analizados más abajo.

Entre los efectos microtérmicos se describe la percepción auditiva de las ondas de radar. Se piensa que estas radiaciones producen elevaciones de temperatura muy rápidas pero muy débiles (10^{-6} °C en un microsegundo). El gradiente térmico genera ondas de presión termoelásticas que se propagan a través del tejido cerebral hasta la cóclea, en donde ese estímulo es percibido como un sonido (84).

Se pueden generar también efectos indirectos, por ejemplo, corrientes eléctricas en implantes metálicos en el organismo, que causan molestias o bien alteran el funcionamiento de estos aparatos (por ejemplo, en marcapasos). La Comisión Federal de Comunicaciones de Estados Unidos de Norteamérica (FCC)⁶ en la hoja de servicio de chequeo del equipo BlackBerry bajo el número de identificación en FCC: L6ARBT70UW (85), advierte que se debe utilizar la funda aprobada por la norma RIM⁷ con una pinza integrada para el cinturón cuando se lleve el dispositivo en contacto con el cuerpo del usuario, o bien que se debe mantener una distancia de 2,5 cm entre el dispositivo y el cuerpo del usuario mientras el dispositivo BlackBerry esté transmitiendo. Además el manual de seguridad del BlackBerry agrega que los efectos a largo plazo pueden presentar el riesgo de daños graves por exceder normas de exposición a RF; indica mantener el BlackBerry alejado de dispositivos médicos, incluidos marcapasos y audífonos, ya que pueden funcionar de forma incorrecta y provocar lesiones graves o la muerte al usuario o a otras personas.

6 La Comisión Federal de Comunicaciones regula las comunicaciones interestatales e internacionales por radio, televisión, cable, satélite y cable en los 50 estados, el Distrito de Columbia y territorios de Estados Unidos de Norteamérica. Fue establecido por la Ley de Comunicaciones de 1934 y opera como una agencia independiente del gobierno Estados Unidos de Norteamérica y son supervisados por el Congreso

7 Research In Motion (RIM) es fabricante de móviles canadiense; dispone de la aprobación y certificación por la Organización del Tratado del Atlántico Norte (OTAN), así como por organismos gubernamentales de Estados Unidos de Norteamérica, Canadá, Reino Unido, Austria, Australia y Nueva Zelanda

Se considera que la mayoría de los efectos descritos más arriba, como el aumento de la morbimortalidad por diversos tipos de cáncer bajo el efecto de radiaciones electromagnéticas de diverso tipo, tanto las de muy baja frecuencia (50 Hz), como las de frecuencias mayores (radiofrecuencias, frecuencias de microondas), son inducidos por mecanismos no térmicos.

La radiación electromagnética también aumenta la proliferación celular, en especial en algunas líneas celulares tumorales (86), contribuyendo a incrementar el desarrollo de tumores.

Melatonina. Stevens *et al.* (87, 88) propusieron que los bajos niveles de luz en horas nocturnas o las radiaciones electromagnéticas causan una disminución de la secreción de melatonina. Se ha demostrado que la melatonina disminuye la tumorigénesis mamaria en animales de laboratorio. Se ha demostrado que la exposición continua a campos electromagnéticos potenciaba la proliferación celular de líneas de células de cáncer de próstata y cáncer de endometrio (89). Henshaw *et al.* analizan en 2005 las evidencias que sugieren el papel de la melatonina en el aumento de riesgo de leucemia infantil (90).

Ferritina. Shao (91) propuso que la ferritina, marcador tumoral que se presenta en altas concentraciones en pacientes portadores de varios tipos de cáncer, puede estar involucrada en el desarrollo de tumores inducidos por radiación electromagnética.

Ornitín descarboxilasa y poliaminas relacionadas. Se las ha relacionado con la inducción de crecimiento tumoral. Se ha demostrado que la exposición a diversas radiaciones electromagnéticas a intensidades bajas induce en diversos cultivos celulares y también in vivo aumento de la concentración celular de ornitín descarboxilasa (92). Estos antecedentes permiten suponer un posible mecanismo que favorecería la carcinogénesis inducida por estas radiaciones.

Alteraciones en la membrana celular. Las radiaciones electromagnéticas afectan diversos canales iónicos de las membranas celulares (93) y aumentan el paso de calcio a través de las membranas celulares (94), proceso en el cual parecen estar involucrados los radicales libres (95).

Aumento de la permeabilidad de la barrera hematoencefálica. Esta aumenta en forma considerable bajo la acción de radiación electromagnética (96), permitiendo el paso de sustancias tóxicas que normalmente no pueden atravesar esta barrera, afectando así el sistema nervioso central.

Proteínas de choque térmico (HSP). Estas pueden también ser inducidas por exposición a niveles sub-térmicos de radiación electromagnética, tal como se ha demostrado experimentalmente en el nemátodo *Caenorhabditis elegans* (97). Las proteínas de choque térmico, como se ha mencionado más arriba, pueden proteger a las células cancerosas contra su rechazo inmunológico y a la vez modificar la acción de diversas hormonas.

Cambios endocrinos. Se han descrito aumento de secreción de opioides bajo el efecto de radiaciones electromagnéticas (70). También se conoce que la melatonina puede modificar los niveles de estrógeno y de prolactina, lo cual puede modificar el riesgo y el pronóstico para varios cánceres hormono-dependientes. Las proteínas de choque térmico también pueden modificar la acción de diversas hormonas vía interacción con receptores hormonales.

Mutagenicidad. Existen diversos estudios que demuestran efectos mutagénicos en animales de experimentación o en células en cultivo. No obstante, ya existe información en el ser humano. Esta información se basa en un estudio de una población de 235.635 niños nacidos poco tiempo después de dos censos diferentes en Suecia; sobre los cuales se realizó un seguimiento desde su nacimiento hasta los 14 años de edad, y los casos de cáncer fueron obtenidos del registro de cáncer sueco. No se encontró una asociación entre cáncer y exposición ocupacional materna a los campos magnéticos. Por el contrario, se demostró que la exposición paterna = ó > 0,3 μ T estaba asociada a un aumento de riesgo de leucemia infantil (RR=2,0, IC 95%=1,1-3,5) (98)

Imprinting. La exposición perinatal o durante la infancia a radiación electromagnética puede provocar cambios en la diferenciación de diversos tipos celulares, que se manifiestan mucho más tarde como cambios irreversibles cuantitativos y cualitativos en receptores de diversas hormonas. Esto puede causar en forma diferida la predisposición para desarrollar diversas patologías en etapas más tardías de

la vida (99-101). La inducción de proteínas de choque térmico es un claro indicio que el fenómeno imprinting puede desarrollarse, en forma directa por la radiación electromagnética, o bien indirectamente, a través de la modificación de los niveles de diversas hormonas que inducen imprinting, tales como las hormonas del stress (catecolaminas, glucocorticoides, hormona de crecimiento, prolactina, endorfinas) y la melatonina.

Un posible efecto causado por este mecanismo es el desarrollo de cáncer cerebral desarrollado en forma diferida después de la exposición prenatal a campos electromagnéticos ELF por el uso de frazadas eléctricas (RR=2,5, IC 95%=1,1-5,5) (102).

RESULTADOS EXPERIMENTALES QUE CONTRIBUYERON A NUEVAS NORMAS Y DECISIONES RESPECTO DE LOS EFECTOS EN SALUD DE LA TELEFONÍA MÓVIL

Entre los años 1974 y 1991, en la Unión Soviética se realizaron los estudios de los efectos biológicos (en animales de experimentación) de radiofrecuencias de 2375 MHz, de 10 a 1000 $\mu\text{W}/\text{cm}^2$, los que dieron origen a las normas soviéticas y actuales de Rusia. Más tarde, se realizó un estudio con científicos rusos y franceses que utilizando las técnicas de aquella época y además otras desarrolladas recientemente, confirmaron los resultados obtenidos anteriormente en la URSS (103). En estos estudios la administración a ratas preñadas de suero de ratas adultas expuestas a 500 $\mu\text{W}/\text{cm}^2 \times 7 \text{ h}/\text{día} \times 30 \text{ días}$ (2375 MHz) se demostró que causaba infertilidad, aumento mortalidad fetal (abortos), disminución de fetos que llegan a término, y baja sobrevivencia postnatal de las crías (103, 104).

Hasta este momento no existe ningún trabajo publicado respecto de los potenciales efectos diferidos (e irreversibles) de la exposición prenatal o perinatal a radiofrecuencia de telefonía celular que se haya demostrado como generado por el mecanismo del imprinting o desprogramación celular, los que de ocurrir estarían determinando el desarrollo de diversas patologías más tarde en la vida (100, 101, 105, 106). No obstante, ya existen estudios que prueban deterioros importantes en el feto, que se manifiestan de manera diferida en el niño, producto de la exposición prenatal y perinatal a tecnologías móviles y otras fuentes de radiación microondas. Por ejemplo, se ha propuesto una

relación entre exposición a radiación electromagnética y desarrollo de autismo (107, 108).

De acuerdo a un reciente informe de la Organización Mundial de la Salud OMS se ha descrito un aumento de gliomas causado por electrofrecuencia de telefonía celular, y se ha clasificado el uso de telefonía celular como probable causante de cáncer, en nivel 2b, afirmando que: "no está claramente establecido que de hecho aumente el cáncer", o "que hay reducida evidencia de carcinogenicidad en humanos, pero suficiente en animales de experimentación", y admitiendo que se ha detectado "una débil pero cierta evidencia de genotoxicidad", es decir, daño en el genoma o en su expresión, aunque no se sepa cómo se ha producido.

La Comisión de Medio Ambiente del Consejo de Europa, que propuso "la prohibición de todos los teléfonos móviles o sistemas WiFi de las clases y colegios", aunque luego solo reclamó que se redujera su uso. El redactor del informe, Jean Huss, recordó cuánto tiempo pasó hasta tomar conciencia del peligro "del amianto, la gasolina con plomo y el tabaco".

En Rusia se han establecido las siguientes medidas para proteger a su población, a través su Comité Nacional de Protección contra Radiaciones No Ionizantes:

1. Cada teléfono móvil debe tener un rótulo que diga que es fuente de Radio Frecuencias Electromagnéticas.
2. En la Guía del Usuario se debe incorporar una frase que diga que las Radio Frecuencias Electromagnéticas son dañinas para la salud.
3. El uso de teléfonos móviles no es recomendable para niños menores de 18 años por la Sanitary Rule SanPiN 2.1.8/2.2.4.1190-03, p 6.9.
4. El uso de los teléfonos móviles no es recomendable para embarazadas para proteger a su feto.
5. La mejor manera de protegerse de estas radiaciones es alejando el aparato del cuerpo y acortando el tiempo de las llamadas.

Además, se ha propuesto y aprobado en Rusia, lo siguiente:

- a. Se deben incluir en los establecimientos educacionales clases de uso de los teléfonos móviles y protecciones contra radiaciones no ionizantes en general.

- b. Es importante definir tiempos máximos de uso del celular en niños y adolescentes.
- c. Prohibir todo tipo de publicidad que incentive el uso de teléfonos móviles en niños y adolescentes y su participación en toda publicidad relativa a ellos.
- d. La agencia está lista para conducir programas de teleaudiencia masiva para explicar y aportar con los nuevos impactos de los campos electromagnéticos en la salud.
- e. Para los nuevos desarrollos de productos mejores criterios se deben aplicar que incluyan procesos bioeléctricos y las características del desarrollo humano a lo largo de su vida, deben quedar reflejados en un documento legal.
- f. Es necesario desarrollar un programa nacional, financiado por el estado, para estudiar posibles efectos a la salud provenientes de la exposición crónica a campos electromagnéticos de cerebros en vías de desarrollo.

RECOMENDACIONES DE LA ORGANIZACIÓN MUNDIAL DE LA SALUD Y NORMAS PARA RADIACIÓN ELECTROMAGNÉTICA NO IONIZANTE EN ALGUNOS PAÍSES SELECCIONADOS.

Radiaciones de Altas Frecuencias o Microondas (RF o HF)

En diversos países se han desarrollado estudios científicos independientes a los que la OMS ha realizado y continúa realizando, para validar que las normas definidas protejan, adecuadamente, a la población. Considerando los resultados estos estudios independientes, en múltiples países, se ha adoptado el Principio Precautorio, para diversos rangos de altas frecuencias.

A continuación, podemos comparar las recomendaciones definidas por la OMS a través de su organismo asesor ICNIRP, definidas en 1998, y algunos países que han restringido sus límites de exposición a ondas electromagnéticas de altas frecuencias. Rusia y China los redujeron hace más de dos décadas, hace unos quince años Suiza, Polonia y en esta década Italia, Bélgica, entre otros países. También, aparecen las recomendaciones de entidades como el Ministerio de Salud de Salzburgo, Austria y el grupo de expertos que revisaron 2000 estudios científicos en Seletun, Noruega, para proponer nuevos límites. Ambas directrices son bastante inferiores a los que incluso tienen, en la actualidad, los países más exigentes.

Tabla 1

Recomendaciones y límites de exposición máximos a radiaciones de altas frecuencias, para público general, en países que han adoptado medidas precautorias, versus los límites vigentes en Chile, medidos en densidad de potencia, según frecuencia de operación

Frecuencia	OMS ¹ /ICNIRP Recomen	Salzburg, Austria ² Recomendado (109-111)		Seletun ³ Recom	China ⁴	Suiza ⁵ Zonas Sensibles	Rusia ⁶ , Polonia ⁷ e Italia ⁸	Bélgica ¹¹	Chile ⁹		Chile ¹⁰ desde Dic 2009 (112)		
		Todo el País	Inter						Exter	Todo el País	Antes 2009	Zonas Urbanas	Zonas Urbanas Sensibles
Mhz	μW/cm ²	μW/cm ²	μW/cm ²	μW/cm ²	μW/cm ²	μW/cm ²	μW/cm ²	μW/cm ²	μW/cm ²	μW/cm ²	μW/cm ²	μW/cm ²	
900-1800	450 a 900	0,0001	0,0010	0,0170	4	4,2 a 9,5	10	11 a 23	435	100	10	450 a 900	
1801-2000	900 a 1000	0,0001	0,0010	0,0170	4	6,6	10	11 a 25	435	100	10	900 a 1000	
2001-2200	1.000	0,0001	0,0010	0,0170	4	6,6	10	25	1.000	100	10	1.000 a 1.100	
2201-3000	1.000	0,0001	0,0010	0,0170	4	9,5	10	25	1.000	1.000	1.000	1.000	
3001-10000	1.000	0,0001	0,0010	0,0170	4 a 13	9,5	10	25	1.000	1.000	1.000	1.000	
10001-15000	1.000	0,0001	0,0010	0,0170	13 a 20	9,5	10	1.000	1.000	1.000	1.000	1.000	
15001-300.000	1.000	0,0001	0,0010	0,0170	20	9,5	10	1.000	1.000	1.000	1.000	1.000	

Nota: Para obtener valores en μW/m² multiplicar por 10.000.

1 ICNIRP, EMF Guidelines, Health Physics 74, pág 511. 1998

2 Límites en espacios interiores y exteriores basados en el Estudio del Síndrome de Microondas, Universidad de Valencia, ver referencia 110.

3 International EMF Alliance, Seletun Statement. Oslo, Norway 3 Feb 2011

4 WHO Comparative International Limits. China: Ministry of Health, Dec 12th, 1987 and Feb 14th, 1989.

5 Antennes de Telephonie Mobile, Technologie Sans Fil et Santé, pag 21-23. Jean Pilette, Nov 2008 ; Swiss: ORNI Dec 23rd, 1999

6 Ministerio de Salud Pública de Rusia 2003: SanPin 2.1.2/2.2.4.1383-03 y SanPIN 2.2.4/2.1.8.055-96

7 Decret 28 Nov 2003 (Polonia)

8 Decreto del Primer Ministro de Italia, 8 Julio 2003, GURI N°200 29.8.2003

9 Subtel, Resolución Exenta 505, 2000, modificada con la Resolución Exenta 1672. 2002 (Chile)

10 Subtel, Resolución Exenta 403, 30 Abril 2008. Última revisión 4/1/2011. Para frecuencias de 400 a 2000 Mhz la densidad de potencia es f/2 (f en Mhz) y para frecuencias entre 2000 y 300.000 Mhz es 10W/m2, con densidades de potencias menores en zonas sensibles y zonas urbanas.

11 Arrêté Ministeriel, May 7th, 1987 et Arrêté Real 10 Aout 2005 (Bélgica)

Los límites de exposición a radiaciones, de altas frecuencias, en Chile, han disminuido sólo para frecuencias de celulares que operan en el rango de 800 a 2.200, en zonas urbanas y zonas sensibles urbanas definidas como: establecimientos de enseñanza básica, hospitales, jardines infantiles, salas cuna y asilos de ancianos. En zonas rurales, las densidades de potencia, **han aumentado, incluso por sobre los límites de la OMS.**

Por lo tanto, la protección real para radiaciones microondas de la población chilena, es mínima.. Pues, para frecuencias de teléfonos móviles avanzados, internet banda ancha (vía WiFi y WiMax), y otras tecnologías, que operan en frecuencias sobre 2.200 Mhz, se han mantenido las altas radiaciones de 1.000 uW/cm², para todo el país, sin restricciones de zona. Es importante notar que la definición de zona sensible, no tiene sentido, puesto estas personas pasan tanto o más tiempo en sus casas y espacios exteriores, bajo altas potencias para frecuencias sobre 2.200 Mhz, que debieran ser, igualmente, mínimas. En su lugar, era mejor definir límites para espacios interiores y exteriores, como se ha efectuado en la ciudad de Salzburgo, Austria, atendiendo a los impactos en la salud, demostrados por el estudio científico desarrollado por el propio Ministro de Salud de esa ciudad Dr. Gerd Oberfeld.

Rusia, Polonia, Italia y China son los países que ajustado sus límites de exposición de manera drástica para todo el espectro de frecuencias. Sin embargo, son igualmente, importantes las acciones que han tomado muchos países de bajar, considerablemente, sus límites de exposición en las áreas sensibles de la población, y para todo el país.

Las recomendaciones científicas son entre 100 veces y 10.000.000 de veces inferiores varios límites de la tabla anterior. Esto significa, que las personas deben hacer esfuerzos importantes para su propia protección, evitando permanecer en lugares al exterior de edificaciones y evitar permanecer cerca de ventanas, en particular, aquellas con vista directa a antenas de telefonía móvil. Adicionalmente, deben minimizar al máximo el uso de tecnologías móviles y fijas de todo tipo, que operen con emisión de microondas como: hornos, monitores de bebés, sistemas de seguridad, entre otros.

Como referencia, los límites de exposición máximos en altas frecuencias, para público general, son cinco veces menores que los límites de exposición ocupacionales, recomendados por la OMS. Por ejemplo, para una frecuencia de 1800 Mhz el límite ocupacional recomendado por la OMS es de 4.500 µW/cm², y para 2100 Mhz es de 5.000 µW/cm².

El Parlamento Europeo, con fecha 2 de Abril de 2009, dio a conocer una Resolución relativa a la Salud y a los Campos Electromagnéticos. En este documento efectuaron un llamado a: todos sus países miembros a la OMS, a las empresas de telecomunicaciones, accionistas, y empresas privadas, para actuar, en conciencia, para disminuir los límites máximos de exposición de la población, redefiniendo productos y redes de soporte para minimizar deterioros en la salud, por la sobreexposición a radiaciones no-ionizantes (incluidas las redes de alto voltaje, y equipamientos médicos entre otros).

OPCIONES TECNOLÓGICAS FACTIBLES DE IMPLEMENTAR

Considerando que los primeros sistemas celulares utilizaban celdas que cubrían radios de varios kilómetros. A medida que el número de usuarios crecía, un mejor cubrimiento era necesario en ciertas áreas, por lo cual el tamaño de las celdas se reducía. El rango de cubrimiento era entonces entre menos de 2 kilómetros y 40 kilómetros y estaba determinado **por la potencia de la señal transmitida y la altura de la antena.** De acuerdo al radio cubierto por una celda, estas son clasificadas en macroceldas, microceldas y picoceldas.

Las macroceldas tienen un diámetro de cobertura mayor a los 1000 mts.

El uso de **microceldas** (con rango de cubrimiento entre 100 y 1000 metros) incrementa la capacidad de la red, ya que permite hacer un mayor manejo de tráfico y hace posible la utilización **de potencias de transmisión muy bajas.** Desde el punto de vista del operador, esto se traduce en ventajas adicionales como una mejor cobertura, bajos costos de la red por suscriptor y mayor eficiencia en la operación del sistema. Los requerimientos claves del sistema microcelular incluyen

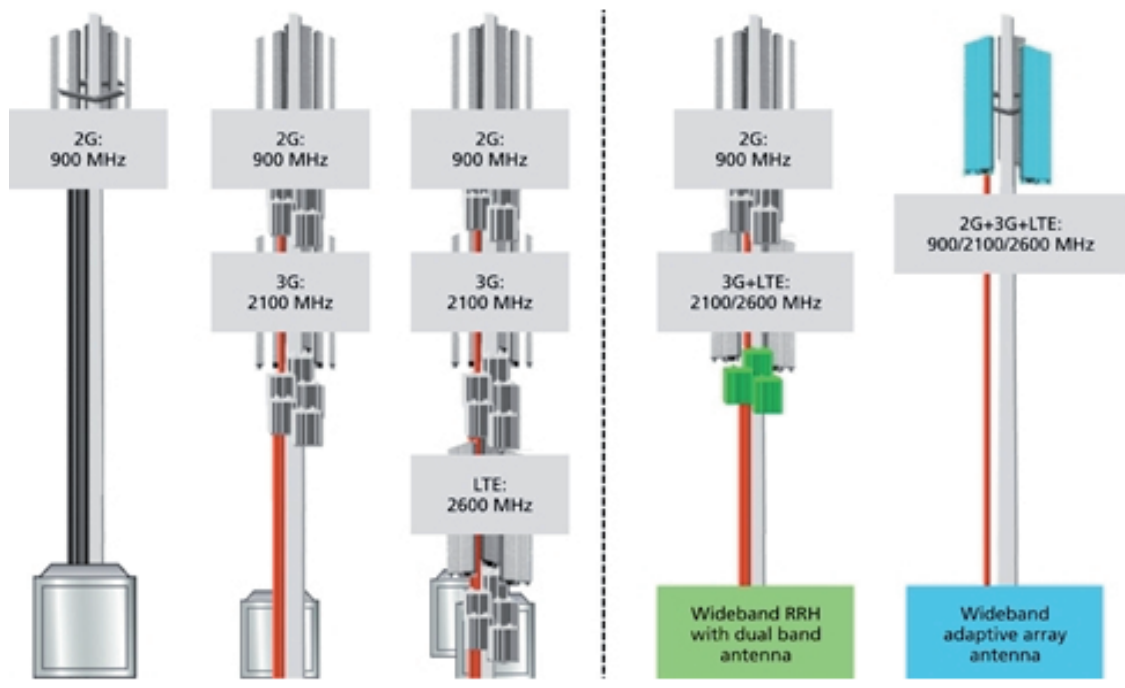
la coexistencia e interoperabilidad con los sistemas ya instalados, necesitando un desarrollo mínimo de ingeniería para su diseño.

Al reducir mucho más el tamaño de las celdas, se logran las **picoceldas** (cobrimiento menor a 100 metros). Como se sabe, una reducción en el tamaño de una

celda implica un aumento en su capacidad (manejo de tráfico), por lo que las picoceldas se utilizan para brindar cobertura en las zonas identificadas como de muy alto tráfico, tales como centros de negocios o centros comerciales, donde los usuarios tienen un patrón de comportamiento de baja movilidad y se encuentran en un ambiente cerrado.

Figura 1

Esquema de instalación de 3 antenas en un solo monoposte, con el uso de nuevas tecnologías



En la figura 1 se puede observar que 3 antenas van a quedar instaladas en un solo monoposte, usando todo el rango de frecuencias de los celulares con el uso de nuevas tecnologías.

Futura legislación y normativa en Chile

El Congreso Nacional de Chile tiene en desarrollo un nuevo proyecto de ley con el objeto fijar el régimen jurídico aplicable a los servicios de comunicación dirigida al cumplimiento de medidas de protección para la salud de la población en general ante los demostrados efectos a la salud que los campos electromagnéticos de altas y extremadamente bajas frecuencias pueden generar, materia e este estudio. Igualmente, se dejará abierta la posibilidad de nuevas restricciones en cuanto

al nivel emisiones electromagnéticas con objeto de incorporar nueva evidencia científica.

Un objetivo importante de la futura legislación es orientarse el desarrollo de las telecomunicaciones hacia antenas de menor **potencia y tamaño**.

También se pretende incorporar en la legislación el reconocimiento de **Zonas Saturadas de instalación de estructuras**, si en un radio de 100 m existen más de dos antenas, y/o **Zonas Saturadas de sistemas radiantes** de telecomunicaciones, si la potencia excede la norma que determinará la Subsecretaría de Telecomunicaciones de acuerdo Resolución Exenta considerando como referencia al promedio de las potencias de los 5 países con límites más estrictos de la

OCDE en base a las normas de emisión electromagnética. Los autores del presente trabajo proponen considerar Italia, Bélgica, Polonia, China y Rusia.

Radiaciones de Frecuencias Extremadamente Bajas (ELF)

Muchos países han disminuido, notablemente, los límites de exposición a ondas electromagnéticas en el rango de 50 o 60 Hz, según corresponda a cada país. Particularmente, las asociadas a tendidos eléctricos, torres de alto voltaje, transformadores y subestaciones eléctricas, en recintos donde las personas permanezcan más de cuatro horas.

En adelante, sólo nos referiremos al componente de campo magnético de las radiaciones electromagnéticas no ionizantes, para relacionarlos con los estudios científicos mencionados, anteriormente, en el presente estudio.

El campo magnético que generan todos los productos eléctricos tanto de consumo masivo (teléfonos móviles e inalámbricos, computadores, televisores, parlantes, automóviles, electrodomésticos, entre muchos otros) y las instalaciones eléctricas de cualquier naturaleza, pueden constituir un serio riesgo para el desarrollo de enfermedades, potencialmente, irreversibles, causadas por sobreexposición voluntaria o involuntaria, como se demostró al comienzo de este estudio.

Los límites de exposición máximos para frecuencias de 50 o 60 Hz, del público general, son mucho menores a los límites ocupacionales, recomendados por la OMS, en un factor de cinco. Es decir, límite máximo que la OMS recomienda para personas expuestas, de manera prolongada a estas radiaciones es de 500 μT , como referencia. Por lo tanto, analizaremos sólo la exposición de la población, para esta frecuencias, porque ya se encuentra sobreexpuesta, como se verá más adelante. Por, lo tanto con mayor razón, lo estarán las personas expuestas a límites ocupacionales que son mucho mayores.

Los países que tienen menores límites de exposición para frecuencias de 50 o 60 Hz son: Suecia, Noruega, Dinamarca, Holanda, Israel, Suiza, Italia, Brasil y Rusia. Sin embargo, paulatinamente, varios países han adaptado sus legislaciones o han emitido decretos/

recomendaciones para acercarse a los valores más bajos que les sean posibles, para proteger a la población.

Es importante notar que Rusia desde el año 1996 ha tenido los límites para 50 Hz en los mismos valores actuales, que además, son idénticos tanto las exposiciones públicas como ocupacionales. Sin embargo, en el año 2007, se restringieron, aún más, para el interior y el exterior de edificaciones residenciales.

En Estados Unidos no existe una legislación federal, para la frecuencia de 60 Hz. Sólo siete estados han establecido estándares para líneas de transmisión eléctricas (Florida, Minesota, Montana, Nueva Jersey, Nueva York y Oregon). Sin embargo, sólo Nueva York y Florida, establecieron límites para campos magnéticos, en la líneas bajo condiciones de máxima carga.

En la ciudad de California, EE.UU, se ha asignado un presupuesto para la inversión que significará disminuir a nuevos límites más exigentes. Además, se han definido nuevas distancias para ubicar establecimientos educacionales: 31 m para instalaciones de líneas eléctricas entre 50 y 133 kV, 46 m entre 220 y 230 kV y 107 m entre 500 y 550 kV.

En Chile, los proyectos eléctricos que se someten a aprobación, sólo se rigen por las directrices del SEIA (Sistema de Evaluación de Impacto Ambiental) donde se menciona que se deben tomar como referencia ejemplos de otros Estados, con similares características ambientales a las del proyecto, para fundamentarlo, adecuadamente. Esto significa, que en muchas oportunidades se comparan las emisiones electromagnéticas de las instalaciones del proyecto con los límites de Estados de EE.UU, o de cualquier otro país del mundo. Al no utilizar los límites de los países más restrictivos, definitivamente, **el proyecto se aleja del objetivo fundamental, que es la protección de la población**, con alto riesgo de ser sobreexpuesta. Esto sucederá, inevitablemente, si el proyecto contempla que sus instalaciones se efectúen en lugares de permanencia o tránsito de personas o vehículos (veredas, calles, autopistas, túneles, entre otros).

Particularmente, resultará más nocivo para la salud de la población, colocar los tendidos eléctricos de forma subterránea, con el objeto de hermoear la ciudad, si

no se toman las precauciones de minimizar los campos magnéticos, pues estarán más cerca del cuerpo de las personas, que cuando eran aéreos.

En la tabla 2 (113) se muestran los límites máximos de exposición a radiaciones electromagnéticas para 50 o 60 Hz, que han adoptado diversos países, para proteger de mejor forma a la población, en algunos casos basados en el Principio Precautorio. Algunos valores son límites

máximos con fuerza de ley y otros son límites para comenzar acciones para disminuir, drásticamente, los campos magnéticos a los valores indicados, a través de acuerdos con la industria de servicios y de productos eléctricos. Las Areas Sensibles, incluyen la variable del lugar y tipo de instalación eléctrica a la que se aplica, si se especifica restricción. Las Otras Areas, son el complemento de lugares y tipos de instalaciones eléctricas, no especificadas en Areas Sensibles.

Tabla 2

Recomendaciones y límites de exposición para público general, de instalaciones eléctricas que operan en 50 y 60 Hz, en países que han adoptado algún tipo de precaución, medidos en densidad de flujo magnético, por país.

País /Estado/ Organización	50 Hz		
	Al Interior	Al Exterior	
	Toda Edificación	Areas Sensibles	Otras Areas
	uT	uT	uT
Recomendación CIPRNI (2)	100	100,0	100,0
Recomend Científicos de Seletun (3)	0,1	0,1	0,1
Suecia (4)	0,1	0,1	4,0
Noruega (5)	0,4	0,4	100,0
Dinamarca (6)	0,4	0,4	100,0
Holanda (7)	0,4	0,4	120,0
Israel (8)	1,0	1,0	30,0
Suiza (9)	1,0	1,0	100,0
Italia (10)	3,0	3,0	100,0
Rusia (11)	5,0	10,0	50,0
Eslovenia (12)	10,0	10,0	100,0

Argentina (13)	25,0	25,0	25,0
Polonia (14)	48,0	48,0	75,0
Chile (15)	N/D	N/D	N/D

País /Estado/ Organización	60 Hz		
	Al Interior	Al Exterior	
	Toda Edificación	Areas Sensibles	Otras Areas
	uT	uT	uT
Recomend IEEE Piernas y Manos (16)	63.160	63.160	63.160
Recomend IEEE Cabeza y Torso	904	904	904
Brasil (17)	3,0	3,0	83,3
Costa Rica (18)	15,0	15,0	83,3
EE.UU (Florida) (19)	15,0	15,0	N/D
EE.UU (New York)(20)	20,0	20,0	N/D

Nota: Para convertir a mG multiplicar por 10 los valores.

- (1) Fuente: Commission of European Communities, Brusel, Belgium. 1.9.2008. National Institute for Public Health and Environmental of The Netherlands. Comparison of International policies on EMF. Rianne Stam, Laboratory of Research. May 2011 WHO Standards Harmonisation Project EMF Exposure Standards Applicable in Europe and Elsewhere, Environment & Society Working Group. Euroelectric Report March 2006 Normas y Recomendaciones de Campos Electromagnéticos de países mencionados en cada punto indicado ().
- (2) Comisión Internacional de Radiación No-Ionizante, Guidelines for the Frequency Range 1Hz to 100 kHz, Revisión 2010, que mantiene los límites recomendados en 1998.
- (3) El Seletun scientific panel revisó más de 2000 estudios científicos para definir nuevas recomendaciones de límites para campos electromagnéticos para frecuencias extremadamente bajas y altas frecuencias.
- (4) Medidos como valor medio anual. Areas sensibles: guarderías de niños y hogares. Sólo se permite que un 10% de los hogares tengan una o más habitaciones con 0,2 uT. Las empresas de transmisión eléctrica tienen un acuerdo voluntario para cumplir con la norma de 0,4 uT anual promedio para la instalación de nuevas líneas. Low-Frequency electrical and magnetic field: The precautionary principle for national authorities. September 1996.

- Estocolmo tiene un límite de 2 uT. Las líneas antiguas deben cumplir con un promedio anual de 4 uT, pero están en ajuste hacia los límites más restrictos aplicado a las áreas sensibles.
- (5) Límite de acción, en valor promedio anual. Areas sensibles: jardines infantiles, colegios, nuevas construcciones habitacionales y todas las nuevas líneas eléctricas. Ley de Radiaciones Electromagnéticas, 12 Mayo 2000.
 - (6) Límite de acción, es decir evaluar las acciones a tomar en áreas sensibles: hogares, guarderías infantiles y colegios, implementando soluciones a un costo razonable (por ejemplo cambiando el lugar de áreas habitacionales en las nuevas edificaciones, entre otros). Desde 1993 no se permiten construcciones residenciales o para el grupo sensible, en terrenos aledaños a cualquier tendido eléctrico de alto voltaje.
 - (7) Aplicables a nuevos tendidos eléctricos, nuevas construcciones residenciales, incluyendo sus jardines, colegios y jardines infantiles. Ministry of Infrastructure & Environmental Recommendation 2007. Si se exceden los límites en alguno de estos lugares se deben vender los recintos excedidos o pagar compensaciones, pero aún no se solicita retirarlos (TSO Policy) Letter of the Ministry of Housing. Oct 2005. Reiteration of the Spacial Planing and the Environment on overhead powerlines, on letter of Nov 4th, 2008.
 - (8) Límite legal. Se han tomado las acciones necesarias para proteger a la población sobreexpuesta por sobre el límite de 1 uT. Las edificaciones debe estar a distancias de al menos 35 m para 400 kV, 20 m para 161 kV, 3 m para 110 KV, 3m de 11 a 36 kV. Tranformadores interiores a 3 m de pared colindante con lugar habitable. WHO EMF Protection.
 - (9) Límite legal, desde el 1 Feb 2000: 1 uT para nuevas líneas eléctricas sobre la cabeza o bajo el suelo > 1kV, subestación o transformador eléctrico (nuevos y antiguos), nuevas líneas de trenes y troles. Las instalaciones existentes tienen tres años para adaptarse a estos nuevos límites. Frecuencias aplicación 0 a 300 Ghz.
 - (10) Areas sensibles: todos los espacios de edificaciones regularmente ocupados, parques con juegos de niños y recintos en que se puedan usarse en para estos fines (aunque no existan construcciones aún). En para el interior de las construcciones, los límites son los que imponen las mejores tecnologías disponibles en el mercado.
Sólo se han emitido 10 excepciones para 3 uT y 1 para 5 uT, puesto que se han tomado las medidas operacionales y financieras para cumplir la norma de 1 uT. 100 uT para las instalaciones antiguas en sitios de operación (no poblados).
Límites legales, aplicables sólo a líneas eléctricas. Establishing the exposure limits, attention values and quality targets at the network of 50 Hz for power lines. Gazzetta Ufficiale Della Repubblica Italiana N°200, 29 Agosto 2003. Frecuencias cubiertas 0-100 kHz.
Límite de atención (acción inmediata) 10 uT para sistemas públicos eléctricos, de operación normal, como valor medio diario, para lugares en donde la permanencia a la exposición es mayor a 4 hrs, en construcciones existentes.
Límite objetivo (final) 3 uT para nuevos sistemas eléctricos públicos, de operación continua, nuevas construcciones y las áreas sensibles: hogares, colegios, y otros donde se permanezca más de 4 hrs.
Desde el año 2000, Veneto, Emilia Romagna y Toscana han impuesto el límite de 0,2 uT como ley
 - (11) Límites Federales Legales, división sólo por espacios interiores y exteriores: The sanity-epidemiological welfare of population. March 30th, 199 N° 52-FZ; SanPin 2.1.2 1002-00 Sanity-epidemiological requirements for living buildings and locations; MSanPin 001-96 Sanitary Norms of permissible levels for physical factors during use of domestic articles. Desde 2007 los nuevos límites son 5 uT al interior y 10 uT al exterior de edificaciones residenciales. Russian National Committee of Non-Ionizing Radiation Protection, 2008 Report. Otro tipo de edificaciones se rigen por las otras normas.
 - (12) Límite Legal, para instalaciones eléctricas <1 kV. Areas sensibles: hospitales, resorts de salud, áreas residenciales, edificaciones turísticas, jardines infantiles, recintos deportivos, parques y recintos recreativos, centros públicos, que incluyen servicios y restaurantes. Decreto para radiaciones electromagnéticas en espacios abiertos y habitables, 1996. Rev 2004..
 - (13) Límites legales. Resolución de la Secretaría de Energía de la Nación, SE 77/98.
 - (14) Aplicable a líneas de transmisión, transformadores y estaciones de compensación ≥ 132 kV
 - (15) N/D No Definidas. La Superintendencia de Electricidad y Combustibles es quien define las directrices generales de seguridad para instalaciones eléctricas, principalmente para contar con la adecuada franja de seguridad. Sin embargo, los proyectos eléctricos que imponga algún riesgo, son sometidos al SEIA (Sistema de Evaluación de Impacto Ambiental) donde se pueden utilizar las normas de Estados con similares características medioambientales, para fundamentar su factibilidad. Reglamento de la Ley 19.300 de Medioambiente fue modificado por el Decreto 95 del Ministerio Secretaría General de la Presidencia, publicado en el Diario Oficial del 07.12.2002. "Artículo 7.- Las normas de calidad ambiental y de emisión que se utilizarán como referencia para los efectos de evaluar si se generara o presenta el riesgo indicado en la letra a) y los efectos adversos señalados en la letra b), ambas del artículo 11 de la ley, serán aquellas vigentes en los siguientes Estados: República Federal de Alemania, República de Argentina, Australia, República Federativa del Brasil, Confederación de Canadá, Reino de España, Estados Unidos Mexicanos, Estados Unidos de Norteamérica, Nueva Zelanda, Reino de los Países Bajos, República de Italia, Japón, Reino de Suecia y Confederación Suiza. Para la utilización de las normas de referencia, se priorizará aquel Estado que posea similitud, en sus componentes ambientales, con la situación nacional y/o local."
En algunos casos se usan los límites de la ciudad de Nueva York o países, según se adecuen al proyecto, sino se comparan con los límites recomendados del ICNIRP. Es decir, no hay un valor definido para las emisiones magnéticas, según el tipo de proyecto.
 - (16) Institute of Electric and Electronic Engineers C95.6. 23 October 2002. Page 11 y 12. Referencia para acción desde 904 uT para la cabeza y el torso; para todo el cuerpo 10 kV/m medido en derecho de paso bajo la línea y manos y piernas es desde 63.160 uT eléctrica.
 - (17) El límite de 83.3 uT se aplica a líneas de transmisión, distribución, subestaciones y generadores > 1 kV, en la superficie de las unidades. ABNT-NBR 15415. En Sao Paulo, desde el 2005, las normas son de 10 uT en promedio de 24 hrs, para las instalaciones existentes > 69 kV y 3 uT para las nuevas instaciones > kV 69. Asociación Brasileña de Estándares Técnicos. Rev 27 Mayo 2011.
 - (18) Líneas eléctricas sobre la cabeza, medidas al borde del derecho de vía peatonal. Reglamento general para el desarrollo y operación de obras de transmisión de electricidad, relativo a campos electromagnéticos y otros aspectos ambientales. Alcance 95-A, La Gaceta 248, 22 Dic 1998. Pronto a ser ley.
 - (19) 15 uT para instalaciones eléctricas de 230 kV y 20 uT para instalaciones eléctricas de 500 kV. N/D: No definido el límite en otras áreas, pues sólo se definieron para lo que se ha indicado.
 - (20) Límites sólo para líneas de transmisión eléctricas, medidos a la orilla de la franja de seguridad, sólo en áreas residenciales. N/D: No definido, en otras áreas, pues sólo se definieron para lo que se ha indicado.

Por qué existen enormes diferencias en las recomendaciones para definir los límites máximos de exposición a radiaciones no ionizantes?: Elementos para análisis.

La principal razón de la gran diferencia entre los límites propuestos por los organismos asesores de la OMS (ICNIRP, IEEE, entre otros) y definidos por los científicos que han realizado estudios, independientes a la OMS, es que los primeros, sólo se han considerado los **efectos térmicos** que puedan producirse en el cuerpo humano. Es decir, para prevenir de daños de quemaduras y efectos de corto plazo, como shocks eléctricos. Con este fin, se definió que a una distancia determinada del objeto radiante, si la temperatura del área expuesta, no sube más de 1° C, durante 6 segundos, no habrían riesgos de efectos negativos para la salud. Lo cual, es válido considerar para múltiples tecnologías del espectro de frecuencias.

Sin embargo, las tecnologías móviles o fijas, que operan en frecuencias que nuestros sistemas biológicos son capaces de reconocer e interactuar, **sin** que exista un efecto térmico de por medio, necesariamente, imponen mayores riesgos al organismo. En particular, en la comunicación de voz y datos, se utilizan frecuencias moduladas pulsadas, bioactivas para el ser humano, las cuales se acoplan a la onda de alta frecuencia que actúa como *carrier* o señal portadora.

Otro aspecto que hay que considerar es que la medición de 6 minutos para controlar la exposición en las tecnologías bioactivas (móviles o fijas), no tiene sentido, como medida de protección. Las siguientes son algunas de las razones:

1. La población **está bajo una permanente exposición** a ellas, de forma voluntaria o involuntaria, produciéndose efectos de sobredosis, por las múltiples exposiciones, simultaneas, a diversas frecuencia durante el día y la noche.
2. La **existencia de una enorme variabilidad de potencias de este tipo de ondas en el tiempo y el espacio**. Primero, porque se producen altos peaks durante el día; segundo, cada persona recibirá diferente exposición por los múltiples efectos pantalla o de amplificación potencias

por reflexiones en objetos metálicos y por las geometrías propias de los objetos que atraviese la proyección el haz de radiación; tercero, las distancias a las fuentes radiantes (de productos y sistemas de soporte o antenas) son relevantes para determinar grupos de personas que siempre tendrán una mayor sobreexposición; y cuarto, el tiempo de exposición es una variable fundamental en el análisis. Por lo mínimo, las potencias debe ser medidas por día, considerando los *peaks* y promedios por tramos, no como promedio en 6 minutos, en cualquier momento del día.

Por lo tanto, la sola consideración térmica, queda obsoleta y fuera de aplicabilidad para la definición de normas que protejan la salud de la población.

Además, las condiciones de salud de las personas son tan variables, que se esperan respuestas muy diversas en cada una de ellas. Entonces, ¿como definir un límite real que considere todas estas variables?.

Basta considerar los descubrimientos que los científicos han realizado respecto de los efectos de las sobreexposiciones, para tomar las medidas a tiempo, como lo han hecho ya muchos países, disminuyendo sus límites. La razón por la que Rusia instituyó, muy tempranamente, límites exigentes, para todo el país, fue para evitar que en el país se presenten enfermedades no vistas, en la magnitud que se observan son en los países del lado oeste.

Al considerar los *efectos no térmicos*, en la salud humana, los límites máximos de exposición son varios órdenes de magnitud inferiores a los recomendado por todos los organismos asesores de la OMS. Sin embargo, ellos aún no reconocen la posibilidad de su existencia, asegurando que no existe estudio científico alguno, que pruebe la existencia de riesgo para la salud fuera de las consideraciones *estrictamente térmicas*, que ellos ya han cubierto.

Hay que definir criterios para planificar el tipo de salud que se inducirá en el país con nuevos límites para radiaciones no ionizantes, y en base a ellos elegir las recomendaciones, que mejor cumplan con el objetivo:

- a. Que respeten la calidad de vida de las personas. Esto significa, no disminuir su funcionalidad y productividad, aún cuando no exista un diagnóstico de enfermedad, sólo sintomatologías propias de sobreexposición, que son muy oscilantes en el tiempo. *Esto podría inducir a adoptar las recomendaciones más restrictivas.*
- b. Que eviten o disminuyan la aparición de enfermedades diagnosticadas que son evitables. *Esto podría inducir a adoptar recomendaciones intermedias.*
- c. Que no anticipen las enfermedades, esperables en el largo plazo, por las propias condiciones genéticas de la población, sobre la base de información clínica más difícil de detectar en tiempo presente. *Esto podría inducir a adoptar recomendaciones menos restrictivas, dado el desconocimiento que, actualmente, existe.*

Particularmente, para la exposición ocupacional, las normas deben ser más restrictivas que las normas de público general. Sin embargo, en la práctica las normas se han definido a la inversa, en todos los países.

CONCLUSIONES

Las evidencias científicamente comprobadas que la exposición a ELF (domiciliaria, tendidos de alta tensión), RF o microondas constituyen un factor de riesgo para la salud humana, son:

1. Aumentan el riesgo de cáncer, por exposición a radiaciones electromagnéticas, el cual tiene un efecto diferido que tiene un largo período de latencia.
2. Existen múltiples efectos negativos causados por mecanismos no térmicos, a niveles miles de veces más bajos que los límites de la actual legislación nacional.
3. La evidencia científica sugiere con alta probabilidad que los efectos adversos para la salud también se producen por las antenas transmisoras de telefonía celular y por los mismos teléfonos celulares. Por lo tanto, ya existe suficiente información para concluir que pueden generar una serie de deterioros paulatinos, antes de que se pruebe en un 100% que son cancerígenos.
4. Existen, también estudios científicos que no han demostrado efectos adversos. Esto se puede explicar porque para encontrar diferencias estadísticamente significativas en donde, realmente, existen diferencias depende del número n de las muestras a comparar. Si el número de casos o el n de la población estudiada es pequeño, no se encontrarán diferencias estadísticamente significativas, aún cuando sí se pueden demostrar diferencias significativas para la misma población en estudio cuando el número n es mayor. Otra alternativa, es que se generen experimentos diseñados para no encontrar lo que no se quiere buscar.

RECOMENDACIONES

Las autoridades deben priorizar y resolver la grave problemática de salud que hoy existe, con la imposición de radiaciones no ionizantes a la población a niveles que no protegen su bienestar o su salud.

Los principales acciones que deben implementarse, al más breve plazo son las siguientes:

1. Aplicar el PRINCIPIO PRECAUTORIO, para definir límites máximos de radiación no-ionizante, en todo el espectro de frecuencias, que protejan la salud de los chilenos, priorizando las frecuencias desde 900 a 10.000 mHz y 50 Hz. Los nuevos límites deben ser los más exigentes, que sean posibles, con el compromiso de las industrias involucradas y las entidades del Estado encargadas de hacer cumplir las nuevas normas. Es importante que las nuevas normas se apliquen a todo el país y no sólo a ciertas zonas. Si se definen zonas sensibles, deben incluirse todo tipo de establecimientos educacionales, en todos los niveles, áreas residenciales, clínicas, hospitales, parques de diversión y deportivos, lugares de trabajo, entre otros.
2. Crear instancias de ACCESO A LA INFORMACIÓN en la legislación para proteger a la población de daños,

- potencialmente, graves a la salud. Esto significa que tanto SUBTEL y las empresas de telecomunicaciones, entre otras, deben proveer de manera inmediata, la información actualizada y en línea por Internet de las radiaciones de cada una de sus antenas. Investigar el sistema de control de radiaciones de altas frecuencias de Israel, que se implementará en el futuro.
3. Crear CONCIENCIA DE PROTECCIÓN en toda la población, particularmente, en los niños, adolescentes, adultos mayores, embarazadas, para evitar ser irradiados voluntaria o involuntariamente. Utilizar todos los canales de difusión que sean necesarios, para comunicar los reales riesgo a los que se exponen, para que tomen una decisión informada. Evitar acciones y avisaje comercial que incentiven a los niños el uso de teléfonos móviles (diseños infantiles, incorporación de juegos infantiles en ellos).
 4. Crear instancias de PLANIFICACIÓN PARA NUEVOS CAMBIOS EN LAS LEYES DE MÚLTIPLES MINISTERIOS, donde las autoridades que les competa (Ministerio de Salud, Ministerio del Trabajo, Ministerio de Educación, Ministerio de Vivienda y Urbanismo, Ministerio de Transportes y Telecomunicaciones, Municipalidades, entre otros), deberán proponer leyes que reduzcan o eviten el uso innecesario de tecnologías móviles. Es decir, pueden ser reemplazadas por tecnologías convencionales anteriores (teléfono con cable, Internet por cable), prohibir el uso de WIFI y WIMAX, en todos los lugares de trabajo y establecimientos educacionales, para todos los niveles educacionales, donde los servicios se pueden disponer, con igual o mejor calidad, vía cable. Minimizar o prohibir el uso de teléfonos móviles en espacios, congestionados de personas y con entornos de metal (metro, buses, trenes, vehículos, al interior de cualquier edificación, entre otras), pues la radiación microonda, se amplifica al interior de estos espacios. Para el caso, de nuevas construcciones, modelar las radiaciones estimadas provenientes de antenas y prevenir la sobreexposición de quienes las habiten: mallas de protección para las paredes, pinturas antirradiación en cielos rasos o prohibiendo su construcción en el área de riesgo, o simplemente, reubicando las edificaciones con mayor riesgo para sus habitantes.
 5. Crear un comité de un NUEVO DESARROLLO TECNOLÓGICO, conformado por expertos de diversas universidades para proponer las mejores soluciones disponibles en el mercado o con posibilidad de que se generen proyecto de innovación tecnológica donde Chile pueda competir o liderar, en conjunto con los expertos de la industria de telecomunicaciones y empresas que generan o comercializan productos de otras tecnologías, que operan en el rango de altas frecuencias.
 6. Definir NUEVOS PROTOCOLOS DE MEDICIÓN de radiación para altas frecuencias de tecnologías móviles. Es necesario que se incluyan mediciones en los lugares que se encuentran en el haz donde se proyectan mayores potencias. Esto significa efectuar las mediciones en diversos puntos de edificios de altura, casas en cerros habitados, y todo lugar donde se sospeche de la existencia de altas potencias, donde permanezcan personas por más de cuatro horas (pisos inferiores a techos con antenas de edificios, por ejemplo). Para el caso de productos de consumo masivo, los requisitos de baja emisión de campos electromagnéticos deben revisarse desde el momento que ingresen al país, si son importados (aún cuando el manual de usuario asegure un cierto valor de seguridad). Lo importante, es que solamente puedan ser comercializados con la certificación de cumplimiento de las normas y con mediciones efectuadas en Chile, antes de su comercialización.
 7. Generar soluciones con SISTEMAS TECNOLÓGICOS EXISTENTES, CON COMPROBADA CALIDAD implementados en países con límites muy restrictivos. Es necesario dar preferencia a la instalación de antenas de menor potencia y tamaño, siendo la emisión electromagnética de las antenas tan baja como técnicamente sea posible para mantener los sistemas funcionando. Estableciendo el criterio ALARA (As Low As Reasonable Achievable). Un número alto de antenas de baja emisión situadas cerca de los usuarios se traduce no solo en la exposición a menores intensidades desde las antenas, sino que adicionalmente en menores potencias desde los teléfonos móviles, lo cual también contribuye a disminuir en forma significativa la exposición y los efectos adversos en

salud. Respecto de los productos y servicios que operan en 50 Hz, es importante prohibir la venta en el mercado aquéllas que no cumplan con los nuevos estándares, o bien solicitar a las empresas que las manufacturan las modificaciones requeridas cumplir con éstos (usando filtros de protección para ELF o diseñados para emitir campos magnéticos de menor intensidad).

8. Solicitar una PARTICIPACIÓN ACTIVA DE LA INDUSTRIA y DE LOS CIENTÍFICOS en la ejecución de acciones tendientes a alcanzar el objetivo, del correcto uso del espacio radioeléctrico, haciéndolo inocuo y seguro. Considerando la evidencia presentada, que los campos electromagnéticos no ionizantes no son inocuos y seguros para la salud humana con los niveles de potencia a los que hoy se expone a la población, y el desarrollo de enfermedades que no tienen un fundamento científico claro, especialmente infantiles, que se están incrementando y que es posible atribuir a la exposición a éstas, un porcentaje importante, de dichas estas enfermedades.
9. Definir al MINISTERIO DE SALUD como organismo responsable de generar los LÍMITES MÁXIMOS DE EXPOSICIÓN A RADIACIONES (IONIZANTES Y NO IONIZANTES), para asegurar el adecuado y oportuno ajuste de normas, ante la evidencia científica, reemplazando a SUBTEL que tiene ese función, hasta hoy.
10. Incluir en las carreras biomédicas la obligatoriedad de ramos de FÍSICA Y ELECTROMAGNETISMO APLICADOS al área biológica, para comprender de mejor forma los fenómenos y mecanismos que afectan a los seres humanos, la flora y la fauna, al convivir con un aumento exponencial de nuevas tecnologías que les imponen mayores riesgos.

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Trastornos por déficit de atención: consideraciones desde la psicología para un diagnóstico comprensivo integral

Attention Deficit Disorder: Considerations from Psychology for an Integral Comprehensive Diagnosis

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Resumen

Se revisa el diagnóstico de Trastorno por Déficit de Atención en niños, en relación a su prevalencia (8% al 12% de los niños en edad escolar), siendo uno de los principales motivos de consulta en nuestro país. El objetivo del artículo es integrar los aportes de la mirada médica y la psicología en el diagnóstico, para que permitan otorgar las directrices de un tratamiento que considere el contexto y la particularidad de cada sujeto.

Se describen los criterios diagnósticos utilizados y las implicancias de éste en el área de la salud mental, educación, familia y sociedad.

Se plantea la comprensión desde la psicología, poniendo énfasis en considerar la inatención como síntoma de diversos cuadros emocionales en la infancia, al observar que desde el modelo médico generalmente este síntoma se reduce a un cuadro neurobiológico y a un posterior tratamiento principalmente farmacológico. La no consideración desde el paradigma de la complejidad y la multicausalidad en el diagnóstico, excluye áreas del desarrollo socio afectivo del niño que pueden ser fundamentales en la generación y el mantenimiento del cuadro.

Se releva la necesidad de abordar este cuadro con una mirada más amplia en el diagnóstico e intervención, considerando los aspectos subjetivos e interaccionales, buscando así dar cuenta de un diagnóstico clínico completo y de un abordaje comprensivo integral.

Palabras clave: Trastorno por Déficit de Atención con Hiperactividad, diagnóstico, diagnóstico diferencial, psicología infantil, salud mental.

Abstract

This study reviews the diagnosis of attention deficit disorder in children, in relation to its prevalence (8% to 12% of school-age children), which makes it one of the main reasons for consultation in Chile. The article seeks to integrate the contributions of the medical and psychological points of view in the diagnosis, allowing the outline of treatment guidelines that take into account the context and the particularity of each subject. We describe the diagnostic criteria and the implications of this diagnosis in the area of mental health, education, family and society. We then approach the discussion from the psychology, underlining the lack of attention as a symptom of various emotional childhood disorders, observing that from the medical model this symptom

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is generally reduced to a neurobiological disorder and leads to an exclusively pharmacological treatment. We estimate that no consideration from the paradigm of the complexity and causality in the diagnosis, excludes the development of socio-affective areas of the child which can be critical in the generation and maintenance of the disorder. We finally propose deliverance of a wider look in the diagnosis of ADD, considering subjective aspects through the articulation of the medical assessment with a psychological evaluation. This would allow a full clinical diagnosis and an integrated comprehensive approach.

Key words: Attention Deficit Hyperactivity Disorder, diagnosis, differential diagnosis, child psychology, mental health.

INTRODUCCIÓN

El objetivo de este artículo es reflexionar acerca del diagnóstico del Trastorno por Déficit de atención (TDA) en niños, aportando una mirada más amplia que integre el modelo médico y el psicológico, de tal forma que permita posteriormente delinear las intervenciones atingentes a cada caso en particular.

El ingreso al sistema escolar no resulta fácil para algunos niños y en la actualidad es muy frecuente encontrarse con padres que manifiestan preocupación al observar que sus hijos son diagnosticados con TDA y medicados debido a que se mueven constantemente, no se concentran al realizar sus actividades, tienen dificultades para seguir el ritmo de aprendizaje así como para acatar las normas, o entorpecen el desarrollo de la clase, siendo considerados "niños problemas", provocando dificultades con profesores y compañeros.

El colegio suele ser un espacio donde generalmente queda en evidencia gran parte de las problemáticas de la infancia. Existen numerosas razones, además del TDA, que podrían coincidir para que un niño manifieste dificultades atencionales: problemas emocionales y familiares, situaciones de violencia y/o abuso, adecuación curricular, problemas socioeconómicos, entre otros. Es por ello que se vuelve relevante profundizar en la historia de cada niño para comprender qué sucede⁵.

El Trastorno por Déficit Atencional, constituye uno de los Trastornos del Desarrollo más estudiados en psiquiatría infantil y posiblemente el más controvertido. Se ha transformado en uno de los diagnósticos de mayor prevalencia, (8% al 12% de los niños en edad escolar),

siendo uno de los principales motivos de consulta en nuestro país⁶.

Debido a esto, este trastorno se ha incorporado en las Políticas Públicas de nuestro país. A partir del año 2010 el Ministerio de Educación a través de la Ley 20.201 creó una nueva subvención para niños con Necesidades Educativas Especiales (NEE) que incluyó a los TDA-H como un nuevo tipo de discapacidad transitoria, mencionada en el decreto N°170⁷.

El Ministerio de Salud, (1996) considera los criterios diagnósticos del CIE-10 en el que se denomina Trastorno de la actividad y de la atención, que incluye el trastorno de déficit de atención y el síndrome de déficit de atención con hiperactividad. Excluyéndose los trastornos hipercinéticos asociados al trastorno disocial. (Clasificación Internacional de las Enfermedades [CIE 10], 1992)

Además, considera de relevancia la base biológica y el ambiente familiar y escolar del niño, los que pueden ser determinantes para la expresión sintomatológica, para la mantención del problema y para el desarrollo de trastornos reactivos.

Desde el modelo médico, el TDA es un trastorno con una base biológica determinado genéticamente, con manifestaciones conductuales fuertemente influidas por el ambiente. Si bien su conceptualización ha ido cambiando con el tiempo, se reconocen características fenotípicas conductuales cuyos síntomas principales son derivados de dificultades de atención, control de impulsos e hiperactividad (López. I, et als, 2006). Estos signos son características que forman parte de una

5 (Untoiglich, G. 2005).

6 (Etchepare y Almonte, 2003; Aboitiz y Carrasco, 2009).

7 (<http://www.mineduc.cl/biblio/documento/201005031126500.DEC200900170.pdf>) (2010).

base neurobiológica más amplia que corresponde a un trastorno del desarrollo que afecta las funciones ejecutivas.

Las funciones ejecutivas son “aquellas que permiten a un individuo regular y conducir voluntariamente su conducta en pos de metas y de una manera flexible y adecuada al contexto y las señales externas”⁸.

Estas funciones comprenden una multiplicidad de operaciones mentales. Según Papazian, Alfonso y Luzondo (2006), las que se encuentran principalmente alteradas en los niños con SDA, son:

- La capacidad para inhibir las respuestas impulsivas y la memorización de información irrelevante, impidiendo la interferencia perceptual en forma de distracción.
- El uso adecuado de la memoria de trabajo, permitiendo almacenar, monitorizar y manejar información.
- La capacidad para cambiar intermitentemente de una a varias reglas.
- La capacidad para planear una respuesta, previendo o anticipando su resultado a fin de solucionar el problema.

Los niños con TDA presentan además, una disminución en la capacidad para organizarse, producto de recurrentes olvidos, escasa atención a detalles y pérdida de materiales e información necesarios para realizar una tarea. Además de una excesiva actividad motora que resulta exagerada para su edad (CFTMEA –R, 2004).

Por medio de la técnica de resonancia magnética, es posible comprobar que ciertas áreas de la corteza cerebral, específicamente el área prefrontal, evidencian un retraso en su desarrollo, de aproximadamente dos años. Esto generaría una disfunción prefrontal que no obedece ni a lesiones ni a malformaciones, sino que se asociaría a la disminución de los niveles de dopamina que afectaría las sinapsis cerebrales.

En forma secundaria, se consideran co-causales del TDA-H, las variaciones de tamaño y/o irrigación de otras zonas del encéfalo. (Aboitiz, F; Carrasco, X: 2009)

Finalmente, cabe señalar que desde la genética se está estudiando la existencia de ciertos genes candidatos “(...) cuyas variables (alelos) podrían estar implicados como responsables del TDAH”⁹. Tales genes participarían en la síntesis de dopamina.

Desafortunadamente aún no se cuenta con un marcador biológico de uso clínico para diagnosticar SDA, y las posibilidades de realizar el diagnóstico adecuado dependen del conocimiento, habilidades clínicas y metodología de trabajo del especialista (López. I, et als, 2006), volviéndose un diagnóstico principalmente clínico.

El ministerio de educación, con el decreto 170, señala que la evaluación diagnóstica de los alumnos con TDA, con o sin Hiperactividad, o trastorno hiperkinético, “constituye un proceso de indagación objetivo e integral, realizado por profesionales competentes, que consiste en la aplicación de un conjunto de procedimientos e instrumentos de evaluación que tienen como objeto precisar, mediante un abordaje multidisciplinario, la condición de aprendizaje y de salud del o la estudiante y el carácter evolutivo de estas.” Además, desde el ámbito educativo debe considerarse información y antecedentes de profesores, familia y alumnos.

Los profesionales competentes para realizar dichas evaluaciones según refiere el ministerio de educación son médico, neurólogo, o psiquiatra, médico familiar, pediatra, o médico del sistema público que cuenten con asesoría de especialistas, de acuerdo a lo establecido al fondo nacional de salud, psicólogo y/o profesor de educación especial/diferencial o psicopedagogo.

A pesar de estas premisas para llevar a cabo el diagnóstico de los niños, es frecuente observar que este proceso se realiza sin comprender a cabalidad el funcionamiento de los niños, apoyado generalmente en cuestionarios e instrumentos que se rigen por un

⁸ Ibid, p. 32.

⁹ Aboitiz, F. Carrasco, X (2009) “Déficit atencional e hiperactividad. Fronteras y desafíos”. Ediciones Universidad Católica de Chile, Santiago, p. 35.

“deber ser” clínico y escolar atemporal, en el que a veces se desconoce o minimiza la incidencia del contexto, en base a lo cual se decide el tipo de indicación como tratamiento.

Niños que se mueven demasiado, que están ensimismados, que hablan de un modo desafiante, que no pueden organizar una tarea o que tienen serias dificultades para armar pensamientos, son englobados del mismo modo en el diagnóstico de Déficit de Atención con o sin Hiperactividad, porque fracasan en alguna de las exigencias de la institución escolar y/o molestan excesivamente en sus casas (Janin, B., Tulio, O., Heuser, C., Rojas, M., Tallis, J., Untoiglich, G. 2004).

Por el contrario, se hace necesario pensar en la particularidad que presenta cada alumno, pues hay algunos desatentos que se quedan quietos y desconectados, otros que se mueven permanentemente, algunos que juegan en clase, otros que reaccionan inmediatamente a cada estímulo sin darse tiempo a pensar.

La atención que se le pide a un niño en el colegio es una atención sostenida y selectiva en que se espera que atiendan durante un tiempo considerable a cuestiones que otros eligieron y que para él pueden no ser prioritarias. El dirigirse al mundo y sostener la audición y la mirada atentos, está motorizada por los deseos: un niño que no atiende a lo que se le pide, que se mueve desordenadamente, generalmente atiende de otro modo y a otras cuestiones diferentes a lo esperable (Janin, B., Tulio O., Heuser, C., Rojas, M., Tallis, J., Untoiglich, G. 2004).

El síntoma de inatención e hiperactividad puede presentarse en diversas patologías, sin constituirse necesariamente en el cuadro de déficit atencional. El resultado es que generalmente los niños son medicados desde edades muy tempranas, lo que logra aliviar el síntoma, pero minimiza las dificultades concomitantes.

El fármaco generalmente se administra en una situación específica, durante la permanencia en el colegio, frente a lo cual observamos que mientras dura el efecto aplaca la disfunción conductual y/o atencional

que es el objetivo principal. Frecuentemente, no se realiza un proceso de comprensión más profunda acerca del cuadro que incluya los dinamismos del funcionamiento y sufrimiento individual y familiar.

Una de las consecuencias de este modelo es que disminuye notablemente la responsabilidad de los adultos de tener que cuestionarse el por qué del sufrimiento y dificultades del niño, desconociendo su participación a través de posibles situaciones emocionales que se repiten de generación en generación y que pueden no haber sido elaboradas. (Untoiglich, G. 2005). De este modo, se rotula al niño reduciendo la complejidad de su vida psíquica a un paradigma simplificador suponiendo exclusivamente un déficit neurobiológico. (Berger, M, 2005; Janin, B, 2004; Rodulfo, R, 1992; Breeding J, 1996 en Consenso de expertos del área de la salud sobre el llamado “trastorno por déficit de atención con o sin hiperactividad”)

En este sentido, el modelo médico etiqueta al niño en una entidad psicopatológica adquiriendo una identidad que lo liga a cierta incapacidad, asumiendo un diagnóstico y tratamiento sin mayor comprensión ni cuestionamiento.

Tener una mirada más amplia del SDA, implica considerar o incluir lo subjetivo e interaccional. De acuerdo con ello, atender es un proceso que involucra una interacción con alguien y algo. Se refiere al modo particular en que cada uno toma y recoge la información del mundo, de las personas y los objetos y que ha sido construido desde los inicios del desarrollo, en una relación diádica, para realizarse posteriormente de manera autónoma. Entonces, tenemos que considerar que la atención es un proceso activo, que protege al niño del caos del mundo externo y de sus propias sensaciones, permitiéndole privilegiar un elemento sobre los otros. En tanto ligado a la conciencia, es como un foco que ilumina una parte del universo en desmedro del resto y, como atención dirigida hacia algo voluntario, es algo que se constituye, que no está dado desde el inicio (Janin, et als, 2004).

Portanto, los trastornos en la atención pudiesen también ser efecto de dificultades vinculares o relacionales que pueden quedar organizadas y/o expresadas en fallas regulatorias, como impulsividad, desorganización,

negativismo, inhibición o dificultad para poner un afecto positivo a cierta realidad, entre otras. De este modo, existen muchos casos con dificultades en el desarrollo emocional, que se esconden detrás de un déficit para atender y concentrarse. De esta manera, resulta de alto riesgo no realizar un abordaje profundo, puesto que la hiperactividad o desatención puede ser el comienzo de una manifestación de conflictos que se intentan simplificar o la manifestación inicial de patologías más severas, pero que a posteriori puede acarrear secuelas significativas que se irán manifestando de otras formas y que pueden ocasionar un deterioro en la personalidad. (Untoiglich, G. 2005).

Este es el caso de niños con dificultad para manejar la ansiedad, tolerar la espera y reprimir impulsos, lo que se expresaría a través de la acción motora o hiperactividad. El niño en vez de patear o llorar, se mueve o actúa impulsado por la necesidad de sacarse de encima la ansiedad y colocarla en otros.

Gisela Untoiglich (2005), señala que algunos niños descargarán corporalmente las situaciones que les acontecen y que será su cuerpo el que hablará, pues al no haber espacio para la tramitación de la angustia, ella se vuelve al exterior, siendo los demás quienes se angustien.

Por otro lado, Beatriz Janin (2004), desde una mirada más comprensiva, considerando los factores emocionales, realiza una clasificación de los diversos tipos de desatención:

- **Niños dormidos:** se trata de niños que se ven desconectados como si estuvieran en su mundo, ensimismados en relación con altos montos de angustia. Pueden sentir cualquier estímulo del mundo como un ataque, en tanto los saca del estado de sopor. La dificultad suele ser en este caso, mantener un estado de vigilia con atención sostenida. Están como dormidos, en una especie de vacío.
- **“No atiende, porque ya lo sé”** Hay niños que no toleran no saber, supone una herida narcisista. Se produce una desmentida contra lo que atente como una imagen de sí como sabelotodo. Se trata

de niños que han afirmado el concepto de sí mismo y del self, en el desarrollo intelectual.

- **“Me quiere o no me quiere”.** Este es el caso de niños que para tomar atención necesitan la mirada y sostén del otro, pero no en relación con el conocimiento. Niños que buscan la aprobación afectiva, los cariños de los profesores, pero no pueden escucharlos, el niño solo puede sostenerse en la mirada amorosa del otro. Requiriendo señales muy evidentes de que hay acompañamiento, de la presencia y de que es importante para el otro.
- **“Niño triste”:** niños que no logran atender por estar en situación de duelo, como crisis normativas e inesperadas, separación, abandono o pérdida.
- **“Niño en alerta”:** Habría una sobre atención, pero es una atención dispersa y errática con muchas dificultades para focalizarse en una actividad. El mundo se percibe como amenazante, compuesto por diversos estímulos, todos igualmente amenazantes. Esto es frecuente en niños criados en situaciones de violencia y abandono, migraciones o privaciones importantes.

Además, es importante considerar que estos niños, debido a su desadaptación conductual, pocas veces reciben retroalimentación que favorezca la continuidad en una tarea; por lo que es importante destacar la necesidad de que los adultos se pongan en el lugar de los niños para comprender su funcionamiento individual y el esfuerzo que realizan a pesar de no recibir feedback positivos o peor aún, recibir uno negativo (Greenspan, 1995).

DISCUSIÓN

Hasta acá hemos querido destacar la multifactorialidad y complejidad de lo que denominamos TDAH para iluminar acerca de cómo esto generalmente se contrapone con el abordaje en el sistema de Salud y de Educación en nuestro país, con el riesgo de simplificar un diagnóstico que debiera abarcar una comprensión más profunda de las distintas áreas que componen el problema.

En oposición al modelo médico, existe una mirada psicológica con una comprensión más amplia del fenómeno, intentando acercarse a la génesis de la situación actual del niño con TDAH. Esto implica intentar precisar e integrar qué elementos constitucionales y cuáles adquiridos fueron interactuando en el desarrollo del niño, buscando entender cómo una condición, que tiene a la base una disfunción neurológica con cierto carácter maduracional, va influyendo y alterando la estructuración del mundo interno del niño (Castro, E., citado en López, et als, 2006).

En otras palabras, esta mirada implica integrar lo que un sujeto trae al nacer, junto con sus experiencias infantiles, esforzándonos por entender cómo es que se han cruzado ciertos factores que desencadenan que determinada sintomatología se manifieste. (Freud en Untoiglich, 2005). Esto se opone a la causalidad única y propone plantear la clínica desde el paradigma de la complejidad y la multicausalidad.

Al considerar que la experiencia del niño es fundamental en la manifestación de los trastornos en la atención, se vuelve necesario pensar acerca de los padres, en tanto figuras de contención, regulación y aprendizaje, los que ante conductas ligadas al desorden o a dificultades de aprendizaje de sus hijos, buscan fármacos para aliviar el síntoma, desligándose y evitando frecuentemente cuestionarse sobre su rol, dejando la responsabilidad en un tercero.

El médico que recibe al niño debería cuestionarse, al menos, que sus dificultades de atención o su movimiento excesivo, pueden deberse a otras causas y no necesariamente a un TDAH, siendo la derivación fundamental para complementar su evaluación, debiendo exigir al psicólogo una comprensión e integración de factores emocionales, contextuales, familiares y relacionales.

En relación con esto, es necesario preguntarse acerca del análisis que los especialistas realizan para dar respuesta a los requerimientos de evaluación provenientes de neurología y psiquiatría. Específicamente los psicólogos debieran ser capaces de integrar al sujeto y su mundo interno, sin reducir todo a los resultados de una batería de pruebas estandarizada.

El abordaje clínico que debiera existir frente a estos niños, que son englobados en un mismo diagnóstico, tendría que respetar la individualidad, tomando en cuenta la subjetividad de éste con el objeto de comprender qué lo llevó a realizar aquel síntoma. Esto implica preocuparse por establecer una relación cercana con el paciente, entendiendo su funcionamiento, mirando más allá de la batería de pruebas, considerando también los aspectos emocionales.

Resulta necesario preguntarse por el lugar que le están otorgando los padres a sus hijos y por la calidad de la relación que están logrando con ellos, reflexionando respecto a cómo están apoyando el proceso de crecimiento de sus hijos, cuánto lo están amparando, sosteniendo y conteniendo en sus angustias, preocupaciones y tareas del desarrollo.

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Programa nacional de infecciones respiratorias agudas y síndrome bronquial obstructivo en Chile

The Chilean National Program for Acute Respiratory Infections and Bronchial Obstructive Syndrome

Dr. Guido Girardi Brière¹

RESUMEN

En Chile, las infecciones respiratorias agudas (IRA), constituyen un importante problema de salud pública. Durante la década del 80; la tasa de mortalidad infantil por neumonía subió y las investigaciones operacionales demostraron que en muchos de estos fallecidos, el deceso ocurría en domicilio o trayecto al hospital. Estos estudios identificaron los factores de riesgo aplicándose un puntaje de riesgo de fallecer por neumonía, y además de esto, demostraron que la etiología era preferentemente viral. Considerando estos antecedentes y el tipo de organización del sistema de salud chileno, se elaboró una propuesta de Programa de IRA, que posteriormente fue adoptada como oficial por el Ministerio de Salud. Este programa consiste en disminuir la morbimortalidad y mejorar la capacidad resolutive de la patología respiratoria del niño en el nivel primario de atención de salud. Se incorpora el manejo moderno del Síndrome Bronquial Obstructivo (SBO), primera causa de consulta y de hospitalización en Pediatría y factor de riesgo de neumonía, agrega Kinesiólogos y transfiere tecnología a los centros de atención primaria para mejorar su capacidad resolutive. En la actualidad el Programa nacional de IRA cuenta con 630 salas de hospitalización abreviada o "salas de IRA" en todo el territorio nacional. Se implementó un monitoreo epidemiológico en 8 centros centinelas que permite conocer diariamente todas las consultas de IRA en APS y tomar medidas adicionales para satisfacer momentos de elevada demanda de atención (Campaña de Invierno).

Entre los resultados sanitarios más importantes destaca la reducción de las hospitalizaciones por SBO y especialmente el reiterado quiebre hacia el descenso de la mortalidad infantil por neumonía, en particular de su componente domiciliario. Las evaluaciones independientes han mostrado un alto rendimiento costo beneficio de los recursos usados en este campo. En la actualidad ante la baja mortalidad por neumonía, los esfuerzos se han enfocado a mejorar la calidad de vida de nuestros niños, en especial si se considera el creciente aumento de pacientes portadores de enfermedades respiratorias crónicas, como Asma Bronquial por ejemplo, subsidiando su manejo.

El Programa IRA ha significado un sustantivo avance y manejo en control de patologías de alta prevalencia y gran trascendencia en salud pública. Su modelo representa la adecuación a los enfoques modernos de administración sanitaria en donde se hace perentoria una medicina integral y la colaboración intersectorial e interdisciplinaria.

Palabras clave: Infección respiratoria aguda, atención primaria de salud, factores de riesgo, Síndrome Bronquial Obstructivo (SBO).

ABSTRACT

In Chile, ARIs are major problem in health. During the 80s the infant mortality rate for pneumonia rose, with studies demonstrating that many of the deaths occurred at home or on route to the hospital. These studies identified risk factors and that the predominant etiology was viral. Taking these facts in account and the type of organization of the Chilean Health Service a program of ARI was elaborate which was later adopted as the official Health Ministry program, This incorporated the modern management of obstructive bronchitis, including physiotherapist and the transfer of technology to primary health care centers to improve their operational capacity. The National ARI Programmed has 630 units throughout the country and has brought about a fairer distribution of health care services and a better technical quality to the poorer populations of our country. Amongst the more important results that the program have achieved, we emphasize the reduction in hospitalizations for obstructive bronchitis, the repeated lowering of infant mortality for pneumonia, especially in death at home. Independent evaluations have

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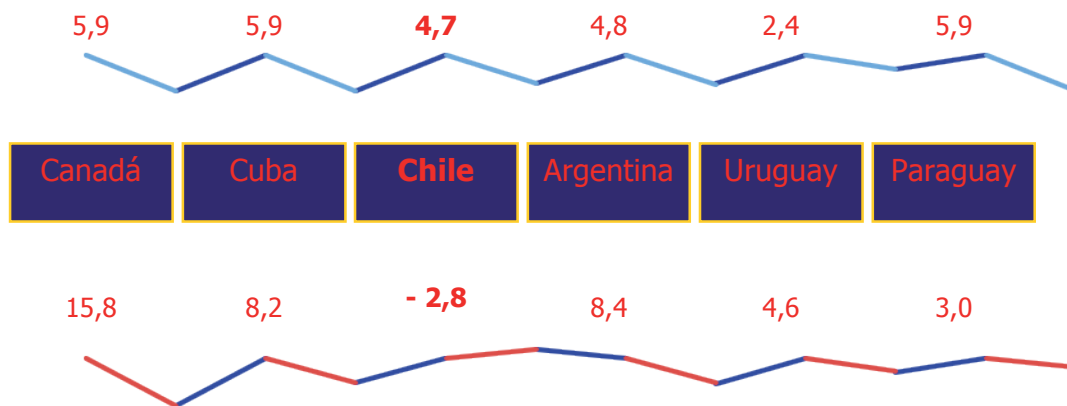
demonstrated a highly efficient cost-benefit ratio used in the program. With the lowering mortality for pneumonia we must stress the need to improve the quality of life for Chilean children, especial when we consider the increasing number of children with chronic respiratory disease.

Keywords: Acute respiratory infection, obstructive bronchitis, primary health cares, risk factors.

INTRODUCCIÓN

Motivación y justificación

Figura 1.
Tendencias de la mortalidad infantil por todas las causas y por Neumonía en la década de los 80



Fuente: OPS

Los indicadores de salud en Chile han logrado ocupar un lugar de privilegio en Latinoamérica a partir de la segunda mitad del siglo XX. Esto ha sido posible gracias a la mejoría de las condiciones de vida, al control de la desnutrición y algunas epidemias, y, sobre todo, a la creación de un sistema de salud con fuertes orientaciones iniciales en la prevención y el trabajo comunitario. En este contexto, las tasas de mortalidad infantil han presentado, en las últimas décadas, un importante descenso, con franco desplazamiento de la desnutrición y los síndromes diarreicos (como primera causa de muerte en los comienzos del siglo) hacia otras entidades. Esto se hace evidente a partir de 1982, en que comienza a observarse un sostenido e inesperado *incremento* en la tasa de mortalidad infantil por Neumonía en contraste con la tasa general (tasa de mortalidad infantil por todas las causas) que persistía a la baja (*Fig. 1*). Estas evidencias motivan a un grupo de especialistas neumólogos pediátricos del área sur de Santiago a dilucidar las causas del fenómeno.

En primera instancia surgen dudas acerca de la importancia de la *bronco aspiración* como causa de muerte en niños fallecidos en domicilio, debido a que esta causa accidental estaba presente en, prácticamente, el 100% de los certificados de defunción emanados del instituto Medico Legal (IML), lo cual suponía, al menos, una eventual falta de acuciosidad en el estudio necrótico.

Por otra parte comienzan a estudiarse los casos de muertes por neumonía, pesquisándose que en muchos de estos niños existían, en los días previos al fallecimiento, síntomas de Infección Respiratoria Aguda (IRA) y que compartían, además, una serie de factores de riesgo, ulteriormente caracterizados.

Entre 1986-87 se inicia el estudio de Mortalidad por Neumonía en menores de 1 año en nuestra área, en el cual no solo se realiza autopsia a todos los fallecidos por esta causa en los hospitales sino también a todos los fallecidos en domicilio, además de una "autopsia oral" a los familiares un mes después de ocurrido el deceso. De este estudio emanó la

evidencia que, de todos los niños fallecidos en domicilio, en un 80% la causa de muerte correspondía a Neumonía (y no bronco aspiración). La Anatomía Patológica reveló además que, en el 70% de los casos, la etiología correspondía a un agente viral.

Los resultados más importantes de este trabajo revelaron que el 60% de los niños fallecidos por neumonía en nuestra área lo hacen en domicilio, hallazgo insospechado hasta ese momento. El 92% de estos niños fallecidos en domicilio eran menores de 6 meses. Mas del 60%, menores de 3 meses y 60% varones. En solo un tercio de ellos, la madre consulta oportunamente. En otro tercio, 5 días antes (por una IRA) y no vuelve a consultar. En el tercio restante, la madre nunca consultó (Ref. 1).

El estudio de factores de riesgo en estos niños reveló presencia de **malformación congénita** de un órgano vital o parálisis cerebral, **bajo peso al nacer, desnutrición, síndrome bronquial obstructivo recurrente, hospitalización anterior** (70% de los casos por síndrome Bronquial Obstructivo -SBO- y Neumonía), **lactancia materna insuficiente, madre adolescente, baja escolaridad de la madre y tabaquismo materno**. A partir de estos factores se calculó el riesgo relativo y, al multiplicarlo por un logaritmo, se obtuvo un puntaje de riesgo (Tabla. 1 y 2).

Tabla 1.
Mortalidad por neumonía

Factor de riesgo	% en fallecidos	% en población
Malformaciones Congénitas	16.8	0.2
PN < 2500g	24.6	7.2
Desnutrición	32.8	3.9
SBOR	16.4	6.0
Hosp. Anterior	41.0	4.5
Madre adolescente	31.1	12.4
Educ. Básica o >	86.9	44.4
Tab. Materno	90.2	39.0
Lacta. Mat. Insuf	61.0	27.6

Factores de riesgo (Ref.1y2),
Girardi G. Abara S. Santa Cruz P

Tabla 2.
Puntaje de riesgo de morir por neumonía

Factor de riesgo	RR (p1/p2)	Log RR	Puntaje
Malformación congénita	255.7	2.30	11
Tabaquismo materno	16.4	1.21	6
Hospitalización anterior	14.7	1.17	6
Desnutrición	12.0	1.08	5
Baja escolaridad	8.3	0.68	4
Baja de peso nacimiento	4.2	0.62	3
Lactancia materna insuficiente	4.1	0.61	3
Madre adolescente	3.2	0.50	2
SBOR	3.1	0.49	2

RR: Riesgo relativo, Log RR: logaritmo en base 10 de RR Puntaje = log RR/ 0.2
Abara S.; Girardi G

A partir de estos datos, se elaboraron algunas hipótesis para explicar esta elevada mortalidad por neumonía en domicilio. Estas fueron:

- Dificultad intrínseca de diagnóstico de IRA baja en lactantes pequeños, producto de sus escasas manifestaciones clínicas.
- Incapacidad (ignorancia, impericia) de la madre para reconocer síntomas y signos de gravedad de IRA
- Mala accesibilidad al sistema, lo que podría ser cierto en los momentos de alta demanda, e implicaría principalmente la baja oferta de atención (horas médicas) más que la accesibilidad física.
- Baja credibilidad en el sistema de salud.
- Muerte brusca e inesperada por neumonía fulminante o ¿Muerte Súbita?
- El peso de los factores de riesgo.
- ¿Desinterés materno?

Coincidentemente un grupo de neumólogos del Área suroriente de Santiago realizaba otro estudio de mortalidad infantil por neumonía, cuyos resultados fueron casi idénticos. (Ref. 2)

En relación a la morbilidad, llamó la atención la importancia del SBO como una de las principales causas de consulta pediátrica en los Centros de Salud del Nivel Primario (APS), los Servicios de Urgencia y también de Hospitalización. Accesoriamente, una Publicación realizada con anterioridad por el mismo equipo ya había demostrado la importancia del SBO como factor de riesgo de neumonía (más del 60% de los niños hospitalizados por neumonía conllevaban el antecedente de SBO recurrente) (Ref. 3).²

Tabla 3.**Seguimiento de una cohorte de recién nacidos a 4 años**

<i>Neumonía</i>	<i>Hospitalización</i>
Sin Sibilancias 11%	1.8%
Sib. Transitorias 32%	7.5%
Sib. Persistentes 78%	23%

López I et al. Rev Chil Salud Pública 1997; 1: 9-15(Ref.4)

Otra investigación realizada en nuestro hospital había demostrado que el 20% de las Neumonías Intrahospitalarias ocurrían en lactantes que habían sido hospitalizados por SBO, especialmente temibles cuando el agente causal era el *Adenovirus* (ADV). Por lo tanto cualquier esfuerzo por evitar estas hospitalizaciones, era de vital importancia.

En 1979 publicamos una investigación en que se demostraba por primera vez la existencia de asma en el niño menor de 2 años (Ref. 5). Siguiendo con esta idea, estando una mañana de 1982 en la consulta de Enfermedades respiratorias de nuestro hospital se nos ocurre administrar a un lactante con obstrucción bronquial un inhalador de dosis medida (MDI) de salbutamol mediante un espaciador o aerocámara que construimos en ese momento con una botella plástica

de suero. El resultado fue espectacular al observarse una muy buena respuesta clínica. Esa Aerocámara tiene hoy un uso universal y ha revolucionado la terapia de la obstrucción bronquial y del asma. ESE DÍA FELIZ NACE LA AEROCAMARA

Por otro lado, habíamos publicado un trabajo en el *Pediatric Pulmonology* (Ref. 6), en el cual habíamos demostrado por vez primera que la musculatura lisa bronquial del lactante respondía a los broncodilatadores y también la eficacia de éstos, administrados con inhalador MDI más aerocámara en revertir rápidamente la obstrucción bronquial, midiendo la respuesta con un puntaje clínico de severidad (Tabla 4), en lactantes hospitalizados por esta causa.

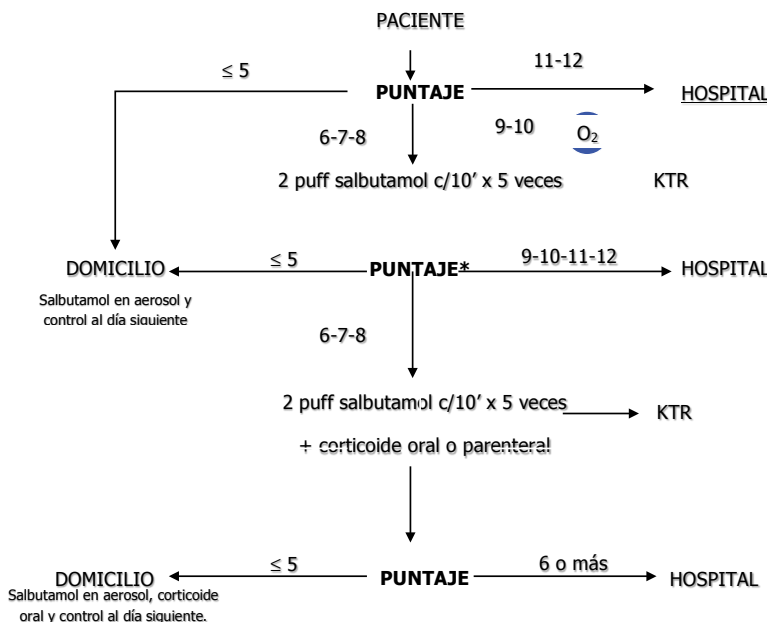
Tabla 4.

Frec Resp	Sibilancias		Cianosis	Retracción	
	<6m.	>6m.			
0	≤ 40	≤ 30	NO(*)	NO(*)	NO(*)
1	41-55	31-45	Fin espiración con fonendoscopio	Perioral con el llanto	(+) Subcostal
2	56-70	46-60	Inspirat. y espirat. con fonendoscopio	Perioral en reposo.	(++) Supraclavicular
3	> 70	> 60	Audibles sin Fonendoscopio	Generalizada en reposo	(+++) Intercostal

El mismo éxito lo obtuvimos cuando aplicamos similar técnica en el Servicio de Urgencia de nuestro hospital (Ref. 7). Luego, al implementar esta técnica en un Centro de Salud Primaria (en una sala especialmente habilitada para ello, en la cual el niño permanecía junto a su madre durante un máximo de dos horas -*Sala de Hospitalización Abreviada*-), se comprobó una reducción de aproximadamente un 80% de hospitalizaciones al hospital base ese mismo año (Tabla 5).

² FeL El SBO como un factor de riesgo de neumonía, se vería confirmado en otras investigaciones posteriores, (Ref.4)

Figura 2.
Hospitalización Abreviada

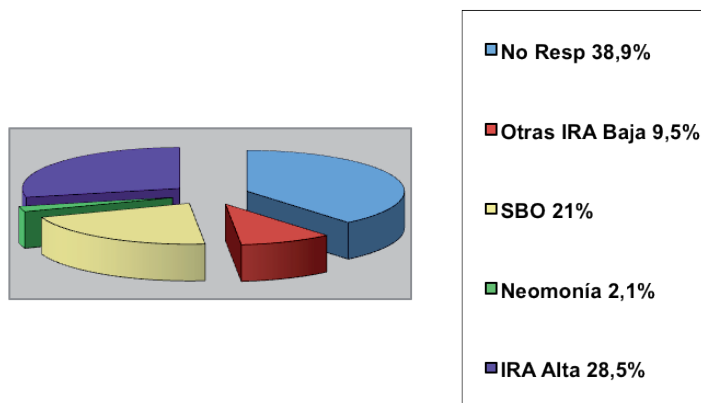


A partir de todos estos antecedentes, surgió la inquietud de elaborar un programa de manejo de las IRAs, acorde a nuestra problemática y basado en nuestra experiencia e investigaciones. Desde ya éste incorporaba al SBO como una Infección Respiratoria Aguda.

Le dimos la misma jerarquía que la neumonía, la cual era, sin embargo, el objetivo central de otros programas (Ej. Programas de la OPS).

Debido a todos los factores implicados, este programa debía, necesariamente, ser de carácter *multisectorial* e *interdisciplinario*, lo cual se insertaba adecuadamente dentro de las nuevas estrategias sanitarias.

Figura 3
Distribución de Consultas Pediátricas Centros Centinela, Santiago



n = 129.034 consultas pediátricas Programa IRA Minsal, Chile

OBJETIVOS DEL PROGRAMA IRA

El objetivo principal de este programa era *disminuir la morbimortalidad por Infecciones Respiratorias Agudas*. Los objetivos específicos eran reducir la mortalidad por neumonía en menores de 1 año (con énfasis en la disminución de la mortalidad domiciliaria), disminuir las hospitalizaciones por SBO, reducir el uso de fármacos inapropiados (en especial el uso irracional de antibióticos) y, en último término, pero no menos importante, dignificar el nivel primario de atención.

Para cumplir los objetivos descritos se diseñaron diversas estrategias de acción:

- En primer lugar, focalización de la atención y de la educación, aplicando el puntaje de riesgo de morir por neumonía (Tabla 2) a toda madre consultante desde el control prenatal, de recién nacido y en adelante.
- En segunda instancia, mejorar el poder resolutivo de los Centros de APS, para lo cual se elaboraron normas *sindromáticas* de diagnóstico, tratamiento y derivación, basado en una adecuada articulación entre los diferentes niveles de atención. Conjuntamente con esto, se inició la creación, en los diferentes Centros de APS, de *Salas de Hospitalización*

Abreviada (HA), donde el kinesiólogo tendría un papel relevante.

- Uso racional de antibióticos y modernización del arsenal terapéutico.
- En el área docente; el ingreso de profesionales específicamente capacitados para gestionar, supervisar y evaluar el Programa en cada comuna, los cuales deberían capacitar a otros profesionales, al resto del equipo de salud y a la comunidad (monitores de salud).
- Realización de investigaciones operativas y científicas, monitoreo epidemiológico y evaluación crítica del funcionamiento del programa.

RESULTADOS DEL PROGRAMA

En septiembre de 1990, el IRA se transforma en el programa oficial del Ministerio de Salud para el manejo de la patología respiratoria.

Resultados

- Creación de guías sindromáticas, nacionales, unificadas, para el manejo de las IRAs. Aplicación de un puntaje y algoritmo de manejo para la obstrucción bronquial aguda (Tabla 3 y Fig. 2)
- Creación de un modelo docente-asistencial: re-dignificación de la atención primaria y campo laboral atractivo en el sistema público.
- Modernización del arsenal terapéutico en la atención primaria.
- Cambio cultural hacia el uso de aerosoles en lactantes.
- Gran reducción en el uso de fármacos técnicamente inadecuados (mucolíticos, antitusivos, descongestionantes, P2 agonistas orales en la APS).
 - Uso racional de antibióticos.
 - Utilización de corticoides inhalados para el manejo del SBO recurrente.

Beneficios directos en Salud

- Salud más equitativa y de mejor calidad técnica para la población de más escasos recursos.
- Transferencia tecnológica a la APS.
- Mejoría en la accesibilidad y credibilidad de la APS.
- Aumento del poder resolutivo de la APS expresado en:
 - o reducción del 80% de las hospitalizaciones por SBO.
 - o reducción de 25-50% de las derivaciones a la especialidad de Neumología Pediátrica o Manejo kinésico de pacientes crónicos en la APS.
 - o Creación de 630 salas de HA en todo el país.

Aplicación del puntaje de riesgo de morir por neumonía (Tabla 2) desde la madre embarazada, para focalizar la educación y, posteriormente, la atención Sistema de Vigilancia Epidemiológica en 8 consultorios centinelas del área Metropolitana, más 2 en regiones (Ref. 10)

Este monitoreo permitió:

- Caracterización diaria del perfil de morbilidad respiratoria en la APS.
- Detección anticipada de brotes de morbilidad (desde 1993 en adelante).
- Aporte en toma de decisiones: **Campaña de Invierno**, a partir de 1994. Esta consiste en un aporte adicional de recursos, en los meses de más alta demanda, para mayor prestación de horas laborales, mayor implementación de fármacos e insumos, montaje de una red adicional de camas y operativos de comunicación social.

Resultados de investigaciones operacionales emanadas del programa

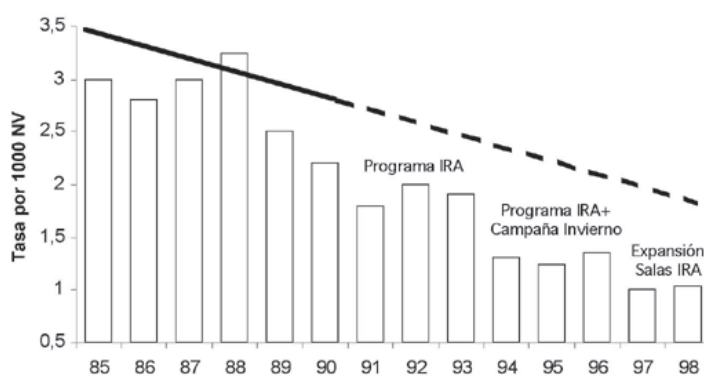
- Evaluación de primeras 13 mil HA (Ref..8.). *Se demuestra que sólo el 3.5 % de los lactantes con obstrucción bronquial moderada y severa se hospitalizan*

- Aplicación de Score de Riesgo de morir por neumonía en otra área, con fines de validación del sistema y predicción de muertes en domicilio (Cristina Pino, Julio Maggiolo, *En el área metropolitana central*).
- Monitoreo epidemiológico (Fig. 3).
- Trabajo de comparación de la eficacia del manejo de la Obstrucción Bronquial entre nebulización y aerocámara (Ref.11)
- Validación del puntaje de SBO con saturimetría (Ref. 12).
- Resultados del programa: IRA 1990-2000:
 - o Cambios en el perfil de egresos hospitalarios.
- Reducción de hospitalizaciones por SBO en beneficio de pacientes con neumonía.
- Reducción de las Infecciones Intrahospitalaria por ADV y otros agentes.
- Disminución de la Mortalidad Infantil por neumonía (Fig. 4, 5 y 6).

Figura 4

Mortalidad Infantil por Neumonía

Chile 1985-1998.

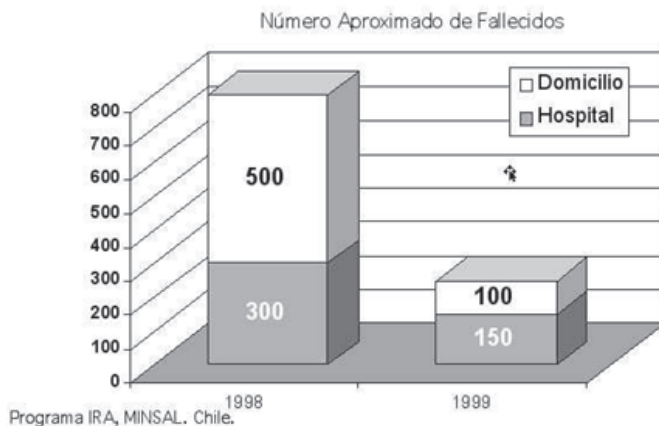


Programa IRA, MINSAL. Chile.

Figura 5

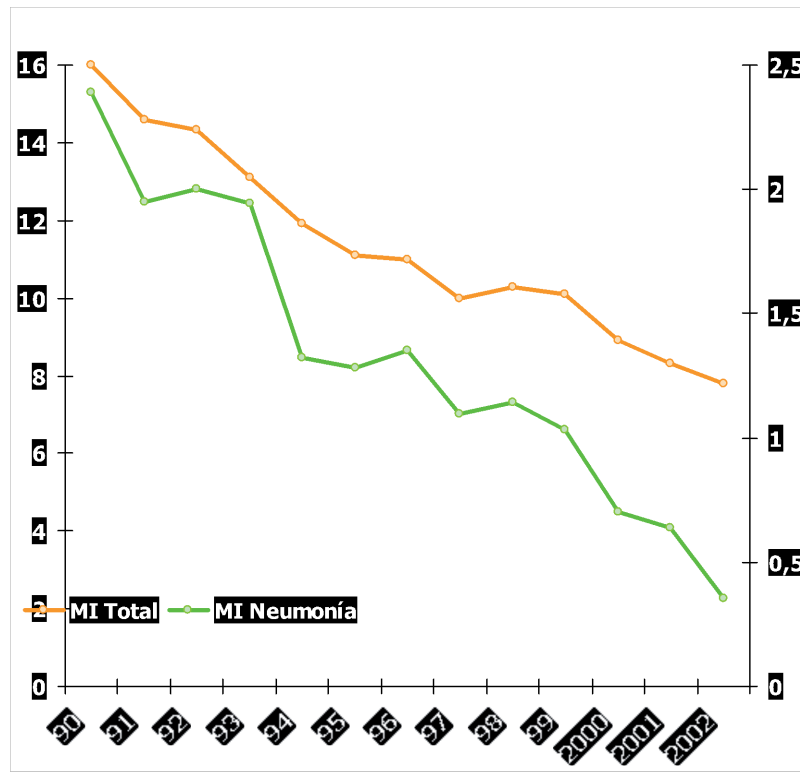
Fallecidos por Neumonía <1 año Hospital y Domicilio

Chile 1990-1999



Programa IRA, MINSAL. Chile.

Figura 6
Mortalidad Infantil Chile 1990-2002



CONCLUSIONES

El Programa IRA ha resultado un significativo avance en el manejo y control de patologías de alta prevalencia y de gran trascendencia en salud pública. Su modelo representa la adecuación a los enfoques modernos de administración sanitaria, en donde se hace perentoria la colaboración intersectorial e interdisciplinaria.

Diversas evidencias han demostrado el gran impacto de este programa en el ahorro de recursos, tanto por la disminución de consultas a Servicios de Urgencia, a Policlínicos de Especialidad como en Ingresos Hospitalarios. Esto quedó confirmado con un estudio realizado por el CIAPEP (de la Facultad de Economía de la Universidad Católica), en el cual se determinó una relación costo-beneficio de 1/3,8.

Aun cuando este programa ha tenido conquistas importantísimas a solo una década de puesto en marcha, no ha estado ajeno a múltiples dificultades y escollos.

Estos han estado determinados principalmente por la *municipalización* de la APS, el déficit de horas médicas en el nivel primario, así como las serias limitaciones para la supervisión local del cumplimiento del programa.

Sin embargo, el panorama sigue siendo esperanzador. El importante descenso (más allá incluso de lo previsto) de la mortalidad por neumonía en menores de un año desde la instalación del programa (*Fig. 11*) es uno de los mejores indicadores de que vamos por la senda correcta.

Se plantean ahora nuevos desafíos, que implican un especial esfuerzo de los equipos de salud en hacer más participe a la comunidad en la resolución de sus problemas sanitarios. Esto hará del programa IRA un modelo atractivo no solo exportable, (Programa de IRA de la provincia de Tucumán, Argentina) sino además digno de imitar por otras especialidades para el adecuado manejo de nuestros grupos poblacionales más vulnerables.

Lamentablemente en estos últimos años hemos asistido a un debilitamiento de su gestión y supervisión. A la progresiva desaparición de los Médicos de IRA verdaderos sostenedores y articuladores del programa en los servicios locales de salud, quienes además cumplen con controlar a los niños con patología más compleja. Capacitar y educar al equipo de los centros de salud como también a la comunidad. Consecuencia de ello, en el Hospital E. González Cortés han aumentado en un 50% las hospitalizaciones por crisis de obstrucción bronquial, es de esperar que no ocurra algo semejante con la mortalidad por neumonía cuya latencia puede ser mayor.

FELIZ EL DÍA EN QUE COMO ESPECIALISTAS NOS CONVENCIMOS QUE EL ENFERMO MÁS INTERESANTE NO ES EL QUE ASISTIMOS EN EL HOSPITAL SINO QUE AQUEL PACIENTE QUE ATENDEMOS EN EL NIVEL PRIMARIO DE ATENCIÓN DE SALUD Y QUE OJALÁ NUNCA SE HOSPITALICE

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EVOLUCIÓN DE LA SALUD PÚBLICA

Cuadernos Médico Sociales se complace de incluir en este número una parte de la conferencia dictada por el Dr. Fernando Monckeberg en el año 2011 sobre el libro "Pobreza: 200 años en la prensa escrita" editado por la "Fundación superación de la pobreza" y la "Escuela de Periodismo, Universidad Diego Portales". Aparte del valor científico e histórico de la conferencia, deseamos que esta publicación sea considerada como una expresión de reconocimiento a la trayectoria académica del Dr. Monckeberg en el campo de la salud pública

Algo importante para celebrar en el Bicentenario

Dr. Fernando Monckeberg Barros¹

Sólo después de doscientos años de vida independiente, hemos comenzado a vivir un proceso de cambios trascendentales. Me refiero al anhelo inherente de toda sociedad humana de alcanzar la seguridad y bienestar para sus descendientes. Que sus hijos nazcan en un medio ambiente generoso y amigable, que les permita crecer y desarrollarse con el mínimo de riesgos posibles, hasta llegar a expresar integralmente su potencial genético, tanto en salud, como en su desarrollo físico y sus capacidades intelectuales, como primer paso para llegar a alcanzar una real igualdad de oportunidades. Este tan fundamental anhelo, está lejos de haberse logrado para la mayor parte de la población del mundo. Aún en muchas regiones y países, los hijos continúan naciendo en condiciones de inseguridad, con altos riesgos de enfermar y fallecer, o desarrollar secuelas irreparables debidas a carencias nutritivas y/o afectivas que se evidenciarán a lo largo de sus vidas.

Las generaciones que han estado naciendo en Chile después de la mitad del siglo XX, por lo general, no se detienen a analizar el porqué de las circunstancias que ellos ahora están viviendo y no reparan en que son muy diferentes a las que existieron en el pasado. No se imaginan que el bienestar relativo que ahora pueden disfrutar, ha sido la resultante del esfuerzo continuo de las generaciones precedentes. Así por ejemplo, se sorprenden cuando se les señala que a comienzos del siglo recién pasado (1910), de cada cien niños que nacían, cuarenta no alcanzaban a vivir lo suficiente como para celebrar su primer cumpleaños. Ni menos podrían imaginar que casi un cuarto de los que nacían, ya habían sido dañados por una desnutrición grave en el vientre materno. Nacían con un déficit de peso superior al 30%, con daños en la funcionalidad de diversos órganos y sistemas. Es que sus madres, a su vez desnutridas, no podían entregarles lo que sus propios organismos no tenían. En esa época, cuando precisamente se estaba celebrando el Primer Centenario, más de la mitad de las muertes se estaba produciendo antes de los cinco años de edad, y la expectativa de vida al nacer solo alcanzaba a los 35 años. Mas impactante aún, era que muchos de los que lograban sobrevivir estaban siendo dañados por vida, tanto física, como biológica e intelectualmente. Se afectaban sus mecanismos de defensa frente a las enfermedades, se restringía su crecimiento físico y se lesionaban sus capacidades intelectuales, hasta el punto de dificultar el proceso de aprendizaje, principal causa de la alta deserción escolar de aquella época. De cada cien niños que lograban comenzar la educación básica, sólo veinticinco lograban terminarla. A partir de allí, sólo una pequeña élite llegaba a reunir los requisitos para ingresar a la educación media, y no más del 1 o 2% podía tener acceso a la educación universitaria, que en aquella época era gratuita. Allí estaban engendrando las desigualdades y con ello consolidando las bases del subdesarrollo.

La desnutrición había estado presente desde siempre, hasta llegar a ser aceptada como un fenómeno natural e inexorable, que ni siquiera merecía mencionarse en las crónicas. En ellas solo se relataba la curiosa tradición de celebrar "la muerte del angelito", que no era sino una sublimación del profundo dolor de los padres ante tan

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inmutable tragedia. ¡Era bueno que muriera el angelito para que fuera al cielo a rogar por sus padres y hermanitos! Fueron necesarias muchas investigaciones para llegar a convencerse que esa tragedia crónica podía prevenirse, ya que eran factores ambientales adversos, los que actuando en conjunto y a edades muy tempranas, los agredían tan cruelmente. Era un mal oculto, que llegando a afectar a un tan alto porcentaje de la población, impactaba no sólo a sus familias, sino también a la sociedad entera, obstruyendo su progreso y desarrollo.

El Chile de hoy es diferente del que fue, y todo parece indicar que a futuro podrá ser también diferente al que es. El Segundo Centenario, a diferencia del Primero, ya se puede celebrar con justificado entusiasmo. ¡Se ha erradicado la desnutrición! Ahora los niños de bajo peso al nacer representan sólo el 3% y ellos no son desnutridos, sino prematuros que han nacido antes de tiempo. Hoy en día los niños chilenos nacen, crecen y se desarrollan dentro de los estándares de niños pertenecientes al mundo desarrollado. La mortalidad del primer año de vida ya no es del 40% de los nacidos, sino del 7 por mil de los nacidos. La expectativa de vida al nacer, ya no es de 33 años, sino de 80 años. Ya la desnutrición no está dañando y otros son los factores socioculturales adversos, propios de la pobreza, los que ahora ya se pueden erradicar. Los que están naciendo crecen indemnes, sin daños por déficit nutricional y pueden ya iniciar su proceso educacional con posibilidades reales de éxito. La deserción escolar es excepcional y en la actualidad están accediendo a la educación media el 75% de los niños del grupo etario correspondiente. Ya no es el 1% el que está accediendo a la educación superior, sino el 40%. Ya la expectativa de escolaridad promedio es de 12 años, mientras que a comienzos del siglo pasado sólo alcanzaba a 2 años.

Al haber hecho realidad el anhelo de proteger a todos los que ahora nacen, desarrollándose con el mínimo de riesgo, con miras a expresar su verdadero potencial genético, se está dando un paso fundamental. No es casualidad que los que ahora ya han terminado su adolescencia, estén alcanzando progresivamente una mayor estatura que la de sus padres.

La pobreza ha disminuido, sin embargo aún persiste en unos ciertos grupos, manteniendo un medio ambiental adverso, condicionando una desigualdad de oportunidades para los que allí nacen. Su erradicación es la próxima meta. Pero lo ya alcanzado es muy significativo, colocando a nuestro país en un lugar destacado dentro del contexto de los países de la región (figura 1 y 2). Ello ha sido posible debido a una estrategia de intervención concienzudamente investigada e implementada a nivel nacional, destinada a proteger al niño desde el momento de su concepción y durante los primeros años de vida. Ha sido una política, mantenida en el tiempo de permanente control del niño sano, de atención primaria de salud y de un adecuado aporte nutricional y educacional del binomio madre-niño. Ello ha necesitado de una ingente inversión económica, que mirada ahora retrospectivamente, no cabe duda que ha sido la mejor inversión realizada, dada la alta rentabilidad social y económica alcanzada. Al prevenir el daño sociogénico-biológico que ancestralmente se venía produciendo al recurso humano, ahora está siendo posible comenzar a progresar en la calidad de vida y el bienestar de todos.

Dentro de esta estrategia preventiva, fue muy necesario también preocuparse del tratamiento de los niños con desnutrición avanzada que necesitaban de cuidados médicos y estimulación cognitiva y afectiva para lograr su recuperación. Para ello nació CONIN (Corporación para la Nutrición Infantil), una fundación sin fines de lucro, que mediante el aporte comunitario, logró construir, habilitar y poner en marcha, 32 centros de internación, con 1.750 camas de lactantes a lo largo del país, integrándolos a la estrategia preventiva ya en marcha. Su aporte significó recuperar 95 mil lactantes con desnutrición avanzada, contribuyendo a disminuir la muy alta tasa de mortalidad infantil de aquellos años.

Ello es algo que todos debemos celebrar, al cumplirse 200 años de historia como país independiente: "el control y prevención de la desnutrición infantil".

Presidente
Corporación para la Nutrición Infantil (CONIN)

CRÓNICA

Pensando en la salud de la humanidad y del ambiente: observación de los últimos eventos significativos relacionados con la energía

Dr. Carlos Montoya-Aguilar¹

A fines de septiembre, el proyecto "24 horas de realidad" daba cuenta, en Nueva York, de grandes inundaciones en Colombia, Pakistán e India, y de incendios masivos en Estados Unidos y Australia. A comienzos de noviembre hacían noticia las inundaciones de Tailandia, las más graves de los últimos 50 años. Poco después, la Agencia Internacional de Energía, dependiente de la OCDE, advirtió que el año 2017 es la fecha crítica para un absoluto cambio de dirección en las prácticas de generación energética en el mundo; al ritmo actual, la temperatura del planeta subirá entre 3,5 y 6° C, en tanto que ya un aumento de 1,5 °C causaría un aumento significativo del nivel del mar.

Las Naciones Unidas han convocado para fines de noviembre a una nueva Conferencia Mundial sobre el Cambio Climático, a realizarse en Sud Africa, y en la cual es imprescindible que los gobiernos, entre ellos el de Chile, obtengan de las grandes potencias industriales el compromiso de limitar drásticamente sus emisiones de gases de invernadero.

En nuestro país, entretanto, la expansión del consumo de electricidad, que era del 12 % anual a mediados de los años '90, fue del 7% anual en los años recientes y en el bimestre agosto-septiembre del 2011 ha sido del 6 % (anualizado). Es posible y necesario lograr una eficiencia que lleve a desacoplar el gasto de energía respecto al crecimiento económico. La cantidad de proyectos energéticos aprobados por el gobierno actual, en sus 19 meses de ejercicio, asciende a un total de 8 400 MW, incluyendo los proyectos de Hacienda Castilla, a carbón, y de Hidro-Aysen.

Después de la aprobación del Estudio de Impacto Ambiental del proyecto Hidro-Aysen, éste ha obtenido que la Corte Suprema rechace (28 de octubre) los recursos presentados en su contra por el Senador Horvath y la organización "Patagonia Sin Represas"; y que falle a su favor con respecto a sus derechos de agua en la hoya de los ríos Pascua y Baker. Sin embargo, la Fiscalía Nacional Económica recurrió al Tribunal de Defensa de la Libre Competencia en contra de la Dirección General de Aguas, por las deficiencias de ésta en cuanto a la información sobre los derechos adquiridos por Hidro-Aysen desde el 2009.

Se ha revelado de extraordinaria importancia la construcción y mantenimiento de las líneas de transmisión. La fragilidad de este sistema, incluida la falla del mecanismo de recuperación a distancia, ha provocado en este año sucesivas suspensiones del servicio eléctrico: en marzo hubo un apagón que abarcó desde la II a la X Regiones y afectó a 14 millones de personas; el hecho se repitió dos veces en julio; ocurrió en el norte en junio; y nuevamente en gran escala, entre la IV y la VII Regiones en septiembre, afectando a 11 millones

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de habitantes, los cuales tienen muy pocas posibilidades de recibir una indemnización de la Compañía Transelec, a causa de los vacíos legales existentes.

Los proyectos Hidro-Aysen y Energía Austral, cuyas represas se ubicarían en la Región de Aysen, necesitarían de la construcción de líneas de transmisión de 2000 Km en el caso de la primera, y de 800 Km en el caso de la segunda. Han convenido tender dos líneas paralelas de torres dentro de una franja común de hasta 140 m de ancho, en una extensión de 600 km, "para reducir el impacto ambiental y social" en este trecho. Ya hay inversionistas extranjeros (China, Colombia) interesados en participar en esta obra, que tiene un costo estimado de 4 mil millones de dólares, tan sólo para la línea de Hidro-Aysén. El estudio de impacto ambiental respectivo sería presentado por Hidro-Aysen en marzo de 2012; y por Energía Austral, en el tercer trimestre de ese año. Dada la enorme cantidad de propiedades y de parques naturales afectados, la Comisión de Expertos creada por el gobierno para el tema de la electricidad en general, recomienda la creación de la Carretera Eléctrica Pública; esto quiere decir que el Estado actúe como "facilitador" de los trámites de otorgamiento de servidumbres y derechos de paso en los terrenos por donde pasarían los tendidos. La "carretera" comenzaría, por el sur, en Pto. Montt.

El desarrollo de fuentes de energía limpias y seguras avanza lentamente. En septiembre se dio cuenta de que la Dirección General de Aguas dio la autorización definitiva al complejo hidroeléctrico de pasada "San José de Maipo", de 530 MW, en construcción por AES Gener para las necesidades de Santiago. Está inaugurada la central de pasada Los Chacayes, 111 MW, de Pacific Hydro (Australia). El proyecto Atacama Solar ha sido iniciado, en forma limitada.

En noviembre se inauguró, con la presencia del Presidente de la República, el Parque Eólico Punta Colorada, en la comuna de La Higuera (Coquimbo). Tiene una potencia moderada, de 10 MW, y pertenece a la empresa minera Barrick (la responsable del megaproyecto minero Pascua Lama); ésta declaró haber invertido en dicho Parque una suma extrañamente elevada (USD 70 millones).

El gas natural licuado, un combustible que contamina, pero en menor grado que el petróleo, ofrece perspectivas de disponibilidad abundante y diversificada, con precios en descenso. En noviembre se anunció, con comentario editorial de El Mercurio, el aumento de producción máxima de la gasificadora de Quinteros (ENAP, ENDESA, Metrogas y British Gas) a 15 millones de m³ diarios (equivalentes a una capacidad de 750 MW): esto se lograba con la instalación de un nuevo vaporizador a un costo de 25 millones de dólares. Subir la producción a 20 millones de m³ implicará un nuevo estanque, a 200 millones de dólares. Colbún estudia crear su propio terminal gasífero, que sería flotante y más barato, sin restricciones de venta.

Se conocen las recomendaciones del consejo asesor para la electricidad, presidido por J. A. Guzmán. Son a favor de Hidro-Aysen, afirmando que, de no construirse, los costos de la electricidad aumentarán en 7 a 7,5 % y las emisiones de CO₂, en 37 a 39 %. Y no descartan la fuente nuclear. Sugieren que el Estado facilite las inversiones, los permisos, que establezca un ordenamiento territorial acorde con las necesidades de la transmisión; y que el Centro de Despacho Económico de Carga no esté a cargo, como hoy, de las propias compañías de generación y transmisión, sino que sea una corporación independiente, de derecho privado y sin fines de lucro.

En suma, las empresas del sector y sus gestores y representantes determinan en forma autónoma lo que se hace en el sector de la energía. Nadie menciona el impacto de éste sobre la salud. No hay una política de Estado en el tema de la energía. El actual ministro del ramo, R. Alvarez, anuncia un gran cambio en este campo, y dice: "Las necesidades de generación y transmisión en Chile en el futuro son gigantescas... Hay un

interés por invertir en Chile como nunca antes se había visto, particularmente en el sector energético... Hoy tenemos 16 mil MW instalados, creceremos en 8 mil más al 2020 y de ahí en adelante probablemente vamos a hablar de un crecimiento de 100 % en cada década...". El ministro Alvarez formula así un planteamiento diametralmente opuesto al que haría y al que hacen quienes conocen la situación en materia de energía, cambio climático y salud: lo que se requiere es un aumento de eficiencia que permita al país crecer en lo económico prescindiendo de tales aumentos del consumo de electricidad, como lo están haciendo los países o regiones desarrolladas. Se refiere además a la interconexión de las redes con Colombia, Ecuador y Perú, y en este contexto destaca que "Colombia tiene importantísimas reservas de energía". Estas reservas consisten principalmente en combustibles fósiles –petróleo y carbón– y Chile, en cambio, debería más bien utilizar toda su influencia en lograr que la región se oriente vigorosamente hacia las fuentes de energía limpias y seguras y no al uso de los combustibles responsables de la emisión de gases de invernadero. Habrá que esperar todavía una propuesta de política de largo plazo que esté exenta de ambigüedad.

Las personas interesadas encontrarán el telón de fondo de esta crónica en:

Montoya-Aguilar C, Salud, energía, clima y contaminación,
Cuad Med Soc, 011; 51 (3): 165-177
y en los volúmenes anteriores de Cuadernos, desde el año 2005.

Los datos expuestos están tomados literalmente de la prensa diaria, principalmente: *El Mercurio*, *La Tercera*, *La Segunda* y *El Diario Financiero*.

ÍNDICE ANUAL

Volumen 51, año 2011

ÍNDICE SEGÚN NÚMEROS

Número 1

- 3 Grandes temas en Cuadernos Médico Sociales
JOCELYN NOVOA, DR. CARLOS MONTOYA-AGUILAR
- 5 Experiencia en la implementación de un policlínico de choque de salud mental en un establecimiento público
DR. PABLO ARAVENA, DR. PATRICIO RUIZ
- 16 Prevención en el marco de la nueva salud pública: consideraciones bioéticas
DR. MIGUEL KOTTOW L.
- 24 Análisis crítico de la nueva norma primaria de calidad ambiental para material particulado fino respirable MP 2,5
DR. ANDREI TCHERNITCHIN V.
- 29 Consejería para uso de condón, basada en etapas del cambio, en un centro de atención a adolescentes
INGRID LEAL F., ELECTRA GONZÁLEZ A., TEMÍSTOCLES MOLINA G.
- 36 La prohibición del uso de la pseudoefedrina en medicamentos no es la solución para impedir la elaboración de drogas ilícitas
MARÍA ANGÉLICA SÁNCHEZ
- 38 La prohibición de la pseudoefedrina
DR. ENRIQUE PARIS M.
- 40 Organización de la atención primaria de salud urbana, con incorporación de especialistas en formación
DR. CARLOS MONTOYA-AGUILAR, DR. NELSON VARGAS C.

Número 2

- 53 Mensaje del nuevo Presidente del Colegio Médico
DR. ENRIQUE PARIS M.
- 54 Cáncer de mama en Chile. Tardanza en su atención médica
DR. IVAN SERRA C., DAYSI MAYA G., DR. RAÚL MARTÍNEZ R., EMILIO DECINTI F.
- 66 Estudios de bioexención (in vitro) para establecer equivalencia de medicamentos
IVÁN SAAVEDRA S., VICTOR ITURRIAGA V., LUZ ÁVILA V., LUIS QUIÑÓNES S.

-
- 80 Aspectos psicosociales, éticos y legales en la atención del adolescente y de jóvenes transexuales
ELECTRA GONZÁLEZ A., INGRID LEAL F.
- 93 Identidad Sexual y Política
DR. SERGIO SÁNCHEZ B.
- 95 Cuadernos Médico Sociales lamenta el sensible fallecimiento del Dr. Hugo Behm Rosas
COMITÉ EDITOR
- 96 Discurso de ceremonia de egreso de médicos especialistas. Universidad de Santiago de Chile
DR. HUMBERTO GUAJARDO
- 100 Reseña Bibliográfica: Health care ideology at the turn of the XXI century by Claudio Sepulveda A., MD. MPH., MSc (Anthr) en Neoliberalism`s Fracture Showcase: Another Chile is Possible”
XIMENA DE LA BARRA (ED.)
- 102 NOTICIAS. Nueva Página Web de Cuadernos Médico Sociales ahora en texto completo desde 1959
- 103 Instrucciones a los autores

Número 3

- 109 Participación y evidencia para la salud de hoy
LOS EDITORES
- 111 Enfermedades no transmisibles: “emergencia de salud pública en cámara lenta”. Un desafío para Chile
DRA. MARÍA CRISTINA ESCOBAR
- 123 Garantía en calidad de salud
DR. JOSÉ CONCHA G.
- 129 Medir desigualdades e inequidades para mejorar la política de salud
EC. RAFAEL URRIOLA U.
- 143 Financiamiento agregado de la salud en Chile: año 2008
EC. CAMILO CID P.
- 151 Huelga de hambre. Consideraciones bioéticas
DR. MIGUEL KOTTOW L.
- 157 Ciencia, técnica y educación: ¿otro caso de desarrollo frustrado?
DR. YURI CARVAJAL B.
- 165 Salud, energía, clima y contaminación. ¿Dónde estamos en agosto 2011?
DR. CARLOS MONTOYA-AGUILAR
- 178 Revisores: 2010 N° 4 al 2011 N° 3
- 179 Nueva página de Cuadernos Médico Sociales
- 180 Instrucciones a los autores

Número 4

- 185 ¿Y ahora, la Salud?
LOS EDITORES
- 187 Efectos de la radiación electromagnética no ionizante sobre la salud y el caso específico de los efectos en la salud humana de la telefonía celular
DR. ANDREI TCHERNITCHIN, DR. LEONARDO GAETE, VERENA ROMERO, MOISES PINILLA
- 218 Trastornos por déficit de atención: consideraciones desde la psicología para un diagnóstico comprensivo integral
ANDREA MOYANO, PAULA TORRES, MARIA JOSE EYHERAMENDY, PAULA BARRERA
- 225 Programa Nacional de infecciones respiratorias agudas y síndrome bronquial obstructivo en Chile.
DR. GUIDO GIRARDI B.
- 234 Algo importante para celebrar en el bicentenario
DR. FERNANDO MONKEBERG
- 236 CRÓNICA. Pensando en la salud de la humanidad y del ambiente: observación de los últimos eventos significativos relacionados con la generación de energía
DR. CARLOS MONTOYA AGUILAR
- 239 Índice anual Vol. 51
- 245 Información para los autores

ÍNDICE SEGÚN TEMA

ATENCIÓN DE SALUD

- 5 Experiencia en la implementación de un policlínico de choque de salud mental en un establecimiento público
DR. PABLO ARAVENA, DR. PATRICIO RUIZ
- 112 Enfermedades no transmisibles: "emergencia de salud pública en cámara lenta" un desafío para Chile
DRA. MARIA CRISTINA ESCOBAR

ÉTICA

- 17 Prevención en el marco de la nueva salud pública: consideraciones bioéticas
DR. MIGUEL KOTTOW L.
- 151 Huelga de hambre. Consideraciones bioéticas
DR. MIGUEL KOTTOW L.

EPIDEMIOLOGÍA

- 55 Cáncer de mama en Chile. Tardanza en su atención médica
DR. IVAN SERRA C., DAYSI MAYA G., DR. RAÚL MARTINEZ R., EMILIO DECINTI F.

ECONOMÍA Y SALUD

- 129 Medir desigualdades e inequidades para mejorar la política de salud
RAFAEL URIOLA URBINA
- 143 Financiamiento agregado de la salud en Chile: año 2008
EC. CAMILO CID PEDRAZA

EVOLUCIÓN DE LA SALUD PÚBLICA

- 234 Algo importante para celebrar el bicentenario
DR. FERNANDO MONKEBERG

EDUCACIÓN EN SALUD

- 157 Ciencia, técnica y educación: ¿otro caso de desarrollo frustrado?
DR. YURI CARVAJAL BAÑADOS

MEDICAMENTOS

- 67 Estudios de bioexención (in vitro) para establecer equivalencia de medicamentos
IVÁN SAAVEDRA S., VICTOR ITURRIAGA V., LUZ AVILA V., LUIS QUIÑONES S.
- 36 La prohibición del uso de la pseudoefedrina en medicamentos no es la solución para impedir la elaboración de drogas ilícitas
M. ANGÉLICA SÁNCHEZ
- 38 La prohibición de pseudoefedrina
DR. ENRIQUE PARIS

SALUD AMBIENTAL

- 25 Análisis crítico de la nueva norma primaria de calidad ambiental para material particulado fino respirable MP 2,5
DR. ANDREI TCHERNITCHIN
- 187 Efectos de la radiación electromagnética no ionizante sobre la salud y el caso específico de los efectos en la salud humana de la telefonía celular
DR. ANDREI TCHERNITCHIN, DR. LEONARDO GAETE, VERENA ROMERO, MOISES PINILLA
- 236 Pensando en la salud de la humanidad y del ambiente: observación de los últimos eventos significativos relacionados con la generación de energía
DR. CARLOS MONTOYA - AGUILAR

SALUD SEXUAL Y REPRODUCTIVA

- 30 Consejería para uso de condón basada en etapas del cambio en una centro de atención a adolescentes
INGRID LEAL F., ELECTRA GONZALEZ A., TEMISTOCLES MOLINA G.
- 81 Aspectos psicosociales, éticos y legales en la atención del adolescente y jóvenes transexuales
ELECTRA GONZALEZ A., INGRID LEAL F.

SALUD INFANTIL

- 225 Programa Nacional de infecciones respiratorias agudas y síndrome bronquial obstructivo en Chile.
DR. GUIDO GIRARDI B.

SALUD MENTAL

- 218 Trastornos por déficit de atención: consideraciones desde la psicología para un diagnóstico comprensivo integral
ANDREA MOYANO, PAULA TORRES, MARIA JOSE EYHERAMENDY, PAULA BARRERA

OPINIÓN

- 36 La prohibición del uso de la pseudoefedrina en medicamentos no es la solución para impedir la elaboración de drogas ilícitas
M. ANGÉLICA SANCHEZ
- 38 La prohibición de pseudoefedrina
DR. ENRIQUE PARIS

CRÓNICA

- 236 Pensando en la salud de la humanidad y del ambiente: observación de los últimos eventos significativos relacionados con la energía
DR. CARLOS MONTOYA AGUILAR

**DOCUMENTOS DEL PROGRAMA DE FORMACIÓN DE ESPECIALISTAS
PARA LA ATENCIÓN PRIMARIA**

- 41 Organización de la atención primaria de salud urbana, con incorporación de especialistas en formación
DR. CARLOS MONTOYA-AGUILAR, DR. NELSON VARGAS C.

ENSAYO

- 165 Salud, energía, clima y contaminación ¿Dónde estamos en agosto 2011?
DR. CARLOS MONTOYA AGUILAR
- 93 Identidad Sexual y Política
DR. SERGIO SANCHEZ BUSTOS

HITOS

- 97 Cuadernos Médico Sociales lamenta sensible fallecimiento del Dr. Hugo Behm Rosas
COMITÉ EDITOR
- 98 Discurso de ceremonia de egreso de médicos especialistas. Universidad Santiago de Chile
DR. HUMBERTO GUAJARDO

NOTICIAS

- 179 Nueva página de Cuadernos Médico Sociales

RESEÑAS BIBLIOGRÁFICAS

- 100 Reseñas Bibliográficas: Health care ideology at the turn of the XXI century By Claudio Sepulveda Alvarez, MD.
MPH., MSc (Anthr) en Neoliberalism`s Fracture Showcase: Another Chile is Possible”
XIMENA DE LA BARRA (ED)
- 178 Revisores:2010 N° 4-2011 N° 3

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3.1. La extensión máxima será de 20 páginas a espacio sencillo, tipo Arial 11 con un margen de 3 cm., incluyendo tablas y gráficos. Las ilustraciones y tablas deben enviarse en páginas separadas, indicando claramente el título, numeración, fuentes y el sitio en que serán intercaladas; deben venir en el archivo original y no ser insertados como "objetos". No se usarán colores. Las notas al texto deben venir al final de cada página con números correlativos.

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- a. Título y autores.** El título puede tener hasta 84 caracteres, incluyendo los espacios entre las palabras y además debe estar traducido al inglés. Los autores figurarán con el nombre y apellido; en nota al pie se consignará la profesión, cargo y principal grado académico. Se colocará la dirección electrónica del autor a cual deberá dirigirse la correspondencia.
- b. Resumen.** No debe tener más de 250 palabras, con los objetivos, métodos, resultados y conclusiones principales. Agregar una versión en inglés. Colocar entre dos y seis palabras clave (descriptores), según la nomenclatura consignada en: <http://decs.bvs.br/E/homepagee.htm>
- c. Introducción.** Describa brevemente el objetivo de la investigación y explique su importancia.
- d. Material y Métodos.** Describa los procedimientos y materiales utilizados, incluyendo los detalles necesarios que permitan repetir la experiencia en futuras investigaciones (en el caso de utilizar metodología cuantitativa).
- e. Resultados.** Presente sus resultados en secuencia lógica. No repita en el texto todos los datos presentados en tablas o ilustraciones. Enfatique o resuma solamente las observaciones importantes.
- f. Discusión.** Enfatique los aspectos nuevos e importantes del estudio y las conclusiones derivadas de ellos. Incluya en esta sección las implicancias de sus hallazgos, tanto como sus limitaciones. Evite detalles ya presentados en las secciones Introducción y Resultados.
- g. Conclusiones y perspectivas**
- h. Referencias.** Limite las referencias (citas bibliográficas) idealmente a 30. Incluya las principales publicaciones aparecidas en revistas chilenas, incluyendo Cuadernos Médico Sociales.

Numere las referencias en el orden en que se las menciona por primera vez en el texto. Identifíquelas mediante numerales arábigos, colocados () al final de la frase o párrafo en que se las alude.

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i. Artículos de revistas

Arredondo A, Hernández P, Cruz C. Incorporación de la perspectiva económica en el análisis del sector salud: segunda parte. Cuad Méd Soc (Santiago de Chile). 1993; 34: 33-44.

ii. Capítulos en Libros

Mehta SJ. Dolor abdominal. En: Friedman HH, coordinador. Manual de Diagnóstico Médico. 5ª ed. Barcelona: Masson; 2004. p.183-90.

iii. Artículos en formato electrónico

Montoya-Aguilar C. Atención primaria de salud. Alma Ata otra vez y la experiencia de Chile. Cuad Méd Soc [revista en Internet]* 2008 septiembre. [acceso 03 de enero de 2009]; 48(3). Disponible en: <http://www.colegiomedico.cl/Default.aspx?tabid=767>

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1

Summary and Recommendations

Background

- 1.1 The widespread use of mobile phones is a recent phenomenon. Their use has escalated over the past decade and to many they are now an essential part of business, commerce and society. Over the Christmas 1999 period alone approximately 4 million phones were sold in the UK and at present (April 2000) there are about 25 million mobile phones in circulation. This is equivalent to nearly one phone for every two people (see paragraph 2.16)
- 1.2 The fact that so many people own mobile phones attests to their perceived importance to the general public. The advent of third generation systems will extend the use of most forms of communications technologies, including fax, e-mail and Internet access. **The use of mobile phones and related technologies will continue to increase for the foreseeable future.**
- 1.3 The extensive use of mobile phones has been accompanied by public debate about possible adverse effects on human health. The concerns relate to the emissions of radiofrequency (RF) radiation from the phones (the handsets) and from the base stations that receive and transmit the signals (paragraphs 3.3–3.7). For the general population, the levels of exposure arising from phones held near to the head or other parts of the body are substantially greater than whole-body exposures arising from base stations (paragraphs 4.28–4.36).
- 1.4 There are two direct ways by which health could be affected as a result of exposure to RF radiation. These are by thermal (heating) effects caused mainly by holding mobile phones close to the body, and as a result of possible non-thermal effects from both phones and base stations (paragraphs 5.5–5.26).
- 1.5 There can also be indirect effects. There is evidence that using a mobile phone whilst driving can increase the risk of accidents. Also some people's well-being may be adversely affected by the environmental impact of mobile phone base stations sited near their homes, schools or other buildings, as well as by their fear of perceived direct effects (paragraphs 5.264, 6.44 and 6.45).

Sources of Exposure

- 1.6 Mobile phones and base stations emit RF radiation. In both cases levels of exposure generally reduce with increasing distance from the source. For mobile phones, exposures will be principally to the side of the head for hand-held use, or to the parts of the body closest to the phone during hands-free use.
- 1.7 For base station emissions, exposures of the general population will be to the whole body but normally at levels of intensity many times less than those from handsets (paragraphs 4.28–4.36). Base stations communicate with mobile phones within a defined area or "cell". These can be of

Summary and Recommendations

three types: *macrocells*, *microcells* and *picocells* depending upon their size and the power output of the antenna (paragraph 4.9).

- 1.8** *Macrocells* provide the main structure for the base station network. The base stations for macrocells have power outputs of tens of watts and communicate with phones up to about 35 kilometres (22 miles) distant. There are at present about 20,000 macrocells covering the country (paragraph 4.9). We believe that this number will continue to increase. Measurements that have been made (see paragraphs 4.30–4.36) indicate that exposures of the general population from these sites are typically many hundreds, or thousands of times lower than existing exposure guidelines. There are concerns, nevertheless, about whether the emissions from all base stations are uniformly low, about whether the emissions could cause unknown health effects, and whether, with the increased use of mobile telecommunications, their output will have to rise.
- 1.9** *Microcells* are used to infill and improve the main network, especially where the volume of calls is high. They are sited in places such as airports, railway stations and shopping malls. Their number is rapidly increasing in line with the growth in demand for mobile phones. The microcell base stations emit less power than those for macrocells and their range is a few hundred metres. We understand that exposures above guidelines do not occur, provided the case surrounding the antenna is kept in place. However, as with some other items of electrical equipment – for example, lasers in CD equipment – there is a possibility of overexposure if the case is removed.
- 1.10** *Picocell* base stations have a lower power output than those of microcells (a few watts) and are generally sited inside buildings. It is likely that the number of picocells within buildings will substantially increase. Although we are satisfied that their emissions should not exceed the guidelines, the system of audits that we propose (paragraph 1.40) will provide an independent check on the output not only from picocell antennas but from all base station types.
- 1.11** As well as mobile phone base stations, there are a large number of other RF emitting sources in our environment, including antennas for radio, television and paging (paragraphs 4.20–4.22). Exposures of individuals to RF radiation from these sources will depend upon their proximity and may be above those from mobile phone base stations, although still well below guidelines.

Current Guidelines on Acceptable Levels of Exposure to Radiofrequency Radiation

- 1.12** Government has in place national guidelines (paragraphs 6.19–6.26, 6.32) established by the National Radiological Protection Board (NRPB) on the maximum levels of exposure to RF radiation emitted from mobile phones, base stations and other sources (“the NRPB guidelines”). These guidelines were established in 1993 when mobile phone technology was in its infancy. The guidelines were based on a comprehensive review of the scientific literature carried out by NRPB, a statutory body, which advises Government on radiological issues related to health.
- 1.13** In 1998 the International Commission on Non-Ionizing Radiation Protection (ICNIRP) published its own guidelines (paragraphs 6.27–6.31) covering exposure to RF radiation. These were based on essentially the same evidence as that used by NRPB, and for workers the limits on exposure are similar. However, under the ICNIRP guidelines, the maximum levels of exposure of the public are about five times less than those recommended for workers. The reason for this approach was the possibility that some members of the general public might be particularly sensitive to RF radiation. However, no detailed scientific evidence to justify this additional safety factor was provided.

Main Conclusions on the Possible Effects of Mobile Phone Technology on Human Health

- 1.14** The ICNIRP guidelines for the public have been incorporated in a European Council Recommendation (1999), which has been agreed in principle by all countries in the European Union (EU), including the UK. In Germany the ICNIRP guidelines have been incorporated into statute (paragraph 6.33).
- 1.15** Both the NRPB and ICNIRP guidelines are based on the need to avoid known adverse health effects. At the time these guidelines were drawn up, the only established adverse effects were those caused by the heating of tissues.

Main Conclusions on the Possible Effects of Mobile Phone Technology on Human Health

- 1.16** Despite public concern about the safety of mobile phones and base stations, rather little research specifically relevant to these emissions has been published in the peer-reviewed scientific literature. This presumably reflects the fact that it is only recently that mobile phones have been widely used by the public (paragraphs 2.1–2.12) and as yet there has been little opportunity for any health effects to become manifest. There is, however, some peer-reviewed literature from human and animal studies, and an extensive non-peer-reviewed information base, relating to potential health effects caused by exposure to RF radiation from mobile phone technology.
- 1.17** **The balance of evidence to date suggests that exposures to RF radiation below NRPB and ICNIRP guidelines do not cause adverse health effects to the general population (Chapter 5, paragraphs 6.33–6.42).**
- 1.18** **There is now scientific evidence, however, which suggests that there may be biological effects occurring at exposures below these guidelines** (paragraphs 5.176–5.194, 6.38). This does not necessarily mean that these effects lead to disease or injury, but it is potentially important information and we consider the implications below.
- 1.19** There are additional factors that need to be taken into account in assessing any possible health effects. Populations as a whole are not genetically homogeneous and people can vary in their susceptibility to environmental hazards. There are well-established examples in the literature of the genetic predisposition of some groups, which could influence sensitivity to disease. There could also be a dependence on age. **We conclude therefore that it is not possible at present to say that exposure to RF radiation, even at levels below national guidelines, is totally without potential adverse health effects, and that the gaps in knowledge are sufficient to justify a precautionary approach** (Chapter 5, paragraphs 6.35–6.42).
- 1.20** In the light of the above considerations **we recommend that a precautionary approach to the use of mobile phone technologies be adopted until much more detailed and scientifically robust information on any health effects becomes available** (Chapter 5, paragraphs 6.35–6.42).
- 1.21** We note that a precautionary approach, in itself, is not without cost (paragraph 6.16) but we consider it to be an essential approach at this early stage in our understanding of mobile phone technology and its potential to impact on biological systems and on human health.
- 1.22** In addition to these general considerations, there are concerns about the use of mobile phones in vehicles. Their use may offer significant advantages – for example, following accidents when they allow emergency assistance to be rapidly summoned. Nevertheless, the use of mobile phones whilst driving is a major issue of concern and experimental evidence demonstrates that it has a detrimental effect on drivers' responsiveness. Epidemiological evidence indicates that this

Summary and Recommendations

effect translates into a substantially increased risk of an accident. Perhaps surprisingly, current evidence suggests that the negative effects of phone use while driving are similar whether the phone is hand-held or hands-free (paragraph 5.213). **Overall we conclude that the detrimental effects of hands-free operation are sufficiently large that drivers should be dissuaded from using either hand-held or hands-free phones whilst on the move** (paragraphs 5.201–5.214, 5.262–5.263 and 6.93–6.95).

- 1.23** We consider below ways in which a precautionary approach to the use of mobile phone technology might be adopted.

A Precautionary Approach and Related Issues

- 1.24** We recommend that national and local government, industry and the consumer should all become actively involved in addressing concerns about possible health effects of mobile phones (paragraph 6.40).

- 1.25** Our recommendations focus on five areas:

- advice to Government,
- advice to industry,
- research requirements,
- the need for better public information and consumer choice,
- the role of NRPB.

Advice to Government

- 1.26** We recognise that the mobile phone industry impacts on people and business around the world and that the UK is a global leader in telecommunications technology. There are benefits that the development of mobile telecommunications can bring, provided there is no adverse impact on health. It is against this general backcloth that we make our recommendations.

Standards

- 1.27** We recommend that, as a precautionary approach, the ICNIRP guidelines for public exposure be adopted for use in the UK rather than the NRPB guidelines. This would bring the UK into line with other countries in the European Union and accord with the Recommendations of the House of Commons Select Committee on Science and Technology Report on Mobile Phones and Health (1999) (paragraphs 6.19–6.42).
- 1.28** We are not convinced of the need to incorporate the ICNIRP guidelines in statutes. We believe that they are liable to change as more scientific information on possible health effects becomes available (paragraph 6.36).
- 1.29** It would be sensible, in line with the precautionary approach, to set in place a long-term follow-up of workers who are occupationally exposed to RF radiation at relatively high levels. **We recommend that a register of occupationally exposed workers be established and that cancer risks and mortality be examined to determine whether there are any harmful effects. If any**

adverse effects of exposure to RF radiation are identified then the Health and Safety Executive should establish a system of health surveillance (paragraph 5.240).

Planning issues

- 1.30** The siting of base stations in residential areas can cause considerable concern and distress. At all our open meetings and in written evidence we heard concerns about the location of base stations in sensitive sites. These include schools, residential areas and hospitals. This concern relates, in part, to the fact that base stations up to 15 m (48 ft) in height can be installed in residential areas without the need for a full planning application. We consider this to be unacceptable.
- 1.31** We are concerned at the indirect adverse impact which current planning procedures are having on those who have been, or are, subjected to the often insensitive siting of base stations. Adverse impacts on the local environment may adversely impact on the public's well-being as much as any direct health effects.
- 1.32** We recognise that exposures of people in the vicinity of base stations are expected to be well within guidelines yet there is no independent audit to ensure that this is the case (paragraphs 4.30–4.35).
- 1.33** **We conclude that the balance of evidence indicates that there is no general risk to the health of people living near to base stations on the basis that exposures are expected to be small fractions of guidelines. However, there can be indirect adverse effects on their well-being in some cases** (paragraphs 5.264, 6.44 and 6.45).
- 1.34** We perceive a lack of clear protocols to be followed in the public interest prior to base stations being built and operated and note that there is significant variability in the extent to which mobile phone operators consult the public on the siting of base stations. We have heard little specific criticism of most of the network operators, apart from Orange. The Department of the Environment, Transport and the Regions and the National Assembly for Wales (DETR, 1998) produced a *Code of Best Practice: Telecommunications prior approval procedures* as applied to mast/tower development. We understand that consideration is being given to extending this to include health concerns (paragraphs 6.104–6.109). We support this development.
- 1.35** Overall we consider that public concerns about the siting of base stations demand changes in the planning process. Thus:
- 1.36** **We recommend that for all base stations, including those with masts under 15 m, permitted development rights for their erection be revoked and that the siting of all new base stations should be subject to the normal planning process** (paragraphs 6.43–6.46 and 6.55–6.62).
- 1.37** **We recommend that, at national Government level, a template of protocols be developed, in concert with industry and consumers, which can be used to inform the planning process and which must be assiduously and openly followed before permission is given for the siting of a new base station** (paragraphs 6.58–6.62). We consider the protocol should cover the following issues.
- All telecommunications network operators must notify the local authority of the proposed installation of base stations. This should cover installations for macrocells, microcells and picocells.
 - The local authority should maintain an up-to-date list of all such notifications, which should be readily available for public consultation.

Summary and Recommendations

- The operator should provide to the local authority a statement for each site indicating its location, the height of the antenna, the frequency and modulation characteristics, and details of power output.
 - Any change to an existing base station which increases its size, or the overall power radiated, should be subject to the normal planning process as if it were a new development.
- 1.38** We recommend that a robust planning template be set in place within 12 months of the publication of this report. It should incorporate a requirement for public involvement, an input by health authorities/health boards and a clear and open system of documentation which can be readily inspected by the general public (paragraphs 6.55–6.62).
- 1.39** We recommend that a national database be set up by Government giving details of all base stations and their emissions. This should include the characteristics of the base stations as described in paragraphs 6.47 and 6.48 and should be an essential part of the licence application for the site.
- 1.40** We recommend that an independent random, ongoing, audit of all base stations be carried out to ensure that exposure guidelines are not exceeded outside the marked exclusion zone and that the base stations comply with their agreed specifications. If base station emissions are found to exceed guideline levels, or if there is significant departure from the stated characteristics, then the base station should be decommissioned until compliance is demonstrated (paragraphs 6.53 and 6.54).
- 1.41** We recommend that particular attention should be paid initially to the auditing of base stations near to schools and other sensitive sites (paragraphs 6.54 and 6.63–6.68).
- 1.42** We recommend, in relation to macrocell base stations sited within school grounds, that the beam of greatest intensity (paragraphs 4.32–4.35 and 6.63–6.68) should not fall on any part of the school grounds or buildings without agreement from the school and parents. Similar considerations should apply to macrocell base stations sited near to school grounds.
- 1.43** We recommend that in making decisions about the siting of base stations, planning authorities should have the power to ensure that the RF fields to which the public will be exposed will be kept to the lowest practical levels that will be commensurate with the telecommunications system operating effectively (paragraphs 6.55–6.62).

Exclusion zones

- 1.44** We recommend the establishment of clearly defined physical exclusion zones around base station antennas, which delineate areas within which exposure guidelines may be exceeded (paragraphs 6.49–6.52). The incorporation of exclusion zones should be part of the template of planning protocols that we advocate.
- 1.45** Each exclusion zone should be defined by a physical barrier and a readily identifiable nationally agreed sign with a logo. This should inform the public and workers that inside the exclusion zone there might be RF emissions which exceed national guidelines. **We recommend that the design of the logo should be taken forward by the British Standards Institute and implemented within 12 months** (paragraphs 6.49–6.52).
- 1.46** We recommend that warning signs should be incorporated into microcell and picocell transmitters to indicate they should not be opened when in use (paragraph 6.52).

Use of mobile phones near hospitals

- 1.47** We are concerned about the indiscriminate use of mobile phones in hospitals and other sites where the RF radiation could possibly interfere with sensitive equipment. **We understand that health authorities/health boards issue guidance on the use of mobile phones. They should ensure that all hospitals comply. This guidance should include the placing of visible warning signs at entrances to buildings to indicate that mobile phones should be switched off** (paragraphs 4.6, 6.91 and 6.92).

Devolution in Scotland, Wales and Northern Ireland

- 1.48** Where recommendations (paragraphs 1.30–1.46) impact on the devolved responsibilities of the Scottish Parliament, the Welsh National Assembly and the Northern Ireland Assembly then they should be considered by their appropriate authorities or bodies. We have noted with interest the recent report on planning procedures for telecommunications developments produced by the Transport and the Environment Committee of the Scottish Parliament (2000) (paragraphs 6.112–6.117).

Advice to Industry

- 1.49** We believe that in the global economy of the 21st Century a competitive edge will be generated by developing innovative, technologically advanced and safe products, which can lead the field and win competitive advantage.
- 1.50** We understand from the Mobile Manufacturers Forum that all mobile phones presently marketed in the UK comply with both NRPB and ICNIRP guidelines. A crucial issue in relation to the exposure of people using mobile phones is the specific energy absorption rate (SAR). This determines the amount of energy absorbed in the body of the user. In most circumstances of use this will be the head. The SAR depends upon the power output of the phone and its design (paragraph 4.37). We understand that an internationally agreed standard testing procedure that will allow the SAR from mobile phones to be compared is being developed and will be finalised this year (2000). Such a procedure should benefit consumers and should also be welcomed by industry. We note that in the case of cars, standard testing procedures for fuel consumption have been developed to inform consumer choice, and have resulted in the development of more efficient engines. We see no reason why, in the case of mobile phones, standard testing procedures should not lead to a progressive reduction in exposures from the equipment.
- 1.51** **We recommend that an international standard for the assessment of SAR values from mobile phones should be adopted for use in the UK once it has been demonstrated to be scientifically sound** (paragraphs 6.74–6.79).
- 1.52** **We recommend that information on the SAR values for mobile phones must be readily accessible to consumers** (paragraph 6.77):
- **at the point of sale with information on the box,**
 - **on leaflets available in stores giving comparative information on different phones and with explanatory information,**
 - **as a menu option on the screen of the phone and as a label on the phone,**
 - **on a national web site, which lists the SAR values of different phone types.**

Summary and Recommendations

- 1.53** If there are currently unrecognised adverse health effects from the use of mobile phones, children may be more vulnerable because of their developing nervous system, the greater absorption of energy in the tissues of the head (paragraph 4.37), and a longer lifetime of exposure. In line with our precautionary approach, at this time, we believe that the widespread use of mobile phones by children for non-essential calls should be discouraged. We also recommend that the mobile phone industry should refrain from promoting the use of mobile phones by children (paragraphs 6.89 and 6.90).
- 1.54** We have examined the value of mast sharing and roaming agreements. These can offer advantages in terms of providing a better service in rural areas and limiting environmental intrusion. We recommend that operators actively pursue a policy of mast sharing and roaming where practicable (paragraphs 6.69 and 6.70).

Health Related Research

- 1.55** The mobile phone industry has supported a substantial and ongoing programme of research internationally. The recent upsurge in the use of mobile phone technology in the UK has not been matched, in general, by the output of good quality relevant research supported by the public sector. Too many studies have been carried out at exposure levels and frequencies not directly related to the use of mobile phones or base stations.
- 1.56** In relation to present research findings, the following three areas deserve particular comment.
- First, the balance of the evidence available does not suggest that RF radiation from mobile phones or base stations causes cancer or other disease. However, there is now evidence that effects on biological functions, including those of the brain, may be induced by RF radiation at levels comparable to those associated with the use of mobile phones. There is, as yet, no evidence that these biological effects constitute a health hazard but at present only limited data are available. This is one reason why we recommend a precautionary approach.
 - Second, concerns have been expressed that the pulsed nature of the signals from mobile phones and masts may have an impact on brain function. This is an intriguing possibility, which deserves further research, particularly if pulsed signals continue to be used in the third generation of phones and related technologies. Research should concentrate on signal modulations representative of present and future phone technology (paragraphs 5.4, 5.12–5.26 and 5.270).
 - Third, we commend the World Health Organization (WHO) for encouraging the use of standard experimental protocols under realistic exposure conditions relevant to mobile phone technology (paragraph 5.284). This should allow experiments from different laboratories to be readily compared.
- 1.57** On the basis of the current state of knowledge we recommend that priority be given to a number of areas of research related particularly to signals from handsets (paragraph 5.270). These should include the following:
- effects on brain function,
 - consequences of exposures to pulsed signals,
 - improvements in dosimetry,
 - the possible impact on health of sub-cellular and cellular changes induced by RF radiation,

- psychological and sociological studies related to the use of mobile phones,
 - epidemiological and human volunteer studies (paragraphs 5.249–5.264), including the study of children, and individuals who might be more susceptible to RF radiation (paragraphs 4.37, 6.29 and 6.30).
- 1.58 We recommend that a substantial research programme should operate under the aegis of a demonstrably independent panel.** The aim should be to develop a programme of research related to health aspects of mobile phones and associated technologies. This should complement work sponsored by the EU and in other countries. In developing a research agenda the peer-reviewed scientific literature, non-peer reviewed papers and anecdotal evidence should be taken into account (paragraphs 5.270–5.272).
- 1.59 We further recommend that this programme be financed by the mobile phone companies and the public sector (industry departments, health departments and the research councils), possibly on a 50 : 50 basis.** The contribution from industry could be made on a voluntary basis or by a continuing levy reviewable every five years (paragraph 5.272).
- 1.60 It will be essential for further research in this area to be kept under review. We recommend that the issue of possible health effects of mobile phone technology should be the subject of a further review in three years time, or earlier if circumstances demand it** (paragraph 5.273).

Public Information and Consumer Choice

- 1.61** We are concerned at the variability and the limited extent of the information made available to consumers on mobile phone products. **We recommend that Government circulates a leaflet to every household in the UK providing clearly understandable information on mobile phone technology and on related health aspects, including the use of mobile phones while driving** (paragraphs 5.201–5.208). **This leaflet should additionally be available at the point of sale. The leaflet should be developed in concert with industry, which has already produced some good leaflets** (paragraphs 3.48 and 3.49).
- 1.62 We recommend that an Ombudsman be appointed to provide a focus for decisions on the siting of base stations when agreement cannot be reached locally, and on other relevant issues** (paragraphs 3.50 and 3.51).
- 1.63** There are various devices that seek to reduce exposure to RF radiation from mobile phones. These include shields and devices that attach to phones. We remain to be convinced of their effectiveness in reducing personal exposure in normal conditions of use of mobile phones.
- 1.64** Hands-free extensions, which allow the phone to be held away from the body, have the potential for reducing exposure, but some recent tests have cast doubt on their general level of effectiveness. For users wishing to reduce their exposure, we advocate the use of hands-free kits of proven effectiveness. A satisfactory design may involve the use of chokes or filters in the connecting lead. A standard testing procedure should be established.
- 1.65** The regulatory position on the use of shielding devices and hands-free kits, which may affect the phone's performance, is unclear. In addition, information available for the public on the use of such devices is limited to that provided by the suppliers of the devices and the mobile phone industry. **We recommend that Government sets in place a national system which enables independent testing of shielding devices and hands-free kits to be carried out, and which enables clear information to be given about the effectiveness of such devices. A kite mark or**

Summary and Recommendations

equivalent should be introduced to demonstrate conformity with the testing standard (paragraphs 6.86–6.88).

National Radiological Protection Board (NRPB)

- 1.66** We believe that NRPB is a valuable UK asset which should be built upon, and that it carries out scientific work which is well-regarded nationally and internationally.
- 1.67** Whilst there is no criticism of its science, **we recommend that NRPB gives greater priority to the execution of a more open approach to issues of public concern such as mobile phone technology and that it is proactive rather than reactive in its approach** (paragraph 3.44).
- 1.68** **We recommend that public concerns about risk be addressed by NRPB in a more sensitive and informative manner** (paragraph 3.45).
- 1.69** **We recommend that NRPB makes more use of specialist time-limited *ad-hoc* committees of experts and lay representatives to bring forward broadly based, well-considered advice** (paragraph 3.42).
- 1.70** **We recommend that in a rapidly emerging field such as mobile phone technology where there is little peer-reviewed evidence on which to base advice, the totality of the information available, including non-peer-reviewed data and anecdotal evidence, be taken into account when advice is proffered** (paragraph 3.46).
- 1.71** We note the paucity of resources available at NRPB for work on non-ionising radiation, including work on mobile phones, and related research on life sciences. **We recommend that work on non-ionising radiation and related life sciences work be strengthened at NRPB** (paragraph 3.47).

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2

Introduction

- 2.1** The telecommunications industry is experiencing rapid growth on a global scale. This is a direct consequence of technological development and has in turn facilitated the application of new technologies, and a consequent increase in economic activity. Within this sector, one of the greatest growth areas of recent years has been the development of mobile or wireless telecommunications.
- 2.2** The first land mobile services were introduced into the UK in the 1940s, but the significant expansion of services offered to the general public, including the introduction of mobile phones, began in the mid-1980s and rapidly attracted a small but significant number of subscribers. Developments in the early 1990s, such as the introduction of digital networks and the entry of additional service providers into the market, fuelled further increases in the numbers of subscribers.
- 2.3** It is now predicted that within a few years around half the population of the UK will be routinely using mobile telecommunications (see Figure 2.1) and that this will become the dominant technology for telephony and other applications such as Internet access. This wide use of a relatively new technology raises the question of whether there are any implications for human health.
- 2.4** There are conflicting reports relating to possible adverse health effects and these have understandably led to some concern. The Minister for Public Health recognised the importance of this issue and, following consultation with the Ministers at the Department of Trade and Industry, decided to seek the advice of an independent group as to the safety of mobile telecommunications technology, and asked the Chairman of the National Radiological Protection Board (NRPB) to establish an Independent Expert Group on Mobile Phones (IEGMP).
- 2.5** Following widespread consultation with interested parties, the Expert Group was set up under the chairmanship of Sir William Stewart FRS, FRSE. Membership of the Expert Group (Appendix A) represented a wide spectrum of expertise with leading figures from physics, radio engineering, biology, medicine, and epidemiology, in addition to lay members. The remit of the Group was
- “To consider present concerns about the possible health effects from the use of mobile phones, base stations and transmitters, to conduct a rigorous assessment of existing research and to give advice based on the present state of knowledge. To make recommendations on further work that should be carried out to improve the basis for sound advice.”*
- 2.6** The Expert Group held its first full meeting in September 1999 and determined from the outset that it must consult widely. To this end, advertisements were placed in national newspapers and scientific journals inviting individuals or organisations to submit evidence for consideration. Public meetings were arranged in Belfast, Cardiff, Edinburgh, Liverpool and London.

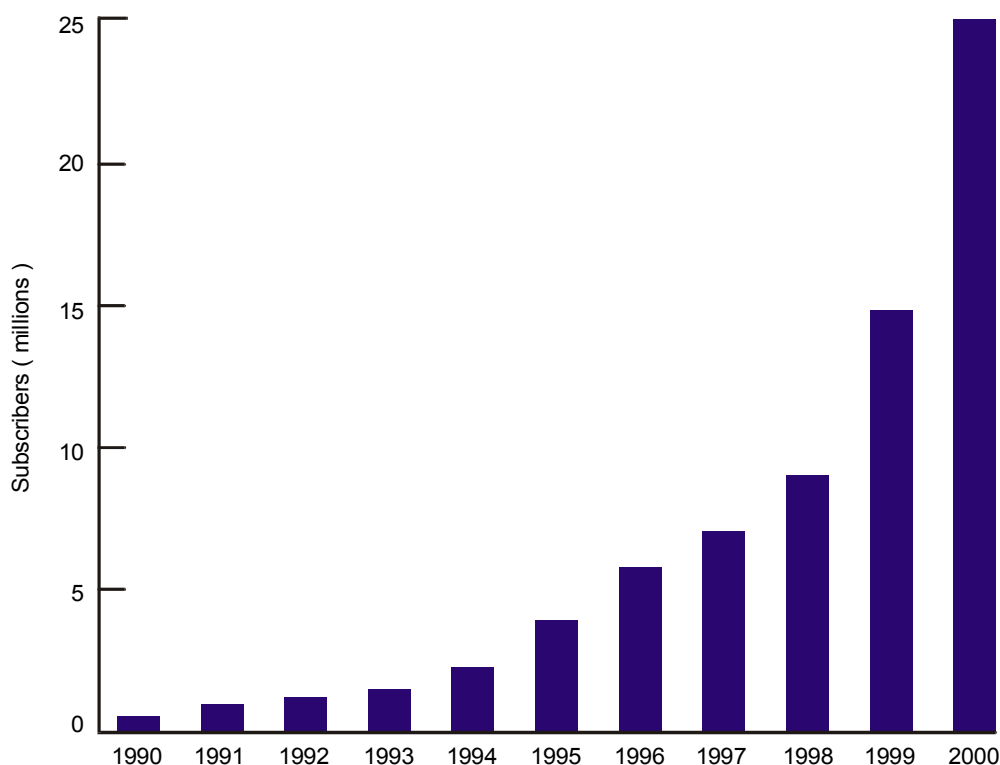
Introduction

Figure 2.1 Growth in mobile phone subscribers in the UK between 1990 and 2000 (based on data from Federation of the Electronics Industry, FEI)

- 2.7** Those who submitted written evidence to the Expert Group are listed in Appendix B. A number of individuals and organisations accepted invitations to present evidence to closed meetings of the Group and these are indicated in Appendix C.
- 2.8** This report describes the work of the Expert Group. It presents the wide picture of mobile telecommunications as they impact on the general public, and recognises the contribution of mobile telecommunications to the quality of life and to the UK economy. It considers the underlying technology and the characteristics of the RF fields generated by present and near future (3–5 years) handsets and base stations, with particular reference to the magnitude of the fields. It provides an appraisal of the experimental and theoretical work that has been carried out which has a bearing on human health, and makes a number of recommendations to Government.

Background to the Introduction of Mobile Telecommunications

- 2.9** The UK telecommunications system was initially developed and operated as part of the General Post Office (GPO). In 1981, this situation changed with the passing of the British Telecommunications Act, which effectively separated the telecommunications and postal businesses of the GPO, and led to the creation of British Telecom (BT). The next stage in telecommunications development was the creation of a competitive marketplace governed by a new regulatory body, the Office of Telecommunications (OFTEL), which was established in 1984. These changes paved the way for the introduction of cellular telecommunications in a competitive environment.

Background to the Introduction of Mobile Telecommunications

2.10 Initially two companies were granted operating licences, Telecom Securicor Cellular Radio Limited (Cellnet) and a subsidiary of Racal Electronics plc (Vodafone). In January 1985, both these companies launched national networks based on analogue technology (see paragraph 4.10). However, in the late 1980s there was a move to develop standards for a second generation of mobile telecommunications throughout Europe in order to provide a seamless service for subscribers. This was achieved with the development and deployment of a new operating standard called the Global System for Mobile Telecommunications (GSM), which employs digital technology (see paragraph 4.11) and is now the operating system for 340 networks in 137 countries (Figure 2.2). Although this system is now used worldwide, the European geographical area is still the dominant user, with more subscribers than any other region. It has, however, been widely accepted in other areas such as the Asia Pacific region.

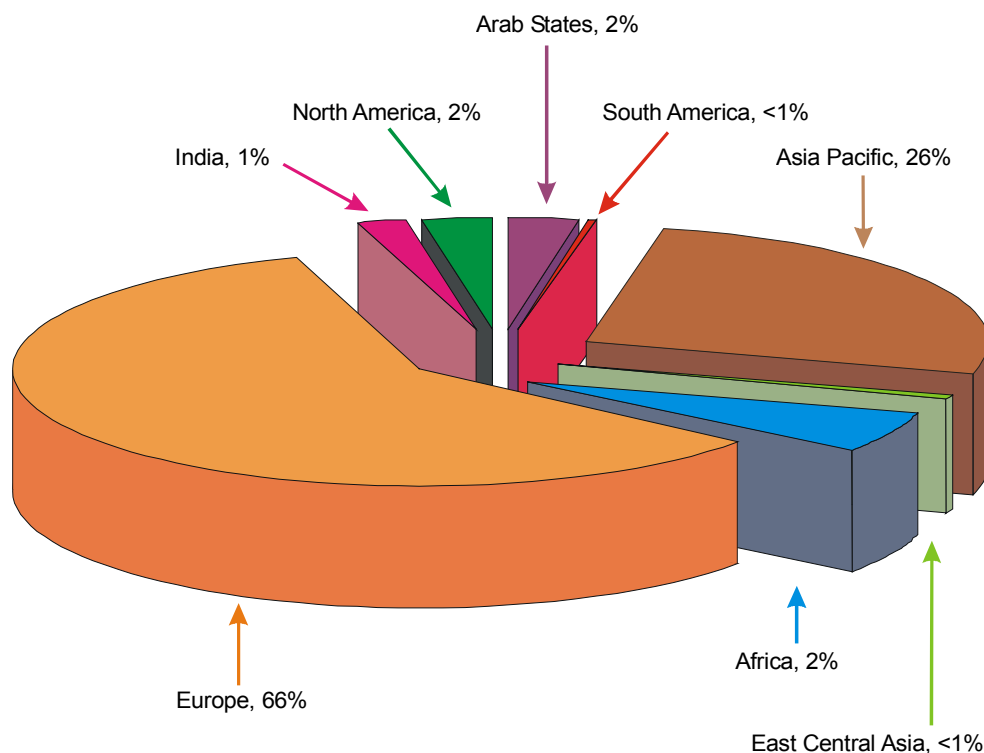


Figure 2.2 Distribution of GSM subscribers by geographical location (based on data from the GSM Association)

2.11 In the UK, the new GSM networks became operational in July 1992 (Vodafone), September 1993 (One 2 One), December 1993 (Cellnet), and April 1994 (Orange) the companies involved being referred to in this report as the network operators. The original analogue networks are still operational, but the Government has indicated that the analogue system should be removed from service by 2005.

2.12 On a worldwide scale, there has been a rapid growth in both the numbers of countries with operational networks and the number of mobile phone operators (Figure 2.3). There are a further 39 networks under construction for the GSM system alone.

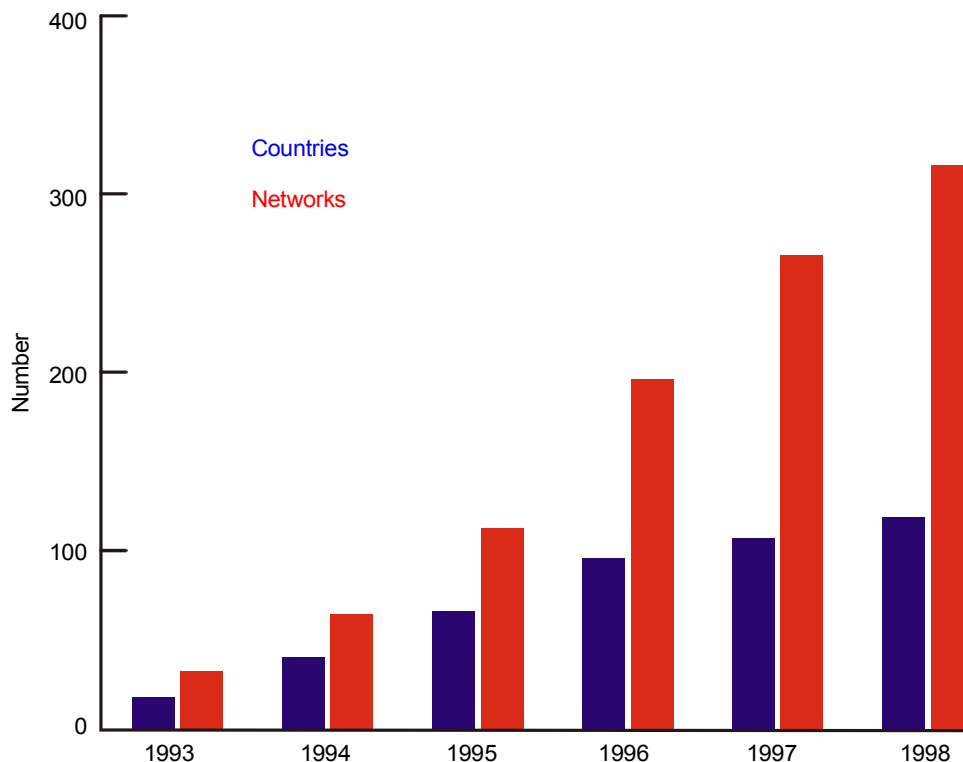
Introduction

Figure 2.3 Growth of GSM networks throughout the world (based on data from the GSM Association)

Mobile Phone Networks and Communication

- 2.13** Individual mobile phones operate by communicating with fixed installations called base stations. These have a limited range (see paragraph 4.9) and mobile phone operators have to establish national base station networks to achieve wide coverage. It takes many years to establish a network that will provide both complete coverage and adequate capacity across the country and, even today, none of the UK networks provides complete coverage. However, since operators invest a great deal of money to purchase licences and establish networks and other infrastructure, they need to offer potential subscribers an effective communication system as quickly as possible. Moreover, operators were required, as a condition of their operating licences, to provide a minimum level of coverage within a given time frame. They established operational networks designed to allow most subscribers to access a base station most of the time. The initial phase of construction of such a network involves the installation of base stations in urban areas with high population densities, and along major transport routes such as motorways. These basic networks are then extended to provide coverage in more rural areas and increased capacity in urban areas. By developing networks in this way, operators can offer a functional system to the majority of the population. The more rural areas of the UK, particularly in the west of the country, still have rather poor coverage.
- 2.14** Base stations can be categorised into macrocells, microcells and picocells (see paragraph 4.9) depending on their size and power output. There are approximately 20,000 macrocells in the UK at present and, in general, all the major operators can now offer coverage to over 97% of the population. The number of macrocells is continuing to rise as operators seek to complete their geographical coverage and improve capacity. Since each base station can only handle a limited number of connections at any one time, operators need to install more base station units in densely

populated areas to cope with increasing demand. It seems likely that these will mainly be microcells and picocells. The overall number of base stations is likely to double within the next few years.

Present and Future Use of Mobile Phones

- 2.15** Initial market penetration by mobile phones was modest, with less than 1% of the UK population subscribing by the end of the 1980s. However, the advent of the more advanced GSM technology, in conjunction with greater competition in the market place, led to continuing growth in the number of subscribers throughout the 1990s (Figure 2.1).
- 2.16** At present there are approximately 25 million subscribers in the UK, which is equivalent to a market penetration of around 40%. Within the next five years it is expected that this will have increased to 75% market penetration or 45 million subscribers. At present it is estimated that around 45% of subscribers have a pre-paid mobile phone. Although it might be expected that many of these phones would not be used on a routine basis, the operators believe that around 90% of them are in regular use.
- 2.17** Within the next three years the “Third Generation” of mobile phones will be launched. This will employ a new operating standard called the Universal Mobile Telecommunication System (UMTS, see paragraph 4.15) and will enable operators to offer a full range of multimedia services. The introduction of these new services will require access to additional RF spectrum,

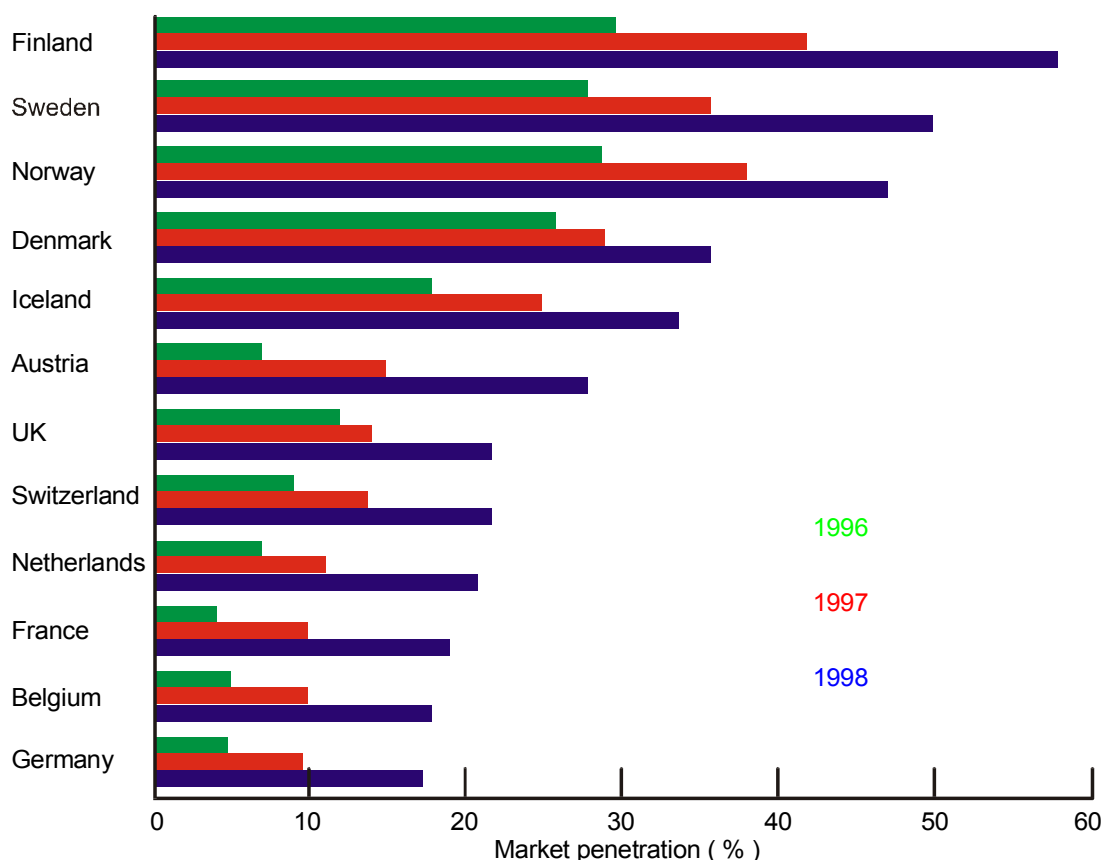


Figure 2.4 Increase in market penetration between 1996 and 1998 in Western European countries (based on data from MobilTeleBranschen)

Introduction

and the UK Government has recently auctioned licences for the use of new spectrum. Five licences are to be issued.

- 2.18** The growth in the mobile phone market that has been observed in the UK reflects similar trends in Europe and elsewhere in the world. In Europe the greatest market penetration has occurred in the Scandinavian countries and in Finland is approaching 60%. However, all Western European countries have experienced a rapid growth in mobile phone use in recent years (Figure 2.4).
- 2.19** It is expected that the recent trends in the use of mobile phone technology will continue for the foreseeable future, with the number of GSM subscribers worldwide predicted to increase by a factor of three or more over the next five years (Figure 2.5).

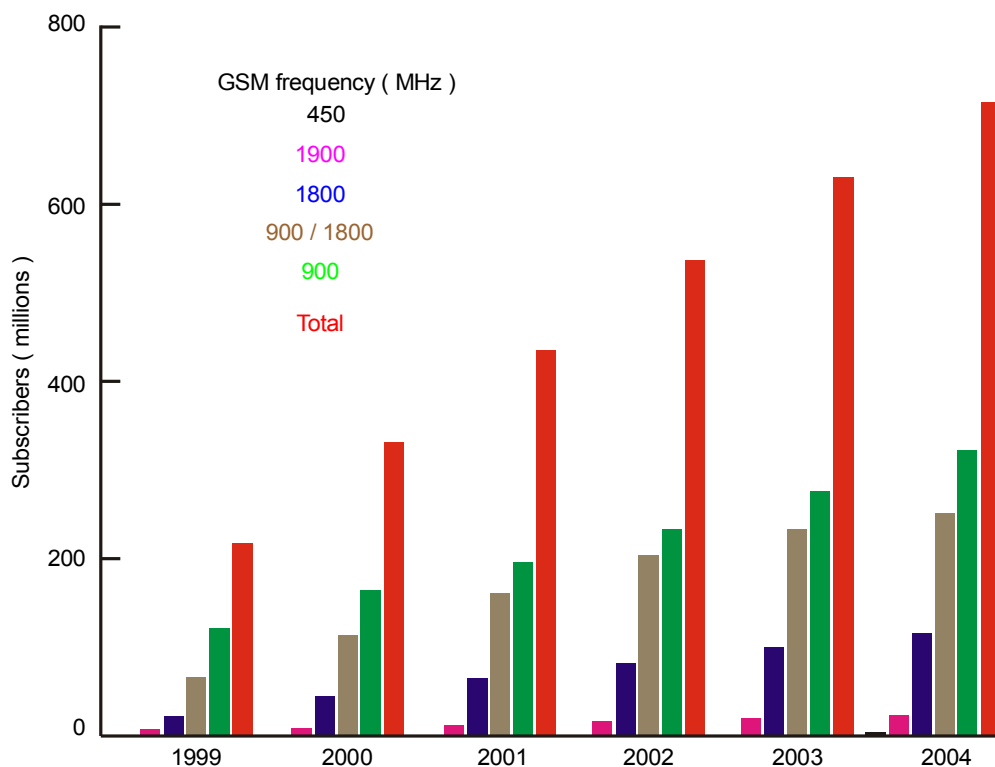


Figure 2.5 Predicted growth in the number of GSM subscribers worldwide. The different GSM frequencies (see paragraph 4.11) are used in different systems around the world.

Benefits of Mobile Telecommunications Technology

- 2.20** An active mobile telecommunications sector brings a number of economic benefits to the UK in terms of employment and tax revenue, which will be discussed in paragraph 2.22. There are also, however, a number of other advantages to be derived from application of this technology. Mobile telecommunications play an increasingly important role in general commercial activity and thereby make an indirect contribution to the national economy. This is difficult to quantify, but is likely to be significant.
- 2.21** It is already apparent that mobile telecommunications also offer benefits in emergency situations. For example, the use of a mobile phone may reduce the time taken to notify the emergency services of road traffic accidents and other dangerous situations including crimes. An assessment

Economic Significance of the Mobile Phone Industry to the UK Economy

of this aspect in Australia has recently been given by Chapman and Schofield (1998a,b). There have also been several accounts of individuals using mobile phones to alert rescue services following mountaineering or skiing accidents. Mobile phone availability may also be helpful during much rarer large-scale emergencies. For example, it is believed that many lives were saved following the earthquake in Kobe, Japan, because those trapped under rubble were able to use their mobile phones to alert rescue teams.

Economic Significance of the Mobile Phone Industry to the UK Economy

2.22 Information supplied by the Department of Trade and Industry indicates that the mobile phone industry is a major contributor to economic activity in the UK. Network operators had an estimated combined turnover of some £5.8 billion in the financial year 1998/99 (Figure 2.6).

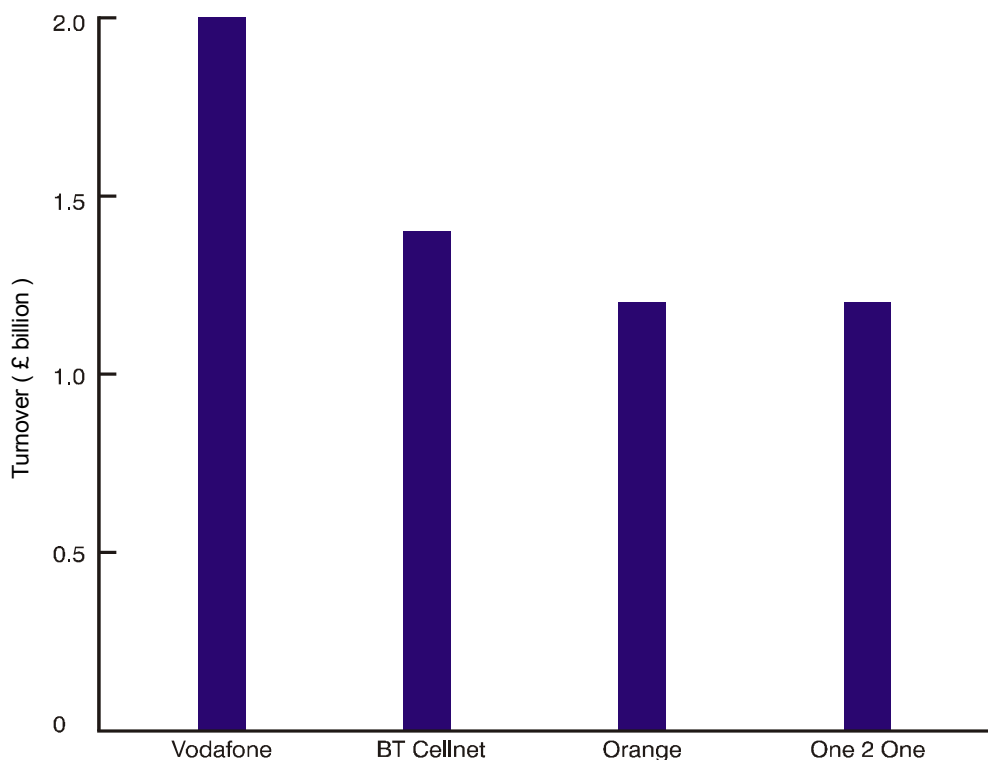


Figure 2.6 Annual turnover of UK network operators (data provided by the Department of Trade and Industry)

2.23 Vodafone has the largest turnover and, since its merger with the US company Air Touch, when it had a market capitalisation of £77 billion, and subsequent takeover of the German company Mannesmann, is now a major multinational. The other three operators (here we treat Orange as an independent company) are smaller, but nationally major companies. In late 1999, BT Cellnet and One 2 One were valued at around £8.4 billion, with Orange slightly more at that time. The Vodafone mergers emphasise the international nature of the mobile phone industry. All four UK operators have expanded into overseas markets in recent years; Vodafone and Orange have taken the lead in this respect. Between them, these two operators now have stakes in over 14 countries, including Australia, France, Germany, the Netherlands, Sweden, South Africa and Switzerland. The manufacture of mobile phone equipment is also an international industry and is dominated by

Introduction

a few large multinationals. Although none of these is based in the UK, three of them, Nokia, Motorola and Ericsson, all have a significant presence through both manufacturing and research and development (R&D) facilities. Nokia and Ericsson bought out UK companies in the early 1990s and both have since expanded their operations. Other manufacturing companies that have invested in the UK include Lucent, NEC, Panasonic and Samsung. This is a rapidly changing sector and the above figures are indicative only.

- 2.24** The manufacturing base generates secondary manufacturing by companies such as Hewlett Packard and Racal, both of which make test equipment. In addition, there is some manufacturing of components by companies such as Filtronic Ltd. The latest available information on manufacturing turnover values the telecommunications sector at £3.5 billion in 1997, but it is growing rapidly. Mobile telecommunications represent a significant and increasing element of this sector.
- 2.25** The UK provides significant input into mobile telecommunications R&D through universities and their spin-off companies. A consortium of UK universities has formed a Virtual Centre of Excellence in this area to provide a focus for this work and ensure effective collaboration with industry. Funding for this Virtual Centre from industry and the Engineering and Physical Sciences Research Council totalled £3 million for the last three years and the budget for the next three is £4.5 million with industry providing 70%.
- 2.26** The mobile sector provides significant employment opportunities in the UK. It is difficult to obtain accurate data because the sector is developing so rapidly. However, taken together, the operators, manufacturers, and sales outlets probably employ about 100,000 people in the UK (industry estimate). This number seems likely to increase when mobile phones become more closely linked to the provision of Internet services.

3

Public Perceptions and Concerns

- 3.1** When the Minister for Public Health announced the formation of the Independent Expert Group on Mobile Phones (IEGMP) she stated:

“In recent years research interest in the effects of mobile phones has increased. To date there has been no consistent evidence suggesting risk to health, but there is continuing public concern about the possibility. It would be wrong to ignore that concern.”

- 3.2** As part of our inquiry we sought information on the specific aspects of mobile phone technology that worry the public, and on the information that is available to them about this issue from different sources. We examined the role of politicians, the media, specific interest groups, the telecommunications industry and the National Radiological Protection Board (NRPB).

The Public

- 3.3** In order to obtain input from the public we placed advertisements in the press, solicited information from various groups and held open public meetings in Belfast, Cardiff, Edinburgh, Liverpool and London. The Secretariat of the Group issued press releases in August and September 1999 explaining the role of the Group and inviting oral and written submissions. It also gave notice of dates and times of the public meetings and all information was featured on the Expert Group web site (www.iegmp.org.uk).
- 3.4** It is unlikely that those who attended the meetings or submitted evidence can be considered representative of the public at large, and it should be recognised that many members of the public are satisfied with all or most aspects of mobile phone technology. However, the relative frequency with which specific concerns were raised at the meetings provides an indication of those aspects of the technology that the concerned public finds most worrying.
- 3.5** People who attended the meetings described various symptoms which they attributed to base stations. Those mentioned most commonly were headaches, sleep disturbance, depression, stress and tiredness.
- 3.6** There was concern about the siting of base stations on or near schools, hospitals and residential areas; current planning processes; and particularly the fact that base stations less than 15 m do not have to follow the normal planning process in full. With regard to the siting of base stations, Orange, in particular, was criticised for inadequate public consultation. Operational practices such as erecting base stations in the middle of the night were an understandable cause for complaint. Other concerns related to possible reductions in the value of property caused by the proximity of base stations to residences, the negative visual impact of base stations, and possible health risks to farm animals.

Public Perceptions and Concerns

- 3.7** The health problems most commonly attributed to the use of mobile phone handsets were impairment of short-term memory, headaches, brain tumours, other cancers, sleep disturbance, depression and tiredness.

Politicians

- 3.8** The Chairman of the Expert Group wrote to all Members of both Chambers of the Westminster Parliament. Out of 659 Members of the House of Commons, 11 acknowledged receipt of the communication and 6 responded in writing highlighting the concerns of their constituents, which related mainly to base stations.
- 3.9** No Member of the House of Lords replied to the letter.
- 3.10** The Chairman also wrote to Members of the Scottish Parliament (129), Members of the Welsh Assembly (60) and Members of the Northern Ireland Assembly (108). Responses were received from four Members of the Scottish Parliament and five Members of the Welsh Assembly. Two Members of the Northern Ireland Assembly acknowledged receipt of the letter, and a further three gave more detailed responses. One member of the Expert Group met four MPs to discuss the issues that concerned their constituents.
- 3.11** Regulatory powers in relation to telecommunications are reserved in the UK Parliament at Westminster. Therefore, although planning is seen as a local authority responsibility and, as a result of devolution, the Scottish Parliament now has a greater say in planning, contentious issues such as the General Permitted Development Order rights, which fall under the Telecommunications Act 1984, have not been devolved.
- 3.12** Devolved political power provides an opportunity for a less centralised approach to planning issues, and this may allow more areas of local and regional concern to be addressed in legislation and guidance. Already the devolved Assemblies and Parliaments have played a key role in raising public awareness regarding the potential health impact of mobile phone technology. In particular, we note with interest the work of the Scottish Parliament's Transport and Environment Committee, whose report on planning issues (see paragraphs 6.112–6.114) was published in March 2000 (Scottish Parliament, 2000).
- 3.13** In the past year UK Ministers received almost 600 letters from members of the public on health issues relating to mobile phone technology, and particularly base stations. In the House of Commons, the Health Ministers answered 85 letters on the same topic from MPs writing on behalf of constituents. There have also been parliamentary questions about possible health effects of mobile phones and base stations.
- 3.14** Of the 80 letters sent directly to the Department of Health by members of the public, 50 concerned base stations and 30 handsets. The Department of the Environment, Transport and the Regions received 350 letters relating to planning and environmental aspects of mobile phone technology, while the Department for Education and Employment received 157 letters about the location of base stations in or around schools.
- 3.15** Parliamentary debates on mobile phone technology have also centred on health and planning issues. An Early Day Motion on the subject of mobile phone masts calls for a more coherent planning policy and for the precautionary principle to be employed in relation to possible health risks. This is the most popular Early Day Motion currently tabled in the House.

- 3.16** In September 1999, the House of Commons Science and Technology Committee produced a report on “The Scientific Advisory System: Mobile Phones and Health”. The Recommendations of this report were noted with interest by the Expert Group.
- 3.17** From the totality of evidence we received, it is clear that the role of politicians in this area extends further than legislation, and that their inputs have helped to inform the public.

The Media

- 3.18** The Expert Group reviewed 641 press cuttings published in the UK between January 1999 and February 2000 and 76 TV and radio programmes broadcast over the same period. In general, the same issues were covered as those cited above (paragraphs 3.3–3.7). Seventy-nine per cent of the media reports alleged adverse health effects from mobile phones and base stations, whereas nine per cent concluded that there was too little rigorous scientific evidence to arrive at a conclusion, or reported no adverse effect. Overall, the safety of mobile phone handsets achieved more coverage than the safety of base stations, although local newspapers tended to report more on issues relating to base stations. Other aspects of safety that were covered included concerns that driving while using a hand-held mobile phone was dangerous.
- 3.19** The adverse health effects most often linked with mobile phones in media reports were brain tumours, other cancers, headaches, and brain damage. However, possible positive effects were also reported (see also the Expert Group web site).
- 3.20** Most media reporting did not refer to specific scientific studies or discuss the biological mechanisms by which RF radiation from mobile phones might cause adverse effects.
- 3.21** Specific precautionary measures were suggested in the media including hands-free operation of mobile phones, use of shields, limiting the duration of mobile phone usage and choosing a mobile phone that emits a lower level of RF radiation.
- 3.22** The main concerns reported in the media about base stations were uncertainties about the distance at which they were “safe”, and about their proximity to schools, homes, hospitals and residential accommodation for the elderly. Adverse aesthetic impacts were also noted. The health effects most often alleged were sleep disorders, fatigue, anxiety, stress, epileptic fits, burning sensations and shaking.
- 3.23** The media particularly targeted operators for ignoring medical evidence of adverse biological effects and for being irresponsible when choosing where to site base stations. Financial gain was sometimes alleged by the media to be more important to operators than the safety of people, particularly children. Operators were encouraged to remove base stations from populated areas. The reported responses from operators noted that the exposures from base stations were within NRPB guidelines.

Specific Interest Groups

- 3.24** About 175 specific interest groups declare an interest in the issue of mobile phone technology. Amongst these, three who have widely publicised their concerns are: Powerwatch, Friends of the Earth Scotland and NIFATT (Northern Ireland Families Against Telecommunications Transmitter Towers). Most of the other specific interest groups have been involved at a more local level.

Public Perceptions and Concerns

- 3.25** Much helpful evidence was submitted to us by these interest groups – in writing, orally and through contributions to public meetings. It focussed mainly on possible adverse biological effects of mobile phone technology and the need for a precautionary approach.
- 3.26** There was criticism of the NRPB exposure guidelines for failing to take adequate account of uncertainties in current scientific knowledge, and the groups called for NRPB to be more open and proactive in communicating with scientists and the public.

The Telecommunications Industry**Mobile phone manufacturers**

- 3.27** The Group received helpful inputs from mobile phone manufacturers in the UK and elsewhere and from the Federation of the Electronics Industry (FEI), an umbrella organisation.
- 3.28** The information provided by the FEI includes the following:
- general safety advice is provided with mobile phone handsets, usually in the accompanying operating guide or manual,
 - the advice notes that all phones comply with the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines (ICNIRP 1998a, see paragraphs 6.27–6.31),
 - all manufacturers emphasise their commitment to safety and report that there is no scientific evidence to show adverse health effects,
 - in general, advice is provided that the mobile phone should be switched off when the user is in an aircraft, in a hospital, in the vicinity of medical equipment, or in hazardous environments such as petrol stations,
 - there is support for the use of hands-free sets when in control of a car, and some manufacturers recommend that a hand-held phone should not be used when driving,
 - all but one manufacturer warn that mobile phones may interfere with the functioning of pacemakers,
 - most manufacturers advise that the antenna of the phone should not be in contact with the user when the phone is operating.
- 3.29** Information relating to the operation of mobile phones can be obtained on request from all the manufacturers. The Carphone Warehouse, an independent retailer, provides an important example of good practice in the way it makes information readily available at mobile phone outlets.

Network operators

- 3.30** The lines of communication between network operators and the general public do not appear to us to be as clear as those between mobile phone manufacturers and consumers. Each operator has opportunities for contact with its customers when they are billed or pay for calls in advance. However, communication with those who might be affected by the placement of base stations is less straightforward.
- 3.31** Overall, we conclude that more could be done in this area. In particular, there is substantial scope for the sharing of best practice in approaches to communication with the general public regarding the placement of base stations, as the public continues to distrust the operators in the area of public health.

National Radiological Protection Board

3.32 NRPB was given a range of responsibilities and powers under the Radiological Protection Act 1970. Amongst these was the responsibility:

“To provide information and advice to persons, including Government Departments, with responsibilities in the United Kingdom in relation to the protection of the community as a whole or of particular sections of the community from radiation hazards.”

3.33 NRPB as a recipient of taxpayers’ monies should play a key role in informing the public. We were told by the Director of NRPB that it receives about 40,000 enquiries per year on a range of questions, and data provided by NRPB indicate that, during the period between August and October 1999, about a quarter of the enquiries related to mobile phones and base stations.

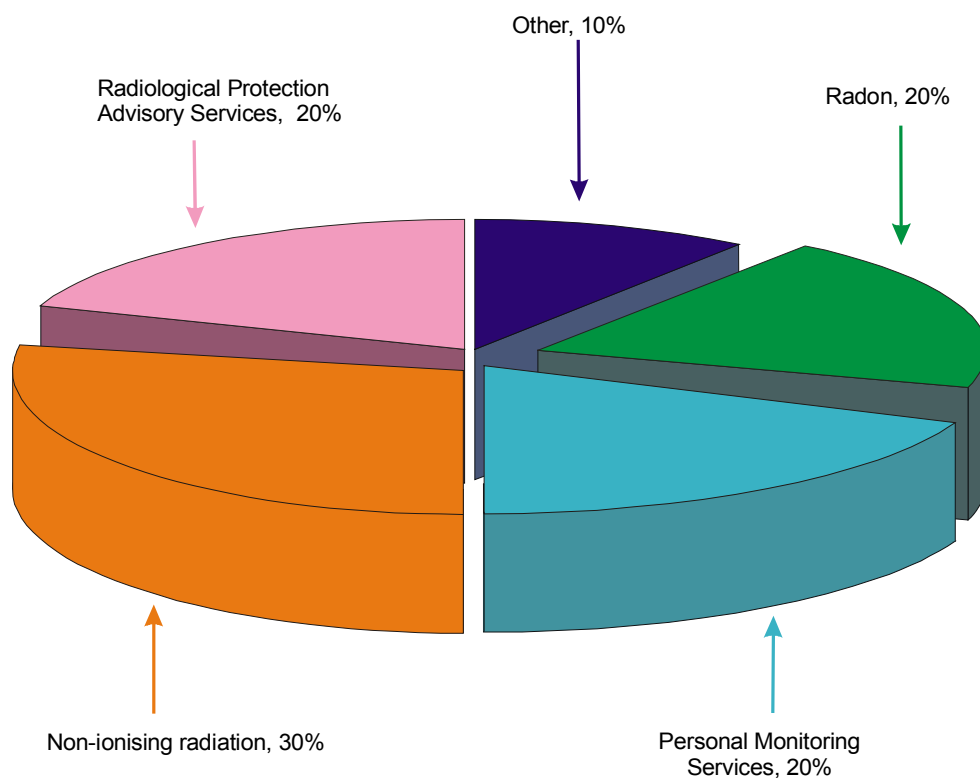


Figure 3.1 Enquiries received by NRPB on radiological protection matters by subject area (data are broad estimates for 1999 based on around 40,000 enquiries)

3.34 The NRPB’s *modus operandi* is broadly as follows: members of the public who contact NRPB are normally sent a standard information pack about the topic on which they are seeking information, but where a more detailed response is required, the enquiry is directed to a member of the scientific staff with specialist knowledge in the relevant area. Members of the public who ask about planning issues are advised to contact their local authority, and for medical queries NRPB advises reference to a general practitioner.

3.35 Despite the fact that the public is currently most concerned about mobile phones and base stations, NRPB resources are largely targeted in other areas. Only about 10% of the total NRPB budget is allocated to non-ionising radiation, which includes work related to mobile phone

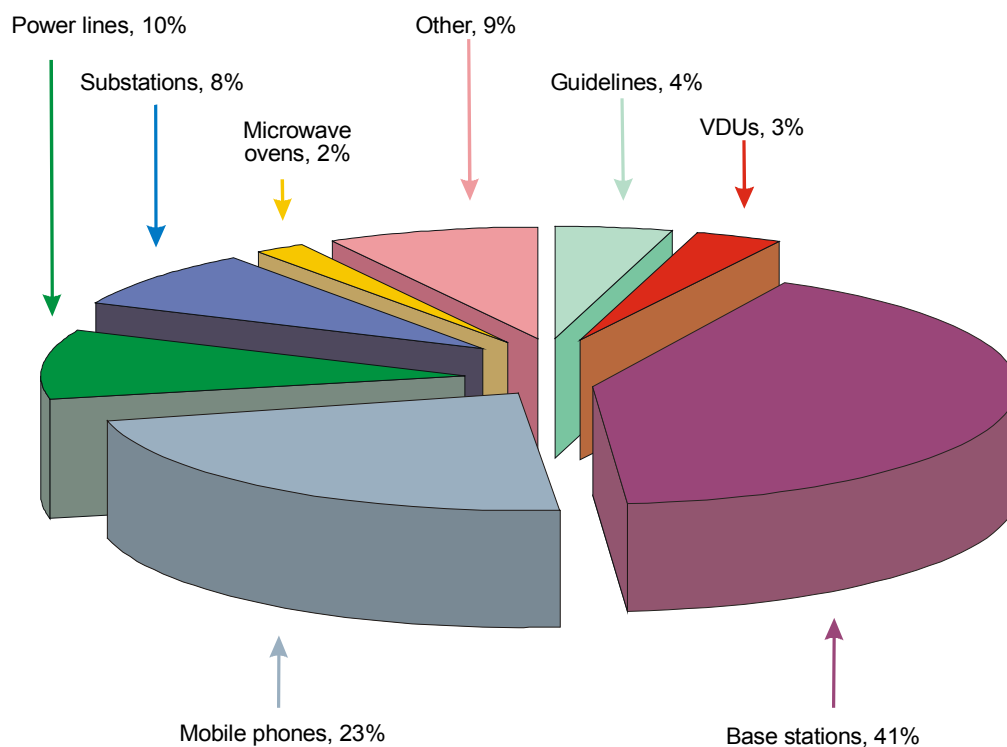
Public Perceptions and Concerns

Figure 3.2 Enquiries received by NRPB on non-ionising radiation issues broken down into specific subject areas

technology, and the number of staff who have specialist knowledge in the mobile phone/base station area is in single figures.

- 3.36** We believe that effective communication on mobile phone technology should be a priority for NRPB and that the organisation should be more proactive in this area. The Director informed us that a new communications strategy is now being set in place by NRPB.
- 3.37** We note with interest that the Department of Trade and Industry has commissioned NRPB to produce an explanatory video on mobile phone technology suitable for the lay person.
- 3.38** As well as producing explanatory leaflets, NRPB publishes material on its web site (www.nrpb.org.uk) which was set up in February 1997. This includes pages giving NRPB views on the alleged health effects of mobile phones and base stations. The quality of the material produced is not universally user-friendly for the public and fails to address all of their current concerns. Nevertheless the site receives about 50,000 “hits” per month.
- 3.39** In summary, while a small minority of highly proactive individuals and groups has led the public debate on possible health hazards from mobile phone technology, NRPB has been mainly reactive. The Expert Group accepts that “scare stories” will always be the most popular focus of many sections of the media, but feels that NRPB should do more to inform the debate.
- 3.40** We note that many of the people who attended the public meetings that we organised expressed dissatisfaction with the advice given by NRPB. Their view was that operators should respond to suggestions of adverse health effects even if the evidence was not conclusive, whereas NRPB advises that current exposure guidelines should not be altered until there is “convincing and consistent” evidence of adverse biological effects at lower levels.

- 3.41** Currently, NRPB does not provide any advice beyond a strict definition of what is and what is not a “safe” level of non-ionising radiation. It has not made recommendations to Government on any need for precautionary policies to reflect uncertainties in current scientific knowledge. It has, however, recommended additional research that may help to resolve some of these uncertainties.
- 3.42** In general, we believe that NRPB has not adopted a sufficiently proactive approach to emerging public concerns about mobile phone technology, and has tended only to be reactive. That the impetus to set up this Expert Group came from Government rather than NRPB is in itself remarkable. NRPB does have its own independent Advisory Group on Non-ionising Radiation although it has not specifically addressed the issue of mobile phones. **We recommend that NRPB makes more use of specialist time-limited *ad-hoc* committees of experts and lay representatives to bring forward broadly based, well-considered advice.**
- 3.43** We further believe that additional resources should be made available within NRPB to address media and communications.
- 3.44** Whilst there is no criticism of its science, **we recommend that NRPB gives greater priority to the execution of a more open approach to issues of public concern such as mobile phone technology and that it is more proactive rather than reactive in its approach.**
- 3.45** **We recommend that public concerns about risk be addressed by NRPB in a more sensitive and informative manner.**
- 3.46** **We recommend that in a rapidly emerging field such as mobile phone technology, where there is little peer-reviewed evidence on which to base advice, the totality of the information available, including non-peer-reviewed data and anecdotal evidence, be taken into account when advice is proffered.**
- 3.47** We note the paucity of resources available at NRPB for work on non-ionising radiation, including work on mobile phones and related research on life sciences. **We recommend that work on non-ionising radiation and related life sciences work be strengthened at NRPB.**

Public Information

- 3.48** We are concerned that too much of the information that is currently presented to the public regarding the health aspects of mobile phone technology is misleading. We therefore believe that it would help if Government provided clear advice on this topic in the form of a leaflet circulated to all households.
- 3.49** **We recommend that Government circulates a leaflet to every household in the UK providing clearly understandable information on mobile phone technology and on health aspects, including the use of mobile phones while driving (see paragraphs 5.201–5.214). This leaflet should additionally be available at the point of sale. The leaflet should be developed in concert with industry, which has already produced some good leaflets.**
- 3.50** It would also help if an Ombudsman were appointed to whom issues relating to the siting of base stations and other aspects of the regulation of mobile phone technology could be referred where there was public dissatisfaction.
- 3.51** **We recommend that an Ombudsman be appointed to provide a focus for decisions on the siting of base stations when agreement cannot be reached locally, and on other relevant issues.**

*Public Perceptions and Concerns***General Conclusions**

- 3.52** The continuing rapid growth in the use of conventional mobile phones, as shown in Figure 2.1, indicates that most people do not consider the possibility of adverse health effects to be a major issue.
- 3.53** Given the much lower exposures to radiation from base stations than from handsets (paragraph 4.32), the greater public concern from the people who gave evidence to the Expert Group about the former is paradoxical. It presumably arises because individuals can choose whether or not to use a mobile phone, whereas they have little control over their exposures from base stations. Furthermore, people derive a personal benefit from the use of a phone, but gain nothing directly from the presence of a base station close to their home or place of work. If anything they may suffer a loss of amenity and perhaps a reduction in the value of their property.

4

Radiofrequency Fields from Mobile Phone Technology

Radiofrequency Radiation Usage

- 4.1** Mobile phones and their base stations transmit and receive signals using electromagnetic waves (also referred to as electromagnetic radiation or fields, or radio waves). Electromagnetic radiation is emitted by many natural and man-made sources and plays a very important part in our lives. We are warmed by the radiation from the Sun or from an electric fire and we see using that part of the electromagnetic spectrum that our eyes can detect. All electromagnetic radiation consists of oscillating electric and magnetic fields and the frequency, f or ν (nu), which is the number of times per second at which the waves oscillate, determines their properties and the use that can be made of them. Frequencies are measured in hertz or Hz, where 1 Hz is one oscillation per second, 1 kHz or kilohertz is a thousand Hz, 1 MHz or megahertz is a million Hz, and 1 GHz or gigahertz is a thousand million Hz or 10^9 Hz. Frequencies between about 30 kHz and 300 GHz are widely used for telecommunication, including broadcast radio and television, and comprise the radiofrequency (RF) band.
- 4.2** In the UK, AM radio uses frequencies between about 180 kHz and 1.6 MHz, FM radio ranges from 88 to 108 MHz, and TV ranges from 470 to 854 MHz. Cellular mobile phone services operate within the frequency ranges 872–960 MHz and 1710–1875 MHz. Waves at higher frequencies but within the RF region, up to around 60 GHz, are referred to as *microwaves* and have a wide variety of uses. These include radar, telecommunications links, satellite communications, weather observations and medical diathermy; intense sources of 2.45 GHz microwaves confined within ovens are used for cooking. At even higher frequencies, radiation takes the form of infrared, then visible, ultraviolet, X-rays and eventually the γ -rays (*gamma* rays) emitted by radioactive material. Electromagnetic radiation is also characterised by its wavelength λ (*lambda*), which equals the velocity or speed of the wave (the speed of light) divided by its frequency.

Radiocommunication

- 4.3** An RF wave used for radiocommunication is referred to as a carrier wave. The information it carries – speech, computer data, etc – has to be added to the carrier wave in some way, a process known as modulation. The information can be transmitted in either analogue or digital form. For example, the electrical signal from a microphone produced by speech or music is an analogue signal at frequencies up to about 15 kHz. So the signal varies significantly with time on a scale of a few microseconds or μ s (1 μ s is a millionth of a second). At a particular time it might have any value within quite a large range. So if this signal is sent by analogue transmission, the size or amplitude of the RF carrier wave at any instant is made proportional to the size of the electrical modulating signal at that instant (this is called amplitude modulation and other forms of

modulation can also be used) (Figure 4.1). The carrier wave varies very much faster than the signal so that the modulation produces a relatively slow oscillation in the amplitude of the carrier wave. Information can also be transmitted in digital form. In this case only a small number of symbols are used. Printed language is an example of digital information since it only uses the symbols of the alphabet. Morse code is another and only uses two symbols, dots and dashes, so is called a binary system. Analogue signals are described by a number, which in general is not an integer (whole number), and the first step in digitising it is to round this to the nearest integer. For example, if the strength of an electrical signal from a microphone at a particular instant is 12793.56 microvolts or μV (1 μV is a millionth of a volt) the number 12793.56 is rounded to 12794. This can then be expressed in binary form in which it is represented by a series of zeros and ones, and these can be transmitted digitally to a receiver that converts them back to a signal of strength 12794 μV . Digital transmission, usually binary, offers many technical advantages over analogue transmission systems. It is, for example, less susceptible to distortion by interference and electrical noise, and it is replacing or has replaced analogue transmission in radio, TV, mobile phones, etc.

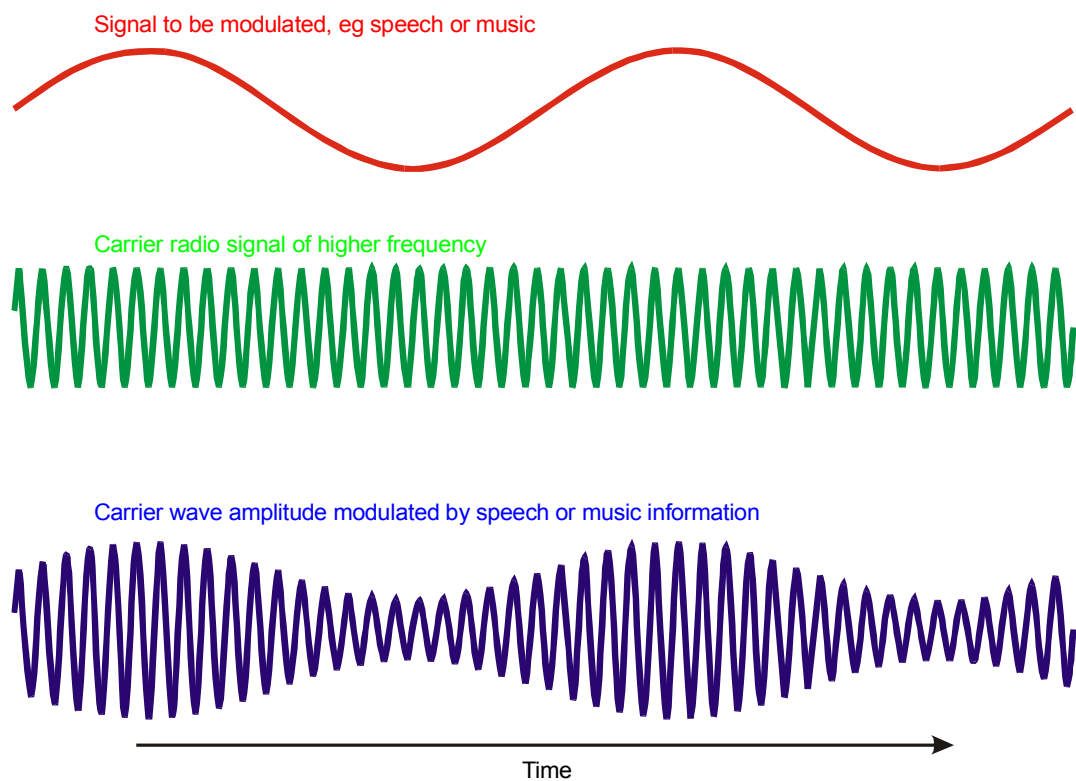


Figure 4.1 Amplitude modulation of a carrier wave

Electromagnetic Compatibility

- 4.4** The ability of electrical and electronic systems to operate in an electromagnetic environment without adverse effects is known as electromagnetic compatibility (EMC). The reality is that all electrical systems can be disturbed if subjected to sufficiently powerful emissions. For this reason, EMC is achieved by limiting or controlling electromagnetic emissions in addition to ensuring that electrical systems are sufficiently immune to electromagnetic interactions.

- 4.5** Mobile phones are intended to be electromagnetic emitters and as such their radiation characteristics (frequency, power, etc) are tightly regulated by standards set by organisations such as the European Telecommunications Standards Institute (ETSI). However, the distance between a mobile phone and an electrical system can vary considerably. A substantial research project recently concluded (DTI, 1999) that future mobile phone systems would have less adverse EMC effects than present systems, and suggested some techniques for reducing the effects still further.
- 4.6** EMC is of particular concern in hospitals because of the diversity of electronic equipment in use and safety-critical circumstances involved. The Medical Devices Agency issued a warning in 1994 and recommendations in 1997 (MDA, 1997) and many hospitals have imposed restrictions of varying degrees on the use of mobile phones in hospitals. Similarly, the use of mobile phones in aircraft is not permitted for EMC reasons.
- 4.7** EMC issues have not been considered in any detail as part of the work described in this Expert Group report.

Technology of Cellular Mobile Phones

Cellular radiofrequency networks

- 4.8** A mobile phone sends and receives information (voice messages, fax, computer data, etc) by radiocommunication. Radiofrequency signals are transmitted from the phone to the nearest base station and incoming signals are sent from the base station to the phone at a slightly different frequency. Once the signal reaches a base station it can be transmitted to the main telephone network, either by telephone cables or by higher frequency (such as 13, 23 or 38 GHz) radio links between an antenna (eg dish) at the base station and another at a terminal connected to the main telephone network. These microwave radio links operate at rather low power and with narrow beams in a direct line of sight between the antennas, so that any stray radiation from them is of much lower intensity than the lower frequency radiation transmitted to the phones (FEI, 2000)*.
- 4.9** Signals to and from mobile phones are usually confined to distances somewhat beyond the line of sight. They can reach into buildings and around corners due to various processes including reflection and diffraction, that allows the radiation to bend round corners to some degree, but the coverage area from a base station is partly governed by its distance to the antenna's horizon. In the current GSM system (see paragraph 4.11), a timing artefact in the signal processing within the receivers limits the maximum distance over which a mobile phone can be used to about 35 km (22 miles). For such reasons an extensive network of base stations is needed to ensure coverage throughout the UK. An ideal network may be envisaged as consisting of a mesh of hexagonal cells, each with a base station at its centre (Figure 4.2), but in practice the coverage of each cell will usually depart appreciably from this because of the topography of the ground and the availability of sites for the base stations. The sizes of the cells are usually less than the 35 km maximum because obstruction by hills, buildings and other ground features reduces the effective range. Frequencies are reused several cells away and the capacity of a network (the number of simultaneous phone calls which may be made) depends on the extent of the frequency spectrum available, the cell diameter and the ability of the system to work against a background of interference from other cells. To accommodate the steadily increasing volume of users, cell sizes have to be progressively reduced (for example, by using base station antennas of lower height and reduced power) so that the frequencies may be reused more often. Indeed in large cities, base stations may only be a few hundred metres apart. The 20,000 or so base stations in the UK

* The maximum intensity on the ground 15 m from an antenna of a microwave link is stated to be $45 \mu\text{W}/\text{m}^2$.

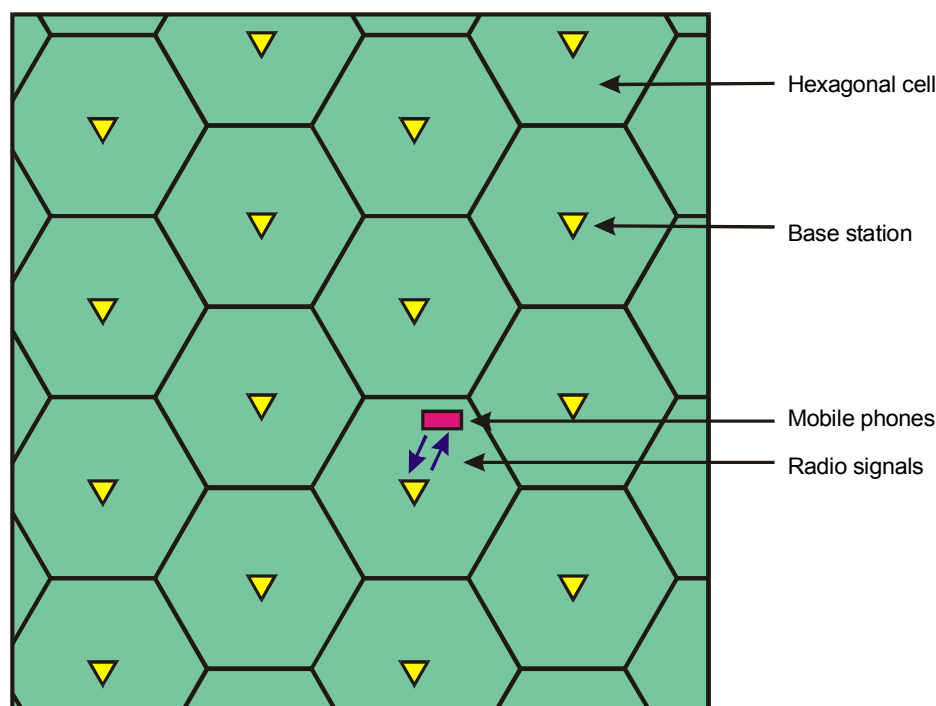


Figure 4.2 Network of base stations at the centre of hexagonal cells

mentioned in paragraph 2.14 each serve a “macrocell”. Additional, smaller base stations* operating over even shorter distances are being installed in places such as railway stations where the density of users is particularly large (“microcells”) and also within buildings such as office blocks (“picocells”). Cellular systems also include technology that ensures that the frequency channels employed by a user in a vehicle change automatically as the vehicle moves from one cell to the next.

Cellular phone technologies

TACS (analogue)

- 4.10** The first cellular system employed in the UK was the analogue TACS (Total Access Communication System) for which the phones have a nominal output of 0.63 W (FEI, 2000). This system is being phased out so that the frequency channels it uses around 900 MHz may be allocated to more recent systems. It uses frequency modulation[†] that results in only very small and essentially random changes in the amplitude of the carrier wave.

GSM (digital)

- 4.11** Systems using the TACS standard have largely, although not entirely, been replaced by the European digital phone standard, GSM, the acronym for Global System for Mobile Communications (Pederson and Anderson, 1999; Steele and Hanzo, 1999), and mostly operate in either the 900 MHz or 1800 MHz band. This standard is now widely used in many parts of the world. The digital processing uses phase modulation[‡] that again results in only very small and essentially random changes in the amplitude of the carrier wave.

* For indoor propagation, it is possible that “leaky feeders” consisting of specially constructed cables may be used as sources of low intensity radiation.

[†] In frequency modulation, the frequency of the carrier is varied by an amount proportional to the size of the modulating signal. The amplitude of the carrier wave is not changed.

[‡] Two electromagnetic waves may have exactly the same frequency but may be “out of phase”. This means that one wave is displaced from the other so that, for example, when one has its maximum positive value, the other has its maximum negative value. When a wave is phase modulated, each digit that is transmitted introduces a phase change in the carrier wave and the change produced by a one is different from that produced by a zero.

- 4.12** In the GSM system, each user requires a frequency channel of bandwidth 200 kHz so there is a maximum of 174 channels (175 minus one needed for technical reasons) within the 35 MHz bandwidth of the 900 MHz band and 374 within the 75 MHz width of the 1800 MHz band available for allocation to network operators. The channels are distributed across the cells in a way that allows neighbouring cells to operate at different frequencies to avoid interference. Cells are very often divided into three 120° sectors with different frequencies for each. These considerations limit the number of frequency channels available to users in a particular sector. Since the wavelengths at 900 MHz are twice as long as those at 1800 MHz, they are better at reaching the shielded regions behind buildings, etc, as a result of diffraction (bending). So, to obtain the same coverage, fewer base stations and hence fewer channels are needed at 900 MHz than at 1800 MHz. One 2 One and Orange were in fact allocated 150 channels within the 1800 MHz band, and BT Cellnet and Vodafone were allocated 113 channels within the 900 and 1800 MHz bands.
- 4.13** To increase the number of users that can communicate with a base station at the same time, a technique called Time Division Multiple Access (TDMA) is employed that allows each channel to be used by eight phones. This is achieved by compressing each 4.6 ms chunk of information to be transmitted into a burst or pulse 0.58 ms long (1 ms or millisecond is a thousandth of a second). So the phones and base stations transmit for 0.58 ms, every 4.6 ms, which results in a 217 Hz pulse modulation* or variation in their output (217 Hz = 1/4.6 ms). For technical reasons, there is, in fact, additional data compression which leads to the phones and base stations transmitting 25 pulses but omitting every 26th, and so on. This produces further pulse modulation of the power output at the lower frequency of 8.34 Hz (= 217 Hz/26). There is, however, no detectable amplitude modulation at the frequency of 271 kHz (every 4 μs) at which the individual digits (zeros or ones) are transmitted since, as noted earlier (paragraph 4.11), this leads to a negligible change in amplitude.
- 4.14** The maximum powers that GSM mobile phones are permitted to transmit by the present standards are 2 W (900 Hz) and 1 W (1800 Hz)[†]. However, because TDMA is used, the *average* powers transmitted by a phone are never more than one-eighth of these maximum values (0.25 W and 0.125 W, respectively) and are usually further reduced by a significant amount due to the effects of adaptive power control and discontinuous transmission. Adaptive power control (APC) means that the phone continually adjusts the power it transmits to the minimum needed for the base station to receive a clear signal. This can be less than the peak power by a factor of up to a thousand if the phone is near a base station, although the power is likely to be appreciably more than this in most situations. Discontinuous transmission (DTX) refers to the fact that the power is switched off when a user stops speaking either because he/she is listening or because neither user is speaking. So if each person in a conversation is speaking for about half the time, he/she is only exposed to fields from the phone for that half of the conversation. In summary, the largest output from a phone occurs if it is mainly used at large distances from the base station or shielded by

* Pulse modulation is equivalent to amplitude modulation by several frequencies at once. Thus pulse modulation at 217 Hz is equivalent to amplitude modulation at 217 Hz (23.4%), 434 Hz (21.6%), 651 Hz (18.9%), etc; the figure in brackets shows the modulation amplitude compared with that of the pulse. At 8.34 Hz, the frequencies and sizes of the amplitude modulation are 8.34 Hz (1%), 16.68 Hz (1%), 25.02 Hz (1%), etc.

[†] To allow for small variations in performance that occur when a batch of phones is produced, standards require these powers to be met to within ±78% (±2.5 dB; a change in power from P_1 to P_2 can be described as a change of $10 \log(P_2/P_1)$ dB or decibels where the log is to base 10). Improvements in manufacturing techniques since the standards were set have, however, substantially reduced the variations in performance and it appears very unlikely that any of the more recently produced mobile phones would approach the upper limits allowed by the standards, particularly as an important aim of the manufacturers is to achieve the greatest possible battery life which requires the power used to be as small as possible. Advice from the Mobile Manufacturers Forum (an international association of seven major manufacturers) notes that members of the Forum are not aware of any phones operating above the standard. Nevertheless it seems possible that some older phones might still be in use whose maximum powers are 3.56 W (900 Hz) and 1.78 W (1800 Hz).

buildings, etc. In this situation, the *peak* powers could approach the values of 2 W (900 Hz) and 1 W (1800 Hz) and the *average* powers could approach the values of 0.25 W (900 Hz) and 0.125 W (1800 Hz).

UMTS/IMT-2000 (digital)

4.15 A third generation of mobile telecommunications technology has now been agreed and will be introduced in the next few years. In Europe this is called UMTS (Universal Mobile Telecommunication System) and worldwide it is known as IMT-2000 (International Mobile Telecommunications - 2000). The frequency bands identified for this system are 1885–2010 MHz and 2110–2200 MHz and the need for additional frequency spectrum to meet the future expected demand for capacity has also been recognised and will be debated at the World Radiocommunication Conference in May 2000. The specifications allow some choice in the modulation to be used but it is expected that the main choice will be CDMA (Code Division Multiple Access). The frequency channels will have 5 MHz bandwidths and, as in GSM, each can be used by a number of users at the same time. However, in CDMA, a transmission is “labelled” by a coding scheme that is different for each user. Since all the transmissions occur at the same time, the changes in amplitude of the carrier wave are essentially random (noise-like).

4.16 Two types of CDMA are likely to be implemented: FDD (Frequency Division Duplex), where separate 5 MHz channels are used for the two directions (to and from the mobile phone), and TDD (Time Division Duplex) where the same channel is used but in different time slots. Both types lead to pulse modulation because of the need to send regular commands from the base station to change the power level. In FDD the pulse frequency is 1600 Hz, while for TDD it can vary between 100 Hz and 800 Hz (Pederson and Anderson, 1999).

4.17 The expected demand for the use of UMTS both for speech and for data and Internet services is such that systems may be expected to employ macrocells and microcells, and also short-range picocells, to meet the various requirements for mobility and wide bandwidth services – for example, in the office environment.

DECT (digital)

4.18 Cordless phones are used at very short ranges between a base station located at the telephone socket outlet within the house or office and the cordless phone handset. Earlier cordless phones used analogue technology and are now being replaced by a digital system, DECT (Digital Enhanced Cordless Telecommunications) which has performance advantages in terms of privacy and protection against interference. DECT is now in widespread and increasing use and operates at similar frequencies, around 1850 MHz, to cellular mobile phones. There are ten channels with a spacing of 1.728 MHz. In each channel there are 24 time slots within a 10 ms frame and the transmission within a slot uses a form of frequency modulation. So a particular phone emits a pulse every 10 ms (100 Hz) during one of the time slots. Since the maximum power emitted is 250 mW, the average power emitted is about 10 mW. Possibly, DECT technology may form part of an overall UMTS system.

TETRA (digital)

4.19 The new TETRA (Terrestrial Enhanced Trunk Radio System) technology is not intended for public systems connected to the telephone network. It is designed for closed groups (eg for communication within an organisation or company) and is coming into use for the emergency services and some commercial applications. Frequency bands are available at about 400 MHz and 900 MHz. The modulation method is complex. The main features, however, are a 25 kHz band divided into four frequency channels, each of which is divided into 56.7 ms frames containing 4 time slots. So the transmission is pulsed at 17.6 Hz (1/56.7 ms).

Other radio systems

- 4.20** A modern environment contains many types of radiotransmitter. Broadcast radio and television transmitters usually have substantially higher powers than those of mobile phone base stations because they are designed to serve large areas of the countryside. For the same reason, their antennas are usually placed on taller masts located on higher ground at some distance from centres of population. Other high power transmitters are used for air traffic control and surveillance radar, which usually employ pulse modulation. Transmitters of much lower power, roughly comparable to those of the macrocell base station transmitters used in mobile telecommunications, are used for other communications purposes such as radiopaging and communications by the police, emergency services, local government, utility services, security personnel, amateur radio operators, and taxi services. They vary widely in the type of coverage needed but a large number of transmitters is needed for many of the services because of their relatively low power outputs. So it is important to recognise that the exposure from mobile phone base stations is just one component of the total RF exposure that people receive. Indeed, the exposure received by people living near to broadcast transmitters of high power output is likely to be appreciably greater than that received by people living near to mobile phone base stations, although less than that from a mobile phone near to the body.
- 4.21** Individuals may also be exposed to radiation from nearby low power transmitting devices such as wireless burglar alarms, toys, baby alarms, microphones, theft protection devices and car door openers. All of these types of equipment are of such low power that they do not need individual spectrum licences.
- 4.22** There are also RF amplifiers, which are used in such a way that they are not intended to radiate. These include RF heating – for example, in the plastics industry – microwave diathermy in physiotherapy and microwave ovens. Some of these sources, such as industrial heat sealers and medical diathermy equipment, give rise to exposures to patients, workers and physicians that are far higher than those to the public from mobile phone base stations, although the exposures are for far less time.

Electric and Magnetic Fields, Intensities

- 4.23** An electromagnetic wave consists of electric and magnetic fields that oscillate between their peak (largest) values (positive and negative) and zero. The size of a field can be indicated either by the magnitude of the peak value or by an average value. Since the field is positive for half the time and negative for the other half, its mean value is zero. So the average used is the rms or root mean square value (the square root of the average of the square of the field) which is equal to the peak value divided by 1.4 ($\sqrt{2}$). All fields in this report are quoted in rms values unless otherwise indicated. The electric (E) fields are measured in volts per metre or V/m and the magnetic (B) fields (or magnetic flux densities) in tesla or T or, more usually, in mT (a thousandth of a tesla) or μ T (a millionth of a tesla). (The magnetic H -field, measured in amperes per metre or A/m, is sometimes stated rather than the B -field. In the materials of interest here, an H -field of 1 A/m corresponds to a B -field of 1.3 μ T.) If an electrically charged object such as an ion (an atom or group of atoms which has lost or gained one or more electrons) or a cell is exposed to an electric field, it feels a force of magnitude proportional to the field. If, however, it is exposed to a magnetic field it only feels a force if it is moving at an angle to the field. The size of the force is proportional to the magnetic field and to the speed at which the object is moving across the field. Magnetic fields can also interact strongly with magnetic material such as iron. The intensity I , or power density, of an electromagnetic wave is the power passing through 1 m², as illustrated in Figure 4.3. The power is usually measured in watts (W), milliwatts (mW) or microwatts (μ W), where 1 W = 1,000 mW = 1,000,000 μ W, and the intensity is measured in watts per square metre

or W/m^2 (or in mW/m^2 or $\mu\text{W}/\text{m}^2$). Since the area of a sphere surrounding a source increases as the square of its radius, then in an ideal case (in the absence of any nearby objects including the ground) the intensity falls off as $1/(\text{distance})^2$, the inverse square law.

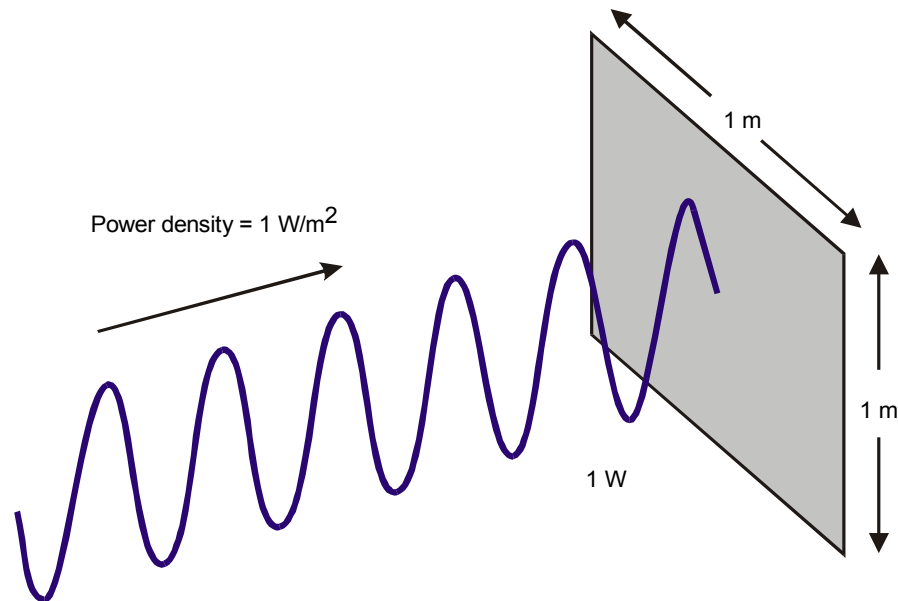


Figure 4.3 Electromagnetic wave passing through 1 m^2 . If the power passing through the area is 1 W , the wave has an intensity or power density of $1 \text{ W}/\text{m}^2$

- 4.24** The properties of an electromagnetic field change with the distance from the source. They are simplest at distances of more than a few wavelengths – around a metre or more at the frequencies of interest here – which is referred to as the far-field region. In this region, the electromagnetic wave consists of an electric field E and a magnetic field B oscillating at right angles both to each other and to the direction in which the power of the wave is travelling (the direction of the intensity). The fields are in phase, so that the point at which E is greatest coincides with the point at which B is greatest, and their magnitudes are related to the intensity I (in W/m^2) by the expressions:

$$E = 19\sqrt{I} \text{ V/m}$$

$$B = 0.06\sqrt{I} \text{ } \mu\text{T}$$

- 4.25** In the near-field region, however, the situation is more complicated. The amount of power being radiated outwards is the same as that in the far-field region, but near to the antenna a considerable amount of electromagnetic energy is also being stored. So as well as the net radiated energy flowing outwards, there is additional energy that oscillates to and fro. These oscillating flows occur perpendicularly to the outward direction from the antenna as well as along it so the net energy flow is tilted with respect to the outward direction. The E -field and B -field are still at right angles to each other and to the direction in which the energy is being carried, but they are no longer in phase and their values can differ appreciably from the simple expressions that apply in the far-field region.

- 4.26** The difference in these properties near and far from an electric dipole antenna is illustrated in Figure 4.4, which shows the directions in which most of the energy flows. (The electric field directions are in the plane of the paper and perpendicular to the directions of energy flow, while the magnetic field directions are perpendicular to the paper.) Far from the antenna, the energy flows outwards. However, near to the antenna, most of the energy is stored around the antenna, flowing to and fro along its length, and only a small proportion is radiated outwards.

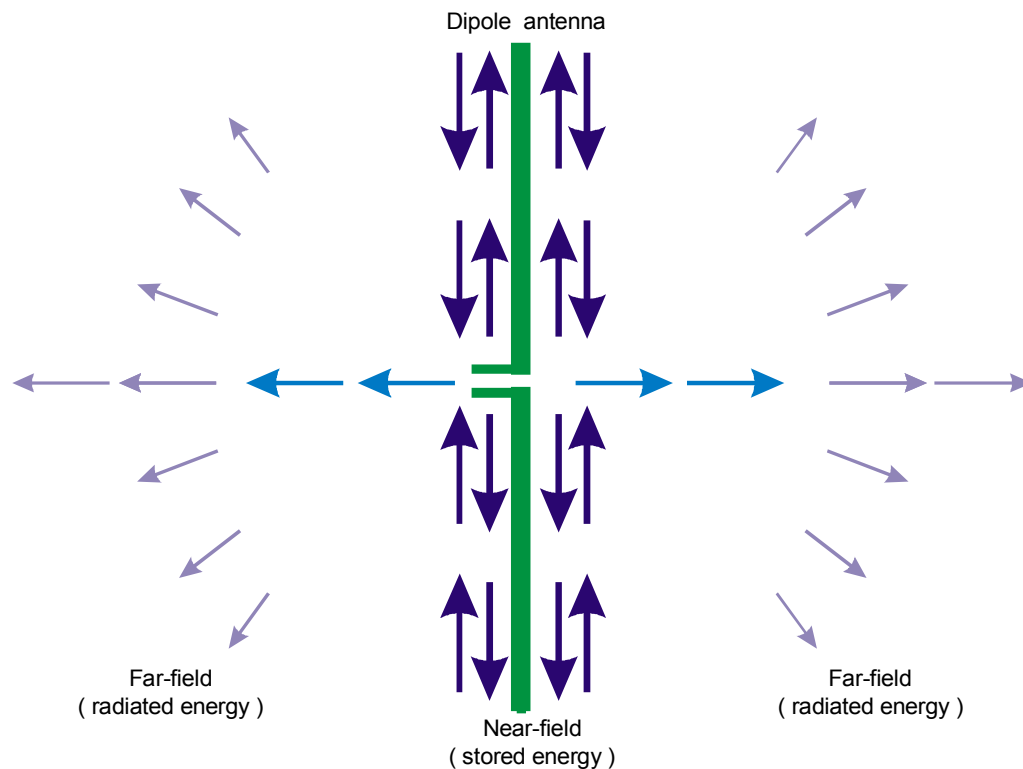


Figure 4.4 Electric dipole antenna showing the directions in which most of the electromagnetic energy flows

Fields from Mobile Phone Systems

- 4.27** The considerations in this section are restricted to the fields produced by GSM mobile phones and base station antennas since these form the large majority of those presently in use in the UK and Europe.

Output from mobile phones

- 4.28** The RF power from a phone is mainly transmitted by the antenna together with circuit elements inside the handset. The antenna is usually a metal helix or a metal rod a few centimetres long extending from the top of the phone. Neither type is strongly directional, although more power is radiated in some directions than others. At points 2.2 cm from an antenna (the distance at which calculations were made), the *maximum* values of the electric field are calculated to be about 400 V/m for a 2 W, 900 MHz phone and about 200 V/m for a 1 W, 1800 MHz phone and the

maximum magnetic field is calculated to be about $1 \mu\text{T}$ for both phones*. For both 2 W, 900 MHz phones and 1 W, 1800 MHz phones the *maximum* intensity 2.2 cm from the antenna is very roughly about 200 W/m^2 (this is about one-quarter of the intensity of the Sun's radiation on a clear summer day, although the frequency of the emission from a phone is a million or so times smaller). These are the fields and intensities when the antenna is a long way from the head or body. When the antenna is near the body, the radiation penetrates it but the fields inside are significantly less, for the same antenna, than the values outside. For example, the largest *maximum* fields inside the head when its surface is 1.4 cm from the antenna are calculated to be about three times smaller than the values given above. (The *average* field values are all appreciably less than these *maximum* values for the reasons explained earlier.) As well as these RF fields, that are pulsed at 8.34 Hz and 217 Hz, there are magnetic fields near to the phone that oscillate at these same frequencies, and are a few μT in magnitude. These are generated by currents flowing from the battery which are switched on and off at these frequencies as a result of TDMA.

- 4.29** An indication of the size of these fields (although not of course any effect they may have) may be obtained by noting that the *maximum* values of these low and high frequency oscillating magnetic fields are about one-tenth the size or less of the Earth's static magnetic field, $50 \mu\text{T}$, while the *maximum* values of the oscillating electric fields outside the body are a few times greater than the electric field at the surface of the Earth due to its static charge. This is directed towards the ground and on a fine day has a constant value of about 100 V/m .

Output from base stations

- 4.30** The base station antennas serving macrocells are either mounted on free-standing towers, typically 10–30 m high, on short towers on top of buildings, or attached to the side of buildings. In a typical arrangement, each tower supports three antennas, each transmitting into a 120° sector. A large proportion of the power is focussed into an approximately horizontal beam typically about 6° wide in the vertical direction and the rest goes into a series of weak beams (called side lobes) either side of the main beam. The main beam is tilted slightly downwards (Figure 4.5) but does not reach ground level until the distance from the tower is at least 50 m (usually 50–200 m).
- 4.31** The base station antennas transmit appreciably greater power than the phones. The limit to the power is formally set by the need to avoid RF interference and defined by a licence issued by the Radiocommunications Agency. This does not directly limit the total power emitted but does so indirectly by fixing the maximum intensity that an antenna can transmit into the main beam. This is done by defining the maximum "equivalent isotropically radiated power" (EIRP) that can be transmitted. The EIRP is the power that would have to be emitted equally in all directions to produce a particular intensity. In fact, as already noted, the antennas used are very far from isotropic, with most of the power being emitted into the main beam, and the ratio of the EIRP to the total power output is called the gain of the antenna. For a 120° sector antenna the gain is usually between about 40 and 60.

* It has already been noted that the electric and magnetic fields vary in rather complicated ways at distances from an antenna that are small compared with the wavelength λ of the radiation (33.3 cm at 900 MHz and 16.7 cm at 1800 MHz). Therefore detailed calculations are needed to obtain accurate values for the intensities and fields near to a phone and the approximate values given here are only intended to give indications of their size. The field values given above, when the antenna is a long way from the head or body, are from computed values for a particular antenna (Dimbylow and Mann, 1994; Mann *et al.*, *in press*). The largest values of electric field E inside a model of a head whose surface is 1.4 cm from the antenna were also computed and are about 120 V/m for a 900 MHz antenna radiating 2 W and 70 V/m for a 1800 MHz antenna radiating 1 W. (These are obtained from their published figures of the specific absorption rates (SARs) inside the head; SAR is defined in paragraph 4.37). The value for the intensity was obtained by assuming the antenna to be a rod of length $l = \lambda/4$. The average value a distance r from the antenna is very roughly equal to $P/2\pi rl$ since nearly all the radiated power, P , has to pass through a cylinder of area $2\pi rl$. The intensities are the same for both 900 MHz and 1800 MHz GSM phones since P/l is the same for both.

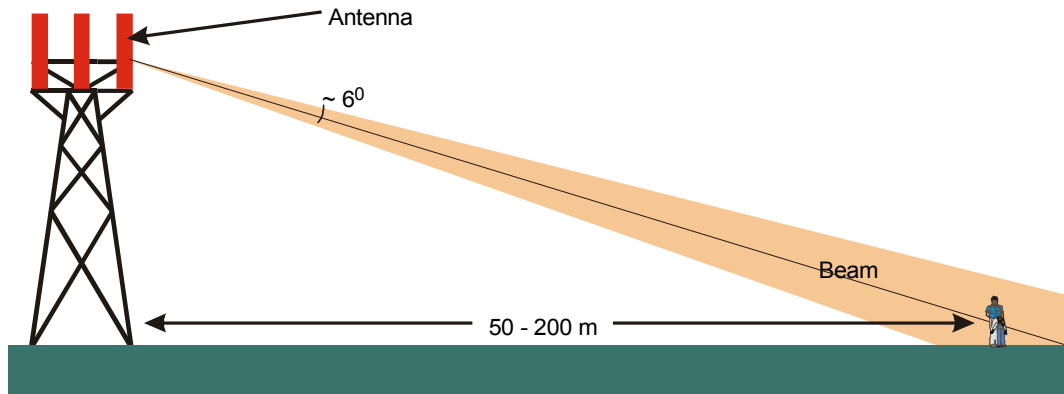


Figure 4.5 Main beam from an antenna mounted on a tower. The beam is in fact less well defined than that shown here and there is a series of weak side lobes either side of it

4.32 The licence sets the maximum EIRP at 1500 W per frequency channel corresponding to a maximum total radiated power of about 30 W per channel (= EIRP/gain). It also limits the number of channels per antenna to 16 (for 1800 MHz) and 10 (for 900 MHz). However, we have been told that in practice the number of channels is typically less than 4 for 1800 MHz and 2 to 4 at 900 MHz (FEI, 2000), which would correspond to maximum radiated powers of less than 120 W and 60–120 W, respectively. Similarly, the total radiated power emitted from an antenna is generally limited by the characteristics of the equipment to somewhat under 70 W (FEI, 2000), and a figure of 60 W will be assumed in this report. It needs to be stressed that the number of channels used, and hence the total radiated power, is limited by technical rather than legal requirements, which would in fact permit significantly larger powers to be radiated. As with a phone, and for largely the same reasons, the *average* power transmitted by a base station is normally less than the *maximum* power, although in this case it could rise to the maximum at times (rather than to one-eighth of the peak power in the case of a phone). By the inverse square law, the *maximum* intensity in the main beam at a point on the ground 50 m from a 10 m tower carrying an antenna transmitting 60 W into a 120° sector is about 100 mW/m² *. This corresponds to oscillating electric and magnetic fields of about 5 V/m and 0.02 μT, respectively, very roughly about 50 to 100 times smaller than those 2.2 cm from the antenna of a phone. The heating effects that these fields would produce will vary with the intensity and are about 5000 times smaller than the maximum value 2.2 cm from the antenna of a mobile phone.

4.33 The RF intensity on the ground is not zero outside the main beam, because of the power emitted into the side lobes. Its value will depend on the design of the antenna but it seems unlikely that it could ever be significantly more than that within the beam. So the values given above should be reasonable indications of the maximum intensity and fields that would be present on the ground around a base station. The intensity will, however, become appreciably larger as the antenna is approached, as it might be by maintenance workers.

* If the power P were transmitted equally into all directions, the intensity at a distance r would be $P/4\pi r^2$ (the power passes through a sphere of area $4\pi r^2$) which is about 2 mW/m² at a point on the ground 50 m from the bottom of a 10 m tower transmitting $P = 60$ W. For a 120° sector antenna with a gain of 50 the intensity at the centre of the beam rises to around 100 mW/m². However, even though the intensity at a particular distance is greatest at the centre of the beam, the intensity on the ground is somewhat larger at angles just away from the centre since the distance from the antenna is less (see Figure 4.5). So the region of greatest intensity lies between the points where the centre of the main beam hits the ground and the points where the nearest edge of the beam hits the ground (for this purpose we define the edge as occurring at the angle at which the intensity falls by half, 3 dB). In this report we refer to the part of the beam producing this region as the *beam of greatest intensity*.

- 4.34** In the last year or so NRPB has made spot checks on the average intensities around base stations. Eight of these stations were mounted on the roofs of schools; four were on tower blocks and five on other buildings. Measurements were made at various points within the buildings, at ground level or at other locations of public access (Mann *et al*, *in press*). The measured intensities were typically between 0.01 and 1 mW/m² and the maximum was never more than 10 mW/m². These values are then very much less than the calculated values in the beam given above, although the sample is small. It is also of note that the calculations and most of the measurements were for towers used by one operator only. The average intensities would be expected to be larger near to a tower used by more than one operator.
- 4.35** We note that these measurements by NRPB were spot checks made under contract at the request of a client such as a local authority. Neither NRPB nor any other independent agency has made any systematic experimental study in the UK of, for example, how the intensity changes with distance from a base station, although such studies have been reported in the USA. The NRPB report also includes the measurements made during these spot checks of the intensities due to radio and TV transmissions but again there have been no systematic studies which would have allowed us to make a useful comparison of the intensity of typical exposure levels received by individuals from mobile phone transmitters compared with those from other RF sources. Surveys of this sort have been conducted in the USA but they are several years old and have been made obsolete by the rapid development of wireless technologies. This is, indeed, a very complex problem given the great diversity of RF sources that are presently in operation.
- 4.36** Two further properties of the electromagnetic waves emitted by both mobile phones and base stations, that might be of significance in their interaction with biological tissue, are their frequency spectrum and coherence time. The emission from a mobile phone is essentially at one frequency and that from a base station is at several specific frequencies and, in both cases, the waves have the relatively long coherence time of around 4 μs (the coherence time is the average time between random phase changes, which in this case are the result of phase modulation, see paragraph 4.11). Both these properties are very different from those of, say, the radiation from the Sun which consists of a broad spectrum of frequencies and electromagnetic waves with coherence times which are shorter by a factor of around a hundred-thousand.

Field penetration into the body: dosimetry

- 4.37** Radiofrequency fields penetrate the body to an extent that decreases with increasing frequency. To understand the effects this might have on biological tissue, the magnitude of the fields needs to be determined within the various parts of the body that are exposed. This requires a knowledge of the electrical properties of the different types of tissue and, once this has been determined, it is possible to calculate E and B at every part of the body caused by a particular source of radiation such as a mobile phone. The rate at which the energy is absorbed by a particular mass of tissue m , is $m\sigma E^2/\rho$, where σ and ρ are, respectively, the conductivity and density of the tissue and E is the rms value of the electric field. The quantity $\sigma E^2/\rho$ is called the specific energy absorption rate or SAR and is measured in watts per kilogram (W/kg). It varies from point to point in the body both because the electric field changes with position and because the conductivity is different for different types of tissue. (The density is much the same for all tissues apart from bone.) Since the average values of the conductivity at 900 MHz and the density of body tissue are 1 S/m and 0.001 kg/m³, respectively, the typical value of electric field needed to produce an SAR of 1 W/kg is about 30 V/m. (The average value of conductivity is somewhat higher at 1800 MHz so lower electric fields, about 25 V/m, are needed.) The SAR produced by a particular value of electric field is somewhat larger in children than in adults because their tissue normally contains a larger number of ions and so has a higher conductivity (Gabriel, 2000). We understand that an internationally agreed standard testing procedure that will allow the SAR from mobile phones to be compared is being developed and will be finalised this year (2000).

- 4.38** It is important to stress that these are the electric fields *inside* the body. The fields outside the body that correspond to these internal fields are typically around three times larger; this was discussed in paragraph 4.28.
- 4.39** It is very well established that electromagnetic radiation can only be absorbed in quanta of energy $h\nu$, where h is Planck's constant. Now the energy needed to remove an electron from (ionise) an atom or molecule is a few electron volts (eV)* (an eV is the energy needed to move an electron of charge e from an earthed plate to one at a negative voltage of one volt). So if the quantum of energy is less than about 1 eV, it is essentially impossible for ionisation to occur†. The quantum of energy of RF radiation is in fact many thousand times less than 1 eV so RF radiation cannot ionise atoms or molecules and is described as non-ionising radiation (NIR). However, higher frequency radiation, such as far-ultraviolet radiation and X-rays, has energy quanta bigger than 1 eV and so can readily ionise atoms and molecules, and produce some damage to biological tissue even at very low intensities. This is referred to as ionising radiation. The intensity determines the number of quanta striking the body per second and, even though this is small at low intensities, each quantum still has a certain probability of ionising and so damaging biological molecules such as DNA. Non-ionising electromagnetic radiation, however, is believed to be harmless at very low intensities, although it can be damaging at high intensities. For example, light at modest intensities produces useful biological effects which allow us to see illuminated objects. However, if the intensity of the light becomes too large, the eye can be seriously damaged. Very high intensity RF radiation can also be damaging as is clear from the strong heating effects produced in a microwave oven. So we need to know at what intensity the radiation starts to produce damage; this might usually be expected to be higher than the lowest intensity at which biological effects can be detected. The current guidelines that are in force to protect people from harmful exposures are discussed in paragraphs 6.19–6.32.

* The ionisation energy has been quoted as a few electron volts, although the usual boundary between ionising and non-ionising radiation in biological material is taken as around 10 eV, reflecting the fact that the atoms that are present have ionisation energies that are greater than average.

† It is possible for two or more quanta to be absorbed simultaneously. However, the probability of this happening falls rapidly with the number of quanta and becomes minute if thousands of quanta are to be absorbed at the same time.

5

Scientific Evidence

- 5.1** Assessment of any health risk resulting from exposure to radiofrequency (RF) fields depends on the results of well-conducted and reproducible scientific studies, and the need for these is all the greater because any effect of exposure to RF fields at the levels encountered from mobile telecommunications is likely to be subtle. Reports of such studies are mainly found in peer-reviewed journals, although the Expert Group considered evidence from all sources of information available to it.
- 5.2** The World Health Organization (WHO) defines health as the state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity. Thus the Expert Group considered ways in which mobile phones and their base stations might jeopardise any of these aspects of the health of people.
- 5.3** We are aware of the concerns about the biological effects and possible health risks of exposure to RF fields expressed by a group of scientists who met in Vienna in October 1998. The evidence reviewed in this chapter addresses the issues in detail.
- 5.4** New telecommunications technologies have been introduced without full provision of information about their nature and without prior discussion within the scientific community about possible consequences for health. The average output power from the antennas of digital mobile phones is lower than that from earlier analogue models, but the maximum powers are greater, the exact patterns of radiation are different and these differences might influence their effects on people. As the costs of mobile phone technology have fallen, their use has increased dramatically and the overall levels of exposure of the population as a whole have therefore increased.

Interaction of Radiofrequency Fields with Tissues

Mechanisms

- 5.5** While risk assessment is generally based on experimental data from biological systems, a consideration of possible mechanisms is nevertheless pertinent, for two reasons. Firstly, as discussed below, the experimental data regarding biological effects of RF fields are fragmentary and inconsistent in many respects, and an understanding of the biophysical mechanisms for reported effects can help to rationalise and understand the data. Secondly, it is necessary to extrapolate data from one exposure condition to others, and for reliable extrapolation some understanding of the underlying mechanisms is needed.
- 5.6** The electric and magnetic fields produced in the body by a nearby electromagnetic source may cause both thermal and non-thermal biological effects. The effects of magnetic fields vary with frequency, and are probably greatest in biological tissue containing small amounts of magnetite. Magnetite (Fe_3O_4) is a naturally occurring oxide of iron. It is a ferrimagnet but behaves similarly in magnetic fields to a ferromagnet such as iron. Magnetite is found in certain bacteria and in the

cells of many animals, including human beings. It is believed to be used by some species of birds and fish to provide magnetic sensitivity, which they employ in navigation. However, no other effects associated with the interactions of electromagnetic fields with magnetite have been demonstrated in animals. It has been calculated that the interaction resulting from the largest RF magnetic fields generated by mobile phones is extremely small (Adair, 1994), and that any other effects of magnetic fields at these frequencies should be even smaller. Indeed, it seems to be generally agreed that any biological effects from mobile phones are much more likely to result from electric rather than from magnetic fields.

Thermal effects

- 5.7** Thermal effects are those caused by the rise in temperature produced by the energy absorbed from oscillating electric fields. The force produced by an electric field on charged objects, such as the mobile ions present in the body, causes them to move, resulting in electric currents, and the electrical resistance of the material in which the currents are flowing results in heating. This heat input causes the temperature to rise and it continues to do so until the heat input is balanced by the rate at which it is removed, mostly by blood flowing to and from other parts of the body. It is estimated that it takes several minutes from the moment RF exposure occurs for the irradiated parts of the body to reach their final equilibrium temperatures. In view of this slow response, the equilibrium temperature arising from the pulsed fields of mobile telecommunications will essentially be determined by the *average* power absorbed. There will, however, be small oscillations about that temperature at the pulse frequency or frequencies.

Heating in the head

- 5.8** It has not yet proved possible to measure these small changes in temperature directly, except those at the outer skin (Adair *et al*, 1999) and, although temperature is a more direct determinant of thermally induced tissue damage, the majority of theoretical studies up to the present time have restricted themselves to the computation of SAR alone (paragraph 4.37).
- 5.9** The relationship between the SAR and the resulting temperature rise is complex, and significantly dependent on antenna configuration, location and frequency. The most problematic feature of a temperature calculation is modelling the effect of blood flow on heat transfer. The traditional continuum heat-sink model developed by Pennes (1948) has been found to give remarkably accurate results in many circumstances, but numerous modifications have been suggested more recently (Arkin *et al*, 1994).
- 5.10** In a recently published study (Van Leeuwen *et al*, 1999) the heat deposition within the head was computed by coupling a finite difference time domain model for SAR with a new thermal model. The thermal model includes the convective effects of discrete blood vessels, whose anatomy was determined using magnetic resonance angiography of a healthy volunteer. For a 915 MHz dipole antenna with a time-averaged power output of 0.25 W (equivalent to a typical mobile phone), this study results in an SAR of about 1.6 W/kg and predicts a maximum brain temperature rise of 0.11°C in the steady state. There is general agreement between the brain temperatures calculated using the Pennes equation and that using the new discrete vessel model, which suggests that the sensitivity of the results to the exact blood flow model may not be critical. However, further work should be done to apply this model to more realistic simulations of mobile phone configuration, and to investigate the effect of different antenna positions and frequencies (particularly in the 1800 MHz band also used by mobile phones).
- 5.11** A recent NRPB study (Wainwright, *in press*) has applied the traditional Pennes thermal model to the SAR patterns predicted by earlier work (Dimbylow and Mann, 1994). The radiation source was modelled as a monopole antenna on a metal box, and both horizontal and vertical orientations

Scientific Evidence

of the antenna were considered. Computations of the final steady-state temperature rise were carried out for a 0.25 W antenna at frequencies of 900 and 1800 MHz. The highest temperature rises found in the brain were around 0.1°C.

Non-thermal effects

- 5.12** The energy quanta of radiation at 0.9 and 1.8 GHz equal 4 and 7 μeV , respectively (1 μeV is a millionth of an eV). Both these values are extremely small compared with the energy of around 1 eV needed to break the weakest chemical bonds in genetic molecules (DNA). As already noted, it seems impossible, therefore, that RF radiation could damage DNA directly, which might start cells on the path to cancer.
- 5.13** Radiofrequency radiation could, however, produce other effects. In general, detectable changes can arise only if the effect of the electric field within the biological system exposed to RF fields is not masked by *thermal noise*. Thermal noise or random motion, also known as Brownian motion, is due to the thermal energy that all objects possess at temperatures above absolute zero. In solids, the atoms vibrate and in gases and liquids they move erratically to and fro following very frequent collisions with other atoms. So all components of biological tissue – ions, molecules and cells – are in constant motion. The thermal energy of each component has an average value of about kT , where k , Boltzmann's constant, is 86 μeV per degree and T is the absolute temperature measured in kelvin, K ($T = 273 + t$, where t is the temperature in degrees centigrade). The value of T is about 300 K at body temperature so that kT is 26 meV and, if this is much larger than the energy of the motion produced by the electric field, any effect of the field will be completely masked (not detected by any component of the biological tissue). This comparison with thermal noise should then provide a good measure of the minimum electric field necessary to produce detectable biological effects. It should be noted, however, that if there was a special case in which the biological system were resonantly sensitive at the frequency of the electric field and rather insensitive to fields at other frequencies, the comparison would need to be made with the thermal motion taking place at frequencies close to the resonant frequency. If the resonance was very sharp, this would be very much smaller than the total thermal noise, so that quite small electric fields might produce detectable effects in resonant systems of this type, should they exist in biological tissue.
- 5.14** This argument can be used, for example, to see whether non-thermal effects could arise from the motion of the ions discussed above. The ions are driven to and fro by an oscillating electric field, although the extent of the motion is severely reduced by the viscosity of the surrounding liquid. For a field of 100 V/m the movement is in fact less than 10^{-14} m – the diameter of an atomic nucleus – and the energy associated with this motion is less than that of the thermal motion of the ion by about a factor of 10^{15} *. This is so small that it can safely be concluded that this ionic motion could not result in any non-thermal biological effects. The expression (in the footnote) shows that the energy increases with the mass of the charged object, although, for $E = 100$ V/m, it would still appear to be small at these frequencies compared with thermal noise for objects such as cells of average size which have radii around 10 μm (Adair, 1994). Adair notes, however, that it could become significant for larger cells with correspondingly greater masses.
- 5.15** Another mechanism involving cells concerns the attraction between them in the presence of an electric field (Schwan, 1985; Adair, 1994). The electric field polarises the cell, that is to say

* The velocity of the ion is $\mu E = \mu E_0 \sin(2\pi vt)$, where μ , the mobility, is about 10^{-7} $\text{m}^2/(\text{V/s})$ for chloride, the ion of highest mobility, and v , the frequency, is 0.9 or 1.8 GHz. This leads to a maximum displacement of $\mu E_0/2\pi v$ which, for an electric field $E_0 = 100$ V/m, equals 2×10^{-15} m and 10^{-15} m at frequencies of 0.9 and 1.8 GHz, respectively. So the average kinetic energy of an ion of mass m in this field is $m\mu^2 E_0^2/4$ or $m\mu^2 E^2/2$, where E is the rms value of the electric field. For a chloride ion this energy is equal to about 10^{-17} eV, or about 10^{-15} kT .

charges in the cell move so that one side of it becomes positive with respect to the other. The cell is then an electric dipole (like a tiny torch battery) and attracts similarly polarised cells. For typical cells and frequencies below about 100 MHz, the energies involved are calculated to become comparable to thermal noise in electric fields of $E = 300$ V/m. The energies are calculated to become appreciably less for RF fields, but Adair (1994) suggests that, since these values would depend on the detailed structure of the biological elements involved, the possibility of biological effects for fields of this size cannot be excluded.

- 5.16** Other possible biological effects are associated with cell membranes and the movement of currents through the membrane in either direction. Membranes are known to have strongly non-linear electric properties (Montaigne and Pickard, 1984). When a voltage is applied across the membrane, the current that flows is not always proportional to the voltage. Part of this non-linearity may, in fact, be due to the effect of the electric field on the proteins in the membrane or nearby, which assist the flow of the product currents through the membrane. The membrane also acts as a rectifier. If a voltage is connected across the ends of a wire, the size of the current that flows depends solely on the magnitude of the voltage: if the polarity of the voltage is reversed, the current changes direction but its size is unchanged. However, if the polarity of the voltage applied across a rectifier is reversed, the current changes direction but now its size also changes. So, if an oscillating voltage (electric field) is applied across a rectifier, the total current that flows when the field is in one direction is not balanced by the current when the field is in the other: an AC field produces a net DC current and hence a net flow of products through the membrane. However, the response times of the ion gates are very much slower than the period of microwave frequencies and, using data obtained from measurements on membranes (Montaigne and Pickard, 1984), it has been shown that, for electric fields of 200 V/m, the relative change in the membrane potential is very small (Adair, 1994; see also Foster, 2000a). Therefore no biological effects seem likely from this mechanism.
- 5.17** Many other mechanisms have been proposed by which significant biological effects from RF fields might arise, but very few, if any, appear to stand up to critical analysis of the sort presented above (Foster, 2000b). One, for which there is recent experimental support (Bohr and Bohr, 2000), is that microwave radiation might cause proteins to unfold (denature). The experiments were carried out in a modified microwave oven at 2.45 GHz, a frequency comparable to the likely torsional modes of the protein. The intensity was not specified, but seems likely to have been above ICNIRP guidelines. The experiments were very recent and have not yet been replicated. Another mechanism that has continued to create interest is based on the assumption that biological systems might interact resonantly with microwave fields. This possibility was initially discussed by Fröhlich (1968, 1980) and his work has had a considerable impact (see, for example, Penrose, 1994; Pokorny and Wu, 1998).
- 5.18** Fröhlich was interested in the mechanism through which the chemical energy taken into the body (food) was channelled into highly ordered processes, such as cell building, rather than into heat. His model involves the mechanical vibrations of large molecules or components of biological tissue and the way they interact with each other, which he argued could lead to the existence of a band of frequencies into which energy could be absorbed, plus a particular “coherent state” of vibration. He also considered whether quite small oscillating electric fields might put energy into this state and hence trigger significant biological changes; that it is to say, whether a living biological system might behave in a manner roughly similar to a radio receiver. A radio can detect and amplify an extremely small signal against a background of very much larger signals. It does this when the operator tunes a resonant circuit to the frequency of the carrier wave. The resonant circuit essentially responds only to electromagnetic waves of frequencies (including those generated by thermal noise – see paragraph 5.13) within a narrow bandwidth. The power

Scientific Evidence

needed to amplify these waves comes from the power supply of the radio. A number of solid state systems behave in similar ways, such as narrow-band optical amplifiers, which are the basis of lasers.

- 5.19** The Fröhlich model has stimulated a range of other work. However, so far there appears to be no direct experimental evidence, and no convincing indirect experimental evidence, for the existence of Fröhlich's coherent state in biological systems. Moreover, the present theoretical treatments of the model do not provide estimates for the magnitude of the electric fields needed to produce biological effects. Fröhlich suggested that the findings of a number of experiments carried out at frequencies of 40 GHz and above on systems such as *E coli* bacteria and yeast cultures (see Fröhlich, 1980) might be (indirect) evidence for his model, since these frequencies lie in the range where cell membranes are expected to resonate mechanically. Four recent attempts to reproduce some of this work have failed to do so (*E coli*: Athey and Krop, 1980; Santo, 1983; yeast cultures: Furia *et al*, 1986; Gos *et al*, 1997), although there have been further reports from Balyaev and colleagues that appear to endorse the earlier research (*E coli*: Balyaev, 1992). A recent appraisal of all this work (Foster, 2000a) notes that the experiments present formidable technical problems and that, while their results may be statistically significant, it may not always be possible to eliminate systematic errors. In view of this appraisal, it is not possible to conclude that this work provides support for the existence of resonant absorption by biological tissue.
- 5.20** Hyland (1998) has suggested that the mechanism proposed in Fröhlich's model might lead to biological effects from electromagnetic fields at the appreciably lower frequencies of mobile phones. This would require the presence of components in the biological tissue with sharp resonant vibrational modes in this frequency range. The frequencies are lower than those expected for most components, although theoretical work (Kohli *et al*, 1981; Van Zandt, 1986; Porkny and Wu, 1998) suggests that DNA polymers and elements of fibre structures (cytoskeletons), such as microtubules and actin filaments, could have modes in this range. However, since these components are surrounded by relatively viscous fluids, their mechanical vibrations would normally be expected to be very highly damped. Thus, resonances they might have out of solution would be almost completely smeared out when they are immersed*. Certainly no evidence of resonant absorption[†] was found from DNA in solution (Gabriel *et al*, 1987), although this might not rule out the possibility that it occurs under the conditions in which DNA exists in tissue.
- 5.21** *CONCLUSION This work on DNA should be repeated under conditions more closely matched to those in tissue and similar measurements should be made on microtubules and actin filaments.*
- 5.22** Another hypothesis is that the interaction with biological tissue depends on the coherence of the electromagnetic fields (see paragraph 4.36). Experimental evidence in support of this idea has been given by Litovitz *et al* (1993, 1997a,b) but not yet independently replicated.
- 5.23** In summarising the physical basis for non-thermal effects, it is convenient to consider separately the situations near to the antenna of a mobile phone and near to a base station.

* Water provides an example of this effect. Water vapour shows strong resonant absorption but the resonances are smeared out in liquid water and absorption occurs over a wide range of frequencies. Scott (1984) and Van Zandt (1986) have, however, proposed models to explain why this might not happen for DNA in solution.

[†] Earlier work on DNA in solution appeared to show strong resonant absorption in this range (Edwards *et al*, 1984). It was shown, however, that this could have been the result of an experimental artefact (Foster *et al*, 1987) and, as noted, the work of Gabriel *et al* (1987), carried out on samples chosen to be as close as possible to those of Edwards *et al*, failed to see any such effects. In this work, three different techniques were used in two different laboratories and the results were essentially identical. It can be concluded, therefore, that DNA in solution does not have resonant modes that couple to microwaves in this range.

Mobile phones

- 5.24** In Chapter 4 it was noted that the *maximum* size of the electric fields produced in the head by the antenna of a mobile phone is around 100 V/m, although the fields inside the brain would be appreciably less. For fields of this size the mechanisms most likely to produce non-thermal biological effects would be through the movement of large cells (paragraph 5.14) or through the attraction between neighbouring cells (paragraph 5.15). At this stage, although there is no experimental evidence to support these mechanisms, the possibility that both of these could produce effects cannot be excluded (Adair, 1994).

Base stations

- 5.25** The maximum size of the electric fields resulting from base stations to which the general public is exposed is around 5 V/m, although the largest field measured to date by NRPB is 2 V/m (Mann *et al*, *in press*). (The corresponding field strengths inside the body will be appreciably smaller.) One mechanism that could lead to biological effects at these relatively low fields is that proposed by Fröhlich and which relies upon the existence in biological tissue of a particular coherent state of mechanical vibration. The absence, even after 30 years, of any convincing evidence for this state, or indeed for any resonant behaviour, would seem to cast considerable doubt on its existence, although it cannot totally be ruled out. It should be noted, however, that Adair (1994) has considered more generally the possibility of energy transfer through a resonant mechanism and his conclusion is that it would be too small to lead to measurable biological effects at any value of electric field.
- 5.26** We conclude that there is little evidence to support resonant behaviour, but further work to investigate this proposed mechanism could be worthwhile.

Experimental Studies

- 5.27** This section considers and interprets research on *in vitro* preparations and on animals (*in vivo*) relevant to the possibility that exposure to RF fields used in mobile telecommunications is associated with adverse health outcomes.

Significance of experiments on molecules, cells and animals

- 5.28** Our principal remit was to report on the possible risks to human health of mobile phones and their base stations. The most direct demonstration of such risks comes from research on people, either through epidemiological studies, which could identify an increased incidence of health problems as a result of exposure to RF fields, or by means of experiments on human volunteers aimed at revealing physiological or behavioural abnormalities resulting from such exposure. However, because of the obvious limitations of human experimentation, more direct methods are necessary to show the underlying biological basis of any health hazards. These involve laboratory studies of biological systems and animals.
- 5.29** Experimental observations on biological molecules (eg solutions of enzymes), and on *in vitro* preparations of isolated cells or tissue samples, could define the mechanism of any action of radiation on living organisms. A great deal of research has been performed on such preparations, particularly on cultured animal or human cells. Such work could, in principle, give insight into the basic mechanisms responsible for more complex effects seen in whole animals or people (eg tumour formation, changes in brain activity and even alterations of behaviour). The results of work on simple molecular and cellular preparations are often easier to interpret, since the nature of any effects can be more precisely defined and the conditions of the preparation (including its

Scientific Evidence

temperature) can be more accurately assessed and controlled than in whole animals. However, even when clear effects are defined *in vitro*, it is often difficult to extrapolate from them to a health risk for people.

- 5.30** Laboratory studies on animals play an essential role in evaluating the integrated reactions of various, intact systems of the body, particularly the nervous, endocrine (hormone) and immune systems. These systems are largely responsible for homeostasis – the essential maintenance of the internal environment. The complex, co-ordinated, interdependent response of these systems when challenged by potentially damaging stimuli cannot be defined through experiments on molecules or isolated cells.
- 5.31** The environment and parameters of exposure to RF radiation can be made virtually the same for all animals in each group; well-matched “control” animals can be identically treated except that they receive no exposure. Valid comparisons can then be made between the exposed and control groups to determine if exposure causes any effects. The precision of this type of study also allows dose–response relationships to be determined.
- 5.32** Of course, phenomena seen in experimental animals do not necessarily imply a health risk for people. In particular, an effect found in only one animal species may be specific to that type of animal and not relevant to people.
- 5.33** Although rodents differ from people in some aspects of their physiology, mice and rats are frequently used in biomedical research. This is mainly because genetically homogeneous strains of rodents are available for research and because they are easy to breed and maintain. Another advantage of rodents accrues from the fact that they have been so widely used for research in the past and consequently much is known of their normal physiology. Moreover, mice have been the preferred species for research on genetic mechanisms and for experimental work involving transgenesis (the modification of genes).
- 5.34** Appropriate animal studies provide the opportunity to test whether lifetime exposure to well-characterised RF radiation causes cancer, something that is obviously impossible using human volunteers. While epidemiological studies do allow human populations to be studied, they are generally not able to assess RF exposure accurately. Research on animals can also demonstrate influences of RF exposure on susceptibility to cancer promotion and progression, as well as on various physiological functions, including behavioural performance in tasks involving learning, memory, etc. It is important to note, however, that the interpretation of any such behavioural effects in small animals is not straightforward. For instance, if radiation affects the performance of mice in tests of learning (as has been claimed: see paragraphs 5.80–5.92), one might imagine that it could influence this aspect of brain function in people. However, given the small size and somewhat different functional and anatomical organisation of the mouse brain, such a result could not easily be extrapolated to suggest a similar effect on memory in people.

Stimulus conditions

- 5.35** As described above, high levels of RF radiation cause heating by inducing small electric currents and increasing the movement of molecules. However, the rise in temperature in the brain caused by the use of a mobile phone for more than a few minutes (the time taken to reach thermal equilibrium) is estimated to be only about 0.1°C (Van Leeuwen *et al*, 1999). Moreover all cells in the body have a mean thermal energy proportional to the absolute temperature T (paragraph 5.13) and the energies of individual cells fluctuate about this mean energy as they interact with other cells, extracellular fluids etc. Any increase in energy caused by radiation is

superimposed on this background of fluctuating energies and would have to begin to be comparable in size to these to cause any additional biological hazard.

- 5.36** Experimental studies have employed a bewildering variety of exposure conditions, with respect to the RF carrier frequency, whether it is continuous, amplitude modulated or pulsed, and, particularly, its intensity. High intensities, above present guidelines (see paragraphs 6.19–6.31), can cause significant heating (ICNIRP, 1998a,b), which itself can lead to a variety of pathological effects in cells and tissues.
- 5.37** We have considered the whole range of research reports, including those that employed intensities that caused heating, since they might provide clues to the mechanism of effects at more modest levels of exposure. However, we have concentrated on studies that used intensities below 50 W/m^2 (5 mW/cm^2) and/or SARs below 1 W/kg , which are less likely to have involved significant heating (see paragraph 5.8). We have also taken note of studies in which investigators used higher intensities but have attempted to prevent what they considered to be significant rises in temperature. It must be noted, however, that it is difficult to be sure of the absence of thermal effects. The absorption of RF energy is necessarily accompanied by temperature increases, which can be minimised, but not prevented. Whole-body SARs less than 1 W/kg have been shown to cause thermoregulatory responses in animals. In the case of pulsed fields, the average SAR is obviously much lower than the peak SAR during pulses, which can generate quite rapid, transient heating and quite large electric fields. This probably accounts for many of the effects, such as ‘microwave hearing’ (see paragraphs 5.76–5.79), that have been described at low average SARs.
- 5.38** We were struck by certain inconsistencies and inadequacies in the scientific literature on the biological effects of RF radiation. Many studies in this field have been exploratory and preliminary in nature, and claims of effects have sometimes been based on single experiments rather than a consistent series of hypothesis-driven investigations. In some cases, study design and statistical analysis have been inadequate, and apparent effects may have been artefactual or due to random variation. Indeed, the field is troubled by failures to replicate previous studies and by a lack of theoretical explanation of some effects that have been claimed. There may also be biases arising from selective publication and non-publication of results. Finally, even for effects that appear to be well substantiated, the biological significance and the implications for health are often unclear.
- 5.39** A considerable problem in the interpretation of experimental reports is that many of them have given insufficient detail concerning exposure conditions, including the important SAR value. Moreover, in the case of pulsed fields, when SAR values are quoted it is often unclear whether these refer to the average SAR or to the peak SAR during pulses. It is very important to make this distinction, since the peak SAR can be 1000 or more times the mean value.
- 5.40** Current mobile phone systems utilise RF radiation between about 800 MHz and 2 GHz, which fall in the microwave part of the spectrum. Emerging telecommunications technologies under development may use up to 60 GHz. Paging systems and two-way radios employ frequency bands down to about 150 MHz. Thus, we have focussed on experimental studies involving RF radiation between 100 MHz and 60 GHz.
- 5.41** *CONCLUSION* We consider that, in future, researchers in this field should provide full details of the experimental conditions used, including the maximum specific absorption (SA) per pulse, for pulsed radiation.

Scientific Evidence**Biological issues**

- 5.42** With regard to possible influences on the head, we have concentrated primarily on functional changes in the brain and consequent changes in behaviour. With regard to whole-body exposure, we have concentrated on possible effects on carcinogenic processes, on reproduction and development, on immune responses, on the cardiovascular system and on overall longevity.

Nervous system: can RF exposure cause functional changes in the brain and affect behaviour?

- 5.43** There is particular concern about the possible effects on the brain and behaviour of repeated, acute exposure to RF fields, largely because mobile phones are conventionally held close to the head. Recent reports in the media, for instance, have implied that the use of mobile phones can cause memory loss, changes in attention, and variation of blood pressure (see Chapter 3).
- 5.44** There is a vast literature on the effects of RF fields on isolated nerve cells (neurons), on cultured nervous tissue, on living brain slices, on brain function in experimental animals, on the blood–brain barrier and on behavioural measures of brain function (see, for example, UNEP/WHO/IRPA, 1993; Cleary, 1995; Hermann and Hossmann, 1997; Repacholi, 1998; D’Andrea, 1999; Jokela *et al*, 1999; Royal Society of Canada, 1999). The behaviour of animals, in particular, can be a very sensitive indicator of adverse health consequences. Early signs of potential insult are often behavioural rather than anatomical (Salzinger, 1994). Behavioural experiments on animals are used to investigate the biological basis of memory, and studies with non-human primates can serve as a model of human cognitive functions. Work on people is reviewed below (paragraphs 5.176–5.200) and here we deal specifically with *in vitro* studies and work on animals. Much of the research, especially the early studies, was conducted with high levels of RF exposure, or low average levels using high peak-power pulses (which are characteristic of radar and quite unlike emissions from telecommunications systems). Few relevant experiments have used low level fields with characteristics similar to those used in telecommunications systems (UNEP/WHO/IRPA, 1993; Repacholi, 1998; Royal Society of Canada, 1999).

Effects on cell membranes: do RF fields affect the movement of substances across membranes?

- 5.45** The lipid bilayer membrane that surrounds cells and the internal membranes within cells are vitally important for normal cellular function. Embedded in the external membrane are important protein molecules. Some act as receptors, detecting extracellular molecules (such as growth factors, hormones and neurotransmitters) and triggering changes in the conductivity of associated ion channels (see below) or activating signalling pathways within the cell. Other membrane proteins, called pumps, actively transport ions across the membrane, using energy derived from the energy source ATP. Yet others are channels that serve as conduits through which ions (eg sodium, potassium, chloride and calcium ions) can move across the membrane. Changes in the conductivity of ion channels, which increase or decrease the flow of ions across the membrane, cause changes in the intracellular potential of the cell. In the case of a neuron, this can affect its excitability and the amount of transmitter substance that it produces at the end of its fibre (or axon) where it makes contact with another nerve cell. Calcium acts as a signalling molecule, influencing a variety of intracellular molecular pathways, as well as having direct electrical effects within or around the cell.
- 5.46** Inside neurons, calcium is held in internal stores, from which it can be released into the cytoplasm. It can enter neurons from the extracellular space through selective ion channels associated with one class of neurotransmitter receptor (the NMDA-receptor). It can also move in

or out of the cell (depending on the internal concentration and electric potential) through calcium channels, the permeability of which is affected by the intracellular potential. In the terminals of nerve fibres, where they form junctions (called synapses) with other neurons, the amount of transmitter substance released when a nerve impulse arrives depends on the entry of calcium caused by the change of intracellular potential.

- 5.47** In neurons in certain parts of the brain (especially a structure called the hippocampus, and in the cerebral cortex, particularly in young animals), changes in the level of intracellular calcium resulting from incoming synaptic activity can lead to long-term alterations in the “strength” of synaptic inputs on to the neurons. Such long-term potentiation and long-term depression are thought to be involved in the mechanisms of memory and learning (see Kandel *et al*, 2000).
- 5.48** Repacholi (1998) has recently concluded from a World Health Organization review of the literature that RF fields, continuous or pulsed, can affect membrane channels, mainly at fairly high intensities, but even at levels that do not cause significant heating. There have been reports of decreased rates of channel formation, decreased frequency of channel openings, and increased rates of rapid, burst-like firing (see UNEP/WHO/IRPA, 1993). However, there is no clear understanding of how low intensity RF fields have such effects.
- 5.49** Cleary (1990a,b 1995) has reported, in reviews of the literature, that the flux of positively charged sodium and potassium ions across cell membranes can also be affected by RF exposure, over a wide range of frequencies (27 MHz to 10 GHz). Although most of these experiments involved very high SARs (up to 200 W/kg), he reported that effects can be produced at much lower intensities, without what he considered to be a significant rise in temperature. However, they seem to occur over a temperature “window” from 17.7 to 25°C, which might imply that the RF energy facilitates lipid phase transitions in the membrane near the phase transition temperature (Tenforde and Liburdy, 1988). In the human body, cells are always well above this temperature window and therefore the effect is unlikely to occur *in vivo*.
- 5.50** RF exposure has been reported to influence the ATP-dependent sodium/potassium pump in the membranes of human red blood cells, and this effect might also perhaps be mediated by membrane phase transitions (Allis and Sinha-Robinson, 1987; Liu *et al*, 1990).
- 5.51** Effects on receptor proteins and their associated ion channels have also been described. For instance, Philippova *et al* (1994) found that 900 MHz radiation, at SARs of 1 and 100 W/kg, specifically affects the binding of odorant molecules to receptor protein in the membranes of olfactory receptor neurons in the rat. They attributed this to shedding of this particular protein from the membrane, probably because of increased peroxidation of membrane lipids (see Phelan *et al*, 1992). Liburdy and Vanek (1987) have also reported protein shedding from membranes as a result of RF exposure. Radiation at very low power densities can affect the ion channels associated with transmitter receptors: D’Inzeo *et al* (1988) reported a decrease in the frequency of opening of sodium channels associated with acetylcholine receptors in muscle membranes as a result of exposure to 9.75 GHz radiation at only 10–20 $\mu\text{W}/\text{m}^2$, which might cause a decrease in the excitability of the muscle.
- 5.52** *CONCLUSION* There is evidence that RF fields can affect membrane proteins and can change the movement of ions across membranes. Some of these effects seem to occur in cells only at temperatures well below normal body temperature or with RF intensities that cause significant heating. However, some evidence suggests that RF radiation at levels produced by mobile phones might influence ion channels and other membrane proteins of neurons in the brain under normal conditions. This might cause subtle changes in cell function, but the significance of such effects

Scientific Evidence

for human health is uncertain. Moreover, these effects have not been independently confirmed, which is important given the frequent lack of reproducibility of RF biological effects.

Calcium efflux

- 5.53** In view of the vital role of calcium in the function of neurons and other cells, considerable work has been done on the effects of RF fields on calcium movement in brain tissue (see Adey, 1981; UNEP/IRPA/WHO, 1993; Repacholi, 1998; Jokela *et al*, 1999; Royal Society of Canada, 1999; Table 5.1).
- 5.54** At high intensities, 2.8 GHz radiation pulsed at 350 pulses per second (pps) – with peak SARs of several tens of thousands of watts per kilogram – can cause an increase in the incorporation of radiolabelled phosphorus into important phosphoinositide signalling molecules (Gandhi and Ross, 1989). Phosphoinositides mediate the release of calcium from internal stores, which could alter calcium-dependent processes inside the cell. In turn, this could lead to a rise in extracellular calcium because of movement through the cell membrane, which could electrically stabilise the membrane by charge-screening the surface. This would be expected to reduce the excitability of neurons.
- 5.55** Several studies, starting with the work of Bawin *et al* (1975), have involved measurement of the efflux of calcium out of large explants of brain tissue, prelabelled by incubation in medium containing radioactive calcium. Bawin *et al* (1975) reported that exposure to 147 MHz fields at intensities too low to cause heating increased the efflux of calcium from chick brain, but only if the field was amplitude modulated at 16 Hz. The RF carrier frequency alone had no obvious effect. This observation was confirmed by Blackman *et al* (1979, 1980a,b), who used a number of different frequencies of amplitude modulation (3–30 Hz) and found that the effect was maximal at 16 Hz. This led to the view that modulation at or near 16 Hz might be critically important and a number of other studies using this frequency of amplitude modulation have also reported increases in the diffusion of calcium out of isolated fragments of nerve cells and cultured human neuroblastoma cells (see Table 5.1). Such calcium efflux may partly reflect movement of calcium out of neurons. Indeed, Kittel *et al* (1996), using electron microscopy to identify labelled calcium in a particular part of the brain (the medial habenular nucleus), found that exposure of mice *in vivo* to 2.45 GHz RF fields, amplitude modulated at 16 Hz, caused a reduction in the number of calcium-containing vesicles inside nerve cells and an increase in the amount of calcium precipitated on the surface of the cells. However, calcium efflux from brain explants almost certainly involves a number of other factors, including the release of calcium bound or adherent to membranes and simply trapped in the interstices of the tissue. It is also likely to be influenced by temperature.
- 5.56** Adey (1989, 1993) has suggested that changes in calcium efflux may be due to an amplification process in which weak electric fields might be set up in the tissue at the extremely low frequency of amplitude modulation, and that these might act as a “trigger” for the initiation of long-range co-operative events within the cell membrane. However, there is no obvious theoretical basis for such effects which would seem to require the presence of a non-linear mechanism operating on the timescale of the carrier frequency. This is not the case for ion-gating mechanisms.
- 5.57** A number of subsequent studies in other laboratories have failed to detect an increase in calcium efflux from brain explants *in vitro* (see UNEP/WHO/IRPA, 1993), but they generally used different conditions of stimulation (see Table 5.1).
- 5.58** There have been only two attempts to determine if such efflux of calcium occurs *in vivo*. Adey *et al* (1982) exposed cats to 16 Hz amplitude-modulated 450 MHz fields (SAR of 0.29 W/kg) and

Table 5.1 Effects in calcium efflux on nervous tissue

Model	Exposure conditions	Result	Reference
Chick brain, <i>in vitro</i>	147 MHz CW; 0.5–35 Hz AM; 10–20 W/m ²	Increase in efflux, maximum effect at 16 Hz AM. No effect of carrier frequency alone	Bawin <i>et al</i> , 1975
Chick brain, <i>in vitro</i>	147 MHz or 50 MHz ; 3–30 Hz AM	Increase in efflux at 16 Hz AM, dependent on intensity	Blackman <i>et al</i> , 1979,1980a,b
Chick brain, <i>in vitro</i>	450 MHz; 16 Hz AM	Increase in efflux dependent on intensity	Sheppard <i>et al</i> , 1979
Human neuroblastoma cells	147 or 915 MHz CW; 16 Hz AM	Increase in efflux dependent on intensity and modulation	Dutta <i>et al</i> , 1984, 1989
Synaptosomes (isolated fragments of nerve cells)	450 MHz; 16 Hz AM	Increase in efflux	Lin-Lui and Adey, 1982
Mouse brain: medial habenula nucleus, <i>in vivo</i>	2.45 GHz; 16 Hz AM	Number of calcium-containing vesicles reduced, level of calcium precipitation on surface of neurons increased	Kittel <i>et al</i> , 1996
Cat cortex, <i>in vivo</i>	450 MHz; 16 Hz AM	Sustained increase in efflux	Adey <i>et al</i> , 1982
Rat brain, <i>in vitro</i>	1 GHz pulsed; 10 or 20 ms pulses; 16 or 32 pps for 20 min; 5–150 W/m ²	No effect on efflux	Shelton and Merritt, 1981
Rat brain, loaded with radiolabelled calcium <i>in vivo</i> , exposed <i>in vitro</i>	1 GHz or 2.45 GHz pulsed; 10 ms pulses at 16 pps for 20 min; 0.29–2.9 W/kg	No effect on efflux	Merritt <i>et al</i> , 1982
Rat brain, loaded with radiolabelled calcium <i>in vivo</i> , exposed <i>in vitro</i>	2.06 GHz pulsed; 10 ms pulses at 8, 16 or 32 pps, OR 2.06 GHz CW; SAR 0.12–2.4 W/kg; 20 min	No effect on efflux	Merritt <i>et al</i> , 1982
Chick cerebral hemispheres, <i>in vitro</i>	147 MHz; 16 Hz AM; 7.5 W/m ²	No effect on efflux	Albert <i>et al</i> , 1987

AM = amplitude modulated CW = continuous wave

reported changes in calcium ion-exchange in the cerebral cortex. However, Merritt *et al* (1982) did not find such an effect in the brain of anaesthetised rats.

5.59 *CONCLUSION* Although the weight of evidence suggests that RF exposure at average levels, too low to cause significant heating, does increase the release of calcium from brain tissue, there are contradictory results. The suggestion that these effects occur specifically with fields that are amplitude modulated at extremely low frequencies is intriguing but difficult to interpret. Further, this finding is of no obvious relevance to mobile phone technology, where the amplitude modulation within the critical frequency band is very small (see paragraph 4.13). If such effects occur as a result of exposure to mobile phones, their implications for cell function are unclear and no obvious health risk has been suggested. Nevertheless, as a precautionary measure, amplitude modulation around 16 Hz should be avoided, if possible, in future developments in signal coding.

Neuronal excitability

5.60 Any tendency for calcium to move out of neurons and to accumulate on the surface of membranes would be expected to stabilise them electrically and hence to decrease the general excitability of neurons. Such effects have been described by Arber and Lin (1984, 1985), who reported an increase in membrane conductance and a decrease in the spontaneous firing of

Scientific Evidence

impulses in neurons of the snail *Helix aspersa* when exposed for an hour to continuous and amplitude modulated 2.45 GHz radiation. The effects were abolished by the application of ethylenediamine tetraacetic acid (EDTA), which chelates calcium. However, they occurred at a high RF intensity and clearly depended on a rise in tissue temperature. McRee and Wachtel (1980) described a decrease in the electrical amplitude of impulses and a reduction in the excitability of the frog sciatic nerve when exposed to 2.45 GHz radiation, but only at high levels. Wachtel *et al* (1975) and Seaman and Wachtel (1978) also described a decrease in spontaneous activity of neurons isolated from the marine gastropod *Aplysia* at relatively high intensities.

5.61 On the other hand, Chou and Guy (1978) found no obvious electrophysiological changes in the frog sciatic nerve exposed to 2.45 GHz (continuous or pulsed) at modest intensities. A slight increase in conduction velocity was found at a very high level and was probably dependent on the temperature rise, since it could be mimicked by a 1°C rise in temperature. Wang *et al* (1991), found no change in the membrane resting potential, electric capacitance, or the properties of impulses in dorsal root ganglion cells exposed *in vitro* to continuous-wave 2.45 GHz radiation under temperature-controlled conditions; recordings were made using sensitive patch-clamp techniques. Linz *et al* (1999), who also employed whole-cell patch-clamping, found no effect of low intensity continuous or pulsed RF fields on the membrane potential, action potentials or calcium and potassium currents of isolated heart muscle cells.

5.62 *CONCLUSION* There is good evidence that exposure to high intensity RF fields, sufficient to cause a significant rise in tissue temperature, reduces the excitability of neurons. Exposure that does not cause an increase in temperature produces no obvious effects.

Neurotransmitter systems

5.63 Changes in the amount of neurotransmitter substance released by nerve terminals could alter brain function. Since release is dependent on intracellular calcium levels, there has been concern that it could be affected by RF radiation.

5.64 Modak *et al* (1981) reported that RF exposure caused a decrease in the concentration of the important transmitter acetylcholine in the mouse brain, but they employed a very intense 2.45 GHz single pulse, causing a 2–4°C rise in temperature. The rate-limiting step in the synthesis of acetylcholine is the uptake of choline by nerve cells. In an extensive series of experiments, Lai and colleagues (Lai *et al*, 1987, 1989a,b, 1990, 1991, 1994) have reported that 20 minutes of exposure of rats to pulsed 2.45 GHz radiation at low intensities causes an increase in choline uptake and a reduction in the concentration of acetylcholine receptors, whereas exposure for 45 minutes has the opposite effects (Table 5.2). These effects were found to be prevented by pretreatment of the animals with naltrexone (which blocks opioid receptors) or with corticotrophin-releasing hormone. Although the average intensities used in these studies were relatively low, the findings might depend on thermal effects, especially since acetylcholine is known to be involved in transmission in the parts of the hypothalamus responsible for temperature regulation, which is acutely sensitive to temperature change. Moreover, as discussed below, the studies by Lai *et al* used radar-like pulses of quite high peak intensity that are capable of eliciting auditory responses in animals, which themselves might have behavioural effects.

5.65 Dutta *et al* (1992) detected an increase in the activity of the enzyme acetylcholinesterase (which hydrolyses acetylcholine) in cultured human neuroblastoma cells exposed to low intensity RF fields, amplitude modulated at 16 Hz. Curiously, these effects were reported to occur over an SAR “window” – ie within a narrow range of SAR values, but not at lower or higher intensities. On the other hand, Galvin *et al* (1981) and Millar *et al* (1984), who examined the effects of continuous and pulsed 2.45 GHz RF fields on purified solutions of acetylcholinesterase, detected

Table 5.2 Effects on cholinergic systems

Model	Exposure conditions	Results	References
Rat brain	2.45 GHz pulsed; 2 μ s pulses at 500 pps; 0.6 W/kg	Exposure for 45 min decreased choline uptake and concentration of acetylcholine receptors. Exposure for 20 min opposite effect seen. Effects blocked with naltrexone	Lai <i>et al</i> , 1987, 1989a,b, 1990, 1991, 1994
Human neuroblastoma cells	147 MHz; 16 Hz AM	Increase in acetylcholinesterase activity at 0.02 and 0.05 W/kg. No effect at 0.005 or 0.1 W/kg	Dutta <i>et al</i> , 1992
Solution of acetylcholinesterase	2.45 GHz CW or pulsed; 16.7 ms pulses, 10–90 pps; up to 100 W/kg	No effects	Galvin <i>et al</i> , 1981; Millar <i>et al</i> , 1984
Guinea pig	3 GHz CW or pulsed; 400 pps (no pulse width specified); 35–250 W/m ²	Decrease in acetylcholinesterase activity	Baranski <i>et al</i> , 1972

AM = amplitude modulated CW = continuous wave

no influence on the activity of the enzyme, even with SARs up to 100 W/kg. The use by Dutta *et al* of 16 Hz amplitude modulation, the frequency of modulation reported to produce calcium efflux (see paragraphs 5.53–5.59) might have been critical, although it is not clear how such modulation can have a specific effect on tissues. Without a theoretical basis, the non-linear dependence of effects on intensity (the SAR window phenomenon) is very surprising: the possibility that such window effects are merely due to chance variation, or some undefined experimental artefact should be kept in mind.

- 5.66** In contrast to the above, Baranski *et al* (1972) reported a decrease in the activity of acetylcholinesterase in guinea pigs exposed to pulsed RF fields at high power densities, but they attributed this to thermal effects.
- 5.67** Attention has also focussed on the amine transmitters norepinephrine (noradrenaline) and serotonin (5-hydroxytryptamine), which may determine arousal and mood, but, more pertinently, are involved in the hypothalamic mechanisms that regulate body temperature (Brück and Hinckel, 1990). Amine transmitters are released in many parts of the brain by the terminals of axons from cell groups in the brain stem. The various changes in levels of these transmitters and their metabolites after acute and long-term exposure to RF (see, for example, Snyder, 1971; Grin, 1974; Merritt *et al*, 1977; Inaba *et al*, 1992) may well be due to short-term and adaptive responses to thermal effects, since most of the experiments involved quite intense stimulation (see Hermann and Hossmann, 1997).
- 5.68** *CONCLUSION* Most of the work on neurotransmitter systems has used high power densities and has probably revealed thermoregulatory or other responses to temperature change. However, in view of the essential role of neurotransmitters in brain function and the involvement of specific transmitter systems in the regulation of emotion, memory, sleep, etc, this area deserves further investigation, including the assessment of these functions in human subjects.

Electroencephalograms (EEGs) in animals

- 5.69** Electrophysiological experiments in animals have mainly involved the recording of “gross” potentials from the brain with electrodes placed on or within the brain. Since the work of Adey and his colleagues in the early 1970s, there has been interest in the possibility that exposure to low levels of pulsed RF alters the electrical activity of the brain in cats and rabbits (Table 5.3).

Table 5.3 Effects on EEG rhythms in animals

Model	Exposure conditions	Results	References
Cats	147 MHz; 1–25 Hz AM; up to 10 W/m ² . SAR estimated as 0.015 W/kg (WHO, 1993)	Changes in EEG conditioned rhythms	Bawin <i>et al</i> , 1973, 1974
Rats and rabbits	2.375 GHz; 7 h/day for 30 days; 0.1–5 mW/m ²	Changes in EEG	Shandala <i>et al</i> , 1979
Rats	425 MHz; 100 W/m ² AND 2.45 GHz; 50 W/m ² ; from late gestation until 92 days old	No effects on spontaneous or evoked EEG	McRee <i>et al</i> , 1979
Rats	2.45 GHz CW; 2.7 W/kg; 7 h	No consistent changes in spectral power	Mitchell <i>et al</i> , 1989
Rats	2.45 GHz CW or AM at 16 Hz	Changes in spectral power with SARs in brain of 8.4 W/kg and above	Thuroczy <i>et al</i> , 1994

AM = amplitude modulated CW = continuous wave

- 5.70** Bawin *et al* (1973, 1974) exposed cats, which had been previously conditioned to produce selected EEG rhythms in response to a light flash, to low level RF fields. Changes were reported in the performance of the conditioned EEG response task and in various other behavioural parameters. It was argued that the fields acted directly on brain tissue causing a minute release of calcium (see paragraphs 5.53–5.59), resulting in changes in membrane excitability (see paragraphs 5.60–5.62), which could possibly affect EEG rhythms.
- 5.71** Takashima *et al* (1979) reported changes in the EEG of rabbits following exposure to a modulated RF field of 1–10 MHz, a frequency range outside the main interest of the present document. Following long-term exposure, changes in the frequency spectrum of the EEG were reported, with enhanced low frequency components and reduced higher frequency activity, similar to the changes that occur during drowsiness. Single, short-term exposures to modulated 1–30 MHz fields were without effect. The SAR could be estimated to be about 1 mW/kg and no rise in body temperature was detected during exposure. This study, however, employed few animals and there might have been artefacts due to the presence of implanted metal electrodes in the head during irradiation.
- 5.72** There have also been reports of subtle effects on the EEG in rats and rabbits exposed to RF fields within the frequency range of interest (Shandala *et al*, 1979; Thuroczy *et al*, 1994). However, the most consistent effects have been found at high intensities. Neither of these studies relates directly to mobile phone exposures, and neither the stimulation conditions needed or the nature of changes in the EEG are firmly established. McRee *et al* (1979) described experiments by Rosensteig of the US Environmental Protection Agency, who exposed rats to RF from late fetal life until adult. He saw no changes in either the spontaneous EEG or the electrical responses evoked by flashes of light (visual evoked responses). Mitchell *et al* (1989) reported the findings of a joint project on this subject carried out in the USA and the former Soviet Union. Both groups exposed rats to fairly intense continuous-wave RF fields for seven hours. Interestingly, both teams found small but statistically significant reductions of power in the EEG, but in different parts of the frequency spectrum.
- 5.73** *CONCLUSION Studies of the EEG in animals have generally not employed conditions that are directly relevant to mobile phone technology, and the results have been mixed. However, some experiments have produced evidence of non-thermal effects from RF fields on brain activity.*

Experiments on human volunteers, with exposure conditions similar to those experienced in using a mobile phone, have been more informative (see paragraphs 5.188–5.193).

Thermoregulatory behaviour

5.74 Mammals employ various physiological and behavioural mechanisms to regulate and stabilise their body temperature and thermoregulatory behaviour can be exhibited when RF exposure is sufficiently intense to generate heat. These studies have been well described by UNEP/WHO/IRPA (1993), who concluded that thermoregulatory responses from RF exposure were similar to those elicited by conventional radiant heat sources. However, the overall response depends on the distribution of RF absorption and thus on the RF frequency. At frequencies below 10 GHz, RF fields are more deeply penetrating than infrared radiation and thus less effective in stimulating superficial temperature-sensitive receptors in the skin, which are particularly involved in local and whole-body thermoregulatory responses (Adair, 1983; Adair *et al*, 1999). Thermoregulatory responses depend largely (but not exclusively) on the total heat load to the animal. Such responses can be elicited by whole-body SARs that are comparable to the basal metabolic rate (which in people is about 1 W/kg). It is therefore important to distinguish between whole-body and partial-body exposures. The latter can be of the order of 1 W/kg for mobile phones, even though the total heat added to the body is negligible.

Motor activity

5.75 Measurement of locomotion is often used to assess gross levels of brain activity and arousal. Some animals decrease their motor activity in order to lower their endogenous heat production, as part of their thermoregulatory behaviour. Acute and long-term RF exposures have been reported to reduce spontaneous motor activity in rodents. Typical studies are described by UNEP/WHO/IRPA (1993) and summarised in Table 5.4. A lifetime study reported that activity

Table 5.4 Effects on motor activity

Method	Exposure conditions	Results	References
Rats	2.45 GHz pulsed; 2.5 μ s pulses at 120 pps; 6.3 W/kg; 30 min	Immediate decrease; no effect after 2 h	Hunt <i>et al</i> , 1975
Rats	2.45 GHz CW; 2.7 W/kg; 7 h	Decrease; plus less responsive to novel acoustic stimuli	Mitchell <i>et al</i> , 1988
Rats	918 MHz CW; 3.6–4.2 W/kg; 10 h/night for 3 weeks	Decrease in activity and changed time-distribution of activity	Moe <i>et al</i> , 1976
Rats	2.45 GHz CW; 0.14 W/kg and 0.7 W/kg; 7 h/day for 14 weeks	No effects at 0.14 W/kg. Decreased activity 30 days after exposure at 0.7 W/kg	D'Andrea <i>et al</i> , 1986a,b
Rats	2.45 GHz CW; 1.2 W/kg and 915 MHz CW; 2.5 W/kg; 8 h/day; 5 days/week for 16 weeks	Decrease using 2.45 GHz, but no change overnight. No effect at 915 MHz	D'Andrea <i>et al</i> , 1979, 1980
Rats	3 or 10.7 GHz CW; 185 h or 3 GHz pulsed; 1.3 μ s pulses at 769 pps; 0.15–0.3 W/kg; 408 h	No effect. Other stereotypic activities also not affected	Roberti <i>et al</i> , 1975
Rats	2.45 GHz pulsed; 10 μ s pulses at 800 pps; pulse-modulated at 8 Hz; 0.15–0.4 W/kg; 2–27 months	No effect except for a decrease in activity during first test session. Lifetime exposure of rats	Johnson <i>et al</i> , 1983 Guy <i>et al</i> , 1985

CW = continuous wave

Scientific Evidence

levels were reduced after 6 weeks continuous exposure of young rats to 2.45 GHz pulsed RF fields at up to 0.4 W/kg. However, activity returned to control levels during subsequent exposure for up to 27 months.

Auditory responses

- 5.76** Animals may perceive auditory sensations when their heads are exposed to radar-like pulsed RF fields. Auditory perception of pulsed RF fields, the so-called “microwave hearing” effect, is an established phenomenon, which is produced by thermally generated sounds, due to minute thermoelastic expansion effects within the soft tissues of the head, which are conveyed to the inner ear by conduction through bone (UNEP/WHO/IRPA, 1993). The transient temperature increase and the duration of the increase (determined by the RF pulse width except for very short widths) determine whether the RF-induced acoustic vibrations can be perceived. There are good theoretical reasons to believe that microwave hearing does not occur with mobile phone signals. The acoustic sound pressure generated by a RF pulse is proportional to the rate of temperature increase. To produce audible acoustic vibrations requires a very high transient rate of heating of tissues in the head, around 1°C per second, which is considerably higher than is produced by current pulsed mobile phone signals. Thus the effect has little relevance to health effects of mobile phone signals, but must be kept in mind when interpreting animal studies that employed radar-like pulses.
- 5.77** Responses to pulsed RF fields can be detected by recording from the auditory nerve or other parts of the auditory pathway in the brain (Taylor and Ashleman, 1974; Chou and Guy, 1979; Chou *et al.*, 1982; Seaman and Lebowitz, 1989). These responses are in all respects identical to ordinary hearing phenomena and there is little doubt that they are perceived as sound by the animal. Chou *et al.* (1985) estimated the threshold in the rat at about 1 mJ/kg for pulses briefer than 35 µs (1 mJ/kg in a pulse lasting 35 µs is equivalent to a peak SAR of 30 W/kg). It is well established that these auditory sensations produce behavioural effects in awake animals. Animals might be slightly stressed if they can hear pulsed RF fields, and this should be taken into account when considering any behavioural effects of RF exposure.
- 5.78** Exposure to very intense pulsed RF fields is reported to suppress the startle response and evoke body movements in conscious mice (NRPB, 1993; Sienkiewicz *et al.*, 1993; UNEP/WHO/IRPA, 1993). The startle response was suppressed by 1 µs pulses with SAs of 200 mJ/kg (equivalent to a peak SAR of 200,000 W/kg), and body movement was elicited by 10 µs pulses with SAs of 2000 J/kg (peak SAR 20,000,000 W/kg) – far above the threshold for auditory perception. Although the mechanism for these effects is not well established, such intense pulses certainly elicit microwave hearing, and it is conceivable that some effects derive from the high electric fields associated with these intense pulses as well as from transient heating.
- 5.79** *CONCLUSION Auditory perception of intense pulsed RF fields may elicit behavioural responses. This phenomenon has not been explored using conditions that are directly relevant to mobile phone technology, but it is unlikely to occur at the peak intensities of pulsed fields associated with mobile phones.*

Learning and memory

- 5.80** To detect changes in learned behaviour, operant techniques are used that investigate behavioural responses, such as pressing a lever following a visual or auditory cue. Spatial memory can be tested in a radial-arm maze, in which a food pellet is placed at the end of each arm and the time is determined for the animal to collect all the food pellets. Animals must remember which arm they have entered so as to collect all the pellets in the shortest time. This technique provides a means of assessing the performance of specific learned tasks in a highly quantified and standardised

manner. However, threshold values for changes in behaviour will depend on many factors, such as the complexity of the task being performed. To quote a single threshold value for a range of tasks would be an oversimplification.

- 5.81** Results of earlier studies on rodents have shown that the threshold at which acute RF exposure disrupts learned operant behaviour lies between 2.5 and 8 W/kg whole-body SARs, with an associated rectal temperature rise of about 1°C. Deficits in the performance of a previously learned behaviour occur following long-term exposure to 2.45 GHz fields at SARs as low as 2.3 W/kg whole-body exposure. The initial acquisition of operant learned tasks by rats appears to be more sensitive to disruption by RF fields, the thresholds for long-term exposure to pulsed 2.8 GHz fields being between 0.7 and 1.7 W/kg whole-body exposure (UNEP/WHO/IRPA, 1993). The pulsed fields used in many of these studies involved brief, rather intense pulses such as those produced by radar equipment, which may have elicited auditory sensations in the animals, a potential confounding factor in the interpretation of the studies.
- 5.82** There is a distinct difference in response between rodents and primates. Changes in operant performance responses in primates occur at higher threshold RF exposures. Such changes were detected from acute exposure of rhesus and squirrel monkeys to 1.3–5.8 GHz fields at whole-body SARs of 4–5 W/kg. Exposure of rhesus monkeys to the RF field at which they absorb the maximum amount of energy (resonant frequency, 225 MHz) resulted in reduced task performance at a whole-body SAR of 2.5 W/kg. As with rodents, these changes in performance were accompanied by a raised body temperature of about 1°C (UNEP/WHO/IRPA, 1993). Since primates are much closer in size to people than are rodents, these data were used as the basis for standards limiting RF exposure.
- 5.83** Under some circumstances, ongoing learned behaviour can be stopped by exposure above a threshold corresponding to a whole-body SAR of about 4 W/kg. Many factors are known to modify this value, however, including the frequency of the applied field, the ambient temperature and relative humidity, and the animal size and species. Under the most adverse environmental conditions, changes in behaviour may be observed with whole-body SARs as low as 1 W/kg.
- 5.84** This interpretation is supported by the results of a study investigating working memory. Mickley *et al* (1994) found that acute exposure to 600 MHz fields at an SAR of up to 10 W/kg for 20 minutes produced significant deficits in memory in rats only when the exposure caused rises in rectal and brain temperatures of at least 1°C. These changes were correlated with an increase in expression of the *c-fos* gene in the cortex (see paragraph 5.119). The authors concluded that the observed changes in memory and behaviour were dependent on a rise in body temperature.
- 5.85** However, some studies conducted on rats exposed to pulsed RF fields appear to challenge the conclusion that learning is disturbed only when radiation produces significant increases in body temperature. In experiments by Lai *et al* (1989a) on spatial learning, rats had to learn to forage for food pellets located at the ends of the arms of a radial-arm maze, using cues in the environment. Animals exposed for 20 minutes to low level, pulsed 2.45 GHz fields (average whole-body SAR of 0.6 W/kg), immediately before daily training sessions in the maze, were reported to show improved learning for the first two days, although final performance and overall accuracy were not affected. The RF fields did not cause a measurable rise in colonic temperature. However, the performance of the exposed animals was generally less stable than that of the controls, which raises questions about the significance of this result.
- 5.86** Later, Lai *et al* (1994) reported that rats acutely exposed to pulsed 2.45 GHz fields (whole-body SAR 0.6 W/kg), for 45 minutes each day, immediately before testing in the maze, consistently made *more* errors than did the control animals. Further work suggested that this apparent effect

Scientific Evidence

on learning might be due to effects of RF exposure on nerve pathways in the brain that use endogenous opioid neurotransmitters.

- 5.87** In the same laboratory, Wang and Lai (2000) have also reported RF-induced changes in spatial memory as assessed in a circular water maze, in which rats had to learn to escape from the water by swimming to a submerged platform that they could not see. Male rats that had been acutely exposed for 60 minutes to pulsed 2.45 GHz fields (pulse width 2 μ s, 500 pps), at a fairly high whole-body SAR of 1.2 W/kg, took longer to find the platform than did control animals during the training sessions. In a “probe trial” without the platform present, the exposed animals spent less time swimming in the quadrant of the maze that should have contained the platform than did control animals. They also spent more time trying to climb up the sidewalls of the maze, as if they had no recollection of the task. It was concluded that exposure had disrupted spatial reference memory functions and that the exposed animals had to use other, less efficient learning strategies to locate the platform. However, the energy per pulse in this study can be calculated to be 2.4 mJ/kg (peak SAR of 2400 W/kg), which would have caused rapid, transient heating. This level of pulse energy almost certainly exceeds the threshold for microwave hearing in rats (Chou *et al*, 1985; see paragraph 5.76). Since the slight stress caused by explicit noise can modify behaviour, it is possible that the results reported in some of the studies by Lai *et al* were due to microwave hearing. It is also conceivable that the electric fields associated with such a high peak SAR might have caused non-thermal effects on nerve cells. If the findings are due to the high peak-pulse energy, they are not relevant to human exposure to mobile phone radiation, which has different modulation characteristics.
- 5.88** For both the Lai *et al* (1994) and Wang and Lai (2000) studies, there are also statistical problems that suggest internal inconsistencies in the results. These studies involved investigation of spatial memory in either a radial-arm or water maze using a time (ie training session) X group (exposed *versus* non-exposed) design. In both studies large time effects were observed, such that the animals became more adept at the task as the training progressed. However, in neither study was there a group X time interaction, indicating that the exposure was affecting the rate at which the task was learned.
- 5.89** Sienkiewicz *et al* (2000), using an experimental design very similar to that of Lai *et al* (1994), exposed mice to 900 MHz RF radiation pulsed at 217 Hz at a whole-body SAR of 0.05 W/kg. The behaviour of the animals was tested each day for 10 days in an eight-arm radial maze, either immediately after exposure for 45 minutes, or after delays of 15 and 30 minutes. There were no significant differences in either the original performance of the exposed animals, the rate at which their learning increased or the final levels of performance. However, the animals tested immediately after exposure took longer to complete the task and exhibited a more erratic performance than the other animals. It is possible that these changes may have been induced by a mild stress associated with auditory perception of the field. This experiment was not an exact duplication of the Lai *et al* (1994) study, since it used mice, rather than rats, an eight-arm instead of a twelve-arm maze, and a much lower SAR.
- 5.90** Overall, these and other studies (see D’Andrea, 1999) provide weak evidence for a specific effect of RF fields on spatial memory, and some artefact associated with exposure may have affected the performance of the rats in those experiments in which effects were found. In particular, it is possible that the animals may have perceived the pulsed RF fields and this may have contributed to the observed behavioural changes. A summary of the results of earlier studies is given by UNEP/WHO/IRPA (1993) and more information about recent work is given in Table 5.5.

Table 5.5 Studies on learning

Model	Exposure conditions	Results	References
Rats, 12-arm maze	2.45 GHz pulsed; 2 μ s pulses; 500 pps; 0.6 W/kg; 20 min/day for 10 days	Fewer errors for two days, no effect overall	Lai <i>et al</i> , 1989a
Rats, 12-arm maze	2.45 GHz pulsed; 2 μ s pulses; 500 pps; 0.6 W/kg; 45 min/day for 10 days	More errors each day	Lai <i>et al</i> , 1989a, 1994
Rats, Water maze	2.45 GHz pulsed; 2 μ s pulses; 500 pps; 1.2 W/kg; 60 min/session; 2 sessions/day for 3 days	Took longer to locate submerged platform	Wang and Lai, 2000
Mice, 8-arm maze	900 MHz pulsed; 576 μ s pulses; 217 pps; 0.05 W/kg; 45 min/day for 10 days	No effect	Sienkiewicz <i>et al</i> , 2000
Operant tasks: rats	2.8 GHz pulsed; 2 μ s pulses; 500 pps; for 30 min	Impaired acquisition threshold at 1.7 W/kg whole-body exposure	Schrot <i>et al</i> , 1980
Operant task: rats	360, 480, 500, 600 MHz CW; up to 25 min or 55 min	Threshold for reduced performance > 4–6 W/kg whole-body exposure	D'Andrea <i>et al</i> , 1976, 1977
Operant task: rats	2.45 GHz CW; 110 5 h sessions over 22 weeks	Impaired performance at 2.3 W/kg whole-body exposure	Mitchell <i>et al</i> , 1977
Operant task: rats	2.45 GHz CW; 60 min	Threshold for reduced performance > 2.5–8 W/kg whole-body exposure	Sanza and de Lorge (1977); de Lorge and Ezell (1980)
Operant task: rhesus monkey	1.2 GHz CW; SAR 0.8 or 1.6 W/kg; 120 min	No effect	Scholl and Allen, 1979
Operant task: rhesus monkey	225 MHz CW OR 1.3 GHz pulsed; 3 μ s pulses; 370 pps OR 5.8 GHz pulsed; 0.5 or 2 μ s pulses; 662 pps	Threshold for impaired performance 2.5 W/kg (at 225 MHz) or 4–5 W/kg (at 1.3 and 5.8 GHz) whole-body exposure	De Lorge, 1984
Working memory task: rats	600 MHz (CW); SAR 0.1–10 W/kg; 20 min	Impaired performance at 1 °C rise in body and brain temperature (>9 W/kg) whole-body exposure	Mickley <i>et al</i> , 1994

CW = continuous wave

5.91 The hippocampus (a forebrain structure, buried on the inside of the temporal lobe) has been implicated in spatial learning in many animals, and in the laying-down of “episodic”, personal memories in people. Damage to the hippocampus interferes with these forms of learning and certain synaptic connections between neurons in the hippocampus are capable of rapid and long-lasting changes in transmission efficiency, which might constitute the cellular basis of the memory trace. The hippocampal slice preparation, in which the activity of neurons and the efficiency of synaptic transmission can be directly measured, *in vitro*, is widely used to investigate these cellular mechanisms (Kandel *et al*, 1991). Wood *et al* (2000) have recently used this technique to examine the effects of RF fields on electrical activity in the hippocampus. Short-term exposure to very low intensity 700 MHz radiation in the absence of any detectable increase in temperature resulted in transient changes in evoked and spontaneous activity. Curiously, the changes were very variable, but exposure at about 0.001 W/kg generally led to a decrease in activity. It is difficult to interpret these results, especially the variability of the effects,

Scientific Evidence

but if they were to occur *in vivo*, they might influence learning and memory. It must be emphasised, however, that the human hippocampus lies deep in the human brain, where very little energy is absorbed from a mobile phone.

- 5.92** *CONCLUSION* Increases in core temperature of 1°C or more certainly lead to changes in the performance of well-learned tasks and other simple behaviours. However, there is no consistent experimental evidence that exposure to low level RF fields affects learning and memory in animals. The studies of Lai and co-workers challenge these conclusions and suggest that spatial learning can be disturbed at average SARs below 1 W/kg. However the peak-pulse energy was much higher than that associated with mobile phones, the effects reported were statistically weak and they have not been reproduced by Sienkiewicz *et al* (2000) using 900 MHz fields. D'Andrea (1999) has speculated that some cognitive tasks may show particular sensitivity to RF exposure, and effects on these behaviours may occur at SARs below those required to disrupt simple, well-learned tasks. Few studies have yet explored this possibility. The hippocampal slice preparation shows great potential for the study of RF field effects: more research is indicated. However, studies on human subjects are needed to assess whether fields associated with mobile phones have any effect on memory or learning.

Blood–brain barrier

- 5.93** Early work suggested that the blood–brain barrier, which normally prevents large molecules from crossing into the cerebrospinal fluid from the blood, might be susceptible to low level pulsed RF fields. Effects on permeability of the barrier have been investigated by comparing the penetration into the brain in exposed and control animals after intravenous injection of various compounds. Interest began when Frey *et al* (1975) reported increased penetration of the blood–brain barrier of anaesthetised rats after acute low level exposure to pulsed or continuous-wave 1.2 GHz fields. Oscar and Hawkins (1977) then reported that the acute exposure of anaesthetised rats to pulsed 1.3 GHz fields at similar SARs increased the uptake of radiolabelled saccharides. However, later, more rigorous studies indicated that the early studies might have been confounded by various factors including alteration in cerebral blood flow, the effect of the anaesthetic, and changes in renal clearance (Blackwell and Saunders, 1986; UNEP/WHO/IRPA, 1993).
- 5.94** Two studies (Neubauer *et al*, 1990; Salford *et al*, 1994) have reported increased blood–brain barrier permeability to protein (albumin) following RF exposure at SARs as low as 0.016 W/kg. Later studies (Fritze *et al*, 1997a; Nagawa and Uneo, 1999) have, however, failed to confirm these results.
- 5.95** *CONCLUSION* The available evidence for an effect of RF exposure on the blood–brain barrier is inconsistent and contradictory. Recent, well-conducted studies have not reported any effects.

Studies of melatonin

- 5.96** Melatonin is a hormone secreted by the pineal gland, which controls our diurnal rhythm (day–night cycle). Peak levels are produced in people during the night (in the dark period). Melatonin affects the mammalian reproductive system, as well as other physiological and biochemical functions (Reiter, 1991). The function of the pineal gland is strongly influenced by visible radiation, because signals from the optic nerve affect the suprachiasmatic nucleus in the hypothalamus, which in turn regulates the secretion of melatonin from the pineal gland. The cyclical pattern of light and dark imposes seasonal as well as circadian rhythms in some mammals (Reiter, 1993). Melatonin is an efficient scavenger of free radicals, which can damage cells, and there is evidence that melatonin has a protective effect against cancer. Thus, changes in melatonin secretion could conceivably alter tumour initiation and promotion (NRC, 1997; NIEHS, 1998).

- 5.97** There are reports that extremely low frequency (ELF) electromagnetic fields may affect pineal function, although the data are inconsistent. This has led to the “melatonin hypothesis”, suggesting a link between ELF fields and cancer (Stevens, 1987). This raises the question whether exposure to RF fields might also have an effect on the pineal gland. Radiofrequency photon energies are much higher than those at ELFs, lying between the ELF and visible parts of the electromagnetic spectrum. In contrast to visible radiation, neither ELF fields nor RF fields directly affect photopigments in photoreceptors in the eye, and they are therefore very unlikely to affect pineal function by the same anatomical pathway as does visible radiation. It is conceivable that RF fields might influence the synthesis or secretion of melatonin by the pineal gland through a direct influence on either the suprachiasmatic nucleus or the pineal gland itself, although there is no obvious theoretical reason to expect such influences.
- 5.98** Only a few studies testing effects of RF exposure on melatonin synthesis have been conducted. Stark *et al* (1997) studied dairy cattle herds located in the vicinity of a short-wave (3–30 MHz) radio antenna. Their data showed no chronic effect on salivary melatonin levels, although a short-term rise in melatonin was noted when the antenna was energised after being turned off for three days. In a laboratory study specifically designed to study pineal function of rats and hamsters exposed to very low level 900 MHz fields for up to six hours, no effects on nocturnal melatonin production were found (Vollrath *et al*, 1997).
- 5.99** *CONCLUSION Although few studies have been conducted, they do not suggest that exposure to RF fields affects pineal function or melatonin production. Relevance to the use of mobile phones could, in any case, be assessed only through laboratory studies of people because of species differences in the pattern of circadian rhythms. It must also be emphasised that the hypothalamus and pineal gland are much further from the surface of the head in people than in animals. Therefore, even if there were an effect on melatonin production in animals resulting from a direct interaction of fields within the brain, it would be much less likely to occur in people.*

Effects on the eye

- 5.100** The lens of the eye is potentially sensitive to RF exposure because it lacks a blood supply and therefore has reduced ability to dissipate heat. Further, the fibres that make up the bulk of the lens have only a limited capacity for repair and hence the effects of minor insults tend to accumulate, resulting in clouding of the lens (cataract).
- 5.101** Many studies conducted to determine the threshold for RF-induced cataracts have concluded that very high exposures are needed for at least 1 hour to produce lens cataracts (UNEP/WHO/IRPA, 1993). The single acute exposure threshold to produce a cataract at 2.45 GHz corresponds to an SAR in excess of 100 W/kg for more than 1 hour, with the temperatures in the eye exceeding 43 °C. Repeated subthreshold exposures at levels just below this threshold would finally produce a cataract, provided that the accumulated damage could not be repaired before the next exposure (Carpenter, 1979). Near-continuous, long-term RF exposures at moderate intensity (100 W/m²; peak SAR in the head 17 W/kg) did not produce cataracts in rabbit eyes (Guy *et al*, 1980).
- 5.102** Degenerative changes have been reported in various eye tissues of primates after exposure to pulsed RF fields (Table 5.6). Studies in this area have been summarised by Kues and Monahan (1992a) and Lu *et al* (2000). Localised exposure of the eyes of anaesthetised monkeys to pulsed 2.45 GHz fields at an SAR in the eye of 2.6 W/kg for several hours resulted in lesions in the corneal endothelium (Kues *et al*, 1985) and increased the vascular leakage from the blood vessels of the iris. Lesions in the cornea were also induced by exposure to 2.45 GHz fields, with pulsed fields being more effective than continuous-wave radiation. Topical pretreatment with the ophthalmic drug timolol maleate (used for treatment of glaucoma) appeared to reduce the

threshold for these effects to 0.26 W/kg (Kues *et al*, 1992). Intermittent exposure over a 10-week period resulted in early degenerative changes in the retina, which were also exacerbated by application of timolol maleate. In contrast, Kamimura *et al* (1994) reported that they were unable to induce corneal, lenticular or retinal lesions in the eyes of non-anaesthetised macaque monkeys exposed to continuous-wave (but not pulsed) 2.45 GHz radiation at levels exceeding the threshold for continuous-wave-induced corneal damage described by Kues *et al* (1985).

Table 5.6 Effects of RF fields on the eye

Model	Exposure conditions	Results	References
Rabbits	2.45 GHz; 100 W/m ² ; 17 W/kg; 23 h/day for 180 days	No cataracts produced	Carpenter, 1979
Anaesthetised monkeys	2.45 GHz pulsed; 10 µs pulses at 100 pps; 26 mJ/kg per pulse; average SAR 1.3–3.9 W/kg; 3 exposures of 4 h	Lesions in corneal endothelium, increased vascular leakage in iris	Kues <i>et al</i> 1985, 1992; Kues and Monahan, 1992a
Rabbits and macaque monkeys	60 GHz; 100 W/m ² ; 8 h, plus 4 h/day for 5 days	No effects on the eye	Kues <i>et al</i> , 1999
Non-anaesthetised monkeys	2.45 GHz CW	No effects	Kamimura <i>et al</i> , 1994
Monkeys	1.25 GHz pulsed; 5.59 µs pulses; 0.59, 1.18 and 2.79 pps; peak SAR 1.3 MW/kg; average SAR in retina 4.3, 8.4 or 20.2 W/kg; 4 h/day, 3 days/week for 3 weeks	No effects on retinal structure. Electric responses of retinal cells slightly increased at higher SARs	Lu <i>et al</i> , 2000
Non-anaesthetised monkeys	1.25 GHz pulsed; 0.5 µs pulses; 16 pps; 0.4 W/kg OR 2.7 GHz; 1 µs pulses; 20 pps; 2.6 W/kg	Transient changes in electrical activity induced by repeated exposure	Kues and Monahan, 1992b
Monkeys	5.6 GHz pulsed; 2.3 µs pulses at 100 pps; 1 W/kg	No effect on visual function	D'Andrea <i>et al</i> , 1992

CW = continuous wave

5.103 Transient changes in the electrical activity of the retina of the eyes of monkeys, in response to light stimulation, have been reported following repeated exposures to pulsed 1.25 or 2.7 GHz fields (Kues and Monahan, 1992b). Changes in electrical responses were attributed to field-induced degeneration of the photoreceptors, particularly of the cones. However, D'Andrea *et al* (1992) reported a lack of effect on visual function of monkeys exposed to pulsed 5.6 GHz RF radiation. This disparity seems puzzling in view of the fact that the average SAR was quite similar in the two studies. However, it is possible that the difference between these two studies is explained by differences in the peak SAR per pulse in the pulsed radiation. Taking into account pulse duration and frequency, peak SARs in the study of Kues and Monahan (1992b) can be calculated to be 50,000 and 130,000 W/kg, while that in the work by D'Andrea *et al* (1992) was 4,000 W/kg. This highlights the crucial importance of specifying the energy per pulse in research using pulsed radiation. Very recently, Lu *et al* (2000) have described a slight enhancement of electrical responses from the retina in monkeys exposed to 1.25 GHz RF fields pulsed at low rates with intense pulses (peak retinal SAR 1,300,000 W/kg), but without any obvious change in retinal structure.

- 5.104** *CONCLUSION* The intensities of pulsed RF fields employed in these studies were well above the SAR and specific absorption that could occur in the eye from the use of current mobile phones. However, the studies do raise important concerns about possible adverse health effects in the eye from high peak-power, pulsed RF fields.

Overall conclusions of effects on the nervous system

- 5.105** *The potential of RF fields to affect the nervous system has been addressed using a variety of model systems. The most consistent evidence indicates that changes in neuronal excitability, neurotransmitter function, and innate and learned behaviours will occur when exposure induces significant heating, such that core body or local tissue temperatures increase by about 1°C or more. The evidence for effects in the absence of heating is generally not consistent and convincing. However, some studies suggest that low level exposure at specific frequencies of amplitude modulation and energy levels may affect membrane proteins, the flux of calcium and other ions across the membranes of neurons, and EEG rhythms. The relevance of these results to mobile phone technology and to human health is unclear.*
- 5.106** *Despite much publicity, the evidence for an effect on spatial memory in rats in the absence of whole-body heating is weak. In addition, there are differences in the pattern of RF energy deposition between rodents and people. This makes direct extrapolation from these animal studies to changes in human cognitive performance uncertain. The tissue penetration of RF fields means that, while the intensity of exposure is fairly uniform within the small brain of a rodent, only regions close to the ear will be effectively exposed in the much larger human brain. Primate brains, however, not only have greater anatomical similarity to those of people, but also have similar proportions, resulting in a better model of the distribution of absorbed energy.*

Cancer-related studies: can RF exposure affect carcinogenic processes?

- 5.107** The DNA in our chromosomes, which controls the growth and function of our cells, is normally remarkably stable: indeed, there are a variety of mechanisms for protecting DNA and repairing damage. Certain substances and other agents (eg X-rays) that cause damage to DNA are called *genotoxic* or *mutagenic*. Genotoxic injury of a cell can reveal itself in various ways, particularly as abnormalities in the appearance of the chromosomes, shrinkage of the cell nucleus, and mutation.
- 5.108** Genotoxic injury occurs constantly in our bodies, partly because we are exposed to a variety of natural and artificial mutagens, and partly because it can occur spontaneously through random errors in the replication of DNA during cell division. Most damage is repaired. If it is substantial, the cell can die. However, certain sequences of modest genetic damage can result in mutations that push a cell in a number of steps towards the cancerous state (conventionally described as *initiation*, *promotion* and *progression*). The cells eventually proliferate through rapid cell division (Santini *et al*, 1988; Cohen and Ellwein, 1991; Wu *et al*, 1994).
- 5.109** It is now widely agreed that cancer is initiated by alterations in the genetic material (DNA) in the cell (genotoxic effects), although some non-genotoxic chemicals and processes (called epigenetic carcinogens) have been recognised. After initiation, the cell may progress to full malignancy without any further external stimulus but more often further events are required, which may be further genomic alterations or other cellular events such as a stimulus to divide or the absence of signals required for cell differentiation. An agent which will cause this further progression towards malignancy is often termed a promoting agent.
- 5.110** Studies of possible genotoxic effects of RF radiation, enhanced cell proliferation and inappropriate gene expression have been carried out at the cellular level. In addition, there have

Scientific Evidence

been a number of long-term studies of cancer induction in animals, including tests of epigenetic interaction with known carcinogens.

Ornithine decarboxylase: does RF exposure, *in vitro* or *in vivo*, affect catalytic action?

- 5.111** Protein kinases, such as ornithine decarboxylase (ODC), are key enzymes that are normally activated as a result of the action of hormones, growth factors and lymphokines on receptors in cell membranes. ODC is the rate-limiting enzyme in the synthesis of substances called polyamines, which can trigger DNA synthesis, cell growth and cell differentiation. Inhibition of ODC activity retards the growth of both normal cells and tumour cells (Marton and Pegg, 1995). ODC activity is modulated by membrane-mediated signalling events, and its activation is associated with the activity of mitogens (substances that cause mutation) and tumour-promoting agents of various types, such as the phorbol ester TPA, during carcinogenesis. Activation of ODC has been related to the late, “promotional” phase of cancer production, which is usually (but not always) correlated with proliferation (an increase in the rate of cell division) in the affected tissue. Most chemical tumour promoters increase the level of ODC in cells (through stimulating expression of the gene that produces ODC). They also increase the activity or enzymatic effectiveness of ODC, leading to an accumulation of polyamines. It is important to note that although all carcinogenic factors stimulate ODC, not all stimuli that increase ODC activity promote cancer.
- 5.112** A report of an Expert Panel of the Royal Society of Canada (1999) has recently reviewed investigations of the effects of electromagnetic radiation on the level and activity of ODC (see Table 5.7). Various cell lines were exposed to RF radiation, including mobile phone radiation, amplitude modulated at frequencies in the ELF range. In general, the studies reported modest increases in ODC activity only at modulation frequencies of about 10–60 Hz. DNA synthesis, which would indicate a proliferative response to raised ODC activity, was not subsequently increased.

Table 5.7 Ornithine decarboxylase (ODC) activity *in vitro*

Model	Exposure conditions	Results	References
Reuber H35 hepatoma; Chinese hamster ovary; 294T human melanoma cells	450 MHz; AM at 5, 10, 16, 20, 60 and 100 Hz; 10 W/m ² ; SAR estimated as 0.08 W/kg; 1 h	Increased ODC activity by up to 100% at 12–20 Hz modulation	Byus <i>et al</i> , 1988 Byus and Hawel, 1997
L929 mouse fibroblasts	915 MHz; AM at 50, 60 or 65 Hz; SAR estimated as 2.5 W/kg; up to 8 h	Increased ODC activity by up to 100%	Litovitz <i>et al</i> , 1993
L929 mouse fibroblasts	835 MHz; AM at 6, 16, 55, 60, 65, or 600 Hz; SAR of 2.5 W/kg	Increased ODC activity by up to 100% at 16–65 Hz modulation	Penafiel <i>et al</i> , 1997

AM = amplitude modulated

- 5.113** Many studies (Royal Society of Canada, 1999) have shown that conventional 50–60 Hz electromagnetic fields (without an RF carrier frequency) can produce a similar increase in ODC activity. Hence, the effect of amplitude-modulated RF fields might be due to the ELF currents within the tissue, although it is difficult to understand how such currents could be generated (see paragraph 5.16). However, the maximum increase in ODC activity produced by amplitude-modulated RF radiation (approximately a doubling) is much less than that elicited by known tumour-promoting substances, which can cause up to 500-fold changes in ODC activity in relevant tissues.

5.114 Although most cancer-producing conditions lead to large rises in the expression of ODC and proliferation of cells (which do not occur with even amplitude-modulated RF fields), promotional changes have been reported despite relatively small rises in ODC activity, and sometimes without cell proliferation (see, for example, Hibshoosh *et al*, 1991; Moshier *et al*, 1993, 1994; Kubota *et al*, 1997).

5.115 *CONCLUSION* Pulse-modulated RF fields from mobile phones may cause a slight increase in ODC levels and activity, at non-thermal levels. However, it is very unlikely that these small changes could, on their own, have a tumour-promoting effect. It is also unlikely that such effects act synergistically with other environmental hazards and contribute to tumour promotion.

Gene expression: does RF exposure initiate changes in the action of genes?

5.116 All the somatic cells (not the eggs or sperm) in the human body contain the same set of genes in their chromosomes. Each gene contains the information to make a particular protein (eg an enzyme or a structural protein). The differences in appearance and function of different types of cells (eg skin cells, liver cells and neurons) are caused by different sets of genes being active in each cell. The activation of genes is known as gene expression. The production of a protein involves two main steps: *transcription* (the synthesis of RNA, which contains the same information as that in the sequence of DNA in the gene) and *translation* (the building of the protein molecule from amino acids, under the control of the RNA). Changes in the characteristics of cells (differentiation), cell growth and programmed cell death can all occur as a result of the modulation of gene expression, which can be initiated by external events, acting through intracellular signalling pathways.

5.117 Certain genes are switched on specifically in response to stressful challenges to the cell. For instance, a set of genes producing *heat shock proteins*, which protect other proteins from damage, are activated by a sudden increase in temperature, and also by other forms of shock, such as toxic challenge. Further, as part of the response to stress, intense sensory stimulation, mitogenic chemicals, etc, other genes called *immediate early genes*, such as *c-fos* and *c-jun*, are turned on. Their proteins activate protective signalling pathways in the cell. The expression of these various genes is, then, a sensitive early marker of the cellular response to stress. The expression of genes called *proto-oncogenes* can be increased by tumour-promoting agents, ultraviolet radiation and X-rays. These genes, including *c-ras*, *c-myc* and *c-abl*, have normal cellular functions but can also contribute to the initiation of cancerous changes.

5.118 Recently, de Pomerai and colleagues have developed an invertebrate model to examine stress-induced gene expression. They used a transgenic soil nematode, *C elegans*, carrying a reporter gene under the control of the genetic mechanism for activation of heat shock genes. Hence the reporter (an enzyme or fluorescent protein that can easily be detected in the worm) is produced whenever the heat shock gene is turned on. Danniells *et al* (1998) and Power *et al* (1998) have shown that exposure of these worms to 750 MHz radiation (continuous or pulsed) for a few hours (0.5 W power), without detectable elevation of temperature, results in elevated expression of heat shock protein genes. Similar results were described after exposure for seven hours to the emission of a conventional digital mobile phone (de Pomerai *et al*, 1999).

5.119 By comparison, results of studies of gene expression in mammals have been variable and generally rather negative (Table 5.8). Studies of changes in the expression of the early response genes *c-fos* and *c-jun* (Mickley *et al*, 1994; Walters *et al*, 1995; Fritze *et al*, 1997b; Morrissey *et al*, 1999) in the brains of rats and mice exposed to RF radiation generally find no effects following exposure at thermally insignificant levels. In any case, *c-fos* expression is known to increase simply as a result of mild stress, such as that associated with immobilisation of an

Table 5.8 Recent studies on gene expression

Model	Exposure conditions	Results	References
<i>In vitro studies</i>			
PC12 rat pheochromocytoma cells	836.55 MHz; TDMA-modulated; 0.5–5 mW/kg; up to 60 min	Expression of <i>c-jun</i> elevated at highest exposure level only; no effect on <i>c-fos</i>	Ivaschuk <i>et al</i> , 1997
Mouse C3H 10 T ½ embryonic fibroblasts	835.62 MHz; FM and 847.74 MHz; CDMA-modulated; 0.6 W/kg; up to 4 days	Slight increase in <i>c-fos</i> expression; no effect on <i>c-jun</i> or <i>c-myc</i>	Goswami <i>et al</i> , 1999
<i>In vivo studies</i>			
Rat brain	600 MHz; whole-body SAR of 9.3 W/kg; 2 h	Increase in <i>c-fos</i> protein levels; brain surface temperature increased by 2 °C	Mickley <i>et al</i> , 1994
Rat brain	0.25–2.5 GHz; high peak power ultra-wide band radiation; 7–8 ns pulses; 60 pps for 2 min; peak <i>E</i> -field of 250 kV/m	No effect on <i>c-fos</i> protein levels; no heating effect	Walters <i>et al</i> , 1995
Mouse brain	1.6 GHz CW or pulsed with 9.2 ms pulses at 11 Hz	Increased <i>c-fos</i> expression in stress-responsive and thermoregulatory regions of brain at an SAR of 2.99 W/kg and above	Morrisey <i>et al</i> , 1999
Rat brain	900 MHz pulsed (GSM); brain SAR 0.3 or 1.5 W/kg OR 7.5 W/kg CW for 4 h	Increased <i>c-fos</i> only at highest SAR; no effect on <i>hsp70</i> or <i>c-jun</i>	Fritze <i>et al</i> , 1997b

CW = continuous wave FM = frequency modulated TDMA = time division multiple access CDMA = code division multiple access

animal (Cullinan *et al*, 1995), and this must be kept in mind when interpreting the results of experiments on awake animals. *In vitro* studies of mammalian cells have produced mixed results (Ivaschuk *et al*, 1997; Goswami *et al*, 1999).

5.120 *CONCLUSION* While there is currently little evidence that exposure to mobile phone radiation causes a stress response in mammalian cells, judged by elevated gene expression, the results on nematode worms are indicative of a non-thermal influence on gene expression. This model and similar model systems, using cultured mammalian cells carrying reporter transgenes linked to important genes, could be valuable in defining genetic responses to RF radiation.

Does RF radiation affect cell growth, survival or proliferation?

5.121 Changes in the kinetics of cell division and in the proliferation of cells play a crucial role in the generation of cancer. Any increase in cell proliferation resulting from RF radiation might indicate a carcinogenic influence. Several studies of the possible effects of exposure to RF radiation are described in Table 5.9.

5.122 Grundler *et al* (1992), pursuing Fröhlich's suggestion (see, for example, Fröhlich, 1986) that electromagnetic radiation in the microwave range could interact with some sort of resonant process in undefined molecules in living biosystems, studied the influence of very low power RF radiation at 41–42 GHz on the cell cycle and growth rate of yeast cells. Even at extremely low SARs, they found that such radiation could cause small, but reliable changes in growth rates (increases of less than 10% and decreases of almost 20%), with sharp resonant peaks, dependent on frequency. They interpreted these results in terms of some internal "oscillator" in the cells,

capable of coupling with these extremely weak fields to modulate growth rate. These results were not confirmed in several further studies (see paragraph 5.19).

Table 5.9 Recent studies of cell growth, survival and proliferation in the presence of RF fields

Cell line	Exposure conditions	Results	References
Yeast cells	41.650–41.798 GHz; 20 mW; forward power of 20 mW for 4 h	Absence of frequency- dependent effects on growth	Furia <i>et al</i> , 1986
Yeast cells	41–42 GHz	Small changes in growth rates, which were frequency dependent	Grundler <i>et al</i> , 1992
Yeast cells	41.682–41.710 GHz; 0.5 or 50 $\mu\text{W}/\text{m}^2$; up to 1 W/kg); 5.5 h	Absence of frequency- dependent effects on growth	Gos <i>et al</i> , 1997
LN71 glioma cells; human lymphocytes	27 MHz or 2.45 GHz; up to 75 W/kg; 2 h; isothermal conditions	Increased incorporation of radiolabelled nucleic acid at SARs of 50 W/kg or less	Cleary, 1995
C6 glioma and primary glial cells	836.55 MHz; TDMA- modulated; 0.6–60 mW/kg; 24 h	Increased uptake of radiolabelled nucleic acid precursors in glioma cells at 6 mW/kg	Stagg <i>et al</i> , 1997
Human epithelial amnion cells	960 MHz pulsed (GSM); 217 pps; 8.3 pps; 24 h	Decrease in cell growth	Kwee and Raskmark, 1998

TDMA = time division multiple access GSM = global system for mobile telecommunications

- 5.123** In general, other studies report modest increases in proliferation (see Cleary, 1990a,b; 1995), no effect except at only one low (5.9 mW/kg) SAR level (Stagg *et al*, 1997), or a decrease in cell proliferation (Kwee and Raskmark, 1998). Only the latter two studies investigated possible effects of exposure to mobile phone radiation.
- 5.124** *CONCLUSION Taken together, these and other experiments on DNA synthesis do not demonstrate convincing, consistent changes in cell proliferation under conditions that mimic emissions from mobile phones or base stations. However, in view of the work by Stagg et al (1997), the effects of RF fields on nucleic acid synthesis deserve further study.*

Genotoxicity: does RF exposure cause DNA damage, mutation or chromosomal aberrations?

- 5.125** Studies of the genotoxic actions of carcinogenic substances and ionising radiation on cells and experimental animals have been of value in supplementing epidemiological evidence about human disease. For instance, many experiments on the effects of tobacco tars on cells and animals have strengthened the hypothesis that smoking causes cancer.
- 5.126** Many studies of potential genotoxicity have been carried out, involving the exposure of molecules, cells, isolated explants of tissue and whole animals to RF radiation in and around the frequency band used for mobile telecommunications (recently reviewed by Verschaeve, 1995; Brusick *et al*, 1998; Verschaeve and Maes, 1998; Jokela *et al*, 1999; Moulder *et al*, 1999; Royal Society of Canada, 1999). Some studies, especially the early ones, are difficult to interpret either because the exposure was very intense or because its exact characteristics and physical effects (local electric field, intensity, SAR, etc) were not fully recorded or computed. In particular, the thermal effects of higher intensity stimulation complicate interpretation, since heating alone can

Scientific Evidence

be genotoxic (Asanami and Shimono, 1999) and can enhance the action of known genotoxic agents (Jorritsma and Konings, 1984; Miura *et al*, 1986).

Mutagenesis

- 5.127** Experiments on bacteria have shown increased mutation rates, but in general the intensities used in these positive studies were high enough to cause significant heating (see, for example, Averbeck *et al*, 1976; Dutta *et al*, 1979; Blevins *et al*, 1980; Anderstam *et al*, 1983). In contrast, many researchers have reported that low power RF radiation produces no change in the rate of mutation of microbes or mouse lymphoma cells (see, for example, Blackman *et al*, 1976; Dardalhon *et al*, 1981; Hamnerius *et al*, 1985; Phillips *et al*, 1999: Royal Society of Canada, 1999).
- 5.128** A large number of studies on whole animals, from fruit flies to rats, have consistently failed to demonstrate mutation of either somatic cells or sperm after exposure to RF radiation, even with power densities up to 1000 W/m² and SARs up to 110 W/kg (Royal Society of Canada, 1999). However, Varma *et al* (1976), Varma and Traboulay (1976) and Goud *et al* (1982) reported increased dominant lethal mutations in the offspring of exposed male mice and abnormal sperm (see Table 5.10). The intensities used were very high and the effects were almost certainly due to elevated temperature. Studies carried out at lower intensities found no effect.

Table 5.10 Effects of RF fields on mutation, as indicated by dominant lethal mutations in male rodents

Model	Exposure conditions	Results	References
Swiss mice	2.45 GHz; 500 W/m ² ; 30 min or 100 W/m ² ; 80 min	Increased dominant lethal frequency	Varma <i>et al</i> , 1976
Swiss mice	1.7 GHz; 500 W/m ² ; 30 min or 100 W/m ² ; 80 min	Increased dominant lethal frequency	Varma and Traboulay, 1976
Sprague-Dawley rats	2.45 GHz; either prenatally and postnatally or as young adults; 50 W/m ² ; about 105 days; 100 W/m ² ; 5 days; 280 W/m ² ; 4 weeks	No increase in dominant lethal mutations	Berman <i>et al</i> , 1980
Swiss mice	2.45 GHz; 1.7 kW/m ² ; 70 s	Increased dominant lethal frequency	Goud <i>et al</i> , 1982
C3H mice	2.45 GHz; 43 W/kg to lower half of body; 30 min	No increase in dominant lethal mutations	Saunders <i>et al</i> , 1983
C3H mice	2.45 GHz; 100 W/m ² ; whole-body SAR 4 W/kg; 6 h/day over 8 weeks	No increase in dominant lethal mutations	Saunders <i>et al</i> , 1988

- 5.129** *CONCLUSION* The balance of evidence suggests that at normal temperatures (consistent with exposures below guidelines), RF fields do not induce mutation of either somatic cells or germ cells.

DNA damage: *in vitro* studies

- 5.130** Studies on bacteria, plant and animal cells exposed *in vitro*, where thermal effects can be directly observed and/or controlled, have failed to reveal direct evidence of DNA damage or repair, even at power densities up to 100 W/m² and SARs up to 20 W/kg (see, for example, Dutta *et al*, 1979; Meltz *et al*, 1987, 1990; Phillips *et al*, 1998; Verschaeve and Maes, 1998; Royal Society of Canada, 1999; Vasquez *et al*, 1999). The studies of Malyapa *et al* (1997a,b) on human cells are

perhaps the most relevant because they were modelled on experiments by Lai and Singh (1995, 1996) who suggested that exposure of rats *in vivo* to pulsed RF fields produces DNA strand breaks in cells of the brain. In one experiment, Malyapa *et al* (1997a) employed 2.45 GHz continuous-wave RF radiation. In the other (Malyapa *et al*, 1997b), they used 836 MHz frequency-modulated radiation or 848 MHz radiation with CDMA modulation, simulating the transmission characteristics of mobile phones in the USA. In neither case did they find DNA strand breaks.

DNA damage: *in vivo* studies

- 5.131** Studies of DNA damage *in vivo* are summarised in Table 5.11 (see also Verschaeve *et al*, 1998). In early work, Varma and Traboulay (1976, 1977) reported DNA damage in mice but the intensities used were high enough to cause thermal effects. More recently, three further studies in rodents have suggested that RF fields at lower intensities may affect DNA directly (Sarkar *et al*, 1994; Lai and Singh, 1995, 1996), although the data are, at best, preliminary. Evidence suggesting that the exposure of mice to 2.45 GHz radiation resulted in large-scale structural rearrangement of DNA in cells in the brain and testes was reported by Sarkar *et al* (1994). In this study, DNA was isolated from the brain and testes after exposure and cut into small fragments using a restriction enzyme. The fragments were separated according to size by electrophoresis, and probed for DNA sequences with a simple probe. The appearance or disappearance of bands could be indicative of some form of structural genomic rearrangement, but this technique is very susceptible to variable DNA digestion.

Table 5.11 Effects of RF fields on DNA damage and repair *in vivo*

Model	Exposure conditions	Results	References
Swiss albino mice	2.45 GHz; 10 W/m ² ; whole-body SAR estimated as 0.2 W/kg; 2 h/day for 120, 150, 200 days	Evidence of increased DNA rearrangement in samples from testes and brain	Sarkar <i>et al</i> , 1994
Mice	34 GHz pulsed (Police radar); 200 mW/m ² ; 17 h/day; 5 days/week for 2 weeks	DNA synthesis in cells from irradiated corneas reduced by 25%, but not statistically significantly	Rotkovska <i>et al</i> , 1993
Sprague-Dawley rats: comet assay for DNA damage in cerebral cortex	2.45 GHz CW; whole-body SAR 1.2 W/kg; 2 h	No effect on the frequency of DNA breaks immediately or 4 h after exposure	Malayapa <i>et al</i> , 1998
Sprague-Dawley rats: comet assay for DNA in rat brain	2.45 GHz CW or pulsed; 2 μ s pulses; 500 pps; whole-body SAR 0.6 or 1.2 W/kg; SA per pulse = 1.2 or 2.4 mJ/kg; 2 h	Increased single- and double-strand DNA damage; maximum 4 h after exposure	Lai and Singh, 1995, 1996

CW = continuous wave

- 5.132** An increase in the number of single-strand and double-strand DNA breaks was reported in the brain cells of rats exposed for two hours to pulsed or continuous-wave 2.45 GHz radiation (Lai and Singh, 1995, 1996). Moreover, this effect was blocked by treatment, before or after exposure, with melatonin (see paragraph 5.96) or another free-radical scavenger (Lai and Singh, 1997). The DNA breaks were revealed using a single cell gel electrophoresis (or comet) assay in which the brain cells were isolated, placed on a microscope slide, lysed and eventually electrophoresed. DNA was stained using a fluorescent stain and DNA “fragmentation” assessed from the DNA migration path length. Curiously, in both studies the background levels of DNA breaks in brain cells from the unexposed animals were unusually high compared to values reported in other studies (see, for example, McKelvey-Martin *et al*, 1993). This raises the possibility that there was

Scientific Evidence

insufficient control of DNA breakage during preparation of the rat brain cells, although this in itself could not explain significant differences between exposed and control groups.

- 5.133** More rigorous studies by Malyapa *et al* (1997a,b, 1998) were not able to reproduce these findings. In particular, no effect was seen in the brain (hippocampal cells) of rats exposed for two hours to 2.45 GHz radiation, nor in mouse C3H10T $\frac{1}{2}$ fibroblast cells and human glioblastoma U87MG cells exposed *in vitro* (Malyapa *et al*, 1997a,b) to 2.45 GHz radiation or modulated 835 MHz radiation. A number of other studies have also failed to reveal any evidence of DNA damage.
- 5.134** *CONCLUSION This area deserves further research, but the evidence of Sarkar et al (1994) and Lai and Singh (1995, 1996) for DNA damage in mice is contradicted by a number of other studies in vivo and is not supported by in vitro work.*

DNA damage: indirect indicators

- 5.135** Various agents (clastogens) induce distortions of chromosomes, visible under the microscope. These chromosomal aberrations are generally thought to be due to damage to DNA or unusual interactions between DNA and protein molecules. Their accumulation is evidence of genotoxicity and is usually associated with cancer, but can also result in developmental abnormalities or miscarriage, if present in the tissue that generates eggs or sperm, or in the developing embryo or fetus.
- 5.136** Genotoxic substances tend to cause sister chromatid exchanges (switching of DNA from one part of the chromosome to another), which can be quite sensitively detected.
- 5.137** The occurrence of cells with unusually small nuclei (micronuclei) is also taken as an indicator of DNA damage. The detection of cells with micronuclei is simple, but is relatively unreliable because of the high and variable incidence of cells judged to be micronucleate in healthy tissues (10%–20% false positive rate). Heating is also known to induce micronuclei.

Chromosomal aberrations

- 5.138** Many studies have not detected obvious chromosomal aberrations in isolated animal cells after exposure to low power RF radiation (see, for example, Alam *et al*, 1978; Lloyd *et al*, 1984, 1986; Wolff *et al*, 1985; Meltz *et al*, 1987, 1989, 1990; Kerbacher *et al*, 1990; Maes *et al*, *in press*). However, a similar number of studies have reported increased chromosomal aberration (Yao and Jiles, 1970; Chen *et al*, 1974; Yao, 1976, 1982; Garaj-Vrhovac *et al*, 1990a, 1991, 1992; Khalil *et al*, 1993; Maes *et al*, 1993, 1995). In those studies with positive results in which the stimulus intensity was properly documented, it was generally rather high and therefore thermal effects cannot be ruled out. The experiments of Garaj-Vrhovac *et al* (1990a, 1991) are a notable exception; they reported an increase in chromosomal aberration after exposure of Chinese hamster V79 cells to 7.7 GHz radiation. Khalil *et al* (1993), in a preliminary report, also described increased chromosomal aberration in human lymphocytes after exposure to 167 MHz RF fields at 55 W/m² for up to 72 h.
- 5.139** Most experiments on whole animals have shown no increase in chromosomal aberration after exposure to RF fields, even though many of them employed high intensities, which were likely to have caused a rise in body temperature (Table 5.12). There have also been a few reports of aberrations *in vivo*, again with intensities near to or above the thermal limit. Of particular interest is the work by Garaj-Vrhovac *et al* (1990b) on chromosomal aberration in the lymphocytes of people who had experienced occupational exposure to 30–300 GHz at 10–50 W/m², although Maes *et al* (1995) found no such chromosomal aberrations in antenna maintenance workers who had been exposed to various RF fields at least one hour each day for more than a year.

Table 5.12 *In vivo* studies of chromosomal aberrations

Model	Exposure conditions	Results	References
Human lymphocytes from antenna workers	2.45 GHz and 954 MHz	Increased CA frequency	Maes <i>et al</i> , 1993, 1995
Mammalian, C3H mice	2.45 GHz CW; 100 W/m ² ; 4 W/kg; 6 hours/day; 120 hours over 8 weeks	No effect on CA frequency	Saunders <i>et al</i> , 1988
Male germ (sperm-forming) cells of C3H/HeH mice	2.45 GHz CW; 1, 100, 400 W/m ² ; 0.05–20 W/kg; 30 min/day; 6 days per week, for 2 weeks	No effect on CA frequency	Beechey <i>et al</i> , 1986
Male germ (sperm-forming) cells of CBA/CEY mice	2.45 GHz CW; whole-body SAR 0.05–20 W/kg; 30 min per day; 6 days per week for 2 weeks	Increased CA frequency	Manikowska-Czerska <i>et al</i> , 1985
Human lymphocytes (radio-linemen)	0.4 MHz to 20 GHz; occupational exposure	No increase in CA frequency	Garson <i>et al</i> , 1991
Human lymphocytes (antenna workers)	Various frequencies (including 450 and 950 MHz); 1 h/day for at least one year; occupational exposure	No increase in CA frequency	Maes <i>et al</i> , 1995
Human lymphocytes (radar station workers)	30–300 GHz, 1000–5000 W/m ² ; occupational exposure	Increased CA frequency	Garaj-Vrhovac <i>et al</i> , 1990b

CW = continuous-wave

Sister chromatid exchange

5.140 Most observations of sister chromatid exchange *in vitro* (Table 5.13) have failed to detect any effect of RF exposure, even at high intensities (see, for example, Lloyd *et al*, 1984 and 1986, Wolff *et al*, 1985, and Maes *et al*, 1993 and 2000, on human lymphocytes; Wolff *et al*, 1985, Meltz *et al*, 1990, and Ciaravino *et al*, 1991, on hamster ovary cells). Maes *et al* (1997) described a very small increase (statistically significant in two out of four samples) in sister chromatid exchange in human lymphocytes exposed to 935.2 MHz at an SAR of 0.3–0.4 W/kg. Khalil *et al* (1993) observed a clear increase in sister chromatid exchange in isolated human lymphocytes after exposure to 167 MHz at 55 W/m². However, this study was described as preliminary, and may have been compromised by the fact that the control cultures were kept in the stable environment of an incubator while the experimental samples were brought out for exposure.

Micronucleus formation

5.141 In contrast to these generally negative results from observations of chromosomal aberrations and sister chromatid exchange, there have been reports of an increase in the number of cells with micronuclei after exposure to RF radiation (Royal Society of Canada, 1999). Increased micronucleus formation has been seen in *in vitro* studies of various plant and animal cells (Garaj-Vrhovac *et al*, 1991, 1992; Maes *et al*, 1993; Haidler *et al*, 1994; Garaj-Vrhovac, 1999). However, the exposure conditions were generally rather poorly defined or sufficiently intense to have caused thermal effects (Table 5.14). Results of observations *in vivo* have been less clear. For instance, Vijayalaxmi *et al* (1997a,b) saw no effect on blood cells in mice exposed to 2.45 GHz radiation for 18 months at a whole-body SAR of 1 W/kg. However, Antipenko and Koveshinkova (1987) found an increase in the numbers of micronuclei in mouse hepatocytes after exposure to continuous-wave or pulsed RF radiation at an intensity of 5 W/m² for 45 days at 7 hours per day. Garaj-Vrhovac *et al* (1990b) reported no increase in micronuclei in the lymphocytes of human subjects who had had occupational exposure of unknown intensity.

However, Balode (1996) found significant effects in the blood of cattle on farms close to a major radar installation in Latvia.

Table 5.13 Effects of RF fields on sister chromatid exchange *in vitro*

Model	Exposure conditions	Results	References
Human lymphocytes in hypothermic or mildly hyperthermic conditions	2.45 GHz; up to 200 W/kg; 20 min	No effect on SCE frequency	Lloyd <i>et al</i> , 1984; 1986
Human lymphocytes and Chinese hamster ovary cells during MRI	100 MHz pulsed; 330 μ s pulses; 100 pps; static magnetic field of 2.35 tesla	No effect on SCE frequency	Wolff <i>et al</i> , 1985
Chinese hamster ovary cells with or without chemical mutagen; mildly hyperthermic	2.45 GHz Pulsed; 10 μ s pulses; 25×10^3 pps; 33.8 W/kg; 2 h	No effect of RF on SCE frequency; no effect on mutagen-induced SCE frequency	Ciaravino <i>et al</i> , 1991
Human lymphocytes	167 MHz; 55 W/m ² ; up to 72 h	Increased frequency of SCE	Khalil <i>et al</i> , 1993
Human lymphocytes maintained at 36.1°C	2.45 GHz; 75 W/kg; 30 or 120 min	No effect on SCE frequency	Maes <i>et al</i> , 1993
Human lymphocytes with or without chemical mutagen (Mitomycin C)	935.2 MHz CW; 0.3–0.4 W/kg; 2 h	Little or no effect of RF alone on SCE frequency; slight enhancement of effects of the mutagen	Maes <i>et al</i> , 1997
Human lymphocytes with or without chemical mutagen	900 MHz CW (pseudo-random signal and dummy burst signal); 0.4–10 W/kg; 2 h	No effect on SCE frequency	Maes <i>et al</i> , <i>in press</i>
Human lymphocytes maintained at 17°C with or without chemical mutagen	954 MHz pulsed (GSM); 1.5 W/kg; 2 h	No effect of RF alone on SCE frequency; RF-enhanced effect of chemical mutagen	Maes <i>et al</i> , 1995

Table 5.14 *In vitro* studies on micronucleus formation

Model	Exposure conditions	Results	References
Peripheral blood of Latvian Brown cows (2000 erythrocytes)	Farm close to and in front of the Skruna Radar	Significant differences in the frequency distribution of micronuclei	Balode, 1996
C3H/HeJ mice (prone to mammary tumours); peripheral blood	2.45 GHz; whole-body SAR 1 W/kg; 20 h/day; 7 days/week for 18 months	Small but significant increase in micronuclei in polychromatic erythrocytes in peripheral blood and bone marrow	Vijayalaxmi <i>et al</i> , 1997b (1998 erratum)
CF-1 male mice, peripheral blood and bone marrow	Ultra-wideband radiation; estimated whole-body SAR 37 mW/kg; 15 min;	No effect on micronuclei in polychromatic erythrocytes in peripheral blood and bone marrow	Vijayalaxmi <i>et al</i> , 1999
Mouse hepatocytes	CW or pulsed RF; 5 W/m ² ; 7 h; 45 days	Increase in micronuclei	Antipenko and Kovesinkova, 1987
Lymphocytes from human subjects (radar station workers)	30–300 GHz; 1000–5000 W/m ² ; occupational exposure	Variable increase in micronuclei in lymphocytes	Garaj-Vrhovac <i>et al</i> , 1990b

- 5.142** Micronucleus formation is thought to reflect DNA damage, and is a sensitive assay (since the aberrant cells tend to accumulate, especially among non-dividing and slowly-dividing cells). However, its implications for health are unclear. In any case, the incidence of micronuclei in normal tissues is rather high and variable, making the assessment of individual experimental results more difficult.

Other evidence

- 5.143** Several publications in Russian, two decades ago or more, described a number of changes in cellular appearance and function after exposure to RF radiation. For instance, Zalyubovskaya and Kiselev (1978, in Russian), cited by McRee (1980), reported various pathological effects of 6.5 mm (46 GHz) RF radiation on cultured embryonic human and pig kidney cells, and Hep-2 cells. The cells developed pyknotic or vacuolised nuclei and damaged membranes, and their survival rate was reduced by 30%–50%. Kiselev and Zalyubovskaya (1976, in Russian), cited by McRee (1980), found that exposure of adenovirus to 6.5 mm (46 GHz) RF radiation reduced the capacity of the virus to infect cultured human kidney cells. Unfortunately the exact conditions of stimulation in many of these early studies were either poorly defined or were so intense that they would have produced thermal effects.
- 5.144** *CONCLUSION Several different assays of genotoxicity have failed to produce clear evidence that RF radiation is genotoxic at non-thermal levels. The most consistent results come from observations of micronucleus formation, but these are not simple to interpret and have uncertain implications for health.*

Long-term studies of cancer induction in animals

- 5.145** A demonstration that long-term exposure to RF fields increases the incidence of tumours in animals would provide direct evidence that such radiation is carcinogenic. Early studies (Prausnitz and Susskind, 1962; Spalding *et al*, 1971; Skidmore and Baum, 1974; Baum *et al*, 1976) in which biological endpoints relevant to carcinogenesis were examined suffered from insufficient dosimetry, poor histopathology or inadequate follow-up.

Spontaneous tumour incidence

- 5.146** Later studies (Table 5.15) avoided many of these deficiencies. Chou *et al* (1992) exposed (from 2 to 27 months of age) 100 rats to low level pulsed 2.45 GHz fields. The total number of benign tumours of the adrenal medulla was higher in the exposed group compared to the control group,

Table 5.15 Effect on spontaneous tumour incidence

Model	Exposure conditions	Results	References
Sprague-Dawley rats	2.45 GHz pulsed; 10 μ s pulses at 800 pps, pulse modulated at 8 pps; whole body SAR of 0.4–0.15 W/kg for up to 25 months	No increase in individual cancers; four-fold increase in primary malignancies	Chou <i>et al</i> , 1992
Spontaneous mammary tumours in C3H/HeA mice	2.45 GHz; up to 6–8 W/kg; to 12 months of age	Increased tumour development	Szmigielski <i>et al</i> , 1982
Mammary tumour prone C3H/HeA mice	435 MHz pulsed; 1 μ s pulses at 1000 pps; whole-body SAR of 0.32 W/kg; 21 months	No effect	Toler <i>et al</i> , 1997
Mammary tumour prone C3H/HeA mice	2.45 GHz; whole-body SAR 0.3 or 1.0 W/kg; 18 months	No effect	Frei <i>et al</i> , 1998a,b

Scientific Evidence

although not particularly higher than that reported elsewhere for this strain of rat. There was no significant difference between groups in the incidence of all benign neoplasms at death. In addition, no single type of malignant tumour was enhanced by exposure and, overall, the incidence of primary malignancies was similar to the spontaneous rate reported for this strain of rat. However, when the occurrence of primary malignant lesions was pooled without regard to site or mode of death, the exposed group had a significantly higher incidence compared to the control group.

- 5.147** Other authors have reported a lack of effect of RF exposure on cancer incidence in mice prone to mammary tumours. Toler *et al* (1997) found that the long-term exposure of mammary-tumour-prone C3H/HeJ mice to 435 MHz pulsed RF radiation had no effect on survival, nor on the latency, incidence or growth rate of mammary tumours compared to sham-exposed animals, nor were there differences in the numbers of malignant, metastatic or benign tumours. Frei *et al* (1998a,b) used the same animal model to investigate the effects of chronic (18-month) low level 2.45 GHz RF exposure and found no differences compared to sham-exposed animals.

Epigenetic effects: does RF radiation interact with known genotoxic agents to enhance their promotional effects?

- 5.148** Epigenetic factors, although not themselves genotoxic, act synergistically to enhance the carcinogenic effects of other agents (Williams and Whysner, 1996). There are several published studies that suggest that RF radiation can have an epigenetic effect *in vivo*, working to exaggerate the genotoxic influences of ionising radiation or cancer-inducing substances, or to potentiate other epigenetic factors. However, the evidence for an epigenetic effect of RF exposure is equivocal, with several failures to replicate positive results.
- 5.149** Balcer-Kubiczek and Harrison (1985, 1991) reported that 2.45 GHz radiation can induce “latent transformation” of a cultured cell line. This RF radiation potentiated the tumour-transforming effect of X-rays or the carcinogenic substance benzo[a]pyrene, but only in the presence of TPA, a known epigenetic agent. On the other hand, Cain *et al* (1997) found no cell transformation in similar experiments involving 836.55 MHz radiation.
- 5.150** Scarfi *et al* (1996) reported that intense RF fields amplified the genotoxic effects of the mitogenic substance mitomycin-C, as judged by the presence of micronuclei in cultured bovine lymphocytes. Maes *et al* (1997) described a small but statistically significant enhancement of the effects of mitomycin-C on human lymphocytes after exposure to 935.2 MHz radiation for two hours. However, Ciaravino *et al* (1987, 1991) found no epigenetic influence of RF radiation on the production of chromosomal aberrations by mitomycin-C or another mitogen, adriamycin. A number of other studies have failed to demonstrate enhancement of the mutagenic action of chemical carcinogens (Meltz *et al*, 1989, 1990; Kerbacher *et al*, 1990).
- 5.151** Heating alone can enhance the action of genotoxic agents (Jorritsma and Konings, 1984; Miura *et al*, 1986) and it is possible that some of the epigenetic influences reported for RF could be due to thermal effects. Indeed, this was one of the conclusions of Pakhomova *et al* (1997), who found that higher frequency RF radiation (61 GHz) did enhance DNA recombination (but not mutagenesis) in yeast cells exposed to ultraviolet radiation.
- 5.152** Chemical tumour-inducing agents have been used to examine possible epigenetic, promotional effects of RF radiation in animals (Table 5.16). Early studies were carried out by Szmigielski and colleagues (Szmigielski *et al*, 1982; Szudinski *et al*, 1982) who reported that the chronic RF exposure of mice resulted in a SAR-dependent increase in the development of spontaneous mammary tumours or skin tumours induced by the repeated application of benzo(a)pyrene. Body temperatures were not raised but the authors suggested a possibility of localised heating at the

highest level of exposure. A further experiment (Szmigielski *et al*, 1988) showed that exposure followed by the application of a “subcarcinogenic” dose of the same carcinogen to the skin, a procedure repeated daily, eventually resulted in a three-fold increase in the numbers of skin tumours appearing. The authors noted that these results needed confirmation but suggested that long-term exposure to RF fields might promote the development of neoplasms that would not normally reach a clinically identifiable stage.

Table 5.16 Promotional studies *in vivo*

Model	Exposure conditions	Results	Reference
Chemically induced skin tumours in BALB/c mice	2.45 GHz; whole-body SAR 2–3 or 6–8 W/kg; 1–3 months	Increased incidence of skin tumours	Szmigielski <i>et al</i> , 1982; Szudinski <i>et al</i> , 1982
Chemically induced hepatomas and sarcomas in mice	2.45 GHz; whole-body SAR up to 4–5 W/kg; several months	Increased incidence of tumours	Szmigielski <i>et al</i> , 1988
Chemically induced colon cancers in BALB/c mice	2.45 GHz; whole-body SAR 10–12 W/kg; 5 months	No effect	Wu <i>et al</i> , 1994
Lymphoma-prone E μ - <i>Pim1</i> transgenic mice	900 MHz pulsed (GSM); 600 μ s pulses; 217 pps; whole-body SAR; 0.008–4.2 W/kg; 1 h per day; 18 months	Two-fold increase in lymphoma incidence	Repacholi <i>et al</i> , 1997
Medium term rat liver tumour promotion model	1.439 GHz pulsed; 6.7 ms at 50 pps; whole-body SAR 0.4–0.7 W/kg; 6 weeks	No effect	Imaida <i>et al</i> , 1998a
Medium term rat liver tumour promotion model	929.2 MHz pulsed; 6.7 ms pulses; 50 pps; whole-body SAR 0.6–0.8 W/kg	No effect	Imaida <i>et al</i> , 1998b
Lymphoma incidence in CBA/S mice exposed to 4 Gy ionising radiation	902 MHz CW; 1.5 W/kg or 902 MHz pulsed (GSM); 0.35 W/kg; 1.5 h/day; 5 days/week	No effect on survival or incidence of lymphoma	Juutilainen <i>et al</i> , 1998; <i>in press</i>
Spontaneous and chemically induced CNS tumours in Fischer rats	836.55 MHz pulsed; 6.7 ms pulses; 50 pps; brain SAR 0.3–0.5 W/kg; perinatally and for 24 months	Fewer CNS glial tumours in exposed group	Adey <i>et al</i> , 1999
Chemically induced sarcomas in female Sprague-Dawley rats	900 MHz pulsed (GSM); whole-body SAR 75 or 270 MW/kg; 2 weeks; 20, 40 or 75 days after carcinogen	No effect on tumour appearance or survival	Chagnaud <i>et al</i> , 1999
Chemically induced brain tumours in Sprague-Dawley rats	860 MHz bipolar RF pulses (MIRS: 11.1 Hz frame rate unipolar wave form) or 860 MHz CW; head SAR 0.4–1.0 W/kg; 6 h/day; 5 days/week; 2–24 months of age	No effect on incidence, multiplicity, volume, malignancy or fatal outcome of neural tumours	Zook, 1998; 1999

CW = continuous wave MIRS = Motorola integrated radio service GSM = global system for mobile telecommunications

5.153 The most positive evidence, as yet unreplicated, of an effect of exposure to RF radiation similar to that used by digital mobile phones was reported by Repacholi *et al* (1997), using E μ -*Pim1* transgenic mice. Experimental transgenic animals have genetic material added to their DNA to predispose them to the endpoint being investigated. Such animals that are prone to cancer can be

Scientific Evidence

used to test the carcinogenic influence of chemical agents in a short time (generally six months). This not only provides a sensitive animal model to test for cancer, but tests can be conducted in a time much less than the animal's lifetime. Eμ-*Pim1* mice, which are moderately susceptible to the development of lymphoblastic lymphomas, were exposed or sham-exposed for one hour per day for eighteen months to pulse-modulated 900 MHz RF radiation. The authors reported an increase in the incidence of all lymphomas (lymphoblastic and non-lymphoblastic) in the exposed mice (43% compared to 22% in the controls), the most significant effect resulting from increased non-lymphoblastic lymphomas. However, lymphoma incidence was rapidly increasing in both exposed and sham-exposed animals when the study was terminated; in addition, only moribund animals were examined histopathologically. Replication of this study and extension with more complete follow-up and improved dosimetry would be useful and is currently under way in Australia. Another replication study is commencing in Europe in 2000. These replication studies will expose the mice to different levels of RF radiation to determine if there is a dose-response relationship. Even if replicated, there will need to be further assessment of the relevance of these findings for human health (Repacholi, 1998).

5.154 Other recent studies investigating a possible promoting effect on chemically induced cancers have generally found tumour incidence to be unaffected by RF exposure. Wu *et al* (1994) reported that the chronic exposure to 2.45 GHz RF radiation had no effect on the incidence or size of colon cancers induced in mice by dimethylhydrazine. Imaida *et al* (1998a) found no effect of exposure at the Japanese cellular phone frequency of 1.439 GHz for six weeks using the standard medium-term rat liver tumour promotion model, in which neoplastic foci are induced in the liver by diethylnitrosamine and partial hepatectomy. Similar results for 929.2 MHz radiation had been reported previously (Imaida *et al*, 1998b). In contrast to these reports, Adey *et al* (1999) found that exposure to 836.55 MHz radiation with North American Digital Cellular Modulation (at SAR levels reported to simulate the localised peak brain exposures experienced by a cell phone user) over a 24-month period had a slight inhibitory effect on both spontaneous and chemically induced brain tumour incidence in rats, the latter resulting from treatment *in utero* with the carcinogen ethylnitrosourea. There was, however, no evidence of any tumorigenic effect.

5.155 *CONCLUSION* Although thermal effects may account for the positive reports that RF radiation enhances the actions of genotoxic agents, the evidence for epigenetic effects must be taken seriously. Further research is needed in this area to clarify the position.

Tumour transplantation: does RF radiation enhance the progression of transplanted tumours?

5.156 The effect on tumour progression of exposure to continuous-wave or pulse-modulated RF radiation following the transplantation of tumour cells into mice and rats has been examined in several studies. Szmigielski *et al* (1982) reported a SAR-dependent increase in the number of neoplastic colonies on the lung surfaces of mice injected intravenously with suspensions of mouse sarcoma cells and exposed to 2.45 GHz radiation. In contrast, other studies (Santini *et al*, 1988; Salford *et al*, 1993; Higashikubo *et al*, 1999) have found no effect of RF exposure (see Table 5.17).

General conclusions from studies of cancer

5.157 *Some individual experimental studies have suggested that RF radiation can initiate tumour formation, enhance the effects of known carcinogens or promote the growth of transplanted tumours. However, in some of these the intensity was high enough to produce thermal effects. The balance of evidence, from both in vitro and in vivo experiments, indicates that neither acute*

Table 5.17 Tumour transplantation studies

Model	Exposure conditions	Results	References
BALB/c mice injected with L1 mouse sarcoma cells	2.45 GHz; whole-body SAR 2–3 or 6–8 W/kg; 3 months	Increased incidence of tumour colonies on lung surface	Szmigielski <i>et al</i> , 1982
Mice injected with mouse B16 melanoma cells after exposure	2.45 GHz CW or pulsed; whole-body SAR 1.2 W/kg	No effect on survival	Santini <i>et al</i> , 1988
RG2 glioma cells injected into rat brains	915 MHz CW or pulsed; whole-body SAR 0.01–2 W/kg; 2–3 weeks	No effect on tumour growth	Salford <i>et al</i> , 1993
9L gliosarcoma cells injected into rat brains	835.62 MHz; FM or 847.74 MHz CDMA; brain SARs estimated as around 0.75 W/kg; 21 weeks after treatment;	No effect on tumour growth	Higashikubo <i>et al</i> , 1999

CW = continuous wave FM = frequency modulated CDMA = code division multiple access

*nor chronic exposure to RF fields increases mutation or chromosomal aberration frequencies when temperatures are maintained within physiological limits (UNEP/WHO/IRPA, 1993). This suggests that RF exposure is unlikely to act as a tumour initiator. Further, a variety of cancer studies using animals have sought evidence of an effect of RF exposure on spontaneous or natural cancer rates, the enhancement of the effects of known carcinogens or effects on the growth of implanted tumours. However, they have provided equivocal evidence for an effect on tumour incidence (ICNIRP, 1996; Repacholi, 1998; Moulder *et al*, 1999; Royal Society of Canada, 1999).*

Haematopoietic system, immune system and longevity

- 5.158** Changes in the haematopoietic system (tissues related to the formation of blood cells) can have a direct effect on health. Information about any effects of RF exposure on this system is fundamentally important, then, for the assessment of possible risks to health and well-being.
- 5.159** No consistent effects of low level RF exposure have been reported on the blood-forming and circulating blood cells (eg changes in numbers of bone marrow cells, lymphocytes or erythrocytes, or in the amount of haematocrit) (UNEP/WHO/IRPA, 1993; Jauchem, 1998). Most of the earlier studies used continuous-wave fields, but a well-conducted lifetime study in rats exposed to low level, pulsed RF fields also found no effect on haematology or serum chemistry parameters (Chou *et al*, 1992).
- 5.160** The immune system defends against micro-organisms, viruses, and some cancer cells. Thus any effects of RF exposure on this system could have significant implications for health. Thermal levels of RF exposure elicit both stimulatory and inhibitory responses in components of the immune system (UNEP/WHO/IRPA, 1993). However, these effects (eg changes in lymphocyte activity and responsiveness) were generally found to be transitory, returning to normal levels following termination of RF exposure. Studies using low level RF exposure have given inconsistent results, making it difficult to attribute any effects to the exposure. Several acute and chronic *in vivo* studies, using low RF exposure levels, have indicated positive effects that were transient and similar to those resulting from thermal stress or physiological changes occurring during thermoregulation (Smialowicz *et al*, 1983; Yang *et al*, 1983). However, Fesenko *et al* (1999) have recently shown that exposure of mice to 10 GHz radiation, or radiation with a frequency swept between 8.15 and 18 GHz, at very low intensity (probable SAR 2–5 mW/kg), increases the production by macrophages of tumour necrosis factor, which is

Scientific Evidence

involved in immune attack on viruses, foreign proteins and damaged tissues. Novoselova *et al* (1999) showed that this effect is enhanced by a diet rich in antioxidants. These authors suggest that “the activation of cellular immunity by RF irradiation and antioxidant treatment may provide therapeutic strategies for interfering with acute immunodeficiency processes”.

- 5.161** In general, studies conducted to determine if RF exposure affects longevity have revealed no influence on lifespan in experimental animals. Indeed, the most convincing changes reported are very slight increases in lifespan, perhaps because of a subtle, thermally-mediated effect on food intake. Summaries of typical studies are given in Table 5.18.

Table 5.18 Longevity and general physiological condition

Model	Exposure conditions	Results	References
Mice	0.80 GHz; 43 W/m ² ; 2 hours/day; 5 days/week; 35 weeks	No effect on lifespan	Spalding <i>et al</i> , 1971
CFW mice (<i>in utero</i> exposure to RF and implantation of tumour cells)	2.45 GHz; 35 W/kg (leading to an increase in body temperature of 2.24 °C); 20 min/day; 3 days; 11-14 th day of gestation	Increased lifespan in tumour-bearing and tumour-free animals	Preskorn <i>et al</i> , 1978
Sprague-Dawley rats	2.45 GHz pulsed; 10 µs pulses; 800 pps; pulse modulated at 8 pps; whole-body SAR of 0.15–0.4 W/kg; up to 25 months	No effect on lifespan	Chou <i>et al</i> , 1992
CD1 mice	2.45 GHz; 30–100 W/m ² ; whole-body SAR 2 or 6.8 W/kg; 1 h/day; 5 days/week throughout their life	Significantly shortened lifespan of mice exposed to 100 W/m ² and slight but not significantly longer average lifespan of mice exposed to 30 W/m ²	Liddle <i>et al</i> , 1994
New Zealand rabbits	2.45 GHz; head SAR of 0.55 or 5.5 W/kg; 7 h per day; 13 weeks	No effect on haematology, cataract incidence or histopathology; slight drop in food consumption in high exposure group	Chou <i>et al</i> , 1983

Reproduction and development

- 5.162** Many of the processes associated with reproduction are especially sensitive to toxic influences. Meiosis (the division of cells to produce sperm and eggs), fertilisation and implantation of the embryo can all be disturbed by toxic insults. The high rates of cell division and differentiation in the developing fetus make it particularly vulnerable. It is well known that some drugs and environmental hazards have damaging (teratogenic) effects on the developing embryo or fetus at exposure levels that pose little or no risk to the adult animal. It is therefore important to assess the possible effects of RF fields on fertility and development.
- 5.163** Extensive research on a wide range of species (from beetles to guinea pigs) has failed to reveal any convincing effects of low level RF fields on developing animals (reviewed by UNEP/WHO/IRPA, 1993; Jauchem, 1998; O’Connor, 1999). For instance, exposure of pregnant Holtzman rats for 20 minutes at SARs of 14 or 28 W/kg, sufficient to raise the rectal temperature to an average of 42°C, produced no observable effects on the offspring (O’Connor, 1980). Only if the field strength was so high that the rectal temperature of the dam reached near-lethal levels

- (43°C) was there an increase in fetal absorption, a decrease in fetal body mass and excessive occurrence of birth defects (Chernovetz *et al*, 1977; O'Connor, 1980). The survival of fetuses was inversely correlated with the temperature to which the dam was raised, and similar effects were produced by raising the dam's body temperature by infrared heating (Chernovetz *et al*, 1977).
- 5.164** Jensch (1997) described extensive studies on the effects of prenatal RF exposure at non-thermal levels on development in rats. Female rats were exposed for six hours each day throughout pregnancy to continuous-wave radiation at 915 MHz (100 W/m²), 2.45 GHz (200 W/m²) or 6 GHz (350 W/m²) and many physiological and behavioural parameters were assessed in both mothers and offspring. Some of the offspring from RF-exposed pregnancies were later bred and the second generation offspring were also assessed. Exposure to 915 MHz radiation (in the range of mobile phone signals) had no detectable effect. For 2.45 GHz radiation, the only positive result was a very slight increase of activity in the offspring. Exposure to 6 GHz radiation at 350 W/m² did have some just statistically significant effects. The number of monocytes (a class of white blood cells) in the mothers' blood was slightly but significantly reduced. The weight of the offspring at term and during the first five postnatal weeks was slightly lower than that for control litters and there were small differences in the relative weights of kidney and liver. The exposed offspring opened their eyes slightly earlier than did control pups. The offspring from exposed litters tended to be more active in an "open field" test of spontaneous activity, and the females were slightly more active on an activity wheel, in a swimming test and in a water T-maze. Their actual performance on the water maze was slightly worse than that of control animals. In subsequent pregnancies from matings of animals derived from exposed mothers, the weight gain of the pregnant females and the size of their litters was slightly reduced. Jensch (1997) concluded that, since all these effects were so minor, and almost all were associated only with 6 GHz radiation, the fields associated with mobile phones do not "produce a significant increase in reproductive risk".
- 5.165** From other experiments on rats and mice, Berman *et al* (1978) and Lary *et al* (1982, 1983) concluded that the threshold for teratogenic effects corresponds to an elevation of temperature of the fetus to 40°C for some considerable time. Prolonged exposure of pregnant rats at thermal levels can lead to behavioural deficits in the offspring, including poorer performance in a water T-maze and an open-field activity test (Jensch *et al*, 1983a,b; Jensch, 1984a,b), and altered thermoregulatory behaviour (O'Connor, 1988).
- 5.166** Exposure to relatively high level RF radiation (but not high enough to be teratogenic on its own) enhances the effects of chemical teratogens (see, for example, Marcickiewicz *et al*, 1986; Nelson *et al*, 1991), but this is almost certainly due to the rise in fetal temperature.
- 5.167** There were early reports of decreased fertility in male rats exposed to RF fields (Varma and Traboulay, 1976, 1977). However, it is likely that these effects were due to heating. Saunders and Kowalczyk (1981) found no abnormality of testis cells or sperm count even in adult male rats that had been exposed to quite strong RF fields (66 W/kg for 10 minutes or 7 W/kg for 260 minutes). Very prolonged exposure to 200 MHz fields, amplitude modulated at 16 Hz, at an SAR of about 2 W/kg, has been reported to decrease male fertility, judged by the number of offspring per litter and by histological changes in the seminiferous tubules (Khillare and Behari, 1998). These effects could well have been caused by modest warming integrated over the long exposure period.
- 5.168** Magras and Xenos (1997) have reported an apparently dramatic decrease in the fertility of mice exposed to extremely low level RF fields near the "antenna park of Thessaloniki" (almost 100 TV and FM-radio antennas on the Chortiatis mountain in Greece). The mice, which were

Scientific Evidence

kept in, and moved between, various locations (including a school) in a nearby village, were exposed to a broad spectrum of RF radiation with an integrated intensity between about only 1.7 and 10 mW/cm². Within three to five matings, the number of pups per litter had fallen literally to zero. Unfortunately there was no matched control group and no account was taken of the possibility that the result was due to noise, smells or other stressful factors in the environment of the experimental mice.

- 5.169** *CONCLUSION* *There is no convincing evidence from studies of rodents that exposure to RF fields at levels associated with mobile telecommunications poses any risk for the fetus or for male fertility. While there are good reasons to doubt whether the decline in female fertility described by Magras and Xenos (1997) was actually due to the very low level exposure, it is important to repeat this study under better controlled conditions.*

Influences on the cardiovascular system

- 5.170** Radiofrequency radiation might affect the heart and circulation through a number of routes. There could be direct effects on the heart and blood vessels. There might be influences on the cardiovascular centres in the medulla of the brainstem, which regulate the heart and circulation via the outflow in the sympathetic and parasympathetic systems. Exposure to RF fields might conceivably affect the receptors in the carotid body, which normally detect blood pressure and blood gases and which initiate reflex influences on the heart and blood vessels. Finally, the cardiovascular system is known to be affected by a variety of circulating substances, especially catecholamine hormones, whose release might possibly be changed by exposure to RF fields.
- 5.171** Exposure of animals to high levels of RF radiation, sufficient to raise body temperature, certainly results in a variety of direct and indirect effects on the cardiovascular system. However, there is no evidence that they differ qualitatively or quantitatively from effects triggered by similar rises in body temperature produced by other means (Jauchem and Frei, 1992). High peak-power pulsed RF fields or broad-spectrum pulses of electromagnetic radiation (which would result in *total* absorbed energy in people well below guidelines) do not cause detectable changes in heart rate or blood pressure in animals (Erwin and Hurt, 1993; Jauchem and Frei, 1995; Jauchem, 1997).
- 5.172** *CONCLUSION* *Studies on animals do not justify any concern about the influence of RF radiation at levels associated with mobile phones on the heart or circulation. Effects at high intensities appear to be due to heating of the body.*

Summary and conclusions on animal and cellular experimental studies

- 5.173** *The thermal consequences of acute RF exposure in animals appear to account for many of the reported effects on the cardiovascular, endocrine and immune system and on behaviour (UNEP/WHO/IRPA, 1993). Rectal temperature increases of at least 1–2°C are needed to produce these effects. Developmental effects, similar to those known to be induced by heat, have been reported in rodents following large (3–4°C) temperature increases in the fetus during prenatal RF exposure (Lary and Conover, 1987).*
- 5.174** *Other effects remain somewhat controversial. The question of whether low level RF exposure might increase the risk of cancer is of particular concern, although, since the radiation lacks sufficient energy to disrupt molecular bonds directly, there appears to be no theoretical basis to suggest that it could adversely affect DNA.*
- 5.175** *It has been reported that exposure to low level pulsed (and sometimes continuous-wave) RF fields can damage ocular tissues in primates and produce non-specific stress-like changes in the*

rat brain. If such effects occur in people they could have implications for health. There is also a body of evidence describing biological responses to amplitude-modulated RF fields at SARs too low to involve any response to heating. This literature is, however, inconsistent, and the effects that are reported are typically small and close to the level of statistical noise. It is thus very difficult to interpret, in terms of either its biological significance or its implications for human health.

Laboratory Studies of the Effects of RF Radiation on People

Brain function

- 5.176** Among the concerns expressed over the use of mobile phones is the possibility that mobile phone signals have deleterious effects on cognitive functions such as memory, attention and concentration. Despite these concerns, relatively few laboratory studies have addressed this issue in people and, of those that have, all have investigated short-term effects of exposure. Further, with three exceptions, studies investigating exposure to low levels of RF radiation in the mobile phone frequency range have focussed not on indices of cognitive performance *per se*, but on physiological measures of brain function such as the electroencephalogram (EEG).

Studies of cognitive performance

- 5.177** Investigation of short-term effects of exposure to electromagnetic fields is, in principle, relatively easy. A wide range of tasks have been developed by experimental psychologists to assess specific aspects of cognitive function (eg short-term and long-term memory, selective attention, speed of decision-making), and the experimental designs required to determine whether electromagnetic field exposure affects performance on such tasks are unproblematic. To date, however, the effects of mobile phone signals on cognitive performance have been assessed in only three published studies (Preece *et al*, 1999; Koivisto *et al*, 2000, *in press*).
- 5.178** Preece *et al* (1999) investigated the performance of 36 volunteers on a wide range of tasks, including short-term and long-term memory, simple and choice reaction time (RT), and sustained attention, which, together, yielded a total of 15 dependent variables. These variables were grouped for combined analysis by multivariate analysis of variance into four sets: RT on attentional tasks (simple, choice and vigilance RT), speed on memory tasks, accuracy on memory tasks and accuracy on attentional tasks. Using a counterbalanced, crossover design, two exposure conditions – continuous and pulsed (217 Hz) 1 W, 915 MHz signals (simulating analogue and GSM mobile phone signals with mean power levels of 1 W and 0.125 W, respectively) – were compared to a no-exposure control condition. The signals were delivered through a simulated headset placed over the left ear with the antenna extending over the temporo-parietal scalp. Initial statistical analyses revealed a significant effect of exposure for RT on the attentional tasks. Follow-up analyses revealed a single statistically significant effect of exposure, which took the form of a shortening of RT (by 14 ms) during exposure to the analogue signal in the choice RT task, which required speeded discrimination between visual presentations of the words “yes” and “no”. The effect was not accompanied by a reduction in the accuracy of responding, suggesting that it did not reflect a “speed–accuracy tradeoff”. Exposure effects on RT in the two other attentional tasks showed trends in the same direction, but were of trivial magnitude (< 3 ms). Exposure effects for the three other groupings of dependent variables were far from statistical significance (minimum $p = 0.144$). However, non-significant trends towards shortened RT during exposure to the analogue signal were observed to varying degrees in all four of the memory tasks. The Expert Group reanalysed the most important parts of the data from Preece *et al* (1999). The reanalysis, in general, confirmed and indeed slightly strengthened the conclusions of Preece *et al*.

Scientific Evidence

- 5.179** Preece *et al* (1999) conjectured that their findings were thermal in origin, and reflected the facilitatory effect of heating on synaptic transmission in cerebral cortex directly underlying the simulated headset. They argued that this explanation was consistent with their finding of an effect for the analogue but not the digital signal (the two signals differed in mean power by a factor of eight, and any heating effect would be proportional to power). They further argued that a local cortical effect was consistent with the task-specificity of their findings, as any effects on behaviour would be greatest for those tasks that depended most heavily on cognitive operations supported by the affected region of cortex.
- 5.180** Koivisto *et al* (2000) studied 48 volunteers, also with a wide range of cognitive tests (12 in total, providing 14 measures of RT and a similar number of accuracy measures). Their test battery included a two-choice RT task very similar to that employed by Preece *et al* (1999). A counterbalanced, crossover design was used to compare performance under conditions of no-exposure with performance during exposure to a 902 MHz GSM signal (modulated at 217 Hz) of 0.25 W mean power. The phone was positioned over the left ear with the antenna located over the posterior temporal scalp. Koivisto *et al* reported that three measures of RT – simple RT, the estimated time taken to perform a mental subtraction of two digits, and the average time taken to detect rarely occurring “targets” in a stream of visually presented letters (a “vigilance” task) – were shortened (by 9, 29 and 25 ms, respectively) to a statistically significant extent when the tasks were performed during exposure to the mobile phone signal. Accuracy scores did not indicate the presence of a speed–accuracy tradeoff; indeed, in the vigilance task errors of commission showed a small but statistically significant reduction during exposure. The effect of exposure on the choice RT task analogous to that employed by Preece *et al* (1999) was far from significant. Koivisto *et al* nonetheless considered their findings to be consistent with those of Preece *et al* (1999), noting that they too had failed to find an effect of GSM signals on a two-choice RT task. Koivisto *et al* argued that their own results suggested that exposure to the mobile phone signals had affected cortical regions, such as the inferior parietal cortex, that support sustained visual attention. Similarly to Preece *et al* (1999), they proposed that the mechanism underlying this effect may be thermal.
- 5.181** The Koivisto *et al* (2000) study can be criticised on the grounds that the data were subjected to an inappropriate form of statistical analysis. Fourteen measures of RT were considered, and the effect of exposure on each measure was assessed by a separate pairwise statistical test performed in the absence of any initial multivariate analysis that demonstrated a general exposure effect. Thus, across all the tests, the chance probability of obtaining a significant effect of exposure was considerably greater than the significance level ($p < 0.05$) that was employed to evaluate the outcome of each test. Indeed, according to the Bonferonni criterion (a standard method of correcting significance levels when multiple tests are performed), of the four “significant” findings reported, only RT in the vigilance task demonstrated a statistically significant exposure effect. That said, it is noteworthy that RT on 11 of the 14 measures was numerically, if not significantly, shorter during exposure. These trends offer some reassurance that a genuine exposure effect was operating, which would be strengthened if it was known that the 14 measures were not intercorrelated to any great extent; the relevant data were not, however, reported.
- 5.182** In a second study, Koivisto *et al* (*in press*) employed a very similar experimental design to investigate the effects of mobile phone signals (dosimetry as in their previous study) on the performance of 48 subjects in an “n-back” “working memory” task. In this task, subjects are presented with a sequence of characters (letters in the present case) and must respond discriminatively according to whether a letter is a “target” or “non-target”. Targets comprise items repeated after a designated number of trials. In the easiest case, targets are designated as items that repeat on the immediately succeeding trial (“1-back” condition). The load on working memory is manipulated by increasing the number of trials that intervene between the first and

second presentations. In Koivisto *et al* (*in press*), 1-back, 2-back and 3-back conditions were employed. Accuracy and RT measures were obtained for both target and non-targets and analysed with analysis of variance. No exposure effects were found for accuracy. For target RT only, a reliable interaction effect was obtained between load (1-back, 2-back, or 3-back) and exposure condition. Pairwise comparisons revealed a significant ($p < 0.05$) RT reduction of 36 ms in the 3-back condition during exposure. Non-significant *increases* in RT were observed during exposure for the 1-back and 2-back conditions (11 ms and 21 ms, respectively).

- 5.183** These findings are consistent with those of Preece *et al* (1999) and Koivisto *et al* (2000) in suggesting that exposure to mobile phone signals facilitates RT during some cognitive tests. The findings further suggest that these facilitatory effects increase along with the cognitive demands of the test. Two aspects of the Koivisto *et al* (*in press*) study suggest, however, that the findings should be interpreted with a degree of caution. First, it is puzzling why exposure should have tended (albeit non-significantly) to increase RT in the 1-back and 2-back conditions. Second, the exposure effect in the 3-back condition was of only modest statistical significance.
- 5.184** Together, the findings of Preece *et al* (1999) and Koivisto *et al* (2000, *in press*) suggest that exposure to mobile phone signals at power levels within existing exposure guidelines has biological effects that are of sufficient magnitude to influence behaviour. Both groups conjectured that their findings reflected the effect of small temperature increases on synaptic transmission in the region of cerebral cortex directly under the headset antenna. An easily testable prediction of this account is that the tasks most sensitive to exposure to mobile phone signals should vary according to the position of the headset, and thus the cortical locus of the heating effect.
- 5.185** Considerably more work along the lines of the Preece *et al* (1999) and Koivisto *et al* (1999) studies is needed before it will be possible to evaluate fully the generality and significance of their findings. For example, it is currently unclear why Preece *et al* found effects only for analogue signals, whereas Koivisto *et al* were able to find effects with GSM signals. It is also unclear why the effects found in the studies of Preece *et al* and Koivisto *et al* (2000) involved different tasks. It is plausible that these disparities reflect differences in the signal powers and antenna positions employed in the two studies, and these variables should be among those investigated in future studies. As already noted, the reliability of some of the above findings is questionable because they were obtained from analysis of datasets containing numerous dependent variables. Future research conducted in light of these findings should, as much as is practical, employ a more hypothesis-driven approach to investigate exposure effects on relatively small numbers of variables.
- 5.186** Two further points should be made about the three studies described in this section. First, it should not be concluded that the findings of these studies indicate that the acute effects of exposure to mobile phone signals, when they are found, will invariably be beneficial to cognitive performance. This may be true for simple tasks of the kind on which Preece *et al* (1999) and Koivisto *et al* (2000, *in press*) were able to find exposure effects, although this result may not extend to more complex tasks which require co-ordination between several concurrently active cognitive operations (eg driving). In such cases, any change in the function of a single component operation may be detrimental for the functioning of the system as a whole.
- 5.187** Second, while further studies along the lines discussed above will be important in establishing whether the biological effects of mobile phone signals are indeed sufficient to cause short-term changes in cognitive performance, these studies will not directly address the question of whether long-term changes in cognitive function follow sustained exposure of the kind experienced by

Scientific Evidence

mobile phone users. The relevance of such studies to the question of whether mobile phone use is detrimental to health is therefore limited.

Electroencephalogram (EEG)

- 5.188** The scalp-recorded EEG is a reflection of synchronous activity in relatively large populations of cortical neurons. The “spontaneous” EEG is conventionally divided into a number of frequency bands, the relative amounts of activity which depend upon the psychological state of the subject, and the nature of the cognitive function in which he or she is engaged. The functional significance of these different components of the normal, waking EEG is poorly understood. Thus, while a demonstration that mobile phone signals influenced these components would be indicative of a biological effect of such signals, interpretation of the effect would be uncertain. This is less so in the case of EEG patterns associated with sleep, which are well characterised and routinely used as indices of the different sleep stages that a typical healthy individual will move between during the night. There would also be little uncertainty in the interpretation of a change from a normal to a frankly pathological pattern of EEG activity, such as might be observed in epilepsy.
- 5.189** A measure of brain function closely related to the EEG is the “evoked” or “event-related” potential (ERP). ERPs are obtained by sampling the EEG time-locked to a reference event such as the presentation of a stimulus or the onset of a motor response, and averaging the samples together so as to obtain an electrical waveform that represents brain activity associated specifically with that class of event. ERPs are commonly used to study the timing and functional integrity of neural systems supporting sensory, cognitive and motor processing.
- 5.190** Laboratory studies investigating the effects of mobile phone signals on the spontaneous EEG in awake subjects have produced somewhat mixed results. For example, Reiser *et al* (1995) reported that exposure to GSM signals was associated with increases some 15 minutes later in the power of EEG frequencies of about 10 Hz and above (although this finding is of questionable statistical validity). Roschke and Mann (1997), however, were unable to detect any differences in EEG spectra related to exposure to GSM signals. A similar inconsistency appears to hold for the study of sleep EEG. Mann and Roschke (1996) reported that exposure to GSM-like signals reduced latency to sleep onset, and altered the abundance and spectral characteristics of REM sleep, although a subsequent study by the same group (Wagner *et al*, 1998) failed to replicate these findings. In a more recent study, however (Borbely *et al*, 1999), exposure to a “pseudo-GSM signal” (15 minute on/off cycles, 900 MHz, duty cycle of 87.5% rather than the 12.5% used in phone signals, and an estimated whole-body SAR of 1 W/kg) was associated with reduced waking after sleep onset and changes in EEG power spectra during the first of the night’s episodes of non-REM sleep.
- 5.191** Krause *et al* (2000) studied the effects of GSM signals (dosimetry and general experimental design as in the studies of Koivisto *et al* (2000, *in press*) see paragraph 5.180) on “event-related” changes in the EEG recorded during the performance of a “memory scanning” task. Each trial involved the auditory presentation of four words (the “memory set”), followed after two seconds by the presentation of a “probe” word which matched an item from the memory set on 50% of trials; subjects were required to indicate whether or not the probe was a match. The principal finding was that the pattern of EEG changes (as indexed by changes in the power of four frequency bands between 4 Hz and 12 Hz) elicited by the probe word differed between exposure and no-exposure conditions. These differences were considered by Krause *et al* to be possible physiological correlates of the short-term effects of GSM signals on behaviour described by Koivisto *et al* (2000, *in press*). Unfortunately, Krause *et al* (2000) did not report measures of task performance. Thus it not possible to determine whether exposure facilitated RT in the memory

scanning task, as would be expected if the reported EEG changes are indeed a correlate of this effect.

- 5.192** In three studies, ERPs were investigated during exposure to GSM-like signals. In the first (Urban *et al*, 1998), visual sensory responses to checkerboard reversal were found to be unaffected during exposure. In two other studies (Eulitz *et al*, 1998; Freude *et al*, 1998) positive effects were reported. In the study of Eulitz *et al*, these took the form of the suppression of high frequency (18–30 Hz approximately) spectral power in ERP waveforms elicited by infrequent auditory “oddball” stimuli interspersed among a more frequent class of auditory stimulus. In Freude *et al*, the effect was a small reduction in the amplitude of response-related potentials in a visual monitoring task; no such effect was found in the potentials preceding spontaneous movements, nor were there any exposure effects on task performance.
- 5.193** Together, the findings from electrophysiological studies suggest that exposure to mobile phone signals influences brain function. The evidence is sufficiently substantial to warrant further investigation, notably with respect to the influence of GSM-like signals on sleep and on event-related EEG changes during the performance of cognitive tasks. It should be emphasised, however, that neither the biological nor the clinical significance of the findings described above is clear at present, and the relevance of the findings to the question of the safety of mobile phone technology is uncertain.

Conclusions from studies on brain function

- 5.194** *Together, the findings of Preece et al (1999) and Koivisto et al (2000, in press) from human laboratory studies of the acute effects of exposure to mobile phone signals suggest that exposure to mobile phone signals at exposure levels that fall within existing exposure guidelines have biological effects that are of sufficient magnitude to influence behaviour. The causal mechanism is unclear, but could include a small, localised heating effect.*
- 5.195** Human studies of cognitive performance and EEG have, however, yet to provide evidence directly relevant to the question of the safety of mobile phones in the long term. As already noted, the experimental designs employed thus far are not appropriate for this purpose, as they focus on the consequences of short-term exposure. To address the question of whether mobile phone use has long-lasting effects on measures of human brain activity or cognitive performance, it will be necessary to conduct laboratory-based studies on carefully matched groups of subjects who differ with respect to their history of exposure to mobile phone signals. A complementary approach would be to follow a group of new phone users over time so as to identify any changes in brain or cognitive function associated with cumulative exposure. Studies such as these should be a priority for future research.

Effects on the heart and blood pressure

- 5.196** As explained above (paragraphs 5.170–5.172), RF fields could, in principle, affect the cardiovascular system via a number of mechanisms. With normal use of a mobile phone, placed against the side of the head, direct influences on the human heart seem very unlikely. However, influences on the cardiovascular centres of the brainstem or the carotid body receptors are more conceivable.
- 5.197** Early reports from the former Soviet Union (see, for example, Drogichina *et al*, 1966; Sadčikova, 1974) implied that occupational exposure to RF radiation can directly or indirectly alter cardiovascular function. The most common observation was a reduction in blood pressure associated with either bradycardia or tachycardia (slowing or speeding of the heart). However, the general conclusion of a number of reviews of this literature is that most of the early studies

Scientific Evidence

were poorly controlled and that the results may have reflected chance variation (Kaplan *et al*, 1971; Resnekov, 1981; Kristensen, 1989; Jauchem, 1997).

- 5.198** More recently, Braune *et al* (1998a) have reported acute effects on blood pressure in human volunteers exposed to a conventional GSM digital mobile phone positioned close to the right side of the head. After 35 minutes of exposure, heart rate, blood pressure and capillary perfusion were measured with the subject either supine or standing for 60 seconds. They found that the heart rate during these tests was slightly lower after exposure to RF radiation than following non-exposed control sessions, and both systolic and diastolic blood pressure were elevated by 5–10 mm of mercury. Since capillary perfusion (blood flow through capillaries of the hand) was decreased, the authors concluded that the effects on blood pressure were due to excessive vasoconstriction, caused, perhaps, by an increase in sympathetic activity originating in the brainstem.
- 5.199** This study has been criticised on the basis of both its design and the statistical analysis (Reid and Gettinby, 1998). In particular, the “placebo” (non-exposed) session preceded the test session for all subjects, and therefore the small cardiovascular changes might have resulted simply from the lengthy period of the experiment. Braune *et al* (1998b) argued that they chose not to randomise the sequences because of other evidence that effects of RF exposure could persist for some time. However, they should, then, have included a true control group in which testing was carried out during a *second* non-exposed session following the first placebo period.

Conclusions on heart and blood pressure studies

- 5.200** *There is, on the basis of published evidence, no basis for concern about effects of mobile phone use on the heart and circulation. However, this is a subject that merits more experimental work on human volunteers. In particular, we advise that a study similar to that of Braune et al (1998a) is carried out with larger numbers of subjects and appropriate control conditions.*

Mobile Phones and Driving

- 5.201** Mobile phones could have a detrimental effect on public health not only through the direct effects of exposure to electromagnetic radiation, but also indirectly by interfering with the phone user’s ability to perform a concurrent task. Perhaps the most important, and certainly the most well-publicised, example of such interference involves the use of mobile phones while driving. These effects are considered by the Department of the Environment, Transport and the Regions to be sufficiently serious to warrant a major publicity campaign (DETR, 2000) aimed at dissuading drivers from using a mobile phone, especially one that is hand-held, when in control of a vehicle.
- 5.202** While it may seem obvious that using a hand-held mobile phone while driving will have negative consequences for road safety, it is perhaps less obvious that similar consequences may follow from the use of hands-free equipment. Experimental psychologists have, however, produced a wealth of evidence indicating that when mental (cognitive) tasks are performed concurrently, performance is often worse than when each task is performed alone. These “dual task” effects arise for a variety of reasons, chief among which are the need to switch or divide attention between the two tasks, and the interference that occurs when tasks compete for the same cognitive processes or mental representations.
- 5.203** In light of the psychological findings, it is likely that, in addition to the purely “peripheral” interference arising when a driver attempts both to operate a vehicle and to manipulate a

hand-held phone, there will also be sources of “central” interference that arise when the cognitive demands of a mobile phone conversation compete with those required for driving. In assessing the possible impact of mobile phones on road safety, it is important, therefore, to understand the relative magnitudes of these two sources of interference; there is little point in stressing the inadvisability of using a hand-held phone if the greater part of the associated risk is also present when hands-free equipment is used.

- 5.204** Evidence concerning the impact of mobile phones on driving ability is reviewed below in two sections. First, experimental studies are discussed in which the effects of phone use on driving have been assessed. Such studies allow the mechanisms by which phones interfere with driving to be elucidated, and the effects of different kinds of phone use to be compared. They provide, however, only indirect information about the actual impact of phone use on road safety. This issue is taken up in the second section, which discusses epidemiological studies that attempted to quantify the increased risk associated with the use of a mobile phone while driving. Finally, the implications of this evidence are discussed in relation to policy regarding the use of different kinds of phones in vehicles.

Experimental evidence for effects on driving

- 5.205** The impact of phone use on various aspects of driving performance has been investigated in a sizeable number of studies. Some studies investigated performance on laboratory tasks analogous to driving, such as a visuospatial tracking task (Strayer *et al*, 1999) or in a driving simulator (McKnight and McKnight, 1993; Alm and Nilsson, 1994, 1995; Haigney, 2000); others employed real cars and road situations (Brown *et al*, 1969; Brookhuis *et al*, 1991; Lamble *et al*, 1999). Some studies limited their investigations to the effects of mobile phone conversations in a hands-free setting, sometimes employing phone tasks that differed with respect to “mental workload”, eg “shadowing” (repeating back) words *versus* “generation” (producing a new word beginning with the last letter of the one just heard). Other studies directly contrasted the effects of using hand-held *versus* a hands-free sets (Brookhuis *et al*, 1991; Strayer *et al*, 1999; Haigney, 2000); or compared the use of hands-free phone to a task requiring some manual control of some other device, eg entering numbers on a keypad (Lamble *et al*, 1999) or a keypad task and tuning a radio (McKnight and McKnight, 1993).
- 5.206** The results of these experimental studies are consistent and easily summarised. Relative to either a “no-conversation” condition (or, in the case of Strayer *et al*, 1999, listening to a car radio), engaging in a mobile phone conversation had a detrimental effect on driving performance as measured by such indices as the time taken to react to an imperative stimulus (Alm and Nilsson, 1994; Strayer *et al*, 1999) or a change in the speed of a leading car (Brookhuis *et al*, 1991; Lamble *et al*, 1991; Alm and Nilsson, 1995); failure to react to a potentially dangerous road situation (McKnight and McKnight, 1993); speed adaptation (Haigney, 2000; interestingly, this measure was found to exhibit a “carry-over” effect, in that adaptation continued to be affected during a 2.5 minute period after the call was terminated); maintaining a safe distance from a leading car (Haigney, 2000); and the ability to control a car in “non-routine” situations (Brown *et al*, 1969). Although the detrimental effect of mobile phone use increased with the mental workload imposed by the conversation (McKnight and McKnight, 1993; Strayer *et al*, 1999), an effect was evident nonetheless with “casual” conversations (McKnight and McKnight, 1993), even when the control condition consisted of listening to a car radio (Strayer *et al*, 1999). Furthermore, in one simulator study (Alm and Nilsson, 1994) it was found that the detrimental effects of a phone conversation on reaction time were greater when driving conditions were relatively undemanding as opposed to when they were taxing. The findings of two studies (McKnight and McKnight, 1993; Alm and Nilsson, 1995) suggest that the negative effects of a phone conversation on driving increase with age. This finding is not unexpected given evidence

Scientific Evidence

of a general age-related decline in ability to divide attention (see, for example, Gottlob and Madden, 1999).

- 5.207** Importantly, the foregoing studies suggest that the “central” effects of mobile phone use on driving are equivalent for hands-free and hand-held operation. Two studies that directly compared these modes of operation (Strayer *et al*, 1999; Haigney, 2000) reported no difference, albeit, in the case of Strayer *et al*, with a laboratory “tracking” task somewhat removed from driving (it is noteworthy that the Haigney study also failed to find any difference between hand-held and hands-free operation even when gear changes were made manually rather than automatically). In a third study (Brookhuis *et al*, 1991) the effects of the two modes of phone operation were compared during real driving (although with only six subjects in each group), and were found to have equally detrimental effects on speed of reaction to the slowing of a leading car. However, dialling with a hand-held set was associated with poor control over steering, especially when driving in city traffic. In the studies of McKnight and McKnight (1993) and Lamble *et al* (1999) the effects of conversation via a hand-held set were compared with those from tasks involving a combined cognitive and manual component (tuning a radio or keying in numbers); in both cases, merely engaging in a demanding conversation had effects equivalent to those of the combined task. According to Lamble *et al* (1999), the effect they observed on braking time was approximately three times that found for drivers with a blood alcohol level of 0.05% (the limit for many European countries; the UK limit is 0.08%).

Conclusions on experimental evidence for effects on driving

- 5.208** *There is strong experimental evidence that engaging in a mobile phone conversation impairs drivers’ ability to react to potentially hazardous road situations. The impairment appears to be greater than that associated with merely listening to a radio or engaging in a relatively “automatic” task such as repeating back words heard over the phone; is evident during a “casual” conversation; increases along with the mental workload imposed by the conversation; is greater in elderly drivers; and is unaffected by mode of phone use (hand-held versus hands-free). There is less evidence as to whether aspects of driving other than speed or accuracy of reaction to changing road circumstances differ according to mode of phone operation. Consistent with what might be expected on the basis of common experience, one study found that placing a call on a hand-held set is associated with a transient impairment in the basic control of the vehicle. The extent to which this “peripheral” effect adds to the risk posed by the more sustained “central” effects that are shared by hand-held and hands-free operation appears to be unknown at present. It should be noted that none of the studies reviewed above compared the effects on driving performance of phone use to the effects caused by conversing with a passenger. Thus it remains to be established whether an in-car conversation that places a cognitive load on the driver equivalent to that imposed by a mobile phone call has similarly detrimental effects on performance. There are, however, good reasons to suppose that the effects of an in-car conversation will be less than those associated with the use of a phone. In contrast to the individual on the other end of a phone call, a passenger can monitor the road situation and “pace” the interaction according to circumstances (for example, suspending conversation during an overtaking manoeuvre). In addition, a passenger can act as a second “pair of eyes”, alerting the driver to potential hazards.*

Epidemiological evidence for effects on driving

- 5.209** There are few systematic studies of the effects of mobile phone use on road traffic accident rates. Violanti and Marshall (1996) conducted a questionnaire survey of 100 randomly selected drivers who had been involved in a “reportable” road traffic accident during a 12 month period, and 100 geographically matched control drivers who had been accident-free for at least ten years.

Fourteen of the drivers who consented to participate were mobile phone users. After controlling for factors such as years of driving experience, Violanti and Marshall reported that there was a significant association between the likelihood of involvement in an accident and the use of a mobile phone for more than 50 minutes per month. These findings are, however, of questionable significance with respect to whether in-car phone use is detrimental to road safety; not only was the number of cases available for analysis very small, but the critical variable – monthly use of a mobile phone – provides, at most, a highly indirect index of in-car usage. The latter criticism also holds for the study of Dreyer *et al* (1999), who reported an association between the amount of mobile phone usage and road accident mortality.

- 5.210** Violanti (1997, 1998) examined accident records from the state of Oklahoma in the USA, where traffic police routinely record whether a mobile phone was present in a car involved in an accident, as well as whether the phone was reported to be in use when the accident occurred. In the first study (Violanti, 1997) rate-ratios were assessed for phone use and presence with respect to a number of accident characteristics. Use and presence were associated with a significantly elevated risk for accidents when these involved, among other things, “driver inattention”, driving in cities, running off the road, overturned vehicles, and injuries and fatalities. Phone users most at risk from fatalities were young males, but otherwise there was a trend for phone-related risks to increase with age. No steps were taken in the analyses as presented to remove the effects of any potential confounding variables that might have acted to exaggerate differences between phone users and non-users. The second study (Violanti, 1998) focussed exclusively on fatal accidents, addressing the question of whether, among drivers who had experienced an accident, the probability of a fatal outcome was influenced by the use or presence in the car of a mobile phone. Logistic regression was used in an attempt to remove the confounding effects of such variables as age and involvement with alcohol or drugs, as well as, puzzlingly, accident characteristics such as “unsafe speed”, and “driver inattention”. It was estimated that the likelihood of a fatality, given involvement in an accident, increased by a factor of about nine if a phone was in use, and was doubled if a phone was merely present in the car.
- 5.211** These two studies suggest there is a strong statistical association between the presence and use of mobile phones in cars and the likelihood of a serious traffic accident. There are, however, possible reasons for this association other than a detrimental effect of phone use on driving. It might be, for example, that drivers who carry or use a mobile phone differ from those who do not in ways that make them more likely to be involved in an accident. The finding that the mere presence of a phone in a car was associated with elevated risk is consistent with this possibility, although the finding could also reflect an underestimation of the proportion of accidents in which the phone was actually in use.
- 5.212** Redelmeir and Tibshirani (1997) employed a “case–crossover” design, in which each participant served as his or her own control. They investigated a group of 699 drivers who had reported involvement in a minor traffic accident, addressing the question whether these individuals were more likely to have been using a phone in the period leading up to their accident than they were during a comparable “control” period in the recent past. A correction factor was employed to allow for the fact that participants may not have driven during a control period. Redelmeir and Tibshirani found that *relative risk* increased with the proximity of phone use to the time of the accident. For example, use of a phone within 10 minutes of the accident was associated with an approximate quadrupling of risk, whereas phone use more than 15 minutes before the accident did not carry a significant risk. These findings were robust with respect to the choice of control period (eg day before, same day a week previously, etc) and were similar for a subgroup of drivers who reported (when questioned some two years afterwards) that they had definitely driven during the control period, and therefore for whom no correction for “driving intermittency” was required. Although numbers were small ($N = 129$ for hand-held;

Scientific Evidence

41 for hands-free), there was no evidence that risk differed according to mode of phone operation; indeed, there was a non-significant trend for hands-free operation to carry the greater risk.

- 5.213** The findings of Redelmeir and Tibshirani (1997) converge with those of Violanti (1997, 1998) to suggest that the use of a mobile phone while driving is associated with an increased risk of an accident. While the study does not suffer from the problems inherent to comparisons involving different groups of individuals, it nonetheless has a number of limitations, as indeed discussed by the investigators. Chief among these is that the findings do not permit the conclusion that the association between phone use and traffic accidents is causal. For example, it might be that the critical variable is the level of stress or time-pressure experienced by the driver, which is associated with an increased probability of making a phone call while on the move and an increased probability of an accident. Among other limitations of the study are its use of a self-selected group of drivers (of 1000 or so candidates, about 300 refused to participate), its focus on minor accidents, and the need, in the overall analysis, to rely upon a correction factor to allow for “driving intermittency” during control periods. These limitations notwithstanding, the study provides persuasive evidence that the use of a mobile phone while driving has a detrimental effect on road safety.

Conclusions on epidemiological evidence for effects on driving

- 5.214** *Experimental studies provide compelling evidence that engaging in a mobile phone conversation impairs driving performance. Consistent with this evidence, epidemiological research points to an association between mobile phone use while driving and an increased risk of involvement in an accident. Together, these two sources of evidence indicate that current concerns about the impact of mobile phones on road safety are well founded. As already noted, however, current experimental evidence suggests there is little or no justification for the assumption that the detrimental effects of phone use on driving are ameliorated by hands-free operation, a conclusion supported by the limited epidemiological evidence relevant to this question (Redelmeir and Tibshirani, 1997). There is therefore no strong empirical justification at present for the enactment of a policy or legislation that differentiates between the use of hand-held and hands-free phone sets in motor vehicles. While an argument might be made for focussing legislation on the more detectable of these two modes of use – it is of course much easier to detect the use of a hand-held set than a hands-free set – such an approach runs the risk of seeming to condone, or at least to tolerate, the use of hands-free phones.*

Epidemiological Studies on General Health Effects

- 5.215** Epidemiology is the branch of science that is concerned with the distribution and determinants of disease in human populations. As such, it provides the most direct evidence on whether and to what extent suspected environmental hazards cause disease. This evidence comes mainly from investigations that compare risks of disease in different groups of people according to their exposure to a suspected hazard. Usually, the results are expressed in terms of an estimate of relative risk, ie the multiplier by which risk is higher in people exposed to the hazard than in others who are unexposed or exposed at a lower level. For example, a relative risk of two for brain cancer in exposed compared with unexposed people would imply that the rate of brain cancer was twice as high in the former as in the latter group. It should be noted that the impact of a raised relative risk will depend on the underlying incidence of the disease to which it applies. A doubling in the frequency of a very rare disease represents a much smaller absolute increase in risk than a doubling of a common disorder.

- 5.216** The practical and ethical constraints on research in human populations mean that all epidemiological studies have limitations that must be taken into account in the interpretation of their findings. There may be deficiencies in their design or execution, often unavoidable, which tend spuriously to inflate or diminish estimates of risk – an effect known as “bias”. Practical restrictions on the numbers of people who can be studied mean that epidemiological studies are subject to statistical uncertainty, and may produce misleading results simply by chance (statistical techniques can be used to quantify the extent of this uncertainty). Even where risk is genuinely elevated, this does not necessarily indicate a causal relationship between the hazard and the disease. There may be one or more “confounding factors” that are associated with exposure to the hazard and that independently influence the chance of occurrence of a disease. For example, an increased risk of lung cancer in people living near to a radio mast might reflect the fact that on average they smoke more than people living elsewhere, rather than an effect of radiation emitted by the mast. In general, the closer the relative risk is to unity, the more difficult it is to rule out bias and confounding as explanations for an association between exposure and disease.
- 5.217** The scope for bias, chance effects and confounding is such that generally little weight can be given to a single epidemiological study in isolation and, when evaluating epidemiological evidence, it is important to base conclusions on the totality of all relevant studies. Sometimes, several studies that address the same problem can produce quite different estimates of risk. As well as differences in the impact of bias, chance and confounding, such discrepancies may reflect differences in the extent or pattern of exposure that was examined or the presence of other factors that modify the body’s response to a hazard.
- 5.218** To date, few epidemiological studies have directly examined the relationship of mobile phones to morbidity or mortality, and none has explored the effects of exposure to RF radiation from base stations. However, rather more information is available regarding exposure to other types of RF radiation – for example, in radar mechanics and radio operators, and from residence near broadcasting towers and masts. These exposures differ in frequency, dose and other characteristics from those produced by mobile phones and base stations, so they give only an indirect indication of the possible risks from mobile phone technology. Nevertheless, they are relevant and worth consideration.
- 5.219** Four main types of study have been used in this area of research – cohort studies, case–control studies, cross-sectional surveys of morbidity, and cross-sectional, “ecological” comparisons of mortality or cancer incidence between populations. In a cohort study, individuals who have been exposed to a known or suspected hazard are identified and their subsequent disease incidence or mortality is assessed over a period of follow-up. This is then compared with the corresponding rate of disease or death in a control group who have been unexposed or only exposed at a lower level. A case–control study starts with patients who have developed a disease (cases) and compares their past exposure to known or suspected causes with that of suitably chosen controls who do not have the disease. Cross-sectional surveys of morbidity focus on a representative sample of a population (eg residents of a specified area), and collect information from individuals in the sample about their disease experience and about current and past exposures to known or suspected causes of disease. The statistical association between exposure and disease is then examined. Ecological analyses of mortality and cancer incidence assess the frequency of death or of new cases of cancer in different populations (eg in occupational groups or residents of defined geographical areas) over a period (say a few years), and relate this to differences in the levels of exposure of the whole population to known and suspected hazards. For example, death rates might be compared in people living close to and further away from a television mast. It should be noted that the first three methods assess disease and exposure in individuals, whereas the ecological method relates to populations. Even where disease rates are consistently high in heavily exposed populations, it does not necessarily follow that the individuals within those

populations who suffer the disease have themselves been exposed. In general, the ecological method, because of the lack of individual data, is the least robust of the four study designs, and often, although by no means always, the cohort method is the most rigorous.

Studies of people using mobile phones

5.220 Widespread use of mobile phones is a recent phenomenon, and as yet few epidemiological studies have looked directly at whether there are associated risks of illness or death.

Mortality and cancer incidence

5.221 One investigation has examined mortality among customers of a large mobile phone operator in the USA (Rothman *et al*, 1996). It covered some 250,000 phone users, who were followed for one year. During this time, the overall death rate was similar in people using hand-held phones and in users of other mobile phones that did not have an antenna in the handset, and therefore gave lower exposures to RF radiation. For those customers who had been listed as continuous users for at least three years, overall mortality was slightly lower in the hand-held phone users than the other mobile phone users, but the difference was not statistically significant (relative risk = 0.86). Numbers of brain tumour and leukaemia deaths were small and showed no substantial indication of increasing risk with number of minutes of hand-held phone use per day, or with years of hand-held phone use (Dreyer *et al*, 1999). No data were reported on whether phones used analogue or digital signals (at this time, in the USA most mobile phone networks used analogue signals). If mobile phones do affect mortality, the impact is likely to be on only certain specific causes of death. Also, any increase in diseases such as cancer may not be manifest until many years after people are first exposed to a hazard. *Therefore, although no significant differences in mortality were demonstrated between the two exposure groups, the conclusions that can be drawn from this report are limited, and it does not rule out important effects.*

5.222 In a case-control study in Sweden, patients with brain tumours were asked about various aspects of their life including their use of mobile phones, and the findings were compared with those in controls selected from the general population (Hardell *et al*, 1999). Overall, the risk of brain tumours did not appear to be elevated in people who used mobile phones, either analogue or digital, even if their use was relatively heavy. In a series of subsidiary analyses, an association was observed between tumours in the temporal and occipital lobes of the brain and reported use of analogue phones on the same side of the head (regardless of whether that was to the left or right). However, this was not statistically significant, and could easily have occurred by chance. Interpretation of this study is complicated because it failed to identify a substantial number of brain tumour patients who were eligible for inclusion according to the reported entry criteria (Ahlbom and Feychting, 1999), and in the absence of an explanation for this under-ascertainment, it is unclear whether important bias could have resulted. Also, as in the study by Rothman *et al*, an effect of exposure that was delayed for ten or more years would not have been apparent.

Other health effects

5.223 In an attempt to identify other, more immediate, adverse health effects that might be associated with the use of mobile phones, Hocking (1998) placed a notice in a medical journal in Australia. From this and subsequent publicity, he recruited 40 individuals with symptoms which they related to using mobile phones. These symptoms were mainly in the head, and included pain, unpleasant warmth or heating, blurring of vision and deafness or vertigo. Most started within five minutes of beginning a call, but some built up over the course of the day. A perceived temporal association between use of a phone and the development of symptoms does not necessarily imply that RF radiation is responsible. Rather, the findings of Hocking's study should be regarded as an

indication of the types of symptom that users claim, and which might merit more rigorous investigation to determine whether there is any causal relationship to mobile phone use. It is notable, however, that there were no reports of epileptic seizures triggered by phone use, although this has been alleged to occur in relation to exposures from base stations.

- 5.224** Larger-scale data on self-reported, subjective symptoms are available from a cross-sectional survey of some 11,000 mobile phone users in Sweden and Norway (Hansson Mild *et al*, 1998). A postal questionnaire was used to collect information about various symptoms including fatigue, headache and warmth behind and on the ear. Of the participants, 13% in Sweden and 30% in Norway reported the occurrence of at least one symptom, which they themselves related to mobile phone use. For both analogue and digital phones, the prevalence of reported symptoms increased with minutes per day of phone use. The proportion of GSM phone users reporting a symptom was rather lower than in other groups. The marked difference in the prevalence of complaints between Sweden and Norway has a number of possible explanations. It is well known that somatic complaints can be influenced by psychosocial circumstances. For example, back pain is more likely to be reported by people who are depressed or dissatisfied in their work. Furthermore, at the time of the survey there had been much publicity in Scandinavia about possible adverse health effects of electromagnetic fields. In these circumstances, it would not be surprising if people who used mobile phones extensively were more aware of and troubled by minor symptoms, and more likely to report them when questioned. Thus as in the Australian study, the various symptoms reported by the users of mobile phones cannot necessarily be attributed to RF radiation. To address this question, further research is needed with a different study design (see paragraphs 5.258–5.260).

Exposure to RF radiation through work and hobbies

- 5.225** A number of epidemiological investigations have examined the risk of illness or death in people potentially exposed to RF radiation through their work or hobbies, and these have been the subject of several previous reviews (EC, 1996; Elwood, 1999; Moulder *et al*, 1999; Royal Society of Canada, 1999). The diseases most often studied have been lymphatic and haematopoietic cancers (including lymphoma and leukaemia) and brain cancer.

Cancer

- 5.226** Table 5.19 summarises the investigations that provide information about lymphatic and haematopoietic cancers. The study by Szmigielski (1996) stands out in suggesting a more than six-fold elevation in the risk of these diseases among Polish military personnel with occupational exposure to RF radiation. However, Szmigielski's report is unsatisfactory, and can be given little, if any, weight. In particular, it appears that the exposures of cancer cases were ascertained from a different source (medical records) from those of the study population as a whole (provided by safety staff), and this could seriously have biased risk estimates. Also, the statistical methods are not adequately described, and certain important data are missing from the report.
- 5.227** If this investigation is discounted, only one study shows a statistically significant increase in risk – of leukaemia in Norwegian electrical workers (Tynes *et al*, 1992). In some of the other studies, risks were also elevated, although not to the point of statistical significance. These elevations of risk were either for leukaemia or for lymphatic and haematopoietic cancers as a group. (This grouping is often used in epidemiological studies, partly because misclassification of cases may occur when more specific diagnostic categories are employed. However, no carcinogen has yet been identified that causes all of the cancers in the group.) In most of the studies, the index of exposure to radiation was relatively crude and non-specific, and the workers may have experienced other confounding exposures. Thus, the observed increases in risk could have been due to chance or to factors other than RF radiation. At the same time, however, because of their low statistical power and the heterogeneity of the exposures examined, the absence of a clear and

Table 5.19 Epidemiological studies of lymphatic and haematopoietic cancer in people potentially exposed to RF radiation through work or hobbies

Type of study	Study population	Exposure condition	Disease outcome	Number of exposed cases	Estimated relative risk (with 95% CI)*	References
Cohort	Radar technicians in US Navy	Occupations with higher exposure to RF radiation (radar)	Death from lymphatic or haematopoietic cancer	26	1.18	Robinette <i>et al</i> , 1980
Cross-sectional analysis of proportional mortality	Men age 20+ years in Washington State, USA	Radio and telegraph operators Radio and television repairmen	Death from lymphatic or haematopoietic cancer	15 12	1.37 1.27	Milham, 1985
Cohort	Amateur radio operators in California and Washington State, USA	Amateur radio operators	Death from lymphatic or haematopoietic cancer	89	1.23 (0.99–1.52)	Milham, 1988
Cohort	White male enlisted men in US Navy	Radiomen Aviation electronics technician	Non-Hodgkin's lymphoma	2 1	0.6 (0.1–2.0) 0.4 (0.0–2.2)	Garland <i>et al</i> , 1988
Case-control	Men aged 20+ years in New Zealand	Radio and television repairmen	Leukaemia	2	7.9 (2.2–28.0)	Pearce and Fraser, 1989
Cohort	White male enlisted men in US Navy	Radiomen Electronics technician	Leukaemia	4 5	1.1 (0.3–2.8) 1.1 (0.4–2.6)	Garland <i>et al</i> , 1990
Cohort	Norwegian electrical workers	Occupations with potential exposure to RF radiation	Leukaemia	9	2.85 (1.30–5.41)	Tynes <i>et al</i> , 1992
Cohort	Norwegian female radio and telegraph operators	Radio and telegraph operators	Leukaemia Lymphoma	2 5	1.1 (0.1–4.1) 1.3 (0.4–2.9)	Tynes <i>et al</i> , 1996
Cohort	Polish military personnel aged 20–59 years	Occupational exposure to RF radiation	Lymphatic and haematopoietic cancer	Not given	6.31 (3.12–14.32)	Szmigielski, 1996
Cohort	Female employees in an Italian plastics factory	Exposure to RF radiation through work in a dielectric heat sealing department	Death from leukaemia	1	5.0	Lagorio <i>et al</i> , 1997
Cohort	Men and women employed in the design, manufacture and testing of wireless devices	Work in occupations with moderate or high peak exposures to RF radiation	Death from lymphatic or haematopoietic cancer	20	0.54 (0.33–0.83)	Morgan <i>et al</i> , 2000

*Confidence intervals, where shown, are as calculated by the authors

Table 5.20 Epidemiological studies of brain cancer in people partially exposed to RF radiation through work or hobbies

Type of study	Study population	Exposure condition	Disease outcome	Number of exposed cases	Estimated relative risk (with 95% CI)*	References
Cross-sectional analysis of proportional mortality	Man aged 20+ years in Washington State, USA	Radio and telegraph operators Radio and television repairmen	Death from brain cancer	1 2	0.38 0.59	Milham, 1985
Case-control	White men aged 30+ years from three areas of USA	Ever worked in a job with likely exposure to RF radiation	Death from brain cancer	69	1.6 (1.0–2.4)	Thomas <i>et al</i> , 1987
Cohort	Amateur radio operators in California and Washington State, USA	Amateur radio operators	Death from brain cancer	29	1.39 (0.93–2.00)	Milham, 1988
Cohort	Norwegian electrical workers	Occupations with potential exposure to RF radiation	Brain tumours	3	0.61 (0.13–1.78)	Tynes <i>et al</i> , 1992
Cohort	Norwegian female radio and telegraph operators	Radio and telegraph operators	Brain tumours	5	1.0 (0.3–2.3)	Tynes <i>et al</i> , 1996
Cohort	Polish military personnel aged 20–59 years	Occupational exposure to RF radiation	Tumours of the nervous system and brain	Not given	1.91 (1.08–3.47)	Szmigielski, 1996
Case-control	Male personnel in US Air Force	Potential exposure to RF radiation	Brain tumours	94	1.39 (1.01–1.90)	Grayson, 1996
Cohort	Female employees in an Italian plastics factory	Exposure to RF radiation through work in a dielectric heat sealing department	Death from brain cancer	1	10.0	Lagorio <i>et al</i> , 1997
Cohort	Men and women employed in the design, manufacture and testing of wireless devices	Work in occupations with moderate or high peak exposure to RF radiation	Deaths from cancers of the nervous system and brain	7	0.53 (0.21–1.09)	Morgan <i>et al</i> , 2000

*Confidence intervals, where shown, are as calculated by the authors

Scientific Evidence

consistent elevation of risk in these studies cannot be taken as strong evidence against an association with specific types of RF radiation.

- 5.228** Where several epidemiological studies have addressed the same question, each individually with low statistical power, it is sometimes possible to draw firmer conclusions by combining their findings in a formal statistical “meta-analysis”. However, this approach is not appropriate for the studies listed in Table 5.19 because they are too disparate.
- 5.229** Table 5.20 lists the studies that give information on the risk of brain tumours. Again, for reasons already stated, little weight can be given to the report by Szmigielski (1996). Apart from this, two investigations have found a statistically significant elevation of risk, both of them case-control studies.
- 5.230** The first (Thomas *et al*, 1987) recruited cases from the general population of three areas of the USA, and classified exposure on the basis of job titles as reported by the subjects’ next of kin. The association with exposure to RF radiation was confined to jobs involving the design, manufacture, installation and maintenance of electrical and electronic equipment, leading the authors to suggest that some aspect of work other than RF radiation might be responsible. The aetiology of brain tumours, however, is largely unknown, so it is uncertain whether these occupations have relevant exposures in common.
- 5.231** The second study (Grayson, 1996) focussed on male personnel in the US Air Force, with exposures assessed from occupational histories. Although risk was significantly higher in men exposed to RF radiation than in those classed as unexposed, the elevation was modest even in those thought to have the heaviest exposures.
- 5.232** Other studies of brain cancer have given inconsistent results. As for haematopoietic and lymphatic cancer, the results overall do not indicate an increased risk of brain tumours from RF radiation, but because of various limitations neither do they provide strong reassurance that there is no hazard. These limitations include poor, often highly indirect, assessment of RF exposure and low statistical power.
- 5.233** Data on other types of cancer are more sparse and although some have suggested increased risks from RF exposure, their limitations are such that these findings should not be a cause for concern.
- 5.234** In a cohort study of Norwegian female radio and telegraph operators, Tynes *et al* (1996) found a relative risk of 1.5 for breast cancer (95% confidence interval 1.1–2.0). However, no relationship to RF radiation was apparent in a large case-control study of female breast cancer in the USA that used occupational information obtained from death certificates (Cantor *et al*, 1995), or in a cohort study of workers employed in the design, manufacture and testing of wireless devices in the USA (Morgan *et al*, 2000). However, this study does not give information directly on mobile phone use or exposures occurring from such use (Owen, 2000).
- 5.235** A cluster of six men with testicular cancer has been reported in a population of US police officers who used hand-held radar guns (Davis and Mostofi, 1993). However, in the only epidemiological study to examine the relationship between testicular cancer and work with radar equipment (Hayes *et al*, 1990), results were inconclusive: the risk of testicular cancer was significantly elevated in men who reported occupational exposure to RF radiation, but not when the radiation exposures were inferred from job titles by an occupational hygienist. This inconsistency between the results from the two methods of assessment raises the possibility that cases recalled their

exposures more completely than controls, or overestimated their exposures, leading to a biased risk estimate.

5.236 In a study in the USA, a raised risk of uveal melanoma was found in men with self-reported exposure to RF or radar (Holly *et al*, 1996), but RF radiation has not been examined in other published studies of this tumour.

5.237 *In summary, the overall balance of evidence from epidemiological occupational studies does not indicate that RF radiation affects the risk of cancer in people. However, the types of exposure investigated have varied between studies and are not identical to those associated with mobile phone technology. Also, many of the studies have had low statistical power and some have suffered from methodological deficiencies. Therefore, the absence of consistently positive findings does not establish firmly that RF radiation from mobile phones carries no important risk of cancer.*

Health outcomes other than cancer

5.238 Although cancer has been the main health outcome studied in relation to work with RF radiation, several cohort studies of occupational groups exposed to RF radiation have also examined non-cancer mortality and in some instances morbidity (see, for example, Robinette *et al*, 1980; Muhm, 1992). These do not provide any overall evidence of hazard.

5.239 In addition, several case–control studies have explored the risk of adverse outcomes of pregnancy in physiotherapists using microwaves in the RF range to treat their patients. One such study found a significantly raised risk of spontaneous abortion (miscarriage) in physiotherapists who reported exposure during the six months before and three months after becoming pregnant (relative risk 1.28, 95% confidence interval 1.02–1.59), and a higher risk in those with more frequent exposure (Ouellet-Hellstrom and Stewart, 1993), although with a relatively low response rate to the questionnaire that was used to collect information. No corresponding association was found with use of short-wave diathermy. Overall, however, studies of pregnancy in physiotherapists have not supported a relation of microwave exposure with miscarriage or other adverse outcomes (Kallén *et al*, 1982; Taskinen *et al*, 1990; Royal Society of Canada, 1999).

5.240 Despite this lack of evidence for health risks resulting from the exposure of workers to RF radiation, it would be sensible to set in place a long-term follow-up of workers who are occupationally exposed to RF radiation at relatively high levels. **We recommend that a register of occupationally exposed workers be established and that cancer risks and mortality be examined to determine whether there are any harmful effects. If any adverse effects of exposure to RF radiation are identified then the Health and Safety Executive should establish a system of health surveillance.**

Residence near radio and television transmitters

5.241 The incidence of cancer in people living near to radio or television transmitters has been examined in studies from the USA, Britain and Australia.

5.242 Selvin *et al* (1992) looked for clustering of childhood leukaemia, lymphoma and brain cancer within 3.5 km of a microwave tower in San Francisco. The main purpose of their investigation was to compare methods of statistical analysis, and they did not adjust closely for potential confounding factors. However, they found no evidence of any excess incidence in the study area.

5.243 In contrast, a case–control study in Hawaii suggested an approximate doubling in the occurrence of childhood leukaemia within 4.2 km of a group of radio masts (Maskarinec *et al*, 1994). The

number of exposed cases was small, however, and the excess was far from statistically significant. Furthermore, the investigation had been prompted by a perceived local excess of the disease, and in this circumstance it is more difficult to rule out the play of chance. In the same way that some communities can have a disproportionate excess of lottery winners purely by chance, a cancer can occur more frequently in a small geographical area (and will then be noticed to be common there) without there being a local cause for the phenomenon.

- 5.244** Concerns about an apparent excess of leukaemia and lymphoma were also the trigger for a geographical analysis of cancer incidence in the neighbourhood of a television and radio transmitter in Sutton Coldfield, England (Dolk *et al*, 1997a). The investigation confirmed that there had been an increased incidence of leukaemia within 2 km of the transmitter, the relative risk being approximately 1.8 in comparison with the regional population. None of the other cancers analysed apart from bladder cancer (relative risk 1.5), showed a statistically significant excess near to the transmitter. The authors recognised that despite their statistical significance, these findings could easily have occurred by chance, and therefore carried out a similar analysis for people living close to other high power radio and television transmitters in Britain (Dolk *et al*, 1997b). This showed no excess of leukaemia within 2 km of the transmitters. Rates of bladder cancer were marginally elevated within a 10 km radius (relative risk 1.09), but did not decline progressively with distance from the transmitters as might be expected if RF radiation were responsible.
- 5.245** In Australia, Hocking *et al* (1996) compared rates of leukaemia and brain tumours in three municipalities of Sydney surrounding television masts and six others at a further distance from the masts. The findings for brain tumours were unremarkable, but there was an approximate 60% excess of leukaemia among children from the three areas close to the towers. Subsequently, McKenzie *et al* (1998) explored this pattern of leukaemia incidence further with an expanded control area. The excess incidence was found to be limited to only one of the three municipalities surrounding the masts, suggesting that chance or some local factor other than RF radiation was responsible.
- 5.246** In addition to these investigations published in scientific journals, some reviews refer to studies of people living near a military microwave generator–detector system in Latvia, and of staff and their dependants in American embassies in Eastern Europe who may have been exposed to microwave radiation beamed into the embassies (Goldsmith, 1995; Repacholi, 1998). However, these have not been published in the peer-reviewed literature, and we have not been able to obtain sufficiently detailed descriptions of these investigations to evaluate them.
- 5.247** The studies to date that have looked at cancer incidence in relation to residence near broadcasting facilities have major limitations, which weaken the conclusions that can be drawn from them. The analyses have not been based on measured levels of radiation. Distance from a broadcasting tower has been taken as a proxy for exposure, but no account has been taken of ground reflections and signal reductions by buildings, vegetation and undulations, which may alter actual exposure considerably. The studies have been based on cancer and exposure data for populations not individuals, with the associated weaknesses of “ecological” studies (see paragraph 5.219). Personal exposures will vary according to how much time people spend at home, whether they are indoors or outdoors, the other sources of RF radiation in and near to their homes, and their levels of exposure at work, when travelling, and from mobile phone use. None of these has been taken into account. Furthermore, the studies have analysed risks in relation to place of residence at the time of cancer incidence or death, but if RF radiation does cause cancer, the relevant exposure may well be years or even decades before the disease becomes manifest. Thus while the balance of evidence from such studies does not indicate a hazard – and where increased rates of

disease have been found they could have occurred by chance or as a consequence of unrecognised confounding factors – the findings do not provide strong evidence against a hazard.

Conclusions from epidemiological studies

- 5.248** *Apart from the risks associated with the use of mobile phones while driving, which are discussed in paragraphs 5.201–5.214, there is no persuasive epidemiological evidence that exposure to RF radiation in general – or to the limited extent that it has been investigated, mobile-phone-related exposures in particular – causes disease in people. Although the epidemiological research that has been carried out to date does not give cause for concern, it has too many limitations to give reassurance that there is no hazard. A substantial number of people report symptoms such as fatigue, headache and feelings of warmth behind the ear that occur during or shortly after the use of mobile phones. However, it is unclear to what extent, if any, these symptoms are caused by RF radiation.*

Proposals for further research

- 5.249** In view of the widespread use of mobile phone technology, any adverse effects on health could affect large numbers of people. This is clearly a source of anxiety among some members of the public. We therefore identify the following epidemiological research to try to resolve the current uncertainty. Details of the methodological considerations needed to conduct these studies with high quality are given by EC (1996), Swerdlow (1997), and Repacholi and Cardis (1997).

Case-control studies of cancer risk in relation to the use of mobile phones

- 5.250** There is a pressing need for case-control studies to examine whether leukaemia and cancers of the brain, acoustic nerve and salivary gland are caused by mobile phone use.
- 5.251** A large case-control study of the risk of brain tumours in relation to the use of mobile phones is close to publication in the USA (Inskip *et al*, 1999), but its results are not yet available to us. An international case-control study of brain cancer, acoustic neuroma, salivary gland tumours and leukaemia co-ordinated by the International Agency for Research on Cancer (IARC), and including components in Britain, has received partial funding from the European Commission. At the time of our review, however, funding is incomplete and it is unclear how much of the study will be undertaken. The IARC study also includes important methodological work to assess the validity of subjects' recall of mobile phone use in comparison with information from billing records.
- 5.252** In view of the possibility that mobile phones might cause malignancies after a long induction period, such case-control studies may need to be repeated in the future when the technology has been in place for a longer time, and also in order to cover the possibility that changes in technology might be material to risk.
- 5.253** *We propose that large case-control studies of brain cancer, acoustic neuroma, salivary gland cancer, and leukaemia should be funded.*

Cohort study of users of mobile phones

- 5.254** The case-control method has several limitations. These include difficulties in the selection of appropriate controls and the possibility that cases recall and report exposures more completely than controls. Also, case-control studies usually focus on only one or two diseases, whereas in a single cohort study many different health outcomes can be examined. In the case of RF radiation from mobile phones, concerns have been expressed about a possible risk of leukaemia or tumours of the head and neck, but there is also uncertainty about the risks of other diseases.

Scientific Evidence

- 5.255** Therefore, despite its cost, we believe that a large cohort study following up individuals according to their use of mobile phones would be desirable, and would complement the case-control studies discussed in paragraphs 5.250–5.253. Such a study would start to produce results within a few years, but because of the need to monitor possible long-term effects, it would need to continue for many years in the future. It could provide information on risks of all cancers and causes of death, rather than the few specific diseases currently being investigated by the case-control method, and would eventually allow examination of effects that might occur with longer induction periods. It would also offer scope for studies of morbidity in subsets of individuals (eg of neuropsychological disorders) if these were required.
- 5.256** We are aware of three existing cohort studies worldwide: one of 250,000 mobile phone users in the USA that we understand is currently in abeyance (Rothman *et al*, 1996; Dreyer *et al*, 1999), one of 550,000 users in Denmark (Johansen and Olsen, 1999), and one of 50,000 users in the UK (Beral, 2000). The US and Danish studies were based on individuals identified from operators' records, and were planned as mobile phone cohorts, whereas the British subjects, who are from a national cohort of women attending breast screening clinics, were not chosen on the basis of mobile phone use and include few long-term users. Although these studies should provide useful information, we think that there would be benefits from a further cohort study in the UK focussing specifically on long-term use of mobile phones.
- 5.257** In order to have statistical power to examine risks of specific cancers and non-cancer outcomes, a cohort study would need to be very large, including tens or even hundreds of thousands of individuals. For this reason, it would be expensive. In order to maximise the information that could usefully be gained within the next few years, it would be essential that it included large numbers of long-term users of mobile phones. There is usually an interval of some years between first exposure to a cause of cancer and the manifestation of an increased risk of the disease. Also, any risks from the use of early models of mobile phone are of particular importance since these early models had greater power outputs than those used more recently. As mobile phone use in the UK started particularly early by international standards, but covered only a small proportion of the population (120,000 in 1986; 500,000 in 1988), there is the potential to conduct a study of international importance, provided that it focusses on this early-user population. The study will therefore need to concentrate on populations where intensive use began earliest; we understand that this was in the London area. It is also desirable that the study should collect information not just on phone use, but also on potentially confounding variables, as far as practical. Early users of mobile phones may have very different characteristics from the general population with regard to, for instance, reproductive history, socioeconomic factors and other factors related to risk of disease.
- 5.258** *We propose that in addition to already ongoing cohort studies, a large cohort study of long-term mobile phone users be undertaken in the UK, which focusses particularly on people who started use in the 1980s and that, given the considerable design difficulties and potential costs entailed, a pilot study should be undertaken before a full-scale investigation.*

Symptoms in mobile phone users

- 5.259** The Expert Group heard several reports of mobile phone users who claimed symptoms relating to phone use, and the evidence from studies enquiring about this has indicated a substantial prevalence of symptoms thought by users to be related to phone use. To determine whether such symptoms are a consequence of RF radiation from phone use, a "double-blind" trial is needed, ie an experimental study of the occurrence of symptoms in circumstances where neither the user nor the observer knows whether a phone device is switched on or not. The Group also heard reports

Conclusions Based on Overall Scientific Evidence

of “highly sensitive” individuals; these individuals particularly need testing as to whether or not they truly have symptoms that relate to phone use under double-blind conditions.

5.260 Although the main focus of research on this question needs to be on trials in volunteers rather than on epidemiology, there would nevertheless be value in conducting a survey in the UK to discover the nature and prevalence of reported symptoms in the British context.

5.261 *We propose that double-blind trials be undertaken to assess the relation of mobile phone use to symptoms such as headache that have been reported by users, and that a cross-sectional survey of symptoms be conducted in relation to mobile phone use in the UK.*

Mobile phone use and motor vehicle accidents

5.262 As reviewed above, the available data suggest that mobile phone use can be a factor causing road traffic accidents, but they do not show greater risk in relation to hand-held as compared with hands-free phones nor whether mobile phones increase risk more than other causes of inattention such as the use of radios or conversations with passengers. The relationship of mobile phone use to the occurrence of accidents has major implications for public health policy, and it is therefore important to gain evidence on which to base this policy, especially on the comparative risks from hand-held and hands-free devices.

5.263 *We propose that further epidemiological studies should be undertaken to clarify the relation of mobile phone use to the risk of motor vehicle accidents, and in particular whether the risk differs between hand-held and hands-free phones, and whether the risk of hands-free use exceeds that of other forms of driver distraction, notably conversation with passengers.*

Effect of mobile phone base stations on well-being

5.264 Whilst we have focussed on the information available in the published literature, the Group was struck by the concerns expressed by many who attended the public meetings and who wrote to us about adverse effects on their well-being which they attributed to the presence of mobile phone base stations near to residences, schools, etc (see paragraphs 3.5 and 3.6). The social impact of mobile phone technologies needs to be fully considered. In addition to the improvements in planning which we consider to be essential (paragraphs 6.55–6.62) *there is a need for a significant research programme to be initiated so that the impact of mobile phone technologies on well-being in its broadest sense is properly addressed and understood through epidemiological or other approaches.* This should be brought to the attention of funding agencies such as the Economic and Social Research Council, the Medical Research Council, the European Commission and other bodies.

Conclusions Based on Overall Scientific Evidence

5.265 We conclude that there is one substantial established risk to health from mobile phone technology, namely through the increased incidence of motor vehicle accidents when drivers use mobile phones. Since the chance of an accident appears to be equally elevated for hands-free and hand-held use, this effect is almost certainly due to the distracting effect of the conversation, rather than to interference with steering the vehicle or to a direct influence of RF radiation on the brain.

5.266 There is also good evidence that exposure to mobile phone signals at intensities within existing ICNIRP guidelines has direct, short-term effects on the electrical activity of the human brain and

Scientific Evidence

on cognitive function. These could have their origin in a variety of biological phenomena, for which there is some evidence from experiments on isolated cells and animals. There is an urgent need to establish whether these direct effects on the brain have consequences for health, because, if so, and if a threshold can be defined, exposure guidelines will have to be reconsidered. It is also important to determine whether these effects are caused by local elevation of temperature or, as seems possible, by some other, “non-thermal”, mechanism.

- 5.267** The epidemiological evidence currently available does not suggest that RF exposure causes cancer. This conclusion is compatible with the balance of biological evidence, which suggests that RF fields below guidelines do not cause mutation, or initiate or promote tumour formation. However, mobile phones have not been in use for long enough to allow comprehensive epidemiological assessment of their impact on health, and we cannot, at this stage, exclude the possibility of some association between mobile phone technology and cancer. In view of widespread concern about this issue, continued research is essential.
- 5.268** Experimental studies on cells and animals do not suggest that mobile phone emissions below guidelines have damaging effects on the heart, on blood, on the immune system or on reproduction and development. Moreover, even prolonged exposure does not appear to affect longevity. The limited epidemiological evidence currently available also gives no cause for concern about these questions.
- 5.269** The balance of evidence indicates that there is no general risk to the health of people living near to base stations where the exposures are only small fractions of guidelines.

Overall Recommendations for Future Research

- 5.270** On the basis of the current state of knowledge **we recommend that priority be given to a number of areas of research related particularly to signals from handsets.** These should include the following:
- effects on brain function,
 - consequences of exposures to pulsed signals,
 - improvements in dosimetry,
 - the possible impact on health of subcellular and cellular changes induced by RF radiation,
 - psychological and sociological studies related to the use of mobile phones,
 - epidemiological and human volunteer studies (paragraphs 5.249–5.264), including the study of children, and individuals who might be more susceptible to RF radiation (paragraphs 4.37, 6.29 and 6.30).
- 5.271** **We recommend that a substantial research programme should operate under the aegis of a demonstrably independent panel.** The aim should be to develop a programme of research related to health aspects of mobile phones and associated technologies. This should complement work sponsored by the EU and in other countries (paragraphs 5.274–5.285). In developing a research agenda the peer-reviewed scientific literature, non-peer-reviewed papers and anecdotal evidence should be taken into account.

- 5.272** We further recommend that this programme be financed by the mobile phone companies and the public sector (industry departments, health departments and the research councils), possibly on a 50 : 50 basis. The contribution from industry could be made on a voluntary basis or by a continuing levy reviewable every five years.
- 5.273** It will be essential for further research in this area to be kept under review. We recommend that the issue of possible health effects of mobile phone technology should be the subject of a further review in three years time, or earlier if circumstances demand it. We note the World Health Organization (WHO) has an established formal process of risk assessment relating to RF fields within this time frame.

ANNEX

Current Research Funding

- 5.274** Funding for research on health effects arising from exposure to RF radiation progressively increased through the 1990s, although it has not been straightforward to raise sufficient funds for a comprehensive programme. This has resulted from a number of reasons. In particular, funding from Government has been limited, as has support from industry and in the latter case there continues to be a problem of potential conflicts of interest, which needs to be addressed in any future funding arrangements.
- 5.275** In the early 1990s, the emphasis of research on possible health effects associated with exposure to electromagnetic fields and radiations (EMFs) was principally driven by concerns about exposure to extremely low frequency (ELF) electromagnetic fields. Substantial funding was made available in the USA for both epidemiological and experimental studies through the RAPID programme, sponsored jointly by the Department of Energy (DOE) and the National Institute of Environmental Health Sciences (NIEHS) with support from industry. This was also the main emphasis for funding in Europe and around the world.
- 5.276** In the mid-1990s, however, in the early days of mass marketing of mobile telecommunications, issues about possible health effects began to arise. A turning point in the debate was a discussion of the issue on the CNN programme, *Larry King Live*, in the early 1990s, which focussed on a brain tumour in a man who had been occupationally exposed to RF radiation from mobile phones. The suggestion on the programme was that this cancer could have been caused as a result of his exposure. This TV programme was probably instrumental in establishing a programme of research in the USA, funded principally by industry, and finally called the Wireless Technology Research programme. It had a budget in the range from about \$20M to \$30M and supported a programme of experimental and epidemiological studies. It came to a close at the end of the 1990s and much of the work that was carried out under the programme is presently being prepared for publication. There are no indications of a further substantial research effort being mounted in the USA at present.
- 5.277** In Europe, concerns about possible health effects of exposure to RF radiation from mobile phones followed those in North America but with a delay of about two years. In 1996, the European Commission contracted an EC Expert Group to make recommendations for a programme of scientific research on personal telecommunications and human health. The EC Expert Group reported in September 1996 but it has taken until the beginning of 2000 for the programme to get under way. The EC Expert Group recommended a number of areas for research including:
- *in vitro* studies;
 - experimental studies in laboratory animals covering
 - genotoxicity,
 - cancer studies,
 - effects on the immune system,
 - nervous system related studies;
 - human laboratory research on possible neurophysiological effects;

- provocation studies involving the acute exposure of people claiming neurological systems, changes in sleep pattern and effects on the immune system;
 - epidemiological studies related to the possible risk of brain cancer;
 - cancers of other exposed tissues.
- 5.278** Although specific details of the programme to be funded by the EC have not been published, many of the proposals have been supported including experimental studies in laboratory animals and epidemiological investigations. Human volunteer studies do not appear to have been supported at present. The telecommunications industry is supporting the EC programme with input on the design and development of exposure facilities and exposure assessment.
- 5.279** Within the EC, a COST Action Plan has also been developed on possible health effects related to the use of mobile phones. The plan contains an update of the report and recommendations of the 1996 EC Expert Group report and the published proceedings of a forum on future European research on mobile telecommunications and health, held at the University of Bordeaux, 19–20 April 1999. The research recommendations are generally in line with those in the 1996 Expert Group report, updated where appropriate.
- 5.280** Within the UK, NRPB has a programme of research related to possible health effects of RF radiation. Its total budget is about £300k per year and covers the development of the application of anatomically realistic phantoms, based on medical imaging data, to assess exposure; experimental studies on cells in culture; and studies on the possible behavioural effects of RF exposure using experimental animals.
- 5.281** NRPB is providing substantial support on exposure assessment protocols and measuring equipment calibration for a national study to investigate occupational exposure to RF electromagnetic fields and radiation from various sources, including broadcast transmitters and telecommunications. The study started on 1 November 1998 and is being carried out in collaboration with the Institute of Occupational Health, University of Birmingham, with support from industry. It aims to determine the feasibility of undertaking an industry-wide epidemiological study and seeks to develop an appropriate exposure metric.
- 5.282** Over the last three years the Department of Health and the Health and Safety Executive have funded two studies in the UK covering human volunteer investigations and experimental studies on the effects of RF radiation on brain tissue *in vitro*. The total budget has been £117k. In addition, £20k per year is contributed to the WHO EMF programme. Presently Government is in discussion with industry about funding a collaborative UK-based research programme to which public funds could be allocated. This is in response to the Third Report of the Science and Technology Committee (1999).
- 5.283** Internationally, a number of other programmes are under way. The WHO Research Agenda is of particular importance in this context. The Agenda was set out by WHO following an evaluation of research priorities based on the recommendations of the EC Expert Group and conclusions from relevant workshops and reviews.
- 5.284** The items on the WHO Research Agenda relevant to mobile phone technology and human health follow.
- Large-scale standard two-year animal bioassays such as those typically conducted by the US National Toxicology Program. These studies should be carried out using normal animals and animals initiated with chemical carcinogens. The exposures should use RF radiation in the

Scientific Evidence

mobile phone frequency range and one of the common mobile phone pulsing patterns for two to six hours daily. Each study should use a range of different intensities (normally 4 SARs).

- At least two large follow-up studies on transgenic mice using study designs similar to the Repacholi study on Eμ-*PIMI* mice. Follow-up research is also needed that provides information on the health implications of effects found in transgenic animals.
- Studies to test the reproducibility of reported changes on hormone levels, effects on the eye, inner ear and cochlea, memory loss, neurodegenerative diseases and neurophysiological effects. Studies to be performed on people where possible and on animals as appropriate.
- At least two large-scale epidemiological studies with well-characterised higher level RF exposures to investigate cancers, particularly in the head and neck, and any disorders associated with the eye or inner ear. These studies should preferably be on mobile phone users or on workers in industries giving high RF exposures provided valid exposure assessments can be developed.
- Well-controlled studies to test people reporting specific symptoms such as headache, sleep disorders or auditory effects, and who attribute these symptoms to RF exposure. Several more studies to investigate neurological, neuroendocrine and immunological effects.
- *In vitro* studies relevant to possible *in vivo* effects and addressing the issues of RF exposure, thresholds and reproducibility for reported positive effects on cell cycle kinetics, proliferation, gene expression, signal transduction pathways and membrane changes.

5.285 WHO also provides advice and information on experimental design criteria, experimental systems and dosimetry, data collection and quality assurance, data analysis, reporting results, independent research review and administration and coordination of research.

6

A Precautionary Approach

- 6.1** Many of those who submitted evidence to the Expert Group, either orally or in writing, urged the application of a precautionary approach to the new technology of mobile phones, and especially to the siting of base stations. Before considering the case for this and the ways in which it might operate, it is helpful to review the general principles of risk assessment and risk management.

Risk Assessment

- 6.2** Risk assessment is the process whereby the potential adverse consequences (hazards) associated with a technology or development are identified, and the probability (risk) of their occurrence is estimated. The hazards may be to human health or to the environment, or may be economic, but below we focus on hazards to human health. The identification of health hazards and the estimation of associated risks may be based on various sources of information.
- 6.3** It is often possible to predict the hazards from a new technology on theoretical grounds, especially where it has evolved from other similar technologies already in use. If these hazards are well understood then risk assessment may only require an estimate of the levels of exposure that will occur. For example, the main hazard associated with a new industrial plant might be one of noise-induced deafness in the people who will work on it. The quantitative relation between noise exposure and deafness is well characterised, and an assessment of risk would therefore be possible once the likely levels of workers' exposure to noise had been established.
- 6.4** Laboratory experiments are another source of information. Experiments may be carried out *in vitro* (eg tests of a chemical's capacity to cause mutations in the genetic material of bacteria), using living animals (eg tests for long-term toxicity when a chemical is regularly inhaled or ingested), or more rarely, using human subjects. Such investigations form the basis for the risk assessment of many new chemicals such as drugs and pesticides.
- 6.5** Epidemiological studies of people are also important. These involve comparing rates of disease in different groups of people according to their exposure to known or suspected hazards.
- 6.6** Each source of information has advantages and disadvantages to its use. Background scientific knowledge can be applied relatively cheaply and quickly. Experience indicates that it is usually reliable, although not always. For example, it would have been difficult to predict the hazard of cancer from asbestos on the basis of scientific knowledge at the time the mineral first came into use. Similarly, before the emergence of new-variant CJD, it seemed unlikely that BSE would pose a significant health risk to people.
- 6.7** Laboratory experiments may take up to several years to complete, but can usually be carried out before any extensive human exposure to a new technology has occurred. There are, however, uncertainties in the extrapolation of findings from animals to people. For example, arsenic is

A Precautionary Approach

known to cause skin and lung cancer in people, but attempts to demonstrate the hazard in animals have failed.

- 6.8** Epidemiological studies provide direct information about risks in people, but by definition elevations of risk can only be demonstrated once disease has started to occur. Ideally, hazards would be prevented or eliminated before any ill-effects in people had resulted. Furthermore, the accuracy with which risks can be estimated from epidemiological studies is limited by the practical and ethical constraints of working with human subjects.
- 6.9** At each stage in the development of a new technology, risk assessment entails a synthesis of all the relevant information that is available from the sources described. Depending on how much information is available, risk estimates will be more or less certain. Thus, our knowledge about the adverse effects of ionising radiation is such that we can predict risks with relative precision. On the other hand, the risks associated with many industrial chemicals have been much less studied, and while current evidence may not suggest any important risk, we cannot always exclude this possibility with the same confidence.

Risk Management

- 6.10** Risk management is the process by which the risks and benefits associated with a technology or development are weighed against each other and decisions are made on whether and how to proceed with its implementation. The benefits may be real or potential, and direct (eg an improvement in health from a new drug) or indirect (eg making an industry more competitive and thereby promoting employment). The balancing of risks and benefits should take account of the uncertainties in risk estimates and also the severity of the adverse effects that might result. A small risk of a minor health effect such as transient headache might be acceptable, whereas the same risk of a more serious outcome such as brain cancer would not be acceptable.
- 6.11** A common approach in risk management is to identify a critical adverse health effect, (usually that which occurs at the lowest level of exposure). The lowest exposure at which this effect has been shown to occur is then multiplied by an “assessment” factor, also known as a “safety” or “uncertainty” factor, to derive an exposure limit or guideline. The aim is that, below this limit, exposures will not cause the adverse effect in any individual. Moreover, because the starting point for the calculation is the adverse health effect that occurs most readily, others, which only occur at higher exposures, should also be prevented. The assessment factor is designed to allow for differences in sensitivity between individuals, and also, if the assessment is based on data from animals, between species. It may be increased if the critical health outcome is particularly serious, eg cancer or congenital malformations. The exact size of assessment factors used, however, is to some extent arbitrary. It should be noted that this derivation of exposure limits or guidelines is based only on observed adverse effects. There may be evidence for other biological effects at lower exposures, but if these are not considered to be adverse, they do not enter the calculation.
- 6.12** Risk management is not a simple accounting process since, in general, risks cannot be quantified in the same units as benefits. For example, it may be necessary to weigh a risk to health against an economic gain. This is not an impossible task. It is something that all of us do regularly in our day-to-day lives. When we buy a new car, we make a decision – conscious or unconscious – whether to pay extra for additional safety features. When we decide to save money by undertaking a “do-it-yourself” (DIY) task in the home, we accept the risks of accidental injury that may be entailed. Such decisions involve value judgements, and individuals will differ in where they draw the balance between perceived risks and benefits.

- 6.13** A further complication arises because the people who benefit most from a new development are not necessarily those who will incur the highest risks. A new municipal incinerator may be to the advantage of most people in a community, but may pose an increased risk of road traffic accidents to those who live nearby. In this circumstance, balancing the risks and benefits poses moral and ethical questions and, in a democratic society, is overseen by the elected representatives of the people.

The Precautionary Principle/Approach

- 6.14** We live in an era in which science and technology are advancing at an ever-increasing rate. This has led to many improvements in health and in the quality of life. Thus in the UK, as in many other developed countries, life expectancy is currently increasing. At the same time, however, many people have anxieties about the pace of change and the potential for major adverse consequences if new developments are not appropriately controlled – if science has greater power to do good, it also has greater power to do harm. They therefore advocate a precautionary approach to new technology where there are uncertainties about the associated risks. In this context it is important to note the recent publication of the European Commission on the precautionary principle (EC, 2000), where guidance is given on approaches that should be used. Most importantly, this document indicates that actions taken under the precautionary principle should be commensurate with anticipated risks of health detriment. This has also been outlined in a World Health Organization (WHO) background publication entitled “Electromagnetic Fields and Public Health: Cautionary Policies” (WHO, 2000).
- 6.15** Some people propose that new developments should only be permitted when they have been shown to be completely safe, but this is unrealistic. Science can never provide a guarantee of zero risk. It may, however, offer strong reassurance that any risks from a technology are small in comparison with many other risks that we accept in our lives.
- 6.16** The precautionary approach is not all or none in nature. Rather, it is a matter of degree. In essence, it requires that before accepting a new development we should have positive evidence that any risks from it are acceptably low, and not simply an absence of convincing evidence that risks are unacceptably high. However, individuals will differ in the strength of evidence that they need before concluding that risks are sufficiently small. The implementation of a precautionary approach carries costs, which may be direct, eg for better engineering, or from a delay in the benefits that the new technology will bring. Important indirect costs may also arise if resources are directed away from a more serious risk to deal with another risk that is in fact very minor. The aim, therefore, must be to follow a policy that is acceptable to most people, and which minimises the chance of adverse outcomes without unnecessarily stifling progress.
- 6.17** The policy by which a precautionary approach is applied to risk management in situations of scientific uncertainty has been termed the precautionary principle. This principle was formally adopted by countries of the European Union in the Treaty of Maastricht (1992), and is evident in a ruling of the European Court of Justice when it upheld the decision of the European Commission to ban beef from the UK with a view to limiting the risk of transmission of BSE. The Court concluded as follows:

“In view of the seriousness of the risk and the urgency of the situation, and having regard to the objective of the decision, the Commission did not act in a manifestly inappropriate manner by adopting the decision, on a temporary basis and pending the production of more detailed scientific information.”

A Precautionary Approach

“Where there is uncertainty as to the existence or extent of risks to human health, the Commission may take protective measures without having to wait until the reality or seriousness of those risks becomes apparent.”

The application of this principle was defined further in an EC Commentary in February 2000 (EC, 2000).

- 6.18** Against this general background, we now consider how the potential health risks from mobile phone technology should best be managed.

Application of the Precautionary Approach to Mobile Phone Technology

Exposure guidelines for RF radiation

- 6.19** As described in paragraph 6.11, one approach that is often adopted in risk management is to define exposure limits or guidelines, below which the recognised adverse effects of a hazard would not be expected to occur. In the UK, national guidelines on exposure to RF radiation were drawn up by NRPB (NRPB, 1993a,b), and have been accepted and implemented by Government Departments and Agencies.
- 6.20** Having reviewed all relevant epidemiological studies, NRPB concluded that the results were inconclusive and did not provide an adequate starting point from which to derive exposure guidelines (NRPB, 1993b,c). Instead, therefore, the guidelines were based on the potential of RF radiation to cause illness or injury through heating of body tissues. While some research had suggested that adverse health effects might occur from exposures lower than those needed to produce significant heating, the evidence for this was not considered sufficiently robust to form a basis for the derivation of exposure guidelines.
- 6.21** The NRPB exposure guidelines incorporate *basic restrictions* on the specific energy absorption rate (SAR, see paragraph 4.37). For mobile phones, the relevant restrictions are for frequencies between 10 MHz and 10 GHz, and these are given in Table 6.1. To verify that the exposure of an individual is within NRPB guidelines, it is necessary to demonstrate that none of the four basic restrictions is exceeded. The SAR is averaged over an exposure time and a specified mass of tissue, depending on the tissue region. Averaging times are specified because of the time taken for the temperature of tissues to equilibrate when they are exposed to the radiation.

Table 6.1 NRPB basic restrictions on exposure in the frequency range 10 MHz to 10 GHz (NRPB, 1993b)

Tissue region	SAR limit (W/kg)	Averaging parameters	
		Mass (g)	Time (minutes)
Whole body	0.4	–	15
Head, fetus	10	10	6
Neck, trunk	10	100	6
Limbs	20	100	6

- 6.22** These restrictions apply equally to workers and to members of the general public. NRPB has taken the view that they provide adequate protection against harmful thermal effects for all exposed individuals under all conditions (NRPB, 1999a,b).

Application of the Precautionary Approach to Mobile Phone Technology

6.23 Since SARs cannot easily be measured in living people, the NRPB guidelines also specify *investigation levels* for external electromagnetic field strengths, at or below which the basic restriction on whole-body SAR will not be exceeded. If an investigation level is exceeded, more detailed investigation of the resultant SAR is indicated. For children, additional reductions in investigation levels for the whole body are applied because, over certain RF frequencies, small children absorb more energy from external electromagnetic fields than adults. Table 6.2 shows these investigation levels for the frequency range covered by mobile phones.

Table 6.2 NRPB investigation levels for exposure at mobile telecommunications frequencies (NRPB, 1993b)

Frequency (MHz)	Electric field strength (V/m)	Magnetic field strength (A/m)	Power density (W/m ²)
400 – 800	100	0.26	26
800 – 1550	125 <i>f</i>	0.33 <i>f</i>	41 <i>f</i> ²
1550 – 3000	194	0.52	100

f is the frequency in GHz.

- 6.24** The three investigation level quantities shown in Table 6.2 are related to each other (the fields are assumed to be in the far-field region – see paragraph 4.24), and it is only necessary to consider one of them. To investigate compliance, measurements are usually made of either electric field strength or magnetic field strength.
- 6.25** For the current generation of mobile phones and their base stations the investigation levels in the frequency range 800–900 MHz are from 26 to 33 W/m² and for the range 1800–1900 MHz the level is 100 W/m².
- 6.26** Since publication of its guidelines, NRPB has continued to monitor and review the published scientific literature relevant to exposure to electromagnetic fields and human health. In this, it is supported by its independent Advisory Group on Non-ionising Radiation chaired by Sir Richard Doll. Its current position is that compliance with its guidelines for exposures to electromagnetic fields will prevent any known adverse effects on human health (NRPB, 1999a,b).
- 6.27** Guidelines on exposure to RF radiation have also been published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 1998a,b). Similarly to the NRPB guidelines, these are designed to prevent illness or injury through heating effects. Their starting point is the behavioural changes that have been found when experimental animals were exposed to RF radiation at levels that produced a rise in whole-body temperature in excess of 1°C. An SAR of 1–4 W/kg or higher is needed to cause these changes (1 W/kg when animals are exposed in conditions of adverse temperature, humidity and air movement, and 4 W/kg under normal environmental conditions). ICNIRP considered that there was no firm evidence for any effects that would impair health at lower levels of exposure to RF radiation.
- 6.28** In contrast to the NRPB guidelines, the ICNIRP guidelines feature a two-tier system with lower limits for exposure of the general public than for occupational exposure. For occupational exposure, the basic restrictions on SAR are the same as those recommended by NRPB (see Table 6.3), except that an averaging time of six minutes and an averaging mass of 10 g apply to the three localised SAR restrictions.
- 6.29** However, for exposure of the general public, the guidelines are five times lower than for occupational exposure. This difference was intended to allow for the following circumstances.

A Precautionary Approach

Table 6.3 ICNIRP basic restrictions on occupational exposure and general public exposure (in brackets) in the frequency range 10 MHz to 10 GHz (ICNIRP, 1998a)

Tissue region	SAR limit (W/kg)	Averaging parameters	
		Mass (g)	Time (minutes)
Whole body	0.4 (0.08)	–	6
Head, trunk	10 (2)	10	6
Limbs	20 (4)	10	6

- *Exposure under extreme environmental conditions – high temperatures, high humidity, low air movement and high activity increase the thermal burden from RF exposure.*
- *Potentially higher thermal sensitivity in certain population groups such as those who are frail or elderly, infants, young children, and people with diseases or taking medications that compromise thermal tolerance.*

6.30 Further arguments in support of the additional reduction factor for public exposure were also given in an earlier publication (INIRC/IRPA, 1988) as follows.

- *Workers are normally healthy adults exposed under controlled conditions, who are trained to be aware of potential risks and to take appropriate precautions to avoid unnecessary exposure. The general public cannot reasonably be expected to take the same precautions.*
- *Workers are exposed only during the working day (usually 8 hours per day). On the other hand, the general public can be exposed for 24 hours per day (this total weekly exposure duration is approximately five times that of workers; hence the derivation of the extra safety factor of five for the general public).*
- *In general, children and babies are normally considered to be more sensitive to exposures to physical, chemical or biological agents. At higher frequencies, children absorb more energy from external electromagnetic fields than adults.*

6.31 The ICNIRP guidelines are presented with *reference levels* analogous to the NRPB *investigation levels*, and these also reflect the factor of five difference between the public and occupational basic restrictions. In general, over the frequency range used by mobile phones, the ICNIRP reference level for the public is lower (in terms of power density) than the NRPB investigation level by a factor of between 6.5 and 11. The ICNIRP public reference levels for the frequencies used by mobile phones are shown in Table 6.4. Reference levels for mobile telecommunications in the frequency range 800–1000 MHz are from 4 to 5 W/m² and for 1800–1900 MHz from 9 to 9.5 W/m² (ICNIRP, 1998a).

Table 6.4 ICNIRP reference levels for public exposure at mobile telecommunications frequencies (ICNIRP, 1998a)

Frequency (MHz)	Electric field strength (V/m)	Magnetic field strength (A/m)	Power density (W/m ²)
400 – 2000	$1.375f^{1/2}$	$0.0037f^{1/2}$	$f/200$
2000 – 3000	61	0.16	10

f is the frequency in MHz.

Application of the Precautionary Approach to Mobile Phone Technology

- 6.32** Following a detailed comparison of the NRPB and ICNIRP guidelines and the implications for practical hazard assessment (NRPB, 1999a), the National Radiological Protection Board issued the following Statement:

“The Board has concluded that for occupational exposure the basic restrictions in the new ICNIRP guidelines do not differ in any significant way from those previously recommended by NRPB and have no implications for the UK guidelines. For members of the public, ICNIRP has generally included a reduction factor of up to five in setting basic restrictions across the frequency range to 300 GHz. There is, however, a lack of scientific evidence to support the introduction of these additional reduction factors. The Board believes that the existing UK advice by NRPB on limiting exposures for the general public already provides sufficient protection from direct and indirect effects and that any health benefits to be obtained from further reductions in exposure have not been demonstrated. It sees no scientific justification, therefore, for altering the advice previously given by NRPB on exposure guidelines for members of the public. It does, however, accept that other factors may need to be taken into account by government in establishing generally accepted exposure guidelines for the public.

“In relation to furthering knowledge on possible health effects of exposure to EMFs, the Board supports the need for further epidemiological and experimental studies.”

The Board also said that the Statement reflected “understanding and evaluation of the current scientific evidence. If and when further relevant information becomes available, the Board will review its advice”.

- 6.33** The ICNIRP guidelines for the public have been adopted in a European Council Recommendation (1999), which has been agreed in principle by all countries in the European Union, including the UK. In Germany the ICNIRP guidelines have been incorporated into statute.
- 6.34** *From a review of the scientific evidence, we conclude that the prevention of heating effects currently remains the best basis for exposure guidelines. We further conclude that the approach adopted by ICNIRP is preferable to that of NRPB. Within the general public there may be people with illnesses that render them unusually susceptible to the heating effects of RF radiation, and this justifies the use of a higher assessment factor than for occupational exposures.*
- 6.35** **We recommend that, as a precautionary approach, the ICNIRP guidelines for public exposure be adopted for use in the UK rather than the NRPB guidelines.** This would bring the UK into line with other countries in the European Union and accord with the recommendations of the House of Commons Select Committee on Science and Technology Report on Mobile Phones and Health (1999).
- 6.36** **We are not convinced of the need to incorporate ICNIRP guidelines into statutes.** We believe that they are liable to change as more scientific information on possible health effects becomes available.
- 6.37** **The balance of evidence to date suggests that exposures to RF radiation below NRPB and ICNIRP guidelines do not cause adverse health effects to the general population (paragraphs 5.267–5.269).**

A Precautionary Approach

- 6.38** There is now scientific evidence, however, which suggests that there may be biological effects occurring at exposures below these guidelines. This does not necessarily mean that these effects lead to disease (paragraph 5.266).
- 6.39** There are additional factors that need to be taken into account in assessing any possible health effects. Populations as a whole are not genetically homogeneous and people can vary in their susceptibility to environmental hazards. There are well-established examples in the literature of the genetic predisposition of some groups, which could influence sensitivity to disease. There could also be a dependence on age. **We conclude therefore that it is not possible at present to say that exposure to RF radiation, even at levels below national guidelines, is totally without potential adverse health effects, and that the gaps in knowledge are sufficient to justify a precautionary approach.**
- 6.40** In the light of the above considerations **we recommend that a precautionary approach to the use of mobile phone technologies be adopted until much more detailed and scientifically robust information on any health effects becomes available. We further recommend that national and local government, industry and the consumer should all become actively involved in addressing concerns about possible health effects of mobile phones.**
- 6.41** On its own, adoption of the ICNIRP exposure guidelines will not allow fully for the current gaps in scientific knowledge, and particularly the possibility of, as yet, unrecognised thermal or non-thermal adverse effects at lower levels of exposure. One way in which this uncertainty could be taken into account would be to apply a higher assessment factor in the derivation of the exposure guidelines. This would have the merit of simplicity. However, as yet, there is no satisfactory scientific basis on which to set the size of any increase.
- 6.42** An alternative would be to adopt the exposure guidelines recommended by ICNIRP, and in addition have a policy that requires best engineering practice for equipment and installations that ensures that fields are kept to the lowest levels commensurate with the telecommunications system operating effectively. We believe that this approach is preferable. We next consider how it might be applied in relation to the design and siting of base stations, and the design, marketing and use of mobile phones.

Base Stations

- 6.43** The location of base stations and the processes by which they are authorised appear to be the aspects of mobile phone technology that generate most public concern (see Chapter 3). Public telecommunications operators have been granted a number of rights similar to those enjoyed by gas, water and electricity companies. These include permitted development rights, which allow them to carry out certain developments, including the erection of masts less than 15 m high, without the need to make a full planning application. (A more detailed description of the current planning situation with respect to telecommunications is given in paragraphs 6.96–6.117.) In assessing the potential impact of a planned base station on health, the current approach in the UK is to determine whether it might cause exposures in excess of NRPB guidelines (NRPB, 1993a,b; 1999). If this can be ruled out satisfactorily, risks to health are not considered further.
- 6.44** We believe this approach is not optimal since it does not allow adequately for the uncertainties in scientific knowledge. Although it seems highly unlikely that the low levels of RF radiation from base stations would have significant, direct adverse effects on health, the possibility of harm from exposures insufficient to cause important heating of tissues cannot yet be ruled out with confidence. Furthermore, the anxieties that some people feel when this uncertainty is ignored can in themselves affect their well-being.

6.45 Other aspects of the planning process for base stations are also unsatisfactory. Some citizens feel that the siting of base stations, and particularly of masts, can result in a loss of amenity and possibly a reduction in the value of property, and it is clear that, in the face of this threat, many feel excluded and disempowered by the planning system now in operation. The resultant frustration also has negative effects on people's health and well-being.

6.46 *We conclude therefore, that changes to the regulation of base stations are necessary.*

National register of base stations

6.47 A first requirement is for reliable and openly available information about the location and operating characteristics of all base stations. Easy access to such information would help to reduce mistrust among the public. Furthermore, the data would be useful when applications for new base stations were being considered, and might also be of value in epidemiological investigations.

6.48 **We recommend that a national database be set up by Government giving details of all base stations and their emissions.** For each this should list: the name of the operating company; the grid reference; the height of the antenna above ground level; the date that transmission started; the frequency range and signal characteristics of transmission; the transmitter power; and the maximum power output under the Wireless Telegraphy Act. Moreover, this information should be readily accessible by the public, and held in such a form that it would be easy to identify, for example, all base stations within a defined geographical area, and all belonging to a specified operator.

Exclusion zones

6.49 Although exposures to RF radiation from base stations will generally be well below exposure guidelines, the need remains to prevent access by workers or the public to places where the relevant guidelines might be exceeded. Therefore, we endorse the practice of defining clear exclusion zones around base stations.

6.50 **We recommend the establishment of clearly defined physical exclusion zones around base station antennas, which delineate areas within which exposure guidelines may be exceeded. The incorporation of exclusion zones should be part of the template of planning protocols that we advocate (paragraphs 6.54, 6.58 and 6.59).**

6.51 Each exclusion zone should be defined by a physical barrier and a readily identifiable nationally agreed sign with a logo. This should inform the public and workers that inside the exclusion zone there might be RF emissions that exceed national guidelines. **We recommend that the design of the logo should be taken forward by the British Standards Institute and implemented within 12 months.**

6.52 **We recommend that warning signs should be incorporated into microcell and picocell transmitters to indicate that they should not be opened when in use.**

Audit of base stations

6.53 There is a need to ensure that base stations are operating within the parameters specified when they were approved.

6.54 **We recommend that an independent, random, ongoing audit of all base stations be carried out to ensure that exposure guidelines are not exceeded outside the marked exclusion zone and that the base stations comply with their agreed specifications. If base station emissions**

A Precautionary Approach

are found to exceed guideline levels, or there is significant departure from the stated characteristics, then the base station should be decommissioned until compliance is demonstrated. We recommend that particular attention should be paid initially to the auditing of base stations near to schools and other sensitive sites. The audit should include appropriate checks to ensure that base stations conform to the operational parameters specified when they were approved, and that exclusion zones are properly demarcated and signed.

Planning process

- 6.55** As described in the annex to this chapter, the erection of base stations for mobile phone networks is not subject to such stringent planning procedures as some other types of construction project. In particular, masts less than 15 m high can be built without the planning permission that would normally be required. The lack of public consultation is a major cause of grievance in people who suffer a loss of amenity when base stations are erected and we consider the current situation to be unacceptable.
- 6.56** One operator has told us that it now seeks full planning permission for all new masts, even if they will be less than 15 m high, but there appears to be significant variation in the extent to which operators consult the public about the siting of base stations.
- 6.57** **We recommend that for all base stations, including those with masts under 15 m, permitted development rights should be revoked, and that the siting of all new base stations should be subject to the normal planning process.** This planning process should also apply when a change to an existing base station will increase its power output.
- 6.58** **We recommend that, at national Government level, a template of protocols be developed, in concert with industry and consumers, which can be used to inform the planning process and which must be assiduously and openly followed before permission is given for the siting of a base station.**
- 6.59** We consider that the protocol should cover the following points.
- All telecommunications network operators must notify the local authority of the proposed installation of base stations. This should cover installations for macrocells, microcells and picocells.
 - The local authority should maintain an up-to-date list of all such notifications, which should be readily available for public consultation.
 - The operator should provide to the local authority a statement for each site indicating its grid reference, the height of the antenna above ground level, the frequency and signal characteristics, and details of maximum power output.
 - Any change to an existing base station that increases its size, or the overall power radiated, should be subject to the normal planning process as if it were a new development.
- 6.60** **We recommend that a robust planning template be set in place within 12 months of the publication of this report. It should incorporate a requirement for public involvement, an input by health authorities/health boards and a clear and open system of documentation which can be readily inspected by the general public.**
- 6.61** **We recommend that in making decisions about the siting of base stations, planning authorities should have power to ensure that the RF fields to which the public will be exposed will be kept to the lowest practical levels that will be commensurate with the telecommunications system operating effectively.**

6.62 Where recommendations (paragraphs 1.30–1.46) impact on the devolved responsibilities of the Scottish Parliament, the Welsh National Assembly and the Northern Ireland Assembly then they should be considered by their appropriate authorities or bodies. We have noted with interest the recent report on planning procedures for telecommunications developments produced by the Transport and the Environment Committee of the Scottish Parliament in 2000 (paragraphs 6.112–6.114).

Base stations near schools

6.63 A common concern among members of the public who attended our open meetings was the siting of macrocell base stations on or near school premises. The placement of a base station on a school building may indirectly benefit its pupils through the income generated in rent. The balance of evidence indicates that there is no general risk to the health of people living near to base stations where the exposures are only small fractions of guidelines. However, it was suggested to us that children might be especially vulnerable to any adverse effects of RF radiation. There is evidence that at the frequencies used in mobile phone technology, children will absorb more energy per kilogram of body weight from an external electromagnetic field than adults (see paragraph 4.37). A one year old could absorb around double, and a five year old around 60%, more than an adult. Additionally, since children are being exposed to RF radiation from base stations (and from mobile phones) from a younger age than adults, they will have a longer time in which to accumulate exposure over the course of their lives, and a longer time for any delayed effects of exposure to develop.

6.64 In recognition of this, some countries have prohibited the placement of macrocell base stations on sensitive sites such as schools. Such policies have the merit of being easy to administer, but they may not always produce the desired effect. For example, because of the way in which emissions are beamed, a macrocell base station located near to a school may cause higher exposure to pupils than if it were placed on the roof of the school building.

6.65 We suggest therefore that a better approach would be to require that the beam of greatest RF intensity (see paragraph 4.32) from a macrocell base station sited within the grounds of a school should not be permitted to fall on any part of the school grounds or buildings without agreement from the school and parents. Furthermore, when consent is sought from a school and parents about this question, they should be provided with adequate information to make an informed decision, including an explanation of the way in which the intensity of radiation falls off with distance from the antenna. This may be particularly relevant for schools with large grounds. If, for an existing base station, agreement could not be obtained, its antennas might need to be readjusted.

6.66 We further suggest that similar considerations should apply in relation to a macrocell base station outside the grounds of a school but at a distance from the edge of the grounds comparable to that of a macrocell base station were it to be placed within the school grounds. In this case, if requested by the school or parents, the network operator should be required to inform the school whether the beam of greatest intensity (see paragraph 4.32) falls on the school grounds or buildings. If it does, the operator should tell them where it falls and the nearest distance from the antenna to these points. It should also provide them with adequate information to make an informed consideration of the level of the intensity of RF radiation. This information should include an explanation of the way in which the intensity of radiation falls off with distance from the antenna. If there is major concern about the situation from the school and parents, it may be necessary for the network operator to make adjustments to the antennas.

A Precautionary Approach

- 6.67** We suggest that the responsibility for monitoring the requirements of paragraphs 6.65 and 6.66 should be given to local authorities with advice from the agency responsible for maintaining the database. Disputes could be referred to the Ombudsman (see paragraph 3.51).
- 6.68** **We recommend, in relation to macrocell base stations sited within school grounds, that the beam of greatest RF intensity should not fall on any part of the school grounds or buildings without agreement from the school and parents. Similar considerations should apply to macrocell base stations sited near to school grounds.**

Developments in rural areas

- 6.69** In urban environments and adjacent to major roads and railways, the need for new base stations will arise principally from growth in the number of phone calls that must be handled at any one time. In rural areas, however, the main drive to expansion of networks at present is the need for wider geographical coverage. In this circumstance, there may be scope to limit the number of masts that are required through agreements between operators on mast sharing and roaming.
- 6.70** **We recommend that operators should actively pursue a policy of mast sharing and roaming where practical,** and that they should be considered by planning authorities as an alternative option when new masts are proposed.

Mobile Phones

- 6.71** Use of a mobile phone can expose tissues adjacent to the antenna to levels of RF radiation more than a thousand times higher than people would normally encounter from base stations. We understand from the Mobile Manufacturers Forum that all mobile phones presently marketed in the UK comply with both NRPB and ICNIRP guidelines for RF radiation and on current evidence, it seems unlikely that the exposures experienced by users would have important adverse effects on health. However, direct empirical support for this assessment is limited, and several observations suggest a need for caution.
- 6.72** As described in Chapter 5, recent experiments in people have suggested that subtle effects on brain function might occur from the use of mobile phones held to the head (Preece *et al*, 1999; Koivisto *et al*, 2000, *in press*; Krause *et al*, 2000), although even if confirmed by further research, these effects on function would not necessarily result in illness. Also of concern is the observation in one study that exposure to pulsed RF radiation may accelerate the development of tumours (Repacholi *et al*, 1997). These findings require independent confirmation. However, the uncertainties that such research raises are a reminder that the current evidence base is not yet so secure that the possibility of harmful effects from the use of mobile phones can be totally discounted.
- 6.73** These uncertainties are less problematic in so far as people can choose whether or not to use a mobile phone. However, it is important they should be adequately informed when making their choice, and that they be advised of the best way in which to reduce their exposure if that is what they wish to do.

Information for consumers

- 6.74** To this end, purchasers of mobile phones should have information to allow them to make informed choices about personal exposures resulting from their use. Based on current evidence, the main points to convey would be as follows.

- At present scientific evidence suggests that the RF radiation produced by mobile phones is highly unlikely to be a cause of direct adverse health effects on the general population of the UK.
 - There is, however, still some uncertainty about this, and individuals may therefore wish to minimise their exposure to such radiation.
 - This can be achieved in several ways including, for example, by making fewer and shorter calls.
 - Specific absorption rate (SAR) values are a relevant measure of exposure in this situation and should allow people to make an informed choice.
 - Another way of reducing exposure would be by use of an approved, hands-free set (see paragraphs 6.86–6.88).
- 6.75** We understand that an internationally agreed standard testing protocol for the assessment of SAR values from mobile phones will soon be available. We welcome this development.
- 6.76** **We recommend that an international standard for the assessment of SAR values from mobile phones should be adopted for use in the UK once it has been demonstrated to be scientifically sound.**
- 6.77** **We recommend that information on SAR values for mobile phones must be readily accessible to consumers:**
- **at the point of sale with information on the box,**
 - **on leaflets available in stores giving comparative information on different phones and with explanatory information,**
 - **as a menu option on the screen of the phone, and as a label on the phone,**
 - **on a national web site, which lists the SAR values of different phone types.**
- 6.78** In order that consumers can interpret SAR values it will also be necessary to provide them with an explanation of the measure and its application.
- 6.79** Such information could be given by mobile phone manufacturers or retailers in addition to that already provided (see paragraphs 3.28 and 3.29). However, we believe that it would carry more weight if it came from Government and were clearly seen to be independent.

Shields

- 6.80** Shields seek to reduce the RF radiation to which users of mobile phones are exposed, and various types of device have been produced for this purpose. For most of them, eg ceramic absorbing devices, there is no apparent physical basis for their alleged effect, and there are no convincing test results to verify that they reduce exposure.
- 6.81** One particular type does have a physical basis. This type consists of a case that fits over the handset and has a metallic or metallic-mesh screen within the case and a “guard” for the antenna. Together these partially screen the radiation emitted by the phone.
- 6.82** Tests by various laboratories, including some that formed the basis of a *Which?* report published in April 2000, have measured the effect of this type of shield on the radiation from a mobile phone when it was set to produce constant power. The shield substantially reduced the radiation by a factor that could be adjusted by the user.

A Precautionary Approach

- 6.83** In most normal use, however, the shield would not reduce the exposure of the user to this extent, since the reduction in radiation produced by the shield would automatically be compensated for by adaptive power control. (This increases or reduces emissions to give an optimal signal at the base station, see paragraph 4.14.) An exception would occur where the mobile phone was already operating at or close to its maximum power, eg because it was a long way from the base station or in a building, but in this situation, the signal at the base station would be weakened by the shield and communication might not be possible.
- 6.84** Some of the test results have shown that the radiation is reduced more in the direction of the head than in the direction away from it. If so, users could reduce their exposure somewhat by turning the appropriate side of their head towards the base station. However, this could only be done if they could see the base station, which is not the usual situation. For other orientations of the head the tests imply that the reduction in exposure would be very small.
- 6.85** We conclude that, in practice, there would be very little reduction in the exposure received by most users through use of a shield of this type, and that their reception could be impaired when they were a long way from a base station or in buildings, cars, etc. If the use of shields became widespread there could also be adverse effects on the environment, since more base stations would likely be needed to maintain the quality of communication.

Hands-free kits

- 6.86** Exposure to RF radiation from a mobile phone can be reduced by increasing the distance of the phone from the body. This could be achieved by using an appropriately designed hands-free kit. Little or no advantage will be gained, however, if the phone is merely moved from the head to, say, the waist since in that case other organs may receive comparable exposure.
- 6.87** Even if the mobile phone is some distance from the body, reduction in exposure may not be achieved if the wires from the handset to the earpiece can carry radio signals to the ear or themselves radiate significantly. Since the original purpose of hands-free kits was to permit the use of both hands while phoning, they may not all have been designed with exposure in mind. The *Which?* report published in April 2000 showed that the hands-free kits tested could increase the exposure to the user. On the other hand, we are aware of other tests which claim a very substantial reduction. In both cases there is insufficient published information about the measurement methods to form a clear view. We believe, however, that it should be possible to design hands-free kits which would significantly reduce exposure to the user if used correctly (ie with the phone some distance from the body).
- 6.88** The regulatory position on the use of hands-free kits and shields is unclear and the only information available to the public appears to be that supplied by their manufacturers. **We recommend that the Government sets in place a national system which enables independent testing of shielding devices and hands-free kits to be carried out, and which enables clear information to be given about the effectiveness of such devices. A kite mark or equivalent should be introduced to demonstrate conformity with the testing standard.**

Use by children

- 6.89** We have already discussed the arguments for minimising the exposure of children in school to RF radiation from base stations (see paragraphs 6.63–6.68). These apply even more to the higher exposures that occur from use of mobile phones. There may be circumstances where the use of a mobile phone by a child can promote safety (eg to ask a parent for a lift rather than walk home alone).

6.90 If there are currently unrecognised adverse health effects from the use of mobile phones, children may be more vulnerable because of their developing nervous system, the greater absorption of energy in the tissues of the head (paragraph 4.37), and a longer lifetime of exposure. In line with our precautionary approach, we believe that the widespread use of mobile phones by children for non-essential calls should be discouraged. We also recommend that the mobile phone industry should refrain from promoting the use of mobile phones by children.

Use near hospitals

6.91 As described in paragraphs 4.5 and 4.6, there is a potential hazard from the indiscriminate use of mobile phones in hospitals and other sites where RF radiation could interfere with sensitive electronic equipment. We support the steps that are already being taken both by mobile phone manufacturers and hospitals to warn people about the dangers of using phones in such sites.

6.92 We understand that health authorities/boards issue guidance on the use of mobile phones. We recommend that they should ensure that all hospitals comply. This guidance should include the placing of visible warning signs at entrances to buildings to indicate that mobile phones should be switched off.

Use while driving

6.93 As described in paragraphs 5.201–5.214, there is strong evidence that use of a mobile phone whilst driving significantly increases the risk of accidents. It has been suggested to us that the use of hand-held phones while driving should be banned, and the Department of the Environment, Transport and the Regions (DETR, 2000) considered this issue sufficiently important to warrant a publicity campaign aimed at dissuading drivers from using a mobile phone, especially one which is hand-held, when in control of a vehicle.

6.94 We welcome this initiative, but note that, perhaps surprisingly, current evidence indicates that the negative effects of phone use while driving are broadly similar whether the phone is hand-held or hands-free.

6.95 We conclude that the detrimental effects of hands-free operation are sufficiently large that drivers should be dissuaded from using either hand-held or hands-free phones whilst on the move.

ANNEX (based on material provided to the Expert Group by DETR)**Current Planning Procedures for Telecommunications Development**

6.96 All development requires planning permission. In most cases, this will entail a full application to the local planning authority (LPA) for express permission. LPAs are required to determine applications in accordance with the development plan, unless material considerations indicate otherwise. These considerations can include views expressed by local people. LPAs have to publicise all planning applications.

6.97 Relatively minor development does not require express permission. It is granted planning permission under the Town and Country Planning (General Permitted Development) Order 1995 – the “GPDO”. These “permitted development rights” are enjoyed by a range of bodies, including householders and statutory undertakers.

Legal position

6.98 Larger developments, such as masts over 15 m high, require a full planning application, which will be considered by the LPA.

6.99 Public telecommunications operators hold licences under Section 7 of the Telecommunications Act 1984 to run telecommunications systems. In order to help them do this, they have been granted Telecommunications Code Powers (contained in Schedule 2 of the Telecommunications Act 1984). These essentially confer on telecommunications operators a number of rights similar to those enjoyed by the gas, water and electricity companies. These Powers enable them to install their systems in the maintainable highway and, with the appropriate consents, on private land. The Code also places a number of obligations on operators.

6.100 Part 24 of the GPDO grants a range of permitted development rights for telecommunications code system operators. These allow operators to carry out specified development, subject to certain conditions and limitations, without the need to make a full planning application to the LPA. This development includes masts of 15 m and below. However, there are special provisions regarding the installation of any mast in designated areas such as National Parks, Areas of Outstanding Natural Beauty, Conservation Areas and Sites of Special Scientific Interest. In these areas the installation of masts of 15 m and below do not enjoy permitted development rights under the GPDO. The installation of all masts in such areas is subject to a full planning application.

6.101 In general, permitted development under the GPDO is subject to various conditions and limitations. For telecommunications permitted development in England and Wales the GPDO includes an important additional control mechanism – the prior approval procedure. Following changes made in 1999 LPAs now have 42 days (rather than the previous 28) in which to determine and notify whether they wish to approve the siting and appearance of ground-based masts. Operators are also now required to post a site notice to publicise the proposed development. These changes were designed to give the public a better opportunity to comment to the LPA on its siting and appearance. There is also a statutory requirement for LPAs to consult the relevant parish council, at the council’s request. Where the LPA considers that the proposed development would have a detrimental effect upon local amenity, it is able to refuse approval. However, LPAs are advised to explore the scope for modifying its siting and/or appearance before doing so.

Current Planning Procedures for Telecommunications Development

- 6.102** For a number of other forms of telecommunications development under Part 24 of the GPDO the 28-day prior approval procedure continues to apply. This includes masts installed on a building or structure. Although there is not a statutory requirement for operators (or LPAs) to publicise such proposals, LPAs are encouraged to give proposals publicity so that local people can make their views known.
- 6.103** It is a condition of the permission granted by the GPDO that apparatus that is no longer required for telecommunications purposes should be removed as soon as reasonably practicable from the land or building on which it is located, and the land restored to its previous condition.

Policy guidance

- 6.104** In England, Government policy on planning for telecommunications development is set out in “Planning Policy Guidance Note 8” (PPG8), issued in December 1992. In Wales, similar guidance is to be found in “Planning Guidance (Wales): Planning Policy, First Revision” (April 1999), together with Technical Advice Note (Wales) 19, “Telecommunications”, August 1998. This guidance should be taken into account by LPAs as they prepare their development plans, and may be material to decisions in individual planning applications and appeals. It is supplemented by DETR Circular 4/99 and Welsh Office Circular 29/99 (“Planning for Telecommunications”), issued in June 1999 in parallel with the GPDO changes outlined in paragraph 6.101 above.
- 6.105** It is Government policy that the number of telecommunications masts should be kept to a minimum and to encourage mast sharing where appropriate. The licences issued to the four existing network operators require them to take all reasonable steps to investigate using, or replacing, an existing mast or other structure before erecting a new mast. Where a new mast is required, operators are required to investigate co-operating with another operator in erecting a mast for joint use.
- 6.106** Planning Circulars 4/99 and 29/99 underline the Government’s expectation that developers should provide the LPA with clear evidence that they have fully considered the use of existing masts, buildings and other structures before seeking to erect any new mast. If the evidence regarding the consideration of such alternative sites is not considered satisfactory, the LPA may be justified in refusing approval to the installation of the mast.
- 6.107** However, mast sharing is not always possible. Although an existing mast might be in close proximity to a proposed site, the precise location and height of the existing mast may not be compatible with the operator’s network. The size of the mast will also affect the ability to mast share; smaller masts may not be suitable for additional operators either because the structure is inadequate for the additional weight, or because there would be insufficient vertical separation between different sets of antennas to avoid interference. In addition, LPAs may consider the merits of mast sharing on a case-by-case basis. In some locations it may appear that a single large mast would have less impact, whilst in others it may be considered that several smaller masts, even in close proximity, are less visually intrusive.
- 6.108** The Government is keen to encourage early discussions between the operator and the LPA about proposed telecommunications development. Under a Code of Best Practice, issued by DETR in 1998, for telecommunications prior approval procedures in England and Wales, operators are encouraged to provide information to the LPA on significant installation plans in the LPA area and to undertake informal discussions on these plans. Close consultation between the operator and LPA before an application for consent for telecommunications development is made will allow the two sides to examine locally not only alternative mast locations, including

A Precautionary Approach

opportunities for site sharing, but also different design solutions. We understand that consideration is being given to extending this to include health concerns.

- 6.109** Draft guidance to LPAs in drawing up development plan policies or deciding planning applications for development giving rise to electromagnetic fields, such as telecommunications base stations, is contained in the joint DETR/DH draft circular, “Land-use Planning and Electromagnetic Fields (EMFs)”, issued for consultation in December 1998. A similar consultation exercise was carried out in Wales by the then Welsh Office. The circulars will be finalised as soon as practicable. In July 1999 the then Minister for Public Health and the then Minister for Planning jointly wrote to all Members of Parliament for constituencies in England, and to all Council Leaders in England, setting out the Government position about the possibility of adverse health effects associated with telecommunications base stations. In October 1999, a similar letter was issued in Wales by the two Assembly Secretaries with responsibility for health and planning to all Members of Parliament for constituencies in Wales, all Assembly Members and to all Council Leaders in Wales.

Scotland

- 6.110** In Scotland broadly similar permitted development rights apply to telecommunications development but with a number of significant differences. For example, the restrictions on permitted development rights for masts in certain designated areas currently relate only to masts for “microwave antennas” (as defined in Scottish planning legislation) in National Scenic Areas and conservation areas. There are no prior approval procedures in Scotland for telecommunications permitted development, the system in Scotland relying more upon the obligations contained in the telecommunications code system operator’s licence. This is also true in relation to the general condition requiring the removal of redundant telecommunications equipment that has benefited from permitted development rights.
- 6.111** The Scottish Executive intends to increase the controls on permitted development rights in Scotland to a level approximating that in England and Wales, including the introduction of a prior approval regime. Work on the relevant legislative amendments is in hand and will be considered by the Scottish Parliament in due course. New guidance will also be issued to update that currently contained in the Scottish Executive’s Circulars 25/1985 and 5/1992. Similarly, a Code of Best Practice for telecommunications prior approval procedures, in the form of a Planning Advice Note, is also intended. These documents will reflect the policies mentioned at paragraphs 6.104–6.109 above. The Scottish Executive produced its own version of the draft circular on “Land-use Planning and Electro-Magnetic Fields”, which will also be finalised as soon as practicable.
- 6.112** The Scottish Parliament’s Transport and the Environment Committee recently produced a report entitled “Planning Procedures for Telecommunications Development” (Scottish Parliament, 2000). This was prompted by public concern about mobile phone masts and the Scottish Executive’s proposals to increase controls on permitted development rights (see paragraph 6.111). The Committee concluded that the existing system was inadequate and that change was required. It expressed significant concern about the prior approvals process and recommended the introduction of full planning controls. In addition, the Committee identified three key factors that should inform policy in this area: amenity, health, and a precautionary approach.
- 6.113** In relation to amenity, the Transport and Environment Committee concluded that environmental impact could be minimised through early discussion of strategic network requirements, site sharing, mast sharing, design and disguise, and the introduction of national roaming. Although guidance was required to minimise the impact of development on environmentally sensitive

areas, this should allow for local flexibility. In relation to health the Committee decided that whilst there was no conclusive scientific evidence for non-thermal effects, there was reasonable doubt about health risks, and it therefore recommended that health should be a material planning consideration. It also recommended adopting a precautionary approach, and urged planning authorities to consider a hierarchy of preferred locations that would favour development in sparsely populated areas, such as industrial sites. However, the Committee concluded that there was insufficient evidence to justify a *cordon sanitaire*.

- 6.114** The Committee recommended the development of a national policy framework in consultation with interested bodies, including telecommunications developers and operators. Within this framework the Committee identified a need for clear guidance based on a precautionary approach.

Northern Ireland

- 6.115** In Northern Ireland planning decisions are the responsibility of the Planning Service, a Next Steps Agency of the Department of the Environment. This Agency has six divisional offices and two subdivisinal offices, each covering a number of district council areas.
- 6.116** As in England and Wales, larger developments, such as masts over 15 m high, require full planning permission. However, telecommunications code system operators enjoy permitted development rights for a range of developments under the Planning (General Development) Order (Northern Ireland) 1993, as amended by the Planning (General Development) (Amendment) Order (Northern Ireland) 1998. These rights are subject to limitations and conditions to protect amenity and the environment, and essentially mirror those in England and Wales.
- 6.117** Some permitted developments, such as erection of masts up to 15 m high, are conditional upon prior approval by the Planning Service. Under this procedure, the Planning Service has 28 days in which to decide whether to approve the site and appearance of the installation. Where it considers that the development would pose a threat to amenity, the Planning Service may refuse approval. In England and Wales the prior approvals process was modified by the Town and Country Planning (General Permitted Development) (Amendment) Order 1999, and similar changes are currently being introduced in Northern Ireland. It is expected that these changes will be implemented in 2000, and will extend to 42 days the period allowed for notification that prior approval is required, and the decision on whether to approve the siting and appearance of the installation.

7

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Glossary

The descriptions below are intended to help the reader understand the text; they are not necessarily definitive scientific terms, for which the reader is advised to consult specialist sources.

Words in bold are defined separately.

Analogue	The original cellular technology used in the transmission of speech by Vodafone and Cellnet since 1985, operating as an analogue system at 900 MHz. Typically accessed by high powered phones installed in cars.
AM	Amplitude modulation.
Action potential	Voltage produced across a nerve cell membrane by a stimulus. It arises from the entry of sodium ions across the cell membrane, which results in membrane depolarisation.
Antenna	Device designed to radiate or receive electromagnetic energy.
APC	Adaptive Power Control. System used to control mobile phones and base stations in order to ensure that the radiated power does not exceed the minimum consistent with high quality communication. The system effectively operates to reduce average radiated powers.
Base station	Facility providing transmission and reception for radio systems. For macrocells, the infrastructure comprises either roof- or mast-mounted antennas and an equipment cabinet or container. For smaller microcells and picocells, the antennas and other equipment may be housed in a single unit.
Case-control study	An investigation into the extent to which a group of persons with a specific disease (the cases) and comparable people who do not have the disease (the controls) differ with respect to exposure to putative risk factors.
CDMA	Code Division Multiple Access. System that encodes signals to a number of users, so that all of these users can simultaneously use a single, wide frequency band. Each user's handset decodes the information for that user, but cannot access information for any other user.
Cell and Cellular	A cell in the context of mobile phone technology is the area of geographical coverage from a radio base station. "Cellular" describes such systems, but is often used to distinguish the original analogue systems from the later digital PCN systems, although the latter themselves have cells.
Chromosomes	Rod-shaped bodies found in the nucleus of cells in the body. They contain the genes or hereditary material. Human beings possess 23 pairs.
Cohort study	An investigation into the extent to which a group of individuals (the cohort) about whom certain exposure information is collected, and the ascertainment of the occurrence of diseases at later times. For each individual, information on prior exposures can be related to subsequent disease experience.

CJD	Creutzfeldt-Jakob disease.
Confidence interval (CI)	An interval calculated from data when making inferences about an unknown parameter. In hypothetical repetitions of the study, the interval will include the parameter in question on a specified percentage of occasions (for example, 95% for a 95% confidence interval).
CW	Continuous wave.
Decibel (dB)	A measure of the increase or decrease in power at two points expressed in logarithmic form. $\text{Gain} = 10 \log_{10}(P_2/P_1)$.
DECT	Digital Enhanced Cordless Telecommunications.
Digital	Technology introduced in the 1990s as a method of transmitting speech and data. Offers increased security, and technical advantages with low powered phones.
DNA	Deoxyribonucleic acid. The compound that controls the structure and function of cells and is the material of inheritance.
DTX	Discontinuous transmission. System regulating mobile phones to ensure that transmission occurs only during speech. The system has the effect of reducing the time of exposure to approximately half (assuming an equal conversation).
EEG	Electroencephalogram. Measurement of changing voltages associated with brain activity.
EIRP	Equivalent isotropically radiated power. This is the power that would have to be emitted in <i>all directions</i> to produce a particular intensity and so takes account of the transmitter power plus the characteristics of the antenna.
Electric field	Produces a force on a charged object. Measured in units of volts per metre.
Electromagnetic fields	The electric and magnetic fields associated with electromagnetic radiation.
Electromagnetic radiation	A wave of electric and magnetic energy that travels or <i>radiates</i> from a source.
EMF	Electromagnetic field.
ERP	“Evoked” or “Event-related” potential.
FDD	Frequency division duplex.
Frequency	The number of complete cycles of an electromagnetic wave in a second. Measured in units of hertz (Hz) .
Genes	Biological units of heredity. They are arranged along the length of chromosomes .
Gene expression	The realisation of genetic information encoded in genes to produce functional protein or RNA .
GSM	Global System for Mobile Communications or <i>Groupe Spéciale Mobile</i> . The international, pan-European operating standard for the new generation of digital cellular mobile communications. Enables mobile phones to be used across national boundaries. PCN operators work to the same standard but at different frequency allocations.
Hertz (Hz)	Unit of frequency. One cycle per second.

Glossary

IMT - 2000	International Mobile Telecommunications - 2000. International name for UMTS .
Infrared radiation	Electromagnetic radiation capable of producing the sensation of heat and found between visible radiation and radiofrequency radiation in the electromagnetic spectrum.
Intensity	The power crossing unit area normal to the direction of wave propagation. Measured in units of watts per square metre (W/m^2). See also power density .
Ion	Electrically charged atom or group of atoms.
Ion channel (gate)	Protein that allows the passage of ions across a membrane, down a concentration gradient.
Ion pump	A protein pump that moves ions across a membrane against a concentration gradient.
Magnetic field B	Produces a force on a charged object moving at an angle to it. Measured in tesla (T). See also magnetic flux density .
Magnetic flux density	Produces a force on a charged object moving at an angle to it. Measured in tesla (T). See also magnetic field B .
Magnetite	Naturally occurring oxide of iron with magnetic properties
Microwave	Electromagnetic radiation of ultra high frequencies between 1 GHz and 300 GHz.
Molecule	Smallest portion of a substance that can exist by itself and retain the properties of the substance.
Mutation	Chemical change in the DNA in the nucleus of a cell. Mutations in sperm or egg cells, or their precursors, may lead to inherited effects in children. Mutations in body cells may lead to effects in the individual.
Neuron(e)	Nerve cell. Basic unit of the nervous system, specialised for the transmission of electrical impulses.
Nucleus	The controlling centre of higher cells. Contains the important material DNA .
Order of magnitude	Quantity given to the nearest power of ten. A factor of ten or so.
OFTEL	Office of Telecommunications.
PCN	Personal Communications Network. A mobile system principally directed towards the hand portable, domestic user market and operating with digital technology at 1.8 GHz. The two main UK operators are One 2 One and Orange.
Power density	The power crossing unit area normal to the direction of wave propagation. Measured in units of watts per square metre (W/m^2). See also intensity .
Radiofrequency radiation	Electromagnetic radiation used for telecommunications and found in the electromagnetic spectrum at longer wavelengths than infrared radiation .
Relative risk	The ratio of the disease rate in the group under study to that in a comparison group, with adjustment for confounding factors such as age, if necessary.
RF	Radiofrequency radiation .

Risk	The probability or likelihood of injury, harm or damage occurring.
RNA	Ribonucleic acid.
SAR	Specific energy absorption rate.
Significance level	The probability of obtaining a result at least as extreme as that observed in the absence of a raised risk. A result that would arise less than 1 in 20 times in the absence of an underlying effect is often referred to as being “statistically significant”.
Specific energy absorption rate	The rate at which energy is absorbed by unit mass of tissue in an electromagnetic field. Measured in units of watts per kilogram (W/kg).
Third Generation	The next evolution of mobile phone technology, based on UMTS and expected to result in widespread use of video phones and access to multimedia information.
TDD	Time Division Duplex.
TDMA	Time division multiple access. System that divides each frequency band into a number of time slots, each allocated to a single user. Allows several users to operate on the same frequency at the same time.
TETRA	Terrestrial enhanced trunk radio system.
Transcription	The synthesis of RNA from DNA .
UMTS	Universal Mobile Telecommunications System.
Wavelength	Distance between two successive points of a periodic wave in the direction of propagation, in which the oscillation has the same phase. Measured in units of metres.

Quantities and units used to characterise electromagnetic radiation

Quantity	Unit	Symbol
Frequency	hertz	Hz
Wavelength	metre	m
Electric field strength	volt per metre	V/m
Magnetic field strength*	ampere per metre	A/m
Magnetic field, B/Magnetic flux density*	tesla	T
Intensity/Power density	watt per square metre	W/m ²
Specific energy absorption rate (SAR)	watt per kilogram	W/kg

*A magnetic field strength of 1 A/m is equivalent to a magnetic field of $4\pi \cdot 10^{-7}$ T in non-magnetic media

Appendix A

Independent Expert Group on Mobile Phones

Following widespread consultation with interested parties, the Expert Group on Mobile Phones was set up under the Chairmanship of Sir William Stewart FRS, FRSE. Members of the Expert Group were chosen to encompass expert knowledge in epidemiology and experimental biology related to exposures to electromagnetic fields and radiofrequencies, and also knowledge of social science, risk perception and legal issues. There are members with medical and scientific skills in oncology, physics, statistics and neurophysiology. One member is from the World Health Organization (WHO) and there are two members from the Advisory Group on Non-ionising Radiation (AGNIR) of the National Radiological Protection Board (NRPB). There are two members with lay interests.

In addition to full Expert Group members there were observers from the Board of NRPB, from the Department of Health (DH) and from the Department of Trade and Industry (DTI). NRPB staff provided the secretariat and administrative support for the work of the Group.

Brief resumes for Members of the Expert Group are given below.

Chairman

Professor Sir William Stewart FRS, FRSE

Sir William Stewart is President of the Royal Society of Edinburgh and Chairman of the Microbiological Research Authority. He served as Chief Scientific Adviser to the Prime Minister and to the Government (1990–1995). He is a biologist by training. He is Chairman of Tayside University Hospitals NHS Trust. He was the first Head of the UK Government's Office of Science and Technology and has served on various advisory committees including the Royal Commission on Environmental Pollution and the Natural Environment Research Council. He was Chief Executive of the Agricultural and Food Research Council and a former Vice-president of the Royal Society of London.

Vice-chairman

Professor L J Challis OBE

Lawrence Challis is Emeritus Professor of Physics at the University of Nottingham. His university education and the first years of his academic career were at the University of Oxford (1951–59); he then moved to the University of Nottingham. He was appointed to an established chair in 1971, was Pro-Vice-Chancellor before his retirement in 1998 and is now a Leverhulme Emeritus Fellow. His current research interests are on the properties of low dimensional semiconductors. He has published 230 papers and, in 1994, was awarded the Holweck Medal and Prize for his research by the Institute of Physics/French Physical Society. In 1996 he was awarded the OBE for services to scientific research. He has chaired the Royal Society Grant Board for Mathematics and Physics, the Physics

Committee of the then Science and Engineering Research Council and the Solid State Division of the Institute of Physics. He is currently Honorary Editor of *Reports on Progress in Physics* and was until recently Chairman of the European Commission Evaluation Panel for Access to Research Infrastructures.

Members

Professor L W Barclay OBE, FREng

Professor Les Barclay was Deputy Director at the Radiocommunications Agency, responsible for research and radio technology. He is now a consultant in radio regulation, spectrum management and radio propagation, and is a visiting professor at the universities of Bradford, Lancaster and Surrey. He has been chairman of the study group on propagation within the International Telecommunication Union and chairman of the Scientific Committee on Telecommunications within the International Union of Radio Science. He is a Fellow of the Royal Academy of Engineering and is currently a member of the Electronics and Communications Divisional Board of the Institution of Electrical Engineers. He has been awarded the OBE and the Polar Medal.

Mrs M-N Barton MBE

Marie-Noëlle Barton is the National Manager of the Women Into Science and Engineering (WISE) campaign, run by the Engineering Council, the Engineering Marine Training Authority, and the Engineering Employers' Federation. She works with educationalists, employers, Government Departments, politicians and the media to spread the word about WISE. She also oversees the WISE in Northern Ireland, WISE in Scotland and WISE in Wales campaigns to cater for the specific needs of women in these countries. Previously she has worked as a careers adviser with local authorities, and was a language teacher between. She holds an Honorary Doctorate of Technology from Staffordshire University.

Professor C Blakemore FRS

Colin Blakemore studied medical sciences at the University of Cambridge and completed his PhD at the University of California, Berkeley, in 1968. He taught at the University of Cambridge for 11 years and in 1979 took up the Chair of Physiology at the University of Oxford. He is also Director of the Oxford Centre for Cognitive Neuroscience, and was President of the British Association for the Advancement of Science for 1997–98. He has worked as a Visiting Professor at the Massachusetts Institute of Technology, New York University, the University of California and the Salk Institute, and also in Japan, Switzerland, Italy, France, the Czech Republic and China. He holds the degree of DSc from the universities of Cambridge and Oxford, honorary doctorates from Aston and Salford Universities and an honorary fellowship from Cardiff University. He is a Fellow of the Royal Society, the Academy of Medical Sciences and the Institute of Biology, a member of the Academia Europaea and a Foreign Member of the Royal Netherlands Academy of Arts and Sciences. His research has been concerned with many aspects of vision and the early development of the brain. His awards include the 1996 international Alcon Prize for vision research and the 1989 Royal Society Michael Faraday Award for the furtherance of the public understanding of science. He is a member of the NRPB Advisory Group on Non-ionising Radiation.

Professor D N M Coggon

David Coggon studied mathematics and medicine at the universities of Cambridge and Oxford. He is currently Professor of Occupational and Environmental Medicine at Southampton University where he works in the Medical Research Council Environmental Epidemiology Unit. He has been engaged in epidemiological research for more than 20 years, focussing mainly on occupational and

Appendix A

environmental causes of disease. Special interests include the relation of musculoskeletal disorders to physical activities in the workplace, and the health effects of chemical pollutants. He is also a consultant occupational physician and carries out clinical work for Southampton University Hospitals Trust. He is a Fellow of the Academy of Medical Sciences, Chairman of the Advisory Committee on Pesticides, and a member of the Expert Panel on Air Quality Standards and the Industrial Injuries Advisory Council.

Professor Sir David Cox FRS

Sir David Cox was educated at St John's College, Cambridge (MA), and the University of Leeds (PhD). After working in industry, he held academic posts at the University of Cambridge and Birkbeck College, University of London. In 1966 he became Professor of Statistics, and in 1970 Head of the Mathematics Department, at the Imperial College of Science and Technology, University of London. He is a former Warden (1988–94) and an honorary Fellow of Nuffield College, Oxford. He is a Fellow and former Member of Council of the Royal Society and was President of the International Statistical Institute from 1995 to 1997. He has been President of the Royal Statistical Society. He holds a number of awards, including honorary Fellowships at St John's College, Cambridge, and the British Academy, the Guy Medal (in Silver and in Gold) from the Royal Statistical Society, and the degree of DSc from a number of universities. He has also been awarded the Weldon Memorial Prize, University of Oxford, and the Kettering Prize and Gold Medal for Cancer Research. He is a Foreign Honorary Member of the US. National Academy of Sciences. He was editor of *Biometrika* from 1966 to 1991.

Mr J Fellows

John Fellows is a graduate of the University of Edinburgh (MA, politics) and a winner of the Sir William Darling Memorial Prize (1997) for an outstanding contribution to the reputation for the university through project work in local schools. He was President of Edinburgh University Students' Association for 1998–99: his activities included lobbying the Scottish Parliament to set up an inquiry into student finance and campaigning against the Bank of Scotland business partnership with Pat Robertson Financial Services in the USA; other areas of interest included the promotion of widening access to university, and the adoption of ethical investment policies within the University. He is currently a co-ordinator for the Lothian Equal Access Programme for Schools, a project to widen access to higher education, based at the Heriot-Watt and Napier Universities in Edinburgh.

Dr M Repacholi FACPSEM, FARPS

Michael Repacholi is a graduate of the University of Western Australia (BSc, physics), London University (MSc, radiation biology) and Ottawa University (PhD, biology). He is the author or co-author of over 150 scientific publications. He is at present the Coordinator, Occupational and Environmental Health, at the World Health Organization (WHO) in Geneva, and has participated in ten WHO non-ionising radiation task groups. He is an Emeritus Chairman of the International Commission on Non-Ionizing Radiation Protection, Fellow and Past President of the Australian Radiation Protection Society and of the Australasian College of Physical Scientists and Engineers in Medicine. He is also a Fellow of the Australian Institute of Physics and a member of the Health Physics Society and of the Bioelectromagnetics Society.

Professor M Rugg FRSE

Michael Rugg obtained his PhD in 1979. Following a postdoctoral year at the University of York, he was appointed to a lectureship in psychology at the University of St Andrews, where he became Professor of Psychology and Head of School in 1992. In 1998 he moved to the Institute of Cognitive Neuroscience, University College London, as Professor of Cognitive Neuroscience and Wellcome Trust Principal Research Fellow. His principal research interests are the cognitive and neurological

bases of human memory, and the non-invasive investigation of human brain function through the use of electroencephalography and functional neuroimaging. During 1998 and 1999 he served on the Department of Health Working Group on Organophosphates.

Professor A J Swerdlow

Anthony Swerdlow was educated in medicine at the universities of Cambridge and Oxford. After junior posts in clinical medicine, epidemiology and public health in the Oxford region and London, he worked in epidemiology at the University of Glasgow and at the Office of Population Censuses and Surveys before moving to the London School of Hygiene and Tropical Medicine in 1987. He is currently Professor of Epidemiology at the School. His research is in chronic disease epidemiology, mainly on cancer but also on other diseases including type 1 diabetes and CJD. His research interests have for many years included non-ionising radiation and he is currently a member of the NRPB Advisory Group on Non-ionising Radiation and of the Epidemiology Standing Committee of the International Commission on Non-Ionizing Radiation Protection.

Mr T R K Varma FRCS (Ed)

T R K Varma graduated in medicine (MB;BS) from the University of Bangalore, India, and is a Fellow of the Royal College of Surgeons of Edinburgh. He is currently Consultant Neurosurgeon at the Walton Centre for Neurology and Neurosurgery, Liverpool, and Honorary Clinical Lecturer at the University of Liverpool. He previously held the post of Consultant Neurosurgeon and Honorary Senior Lecturer at Ninewells Hospital and Medical School, Dundee. He is a member of the Council of the Society of British Neurological Surgeons (SBNS) and of the Clinical Standards Committee of SBNS. His special expertise is in the field of stereotactic and functional neurosurgery, including the use of chronic electrical stimulation of the brain in the treatment of movement disorders.

Observers

Professor A D Baddeley FRS (*Member of the National Radiological Protection Board*)

Dr H Walker (*Department of Health*)

Mr G Worsley (*Department of Trade and Industry*)

Secretariat

Dr J W Stather (*National Radiological Protection Board*)

Dr N A Cridland (*National Radiological Protection Board*)

Administrative Support

Karen Roberts (*National Radiological Protection Board*)

Maxine Smith (*National Radiological Protection Board*)

Kate Christie (*Chairman's Office, Dundee*)

Isa MacLean (*Chairman's Office, Dundee*)

*Appendix A***Acknowledgements**

The work of the Independent Expert Group on Mobile Phones has been dependent on the co-operation of many individuals and organisations. We are particularly grateful to Professor Ken Foster, Professor Robert Adair, and Dr Mario Cortina Borja for helpful advice and useful discussions. Special thanks are also due to Dr Mika Koivisto, who allowed us access to his data prior to publication and to Dr Alan Preece, who permitted us to re-analyse his data on reaction time.

Our work could not have been completed in so short a time without the hard work and excellent administrative support provided by Karen Roberts, Maxine Smith, Kate Christie and Isa MacLean to all of whom we express our gratitude.

Appendix B

Written Evidence

Evidence was submitted to the Expert Group by 174 individuals and organisations:

Mr H Aitkin, Edinburgh
 Anonymous, Manningtree, Essex
 Anonymous, Surrey
 Mrs A C Arnold Silk, Princes Risborough, Bucks
 Mr & Mrs R S Ashwood, Tamworth, Staffs
 Ms S Atkinson, Atlantic Telecom, Aberdeen

Professor R Baker, Biotechnology & Biological Sciences Research Council (BBSRC), Swindon, Wilts
 Dr M Bastide, Laboratoire D'Immunologique et Parasitologie, Université Montpellier I, France
 Ms J Bates, Stockton-on-Tees, Cleveland
 Mrs G Batter, London
 Mr G Berry, Newry, Co Down, Northern Ireland
 Mr H Best MP, House of Commons, London
 Mr R Bolton, Broadcasting, Entertainment, Cinematograph and Theatre Union (BECTU), London
 Mr C H Bowden, Department of the Environment, Transport and the Regions, London
 Mr S Box, Holmer Green Upper School, Holmer Green, Bucks
 Mrs J Bramwell, Russell Lower School, Amphthill, Beds
 British Medical Association, London
 Professor R Brook, Engineering and Physical Sciences Research Council (EPSRC), Swindon, Wilts
 Ms J Brookes, Federation of Communication Services Ltd (FCS), London
 Mrs G Burkitt, Holmer Green, Bucks
 Mr P D Burrill, Oakwood, Leeds, Yorks

Ms M Cahill, The Wessex Astrologer Ltd
 Professor I Campbell, The Maudsley Institute of Psychiatry, London
 Dr G L Carlo, Wireless Technology Research, Washington, USA
 Master A Carmody, Barnet, Herts
 Mr E Carson, Orange PCS Ltd, Dundonald, Northern Ireland
 Mr B Claridge, Holmer Green, Bucks
 Mrs V Clarke, Oxford, Oxon
 Mrs T Clarkson, Leeds, Yorks
 Professor R Clausen-Sternwald, Burnley, Hants
 Mr I Clement, Glasgow
 Professor D Clements-Croome, Department of Construction Management and Engineering, University of Reading, Berks
 Mrs F Clifford (e-mail)
 Mr R Coghill, Coghill Research Laboratories, Pontypool, Gwent
 Ms D C Collins, Belvedere, Kent
 Mr B Compton, Solihull, West Midlands
 Dr J Connor, Ministry of Defence, London
 Dr R A F Cox, Fowlmere, Cambs

Appendix B

Dr D de Pomerai, School of Biological Sciences, University of Nottingham, Notts
 Mr E P D'Alton, Irish Campaign Against Microwave Pollution (ICAMP), Dublin, Republic of
 Ireland
 Mrs M Dafforn, Hook, Hampshire
 Mr G H David, Aerial Group Limited, Chesham, Bucks
 Mrs M Dean, Northern Ireland Families against Telecommunications Transmitter Towers (NIFATT),
 County Antrim, Northern Ireland
 Dr M T Deans, London
 Mr J M Dilks, Brant Broughton, Lincs
 Mr K Diment, Wantage, Oxon
 Mrs E G M Dixon, Christchurch, Dorset
 Mrs A R Dobbs, Gilwern, Abergavenny
 Mr M Dolan, Mobile Telecoms Advisory Group, Federation of the Electronics Industry, London
 Dr D Doyle, Southern General Hospital NHS Trust, Glasgow
 Mr M Durrant, Bucksburn, Aberdeen

Mr L Feetham, Winchester City Council, Winchester, Hants
 Mr S Fielding, Maidstone, Kent
 Mr A Firstenberg, Cellular Phone Taskforce, New York, USA
 Mr A Foster, Ampthill, Beds
 Mr P Foster, Holmer Green, Bucks
 Mrs C Frank, London
 Mr P Franklin, Orange plc, London
 Mr A Freeman, BT Cellnet, Slough
 Mr G Fulford, Leigh-on-Sea Town Council, Leigh-on-Sea, Essex

Ms C Gabriel, Microwave Consultants Limited, London
 Mr R Gardner, Ministry of Defence, London
 Mrs P Garrett, Long Crendon, Bucks
 Ms C Gillan MP, House of Commons, London
 Mr A W Glass, Aberdeen
 Ms J Goddard, Ampthill, Beds
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 Mr J N W Hartley, Acklam, Middlesbrough, Cleveland
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 Mrs J Mortimer, Monifieth, Angus
 Ms Joanne Mueller, USA
 Mr R Murtagh, Fowey, Cornwall
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Appendix B

Mr R Riedlinger, Abbotsford, British Columbia, Canada
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 Mr P Roche, Northern Ireland Assembly, Belfast, Northern Ireland
 Mr J Royds, Greystones, Co Wicklow, Republic of Ireland

Ms C Sage, Sage Associates, Santa Barbara, California
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 Mr A Scott, Salisbury, Wilts
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 Mr M Simpkins, Holmer Green, Bucks
 Mr K Simpson, Bedford, Beds
 Mr M Smith, Ampthill, Beds
 Mrs M Somers, Cookridge, Leeds, Yorks
 Mr D Stevens, Marketex (UK) Ltd, Barham, Kent
 Mr P Sutton, Wantage, Oxon

Mr D K Tamerlane, Woking, Surrey
 Dr J Tattersall, Defence Evaluation and Research Agency (DERA), Porton Down, Wilts
 Mr B Taylor, Essex
 Mrs C Terry, Dover, Kent
 Mr L F W Thomas, Swanley, Kent
 Mrs A Trattles, Stockton, Cleveland
 Mr A E Trenary, Fowey, Cornwall
 Mrs J Tiffany, Watford, Herts
 Ms R Tilly, London
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 Ms M Turner, Monifieth, Dundee

Mr J Van Montfoort, Porlock, Somerset

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 Mrs J Watts, Long Ashton, Avon
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 Mr N Wenham, Ambrosden, Oxon
 Mr P & Mrs J Weychan, Fowey, Cornwall
 Ms J Whalley MP, House of Commons, London
 Ms R C Whetstone, One 2 One, Borehamwood, Herts
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 Mr W G Williams, Southport
 Mr P Willis MP, House of Commons, London
 Mr A Wilson, Macclesfield, Cheshire
 Mr L Wilson, Microshield Industries plc, Enfield, Middlesex

Appendix C

Meetings

Open Meetings

Summaries of the open meetings of the Expert Group have been placed on the Group's web site at www.iegmp.org.uk.

Thursday 11 November 1999, The Playfair Library, University of Edinburgh

Thursday 9 December 1999, The Medical School, University of Liverpool

Thursday 20 January 2000, The Medical School, University of Cardiff

Thursday 27 January 2000, Scientific Societies Lecture Theatre, New Burlington Place, London

Thursday 3 February 2000, Peter Froggatt Centre, The Queen's University of Belfast

Closed Sessions

Summaries of the oral evidence presented to the Expert Group by 28 witnesses in closed sessions have been placed on the Group's web site at www.iegmp.org.uk.

Friday 10 September 1999, Adam House, Adam Street, London

Witnesses Dr P J Dimbylow, National Radiological Protection Board (NRPB)
 Dr S M Mann, National Radiological Protection Board (NRPB)

Friday 8 October 1999, Adam House, Adam Street, London

Witnesses Dr A F McKinlay, National Radiological Protection Board (NRPB)
 Professor P Ramsdale, One 2 One
 Ms R Whetstone, One 2 One

Friday 12 November 1999, The Elder Room, University of Edinburgh

Witnesses Dr H Irvine, Greater Glasgow Health Board
 Dr R A Lerski, Ninewells Hospital, Dundee
 Mr G McAlister, Friends of the Earth Scotland
 Mr J McDonald, Houston, Renfrewshire

Appendix C**Thursday 9 December and Friday 10 December 1999, Crowne Plaza Hotel, Liverpool**

Witnesses Dr A W Preece, University of Bristol
 Dr G J Hyland, University of Warwick
 Mr M Dolan, Federation of the Electronics Industry
 Professor P Ramsdale, One 2 One
 Mr P Rumbalow, Orange plc
 Mr P Harrison, Nokia UK Limited
 Mr J Berle, Federation of the Electronics Industry

Thursday 20 January and Friday 21 January 2000, The Angel Hotel, Cardiff

Witnesses Mr A Philips, Powerwatch
 Mr R Gardner, Ministry of Defence
 Mr J Mackay, Ministry of Defence
 Mr K Tench, Ministry of Defence
 Dr J Tatersall, Defence Evaluation and Research Agency (DERA), Porton Down
 Dr D de Pomerai, University of Nottingham

Thursday 3 February and Friday 4 February 2000, The Stormont Hotel, Belfast

Witnesses Dr H Kennedy, Northern Ireland Families against Telecommunications Transmitter
 Towers (NIFATT)
 Mrs M Dean, Northern Ireland Families against Telecommunications Transmitter
 Towers (NIFATT)
 Mr J Royds, Greystones, Co Wicklow
 Mr A Meyer, Halsey, Meyer Higgins, Solicitors

Friday 3 March 2000, Adam House, London

Witnesses Mr P Myott, Liverpool
 Mr L Wilson, Microshield Industries

Tuesday 21 March – Friday 24 March 2000, NRPB, Chilton, Didcot

Witness Professor R H Clarke, National Radiological Protection Board (NRPB)

Thursday 6 April 2000, Royal Over-Seas League, London

Emerging EMF technologies action on possible health risks

Alastair McKinlay

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Abstract In recent years, there has been an unprecedented increase in the use of devices emitting electromagnetic fields (EMF). This impinges on every aspect of day-to-day living, whether in the home, in public places or at work. While the benefits to society of such technologies, for example in mobile and other personal radio-communications, are accepted, significant public and media concern continues to be expressed about increases in EMF exposure of people and potential-related adverse effects on health. Particular concerns are focussed on what people often regard as the involuntary aspects of EMF exposure and often on the exposure of children or the unborn child. The key to addressing anticipated public and media concern about potential adverse health effects is foresight in respect of carrying out, co-ordinating and sharing knowledge of relevant multidisciplinary scientific research. This prompted a successful submission to the European Co-operation in Science and Technology (COST) programme for support for an Action entitled “Emerging EMF Technologies: Health Risk Management”. The four-year Action in the COST Domain “Biomedicine and Molecular Biosciences” will provide researchers with an effective vehicle for sharing multidisciplinary knowledge, encouraging multi-laboratory collaboration and for training of early-stage researchers in EMF health-related research. It facilitates identifying how existing technologies change, what entirely new applications and services are introduced, what impact these would have on the levels and spectral nature of EMF exposure of people and what potential health consequences might arise.

Keywords Electromagnetic fields · Health risks · Exposure · European projects

1 Introduction

The use of devices emitting electromagnetic fields (EMF) ranging from static to microwave frequencies has significantly increased in recent years. Their presence has affected almost every aspect of day-to-day living, at home, while travelling and at school, college and work. By far, the most significant impact has been through the rapid expansion of personal mobile telecommunication and wireless network systems for voice, picture and video communication, internet access and other data transfer applications. Other applications of EMF are found in the widespread use of electronic article surveillance, radiofrequency identification, metal detection and inductive heating devices. New digital public and commercial radio and television broadcast systems are currently being introduced throughout Europe. Applications in medicine abound, including advances in novel magnetic resonance imaging (MRI) equipment design and new MRI scanning techniques. There is also a potential for new medical applications of ultra wide band (UWB), for example in cardiology, detection of breast tumours, detection of intracranial haemorrhage and the use of implantable sensors that rely on UWB communication.

While the benefits of technologies that have already been introduced are clear and widely accepted by society, significant concern continues to be expressed about consequential increases in EMF exposure of people and potential-related adverse health effects. Generally, in the public arena, concern has been often expressed about potential effects of EMF exposure on children's health and on that of older and/or sick people and pregnant women (including the

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unborn child). This is exemplified by public and media concern about the potential adverse health effects that might result from the exposure of young people through the rapid expansion of the use of WiFi systems in schools and colleges.

In contrast, in one important occupational setting, concern has been expressed by medical practitioners and other clinical staff using MRI for diagnosis and for research and by those concerned with the manufacture, calibration and maintenance of MR equipment, over the likely adverse effect on working practices and patient care of the implementation of the EC Physical Agents Directive. The clearest trend in MRI is the move to systems utilising higher field strengths, with 3-T installations accelerating and moving into clinical rather than solely research settings. The use of high and ultrahigh systems for structural and molecular imaging will increase particularly in the study of degenerative neurological diseases, high-resolution vascular imaging, detailed monitoring of the effectiveness of anti-angiogenic and genetic-based drugs for the treatment of cancer. MRI is increasingly being used for physiological and metabolic investigations, and molecular applications such as quantitative imaging of gene expression, marking stem cells and tracking their evolution or monitoring targeting of malignant cells with targeted contrast agents. There may be some interest in new low field systems that are more ‘patient-friendly’, e.g. superconductive open scanners at 1 T or very short-bore 1.5-T cylindrical systems, which would normally complement an existing 1.5-T installation. At present, these systems are relatively expensive, but there are already a number of such installations in Europe. Low field, open scanners are often used in interventional MR.

It is clear that there is generally a paucity of data on these and other occupational exposures, and that experimental and computational studies are needed to resolve these issues.

Against this background, a successful submission was made to the European Co-operation in Science and Technology (COST) programme for support for an Action entitled “Emerging EMF Technologies: Health Risk Management”.

The Action, in the COST Domain “Biomedicine and Molecular Biosciences”, has been developed by and represents a consensus of scientific experts covering the disciplines of medicine, epidemiology, biology, physics, engineering and risk assessment and management. Experts from some 27 European countries have expressed interest in the Action.

Through key individual experts, the Action will also enjoy co-operative interaction with a number of national and international agencies including the World Health Organization (WHO) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

The European Commission, national governments and international advisory bodies, such as the World Health Organization, have all recognised the importance of high-quality scientific research as fundamental to addressing such concerns and the Action will effectively facilitate the ongoing exchange of information and the results of such research and provide information that can be transposed by relevant authorities into sound health risk management based on scientific evidence. The Action will also contribute to the training of early-stage scientists in respect of supporting their interaction with more experienced scientists and the skills and knowledge transfer that ensues. In this regard, the Action plans for short-term scientific missions where early-stage researchers may seek support for working in established centres of relevant scientific expertise elsewhere. Scientists from new EU member states will have the opportunity to further collaborate and share experiences and knowledge in the field.

2 Current position

International co-ordination of activity in EMF-related scientific research and health risk management has been significantly improved by the activities of previous COST actions in this field, particularly COST Action 281. Through effective multidisciplinary scientific collaboration, major improvements in providing stakeholder-specific information for health risk communication will be possible. There are many partners contributing to this process including WHO, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and national agencies and advisory bodies. In Europe, one such anticipated partner is “EMF-NET”. The roles of the COST Action and of such other bodies are complementary but distinctly different. COST provides a forum for expert scientific discussion, knowledge sharing and research collaboration at the grass roots level of scientific research, while interpretive and advisory bodies, including EMF-NET, deal principally with the interpretation of the science and dissemination of scientific review reports. The Action seeks to build upon and strengthen this co-operative complementary approach with other bodies.

3 Objectives

The main objective of the Action is to create a structure in which researchers in the field of EMF and health can share knowledge and information on:

- How existing EMF technologies change either in their operating characteristics or in novel ways and applications in which they are used.

- Identifying what entirely new EMF technologies are introduced and on what timescale.
- What novel emission and operating characteristics might result and what impact these would have on the device-specific and overall EMF exposure of people.
- What possible health effects could consequently arise and the scientific evidence for health concerns if any.
- How such concerns should be addressed through the use of evidence-based information.
- What tools are effective in communicating and managing such risks and perceived risks. And, effectively publish all such information in the public sector for the benefit of all stakeholders.

The secondary objectives are:

- To facilitate multidisciplinary co-operation and knowledge sharing amongst EMF and health researchers across Europe, and include new researchers in the process, in particular those from new EU member states. Emphasis will also be placed on helping early-stage researchers, including post-graduate students, to present and discuss their work and learn from experienced researchers in the various fields of activity. Primary end users are scientific researchers.
- To enlarge the field of co-operation to other disciplines. This to include researchers in wireless engineering, sensor development, medicine, epidemiology, biology, dosimetry, risk analysis, communication and public health. Primary end users are scientific researchers.
- To identify where answers to addressing health issues related to emerging technologies require additional research effort and provide early warnings of problems ahead. Primary end users are the general scientific community and academic institutions across the EU.
- To provide scientific information that can be used by international and national advisory bodies in producing interpretive and advisory documents. Primary end users are the EC, national government agencies and advisory bodies and manufacturing and service industries.
- To further develop EMF exposure measurement and computational techniques and facilitate multidisciplinary collaboration between epidemiologists, biologists and dosimetrists in quantifying EMF emissions and exposures of people. Primary end users are scientific researchers.
- To share the results of ongoing epidemiological, medical and biological EMF research including experience with novel biological techniques. Primary end users are scientific researchers.
- To share knowledge of methods and tools for assessing public risk perception of emerging EMF technologies. Primary end users are national and local government agencies, advisory bodies, risk assessors and communicators.

4 Programme

The initial focus will be on those existing EMF technologies where there is already concern about their use and where further developments in respect of their applications are foreseen in the shorter term. These include:

- *WiFi*—and more generally wireless networks—particularly in respect of their mass roll-out across Europe in schools, other educational establishments and elsewhere, and the potential exposure of young people. Research is ongoing on exposures from WiFi and similar EMF technologies, including WiMax, baby alarms and monitors etc. This is a complex issue due to the variable proximity of such devices and the efficiency of coupling of EMF with the body. To be effective, research effort must involve the manufacturers and providers of such equipment, experienced RF measurement experts and the co-operation of users, such as schools and colleges. It is important that the results of such research are shared and their implications discussed as early into the Action as possible.
- *MRI*—where there is already considerable research in progress in assessing occupational exposures to medical staff and to patients and volunteers. Increases in specialised MRI techniques, such as cardiac imaging and interventional procedures, will lead to the emergence of greater numbers of specialised medical units with further uncertainties in exposures of staff. It is important that the results of dosimetry and other studies are shared and discussed in respect of assessment of compliance with the EU Physical Agents Directive and in national and European policies for the care of patients and volunteers undergoing MRI procedures.
- *Electronic article surveillance and RFID devices*—where the International Commission on Non-Ionizing Radiation Protection (ICNIRP), in a report commissioned by the EU, recommended the measurement of levels of exposure. Such exposures include those to workers and to the general public (including children). For this, and for other exposure characterisation purposes, the further development and dosimetric application of anatomically realistic computational phantoms, including those of children, based on medical imaging data is recommended. ICNIRP emphasised that, in the development of security systems, minimisation of exposures should be considered as a primary design criterion. It is important that the results of such scientific work should be shared and discussed, and the Action provides an effective vehicle for this.

Under the guidance and monitoring of a Management Committee, the focus will subsequently shift to identify

those EMF technology applications and services currently in use and/or likely to be rolled out over future years and, where possible, to characterise likely exposures and identify potential health concerns associated with their use. Likely candidates might include, for example: so-called 4G (and further developments in mobile telephony), ad hoc networks, W-LANS, WiMax, Zigbee, Bluetooth, Wimedia, UWB, broad-band over power transmission lines, various EASD and RFID applications and further digital broadcasting.

In parallel with these activities, horizon scanning will be carried out of devices and applications at present in concept stage, with the purpose of advising engineers, designers and those responsible for marketing and rolling out EMF systems and products to consider exposure of people and possible health concerns in their development plans.

In the fields of epidemiology and biology, the primary focus will be on keeping up to date with and sharing information on ongoing studies relevant to EMF exposure and health and interpreting the results in relation to the nature of possible exposures related to emerging technologies.

Innovative biological techniques are also of interest, and it will be proposed to the Action Management Committee that the Action should keep abreast of developments in the area of High Throughput Screening Techniques (HTST) applications in studying low intensity exposure to EMF by:

- Analysing new relevant scientific publications.
- Preparing a set of good scientific practice guidelines for scientists who are executing HTST studies in EMF research in order to help in increasing the scientific quality of the studies.
- Developing a database where information from HTST analyses could be stored and used as reference in designing new studies that would look at physiological effects of EMF.

5 Benefits

The benefits of the Action are in:

- Identifying emerging EMF technologies, applications and services and, in advance of their roll out, elaborating the basis for answers to health-related issues of potential concern, thus providing the opportunity for pre-emptive actions on product design, policy development, etc.
- Sharing knowledge of likely emissions and exposures of people associated with the use of such technologies, thus enabling comparison with exposure standards for the general public and occupational exposure limits and the opportunity for pre-emptive advice and, if necessary, controls on their use.

- Providing information on ongoing life science studies and assessing the potential for emerging biological investigation techniques for application to EMF health risk investigations.
- Providing scientific information to assess the likely impact, if any, on health from the use of such technologies, thus supporting policy development as to their use in society.
- Providing scientific and technical information supportive of health risk assessment, risk communication and planning future research.

The vehicles for dissemination include scientific reports from working groups and proceedings of workshops and conferences, peer reviewed papers, a newsletter and an Action website.

6 Beneficiaries

The Action will be of significant benefit to:

- *Researchers*—in respect of sharing information on ongoing research multidisciplinary forums, early identification of research gaps and needs, encouraging opportunities for international collaboration and co-publication and, for early-stage researchers, the opportunity to acquire relevant further experience, skills and knowledge.
- *Risk managers and communicators*—in providing multidisciplinary forums to share complementary knowledge with scientific researchers supporting the development of health risk communication strategies.
- *EU and national and local government officials and elected representatives*—in their task of developing proportionate policies to minimise health risk in the face of often technically complex and apparently conflicting health information.
- *International health protection advisory and technical standardisation organisations*—in providing scientific information on EMF and health related to emerging technologies, useful to the work of bodies such as WHO, ICNIRP, CENELEC, IEC, etc.
- *Industry and commerce*—in respect of having the information to judge whether there is likely to be adverse public and media concern about their products and services before launching them, to consider likely EMF emissions and exposures of people at an early stage of product design and development.
- *Society as a whole*—in ensuring that, when new EMF technologies are introduced, potential risks are seen in perspective with the benefits. This supports open communication and dialogue based on facts rather than ‘beliefs’.

- *The media*—in making available facts about new EMF technologies in order to inform their readers/viewers/listeners.

7 Administration

The Action is structured around the co-ordinated activities of specific Action Working Groups and through cross-group tasks. Initially, it is envisaged that the Action Working Groups will comprise:

- *EMF Measurement and Monitoring*—This group will maintain a watching brief to identify and report on new technologies utilising different parts of the frequency spectrum. It will contribute to the further development of EMF measurement techniques appropriate to existing and new technologies and provide exposure data for both public and occupational situations.
- *Computational Dosimetry*—This group will contribute to the further development of EMF computational dosimetry techniques for existing and new technologies including (statistical) uncertainty management for both public (including children's) and occupational exposures. These activities are vital to quantifying exposure of people its spatial distribution within the body.
- *Epidemiology*—This group will address epidemiological research and will analyse and discuss the outcomes of studies.
- *Biology*—This group will cover ongoing biological research studies including novel biological investigational methods with potential application to EMF and health research.
- *Risk Communication and Management*—This group will share multidisciplinary scientific knowledge in identifying and assessing methods and tools for use in health risk communication and management.

8 Collaboration

International co-ordination of activity in EMF and health risk management has been significantly improved by the complementary activities of a previous COST Action 281 and those of international and national interpretive and advisory bodies. COST provides a forum for expert scientific discussion, knowledge sharing and research collaboration at the grass roots level of scientific research, while interpretive and advisory bodies deal principally with the interpretation of the science and dissemination of scientific review reports. The Action will seek to build upon and strengthen this co-operative complementary approach with other bodies.

In conclusion, as with all COST actions, the focus in this Action is on active collaboration and communication between scientists and other relevant professions at the research working level. Anyone interested in participating in the Action is encouraged to contact the author for further information.

Alastair McKinlay is the Head of the Physical Dosimetry at the United Kingdom Health Protection Agency's Centre for Radiation, Chemical and Environmental Hazards. Appointments he has held include: Membership of the United Kingdom "Application of Radioactive Substances Advisory Committee" (ARSAC); President of the UK National Committee of the International Commission on Illumination (CIE); Chairman of a European Commission Expert Group on Mobile Telephony and Human Health; President of the European Society of Skin Cancer Prevention (EUROSKIN); Vice-chairman of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) from 1996 to 2000 and Chairman from 2000 to 2004. He is currently a member of the Programme Management Committee of the UK Mobile Telephone Health Research Programme and a member of the International Advisory Committee of the WHO EMF Project.

Evaluation of the SAR induced in a multilayer biological structure and comparison with SAR in homogeneous tissues

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Abstract Wireless systems usage has evolved, for instance, with the recent increase in the use of a hands-free kit, the mobile phone is used more and more in a body-worn position. Therefore, to check the compliance to the international limits, new methods have to be developed. In this study, we analyze the relevance of using the equivalent head liquid for the biological structure of organs that are different from that of the head. This paper compares the Specific Absorption Rate (SAR) values assessed using simulations in a flat phantom filled with the liquid used to test the compliance of mobile phone close to the head to those values obtained using a multilayer model representing the tissues of the trunk. The multilayer structures are derived from the anatomical analysis of the visible human model and corresponding to reasonable positions of a handset in a body-worn configuration. The employed sources are half-wavelength dipoles placed at different distances from those structures and operating at frequencies between 300 MHz and 6 GHz.

Keywords Body worn · Compliance testing · Dosimetry · Electromagnetic exposure · Specific Absorption Rate (SAR)

1 Introduction

Wireless communications are more and more used and new usages such as the use of a hands-free kit have appeared over the last few years. To protect the public from overexposure to electromagnetic fields, limits have been established by international organizations such as ICNIRP (International Commission on Non Ionizing Radiation Protection) [1] and IEEE [2]. Dealing with a handset close to the head, methods, and protocols to check the compliance have been studied and standardized [3, 4]. Test positions, a phantom (SAM for Specific Anthropomorphic Mannequin used in international standards) and an Equivalent Head Liquid (EHL) have been designed to assure that the Specific Absorption Rate (SAR) assessed in such a phantom overestimated the SAR induced by the handset under test close to the head [5–7]. Since the tissues of the front of the body are different from those of the head, it has to be verified if the EHL can be conserved to represent them.

The aim of our study is to analyze the relevance of the EHL and the value of the Correction Factor (CF) that should be applied to the SAR evaluated using EHL to guarantee an overestimation of the SAR over 10 g in heterogeneous tissues. The front of the body is composed of tissues such as skin, fat, and muscle. Depending on the morphology of a person and on the phone location on the front of the body, the thickness of these tissues can vary, therefore the correction factor, to be relevant, has to take into account such variability. In this study, the SAR is evaluated in multilayer structures having different thicknesses and the result is compared to the results in the homogeneous liquid EHL. For both cases, the employed source is a half-wavelength dipole located at different distances from the multilayer.

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The different multilayers used in this study are derived from the numerical Visible Human (VH) [8] model segmented by Brooks Air Force laboratories. It is described with 38 different tissues. On the body, the thickness of organs like skin and subcutaneous fat tissues varies according to the localization. From the front surface of the VH body, a total number of 176,749 different structures have been found. The ten most frequently encountered layers have been used in this study. For different distances between the multilayer structure and the source, simulations are performed to determine the SAR induced in different multilayer structures as well as in the homogeneous structure. For different frequencies, and at source distances from multilayers, the ratios (CF_i) between the maximum SAR over 10 g assessed in a multilayer structure of index i and that calculated in the homogeneous structure have been evaluated. The maximum of these ratios provides a conservative ratio named in this paper as Global Correction Factor (GCF). On the other hand, depending on the localization on the body, the SAR over 10 g in human tissues does not involve all the layers, therefore we combined the CF_i using a weight based on the occurrence of these structures in ten grams of tissues to estimate a local (over 10 g) ratio. The maximum of these ratios provides a second conservative ratio that we call Global Local Factor (GLF).

2 Models and methodology

To evaluate the SAR in the front of the body, we employed models of biological multilayer structures [9] having different thicknesses derived from the Visible Human (VH) model [8] segmented by Brooks Air Force laborato-

ries (Fig. 1). The multilayer structures and their thicknesses have been derived from the front of the body of the VH and expressed in integer numbers of millimeters since the resolution of the VH model is the millimeter. A total number of 176,749 structures are found. Only six tissues are represented in these layers of tissues, namely: the skin, the subcutaneous fat, the muscle, bone marrow, bone cortical, and ligament. We have extracted the ten most probable layers (see Table 1), in the area of the front of the body, which represent 54% of the total. The layered structured ML1, 2 and 9 identified in Table 1 are terminated on an infinite layer of fat. Figure 2 shows that these multilayer structures are composed of two (skin, subcutaneous fat) and three layers (skin, subcutaneous fat, muscle). Two areas are observed, on one hand, we have the abdomen which is mainly composed of the skin and subcutaneous fat (these structures are the ones with a major occurrence), and on the other hand we have the chest where the main structures are those with skin, subcutaneous fat and muscle.

These ten structures have been exposed, as shown in Fig. 3, to RF electromagnetic field produced by a matched half-wavelength dipole to determine the electric field distribution and consequently the Specific Absorption Rate (SAR) distribution in tissues. The SAR, in these biological structures is calculated using the well known formula (1):

$$SAR = \frac{\sigma \cdot |E|^2}{2\rho} \tag{1}$$

where E is the amplitude of the electric field in the body tissue in V/m, σ the tissue conductivity in S/m and ρ the tissue density in kg/m^3 .

The electric field in tissues is evaluated using the commercial simulator Feko [10]. This software uses integral equations techniques solved by the method of

Fig. 1 Extraction of the multilayer from the phantom

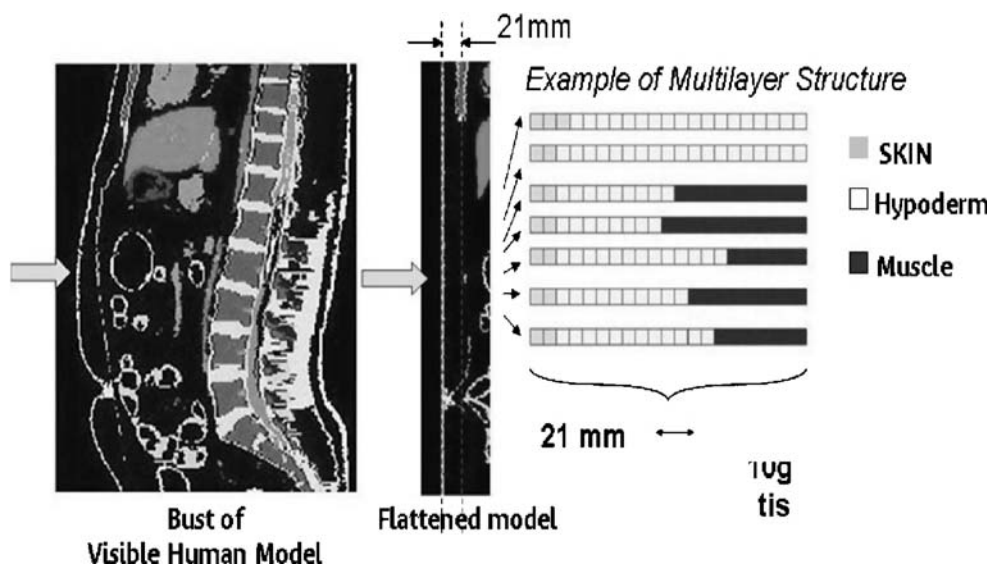


Table 1 Characteristic for some structure (the dashes in lines 1, 2, 9 in muscle mean that such tissues do not exist)

ML#	Thickness skin (mm)	Thickness subcutaneous fat (mm)	Thickness muscle (mm)	Number of structure	%
1	3	17	–	30,335	17.16
2	2	18	–	28,972	16.39
3	2	9	10	5,735	3.24
4	2	8	11	4,662	2.64
5	2	10	9	4,472	2.53
6	2	13	6	4,440	2.51
7	2	12	7	4,357	2.47
8	2	14	5	4,282	2.42
9	1	20	–	4,236	2.40
10	3	14	4	4,001	2.26
Number of total structure for the 45 ML#			176,749		

moments through the determination of Green's function [11–13]. In this study, simulations are performed for seven frequencies: 300 MHz, 450 MHz, 900 MHz, 1,800 MHz, 2,100 MHz, 2,400 MHz and 5,800 MHz, the dielectric properties of tissues are those that are nowadays used internationally [14]. For each studied case, the structure is placed in front of the source (Fig. 3). The distance, d , between the dipole and the stratified media varies, for the frequencies 900 MHz, 1,800 MHz, 2,100 MHz, 2,400 MHz and 5,800 MHz from 5 mm to 160 mm with a step of 5 mm close to the source (5 mm to 50 mm) and then 10 mm. A simulation is carried out for each step. For the frequencies 300 MHz and 450 MHz, the distance between the source and the media varies from 5 mm to 1,060 mm. In this manner, the near field zone and the far field zone are taken

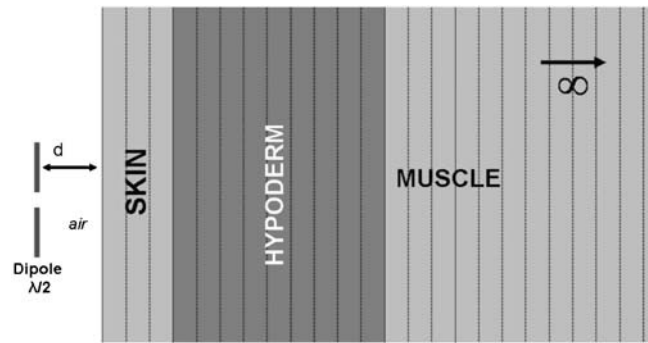


Fig. 3 Multilayers structure model for electromagnetic simulations

into consideration. In parallel, the case of the homogeneous structure filled with the EHL in front of the same dipole at the same position is also studied.

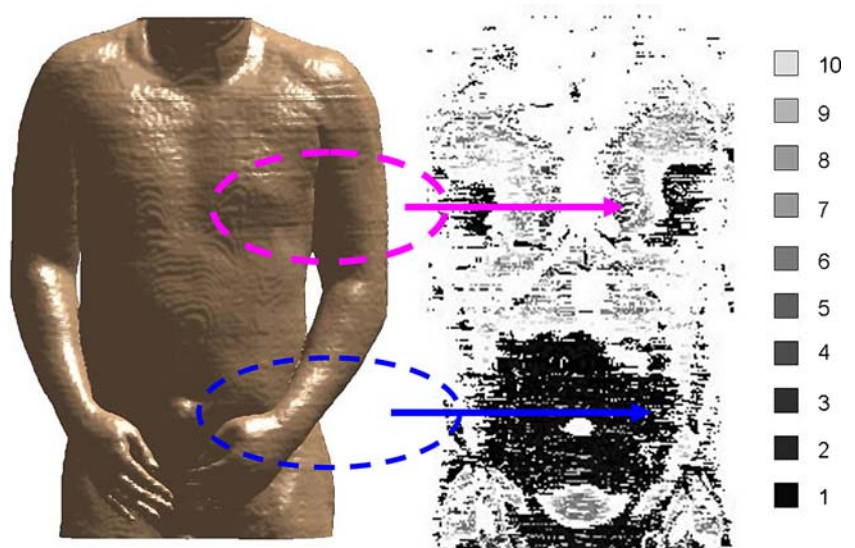
3 Results

3.1 Electric field distribution

In all of the results, the dipole has been excited to give a total radiated power of 1 W, some of which is absorbed in the relevant multilayer body model and the remainder of which is propagated away.

Analyzing the calculated electric field (E field), distribution in the different simulated cases, it can be seen that the presence of the structure perturbs significantly the radiated field distribution. In order to estimate the influence of the multilayer structure composition, a comparison of the E field distribution results for two different structures is realized (Fig. 4a and b). The general form of the E fields inside and outside the structure is nearly the same. Figure 4b shows results for a

Fig. 2 Position of the 10 most encountered multilayer structures



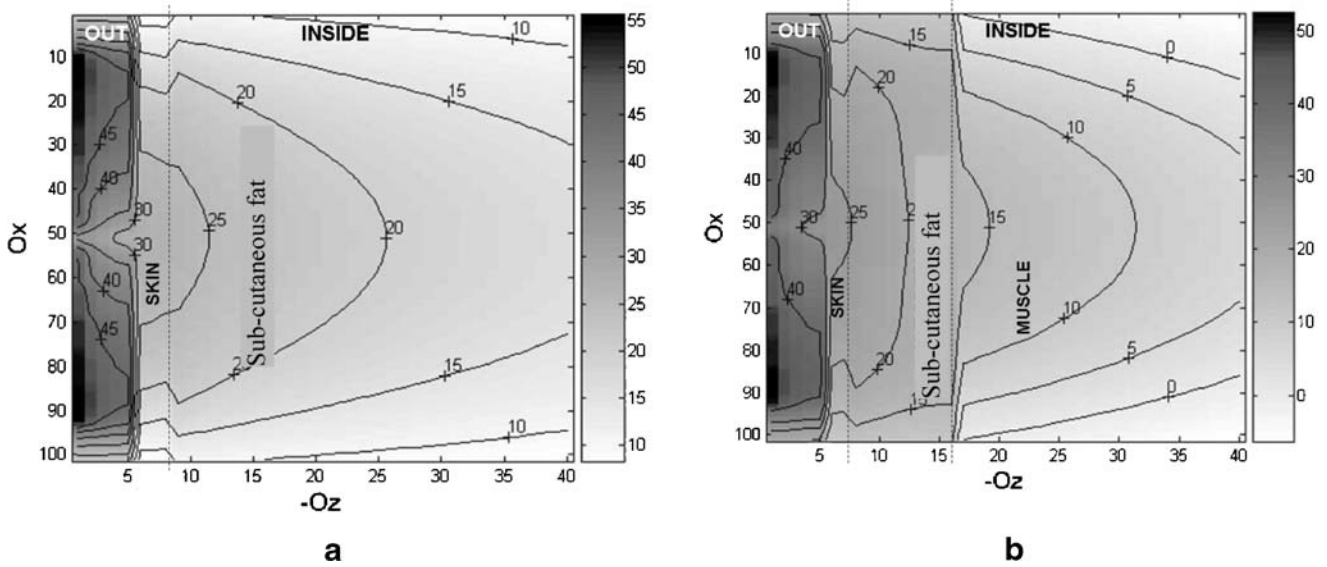


Fig. 4 E field distribution (in dB V/m) for different structure at 5 mm from the source. a E field ML#1. b E field ML#3

structure composed of skin, subcutaneous fat and muscle, compared to those given in Fig. 4a in which the structure is composed only from skin and subcutaneous fat. It can be seen that the presence of the muscle thickness concentrates the E field in the subcutaneous fat thickness. The presence of muscle in the structure induces reflections at the interface between the subcutaneous fat and the muscle, with result of having more field concentration in the subcutaneous fat than in the muscle, provided the thickness of subcutaneous fat does not correspond to the matched length.

This E field distribution influences the SAR calculation. Moreover, the dielectric properties of the tissues have to be taken into account because the dielectric properties are similar for the skin and the muscle, while for the subcutaneous fat, the permittivity and the conductivity are different.

3.2 Source input impedance

The study of the source input impedance allows an estimation of the mismatching of the dipole induced by the presence of the structure. It results from this study, as one can expect, that the higher the distance between the dipole and structure, the less the influence of the structure on the dipole matching and the source input impedance tends to approach the free space impedance value. Figure 5 gives the source input impedance for the ten first multilayer structures for varying distances (d). The variations of the calculated input impedance at a certain distance, d , are represented by the shown black segment. Close to the source, the large segment corresponds to high variations of the input impedance values.

3.3 Comparison of SAR over 10 g in EHL and in multilayer structures

The “10 g SAR” is averaged in the cube of $21 \times 21 \times 21 \text{ mm}^3$ and this volume is approximately equivalent to a mass of 10 g. Analyzing the variations of 10-gram SAR for different structures, including those with the EHL, for several distances dipole–structure, shows that the higher the distance, d , is, the less the 10-gram SAR values are significant. For short distances source–multilayer (i.e. about 16 mm at an operating frequency of 1,800 MHz as shown in Fig. 6), the 10-gram SAR assessed in the EHL is higher than that obtained in multilayer structures. For higher distances, the 10-gram SAR assessed in the EHL can be smaller or higher than that obtained in multilayer

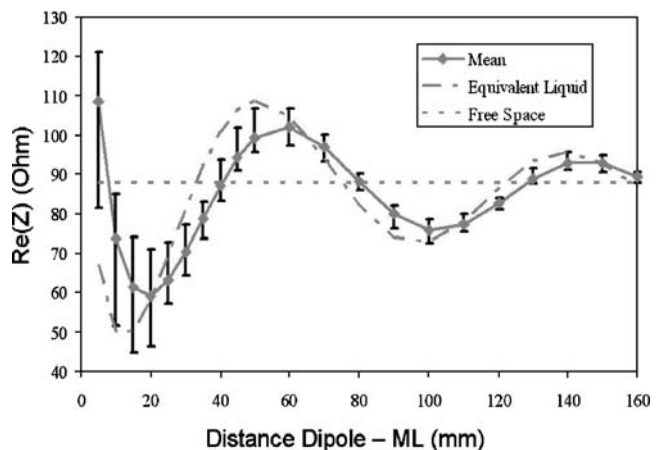


Fig. 5 Source input impedance variation for the 10 first structures as a function of the distance from the dipole at 1,800 MHz

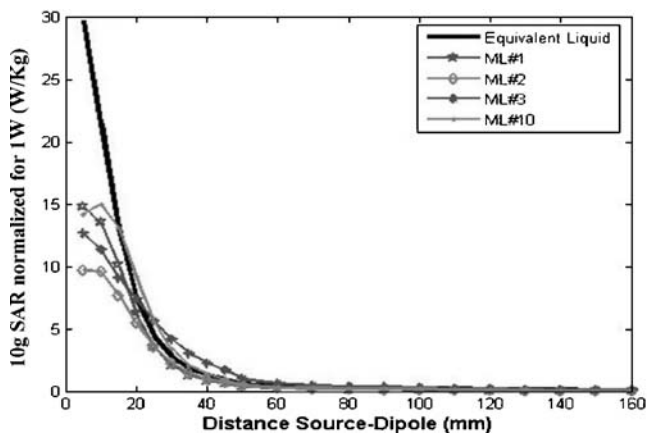


Fig. 6 10-gram SAR normalized to 1 W input power as a function of the distance dipole–ML for layers ML# at 1,800 MHz

structures depending on the composition of the multilayer structure.

3.4 SARs for heterogeneous and homogeneous structures

As discussed in the previous section, the distance, d , has an influence on the SAR over 10 g assessed in the EHL and that assessed in a multilayer structure but such variations depend also on the frequency. Therefore the ratios between the 10-gram SAR calculated in the EHL and that estimated in heterogeneous structures are calculated for each studied frequency and for each multilayer ML, corresponding to different distance d . For each multilayer i , a Correction Factor (CF_i) is defined as given in (2) and evaluated:

$$CF_i(f, d) = \frac{10g \text{ SAR}_{ML_i}}{10g \text{ SAR}_{\text{equivalent liquid}}} \quad (2)$$

These CF_i ratios can be used to determine a Global Correction Factor (GCF) since it allows to determine a

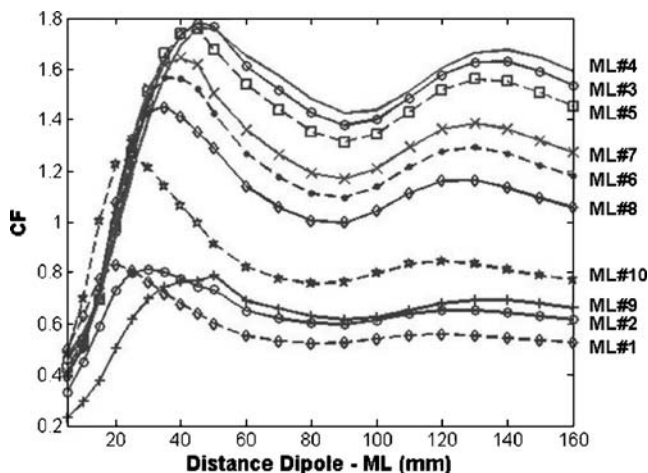


Fig. 7 CF as function of the distance dipole–ML at 1,800 MHz for different MLs

factor to be applied (e.g. its maximum value) on the SAR assessed in the EHL in order to never underestimate the SAR induced in multilayer tissues. Figure 7 shows the results obtained at 1,800 MHz for the ten first multilayer structures of higher occurrence. The observed variations are caused by the fluctuation of the matching of the source to the considered multilayer.

As shown in Fig. 7, for 1,800 MHz, the correction factors (CF_i) for the ten first multilayer structures are below 1 for distances up to 15 mm and the maximum value of the maximum CF_i curve is 1.8. For each studied frequency, we determined the envelop of the maximums (see Figs. 8 and 9). As shown in Figs. 8 and 9, for all multilayer structures and for all frequencies, the higher CF_i value (1.8) is obtained at the frequency of 1,800 MHz. The maximum of the envelop of the CF_i curves provided the Global Correction Factor, GCF, (e.g. 1.8 at 1,800 MHz) that guarantees that the approach is conservative.

3.5 Statistical ratio between SARs for heterogeneous and homogeneous structures

The human body is composed of heterogeneous tissues. The layers that have been determined using a local analysis of the front of the VH model body have not the same occurrence. For instance, in the abdomen of the Visible Human model and dealing with peripheral tissues, only few multilayers contain muscle, thus in the statistical ratio, the occurrence of structure composed only of skin and subcutaneous fat is more important than that composed of skin, little subcutaneous fat and muscle in the part near the abdomen. Figure 10 presents the histogram of the 10-gram

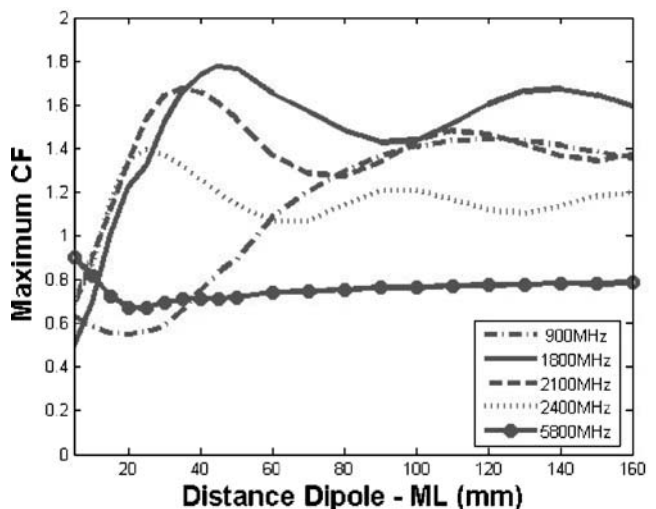


Fig. 8 Maximum correction factor as a function of the distance dipole–ML at 900 MHz, 1800 MHz, 2100 MHz, 2400 MHz and 5800 MHz

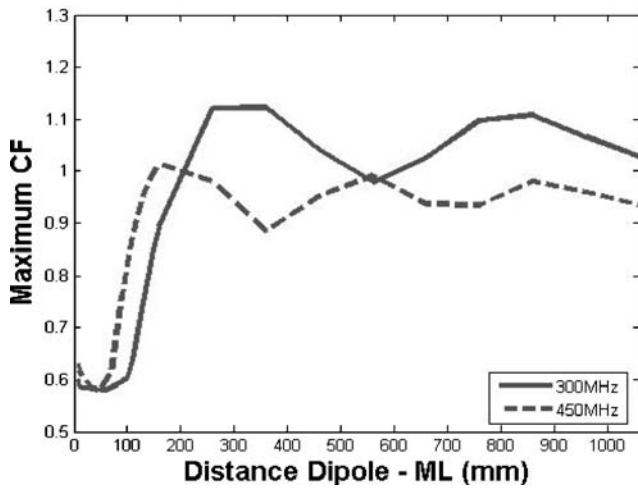


Fig. 9 Maximum correction factor as a function of the distance dipole–ML at 300 MHz and 450 MHz

SAR assessed at 1,800 MHz, for the ten most encountered multilayers in the studied structures (bold line).

However, a global statistical analysis is not relevant since the maximum SAR over 10 g is assessed locally. Moreover, since the human body is locally composed of heterogeneous tissues, it is also of interest to consider a CF estimated using the local occurrence of multilayer structures. A local ratio can be defined to take into account the local composition of the model. This local ratio, named Local Coefficient Factor (LCF_i), is defined as follows (3).

$$LCF_i(f, d) = \frac{\sum C_j^i CF_i}{S} \quad (3)$$

Where C_j^i corresponds to the number of the different multilayer of index j in the local volume of index i , LCF_i is

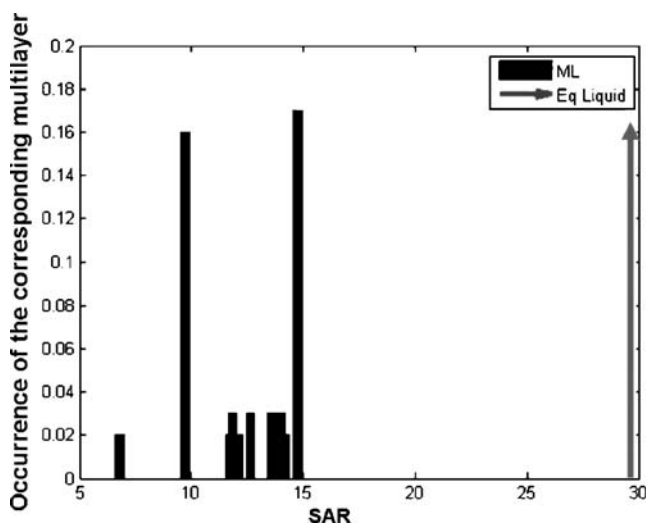


Fig. 10 Histogram of the 10-gram SAR (for 1 W input power) assessed in different multilayer structures (bold line) and the EHL (arrow line) for the distance 5 mm at 1,800 MHz and for the distance 50 mm at the 1,800 MHz

the correction factor for the volume of index i and S is the number of cells in the surface of the 10-gram cube. The local occurrence of ML (i.e. C_j^i) is evaluated using a moving window with a square footprint of 21 mm width (Fig. 11). The square window can be associated to 441 ML (each voxel on this surface can be considered the outermost voxel of a multilayer structure). These ML are not necessarily in the ten most encountered multilayers and do not really exist since they are often limited in surface. Because of that, the result should be considered as an approximation.

Using these data for each frequency, the Global Local Ratio, GLR, which is defined as maximum of local correction assessed using Eq. (3) and evaluated over the front of the body for each distance between the dipole and the structure. Figure 12a and b show the variations of the location of the maximum Local Correction Factor (LCF_i) changes as a function of the distance, d . Close to the source (Fig. 12a), the maximum LCF_i is in the abdomen, while for a higher distance (Fig. 12b), the maximum LCF_i is located in the chest.

From Fig. 13, it can be seen that the GLR factor at 1,800 MHz, for distances up to 25 mm, is below 1 while for other distances, the GLR is never higher than 1.2.

4 Conclusion

This paper compares the SAR values assessed using simulations in a flat phantom filled with the liquid used to test the compliance of mobile phone close to the head to those values obtained using a multilayer model representing the tissues of the trunk.

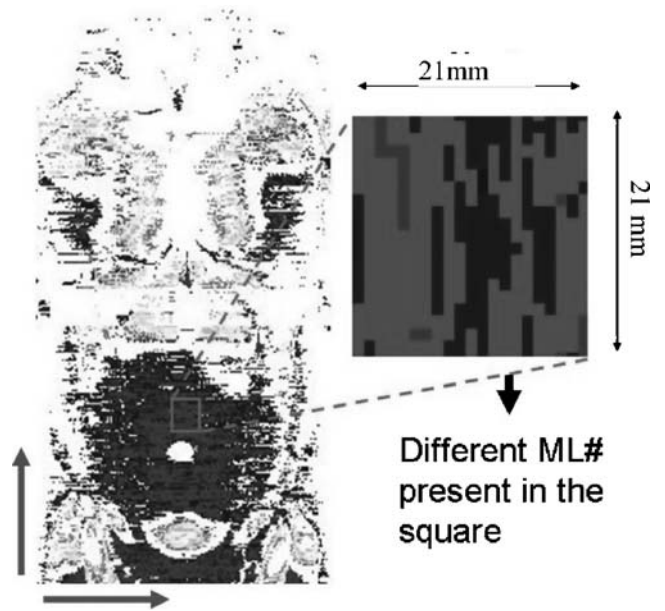
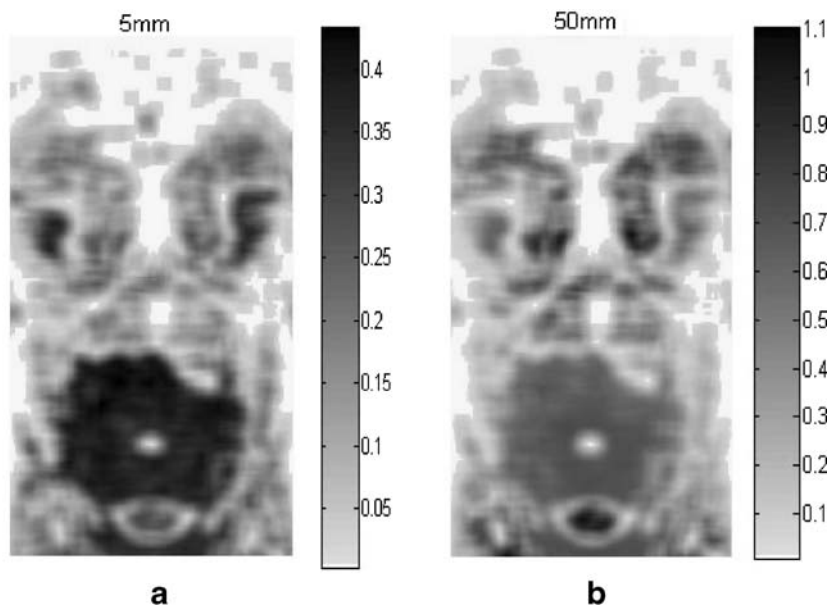


Fig. 11 Determination of the local ratio, R_L

Fig. 12 Probabilistic ratio at different distances (d) from the front of the body of Visible Human at 1,800 MHz. **a** $d=5$ mm. **b** $d=50$ mm



For the front of the body representations employing the Visible Human model, multilayer structures and a selection of the most frequent ones have been defined. Electromagnetic simulations using integral equation techniques for different frequencies 300 MHz, 450 MHz, 900 MHz, 1,800 MHz, 2,100 MHz, 2,400 MHz and 5,800 MHz are realized. The studied problem consists of the defined structures in front of a dipole for distances that cover both the near field and far field zones. The calculation of the E field is realized using electromagnetic simulation that uses the integral equation techniques solved by the method of moments through the determination of Green's function. From these simulations, the SAR is calculated and a comparison is carried out between

the SAR values obtained for these multilayer structures and those obtained for a homogeneous structure. In order to take into account the composition of the utilized model, a local ratio is defined LCF, which depends on the occurrence of the multilayer structure and on the position of the dipole.

From our simulations, it results that the thickness of subcutaneous fat has a significant influence on the SAR calculation. Moreover, to determine a precise and correct CF, it is found that it depends on: the distance between the dipole and the multilayer structure, the composition of the considered structure and the coupling between the source and the structure. For all studied frequencies, a maximum ratio GCF of 1.8 is determined. However, when taking into

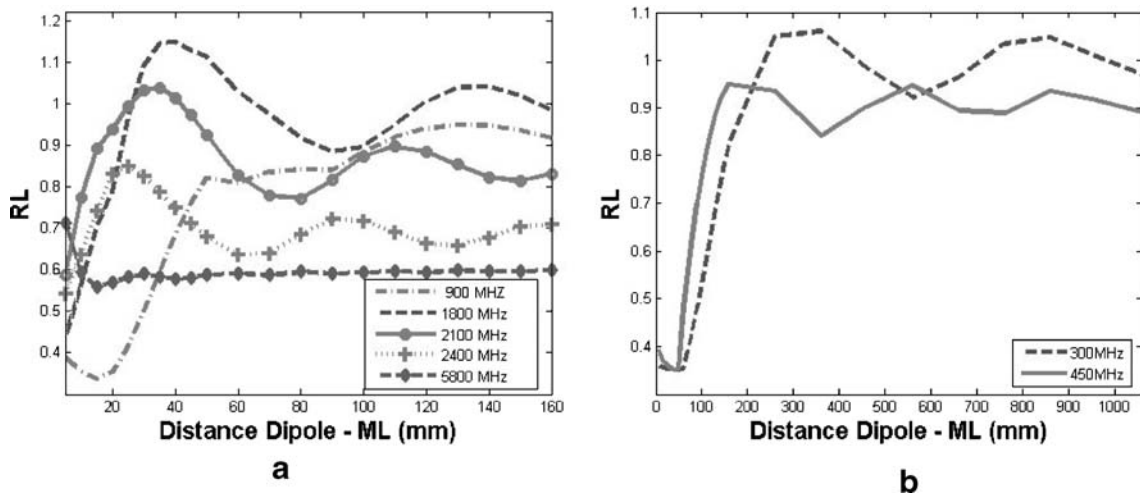


Fig. 13 Local maximum ratio for different frequencies. **a** At 900 MHz, 1,800 MHz, 2,100 MHz, 2,400 MHz and 5,800 MHz. **b** At 300 MHz and 450 MHz

account the composition and the occurrence of the multilayer structures, a maximum GLR of 1.2 is obtained.

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The interpretation of the results of the research on electromagnetic fields and health in Europe: the EC Coordination Action EMF-NET

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Abstract Research on possible health implications of EMF exposure is currently active in Europe, with research programmes and activities at both the national and European Commission level. The coordination action EMF-NET, established by the European Commission in 2004, in the framework of the 6th EC Framework Programme, aims to produce the interpretation of the research results on electromagnetic field and health. These will then be used as building blocks by policy and health authorities, starting with the European Commission. This paper will provide an overview of EMF-NET activities.

Keywords EMF and health · Interpretation · Support to policy

1 Introduction

Among the increasingly environmentally related health issues and potential health hazards stemming from new, modified and combined exposure to environmental factors, exposure to electromagnetic fields (EMF) at all frequencies and modulations represents one of the most common and fastest growing environmental concerns.

Research on possible health implications of electromagnetic fields (EMF) exposure is being carried out by a number of research centres, laboratories and universities, supported by international, national and industrial funding.

As societies develop, one can expect that the increasing need and use of certain technologies will lead to greater exposure to EMF fields and a consequent need to proceed in studying the potential impact on human health and the environment is expected. Moreover, new exciting applications of EMF are appearing in various scientific and technological fields, such as medicine, genomics, and security control. Despite the fact that only for some of these applications a wide public exposure with the present state of the technology can be found, a timely assessment of potential hazards and health effects is required. For these reasons emerging technologies should be monitored to allow immediate intervention by science, industry, regulatory bodies, political and health authorities.

In this perspective, a major problem is to present sound scientific information about the results of research already completed in a way that is easier to be comprehended by policy and health authorities and all the other concerned stakeholders, including industry, consumer and worker associations and the general public. Although an increasing number of critical reviews, public inquiry reports, public review drafts, summaries are published by universities, government departments, public utilities, international organizations, regulatory and other expert bodies (see e.g., [1–14]), the need for deep harmonization and coordination is still present not only from the scientific point of view, but even more, from a social and political perspective.

Given the range of research being undertaken it is often difficult to provide relevant, authoritative and timely input for policy development at the European Union (EU) level (and elsewhere). This is often due, from the scientific point of view, to the large differences in the scientific approaches, methods and endpoint results, making the comparison of different laboratories findings difficult. One should keep in mind, as examples, the difficulties in establishing standards

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in exposure assessment, in defining the minimum level of quality of the research and in the dissemination of “good practice” of laboratories. This is even more true when occupational exposure is taken into consideration.

Furthermore, research results can be misinterpreted, inappropriately applied to other sources or exposure conditions, or may not adequately address the concerns of stakeholders having an interest in EMF emissions.

In order to properly address the issue of interpretation of scientific results on potential health effects of EMF, the European Commission lunched in 2004, at the beginning of the 6th Framework Programme, the Coordination Action EMF-NET *Effects of the Exposure to Electromagnetic Fields: from Science to Public Health and Safer Workplace*. The aim of this paper is to provide an overview of EMF-NET activities.

2 The EC coordination action EMF-NET

2.1 EMF-NET objectives

EMF-NET aims to provide a framework for the coordination of the results of the research activities related to the biological effects of electromagnetic fields, considering also the potential risks related to exposure in the working environment (occupational exposure). Its main objectives can be summarized as follows:

1. Provide a framework for the coordination, and collation of the results of the research, considering both laboratory studies (ELF, RF, Intermediate Frequencies, THz, Interaction Mechanisms and Medical Applications) and epidemiological studies.
2. Provide a framework for the coordination of the results of on-going and completed studies conducted in different European countries on the measurement methods and computer simulations used for specific EMF exposure assessment for occupational risk evaluation.
3. Establish expert groups focused on the improvement of specific aspects common to any type of the research in this field.
4. Support “informed decision-making” for regulation and risk communication, to harmonize the results providing information to regulatory bodies and industries and supporting informed decision-making by health and environmental authorities, consumer associations as well as individuals.
5. Monitor emerging technologies, identifying the main needs in terms of coordination and studies.
6. Monitor EMF research plans in terms of objectives, endpoints, priorities, gaps, results and prospects from on-going research.
7. Provide a framework for the co-ordination of the results and of the dissemination plans of the research activities among the European Union Area, and the Associated and Third States, with particular reference to Eastern Europe.
8. Provide an inventory of the ongoing research on EMF and health and prompt identification of the research priorities and needs, to provide the European Commission and other bodies of the appropriate information for the facilitation of policy development options.

2.2 EMF-NET participants

All coordinators of recent European Commission projects and activities on EMF and health are members of EMF-NET:

- Paolo Ravazzani (Coordinator of EMF-NET) also served as coordinators of the FP5 GUARD project (Potential Adverse Effect of GSM Cellular Phones on Hearing) and the EC EMFnEAR project (Exposure to UMTS Electromagnetic Fields: Study on Potential Adverse Effects on Hearing).
- Clemens Dasenbrock / Jochen Buschmann: PERFORM A: In Vivo - Research on Possible Health Effects Related to Mobile Telephones and Base Stations (Carcinogenicity Studies in Rodents)
- Jürgen Bernhardt: ADVICE PULSED FIELDS: Development of Advice to the EC on the Risk to Health of the General Public from the Use of Security and Similar Devices Employing Pulsed Electromagnetic Fields
- Jukka Juutilainen: CEMFEC (Combined Effects of Electromagnetic Fields with Environmental Carcinogens); La Vita Project: Health risk assessment of wireless communication
- Luis Mir: Cliniporator—a new adaptative generator for DNA electrotransfer in vivo for gene therapy; ESOPE (European standard operating procedures for electrochemotherapy and electrogenetherapy)
- Demosthenes Papamelethiou: EIS-EMF (European Information System on EMF)
- Elisabeth Cardis: INTERPHONE (International Case-Control Studies of Cancer in Relation to Mobile Telephone Use)
- Bruno Bianco: RAMP 2001: Risk Assessment for Exposure of Nervous System Cells to Mobile Telephone EMF: From In Vitro to In Vivo Studies
- Franz Adlkofer: REFLEX: Risk Evaluation of Potential Environmental Hazards from Low-Energy Electromagnetic Field (EMF) Exposure Using Sensitive in Vitro Methods

- Gian Piero Gallerano: THz-BRIDGE: Tera-Hertz Radiation in Biological Research, Investigation on Diagnostics and Study on Potential Genotoxic Effects
- Norbert Leitgeb: COST 281 ACTION “Potential Health Implications from Mobile Communication Systems”
- Jolanta Karpowicz - Test-pro-Safety Life (EMF) on occupational exposure

These projects and initiatives are currently ended. They covered EMF and health topics such as: i) exposure of low-energy EMF (REFLEX); ii) radiofrequency and mobile telephony related exposure (GUARD, RAMP2001, CEM-FEC, PERFORM-A, REFLEX, COST 281 ACTION); iii) frequencies between RF and infrared (THz-BRIDGE); iv) epidemiological studies (INTERPHONE); v) risk advice and communication relative to EMF (EIS-EMF, ADVICE PULSED FIELDS); vi) medical application (CLINIPORATOR and ESOPE); vii) occupational exposure (Test-pro-Safety Life (EMF)).

Moreover coordinators of other projects and initiatives of other bodies are participating in EMF-NET, such as the representatives of the WHO “The International EMF Research Project” (Emilie Van Deventer) and the representatives of the main National Research Projects/Activities of France, Finland, Germany, Greece, Hungary, Italy and UK.

Concerned stakeholders are also participating in EMF-NET, such as industry associations (GSM Association, MMF Mobile Manufacturers Forum, European Telecommunications Network Operators’ Association ETNO, Union of the Electricity Industry EURELECTRIC, and Fédération des Industries Electriques et Electroniques FIEEC), and the European Trade Union Institute for Research, Education and Health and Safety to consider their view on health implications of EMF exposure. Moreover, a representative of ICNIRP is participating, providing scientific inputs in the full respect of the ICNIRP advisory role.

Last but not least, EMF-NET is covering the full spectrum of the studies of the health effects of EMF exposure, including through the participation and contribution of the leading European experts in the various EMF exposure related fields.

3 EMF-NET outcomes and current activities

Over the last three years, EMF-NET has improved the understanding of EMF and health issues and coordinated research activities. It has become one of the main international actors in this area. EMF-NET has collated research results from EU-funded projects and other national and international actions. Furthermore, it has provided a

regular update on EMF research (plans, priorities, gaps, prospects from on-going research, results) and relevant interpretation/advice for the facilitation of policy development options by the EU and other bodies. Such advice is helping the EC to develop policy options related to public health and consumer protection, health and safety at work, European competitiveness and environmental issues. The EMF-NET European Fast Response Team (EFRT) on EMF and Health, is answering, on extremely short notice, specific questions of the European Commission services concerning the potential health impact of EMF. Strong, fruitful cooperation has been established by EMF-NET with complementary initiatives in the field of EMF and health, such as the EC COST Action 281 on telecommunication, the European Information System on EMF (EC EIS-EMF) project and the WHO EMF Project, thus creating a synergetic and coordinated framework in this area.

In the course of its lifetime, EMF-NET has published more than 25 reports and 20 fact sheets and expert opinions, three EMF and health-related volumes, and organized and co-organized various seminars, workshops and conferences on specific policy-related EMF and health topics, acknowledged in Europe and worldwide as representing an essential infrastructure for the interpretation of the research results in an area in which such assistance is of utmost importance. This is bringing the European Union to the forefront in the approach of such a sensitive issue as the possible EMF interactions with health.

Recent examples of reports and fact sheets published by the EMF-NET are the reports on the effects of RF on reproduction and development [15], on RF and hypersensitivity [16], on EMF and health recent research plans [17], on recommendations in bioelectromagnetics research [18], on ELF laboratory studies [19], on RF cancer-related projects [20] and on IF exposure [21].

Among the recent documents published by the EMF-NET European Fast Response Team, one can mention the fact sheets on exposure to short-range wireless technologies [22], on epidemiological studies on mobile phones and brain cancers [23], on health risk posed by high voltage power lines [24], on the distance from radio base station [25] and on radio frequency identification [26].

As to very recent initiatives, 26–27 November 2007 in Brussels, EMF-NET organized the GLORE Global Coordination of Research on Electromagnetic Fields and Health, in which the delegations of government officials and research experts from Australia, China, European Union, Japan, Korea, USA and WHO met together to share information about the different EMF and health activities in the various countries and to discuss concrete possibilities of harmonization in research and regulation.

Information on all EMF-NET initiatives and publications can be found on the project website (<http://emf-net.isib.cnr.it>)

4 Conclusions

EMF-NET is providing the building blocks for the development of the appropriate policy options by the European Commission and other bodies, becoming, over the last three years, one of the main international actors in the area of EMF and health.

However, in spite of all that has been done, there is still much more to achieve. Interpretation of scientific data for use by policy-makers, standards setters, health and environmental authorities, industry and concerned stakeholders must be a continuous process, even more, as it is expected that many projects will be active within the European Commission 7th Framework programme, which was started at the beginning of 2007. Moreover, the research projects at national level in the EU need careful coordination, in order to try to avoid overlap and help national authorities concentrate on the European research agenda on EMF and health. So far, such a crucial activity for Europe has been only partially part of the mandate of EMF-NET, and cannot be delayed anymore.

Similar considerations hold also for occupational exposure, adequate risk communication, monitoring of emerging technologies, coordination with activities in European countries other than EU Member States, and outside Europe.

In these years EMF-NET, that is expected to end in 2008, started to play its role in interpreting the main needs, to allow policy and health authorities to act in the most appropriate way, but these activities should be continued in European Union, and similar initiatives should be implemented in other countries worldwide.

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Personal RF exposimetry in urban area

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Abstract The purpose of the current study was to evaluate the usefulness of a radiofrequency (RF) personal exposimeter (dosimeter) for assessing individual RF exposure in an urban environment. Measurements taken by RF personal dosimeter were also compared to preliminary site measurements taken around mobile base stations. The results from personal exposure showed that one third of the participants spent 40–70% of 24 h recording time above the detection limits (0.05 V/m), and half of subjects spent less than 10%. The highest exposure was detected during the traveling period and the lowest in bed at home. Based on our results, we concluded that site measurements cannot be used to accurately determine personal exposure. We also concluded that duration of time exposed to RF levels above the detection limit of the personal dosimeter is a useful exposure metric to compare and contrast individual RF exposure of study subjects.

Keywords Radiofrequency radiation · Public exposure · Personal exposimetry · Urban area

1. Introduction

In the past few years, the explosive growth of mobile communications has brought up several environmental and health problems in the field of non-ionizing electromagnetic

radiation. The number of personal communication terminals using radiofrequency (RF) and microwave radiation and the underlying base stations has increased considerably, which means electromagnetic exposure from mobile terminals for the population as a whole. The interest of scientific community towards biological effects of electromagnetic fields (EMF) has grown also recently. One of the reasons for this interest is the appearance of new emerging technologies, which is going to increase the EMF exposure of the environment further. Because there are very differing opinions about RF exposure because of the mobile phone and other new wireless technology usage, it is advisable to study the possible methods of exposure assessment with the following considerations:

- How did the RF radiation coming from wireless devices increase the exposure of population as compared with previously acting artificial and natural exposures looking back to several years?
- What is the proper and absolute measurement methodology of the exposure regarding the technologies, fixed and mobile sources and how much is it in the view of current radiation protection guidelines and recommendations?
- How much is the real biological effect and how can we use the data from exposure assessment for further epidemiological studies? What is the proper exposure metric for the investigation of any long-term health effect of RF radiation?

Different sources of RF fields have been introduced over a long period of time. The time of introduction has varied both between and within countries. Fixed outdoor sources that have been present for up to a century are the radio and TV broadcast antennae. The public analogue portable phone system was introduced in most European countries during the 1970s and 1980s. Later mobile phones systems,

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first the analogue and then the digital systems (i.e., in Europe, the Global System of Mobile communication (GSM)), have been built for near 100% coverage of both urban and rural areas. Most typical so far have been the base stations with antennae mounted on buildings and on masts to cover relatively large area [1]. For example, in the case of a mobile phone base station with an effective radiated power of 100 W, the power density typically decreases below 0.01 W/m^2 ($\times 2 \text{ V/m}$) in the distance of 30–40 m in the antenna plane. In the environment of a properly installed base station, in a distance of 10–15 m from the radiating antenna, the amount of the exposure remains below approximately 6 V/m [2].

During more recent years, mobile phone base stations and distributed antennae have been located inside larger buildings to cover the in-house calls. Now, large outdoor mobile masts are being replaced partly by small antennae supplemented by indoor base stations. This is the case especially in urban areas where the macro- and microcells will make networks denser to accommodate the increasing number of users and uses of mobile communications. Today, the 3G systems are present in many regions and are being developed further [3].

The environmental exposure depends on several factors, starting with the characteristics of the signal emitted from the RF source, which have to be taken into account. The output power, as well as the directional characteristic of the antenna, is important. Some antennae are omni-directional (i.e., the field strengths are the same in all directions), while others may have a relatively narrow main beam, and little power is emitted in other directions. Also, the frequency, or the frequency range, and the modulation describe the RF signal characteristics. Indoor exposure measurements may be used to estimate residential exposure from nearby fixed

RF sources. However, the space variation of the RF field may vary over six magnitudes, and, therefore, a mapping covering different positions may be needed. Long-term monitoring shows that the RF fields also change with time [1, 4].

Although it is difficult to determine, the power density (because of the near field exposure) can amount to $10\text{--}20 \text{ W/m}^2$ within a few centimeter distance from a mobile handy device. Because the antenna of the handy device is very close to the head of the user, which has higher dielectric properties than the air, the absorption efficiency in the head may lead to relatively high specific absorption rate (SAR) in the head [5]. Some 40–70% of the radiated RF power may be absorbed in the head.

Nowadays, there are significant challenges in assessing the exposure of individuals in the general population to radiofrequency signals, including the number and range of sources involved and the effect of the environment on signal strengths as people move around. For more realistic epidemiological studies, individual RF exposure assessment is needed. The exposure metric must separate the exposures from the possible RF sources and provide information on the duration of time the subject is spending at the given exposure [6]. Therefore, the personal exposimeter for public exposure assessment must be frequency band selective, and the sensitivity must be far below the current guidelines and recommendations to meet the real exposure situations.

The present study aims to characterize the personal RF exposure of volunteers measured with newly developed RF personal exposure meter (PEM) with respect to its use for epidemiological studies involving exposure of the general public. Individual exposures were analyzed according to recorded frequency bands (FM, TV, and mobile channels) and characterized in terms of selected exposure metrics.

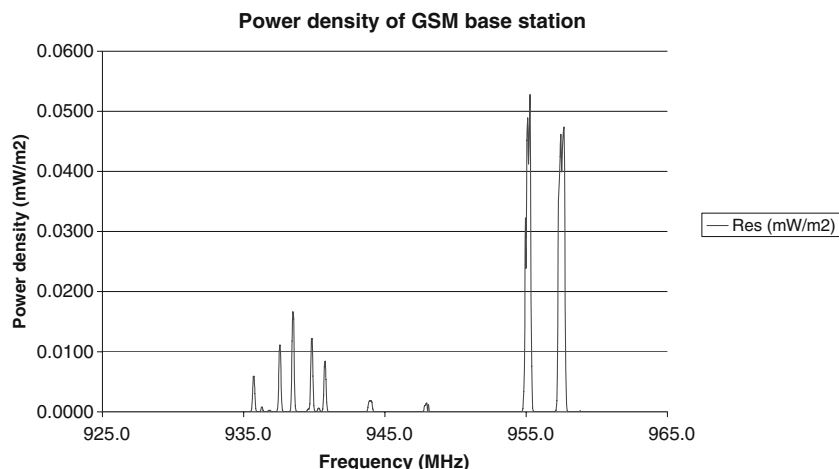


Fig. 1 Typical power density spectrum in the GSM 900-MHz downlink frequency band at the living area close to base stations. During the measurement, the sample time was 1 min in each direction,

the maximum field strength was obtained by using the peak hold function of the spectrum analyzer

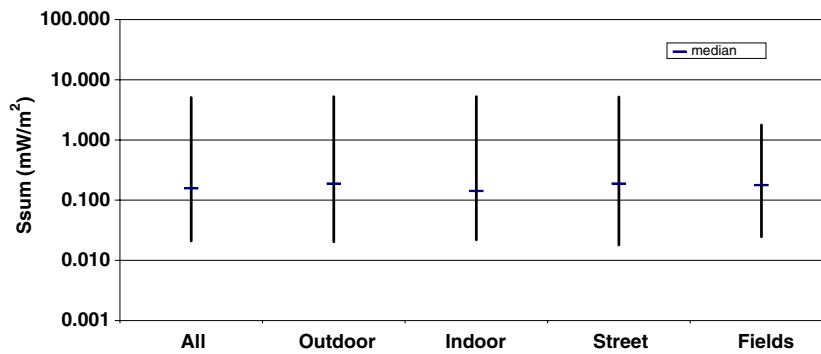


Fig. 2 The median values and exposure ranges of power densities around the base stations in the GSM 900/1,800 downlink frequency range at different types of environment. The power density [mW/m^2]

represents the sum of power density peaks in the respective GSM bands. Note that the limit of EU recommendation at 900 MHz at $4,500 \text{ mW}/\text{m}^2$ at 1,800 MHz at $9,000 \text{ mW}/\text{m}^2$

2. Site measurements around mobile base station

In our preliminary investigations, site measurements of RF exposure were performed around mobile base stations by spot measurements ($n=292$ sites) with spectrum analyzer and broadband RF antenna [7]. The resultant field was calculated according to the sum of E -field strength vector components. In this study, the site measurements were made by portable spectrum analyzer (Advantest U4941) using wide band (80–2,200 MHz) biconical antenna (ARC PBA 10200). The GSM 900/1,800 MHz downlink frequency bands were investigated in this measurement campaign. In the GSM 900/1,800 band, the range of span was 40 MHz between 925 and 965 MHz at GSM 900 MHz and 1,790–1,830 MHz at the GSM 1,800 MHz, respectively. The assumption was made that far field conditions were applied. Therefore, the measured electric fields were converted into power densities. During the 60-s sample (scanning) time, the maximum field strength in each direction could be obtained by using the “peak hold” function of the analyzer (Fig. 1). The RF exposure levels at the living area of general public were collected and evaluated according to

the EU recommendation (1999/519/EC) and the reference levels of International Commission on Non-Ionizing Radiation Protection (ICNIRP) [8, 9]. The evaluation was made also by the type of areas, i.e., city vs countryside, indoors vs outdoors (Fig. 2). The distance between the measurement site and the base station (when a particular station was identified) was also reported if this information was available. In case of the antennas placed on the top of masts, the selected distance of measurement sites were preferred at 100 and 200 m from the masts, depending on the availability and the public area, respectively. Otherwise, the residential living area was intentionally selected for measurement sites in any case.

The most important results of the preliminary site measurements were that within 300 m of the mobile phone base station, no clear expression was found between the exposure levels and distances in the sites of public residential area (Fig. 3). Similar results were obtained by other recent studies [10, 11]. The median value of exposure in GSM band was $0.00025 \text{ W}/\text{m}^2$ at outdoors and $0.00013 \text{ W}/\text{m}^2$ at indoors sites. The main disadvantage of the site measurements is that, in most cases, no information on the variations of the field strengths vs time are available; therefore, the personal exposure of the moving subjects were also not available.

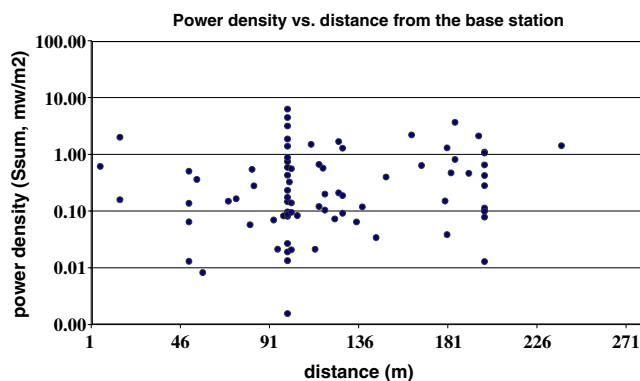


Fig. 3 The values of power density measured around GSM-base stations in downlink frequency bands vs the distance from the base station. No clear expression was found between the exposure levels and distances. The power density [mW/m^2] represents the sum of power density peaks in the respective GSM downlink band

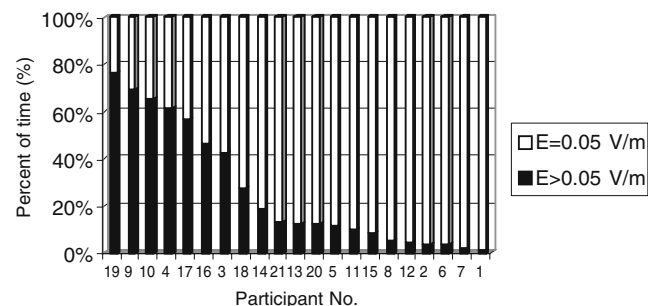


Fig. 4 Percent distribution of time between exposed ($E>0.05 \text{ V}/\text{m}$) and “not exposed” ($E<0.05 \text{ V}/\text{m}$) time by each participant

Table 1 Percent of total recording time (24 h) when exposure was higher than 0.05 V/m according to channels

Subject no.	Percent time of total recording time, $E > 0.05$ V/m								
	FM	TV3	TV4&5	GSM (tx)	GSM (rx)	DCS (tx)	DCS (rx)	UMTS (tx)	UMTS (rx)
1	0	0	0.31	0.12	1.04	0.07	0.68	0	0
2	0	0	0.35	2.04	0.77	1.23	0.09	0	0
3	33.73	0	2.5	0.68	7.78	0.42	2.33	0	0
4	0.33	0	28.54	0.66	60.3	0.52	1.46	0	0
5	0.87	0.02	2.73	3.18	7.15	1.74	4.36	0	0.09
6	0.1	0	1.02	0.73	2.48	0.12	1.44	0	0
7	0.03	0	0.3	0.94	1.13	0.09	0.45	0	0
8	0.09	0	1.38	1.33	3.05	0.34	2.62	0	0
9	0.64	0	3.72	24.84	8.4	5.75	41.22	0.02	0.66
10	51.62	0	35.36	1.24	23.31	1.73	3.04	0	0.1
11	0.38	0.02	3.98	2.59	5.12	1.48	3.33	0	0
12	0.58	0	1.71	1.23	3.14	0.41	1.54	0	0
13	1.15	0.02	5.51	3.34	8.83	2.49	5.58	0	0.05
14	0.45	0.02	6.44	3.21	15.03	4.17	9.34	0.17	1.28
15	0.07	0	1.77	2.86	4.76	1.7	2.67	0	0
16	35.63	0	21.91	2.92	14.79	4.86	17.31	0	0.05
17	51.94	0	32.92	0.75	6.28	0.66	19.43	0	0.03
18	26	0	9.4	0.24	0.71	0.03	0.57	0	0
19	0.03	0	3.54	5	7.6	0.61	73.18	0	0.1
20	0.17	0.02	3.96	4.39	7.66	0.66	3.11	0	0.07
21	0.24	0	3.94	2.92	8.28	4.43	3.49	0	0.02
Mean (%)	10	0	8	3	9	2	9	0	0
Min (%)	0	0	0	0	1	0	0	0	0
Max (%)	52	0	35	25	60	6	73	0	1

3. Exposure measurements with personal RF exposimeter

3.1 Methods

In the present survey, 21 participants were involved. Most of them are employees of the authors' institute, and all of them have residency in Budapest (capital of Hungary with 2.5 million inhabitants). Volunteers carried a PEM with them, sometimes mounted on their body, over a period of 24 h while it logged their personal RF exposure. The volunteers kept a diary of their whereabouts over the

24-h period, so that the PEM data could be correlated with their location and activity. Fixed location was near the bed at night and close to subjects indoors (i.e., on the desk, table etc.). The planning, logistics, and evaluation process of present RF personal dosimetry investigation were strongly supported by the experiences from our previous extremely low frequency (ELF) personal dosimetry studies. [12]. Participants used standard time-activity-diary form previously designed for personal dosimetry of ELF fields. The survey was carried out between June and July, 2005.

Personal exposure meter DSP-090 (SN: DE_003_1005), developed and calibrated by the Antennessa company

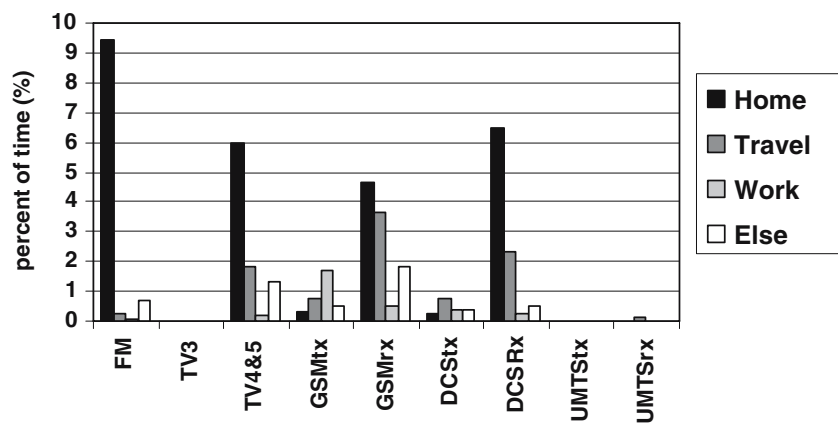
Table 2 Average time spent by different activities

Activity	Minutes	Hours	Percent ^a
Home ^b	835.5	14	58.4
Else	42	0.6	2.5
Travel	155.6	2.6	10.8
Work	406.1	6.8	28.3
Bed	461.6	7.7	32
Total	1,439.2	24	100

^a Mean percent of time spent by different activities (percent of total time 1,440 min=24 h).

^b Bed included

Fig. 5 Mean percent of total time (24 h) when subjects were surely exposed ($E > 0.05$ V/m) by channels and activity types



(Plouzané, France, <http://www.antennessa.com>), was used in the study. The selected sampling rate was 15 s as it was allowable for 24 h because of the capacity of the memory of the device. The PEM has a measuring range of 0.05–5.00 V/m. It has a frequency built in selective RF exposure recording with the following 9 RF bands: FM (88–108 MHz), TV3 (174–223 MHz), TV4&5 (470–830 MHz), GSMtx (uplink: 875–915 MHz, mobile device), GSMrx (downlink: 935–960 MHz, base station), DCS1800 tx (uplink: 1,710–1,795 MHz, mobile device), DCS1800rx (downlink: 1,805–1,880 MHz, base station), UMTStx (uplink: 1,920–1,980 MHz, mobile device), and UMTSrx (downlink: 2,110–2,170 MHz, base station). The device measures the total RF field within the given frequency bands and provides frequency band-selective electric field strength in volts per meter. The maximum values from sequences of 70 samples are recorded in the GSMtx and DCStx bands, and the minimum values from sequences of 20 samples are recorded for the other bands except the UMTStx where the average value of 20 samples is recorded. The axial isotropy varies from ± 0.5 to ± 2.5 dB, depending on the frequency band [13]. The device is functioning as a data logger saving the RF field intensity in each frequency range according to the selected sampling rate. The duration of sampling (scanning) time is approximately 2 s.

3.2 Data evaluation

The resultant of the three axis of electric field were logged and downloaded via the USB serial port and exported to an Excel spreadsheet. For further data evaluation, the following exposure metrics were selected by frequency bands:

- Duration of exposure above the detection limit (0.05 V/m) in minutes and percents
- Field intensity [V/m]: maximum, arithmetic mean, SD
- Time weighted average (TWA) exposure (average exposure of a given time period) [V/m]
- Total exposure (TWA exposure multiplied by the given time period) [$V\ m^{-1}\ min$]

The exposure was analyzed according to recorded frequency bands (FM, TV, and mobile channels), time periods, and the activity of the subjects. The following time periods were selected:

- Total exposure time (1,440 min)
- Periods according to *activity types*: (1) home, (2) bed, (3) travel, (4) work, (5) others
- Periods when the measured field exceeded the detection threshold of the meter (0.05 V/m)
- Periods when the measured field fall into different bins according to field level ranges: (a—*low*) 0.05–0.1 V/m, (b—*medium*) 0.1–1.0 V/m, (c—*high*) 1.0–5.0 V/m

4. Results

4.1 Duration of exposure

Participants spent small fraction of the total measuring time above the detection limit of the meter ($E > 0.05$ V/m) in average. Half of the subjects spent less than 10%, and only

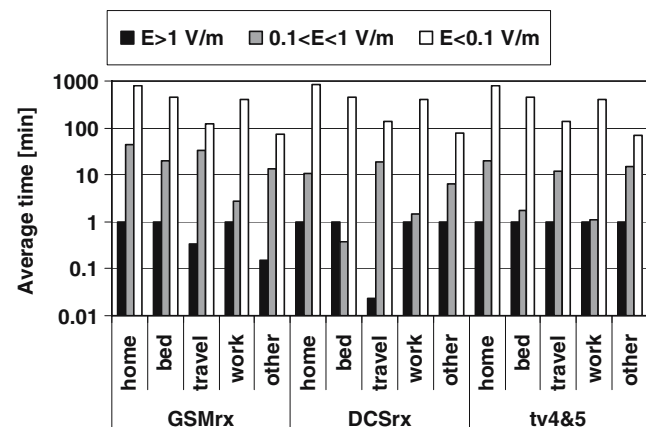


Fig. 6 Averages of periods (minutes) when the data of measured field fall into different bins of exposure ranges according to selected channels (base stations and TV4&5) by different activity types

Table 3 Mean exposures during total measuring time (V/m) by participants according to the different recording RF channels of the PEM

Subject no.	Mean exposure during total measuring time (V/m)								
	FM	TV3	TV4&5	GSM (tx)	GSM (rx)	DCS (tx)	DCS (rx)	UMTS (tx)	UMTS (rx)
1	0.05	0.05	0.05	0.052	0.051	0.05	0.05	0.05	0.05
2	0.05	0.05	0.05	0.065	0.051	0.053	0.05	0.05	0.05
3	0.055	0.05	0.052	0.052	0.061	0.051	0.052	0.05	0.05
4	0.05	0.05	0.054	0.057	0.119	0.051	0.051	0.05	0.05
5	0.05	0.05	0.052	0.062	0.058	0.062	0.052	0.05	0.05
6	0.05	0.05	0.051	0.058	0.052	0.05	0.051	0.05	0.05
7	0.05	0.05	0.05	0.057	0.051	0.051	0.05	0.05	0.05
8	0.049	0.049	0.05	0.058	0.051	0.05	0.05	0.049	0.049
9	0.052	0.05	0.053	0.076	0.06	0.064	0.067	0.05	0.05
10	0.093	0.05	0.096	0.054	0.069	0.054	0.052	0.05	0.05
11	0.05	0.05	0.053	0.071	0.058	0.054	0.053	0.05	0.05
12	0.047	0.047	0.048	0.05	0.051	0.047	0.048	0.047	0.047
13	0.051	0.05	0.056	0.057	0.064	0.055	0.057	0.05	0.05
14	0.05	0.05	0.055	0.058	0.071	0.062	0.068	0.05	0.05
15	0.05	0.05	0.051	0.056	0.054	0.053	0.052	0.05	0.05
16	0.063	0.05	0.055	0.057	0.062	0.058	0.069	0.05	0.05
17	0.076	0.05	0.061	0.054	0.054	0.051	0.059	0.05	0.05
18	0.056	0.05	0.051	0.05	0.051	0.05	0.05	0.05	0.05
19	0.05	0.05	0.051	0.061	0.054	0.051	0.076	0.05	0.05
20	0.05	0.05	0.053	0.073	0.058	0.054	0.052	0.05	0.05
21	0.05	0.05	0.053	0.056	0.061	0.083	0.052	0.05	0.05
Mean	0.054	0.05	0.055	0.059	0.06	0.055	0.055	0.05	0.05

one third of the participants spent 40–70% of 24-h recording time in RF fields above the detection limit ($E > 0.05$ V/m) of the PEM (Fig. 4).

The percentage of the 24-h measurements above the level of 0.05 V/m (detection limit of the 24 h measurements above the PEM) was calculated for each channel by each subject. Mean percent of total measuring time by participants were 10% (0–52%), 0%, 8% (0–35%), 3% (0–25%), 9% (1–60%), 2% (0–6%), 9% (0–73%), 0%, and 0% (0–1%) for FM, TV3, TV4&5, GSMtx, GSMrx, DCSrx, DCSRx, UMTStx, and UMTSrx channels, respectively

(Table 1.)

Average exposure durations by activity types are shown in Table 2. The mean percentage of activity durations distributed according to channels when the measured RF field was above the detection limit (0.05 V/m) is shown in Fig. 5. Figure 5 also shows a case when the percent of exposed time (i.e., exposure time above the detection limit) was chosen as the exposure metric for the characterization of personal exposure. The highest exposure resulted from

Fig. 7 Mean exposures during total measuring time (V/m) by participants according to channels

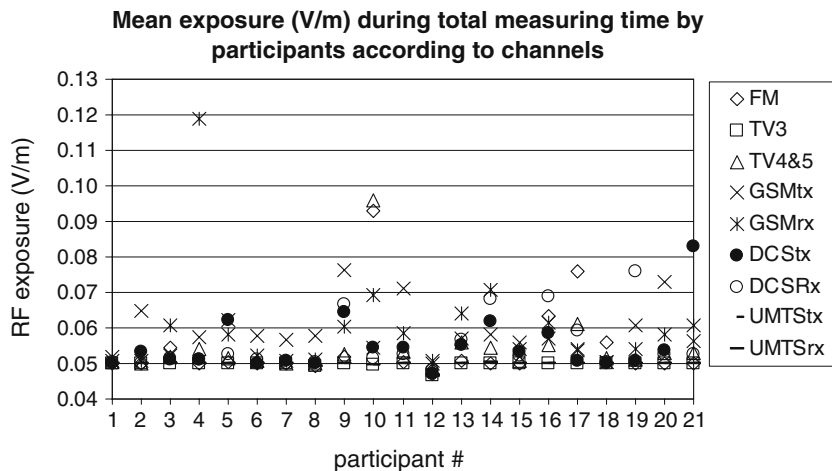


Table 4 Maximum exposures during total measuring time (V/m) by participants according to the recording RF channels of the PEM

Subject no.	Maximum exposures during total measuring time (V/m)								
	FM	TV3	TV4&5	GSM (tx)	GSM (rx)	DCS (tx)	DCS (rx)	UMTS (tx)	UMTS (rx)
1	0.05	0.05	0.34	5.01	0.74	0.08	0.35	0.05	0.05
2	0.05	0.05	0.11	5.01	0.55	3	0.12	0.05	0.05
3	0.29	0.05	0.64	2.1	2.21	1.72	0.39	0.05	0.05
4	0.12	0.05	0.56	5.01	0.77	3.87	0.45	0.05	0.05
5	0.34	0.14	0.28	5.01	1.93	2.25	0.41	0.05	0.1
6	0.11	0.05	0.85	5.01	0.92	0.65	0.36	0.05	0.05
7	0.08	0.05	0.12	5.01	0.47	2.52	0.18	0.05	0.05
8	0.09	0.05	0.61	5.01	0.8	2.18	0.35	0.05	0.05
9	1.08	0.05	0.59	5.01	1.54	4.8	0.83	0.07	0.11
10	0.65	0.05	0.52	5.01	0.71	1.48	0.45	0.05	0.07
11	0.33	0.13	0.96	5.01	1.85	1.96	0.54	0.05	0.05
12	0.24	0.05	0.42	4.74	0.84	0.32	0.74	0.05	0.05
13	0.2	0.09	0.58	5.01	1.07	5.01	0.81	0.05	0.09
14	0.12	0.06	0.54	3.75	1.44	5.01	2.01	0.25	0.25
15	0.06	0.05	0.51	3.29	0.89	1.59	0.73	0.05	0.05
16	0.63	0.05	0.62	5.01	2.26	5.01	0.8	0.05	0.07
17	0.14	0.05	0.35	5.01	0.69	0.68	0.43	0.05	0.06
18	0.13	0.05	0.24	0.31	0.47	0.18	0.34	0.05	0.05
19	0.08	0.05	0.73	5.01	0.87	0.45	0.44	0.05	0.15
20	0.21	0.2	0.61	5.01	2.05	5.01	0.46	0.05	0.08
21	0.18	0.05	0.92	3.18	1.01	5.01	0.46	0.05	0.06
Average	0.247	0.068	0.529	4.406	1.147	2.513	0.555	0.06	0.076

FM sources. The average time in minutes when the data of measured field fall into different bins of exposure ranges according to selected channels (GSM-base stations and TV4&5) by different activity types were also evaluated (Fig. 6).

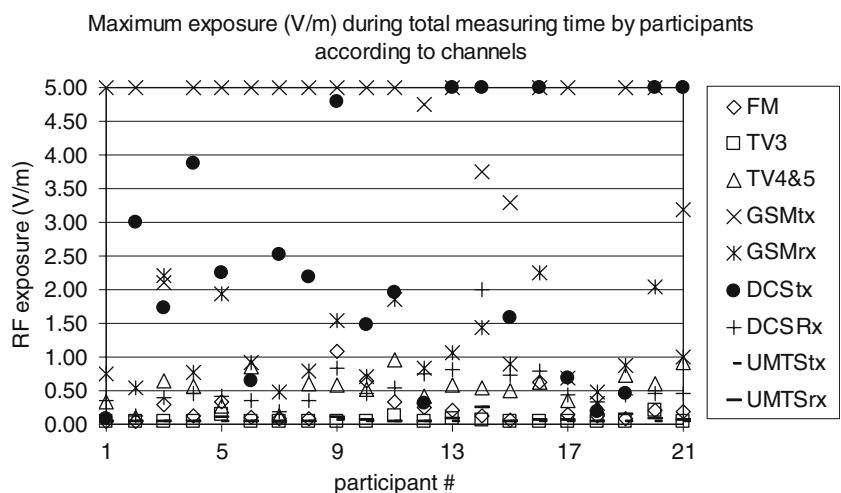
4.2 Evaluation of RF field intensity

Average field intensities for the total 24-h measuring period in all channels were very low. The range was between 0.05 and 0.119 V/m (GSMrx; Table 3 and Fig. 7). The UMTS

frequencies were present as a test service only and were not supplied for the public at the time of the survey in Hungary yet. The arithmetic mean of average exposures of participants were 0.06, 0.059, 0.055, 0.055, 0.055, 0.054, 0.050, 0.050, and 0.050 V/m for channels GSMrx, GSMtx, DCStx, DCSRx, TV4&5, FM, TV3, UMTStx, and UMTSrx, respectively (Table 3).

Maximum field intensities for the total 24-h measuring period for different channels were between 0.05 and 5.0 V/m (for GSMrx). Arithmetic mean of maximum exposures of participants were 4.406, 2.513, 1.147, 0.555, 0.529, 0.247,

Fig. 8 Maximum exposures (V/m) during total measuring time by participants according to the RF channels



0.076, 0.068, and 0.06 V/m for channels GSMtx, DCStx, GSMrx, DCSrx, TV4&5, FM, UMTSrx, TV3, and UMTStx, respectively (Table 4 and Fig. 8). The highest maximum exposure was detected during the traveling period and the lowest in the bed at home (Fig. 9). The highest average exposure was detected during the traveling period and the lowest in the bed at home (Fig. 10).

4.3 TWA exposure

The TWA exposure was calculated for durations (minutes) of time when the exposure was above the detection limit (0.05 V/m) of the PEM (Fig. 11). The mean RF exposure by each participant according to selected frequency bands during total measuring time when $E > 0.05 \text{ V m}^{-1}$ is shown at Fig. 11. According to the evaluation, the exposure levels from base stations and FM broadcast antennae are low, while the duration of time is long, and the case for handsets (GSMtx, DCStx) is the opposite.

The total exposure [$\text{V m}^{-1} \text{ min}$] was calculated for each participant for selected channels. The average total exposure of participants ($N=21$) coming from selected fix RF sources were 16.78, 15.07, 14.23, 12.22, and 8.44 $\text{V m}^{-1} \text{ min}$ for channels GSMrx, DCSrx, GSMtx, TV4&5, and DCStx, respectively.

5. Discussions

International guidelines and the relevant EU recommendations propose the limits for the population 4.5 W/m^2 (41.2 V/m) at 900 MHz, 9 W/m^2 (58.2 V/m) at 1,800 MHz, and 10 W/m^2 (61.4 V/m) above 2,000 MHz, respectively. These values are several orders higher than exposures specified for the public from base stations and other fixed RF sources. For mobile handsets, the human exposure is several orders higher, but the SAR is below the

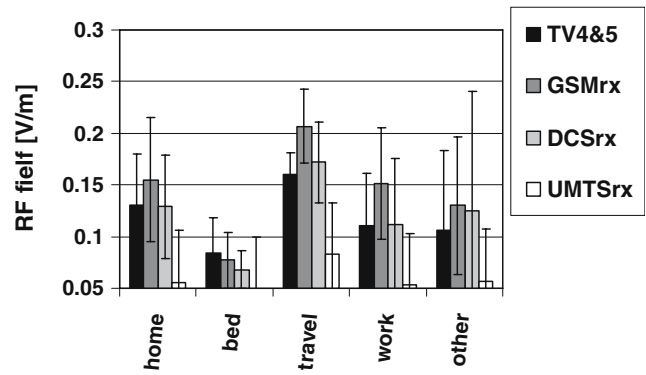


Fig. 10 Average of mean electric field exposures coming from selected fix RF sources by all participants ($N=21$) during the whole recording periods (24 h) according to activity types

international guidelines, EU recommendations and national standards, which varies from 1.6 to 2 W/kg [8, 9, 14]. However, the guidelines and recommendations propose a threshold concept in relation to the adverse health effects of EMF radiation, and most epidemiological studies related to mobile phones investigate the possible long-term effects. However, in many cases, exposure assessments of these studies are based on radiation levels and time duration of RF exposure.

Because of the very low RF levels at the environment, the sensitivity (detection level) of the meter is an important factor, because it influences the information one can get from the data obtained in a great degree. It is important that the device works selectively according to the given frequency band (channels), and because of this, it is possible to differentiate between body-worn devices and installed RF sources. Obviously, it gives only representative information about the telecommunication devices, because it gives local data. The PEM was developed to have good isotropy, and that is why we preferred to analyze the installed sources in details, preferably the telecommunica-

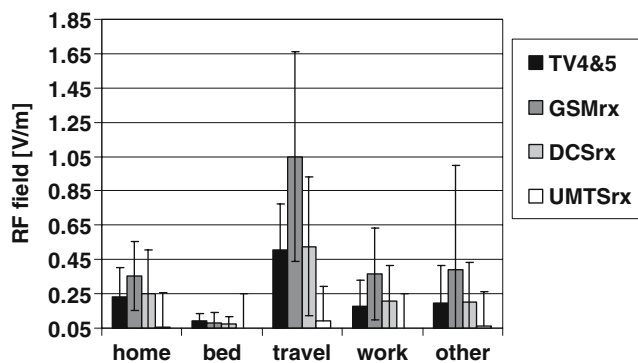


Fig. 9 Average of maximum electric field exposure coming from selected fix RF sources by all participants ($N=21$) during the whole recording periods (24 h) according to activity types

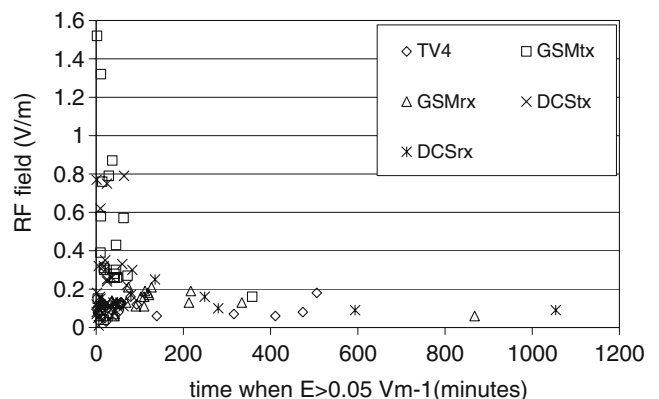


Fig. 11 Mean RF exposure by each participant according to frequency bands during total measuring time when $E > 0.05 \text{ V/m}$

tion system devices, which are in the front line of interest of the public as well.

Most commonly, exposed people are in the far field of the signal from fixed sources. Then, the electromagnetic waves propagate from the source to the individual. The field strength and thus, the power density, decreases with increasing distance. In addition, absorption and reflections because of hills, buildings, etc., determine the exposure level at a certain position. The attenuation of the RF signals in vegetation, house, walls, etc., degree of decrease, is also frequency dependent [1, 7]. However, one cannot neglect the effect of the person who is wearing the dosimeter. Preliminary studies have been performed on the device characteristics with body-worn conditions. In laboratory environment under intended use conditions on a test person, the mean values as obtained with the PEM tend to underestimate the free field measurements. Otherwise, taking into account this underestimation of the free field conditions, the simple free space model might be a valid approximation for the real environmental exposure [14].

Base stations are especially numerous in big cities, and it is difficult to define the actual exposure because of variations in wave propagation. This fact has been also confirmed by our in situ measurements nearby the base stations. Because of the fact that in case of FM and TV broadcast sources the exposure from a given source can be calculated more easily than in case of base stations, we think that personal exposure measurements are especially useful for exposure assessment, and that is why we placed emphasis on exposure analysis from base stations. It has been found that the PEM gives obvious measurement uncertainty according to the site of emplacement, which can hardly be forecasted, but they have already started investigations to solve this problem [15, 16, 17].

The user of mobile devices, for instance, the user of mobile phones or 3G terminals, is often in the near field of the emitting antenna. The field strength decreases rapidly with the distance between the device and the user. The way the device is used, i.e., determining the distance between the source and the user's body and which part of their body part is most highly exposed, is important. A mobile phone may be held next to the user's head, but it might also be used with a headset, and the phone might be kept in the user's hand or in a pocket. Other mobile communication devices (i.e., laptop computers) are used primarily in different ways than mobile phones, with different distances from the user and with exposures to different parts of the body.

In view of the usually very low RF levels in our environments and to the relatively higher detection limit of the PEM, if we are intending to compare the individual RF exposures of the participants, the most useful exposure metric is the duration of time exposed over the detection

limit. In view of the detection limit, the PEM does not measure levels below 0.05 V/m. It is an important quality of the PEM that TWA [V/m] and total exposure [$V\ m^{-1}\ min$] can be calculated and used as exposure metrics for exposure durations when the levels are above the detection limit (Fig. 11). On the other hand, it is also obvious that the concept of total exposure contradicts the ICNIRP's concept of threshold theory of basic restrictions and reference levels, but it might be useful for public health estimations in the future.

In the present survey, the measurements were done with only one type of dosimeter setting (24-h measuring time with 15-s sampling rate). Because of the chosen sampling rate, some transient exposures did not appear among the detected data, and it needs further investigation to figure out how high the frequency of the sampling rate is worth to be raised [13].

The use of digitally enhanced cordless telecommunications (DECT) is continuously increasing both in homes and in work places. No data is available on the exact numbers of such phones. Another increasing technology that appeared recently is the wireless local area network with access points distributed in buildings and with client cards with RF sources of portable computers. The Bluetooth wireless system is widely used to transmit signals between devices (e.g., between the mouse and the computer). Another application of RF technology for information transmission is the radio frequency identification system that has been introduced lately and is developing further applications. These contribute strongly to the indoor use of RF sources. According to our findings, it may be hypothesized that although the PEM does not include DECT, there is an overlapping between the bands DECT and DCS1800 exposure, nevertheless, it was not the goal of the present study to investigate this error.

It was found that the TWA exposure level during exposed periods above the detection limit ($E > 0.05\ V/m$) was highest during traveling, and analysis of the diaries by the participants showed that presumably it occurred during traveling by underground, but this needs further investigations. Further question is that the carrier person may influence the accuracy of the measurement and affect the isotropy of the PEM because of the size of the exposimeter and the dielectric properties of the human body, considering the fact that the participants carried the meter differently with them (clipped on the waistband, in a backpack). On the other hand, its advantage is that in case of the person's resting situation, the PEM is on a fix location and measures in an isotropic way (i.e., office work, bed at home) [13].

In the present study, we found that the longest exposure time over the detection level of the PEM device occurred from the FM broadcast channels. The public exposure to RF from the radio and TV broadcasts has a long history,

and we assume that the total exposure may have sustained part within the RF exposure of the environment. Therefore, it is a useful advantage of the DSP-90 personal exposimeter that it provides the exposure levels in the FM and TV frequency bands. Adult subjects were selected for personal exposimetry within the present study living in a big city (Budapest, capital of Hungary). Personal RF exposure needs to be measured in extended frequency bands with the next generations of RF PEM extended with additional channels, like TETRA (380–400 MHz), DECT (1,880–1,900 MHz), and WiFi (2,400–2,500 MHz) – as in case of EME SPY 120 by Antennessa – and also should be extended in the future on different population groups (i.e., children, elderly persons, countryside residents, etc.).

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Providing Outdoor To Indoor Cellular Signal Coverage

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Abstract— In this paper an experimental prediction model is developed for outdoor to indoor signal propagation losses. This model has been developed by performing measurements at the ground floor of 31 buildings in Santiago Chile, some of them located in sparsely built areas, others in medium and high density building areas. Radio signal coverage of outdoor cell stations in indoor areas is a particularly complex problem in buildings with heavily reinforced concrete walls, which introduce great attenuation. Therefore an experimental prediction model for the outdoor-indoor attenuation is a relevant solution to a problem for cellular service providers. It is also experimentally demonstrated that important indoor signal coverage improvement can be achieved by use of low-cost passive repeaters for the 800-MHz cellular band.

Index Terms—Cellular telecommunications, wave propagation and passive antenna repeaters

I. INTRODUCTION

ASSURING adequate signal coverage of indoor areas is an important problem for cellular systems. Sometimes indoor coverage can be established by the fact that enough electromagnetic signal leaks into the building through openings like windows and doors, or simply by penetrating through walls. This is usually accomplished if a base station is located in the neighborhood of the building that is being considered. However, sometimes buildings have walls which strongly attenuate the electromagnetic signal. This is often the case in large malls, pedestrian walkways, train stations and underground parking lots.

In this paper we present some simple, but effective means to estimate the signal strength in buildings, based upon some general ideas related to the architectural environment, where signal coverage is desired. If the signal strength is less than the minimum required to provide coverage, the cellular service provider may perform a site inspection to determine whether a repeater is to be considered.

Active repeaters are the normal solution to indoor coverage problems, provided that the cellular service provider agrees to go into the expense of acquiring the required equipment,

install and maintain it, [1]-[2]. Passive repeaters can of course not be expected to substitute active repeaters at all circumstances, but they may provide significant signal improvement in limited areas (“hot spots”). Cellular antenna passive repeaters operate in a similar fashion to those employed in the microwave radio relay links years ago for redirection of wave propagation over hilly terrains [3]-[5]. The use of these devices can be justified if: signal strength is good at some point on the outside of the building (-50 dBm or more) and strong outdoor-indoor signal attenuation is experienced (25 dB or more). They may be a cost-effective solution for relatively small area coverage areas (usually less than 100 m²) and if installation and maintenance costs are to be kept low.

II. OUTDOOR-INDOOR ATTENUATION

There has been significant research to estimate the signal strength to be expected at a given distance from the base station of a cellular system. Some good references on the topic are [5] and [6]. Typically, the free space, two-ray, Fresnel, Okumura-Hata and Cost 231 propagation models are presented, [6]. References [7], [8] and [9] indicate that signal losses reduce by 2 dB per floor above the first floor (although floors in altitude may present less signal strength because base station antennas are prevented to have high gain patterns in altitude), which indicates that floors mostly affected by path losses are the first floor and underground levels of buildings. However, if the first floor of a building has a very high ceiling, more signal strength is to be expected, [7]. Polarized windows may introduce signal attenuations in the order of 3 to 30 [dB], [5].

Normally, cellular service providers plan service coverage using software planning tools that make use of the prediction models described before to establish large scale propagation losses, [5]. In case of doubts, drive tests are performed to establish signal strength in their area of coverage. These test drives are usually conducted by a technician driving a car through the areas of interest, equipped with appropriate equipment to record signal strength statistics. However, drive tests are normally not made in the interior of buildings, since the cost associated to such practices is prohibitive. We performed a set of extensive measurements to find out if an outdoor to indoor attenuation prediction model could be constructed, [10].

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A. Experimental Measurement Procedures

To perform the measurements, a Gator™ transmitter, a PathSearch® receiver from MLJ, 1.9 GHz omni-directional antennas, a Berkeley battery powered ac source and a notebook were used to perform the measurements. The transmitter was installed on the base station that provided cellular coverage to the building area to be measured, while the rest of the equipment was placed on a small cart. Positioning was accomplished using a GPS receiver. The frequency spectrum at the measuring site was checked using a portable spectrum analyzer, which was also used to detect that the GSM radiofrequency carrier was at its full transmission power. Although cellular devices can be used to perform measurements, this method was not used since under adverse propagation characteristics the transmitter of the mobile unit would saturate.

The procedure consisted of carrying out measurements on 2 to 6 reachable locations on the outside of the building. On each location the receiver was moved in an area of about 5 m², performing measurements for about 3 to 5 minutes, which were averaged out. In each location 4 variables were recorded; 2 of them related with the received power of the RF control channel of the closest GSM base stations (frequencies vary from location to location), 1 of a 1962.5 MHz CDMA cellular carrier and one of them related to the transmitted signal from the reference 1957 MHz, 40 dBm transmitter, whose antenna was located on a base station tower, as stated before. The variable transmission power factor of GSM was greatly reduced by checking each signal with the spectrum analyzer, working in the receiver mode. If not all channels of the GSM radio channel are used, this will show in the spectrum analyzer when in GSM receiver mode.

Inside the building similar measurements were made, however only on the ground level floor (except in one building, where we could confirm that for each additional floor the equipment was raised, a 2 dB signal strength gain was observed, [7], [8] and [9]). A field report was made for each location characterizing the architecture of the building and its neighborhood.

In total 31 public buildings of Santiago, Chile, were chosen to perform the measurements. Table I summarizes the selected buildings, their address and main use. Quite a few of them are shopping galleries, business and government office buildings. One museum and one theatre building were part of the group. Some of these structures are in densely built areas and some are at the edges of public parks and mayor avenues.

Figure 1 shows the locations of the buildings in the city (blue numbered rectangles) and their relative position to the base stations (red circles).

B. Measurement Outcomes

Table II shows the difference of indoor and outdoor measurements for location 15. Each value is an average of 6 indoor and 3 outdoor measurement runs of 4 minutes each, while moving the receiver in a 5 m² area. The signal strength difference for technologies at this place can be explained by the relative position of the base station site and the measurement location of the transmitters, and the openings of the building structure that affect attenuation differently.



Fig. 1. Measurement site and base station locations in Santiago, Chile

TABLE I
MEASUREMENT SITES. LOCATION AND MAIN PURPOSE

N°	Building	Location	Business
1	Galería Capri	Monjitas 825	Shopping gallery
2	Biblioteca Nacional	Av. Lib. B. O'Higgins 651	Library
3	Edif. Las Américas	Miraflores 224	Office Building
4	Tribunales de Justicia	Compañía 1104	Government Offices
5	Ministerio de Salud	Monjitas 689	Government Offices
6	Centro Médico Araucana	Santa Lucía 360	M.D. Offices
7	Mercado Central	San Pablo & 21 de Mayo	Market
8	Edif. Corp. EMOS S.A.	Balmaceda 1398	Customer Services
9	Galería Consistorial	Monjitas 843	Shopping gallery
10	Torre Interamericana	Agustinas 640	Office Building
11	Correo Central	Plaza de Armas 983	Customer Services
12	Edif. Banco Santander	Bandera 140	Customer Services
13	Casa MUSA	San Pablo 1055	Shopping Center
14	Pasaje Anibal Pinto	Agustinas 1022	Shopping gallery
15	Estación Mapocho	Plaza de la Cultura s/n	Events - Exhibitions
16	Ministerio de Educación	Av. Lib. B. O'Higgins 1371	Government Offices
17	Teatro Municipal	San Antonio 149	Theatre
18	Palacio de Bellas Artes	Parque Forestal	Museum
19	Alcalde M.Fernandez D.	Amunátegui & Balmaceda	Justice Building
20	Promepart Isapre	Merced 360	Customer Services
21	Edif. Santiago 2000	Huérfanos 770	Office Building
22	Galería La Merced	Huérfanos & Mac Iver	Shopping gallery
23	Galería Antonio Varas	Bandera 24	Shopping gallery
24	Galería Imperio	Huérfanos b. Estado & San Antonio	Shopping gallery
25	Pasaje R. Mac Clure	Ahumada 254	Shopping gallery
26	Pasaje A. Edwards	Ahumada 312 (corner. Huérfanos)	Shopping gallery
27	Pasaje Matte	Ahumada 339	Shopping gallery
28	Edif. Plaza de Armas	Puente 516	Shopping gallery
29	Galería Victoria	Huérfanos 827	Shopping gallery
30	Galería Alessandri	Bandera 248	Shopping gallery
31	Edificio Cordillera	Coronel Pereira 72 - Las Condes	Office Building

TABLE II
RELATIVE ATTENUATION, INDOOR TO OUTDOOR IN ONE LOCATION OF A MEASUREMENT SITE

Technology (signal)	Outdoor signal strength [dBm]	Indoor signal strength [dBm]	Attenuation [dB]
CDMA	-76.04	-79.36	3.32
GSM (1)	-88.54	-90.76	2.22
GSM (2)	-71.02	-79.59	8.56
Pilot	-90.20	-97.76	7.56

As stated before, the number of indoor and outdoor measurement runs varies for each location, depending on the available open space to create significant records. However each measurement set is performed for CDMA (wideband), 2 of the strongest GSM signals available (narrowband) and the CW signal. In total 367 records were obtained from 117 measuring locations in 30 buildings. If these records are ordered statistically, they distribute according to a Gaussian distribution both in general as for the special cases to be discussed, with an error that is less than 5% in general (except in one specific case, where the error is 9%).

Architectural similarities among the buildings and their surrounding environments make it possible to establish 3 categories: a) SCE: sparse construction environment and low buildings; b) MSE: medium sparse environments and c) HDE: high density environments. Table III shows a list of the buildings that can be categorized this way. When ordered this way, the average value and standard deviation of outdoor to indoor attenuation can be obtained and plotted. The result of this exercise is shown in figure 2. These results are compared to a cumulative normal distribution with the parameters indicated in Table III.

TABLE III
AVERAGE AND STANDARD DEVIATION OF OUTDOOR TO INDOOR ATTENUATION ACCORDING TO BUILDING CLASSIFICATION

Location Classification	Buildings complying with classification	Average Attenuation [dB]	Std. Dev. Attenuation [dB]
SCE	8, 15, 18	8.9	6.1
MSE	2,7,9,11,13,19,28,31	15.7	9.1
HDE	1,5,10,12,14,16,17, 21,22,24,25,26,27,30	19	8.8

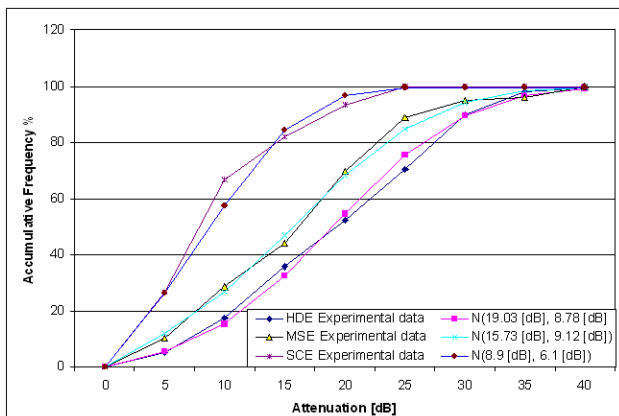


Fig. 2. Accumulative Frequency Distribution of Outdoor-Indoor Attenuation

These measurement outcomes show that building location plays an important role to predict outdoor-indoor attenuation. Also, that it is possible to establish a statistical prediction model that closely matches actual measurements. Actual measurement outcomes differ from a normal distribution with average and standard deviation, as indicated in figure 2, by less than 5%, except in one case. This means, it would be safe to consider a 27 dB fade margin in high density edifice environments (HDE) for indoor coverage at ground level in buildings.

Additionally, an interesting coverage problem is to establish the expected signal loss a subscriber cellular unit

experiences as it enters a pedestrian hallway. 12 buildings of the ones surveyed have such galleries. These galleries may change in their size (width and height), in their shape (straight, L or T shape) and the building might be relatively new (and therefore complying with several structural design criteria for an earthquake prone area), not so old (30- 40 years old) and old (50 or more years). The latter might have brick walls with cement plaster and supporting cement and iron columns and beams, whereas the former may have steel reinforced cement walls. We tried several ways of grouping the outcomes of our measurements in such a way that a significant difference could be noticed. We concluded that the best way to categorize these galleries was to define 2 groups: one consisted of relatively new and middle aged buildings with straight, L or T shaped galleries (NMB), the other group consisted of middle aged and old buildings with straight galleries (MOB). With this classification in mind, it was possible to establish significant differences, as can be seen in Table IV and figure 3, where the same approach has been taken to analyze measurement results as in Table III and figure 2.

TABLE IV
AVERAGE AND STANDARD DEVIATION OF OUTDOOR TO INDOOR ATTENUATION IN SHOPPING HALLWAYS

Building Classification	Buildings complying with classification	Average Attenuation [dB]	Std. Dev. Attenuation n [dB]
NMB	1, 9, 22, 23, 24, 28, 29	15.7	7.2
MOB	14, 25, 26, 27, 30	25.0	7.3

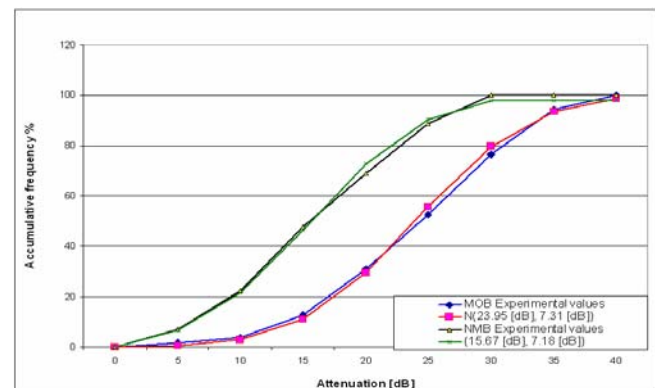


Fig. 3. Accumulative Frequency Distribution of Outdoor-Indoor Attenuation in Hallways

It can be seen that the expected attenuation in older building galleries and hallways experience almost a 10 dB increase in attenuation with respect to newer building galleries. A possible explanation for this phenomenon may be that steel reinforced concrete walls in hallways produce the effect of electromagnetic wave guides, which result in lower propagation losses as compared to corridors with brick walls, as they are found in older buildings. From these measurements it may be stated that 22 dB to 30 dB attenuations should be expected in open hallways, compared to outdoor signal strength predictions.

C. Prediction Model for Ground Floors and Hallways

These results make it possible to establish an outdoor to indoor attenuation prediction model based on experimental evidence for buildings, which is summarized in equation (1).

$$P_{indoor} [dBm] = P_{outdoor} [dBm] - N(\mu, \sigma) [dB] \quad (1)$$

In equation (1) P_{indoor} is the predicted indoor signal strength, $P_{outdoor}$ is the predicted or measured power of the signal on the outside of the building, and $N(\mu, \sigma)$ is the predicted attenuation, where μ is the predicted average and σ is the predicted standard deviation as defined in Tables III and IV. The error of the prediction model with respect to measurement outcomes is less than $\pm 5\%$ in all cases, except for one case (SCE at 10 dB attenuation in figure 2).

Practical implications of this model are straightforward, as pointed out before. From figure 2 it can be established that if a service provider wants to provide 70% of coverage in an indoor area of an edifice which is located in an area surrounded by many high rise buildings (HDE column), then he will have to provide an outdoor signal strength 25 dB above the sensitivity of the cellular units he sells to his clients. Any other percentage can be calculated by means of the normal distribution with average and standard deviation values as shown in Table III for buildings, and Table IV for hallways.

Attenuation in higher floors can be easily calculated by adding 2 dB signal strength for each floor as it was reported in [7], [8] and [9]. Our measurements confirmed these results as well, [10].

Cellular coverage in underground parking lots and pedestrian walkways in subway stations usually requires the deployment of repeaters. Normally, larger attenuations may be expected in this case, in the order of 25 dB or more as compared to outdoor values of signal strength, due to the fact that normally heavily steel reinforced walls are being used to sustain the buildings and also heavily steel reinforced concrete floors are used to provide a solid surface for cars and trucks to transit above subway pedestrian walkways and underground parking lots.

III. EXPERIMENTAL STUDY OF PASSIVE REPEATER FOR UNDERGROUND PARKING LOT

The possibility of exploring the potentials of using passive repeaters in underground areas is not easy. It requires the willingness of the building administration to perform measurements, install antennas and coaxial cables. However, we were able to perform such an experiment in a building where a 70 m² space in an underground parking lot was being considered to provide room for an emergency meeting and conference room. The owner of the building was a cellular service provider and was therefore interested in exploring the use of passive repeaters, since their installation and maintenance cost is at least an order of magnitude less than the deployment of active repeaters, [11]. In this case, however, the operating frequency band was in the 800 MHz range instead of 1.9 GHz.

Our recent simplified theoretical study [12] has shown that for wall attenuation less than 10-12 dB (a brick wall, single-mesh reinforced concrete and wood walls, etc.), the signal enhancement due to the passive repeater with a medium gain antenna is moderate. Significant benefits can only be expected

at limited ranges or by using high gain antennas at expense of angular coverage. For the case of a high loss wall however, with attenuation larger than 20-25 dB, a considerable improvement in indoor signal coverage can be easily achieved using passive repeaters.

A. Assessment Of Signal Coverage Previous To Repeater Installation

A survey of the received signal power of the control channel of the cellular base station covering the building was conducted in the area of interest, as it is shown in figure 4 and 5. Figure 4 shows the area to be used as occasional meeting and conference room for staff members at the parking level -1 of the building. Figure 5 shows the signal power strength recorded in this area prior to repeater installation. The equipment used for these measurements were a portable spectrum analyzer, a radiofrequency power meter and the TEMS CellPlanner Universal® instrument developed by Ericsson.

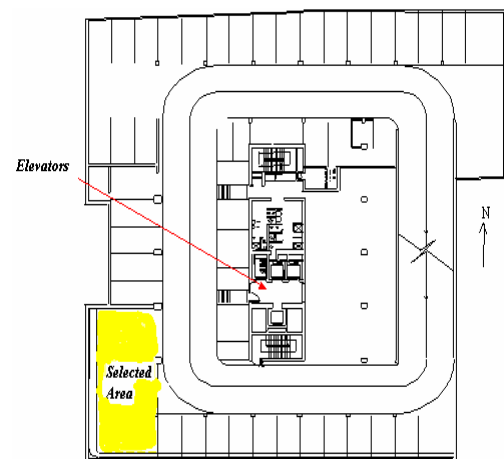


Fig. 4. Underground parking with space to be used for occasional staff meetings

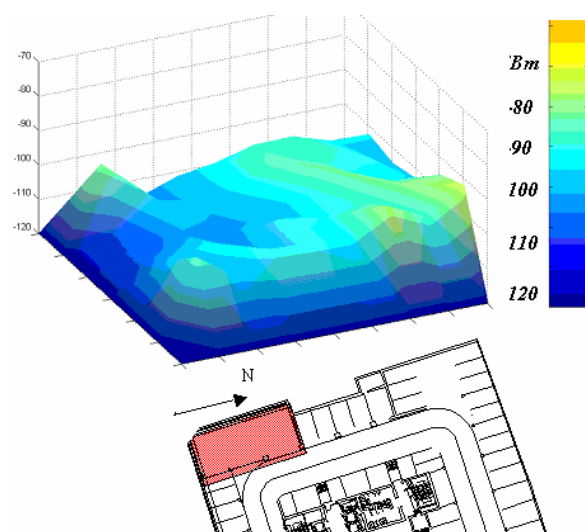


Fig. 3 Signal strength prior to installation of passive repeater

Received power was in the range of -105 dBm, as it is shown in figure 5, too low to provide reasonable cellular service. At some spots of the selected storage area, calls could be initiated but could not be maintained. Therefore this was a situation where the use of passive repeaters could benefit users and the company, by reducing installation and maintenance costs.

B. Passive Repeater Installation And Measurements

After a brief inspection of the architecture of the building, it was discovered that from a 7-meter high terrace of the building, line of sight (LOS) to a nearby (approximately 1 Km distance) cellular base station existed. The signal power level at the terrace was found experimentally to be -46 dBm at the selected antenna location.

A 12-dBi gain Yagi antenna was secured on the building terrace. It was connected to a 8-dBi gain patch antenna placed on the northern wall of the selected underground area using a 100-meter long, 7.5-dB loss coaxial cable.

Considering the total antenna gain of 20dB, cable and mismatch losses, the expected radiated power level at the interior patch antenna is ERP = -33.5dBm. Once the passive repeater system was installed, a similar set of measurements performed in the same area gave way to the results shown in figure 6, with an average signal level of -80 dBm at the space of interest, thus providing a 25 dB signal improvement, on the average.

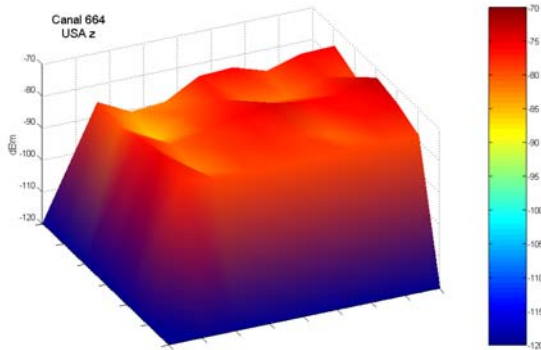


Fig. 6 Signal strength after installation of passive repeater

After repeater installation, calls could be initiated and maintained normally, without experiencing call losses in the area covered by the indoor antenna.

This shows that the use of passive repeaters in practical applications in underground spaces may provide an interesting cellular coverage solution. It will reduce installation and maintenance costs, since no expensive active repeaters and their power source need to be installed, as well as maintenance will be minimal, since no active devices are involved. Since normally the use of passive repeaters is only considered for fixed wireless systems, this is an interesting result.

C. Power Transfer In Single-Ray Passive Repeater

We consider a link budget analysis for a situation like the one described in the previous section. A simple, single-path repeater scheme is considered, other possible transmission

paths, penetrating and being reflected by the building walls are neglected, or are not present, as in the case of electromagnetically shielded areas, as it was found in the example of the previous section. A quick check using basic electromagnetic signal propagation concepts may provide a means of checking the feasibility of using passive repeaters on that location.

The power P_A received at the output of the donor antenna A_D can be determined using Friis line of sight (LOS) equation (2).

$$P_A = \frac{P_S G_S(\Phi_A, \theta_A) G_A \lambda^2}{(4\pi \cdot d)^2} \quad (2)$$

where P_S is the power radiated by the base-station antenna S , λ is the free-space wavelength, $G_S(\Phi_A, \theta_A)$ is the base-station antenna gain in direction to the donor antenna A_D , and G_A is the gain of antenna A_D , with the main lobe looking at base-station antenna and d is the distance between base station and donor antenna.

Assuming that the transmitter from the base station delivers $P_S = 1 \text{ W} = 30 \text{ dBm}$, that the antenna gains are $G_S(\Phi_A, \theta_A) = 13 \text{ dBi}$, $G_A = 0 \text{ dBi}$, the distance from the base station to the donor antenna $d = 1 \text{ Km}$, then $P_A = -47.5 \text{ dBm}$. Although certainly free space conditions do not apply, the result is close to the measured value.

The power at the input of coverage repeater antenna A_R connected to the antenna A_D by the coaxial cable C_R is proportional to the power P_A , or

$$P_B = \eta_c P_A \quad (3)$$

where the total cable efficiency η_c is calculated by equation (4).

$$\eta_c = (1 - \rho_D^2)(1 - \rho_R^2) \exp(-2\alpha_c l_c) \quad (4)$$

Here α_c is the cable attenuation constant, l_c is the cable length, $(1 - \rho_D^2)$ and $(1 - \rho_R^2)$ are the match efficiencies, and ρ_D and ρ_R are the reflection coefficients at the repeater antenna (donor and repeater) ports.

Using Friis equation again, this time for the indoor propagation path, leads to an expression for the power P_M received by the mobile unit antenna,

$$P_M(\varphi, \vartheta) = \frac{P_S G_S(\Phi_A, \theta_A) G_A \lambda^2 \eta_c G_M G_R(\varphi_M, \vartheta_M)}{(4\pi)^2 (d \cdot m)^2} \quad (5)$$

where m is the distance from the repeater antenna to the mobile unit antenna, G_M (assumed omni directional) and $G_R(\varphi_M, \vartheta_M)$ are the gain radiation patterns of the mobile and repeater unit antenna, respectively. It is assumed that the mobile unit is at angles φ_M and ϑ_M from the maximum gain of the repeater antenna. This equation can be expressed in logarithmic terms, as it is done in equation (6).

$$P_M(\varphi, \vartheta) [dBm] = P_S [dBm] + G_S(\Phi_A, \theta_A) [dB] + G_A [dB] - 124.9 [dB] - L [dB] + G_R(\varphi_M, \vartheta_M) [dB] - 20 \log d_{Km} - 20 \log m_m - 40 \log \{f_{GHz}\} \quad (6)$$

In equation (6), instead of calculating the received power in terms of the wavelength, the frequency f_{GHz} , expressed in GHz is used, the distance d is expressed in Km and the distance m is expressed in meters. It is assumed that the cellular unit antenna gain $G_M = 0 \text{ dB}$, also $L [dB] = -10 \log \eta_c$ is the cable loss, expressed in dB.

For instance, assuming that the transmitter from the base station delivers $P_S = 1 \text{ W} = 30 \text{ dBm}$, that the antenna gains are $G_S(\Phi_A, \theta_A) = 13 \text{ dBi}$, $G_A = 12 \text{ dBi}$, the distance from the base station to the donor antenna $d = 1 \text{ Km}$, $G_R(\varphi_M, \vartheta_M) = 8 \text{ dB}$ and $G_M = 0 \text{ dB}$ and the distance in the desired area is $m = 10 \text{ m}$, $L = 7.5 \text{ dB}$, then $P_M(\varphi_M, \vartheta_M) = -85.5 \text{ dBm}$. Measured values at the far end of the area of interest are -83 dBm . Thus, equation (6) provides a reasonable means of calculating the received signal power strength, provided the base station antenna and the donor antenna are in line of sight.

IV. CONCLUSIONS

We have been able to provide a prediction model for outdoor to indoor attenuation for cellular coverage in office and government buildings in cities, based on experimental data. Not only does this model predict attenuation to be expected at the ground floor, but on the floors above as well, as it was reported in [8], [9] and [10] and confirmed by our measurements. We are also able to predict attenuation in shopping galleries as well. Finally, we show that under given circumstances, passive repeaters can be deployed to cover limited areas in underground parking lots or hallways. Originally we conceived this as a good solution to provide cellular coverage for pedestrian walkways that give access to subways. However, we realized that in most cases this was not a practical solution, at least in Santiago, Chile. In this city, cellular service for the subway is associated to one cell. Cellular systems provide information to the mobile units about the neighboring sector control channels so as to assist the mobile in identifying a convenient control channel for the handoff or handover. This information would be valid only in certain subway station access hallways, but not in all of them. Therefore, for most cases the user would experience a dropped call anyway. However, the passive repeater solution might be useful for underground parking lots and underground working areas, where it may be important to reach employees by phone as they work in a mobile environment.

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