行政院所屬各機關因公出國人員出國報告書

（出國類別：研　習　　　　）

研習美國非屬原子能游離輻射管制方式及其生物效應計畫
出國報告書

服務機關：行政院環境保護署空氣品質及噪音管制處
出國人　職　　稱：科　長
姓　　名：莊訓城

出國地點：美國
出國期間：九十二年八月二十六日至九月五日
報告日期：九十二年十二月二日

行政院研考會/省（市）研考會編號欄
I5/C09202297

系統識別號：C09202297

行政院及所屬各機關出國報告提要

報告名稱：研習美國非屬原子能游離輻射管制方式及其生物效應計畫

頁數　　含附件:☑是☐否

出國計畫主辦機關：行政院環境保護署

聯絡人/電話：李秋燕 電話：(02)23117722-272

出國人員：莊訓城　服務機關：行政院環境保護署

單位：空氣品質及噪音管制處　職稱：科長　電話: (02)2311-7722-2790

出國類別：☐1考察　☐2進修　☑3研究　☑4實習　☐5其他

出國期間：民國92年8月26日至民國92年9月5日

出國地區：美國

報告日期：民國92年12月2日

分類號/目：I5/化學與環境科學/I5/化學與環境科學

關鍵詞：

內容摘要：

近年來由於無線通訊技術的日新月異，大哥大基地台之設置非常普遍，一根根近一米長的天線密集排列，其產生之電磁波是否會影響人體健康，常為民眾所關切。因此，我國參考 ICNIRP 1998 之標準，於民國 90 年 1 月 12 日公告我國非游離輻射環境建議值，作為相關非游離輻射設備主管機關訂定管制規範之參考。

綜合本次研習及世界上有關議題之研究結果所獲取之初步結論為：國際上大部份之研究結果，並無明確證據顯示，長期或短期曝露於電磁輻射的環境下，會產生特定之生物效應。世界衛生

組織(WHO)與全球 29 個國家，自 1996 年開始執行「國際電磁輻射計畫」，希望計畫執行後，可明確公布各種電磁輻射對人體健康之影響，並進一步討論其安全管制範圍。另國際非游離輻射組織(ICNIRP)亦將依據 WHO 之研究結果，預定於公元 2005 年訂定非游離輻射標準安全管制值。

未來本署亦將持續注意非游離輻射之國際研究成果及發展趨勢，並全面量測基地台、變電所・・・等，建立我國環境非游離輻射資料庫，以隨時修正我國之公告值，並與世界管制同步。

研習美國非屬原子能游離輻射管制方式及其生物效應計畫

目　錄

壹、前言 · 1

貳、行程 · 2

參、研習紀要 · 3

肆、研習心得與建議 · · · · · · · · · · · · · · · · · 6

伍、附錄

一、美國電力研究所(EPRI) · · · · · · · · · · · · · 15

二、美國聯邦通訊委員會(FCC) · · · · · · · · · · · 65

三、美國藥物食品管制局(FDA) · · · · · · · · · · · 143

四、美國環保署 · · · · · · · · · · · · · · · · · · · 159

五、康州環保處 · · · · · · · · · · · · · · · · · · 169

壹、前言

隨著無線通訊技術的日新月異給人類生活革命性的突破，諸如：現在幾乎人手一機的行動電話系統，在高山或荒島上仍可與家人報平安，無一不是利用電磁波無遠弗屆的傳播特性，使人類可以保持持續的通訊而不受其活動限制。

我國交通部於五年前陸續開放行動電話通訊執照後，一般民眾已開始享受無線通訊之方便性。然而業者於許多建築物頂樓架設行動電話基地台，一根根近一米長的天線密集排列，其產生電磁波是否會影響人體健康，常為民眾所關切。

因此，我國自民國 90 年 1 月 12 日公告我國非游離輻射環境建議值，對於頻率一赫茲(Hz)至三百至赫茲(Hz)之電磁波之電磁場強度予以規範，可作為交通部、經濟部・・・等非游離輻射設備主管機關，訂定相關管制規範之參考。

目前世界衛生組織（WHO）與全球二十幾個國家，自一九九六年開始執行「國際電磁輻射計畫」，希望計畫執行後，可明確公布各種電磁輻射對人體健康之影響，並進一步討論非游離輻射的安全管制範圍，另國際非游離輻射組織(ICNIRP)將依據ＷＨＯ之研究結果，擬於公元 2005 年訂定非游離輻射標準安全管制值。

美國非游離輻射之管制一向領先世界各國，其管制業務分散於美國環保署(USEPA)，美國通訊委員會(FCC)、美國藥物食品管制局(FDA)，故本次研習考察即安排這些單位，並特別參訪其電磁波研究重鎮－美國電力研究所(EPRI)、以搜集其最新管制法規標準，及最新生物效應之研究，以作為本署擬訂相關法規、標準及管制措施之參考。

貳、行程

日　　期	地　　點	研習內容
8 月 26 日至 27 日 (星期二至星期三)	台北至舊金山	台北出發，抵達舊金山
8 月 28 日 (星期四)	舊金山	參訪舊金山美國電力研究所 EPRI
8 月 29 日 (星期五)	舊金山至華盛頓 DC	自舊金山出發，移動至華盛頓 DC
8 月 30 日至 31 日 (星期六至星期日)	華盛頓 DC	1.整理資料 2.聯絡參訪事宜
9 月 1 日 (星期一)	華盛頓 DC	參訪 EPA
9 月 2 日 (星期二)	華盛頓 DC	參訪 FCC、FDA
9 月 3 日 (星期三)	華盛頓 DC 至紐約	移動，自華盛頓 DC 搭機至紐約
9 月 4 日 (星期四)	紐約	1.參訪康州環保處 2.研習其非游離輻射管制法規及標準及管制方式
9 月 4 日至 5 日 (星期四至星期五)	紐約至台北	搭機返國

參、研習紀要

一、美國電力研究所(EPRI)

EPRI 是美國於發電廠輸配電線產生之電磁波對於人體及工作人員身體健康影響之研究重鎮，其研究之觀點及成果如下：

(一)電場及磁場存在於我們日常生活空間的每一個地方。

(二)曝露於電磁場可能之健康效應研究,已持續 25 年之久。

(三)尚未有確切的證據,證明電磁場會導致不良健康效應。

(四)科學研究學者,仍將繼續調查電磁場與健康之關係。

(五)EPRI 之有關安全之研究報告，可以幫助電力公司保護其作業員工之安全。

(六)EPRI 可提供亞洲國家有關電磁場的研究合作計畫。

二、美國聯邦通訊委員會(FCC)

(一)美國所有相關之非游離輻射設備，如廣播電台．．等相關通訊設施之設置，皆必須符合美國聯邦通訊委員會設定之非軍用電台射輻(RF)之標準。

(二)美國境內有關手機及無線電通訊器材之生產，亦必須符合 FCC 公佈的 SAR(比吸收率)的標準,其規定手機之 SAR 值，為每公斤(或 mw/g)克身體組織的輻射量平均為 1.6w/kg。

三、美國食品藥物管理局(FDA)

食品藥物管理局在無線電話安全問題方面的責任是什麼?

依法，在諸如無線電話之類會發射輻射能量的消費性產品上市之前食品藥物管理局(FDA，簡稱該局)並不會審查它們的安全性，這點與他們對新的藥物或醫療器

材的作法不同。然而，如果無線電話所發射的射頻能量準位被證實對使用者有害的話，該局也有權利採取行動。在這個情況下，該局可要求無線電話的製造商將健康危害問題通知使用者並維修、更換或召回這些電話直至危害消失為上。

雖然現有的科學證據並不能構成該局採取上述管制行動的理由，該局也已呼籲無線電話產業採取一些步驟，其中包含下列幾點：

◎贊助與無線電話所發射的射頻信號類型有關的可能生物效應研究;

＊設計無線電話使其對使用者所造成與電話功能無關的射頻曝露減至最小;

＊和該局合作以將無線電話使用對人體健康的可能作用方面的最佳通訊提供給無線電話使用者。

為確保聯邦政府各相關單位在射頻電磁場安全性方面的工作能獲得協調，這些單位已組成一個跨部會的工作小組，該局亦為成員之一，其它成員包括:

◎國家職業安全與衛生研究所(NIOSH)

◎環保署 (EPA)

◎聯邦通訊委員會(FCC)

◎職業安全與衛生管理局(OSHA)

◎國家電信與資訊管理局(NTIA)

國家衛生研究院(NIH)也參與部份的跨部會工作小組的活動。

該局與 FCC 共同分擔無線電話的管制責任。所有在

美國銷售的無線電話都需符合 FCC 安全準則對射頻曝露的限制。在無線電話的安全性問題方面，FCC 則仰賴該局及其它衛生部門的建議。

FCC 也負責管制無線電話網路運作所需的基地臺。雖然基地臺的發射功率比無線電話大，一般說來，基地臺對人們所造成的射頻曝露比無線電話所造成的曝露量小千倍以上。

四、美國環保署(USEPA)

由其簡報資料，得知其長期及短期政策目標如下：

(一)長期策略及政策之研究

1.科學及研究

2.政策

3.分析

4.資訊及溝通

(二)短期加強資訊及教育功能

1.不確定性的說明

2.解釋風險的可能性

3.繼續研究

4.教導民眾如何獲得非游離輻射相關資訊

5.建立非游離輻射網站

五、康州環保廳(Conn. EPA)

該廳目前之作法，即依 FCC『地方政府如何建立非游離輻射法規、步驟指引』，正逐步從其環境監測中著手，執行其非游離輻射之相關管制業務。

肆、研習心得與建議

經由本次研習考察及搜集世界各國之研究結果，獲致之心得及建議，說明如下：

一、謹慎的策略

自十九世紀末期起，科學界就對人為電磁場的潛在健康效應感到興趣 ，尤其是最近的四十年。這些電磁場的常見來源包括電力線、室內配電線路、電器產品和馬達驅動的儀器設備、電腦螢幕、電信與廣播設施、行動電話及其基地臺。

電磁場對民眾的曝露受到許多志願性或具法律效力的限制值管制。其中最重要的是由國際非游離輻射防護委員會(ICNIRP)所研擬的國際性曝露準則和許多國家安全標準。此一曝露準則係為避免所有已被確認的危害而設計，包括短期和長期性曝露，而限制值亦已含很大的安全界限。一般人實際遭遇的曝露值幾乎都遠低於準則所建議的限制值。但因相關之研究及評估報告，仍存有許多之未確定性，所以,「謹慎的策略」是必須採行的最佳選擇。

二、電磁場的未確定性

電磁場潛在健康風險的評估包含許多的未確定性。特別是有一些流行病學研究暗示電磁場曝露與人體疾病之間存在微弱的關聯。這些研究涉及許多不同的疾病與曝露條件。然而，最大宗的證據與住家交流電力頻率 50 或 60 赫)電磁場的曝露和兒童白血病罹患風險可能增高的關聯性有關。其它的科學證據，包括大量的動物

研究，並不支持這個結論，而流行病學研究本身之中也有許多(在研究品質方面)出現一些包括曝露的評估不過適當之類的問題。

審查過這類證據的專家委員會都一致地發現這類證據太過微弱而難以令人信服。例如，1997 年時美國國家研究評議會(NRC)的審查結論為：現有證據並未顯示曝露(於住家交流電力頻率的電場或磁場)會構成人體的危害。類似地，ICNIRP 在 1998 年所公佈的電磁場曝露準則中作出下列敘述:流行病學在電磁場曝露與癌症方面所獲得的結果並未強大到足以構成制定曝露準則所需之科學依據。沒有任何一個主要的委員會作成低準位的電磁場真的會造成危害的結論。但科學上確實仍存有很大的未確定性而民眾對這個議題也仍抱持高度的憂慮。

三、審慎的迴避

在美國，「審慎的迴避」仍未正式被採用作為通訊或商業廣播設施的管制辦法。然而，政府部門已向電信業者提出同被視為具「審慎的迴避」形式的建議。美國食品藥物管理局(FDA)於 1999 年呼籲行動電話手機業者的手機設計應將使用者所受到的射頻曝露最小化到足以滿足通訊功能所需的最低準位。

由各個國家的施行力式觀之，「審慎的迴避」的文字含意中，審慎指的是經費的支出，而非對風險的心態。它並不暗示將曝露限制設定於任意低的準位，並要求不計代價的予以達成，而是採行成本不致太過份的減低民眾曝露措施。此一作法並不要求評估它們對健康可能帶

來的利益。

ALARA 為『在合理可達成範圍內的最低程度』的英文字母縮寫。這是用來將已知風險最小化的一種策略，其作法為考量成本、技術、對民眾健康與安全上以及其它的社會和經濟議題的利益之後將曝露保持在合理可達成範圍內的最低程度。目前 ALARA 主要用於游離輻射的防護，其曝露限制的設定並非根據某一臨界值，而是根據『可接受的風險程度』。在這些情況下，基於不同的人『可接受的風險程度』的變化很大的原因，即使曝露準位低於建議的限制值，將假設可能存在的風險減至最低也是合理的。

ALARA 仍未被用來制定與電磁場曝露有關的公共政策。事實上，對電磁場而言(電力線或射頻的電磁場)，在低曝露準位並不預期有任何風險以及曝露又無所不在的考量下，這並是一個合適的政策。

四、電磁場的預防策略

『審慎的迴避』以及其它與電磁場曝露有關的謹慎策略愈來愈受到許多人的歡迎，這些人覺得這些策略可為科學尚未證實的風險提供額外的保護。然而，這些方法在實施上很有問題。最大的困難在於缺乏長期受到低於曝露準則建議值的電磁場曝露會構成危害的明確證據，或，如果真有任何危害存在的話，缺乏對其本質的瞭解。雖然引發謹慎策略比制定曝露準則所需的證據份量低是無庸置疑的，但顯然地危害必需被確認而可能造成危害的條件也需瞭解到某一程度。

另一個困難點為在現代社會中，電磁場是無所不在的，場強大小變動很大而頻率分佈範圍也很廣。因此要制定具一致性和等同性的謹慎策略並不容易。例如，典型的都會環境中包含眾多的射頻發射器材，其範圍由低功率通訊發射機到功率非常高的廣播電台發射機。當同一個都會區內存有更高功率的電磁場源時，我們很難想像如何為降低行動電話基地臺所造成的射頻電磁場曝露制定一套一致又等同的謹慎政策。事實上，為行動電話基地臺天線結構施行謹慎策略的各種嘗試都是片斷的，它們並未注意到環境中其它(更為強大)的射頻能量來源。

五、合理的曝露準則限制值

上述考量建議對電磁場採行謹慎的策略應多加小心和慎重考慮。對電力或無線電波頻率的電磁場來說，歐盟委員會所指示採行此一策略所需的各種要求看起來並不被符合；然而，其它的相關策略，比如「審慎的迴避」，則可能是合理的。

其中一個主要的要求為這類策略僅能於科學性的風險評估結果與以科學研究結果為依據的曝露限制值不應被隨意採行的謹慎方法所損害的條件下才可採行。這些狀況可能發生於，例如，限制值被壓低到與已被確立的危害毫無關係的準位或為包容科學未確定性的程度而對限制值作不適當的隨意調整。

引用謹慎的策略而不損害以科學研究結果為依據的曝露標準也是可能的。1999 年時，紐西蘭政府參照

1998 年版的 ICNIRP 曝露準則公佈該國的射頻曝露標準。衛生與環境部特別提到它認為這項標準中的「基本限制」與「參考準位」標準能 『提供適當的防護』。然而，它也提到社區居民對射頻曝露的疑慮可能可由『在能以合理的代價達成的前題下，將對服務目標的達成或程序上的要求非屬必須或只是偶而需要的射頻曝露適切地壓低到最小的程度』。此一作法強調以『合理的代價』達到曝露的降低但並沒有任何預期的健康上的利益的證據或成本一利益的比較分析，因此它是一種「審慎迴避」的策略，而非如歐盟委員會所說明的「預防性原理」的應用。

其它的措施，與預防性方法無關，也可能對處理新建電氣設施所引發的民眾疑慮有所幫助。這些可能包括在電力線路、變電所或射頻發射設施選址過程中讓民眾發表意見或參與決定。此外，個人亦可就其所遭遇的情況與條件選擇採用他們覺得適當的任何措施。這類作為可能包括重新調整床邊電氣設備的位置，如其時鐘功能的收音機，或將兒童的床移到房間內磁場較低的區域。在上床睡覺之前將電毯關掉也可能是一種選擇。行動電話通話時間較長的人也可利用含耳機和麥克風的頭上收話器(免持聽筒套件)並使手機遠離身體。國家政府當局不應以健康為理由而建議民眾採取這類行動，但對個人而言，視其對相關風險認知的程度而定，則可能是合適地。

六、建置我國電磁波地理資訊系統宣導網站，適時修正管制建議值

世界衛生組織(WHO)與全球二十幾國自 1996 年開始進行「國際電磁輻射計畫」，國際非游離輻射防護委員會(ICNIRP)將依據其研究結果，擬於 2005 年訂定非游離輻射標準安全管制值，屆時本署將適時參考修正我國之環境建議值。

同時，本署亦將密切注意國外管制情形，並持續監測環境中之電磁波，逐年建立全國電磁波宣導網站及地理資訊系統，廣為宣傳，供民眾查詢，以釋群疑。

拜訪美國 EPRI MICHAEL SILVA, P.E. 及 ROBERT KAVET

參訪美國 FCC Robert F. Cleveland 博士

美國 EPA　EDWARD PARKER

康州環保廳
DEANIS DEMCHAK

EPRI RF Safety Report Helps Electric Power Companies Protect Workers

THE PROBLEM Radio-frequency (RF) and wireless communications are among today's most rapidly growing technologies. In recent years, an increasing number of electric power companies have installed RF and wireless antennas to expand their own communication infrastructure. As a business venture, many companies have also leased space on their transmission and distribution structures for third-party RF antennas for use mostly in connection with cellular and personal communication system (PCS) telephone base stations. While the power levels associated with these antennas are relatively modest, the adjacent RF fields can, in some cases, exceed Federal Communications Commission (FCC) limits for occupational exposure.

Although power company workers are trained to use safe practices when working with 60 Hz transmission and distribution equipment, they generally have little or no experience with RF antennas. This combination of a lack of familiarity with new technologies and the need for RF safety awareness has motivated the electric power industry to develop RF safety programs for its employees.

THE PROJECT To help power companies develop safety programs, EPRI's new report, *Radio Frequency Safety for the Electric Power Industry* (1005419), provides information on:

- RF safety basics, including exposure fundamentals, power density calculation, near-and-far field concepts, and specific absorption rates.
- Maximum permissible exposure limits and compliance requirements established for both public and occupational exposure by U.S. and international organizations.
- Important factors related to exposure of personnel to RF fields, including the physical size of the antenna, power transmitted, transmission frequency, mounting height, and direction.
- Overview of field instruments and measurements, including the use of field probes and survey meters, measurement methods, induced and contact currents, and personal RF monitors.
- Personal protective equipment overview.
- Methods for assessment of extreme near-field exposures for low-power portable devices such as handi-talkies, cellular telephone handsets, and mobile radios.
- RF safety program requirements for complying with FCC RF rules. These programs should include an RF safety officer and RF safety committee; a company RF safety policy; an assessment of the company's inventory of RF-emitting equipment, RF safety awareness training; coordination with wireless telecommunication companies; identification of employees with implanted medical devices; and development of safe practices and procedures such as RF safety signs and specification of safe working distances.

Mike Silva, Manager of EPRI's Radio-Frequency Safety and Wireless Technology Program, notes: "RF-field exposures can be managed safely through a well-designed program. This report can help environmental safety personnel understand RF exposure issues and develop occupational programs to both protect exposed workers and ensure regulatory compliance."

EPRI's Radio-Frequency Safety and Wireless Technology Program builds on the Institute's 20 years of EMF studies and its worldwide reputation for objective, state-of-the-science research. Other possible program products include safety awareness seminars, RF exposure assessment fundamentals, RF engineering tutorials, and a review of existing RF monitors.

USERS RESPOND Customers have been very enthusiastic about the report. Engineering and safety managers from several electric power companies have commented:

- I think it is very well done and can be extremely useful for individuals approaching this subject for the first time. I especially liked the sections on RF Field Instruments and Measurements, PPE, and the RF Safety Program Guidance. I wish we'd had this type of document three years ago when we first developed our RF policy and procedures. It would have provided a good procedural framework and saved a lot of time in choosing our field instruments. We spent six months without focus or direction putting our program together whereas, if we'd had the handbook, we could have set it up in one-third of the time.
- The safety report is both timely and appropriate—our use of RF technology (wireless meter reading, antennas) is increasing rapidly—as are the safety questions and concerns from our employees and our customers.
- The report was extremely informative. It was quite user-friendly, presenting the concepts in an informative, but not overly technical way. It also provided great examples of what to do and how to comply with the rules. This is critical as our audience consists of the workers who primarily interface with the equipment. Although regulatory guidelines have been issued, we anticipate that OSHA will soon expect compliance data. The last third of the document focused on the specifics of setting up a safety program. We relied heavily on this report for guidance in establishing our own program, enabling us to be proactive in regulatory compliance.

CONTACT INFORMATION For more information, contact the EPRI Customer Assistance Center (EPRI CAC) at 800.313.3774 or askepri@epri.com

TECHNICAL CONTACTS Mike Silva, 650.855.2815 or msilva@epri.com; Brian Cramer, 815.478.5344 or bcramer@epri.com

1007619

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

Why EMC is Important Today

The proliferation of sensitive electronic equipment and industry restructuring are exacerbating electromagnetic compatibility (EMC) problems, heightening the demand for cost-effective solutions.

- **TECHNOLOGY IS CONSTANTLY CREATING NEW EMC CHALLENGES.**
  One of today's most common EMC problems is computer monitor jitter induced by nearby power lines or electrical equipment. Interference with aircraft communication and navigation systems has also been reported. Other potentially vulnerable customer applications of economic or social significance are railroad signals, data transmission systems, electron microscopes, computer-chip manufacture, and augmentations to the Global Positioning System, to name just a few. The electricity infrastructure is also not immune to interference, particularly from components that incorporate microprocessors, for example, flexible ac transmission system (FACTS) controllers or other load control devices.

  Power-frequency electric and magnetic fields originating from basic operation of the electric power system can be sources of electromagnetic interference. So can higher frequency fields generated by corona discharges from lines and equipment, arcing from small gaps in system hardware, and transients from lightning and switching operations. The frequency spectrum spanned by these interference sources impinges on all modern communication and control systems. Of recent concern is interference from the power system with rapidly spreading digital communications. As new technologies are introduced, EMC will continue to be a problem.

- **A CHANGING BUSINESS ENVIRONMENT MAY CREATE OBSTACLES TO SOLVING EMC PROBLEMS.**
  As traditional electricity providers downsize, restructure, and enter new markets, much of their talent and in-house experience with interference issues may no longer be available or applicable. Further, organizations that are new to the industry may lack expertise in this area.

- **EPRI HAS A PROGRAM IN PLACE TO SOLVE EMC PROBLEMS.**
  EMC problems are not new to the electricity industry. Early EMC problems included radio and television interference noise from extra-high-voltage transmission lines. EPRI's EMC expertise grew from its involvement with research on these problems, beginning shortly after its organization in 1973. Projects such as interference with fuel ignition and nuclear power plant instrumentation followed; more recent work has focused on computer monitors and air traffic controls.

  EPRI's EMC program includes an EMC Center where participants can gain advice on interference problems and available solutions. In the meantime, EPRI research is developing new, cost-effective ways to address emerging EMC challenges. Results are now available on, for example, solutions for interference with the new Nationwide Differential Global Positioning System network. Current and upcoming work includes assessments of EMC for wideband power line communication systems, FACTS devices, and railroad communication and signaling equipment.

- **EMC IS IMPORTANT FOR GOOD CUSTOMER RELATIONS.**
  In the new, competitive electricity enterprise, EMC could affect customer relations. EPRI offers products of indispensable value in maintaining customer satisfaction to both the electricity enterprise and other industries experiencing EMC problems.

1007591

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

magnetic fields of 3 to 4 milligauss or more may increase the risk of leukemia in children. (Only about five percent of U.S. residences have magnetic fields this high.) The NIEHS and CDHS also concluded that magnetic fields in the workplace cannot be dismissed as a possible cause of adult leukemia. CDHS identified other health effects, including adult brain cancer, miscarriage, and amyotrophic lateral sclerosis, or Lou Gehrig's disease, as possibly linked to magnetic field exposure. A comprehensive evaluation scheduled for completion in 2003 by the World Health Organization may shed further light on health risks.

There is no conclusive evidence that exposure to EMF causes health effects.

Although epidemiologic studies show that magnetic field exposure at or above 3 to 4 milligauss may increase the risk of childhood leukemia, it cannot be concluded that a cause-and-effect relationship exists. The reported association between magnetic fields and childhood leukemia is weak (children with exposures above 3 milligauss might have roughly double the risk of unexposed children). For such weak epidemiologic associations, supporting data from laboratory studies are usually critical for establishing a causal link. For example, exposures or agents that are known to cause cancers in humans (such as ionizing radiation and benzene) also cause cancers in laboratory rodents. Such laboratory evidence should also be supported by an understanding of the mechanisms by which the exposures or agents interact with biological tissue. For magnetic fields, lifetime studies of rodents almost all report no adverse effects, and scientists have not identified a mechanism by which the low-level fields found in homes can possibly interact with tissue. In the absence of supporting laboratory and mechanistic evidence, scientists are investigating the possibility that the epidemiologic results have been generated by inadvertent errors in study design or that magnetic fields occur along with another exposure that could plausibly cause leukemia.

Scientists continue to investigate the possible relation between EMF and health effects.

EMF research is continuing throughout the world. At EPRI, the EMF research program is focused on resolving uncertainties about EMF and childhood leukemia. In fact, EPRI is the only U.S. organization currently funding a multidisciplinary research program in this area. The program includes investigation of the possible role of inadvertent error in epidemiologic study designs and a study of the possible influence of magnetic field exposure on the long-term survival of children who already have leukemia.

EPRI research is also exploring the hypothesis that an alternate exposure, contact current, is responsible for the magnetic field–childhood leukemia association. Contact current occurs when a person touches two conductive surfaces that are at different voltages, causing current to flow through the body. An important property of contact current is that imperceptible amounts of voltage produce appreciably higher electrical doses in tissue than those produced by exposure to magnetic fields in homes. EPRI research suggests that exposure to contact current is associated with exposure to magnetic fields. Although this finding supports the contact current hypothesis, a number of years of multidisciplinary research will be necessary before answers can be found.

EPRI scientists are also conducting new research on occupational EMF exposures in collaboration with the National Institute for Occupational Safety and Health (NIOSH). In addition, the EPRI program includes research in other areas of possible concern, including miscarriage, cardiovascular disease, and magnetic field interference with the functioning of implanted medical devices.

Contact Information For more information, contact the EPRI Customer Assistance Center (EPRI CAC) at 800.313.3774 or askepri@epri.com

Printed on recycled paper in the United States of America

1009009

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

Electric and Magnetic Fields (EMF)

Electric and magnetic fields exist everywhere.

The generation, delivery, and use of electricity produce electric and magnetic fields (EMF). Electric fields are produced by voltage, the electric "pressure" that causes current to flow in a wire, while magnetic fields are produced by current, the movement of electric charge. Electric and magnetic fields can be imagined as invisible lines of force diminishing in strength with distance from their source.

Electric and magnetic fields also occur naturally. An electric field is present between the earth and the upper atmosphere; this field can increase and discharge as lightning during thunderstorms. The earth has a magnetic field that is the basis for the magnetic compass. Because these natural fields change little from one moment to the next, they are referred to as static fields.

In the electric power system in the United States, voltage and current flow back and forth, or alternate, at a rate, or frequency, of 60 cycles per second (60 hertz). Similarly, the electric and magnetic fields created by the power system alternate at 60 hertz. When people are exposed to these alternating electric and magnetic fields, very weak, imperceptible electric currents are produced in their bodies. Although these currents are weaker than those from natural electrical activity in the heart and nervous system, scientists have investigated the possibility that they can produce biological and health effects.

Possible health effects from exposure to EMF have been studied for more than a quarter of a century.

Questions about health risks from EMF exposure first arose in the 1960s and 1970s with the introduction of higher voltages for electricity transmission in the United States. During that period, research focused on electric fields because electric fields near high-voltage transmission lines produce more current in the body than the magnetic fields from these lines. Overall, studies of electric fields found no evidence of biological changes that could lead to health effects. EMF research began to focus on magnetic fields in 1979 when Wertheimer and Leeper published an epidemiologic study suggesting that magnetic fields from power lines in Denver might be linked to childhood cancers. In 1988 Savitz and colleagues published a second study that was generally consistent with these results. Since then, a large number of epidemiologic studies (which examine patterns of diseases and their possible causes in human populations) have investigated the possible role of magnetic fields in the development of cancer and other diseases. Studies of most health endpoints, including miscarriage, neurodegenerative diseases such as Alzheimer's and Parkinson's diseases, and various cancers other than leukemia, have produced either inconsistent or negative results. Studies of childhood leukemia, however, have shown a generally consistent association with magnetic fields in homes.

Along with human health studies, scientists have conducted hundreds of studies in laboratory animals and cells to investigate possible health effects of exposure to power-frequency magnetic fields and explore possible mechanisms by which these fields could interact with biological systems. The vast majority of laboratory studies of animals and cells exposed to magnetic fields at levels to which humans could be exposed do not report adverse effects.

Several expert panels convened by organizations concerned with public health have evaluated the possible health risks of exposure to magnetic fields. These organizations include the National Institute of Environmental Health Sciences (NIEHS) in the United States, the National Radiological Protection Board (NRPB) in the United Kingdom, and the International Agency for Research on Cancer (IARC), a branch of the World Health Organization. These panels and, more recently, a California Department of Health Services (CDHS) panel concluded, based on epidemiologic studies, that exposure to

Why a Viable EPRI EMF Program Is Essential

Electric power companies have relied on EPRI's electric and magnetic fields (EMF) program for credible research on the possible health effects of EMF exposure, as well as objective, comprehensive, and timely information and analyses based on continuous monitoring of the EMF issue. For a number of compelling reasons, a viable program continues to be vital.

- **THE CHILDHOOD LEUKEMIA ISSUE IS UNRESOLVED.**

  The 1999 National Institute of Environmental Health Sciences (NIEHS) report concluded that EMF exposure "cannot be recognized as entirely safe because of weak scientific evidence that exposure may pose a leukemia hazard." In 2000, two research papers on pooled childhood leukemia studies reported a consistent, statistically significant effect for estimated magnetic field exposures above 3–4 milligauss. An International Agency for Research on Cancer (IARC) evaluation in 2001 assigned EMF a 2B classification (possible carcinogen). Also in 2001, reviews by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the United Kingdom's National Radiological Protection Board (NRPB) concluded that EMF exposure may increase the risk of leukemia in children. A 2002 California Department of Health Services (CDHS) health risk evaluation supported this conclusion.

- **OTHER DISEASES HAVE BEEN IMPLICATED BUT NOT ADEQUATELY STUDIED.**

  If a risk is strongly suspected for the more common health outcomes, such as miscarriage or heart disease, the estimate of potential public health impact will be much higher than that for a rare disease like childhood leukemia. Sporadic efforts are being made to study other diseases. Without a concerted effort to conduct comprehensive studies of the highest quality, EMF research could once again become dominated by poorly funded studies with inadequate emphasis on study design, implementation, and reporting of results.

- **A CRITICAL ASSESSMENT IS UNDER WAY.**

  A comprehensive EMF health risk assessment by the World Health Organization (WHO) is under way. This influential assessment, along with other recent evaluations, is likely to drive the EMF issue in the United States and internationally for the next 2–5 years. While EPRI staff and scientific advisors played key roles in previous assessments, severe reductions in the program substantially reduce our ability to participate and contribute.

- **PUBLIC CONCERN IS INVOLVED.**

  EMF is often perceived as an unknown, unseen, and undetectable exposure that is present in every home and involves children. Further, exposure is sometimes perceived—however unfairly—as being imposed by corporate interests who evade responsibility for correcting the harm they cause. These concerns make the EMF issue both unpredictable and volatile, and magnify the impact of any study that supports the existence of health effects.

- **COSTS COULD BE CONSIDERABLE.**

  Both Switzerland and Italy have adopted extremely low exposure limits (2–10 milligauss) in residential environments, and the United Kingdom and Australia are considering lower limits. Some occupational exposure guidelines are also becoming more stringent. Adoption of similar limits or other regulations in the United States would impose considerable costs on power delivery. In addition, new transmission line construction continues to raise public concern about EMF and health. Public concern increasingly influences decisions on the siting, construction, and operation of electrical facilities, resulting in controversy, delay, and increased costs.

The electricity industry retains a vital stake in future EMF health research outcomes. Research will continue and, unquestionably, some positive results will be found. Timely, relevant, high-quality research to understand and replicate results is the only sensible solution. This does not mean that each and every finding should be addressed; rather, the response should be focused. EPRI's ability to follow international research and identify results reported either by several independent investigators or by scientists with solid scientific reputations ensures a focused response. This focus is further refined through the guidance of a blue-ribbon scientific advisory committee and electricity industry advisors.

While sound science is critical to issue management in the United States, EPRI's EMF program is currently able to address only high-priority issues. An adequate level of funding is necessary for maintaining the viability of the program and EPRI's crucial ability to remain actively involved "at the table." Participation in the EMF program will ensure that EPRI continues to bring to the table its invaluable leadership, experience, and expertise. In addition, participants will receive timely research results and perspectives on studies; access to materials and tools that clearly and concisely communicate complex information to both scientists and nonscientists; and access to scientific experts for consultation on specific issues.

Printed on recycled paper in the United States of America

1008896

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

EMF Exposure Guideline Research: An Electric Power Industry Priority

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) and other national and international organizations have established guidelines limiting occupational and public exposure to electric and magnetic fields (EMF) and contact currents (see EPRI EMF Brief 1001048). Several guideline issues could have a major impact on the electric power industry.

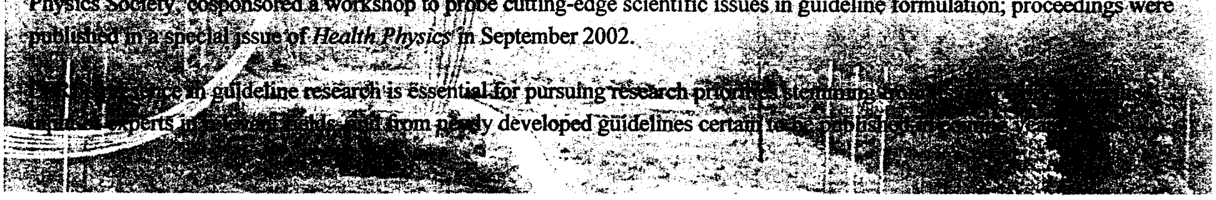
- **THE SCIENTIFIC BASIS FOR EXISTING GUIDELINES IS UNCLEAR.**
  Guideline organizations have set limits for electric and magnetic fields corresponding to induced current densities in the body that, for workers, are about two orders of magnitude below an effect threshold, thus incorporating a safety factor of about 100. For the general public, some guideline organizations include an additional safety factor. Guideline limits are designed to prevent acute neural stimulation, the only validated effect relevant to safety that is based on established biophysical principles; evidence for chronic effects, such as childhood and adult leukemia, is deemed insufficient for formulating exposure limits. The effect threshold for neural stimulation is based on limited data and crude estimates. Further research would help clarify the scientific basis for guidelines and reduce the uncertainty that needs to be incorporated into safety factors.

- **EXCEEDANCE OF EXPOSURE LIMITS NEAR ELECTRIC POWER FACILITIES HAS BEEN DOCUMENTED.**
  EPRI research has indicated that occupational exposure limits can be exceeded in certain power company operations near conductors carrying high loads. In the public domain, exceedance of guideline levels for electric fields may occur within rights-of-way of overhead high-voltage transmission lines of 115 kV and above. The implications of exceedance with respect to occupational practices and right-of-way and line design are topics the electricity industry needs to address.

- **GUIDELINES CAN AFFECT ACCEPTABLE PRACTICES AND COSTS FOR THE ELECTRIC POWER INDUSTRY.**
  Guideline organizations periodically evaluate the literature to determine whether the basis for existing guidelines is in tune with current scientific thought. Evaluations can lead to guideline revisions. So far, revisions have in some cases resulted in more stringent guideline limits. Compliance with ever-stricter limits can have a substantial impact not only on work practices and costs within the electricity industry, but also on the siting and design of electric power facilities.

EPRI's EMF Health Assessment program is a leader in guideline research, providing state-of-the-art data and perspective to the scientific community. Among our efforts are scientific review, exposure assessment, dosimetry, and evaluation of medical device interference. We have published an in-depth analysis of the technical basis for the guidelines as well as a combined analysis of magnetic field exposure assessments within the electric power industry. We have also conducted preliminary exposure assessments for previously uncharacterized power company job sites and tasks and an analysis of exposure among vault workers, published in the peer literature in 2001. In addition, we have published a number of reports and peer-reviewed papers detailing induced current densities and electric fields in the body based on anatomically correct models, under a variety of exposure conditions. In the area of EMF interference with implanted medical devices, particularly pacemakers, we review and continuously monitor the literature. Recently, we published new techniques for evaluating interference through computer modeling. In June 2000 EPRI, along with National Grid, Électricité de France, and the Health Physics Society, cosponsored a workshop to probe cutting-edge scientific issues in guideline formulation; proceedings were published in a special issue of *Health Physics* in September 2002.

[illegible]ence in guideline research is essential for pursuing research [illegible] stemming [illegible] experts [illegible] from [illegible] developed guidelines certain [illegible]



Printed on recycled paper in the United States of America

1007590

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

Exposure Assessments Relevant to Occupational Exposure Guidelines


Hign current capacity bus to static var compensator

Participants will work with EPRI to develop electric and magnetic field exposure assessments for workers at their facilities

Guidelines for occupational (and general public) exposure to electric fields, magnetic fields, and contact currents have been promulgated by various organizations in the United States and Europe, and others are in development. The newer guidelines, which are advisory rather than legally binding, tend to be more restrictive than their predecessors. EPRI-sponsored research has identified job sites in the electric power industry for which magnetic field exposure is inadequately characterized.

PROJECT SUMMARY The project's objective is to work with host companies to obtain a statistically valid exposure assessment of workers in job sites for which exposure data are presently inadequate. These may include network vaults, distribution substations, transmission substations, static var compensators, and generating plants. EPRI researchers will conduct an initial visit to become familiar with company operations and personnel, and then design an exposure monitoring plan to be conducted in close coordination with company technical staff.

DELIVERABLES

EPRI will provide a report that details the magnetic field exposure of the work crews that were monitored. The data will be prepared in a manner that is suitable for evaluating the probability of exceeding guidelines for the scenarios characterized. The EPRI manager and contractor will visit the company to make a formal presentation of the results and answer questions.

BENEFITS OF PARTICIPATION Compliance with guideline limits protecting worker health and safety will be enhanced since the host company will have an assessment of actual job site exposures at its own facilities, rather than relying on inference from measurements conducted elsewhere. Questions about job site exposure from company employees can be addressed directly with data collected locally. Additional benefits are improved decision-making and risk management.

DEMONSTRATED VALUE An exposure assessment of network vault workers was completed in 2000 under a Tailored Collaboration agreement. The results provided the company with data on the actual exposure levels of their vault workers, the activities that resulted in the highest worker exposure levels, the percentage of time that exposure guidelines were exceeded, and insights for reducing exposure, if necessary.

PRICE OF PROJECT The price to participate in this project is $180,000. Companies that fund any Environment program can use Tailored Collaboration (TC) funds, if available, for up to half of the cost ($90,000 matched by EPRI TC funds). Companies that have not purchased any Environment programs can participate through cofunding.

PROJECT STATUS AND SCHEDULE The project is ongoing and open to new studies at any time. Once in progress, a full project will take about 18 months to complete.

WHO CAN PARTICIPATE Any company, public agency, or nonprofit organization can participate in this EPRI Project Opportunity.

CONTACT INFORMATION For more information, contact the EPRI Customer Assistance Center (EPRI CAC) at 800.313.3774 or askepri@epri.com.

TECHNICAL CONTACT Rob Kavet, 650.855.1061, or rkavet@epri.com.

Destinations 2003 This sheet relates to the supplemental opportunity, *Exposure Studies to Address EMF Guideline Issues* (S60.002)

1007140

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

Northern California Childhood Leukemia Study

This study will help elucidate the possible role of contact current exposures in the development of childhood leukemia and their role as a possible explanation for the magnetic field–childhood leukemia association. Resolution of the childhood leukemia question is the most effective response to public concern about power system EMF.

Investigation of residential magnetic field and contact current exposures in the Northern California Childhood Leukemia Study will help resolve key uncertainties about the reported link between magnetic fields and childhood leukemia.

For well over two decades researchers have investigated the possibility that exposure to power-frequency electric and magnetic fields (EMF) might lead to the development of leukemia in children. Evaluations of the EMF research by organizations such as the National Institute of Environmental Health Sciences (NIEHS), the United Kingdom's National Radiological Protection Board (NRPB), the International Commission on Non-Ionizing Radiation Protection (ICNIRP), and the California Department of Health Services (CDHS) have concluded that exposure to magnetic fields may be a risk factor for childhood leukemia. Based mainly on epidemiologic studies of magnetic fields and childhood leukemia, the International Agency for Research on Cancer (IARC) has classified EMF as a 2B, or possible, carcinogen. Public concern about EMF and childhood leukemia has been high and continues to arise when new power facilities or upgrades to existing ones are proposed near residential areas.

Recent EPRI research suggests that exposure to magnetic fields is associated with exposure to contact current, which flows through the body when a person simultaneously touches two conductive surfaces that are at different voltages. Computer modeling research supported by EPRI indicates that modest amounts of contact current (tens of microamperes) can produce biologically significant doses in bone marrow, the site of leukemogenesis. Contact current could thus be responsible for the magnetic field–childhood leukemia association found in epidemiologic studies. To further investigate the role of contact current in childhood leukemia development and its relation to magnetic fields, it is necessary to measure and analyze contact current sources and magnetic fields in the homes of childhood leukemia cases and leukemia-free controls in a well-designed epidemiologic study.

The Northern California Childhood Leukemia Study (NCCLS) is a population-based case-control study begun at the University of California, Berkeley in 1995 with the aim of investigating the relationship between environmental exposures and genetic risk factors for childhood leukemia. Among exposures under investigation are viruses, residential chemicals, tobacco smoke, micronutrients in mothers' and childrens' diets, and parental occupational exposures. Important aspects of the study include estimation of the timing of exposures and, through the use of molecular-biological techniques, the timing of biological changes that could lead to leukemia. The study is designed to minimize bias (error) arising from control-selection methods.

EPRI is planning to add an EMF component to the NCCLS consisting of about 500 subjects, approximately one-third of which are leukemia cases. This group represents a subset of the entire study's subjects.

PROJECT SUMMARY In 2002 EPRI's EMF Health Assessment Program conducted measurement and modeling studies to determine the feasibility of adding measured magnetic fields and contact current to the NCCLS. After a review of the data from this work by the program's external Scientific Advisory Committee, the planning phase was initiated with the University of California team. As a result, an EPRI component is planned for the study. Magnetic field and contact voltage measurements in the homes of cases and controls will enable an evaluation of the hypothesis that contact current may be responsible for the association between magnetic fields and childhood leukemia. This research is planned for a period of three years.

DELIVERABLES The results of the modeling study were delivered in an EPRI Technical Report in 2002 (1005414). In 2003, exposure measurements will be published as an EPRI Technical Report, and the results of the feasibility studies will be submitted to the peer literature. Final study results will be submitted to the peer literature in 2006.

BENEFITS OF PARTICIPATION Participants in this project will help increase understanding of a serious childhood disease that has been linked to exposure to power-frequency magnetic fields. A clearer understanding of the exposure-disease relationship can mitigate public concern about residence near power facilities—an increasingly important priority for power companies building new transmission lines, upgrading existing ones, or developing new distributed generation facilities that may be located near residential areas.

PRICE OF THE PROJECT Participation in a large, well-designed case-control study is essential for clarifying the possible role of magnetic fields and contact current in childhood leukemia development. However, the cost of conducting such a study independently is substantial. The Northern California Childhood Leukemia Study presents an opportunity to conduct critical research in a high-quality study at a reduced cost. The estimated cost to complete this project in 2006 is $3 million (although further cost reductions are possible through co-funding of the research from federal sources). The cost of participation is $75,000. Companies that fund any Environment program can use Tailored Collaboration (TC) funds, if available, for up to half of the cost ($37,500 matched by EPRI). Companies that have not purchased any Environment programs may co-fund this project for a negotiated price not lower than $75,000.

PROJECT STATUS AND SCHEDULE Research will begin in early 2003. Results will be submitted to the peer literature by December 31, 2006.

WHO MAY PARTICIPATE Any company, public agency, or nonprofit organization may participate in this EPRI Project Opportunity.

CONTACT INFORMATION For more information, contact the EPRI Customer Assistance Center (EPRI CAC) at 800.313.3774 or askepri@epri.com

TECHNICAL CONTACT Rob Kavet at 650.855.1061 or rkavet@epri.com

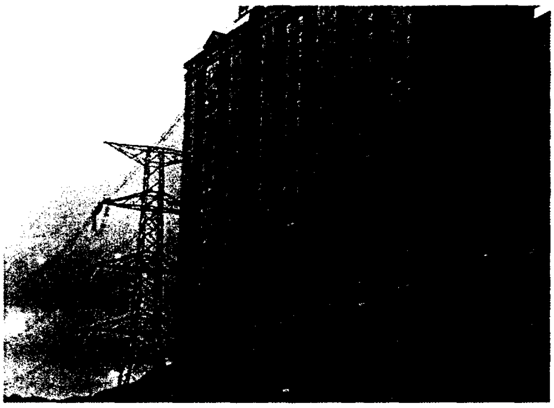
Printed on recycled paper in the United States of America

1007819

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

project opportunity

Residential Magnetic Field Exposure Assessment in Asia



Assessment of residential magnetic field levels in Taiwan will provide unique data on exposure distribution in a region of Asia.

This residential magnetic field exposure assessment project will be the first to systematically measure residential magnetic field levels in a representative sample of an Asian population.

National and international organizations, including the National Institute of Environmental Health Services (NIEHS) in the United States, the National Radiological Protection Board (NRPB) in the United Kingdom, and the International Commission on Non-Ionizing Radiation Protection (ICNIRP), have recently evaluated possible health risks from exposure to electric and magnetic fields (EMF). These evaluations have uniformly concluded that an epidemiologic association exists between residential exposure to magnetic fields and childhood leukemia risk. In addition, the International Agency for Research on Cancer (IARC), a branch of the World Health Organization (WHO), has classified power-frequency magnetic fields as a possible (2B) carcinogen.

The IARC evaluation and other EMF health risk assessments were based primarily on evidence from epidemiologic studies. However, the epidemiologic evidence is limited, clear supporting laboratory evidence is lacking, and there is no known mechanism by which magnetic fields could interact with biological systems to initiate changes that could lead to health effects. Thus, uncertainty exists as to whether the association between magnetic field exposure and childhood leukemia is causal or spurious.

One of the significant limitations of the epidemiologic studies of magnetic fields and childhood leukemia conducted to date—mostly in Europe and North America—is the small number of relatively highly exposed children in the populations investigated. To overcome this limitation, further research is needed in populations residing in areas where average magnetic field exposures are significantly higher than those in previous studies. It is generally assumed that such populations might be found in densely populated, highly industrialized areas in the Far East and Southeast Asia. There is limited evidence that residential magnetic field levels may be higher in Taiwan. However, no results from any in-depth evaluation of residential magnetic field levels in Asia are available.

To systematically assess the residential magnetic field exposure distribution in Taiwan, EPRI plans to carry out a measurement study of residential magnetic field levels in a representative sample of Taiwanese children. This work will help clarify the relationship between magnetic field exposure and potential health risks. Scientists from Fu Jen Catholic University and National Taiwan University in Taipei, Taiwan will be assisting EPRI in the design and implementation of this project.

PROJECT SUMMARY In cooperation with Taiwanese scientists, EPRI will carry out a residential magnetic field exposure assessment study in a representative sample of children in Taiwan over an 18-month period. In-home magnetic field and other related engineering measurements will be conducted in residences selected by random cluster sampling from all Taiwanese residences where children are living.

DELIVERABLES Project participants will have the opportunity to directly interface with researchers during the time that the work is in progress. The final results of the measurement study will be summarized in an EPRI Technical Report to be published at the conclusion of the work.

BENEFITS OF PARTICIPATION Participants in this project will contribute to, and benefit from, the collection and subsequent analysis of data to assess average levels of residential magnetic field exposure in an Asian region that could have significantly higher exposure levels than Europe or North America. This assessment represents an important step towards the objective resolution of the EMF–childhood leukemia issue.

Resolution of the EMF health risk issue becomes increasingly important in light of growing public concern about potential health effects associated with magnetic field exposure. The issue has gained significant momentum globally as new power lines are proposed, and concern has been rising in recent years in Asia.

Participants in this project will lead the effort to define and understand the issue of EMF and health effects in Asia. They will also have the opportunity to provide input for additional research projects focused on resolving the childhood leukemia question.

PRICE OF PROJECT The price to participate in this project is $50,000.

PROJECT STATUS AND SCHEDULE The project is scheduled to start in August 2003. Measurements will be completed by December 2004. Results will be summarized and published in 2005.

WHO MAY PARTICIPATE Any company, public agency, or nonprofit organization with an interest in EMF should consider participating in this EPRI Project Opportunity.

CONTACT INFORMATION For more information, contact Burk Kalweit at the EPRI Worldwide headquarters office in California.

He can be reached by phone at 650.855.2329 or by e-mail at bkalweit@epriww.com.

TECHNICAL CONTACT Gabor Mezei, 650.855.8908 or gmezei@epri.com.

Printed on recycled paper in the United States of America

1009061

EPRI Worldwide• 3412 Hillview Avenue, Palo Alto, California 94304 • USA
650.855.2559 • www.epriww.com

Applied Occupational and Environmental Hygiene
Volume 16(12): 1118–1138, 2001

1047-322X/01 $12.00 + .00

Evaluation of Biological Effects, Dosimetric Models, and Exposure Assessment Related to ELF Electric- and Magnetic-Field Guidelines

R. Kavet,[1] M. A. Stuchly,[2] W. H. Bailey,[3] and T. D. Bracken[4]
[1]EPRI, Palo Alto, California; [2]University of Victoria, Victoria, British Columbia, Canada; [3]Exponent, New York, New York; [4]T. Dan Bracken, Inc., Portland, Oregon

Several organizations worldwide have issued guidelines to limit occupational and public exposure to electric and magnetic fields and contact currents in the extremely low frequency range (<3 kilohertz). In this paper, we evaluate relevant developments in biological and health research, computational methods for estimating dosimetric quantities, and exposure assessment, all with an emphasis on the power frequency (60 hertz in North America, 50 hertz in Europe). The aim of each guideline is to prevent acute neural effects of induced electric fields. An evaluation of epidemiological and laboratory studies of neurobiological effects identified peripheral nerve stimulation as the response most suitable for establishing a magnetic-field guideline. Key endpoints that merit further study include reversal of evoked potentials; cardiovascular function, as measured by heart rate and heart rate variability; and sleep patterns. High-resolution computations of induced electric fields and current densities in anatomically correct human models are now achieved with finite-difference methods. The validity and limitations of these models have been demonstrated by computations in regular geometric shapes, using both analytic and numeric computations. Calculated values for average dosimetric quantities are typically within a few percent for the two approaches. However, maximum induced quantities are considerably overestimated by numerical methods, particularly at air interfaces. Overestimates are less pronounced for the upper 99th percentile level of a dosimetric quantity, making this measure a more useful indicator of maximum dose. Neural stimulation thresholds are dependent on the electric field around the excitable cell rather than on the current density, making the former preferable for expression of basic restrictions based on nervous system function. Furthermore, modeling data indicate that the induced electric field is much less strongly influenced by tissue conductivity than is the induced current density. In the electric utility industry, most magnetic-field exposures at or near guideline levels occur in highly nonuniform fields. Two methods are described for simplified estimation of induced quantities in such fields, with each method using as input modeling results for uniform field exposure. These methods have practical value for assessing occupational exposures relative to guideline levels.

Keywords ELF Electric and Magnetic Fields, Guidelines, Health Effects, Nervous System Effects, Public and Occupational Exposure, Dosimetry

Several organizations worldwide have published guidelines to limit exposure to electric and magnetic fields (EMF) and contact currents at extremely low frequencies (ELF, 3–3,000 hertz [Hz]).[1–4] The common objective of the guidelines is to protect the health and safety of both workers in their occupational environments and the general population in residential areas and locations with public access. Specifically, these guidelines aim to prevent acute nerve or muscle stimulation associated with induced or conducted currents. To date, guidelines have not been established for the prevention of chronic outcomes, such as cancer, because of insufficient scientific evidence.

The technical background and basis for many of these guidelines were reviewed by Bailey et al.[5] After that review was published, two major guidelines were completed: the International Commission on Non-Ionizing Radiation Protection's (ICNIRP) guideline for occupational and public exposures,[2] and the European Union's (EU) adoption of public exposure limits from the new ICNIRP guideline.[3] Table I summarizes occupational and public exposure limits for these major guidelines.

The objective of this paper is to review recent scientific developments relevant to guideline formulation, to suggest useful applications of those guidelines, and to point the way to future areas needing research. The following sections review and integrate developments with respect to biological and health effects,

TABLE I
Whole-body occupational/public exposure limits for 60-Hz electric and magnetic fields

Organization[A]	Year	Electric field, kV/m	Magnetic field, mT	Contact current, mA	Comments
ACGIH	2000	25/NA	1.0/NA	NA	Ceiling limits: not to be exceeded
ICNIRP	1998	8.3/4.2	0.42/0.083	1.0/0.5	Reference levels: determine whether basic restriction of 10 mA/m^2 is exceeded
NRPB	1993	12/12	1.6/1.6	1.0/0.5[B]	Investigation levels: determine whether basic restriction of 10 mA/m^2 is exceeded
EU	1999	NA/4.2	NA/0.083	0.5	Adopted ICNIRP levels for areas where members of the public spend significant time

[A]ACGIH,[4] ICNIRP,[2] NRPB,[1] EU.[3]
[B]1.0 mA where children will not be exposed; 0.5 mA where they will.

dosimetry, and exposure assessment as they relate to the aims of current guidelines and the challenges of formulating future guidelines. The industrial hygienist is offered a practical tool to assess compliance using straightforward exposure assessment tools. Because power-frequency (50/60 Hz) EMF dominate exposures and biological research in the ELF range, this review emphasizes results and applications at power frequencies and their lower harmonics.

BIOLOGICAL BASIS FOR DEVELOPING ELF FIELD GUIDELINES

When the International Non-Ionizing Radiation Committee (later known as ICNIRP) was established in 1974 to assess research and develop exposure guidelines, there was insufficient evidence to conclude that exposure to electric or magnetic fields increases the risk of cancer or other chronic disease. Without any firm basis for addressing potential adverse effects of chronic exposures, guidelines have focused on protecting populations against acute safety risks related to tissue stimulation by induced currents. This emphasis is still in force today.

Nevertheless, because the results of epidemiological studies were inconclusive, further investigation has been recommended, specifically into associations between magnetic fields and childhood leukemia and between magnetic fields and one form of leukemia in electrical workers.[6] However, there is no support from experimental or mechanistic studies for a causal relationship between cancer and field exposure.[7–11]

One would expect that the nervous system's electrical nature makes it more susceptible than other tissues to electrical signals from environmental sources. That expectation of sensitivity is confirmed by observations that adverse effects of direct electrical stimulation at levels too low to cause tissue damage are confined to excitable tissues, such as the heart and nervous system.[12] The following discussion identifies and evaluates the nervous system data germane to setting ELF guidelines based on critical, short-term adverse effects.

Epidemiological Studies

Occupational Studies

We know that workers in electric utilities have exposures to EMF demonstrably greater than the general public.[14] Studies of populations exposed to power-line EMF began back in the late 1960s and early 1970s. These studies reported vague health complaints of headache, fatigue, and fluctuating blood pressure and heart rate among Soviet workers in 400–750 kilovolt (kV) switchyards.[13,14] The type of symptoms reported suggested the hypothesis that field exposure had adverse effects on the nervous system. However, the Soviet studies had no adequate control groups and did not address the possibility that the reported health problems could be due to other environmental or lifestyle factors. On the other hand, studies of electrical utility workers in Canada,[15] Sweden,[16] Great Britain,[17] and the United States[18] have not confirmed either the presence of adverse effects on general health or the complaints reported by the Soviets.

In addition, studies of large cohorts of these workers have failed to uncover convincing evidence for an association between electric- or magnetic-field exposure and suicide in Québec[20] or exposure to magnetic fields and suicide in Denmark.[21] Based on these and other studies, the National Institute of Environmental Health Statistics Working Group (NIEHS) report states that "these studies do not support an association [of depression and suicide] with ELF-EMF exposure."[22] A recent analysis of data collected in a mortality study of workers at five U.S. utilities has suggested a link between jobs involving exposure to magnetic fields and increased risk of death by suicide.[23] However, because information about relevant lifestyle factors for suicide was not available, the interpretation of this finding is unclear.

Community Studies

Early research in England focused on a possible relationship between suicide and magnetic fields from overhead power lines.[24,25] The studies have serious design flaws, and these reports provide no support for a finding of a cause-and-effect relationship. Another study in England found no association between suicide and living near utility power lines or pole-mounted transformers (called "substations").[26] More recently, several studies have evaluated depression as related to either magnetic field at the residence or proximity to overhead transmission-line rights-of-way.[27–29] Although several associations suggestive of a field effect were reported, the current scientific consensus is that the evidence is insufficient to validate any such relationship.[9]

In summary, epidemiological studies have not identified persons with exposures to EMF on the job or in the community as being at higher risk for disorders of the brain and nervous system or as reporting higher rates of complaints associated with the nervous system. Laboratory research that hypothesized a link between magnetic fields, melatonin levels, and circadian rhythms has prompted a renewed interest in depression or depressive symptoms. However, to date, there is no convincing experimental evidence that electric or magnetic fields decrease melatonin levels in humans.[9,30,31] Epidemiological research on melatonin levels in workers and the general population in relation to magnetic fields is in its early stages.[32,33]

Epidemiological research has recently begun to address the question of potential effects of EMF on the development of chronic neurodegenerative diseases such as Alzheimer's disease and amyotrophic lateral sclerosis, but this research has not yielded any definitive insights and is considered inadequate for "interpreting the possibility of an association."[34] Utility workers in the United States are generally exposed to fields below 10 microtesla (μT),[19] and exposures in the community are very much lower.[35] Given these facts, the literature suggests that adverse effects of EMF on neural systems need to be examined at higher levels of exposure, if effects are to be found.

Field Perception Studies

Unlike other body cells, some types of neural cells have the capacity to generate conscious indicators of stimulation, i.e., perceptions, and, at higher levels, pain and discomfort. Therefore, data regarding thresholds for detection, discomfort, and pain associated with ELF field exposures assume special importance for the setting of limits on exposure to EMF. There is a wealth of past research on field perception. However, one might best focus on recent research studies in which particular attention was given to study design, exposure assessment, and the elimination of confounding variables.

Laboratory studies conducted on seated human volunteers indicated detection thresholds for electric fields above 9 kV/meter (m) for 90 percent of the subjects tested.[36] (Of their experimental subjects, 90 percent could not detect an electric field with an intensity of less than 9 kV/m.) The average threshold for field detection in these studies was 15 kV/m. In another study, the median threshold for detection was 23 kV/m for a standing upright posture with the hands by the sides. The threshold decreased to 7 kV/m for a person with an arm raised above the head.[37]

The longest studied perceptual response of humans to alternating current (AC) fields is the occurrence of visual "phosphenes." This research is firmly grounded in compelling observations and experiments. Vague visual sensations were reported as early as 1896 in response to intense alternating magnetic fields.[38] Subsequent investigations have all confirmed these findings. The optimal frequencies for eliciting sensations are between 15 Hz and 25 Hz. At 20 Hz, where the lowest threshold for producing magnetophosphenes was reported with a field exposure of 10 millitesla (mT), it was first estimated that an induced current density of 1 milliampere per square meter (mA/m^2) was an effective stimulus for these sensations.[39]

More recent modeling of the exposures in the Lövsund study suggests that the exposure yielded much greater current densities. Reilly[40] estimated the current density in the retina of Lövsund's subjects to be 8 mA/m^2, similar to that estimated to be required to produce phosphenes by direct electrical stimulation near the eye. Accurate numerical modeling indicates that the average and maximum computed current densities in the retina in this experiment are 27 mA/m^2 and 70 mA/m^2, respectively.[41] Whether phosphenes reflect stimulation of structures strictly limited to the eye (e.g., photoreceptors or neural cells) is not known. However, there is absolutely no indication that their occurrence is related to adverse biological effects.[2,38,42]

Tucker and Schmitt[43] and Graham and Cohen[36] have most thoroughly studied the possibility that 60-Hz magnetic fields can be sensed or perceived by humans at intensities below those producing magnetophosphenes. Tucker and Schmitt initially found that some individuals could apparently detect magnetic fields of 0.75 mT. However, after efforts were made to eliminate visual, tactile, and acoustic clues, Tucker and Schmitt found that none of 200 volunteers tested could detect the presence of the field even at intensities of 1.3, 1.5, or 7 mT over some 30,000 trials.

Electrophysiological and Cognitive Responses

Magnetic or electric fields at the higher end of exposures encountered in the environment (up to 5 mT or 20 kV/m) are generally reported to have no or minimal effects on electrophysiological (electroencephalogram [EEG], evoked potentials) or cognitive responses of human subjects.[44–48] Exposures of monkeys to combined EMF as high as 30 kV/m and 90 μT similarly have small or no effects on evoked potentials to somatosensory, auditory, and visual stimuli.[49]

However, one study regarding cognitive responses appears to be an exception. Preece et al.[50] reported small reductions in attentional and mnemonic aspects of task performance when volunteers were exposed to a 0.6-mT, 50-Hz magnetic field. While there is no other human data that would provide strong support for such a finding, the performance of rodents on certain tasks when exposed, before testing, to a magnetic flux density of 0.75 mT[51–54] has prompted speculation that 50/60-Hz magnetic fields influence memory processes. However, Sienkiewicz et al.[55] reported no effect on the performance of animals at four magnetic-field exposure levels up to 5 mT, when the magnetic field was present during testing. Few of the studies (whether reporting effects or not) tested for effects at multiple exposure levels (dose response) that would more conclusively confirm the magnetic field as a causal factor. Other concerns in the animal studies relate to the difficulty of distinguishing effects of magnetic fields on memory from those of other factors, e.g., stress.[9] Additionally, exposure levels need to be scaled to account for differences in animals and humans for body size. The NIEHS Working Group described research on human cognition and performance as showing that "Human performance of many types of task appears to be unaffected by exposure to relatively high electric and/or magnetic fields . . . and little reliable evidence exists for a consistent dose-response relationship."[56]

Very little research has been done on the effects of fields at higher intensities (producing induced current densities greater than 100 mA/m^2), but one report is of particular note. Silny[57] reported that a 50-Hz magnetic field with an intensity of 60 mT in the head region markedly altered the evoked potential to visual stimuli, though the field itself did not stimulate evoked potentials. In this study, the current density in the head has been estimated to be 200 mA/m^2.[1] Silny reported that the polarity of some evoked potential responses was reversed, while the amplitude of others was reduced. After the field was turned off, 45 minutes elapsed before evoked potentials of normal polarity returned. This effect represents a shift in excitatory and inhibitory potentials at synapses in the superficial and deeper layers of the cerebral cortex.

The extended duration of the polarity reversal is potentially cause for concern. Most neurophysiological and other responses to field stimulation of a minor nature are usually short-term and persist for seconds or less, not minutes. Moreover, subjects exposed to the 60-mT magnetic field by Silny "complained about indisposure and headaches" that appeared to be caused by field exposure.[58] However, Silny's results are not easily evaluated because the study had limited description and findings in the report.[57] There has been no reported attempt to replicate these observations.

Tissue Stimulation

The focus on electrical stimulation of tissue as a mechanism to explain effects of electric- and magnetic-field exposure is based on 100 years of observation that induced currents and electric fields from alternating fields produce effects qualitatively similar to stimulation produced by contact with energized conductors. Experimental evidence has led to well-established models of passive and active behavior of neurons in alternating electric fields.[40,59–67] While many experimental studies report the current density values for a stimulating small electrode in close proximity to a neural test cell, it has been firmly established that the activating function is the first derivative of the electric field with respect to distance along the cell. The ambiguity and uncertainties related to the use of the current density rather than the electric field are emphasized in a recent report by McIntyre and Grill.[67]

Where electric fields in situ exceed 5–10 V/m, their ability to depolarize the axons of neurons and affect tissue responses is well-established. Most of the research has involved direct electrical stimulation of tissue in vitro and in vivo using electric or magnetic pulses. Very few studies have measured nerve or muscle stimulation thresholds for harmonic (sinusoidal) electric or magnetic fields at ELF frequencies.

Magnetic-Field Stimulation

Stimulation of neural cells in the brain and peripheral nervous system may cause adverse effects. Two factors render the peripheral nerves more susceptible than the brain to stimulation by magnetic fields. First, the threshold for electrical stimulation varies inversely with cell diameter. The largest peripheral nerves (20 micrometers [μm]) are larger than the largest neurons in the brain (10 μm) and are therefore more susceptible to stimulation. Second, numerical modeling of induced electric field and current density in heterogeneous models of the body shows that induced maximum values are greater in the torso periphery than in the brain.

There is a lack of data regarding effects of sinusoidal 50/60-Hz magnetic fields on the nervous system that are applicable to the standard-setting process. The data that we do have from pulsed magnetic-field studies can still be used quite effectively for developing ELF field-exposure guidelines.

Most existing experimental studies on neural stimulation have used strong low-frequency pulses produced by magnetic resonance imaging (MRI) and magnetic-field stimulation of motor and peripheral neurons for diagnostic purposes.[e.g.,68,69] For magnetic fields, the factor that determines the electric field induced in tissue is the time rate of change of the field (dB/dt). For example, the response of 38 human subjects to pulsed magnetic fields reported by Bourland et al.[70] illustrates the classic strength-duration curve: Stimuli of shorter duration must be of greater intensity to produce stimulation than stimuli of longer duration (Figure 1). In this study, the observed response is the sensation produced by stimulation of nerves in the torso by the induced electric field. For these data, the lowest time rate of change of magnetic field capable of stimulating peripheral nerves is reported to be 14.4 tesla/second (T/s) or 38 mT for a 60-Hz magnetic field. The continuous plotted line represents average threshold values predicted from experimental parameters fitted to a hyperbolic function. Note that the average thresholds predicted from the Bourland et al. data can be more than four times lower (i.e., more conservative) than the thresholds reported by other studies[71–75](see Figure 1) and Reilly.[40] Experimental studies clearly indicate that using such pulsed magnetic-field data for setting exposure limits for sinusoidal or biphasic stimuli will be conservative; thresholds for these continuous waveforms are always lower than for monophasic magnetic pulses.[40,76]

The example of the Bourland et al.[70] study shows that data from one study can be used to predict thresholds expected for other combinations of dB/dt and pulse duration in other studies. This supports the utility of using modeled strength duration data

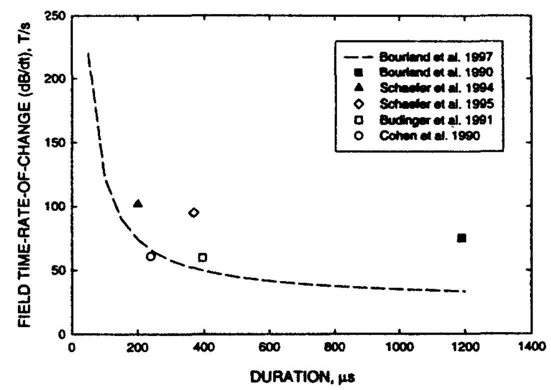


FIGURE 1
Neural stimulation threshold as a function of magnetic-field time rate of change and duration, as reported by Bourland et al.,(70,71) Schaefer et al.,(72,75) Budinger et al.,(73) Cohen et al.(74)

to derive nerve stimulation thresholds. However, it is also evident that, given the considerable variability in the data, there is a need to quantitatively account for the sources of uncertainty and variability in the observations in the use of these data for standard setting.

It is possible that neural cell function may be perturbed by stimuli that do not trigger action potentials. Endogenous electric fields or those produced by electrical stimulation at about 4 V/m are reported to affect neuronal excitability and evoked potentials in the central nervous system.(77) However, there is no research to directly relate induced electric fields at subthreshold levels in the brain to any functional response (either adverse or benign) in animals or humans. It is possible that some cell groups in the brain might be more sensitive to stimulation than others because of a greater prevalence of gap junctions. Yet, the experimental data, while sufficient for speculation, do not provide a clear-cut basis to assert that the brain's responsiveness to external field exposures is simply determined by the prevalence and distribution of gap junctions between cells.(77)

While the thresholds for peripheral nerve stimulation are known to be lower than those for cardiac stimulation,(40) the cardiac rhythm is reported in some studies to be influenced by magnetic fields too weak to invoke tissue stimulation. Several laboratories have reported that turning "off" a 50/60-Hz magnetic field can elicit a brief lowering of heart rate by about 2–3 beats per minute,(45,46,78–80) but that the response may be inconsistent(81) and not observable outside the laboratory.(82)

In addition, heart rate variability (HRV), an indicator of autonomic nervous function activity, has been reported to be altered in subjects exposed to intermittent 60-Hz magnetic fields.(80) However, follow-up experiments reported no field-related differences,(83,84) and the inconsistent effects on HRV may be related to subtle differences in experimental design related to the physiological arousal of the subjects.(85) This possibility is suggested by altered sleep patterns observed in volunteer subjects during overnight intermittent magnetic-field exposure.(86) The physiological and anatomical bases for these responses are unknown.

It has been suggested that induced electric fields and currents in the retina that produce visual phosphenes should be used to estimate thresholds for ELF field effects on function of the central nervous system.(1,2) However, as noted before, phosphenes are not adverse: There is no basis at this time to assert that effects specific to the retina, a photosensory transduction organ, would necessarily apply to central nervous system structures, such as the hippocampus.

Electric-Field Stimulation

In principle, concern about effects of electric fields on the brain and nervous system should parallel that for magnetic fields: It is the in situ electric field, not the source of coupling of a field to the body, that stimulates neural and muscular tissue.

However, as a practical matter, noxious stimulation of the skin by surface charges and the use of protective clothing in areas of highest occupational exposure essentially preclude exposure to electric fields of more than 20 kV/m. While a vertically directed field of this magnitude would produce high-current densities in the neck and ankles, the electric field in critical organs such as the brain would not pose a threat of nerve stimulation. For example, the internal electric field in the brain produced by a 30-kV/m vertical electric field would be only about 57 mV/m,(41) a value about 210 times lower than the estimated threshold for stimulating the largest nerve fibers in the brain. Other comparisons of exposures to EMF between 100 Hz and 100 kilohertz (kHz) indicate that, for most environments, the magnetic-field component is more important in terms of the electric field induced in the body.(33)

PHYSICAL DOSIMETRY MODELS

EMF dosimetry describes the relationship between environmental exposures and electrical quantities induced in the body. For ELF fields (3 Hz–3 kHz), these quantities include electric field and current density within tissue. Since these quantities cannot be measured inside the body, interaction of exposure fields with the human body is best understood through modeling. Dosimetry serves at least three purposes: (1) to identify exposure scenarios for which a given threshold (e.g., basic restriction) is exceeded, (2) to estimate the quantities associated with a documented effect, and (3) to assess the plausibility of biological effects.

Biological bodies are nonmagnetic and, relative to air, are highly conductive at ELF. Consequently, people and animals perturb electric, but not magnetic, fields. Because of the size of the human body compared to the wavelength at ELF, the quasistatic approximation applies,(87) such that electric and magnetic field dosimetry can be considered separately. For a simultaneous exposure to both fields, the induced quantities can be obtained by superposition. Because of its irregular geometry and organ- or tissue-specific conductivity, EMF dose cannot be accurately estimated in a human body with a model of simple geometric shape and uniform conductivity. Among the modeled measures often reported are the average, root mean square (rms), and maximum induced electric field and current density values. An additional measure introduced here is the 99th percentile (L99) for the modeled quantities.

Safety guidelines typically specify limits on the external (exposure) electric field, magnetic flux density, and contact current. These limits are derived from restrictions imposed on internal (dosimetric) measures. EMF dosimetry models have now evolved to a state where much has been learned about their accuracy and limitations. Induced fields and currents can be quantified in representations of anatomically correct human models, with conductivity values assigned to all tissues and organs. This section describes briefly the development of EMF dosimetry and summarizes what has been learned from this research.

Historical Overview: Models and Methods

Homogeneous Bodies of Revolution and Other Simplified Body Shapes

Early EMF dosimetry models represented the human body as a homogeneous body of revolution with a single conductivity value. Examples of analytic solutions in homogeneous geometric shapes for electric-field exposure are available in Spiegel,[88] Shiau and Valentino,[89] Kaune and McCreary,[90] Kaune et al.,[91] Foster and Schwan,[92] and Hart.[93] Measurements of currents within the body have also been performed.[37,91,94] As an intermediate development, highly simplified body-like shapes have been evaluated by various numerical methods.[95–98]

For the magnetic field, the induced electric field and current density can be calculated directly from Faraday's law for a loop within the model. These simple models have been used in early guidelines; they also provide the means for comparison with and verification of numerical models.

Heterogeneous Human Body Models

Several laboratories have developed sophisticated heterogeneous models of the human body.[99–104] These models partition the body into volumes of different conductivity. Typically, over 30 distinct organs and tissues are identified and represented by cubic cells (voxels) of 1 to 10 millimeters (mm) on a side. Voxels are assigned a conductivity value based on measured values for various organs and tissues. A human body model constructed from several geometrical bodies of revolution has also been used.[105,106] The model is symmetric and is divided into about 100,000 tetrahedral elements, which represent only the major organs. Table II summarizes the features of three voxel models of the human body used for computations of induced quantities from EMF exposures. The most extensive set of conductivity data has been developed by Gabriel et al.[107] At present, this data set is preferred by researchers in the field.

Numerical Methods

Various computational methods have been used to evaluate electric fields induced by the externally applied EMF in the high-resolution heterogeneous models. Most methods take advantage of the quasistatic approximation, which simplifies the computations without loss of accuracy. Because the human body is highly conductive at ELF,[108] it suffices to consider only tissue conductivity and to ignore displacement current.

The following have been used for exposures to a uniform electric field: the finite-difference (FD) method, the finite-difference time-domain (FDTD) method, the quasistatic FDTD, and a hybrid method. In the FD method, the volume requiring the computation must include the external perturbed field, a space that is typically three times the body dimension in each direction. With most available computers, high-resolution FD modeling can be done only in several steps, using nested sub-grids and interpolation.[109] The FDTD method is computationally efficient, because (1) computational volume is limited to a box surrounding the human body, with only a few additional air voxels, and (2) matrix inversion is not required. Classical FDTD analysis is a high-frequency method and does not take advantage of the

TABLE II
Main features of the models of the human body

Model	National Radiological Protection Board[A]	University of Utah[B]	University of Victoria[C]
Height and mass	1.76 m, 73 kg	1.76 m, 64 scaled to 71 kg	1.77 m, 76 kg
Original voxels	2.077 × 2.077 × 2.021 mm	2 × 2 × 3 mm	3.6 mm
Posture	Upright, hands on sides	Upright, hands on sides	Upright, hands in front
Resolution in calculations	2 mm	6 mm	3.6 & 7.2 mm
Frequency in computations	50 Hz	60 Hz	60 Hz
Tissue conductivity sources	Gabriel et al. (1996)[107]	Gabriel et al. (1996)[107] and Dawson & Stuchly (1998)[121]	Gabriel et al. (1996)[107] and Dawson & Stuchly (1998)[121]

[A]NRPB data from Dimbylow (1997).[104]
[B]University of Utah data from Gandhi and Chen (1992).[99]
[C]University of Victoria data from Dawson et al. (1997a).[103]

quasistatic approximation. This method has been used at 10 MHz and the results scaled to 60 Hz.[99,110] Computations in this case are made for a plane wave.

The quasistatic FDTD method for highly conductive bodies takes advantage of the known behavior of the external and internal electric fields.[111] The electric field at the body exterior is proportional to the applied field, while the interior field is proportional to the time derivative of the applied field. Two plane waves are arranged in such a way that either electric or magnetic fields cancel where the body model is placed. This method has been used alone for lower resolution of 7.2 mm with limited computer resources.[111]

The quasistatic FDTD can be hybridized with the scalar-potential-finite-difference (SPFD) method.[112] In the SPFD method, the computational space is limited to the conducting body.[113,114] The electric-field components in each voxel are directly derived from Maxwell's equations. The electric-field components (E_x, E_y, and E_z) are defined at voxel centers by averaging the three sets of four parallel edge components. In the hybrid method, the surface charge density computed with FDTD for each voxel at the modal surface is interpolated to a finer grid.[112] The code for electric-field exposures has been extensively verified;[102,113,115] the main advantage of the hybrid method is improved computational efficiency and accuracy.

For magnetic-field dosimetry, two methods have been used: an earlier developed impedance method (IM) and the SPFD. In the IM, a three-dimensional network of resistances represents all voxels into which the body is divided.[101] For each network (loop), Kirchhoff voltages are equated to the electromotive force produced by the magnetic-field flux normal to the loop surface. The system of equations for loop currents can be solved using the successive overrelaxation or another iterative method. For each loop, the line currents or current density values in the direction of the three coordinates are computed.[99,116]

The SPFD method is directly applicable to magnetic-field exposures.[112] The main difference between the IM and the SPFD is in their computational efficiency. A comparison by Dimbylow[117] has indicated that 14 percent less memory is required by the SPFD for the same size of voxels, and computation times for this method are between 1.5 and 11 times less than for the IM. The greatest time saving was for the problem that required the longest computing time.

Electric-Field Dosimetry

Environmental electric fields are distorted at the surface of conductive objects such as people, animals, vegetation, and even housing structures. Generally, the "exposure" field value is the unperturbed field strength before the exposed subject is introduced. Electric-field dosimetry published to date has assumed a uniform vertical field, when unperturbed. Induced electric fields and current densities vary, depending on the exposed subject's degree of contact with ground. Correspondingly, dosimetric studies have modeled fully grounded subjects as well as off-ground subjects to provide the range of possible induced quantities.

Validation

Hybrid and quasistatic FDTD methods used at the University of Victoria have been compared with analytical models of homogeneous and layered spheres.[114,118] The results of these analyses are summarized in Table III. The differences between computed and analytical values of induced fields in a homogeneous sphere (Table IIIa) and in the inner sphere of a layered sphere (Table IIIb), are small, on the order of 2–3 percent. Very large errors (above 100 percent) in the maximum induced field values occur at the outer layer (air interface) of the modeled sphere.

Two factors related to the staircase approximation of smooth surfaces by finite voxels cause the error. First, staircasing introduces singularities in charge density at voxel vertices bordering on free space. Second, "leakage" of the large external electric field into internal voxels occurs across the air-conductor boundary (infinite conductivity contrast). The source of this problem is due to noncollocated field components in the approximation of smooth surfaces (they are defined at voxel edges rather than vertices). The electric fields at the edges are required to satisfy the condition of continuity of tangential electric fields across material boundaries.[119] Proper postprocessing of results,[120] as illustrated in the last column of Table IIIa, can significantly reduce the errors due to staircasing.

The large errors in the maximum value can also increase the errors in the average in the outer layer of the layered sphere (Table IIIb), as this layer has relatively few voxels. The errors in L99 are smaller than those in the maximum values, and are about 30 percent. Errors in human dosimetry can be estimated based on the analysis of layered spheres. Therefore, the errors in the maximum induced values (as well as in L99) are smaller in organs that border on other tissues for which the conductivity contrast is smaller (inner spheres in Table IIIb).

TABLE IIIa

Comparison of induced electric fields (μV/m) obtained from analytic method with those from hybrid method for a homogeneous sphere of 1-m diameter and 0.1-S/m conductivity for uniform electric-field exposure (60 Hz, 1 kV/m)

	Modeling method and resolution			
Measure	Analytic	Hybrid 3.6 mm	Hybrid 7.2 mm	Hybrid 7.2 mm[A]
Average	100.1	102.5	102.5	99.3
L99	100.1	118.4	127.9	103.3
Maximum	100.1	359.3	287.8	128.8

[A]Edge electric fields corrected in postprocessing as described in Potter et al. (2000).[120]

TABLE IIIb

Comparison of induced electric fields (μV/m) obtained from analytic method with those from hybrid method for a two-layer sphere of 1-m diameter with 3.6-mm voxels and two contrasts in conductivity for uniform electric-field exposure (60 Hz, 1 kV/m)

	Contrast 1^A				Contrast 2^B			
	Inner sphere (0.8 m)		Outer sphere (1 m)		Inner sphere (0.8 m)		Outer sphere (1 m)	
Measure	Analytic	Hybrid	Analytic	Hybrid	Analytic	Hybrid	Analytic	Hybrid
Average	55.0	56.0	75.3	77.8	23.4	24.0	61.6	63.8
L99	55.0	60.3	105.7	134.1	23.4	26.4	110.1	132.6
Maximum	55.0	77.2	110.0	354.6	23.4	44.2	116.9	354.6

^A Conductivity: outer layer σ = 0.1 S/m, inner σ = 0.2 S/m.
^B Conductivity: outer layer σ = 0.1 S/m, inner σ = 0.5 S/m.

Modeling Results

Computations with the hybrid method have allowed an examination of the effects of voxel size (3.6 mm or 7.2 mm), conductivity, and separation from ground(114,118) on induced electric field and current density. Voxel size relative to organ size affects modeled quantities. Organs small in any dimension are poorly represented by large voxels. The difference between 3.6-mm and 7.2-mm voxels is 10 to 20 percent in the average electric field and current density for the whole body and for most organs.(118) Larger differences in average and rms quantities (approximately 30 percent) occur in organs whose volumes and/or shape are poorly represented by the coarser model, e.g., pancreas, testes, and adrenals. The maximum and L99 induced quantities are consistently higher as the voxel dimension decreases (i.e., as resolution increases). Typical (in all but very small organs) differences in the maximum values are on the order of 30 to 50 percent for 3.6-mm versus 7.2-mm voxels. The differences are smaller for L99 (typically 20 to 30 percent).

For a vertical electric field, the use of two different sets of conductivity values(121) results in negligible changes in short-circuit current (for the grounded model) and very small effects on all dosimetric quantities in horizontal body slices. For the whole body, the average values for both sets of conductivity are within 2 percent of each other, while maximum and L99 values differ by up to 30 and 10 percent, respectively. The electric field (or current density) within a given tissue or organ is a function of both the conductivity of that site and the conductivity of surrounding tissues and organs. In general, all the measures of the induced electric fields vary (but less than the induced current density) for the two sets of conductivity values. Table IV shows the induced electric field for two sets of conductivity values.(121)

TABLE IV

Induced electric fields (mV/m) of a grounded human body model in a vertical uniform electric field (60 Hz, 1 kV/m) for two sets of conductivity

Tissue/Organ	Conductivity (S/m)^A	Average^B	L99^B	Maximum^B
Blood	0.70/0.60	1.43/1.52	8.91/9.06	23.76/22.96
Bone marrow	0.05/0.14	3.55/2.99	34.38/22.68	40.76/32.19
Brain	0.10/0.12	0.86/0.78	1.95/1.69	3.70/3.02
Csf	2.00/1.60	0.35/0.37	1.02/1.06	1.58/1.58
Heart	0.10/0.25	1.42/0.94	2.83/1.56	3.63/2.12
Kidneys	0.10/0.17	1.44/1.47	3.12/2.67	4.47/3.32
Lungs	0.08/0.07	1.38/1.44	2.42/2.35	3.57/3.71
Muscle	0.35/0.30	1.57/1.70	10.1/10.2	32.12/26.48
Prostate	0.40/0.14	1.68/2.14	2.81/3.59	3.05/3.93
Spleen	0.10/0.14	1.79/1.60	2.61/2.40	3.22/3.08
Testes	0.40/0.13	0.48/0.88	1.19/1.72	1.63/2.11

^A σ_1/σ_2, where the two conductivity sets, σ_1 and σ_2, are from Dawson & Stuchly (1998).(121)
^B Each cell has the induced electric field with σ_1 to the left of the slash, followed by the electric field with σ_2 to the right.

Induced quantities for the grounded body are about twice those for the body in free space and have intermediate values for various separations from the ground. This dependence on the contact with and separation from a perfect ground is in agreement with earlier experimental data.[37]

A comparison of the University of Victoria data with computations from other laboratories indicates that the average induced quantities are within 10 to 30 percent for most organs, with maximum differences of 60 percent.[122] Differences between average induced currents are greater for most organs than the differences between average electric field. The interlaboratory differences are ascribable to differences in model anatomy, posture, allocated conductivity values, and resolution (i.e., voxel size). However, when different numerical methods are applied to the same body model, two laboratories consistently have produced data that agreed within two percent.[109,118] The results from different laboratories are compatible and show the dependence of computed current density on voxel size.[109,118]

Magnetic-Field Dosimetry

Validation

The SPFD method has been used extensively to model induced electric fields and current densities due to magnetic-field exposure. As with the electric field, the University of Victoria group employed simple geometric shapes, such as spheres (homogeneous and layered) and ellipsoids, to assess the accuracy of the SPFD relative to analytic solutions.[112,121,123,124] The spheres and ellipsoids were subdivided into 3.6-mm and 7.2-mm voxels of various dimensions and analyzed to evaluate the staircasing error for a given resolution. Representative results of these analyses are summarized in Table V. For 3.6-mm voxels, the errors in the average induced quantities are on the order of 1 percent. There appears to be an inherent error on the order of 25 percent in maximum values associated with representing smooth surface bodies by cubic voxels. This large error, where the maximum is overestimated, is caused by the alteration of the field patterns in the staircased body in the vicinity of inner corners, where the induced electric fields are concentrated. The error is the greatest at the interface with air and is smaller when the tissue conductivity difference across an interface is lower (as occurs within the body).

When the conductivity contrast is lower (as shown in Table V for layered spheres), the uncertainty in the maximum induced field is also smaller, ranging from 4 percent for a conductivity contrast of 1:2, to 21 percent for 1:10. Errors in the 99th percentile (L99) range from relatively small, below 2 percent, to about 10 percent. The error is small for all boundaries except those with air. For boundaries with air, the ratio of the number of voxels at the boundary to the total number of voxels of a given conductivity determines the magnitude of error in L99. This is illustrated in Table V, where analytic and numerical values of L99 are very close for the homogeneous sphere, but are quite different for the layered sphere where outer layer volume is about 27 percent of the sphere volume and a large surface area borders on air. Numerical codes can reduce the maximum error quite dramatically by smooth surface representations.[120]

Uniform Magnetic-Field Modeling Results

Studies of anatomically correct human models with tissue/organ-specific conductivity have resulted in key observations on the effects of voxel size, conductivity, field orientation, and anisotropy on dosimetric calculations. As with electric-field modeling, smaller voxels more accurately represent organs and tissues, especially those that are small (e.g., thyroid) or small in one dimension (e.g., skin). For larger organs that are well represented by either 3.6-mm or 7.2-mm voxels, average induced values are within 20 percent for the two-voxel sizes. However, the maximum values in any tissue are always associated with smaller voxels used in the model.

For magnetic-field exposures, induced electric fields remain relatively well conserved for different sets of tissue conductivity. This is because the integral of the electric field around

TABLE V

Comparison of induced electric fields (μV/m) from analytic method with those from SPFD method with 3.6-mm voxels for homogeneous and layered spheres for uniform magnetic-field exposure (60 Hz, 1 μT)

			Layered 1[B]				Layered 2[C]			
	Homogeneous[A]		Inner		Outer		Inner		Outer	
Measure	Analytic	SPFD	Analytic	SPFD	Analytic	SPFD	Analytic	SPFD	Analytic	SPFD
Average	6.77	6.75	6.08	6.08	8.58	8.53	6.08	6.07	8.58	8.56
L99	11.22	11.33	10.08	10.02	11.39	12.03	10.08	10.09	11.39	12.51
Maximum	11.47	14.15	10.31	10.72	11.47	14.07	10.31	11.94	11.47	13.91

[A]Homogeneous sphere, radius 0.122 m, conductivity σ = 0.25 S/m.
[B]Layered sphere, outer layer: radius 0.122 m, conductivity σ = 0.125 S/m, and inner layer: radius 0.110 m, conductivity σ = 0.25 S/m (contrast 1:2).
[C]Layered sphere, outer layer: radius 0.122 m, conductivity σ = 0.025 S/m, inner layer: radius 0.110 m, conductivity, σ = 0.25 S/m (contrast 1:10).

TABLE VI
Induced electric fields (μV/m) in the human body model in a uniform magnetic field (60 Hz, 1 μT) oriented front-to-back: for two sets of conductivity

Tissue/Organ	Conductivity (S/m)^A	Average^B	L99^B	Maximum^B
Blood	0.70/0.60	6.85/6.75	23.41/23.96	82.73/80.31
Bone marrow	0.05/0.14	16.20/12.19	92.90/61.88	154.10/109.90
Brain	0.10/0.12	10.68/10.08	30.53/27.01	73.89/58.87
Csf	2.00/1.60	5.23/5.52	17.03/16.68	25.13/23.22
Heart	0.10/0.25	13.75/9.87	38.14/21.78	48.65/35.42
Kidneys	0.10/0.17	25.13/23.05	53.42/43.76	70.60/54.80
Lungs	0.08/0.07	20.84/21.54	49.28/53.01	85.72/92.65
Muscle	0.35/0.30	14.93/15.32	50.99/51.02	146.70/133.30
Prostate	0.40/0.14	16.70/25.11	36.21/51.36	52.39/67.79
Spleen	0.10/0.14	41.49/36.89	71.51/60.93	91.63/79.57
Testes	0.40/0.13	14.60/26.20	40.64/67.53	72.73/84.98

$^A\sigma_1/\sigma_2$, where the two conductivity sets, σ_1 and σ_2, are from Dawson & Stuchly (1998).[121]
^{B}Each cell has the induced electric field with σ_1 to the left of the slash, followed by the electric field with σ_2 to the right.

an arbitrary loop is predominantly influenced by the time rate of change of the total flux in that loop, and only secondarily by charge effects at interfaces. In general, lower electric field is associated with higher conductivity. Table VI shows the induced electric field in selected organs for two sets of conductivity values.

The effect of muscle anisotropy has also been investigated for a simplified arrangement of muscle fibers, where conductivity values varied from 0.2 (transverse) to 0.7 (longitudinal) siemens/meter (S/m). The induced average electric field in the muscle is not much different compared to isotropic muscle with a conductivity of 0.35 S/m. On the other hand, large changes occur in the muscle current density. The change in the muscle conductivity also produces a change of induced electric field in most other tissues. The magnitude of the change depends on the tissue location with respect to the muscle and the exposure field orientation. For instance, the changes are negligible for the brain (not close to muscle) and large (above 50 percent) for bone marrow, with the exposure field oriented from side to side. In the latter case, bone marrow and muscle in the limbs provide competing, relatively high conductivity paths for the current flow.

Many past estimates of magnetic-field-induced quantities in specific organs have relied on the assumption that the organ can be considered as an isolated shape of specified conductivity suspended in free space and exposed to a uniform field. Using 3.6-mm voxel models, Dawson et al.[125] compared induced quantities in an isolated heart to the same heart in situ. The induced electric field and current density levels are consistently about 1.5–3 times greater for the in situ case, for all orientations of the uniform magnetic field. Furthermore, even when the heart is incorporated into a homogeneous ellipsoid whose dimensions approximate the torso, the induced levels are lower by as much as 50 percent than those in situ in the heterogeneous model.

As expected, for uniform exposure fields, the magnetic-field orientation normal to the torso (front-to-back) gives the highest values of all induced quantities for the whole body and many organs and tissues. However, in the brain, cerebrospinal fluid (csf), heart, bladder, eyes, and spinal cord, the highest quantities are induced by the magnetic field oriented side-to-side.[103,121,126] For blood, all measures except the maximum attain the highest values for the exposure fields oriented from side to side. The lowest induced fields consistently occur for the magnetic field oriented along the vertical body axis.

Finally, dosimetric data obtained in three laboratories have been compared for different models of an average male.[122] Maximum differences are up to 60 percent for the average induced electric field, and up to 110 percent for the average current density. Typical differences between laboratories are usually smaller, particularly for the induced electric field. Model specifics, conductivity values, and voxel size generally explain the interlaboratory differences.

Nonuniform Magnetic-Field Modeling Results

Although laboratory research addressing biological effects from magnetic fields has used relatively uniform fields, high magnetic fields in most real-world situations are nonuniform. To enhance our understanding of induced quantities in nonuniform field situations, scenarios characteristic of work in the electric utility industry have been modeled. These have included live-line work near high-voltage transmission-line conductors, maintenance of highly loaded secondary cables in a network vault, and an inspection of the isophase buses of a large steam generator.[127–129] For the live-line scenario, the modeling ignored other, more distant conductors on the same tower (their inclusion would actually lower induced quantities), and assumed the conductors were infinitely long. For the network vault scenario, infinite and finite conductors were used in two separate models. (Finite conductor calculations required expanded code for the magnetic vector potential associated with discrete conductor segments.) A finite conductor analysis was also applied to the isophase buses of the generator.[129] The finite line solution in the vault yielded induced quantities that, depending on body location, were roughly one-third to two-thirds of the values estimated with an infinite line assumption. In the situation modeled, an infinite line model results in overestimates of induced quantities compared to a more realistic finite-conductor model, but this may not be true in other exposure scenarios. The practical application of dosimetry modeling for nonuniform field conditions is presented in the next section in conjunction with measurement-based dosimetry assessment.

EXPOSURE ASSESSMENT AND GUIDELINES

Value of Exposure Assessment

Occupational exposure assessments support the development and evaluation of guidelines in two ways: (1) by indicating where, when, and to whom exposures approaching guideline levels ($\geq$0.1 mT) might occur;[19,130] and (2) by providing a foundation for dosimetric analysis of realistic exposures.[129] For most occupations, EMF exposures in the workplace are comparable with those found in the home and are orders of magnitude below the limits recommended in guidelines. Typically, average and maximum occupational electric fields are 10 V/m and a few hundred V/m, respectively, and average and maximum magnetic-field exposures are 0.1 μT and tens of μT, respectively. However, there are a few occupations, principally in the electric utility industry, that entail work where magnetic-field exposures may exceed the levels cited in guidelines ($\geq$0.4 mT).

Exposed Groups

Personal exposure (PE) measurements of large groups of workers have identified a few occupational groups that are likely to have exposures that approach or exceed guideline levels.[19] Other studies have targeted specific occupations and tasks to quantify and better understand the frequency and nature of guideline-level exposures.[131] The most likely candidates for high exposures are occupations within the electric-utility industry that entail work near conductors carrying large currents. Job categories of particular interest are those of line workers, cable splicers, generator mechanics, and substation workers.

Measured exposures for transmission-line workers performing bare-hand maintenance on 500-kV lines have exceeded guideline levels (>0.42 and >1.0 mT) for several minutes during the performance of a single task.[19] Bare-hand transmission-line maintenance involves working on the conductors of an energized overhead line. The worker wears a conductive hooded suit that is electrically bonded to the energized conductor to provide shielding from electric fields.

Some PE measurements by cable splicers working in underground distribution network vaults have exceeded guideline levels (>0.42 and >1.0 mT) for extended periods (>1 hr) during tasks.[131] For these workers, exposure to high fields occurs during tasks that involve contact or very close proximity to low voltage (240 and 480 V) service cables (i.e., secondaries) carrying currents of more than 500 amperes (A).

Outside of the electric utility industry, occupations that involve operation or maintenance of equipment using large currents can also experience exposures above guideline levels. Included in this category are welders, electric steel industry workers, and operators of industrial demagnetizers.[132,133]

Nature of Guideline-Level Exposures

Temporal Variability

High field exposures can be relatively continuous or momentary. Continuous exposures are task-related and can be experienced by persons working on energized electric transmission or distribution conductors, as noted above for transmission-line workers and cable splicers. Such long-duration exposures associated with a task may involve prolonged periods in one posture and orientation with respect to the field source. These exposures can be modeled and used to estimate induced fields and currents for realistic exposures.[129,134]

Momentary high-field exposures generally entail passing near a local source of high magnetic fields. Such sources are related to the type of facility where work is performed and can be identified and characterized through survey measurements. However, momentary incidental exposures at guideline levels are often difficult to predict and characterize as to source and the posture and orientation of the worker. Therefore, they are less amenable to dosimetric evaluation.

Spatial Variability

Exposure assessments have indicated, not surprisingly, that guideline-level exposures to magnetic fields occur close to conductors carrying large currents. Moreover, magnetic fields that produce exposures close to guideline levels are generally not uniform over the volume of the human body. For a field to be uniform over the volume of the human body, a single- or multiphase line source would have to be far from the body relative to the dimensions of the body. No line source is known to carry currents large enough to produce uniform exposures that approach guideline levels. Figure 2 illustrates why this is so: It shows the field at the surface of the body from a straight conductor as a function of current and distance from the body. For example, a conductor carrying 1,000 A must be closer than 0.5 m to produce the ICNIRP 60-Hz limit of 0.42 mT at the body.

Uniform ELF fields across the body can be produced by a coil or set of coils, as used in laboratory exposure systems. However, even in such cases, the currents required to achieve whole-body exposures approaching guideline levels are unrealistically large, unless a system is constructed especially for producing such exposures. Occupational settings that would contain such a source

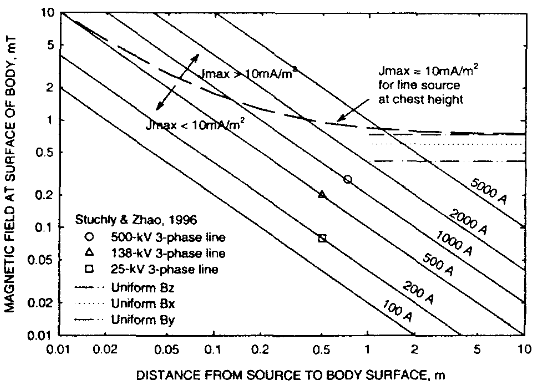


FIGURE 2

Evaluation of 10 mA/m^2 induced current basic restriction for a line source based on surface field and source distance to the surface of the body. Data reported from Stuchly and Zhao.[134]

have not been identified. (Medical MRI systems use superconducting coil systems with direct currents [DC] to produce very large [> 1 T], stable, uniform static fields over the volume of the patient.) The high-current secondary service cables in vaults can wrap around three sides of a work space to produce a uniform field over large portions of the area. However, even in these situations, maximum exposures occur when the worker is near the conductors, again in a nonuniform field. Therefore, the evaluation of occupational exposures above 0.1 mT with respect to guideline limits must explicitly address the nonuniformity of exposure fields.

Sources

Because exposures at guideline levels are generally dominated by one source and because guideline limits are ceiling values, the representation of workplace sources by a single simple source is justified for practical evaluation of guideline-level exposures. To accurately characterize average exposures during a task or over a larger area requires a much more sophisticated approach. PE monitoring is often the preferred approach to characterize long-term measures of exposure.

The assumption that only a few source types are responsible for guideline-level exposures greatly simplifies the translation of a practical field measurement into a dosimetric quantity. Typical sources with accessible magnetic fields exceeding 0.1 mT can be placed in four simple categories with well-known field distributions: single-phase infinite line sources, multiple-phase line sources, current loop sources, and uniform fields. Once exposures are characterized for these simple sources over a range of source parameters, the results can be used to estimate induced quantities for actual exposures.

On the other hand, if there are exposure scenarios that do not fit these simple cases, their respective sources can be analyzed independently in dosimetric models to produce induced quantities for evaluation purposes. In addition, realistic exposures in some utility workplaces have already been analyzed and can serve as the basis for evaluating other similar exposures.[128,129]

To evaluate nonuniform exposures in terms of the simple sources described above requires information about the physical configuration of the source and the distance of closest approach to the worker. Once the type of source of the guideline-level exposure has been identified, the strength of the source can be established from PE or survey measurements or from the maximum current. Figure 2 shows the distribution of fields around a line source. This figure can be used to estimate exposures when line current and body location are known.

Determination of Exposure Levels

Evaluation of exposures at guideline levels requires a two-tier approach. First, the exposure must be characterized by a field level; then, if the field exceeds the guideline limit, it must be determined whether the basic restriction on current density is exceeded. This latter step is accomplished through modeling of the interaction of the exposure field with the body. Exposures at guideline-level fields can be identified and quantified by PE measurements, survey measurements, or calculations. No matter which approach is used, knowledge of the source, subject, and field-determination method is important for ultimately linking a real exposure situation to that simulated in a model. To establish a correspondence between the input field for the model and the actual exposure field requires knowledge of what the source characteristics are, how and where the exposure field is measured or calculated, and how far the measurements and the person are from the source.

PE Measurements

PE measurements are an essential tool in assessing exposures where the work environment is complex and more than one source contributes to exposures. Where workers are changing locations in complex environments, it may be totally impractical to survey each location or to estimate exposures with field calculations. On the other hand, without knowledge of where or when peak exposures occur, PE measurements cannot provide certainty about the maximum exposure for a task or worker.

For practical reasons, PE measurements generally involve measurements at one point on the body. Because of the nonuniformity of high-field exposures, PE measurements at a single location may not adequately characterize whole-body, head, or extremity exposure for guideline purposes. The PE measurements used to identify high-field exposures have been performed with the meter worn at the hip or chest for convenience and, at least partially, for reasons of safety. Under such circumstances, whether the basic restriction is exceeded anywhere in the body is not directly apparent from the measured field. Also, the current density or electric field in target tissue, such as brain or heart, may be under- or overestimated by measurements, depending on the body's spatial relationship to the source.

In order to translate a single PE measurement at the surface of the body into a field distribution suitable for estimating induced quantities, simplifying assumptions about meter, subject, and source is required. Based on PE meters that have been used in high-field exposure assessments (EMDEX II, Enertech Consultants, Campbell, CA), the meter is assumed to record the average resultant magnetic field at a distance of 0.02 m from the surface of the body in a sufficiently small volume ($\sim 10^{-6}$ m^3) to represent the calculated field at the center of the sensor. Furthermore, it is assumed that the closest a magnetic-field source can approach the meter or body is 0.02 m. This spacing accounts for the diameter of the conductor, the distance between the sensing volume and the outside case of the meter, and the thickness of the meter pouch and clothes. Other factors that could increase the spacing between source and body or PE meter are thick insulation on the conductor, physical obstructions, or physical inaccessibility, such as with a conductor above the head.

For both the hip and chest locations with a chest-high conductor, it is assumed that the maximum exposure field at the surface of the body is the same as the maximum field measured by the meter. This seems reasonable for line workers and cable splicers whose bodies are in direct contact with the conductors. However, observations of other tasks with high-field exposures may indicate that a larger distance between source and worker and between source and meter is appropriate for the model. For example, this assumption would not be valid for fields measured by a meter worn at the chest or hip when working on a conductor above the head.

Survey Measurements

For locations where tasks are performed repetitively or continuously under the same field conditions, survey measurements may be the optimal method for characterizing high-field exposures. In such cases, several measurements within a work area can characterize the field distribution. Measurements can be performed at different locations to characterize exposures to the torso, head, and extremities. The locations for survey measurements must be carefully selected so they can be accurately placed with respect to body locations during a high-field exposure. When making survey measurements near sources, the minimum distances corresponding to body locations are assumed to be 0.2 and 0.02 m from the center and surface of the body, respectively. Unless survey measurements are timed to coincide with peak current conditions, those measurements may not capture the maximum fields at a work location.

As with PE measurements, the fields measured during a survey are assumed to represent the average field in a sufficiently small volume ($\sim 10^{-6}$ m^3) to yield a point value for the field at the center of a sensor. The measured field distribution can be approximated with a computational model based on a generic source type or, in special cases, used directly as the external field in a dosimetric model.

Calculated Magnetic-Field Exposures

Future or past magnetic-field exposures in workplaces can also be estimated using simple or sophisticated computational models for the sources present. In this case, a calculated field at the assumed location of the worker is used in the dosimetric model. The previously mentioned analyses of exposures near transmission lines, near a generator, and in a vault are examples of incorporating source information directly into a dosimetric model. The computed field distribution may also be approximated by a simple model (Figure 1). As with survey measurements, the locations of the worker and source with respect to the computed field point must be ascertained carefully to accurately link the actual exposure to that simulated in the dosimetric model.

LINKING EXPOSURES TO DOSIMETRIC QUANTITIES

The practical evaluation of actual ELF exposures vis-à-vis guideline levels requires consideration of many other factors besides field level. Chadwick[135] has addressed questions of frequency content, pulsed and transient fields, and combined EMF exposures in the context of meeting guideline basic restrictions. Our objective in this section is to address the linkage of realistic 50/60-Hz field exposures at guideline levels to the induced field and current doses that provide the bases for guidelines.

The best estimate of induced dosimetric parameters is obtained when an exposure field is accurately replicated as the incident field in a high resolution, anatomically correct model. However, because of complex conductor geometry and computer hardware and software requirements, it is not practical to compute induced quantities for the large number of nonuniform scenarios that may arise in occupational situations. Therefore, we propose two approaches, discussed in detail below, for linking actual nonuniform magnetic-field exposures to dosimetric quantities. Both methods rely on the results of computations with anatomically correct models but do not require access to such models to estimate induced quantities for various exposure scenarios in the workplace. The two approaches differ in how they integrate field nonuniformity into their estimates and how the approach is implemented in the field.

- The first approach, the "simple-source" method, relies on simple source models and the source-to-subject distance to emulate the nonuniform field distributions inherent in realistic exposures.
- The second approach, the "field-ratio" method, uses the ratio of the field at a specific body location to the whole-body average field to estimate induced quantities at the specific location.

At present, only current density has been identified as a fundamental limit. The ICNIRP guidelines contain a basic restriction of 10 mA/m^2 for induced current density, as do the NRPB guidelines and ACGIH®Threshold Limit Values (TLVs®)[1,2,136] The ICNIRP basic restriction requires that induced current density not exceed 10 mA/m^2 across any 10^{-4} m^2 surface in the torso or head.

Future research may indicate that more specific dosimetric quantities than maximum current density are of interest for establishing guideline field limits. As an example of meeting such a need, the "field-ratio" method is applied to induced electric field in specific organs for the vault and generator exposure scenarios.

"Simple-Source" Method for Magnetic-Field Exposures

The guideline limits are maximum or ceiling levels. Therefore, the field of interest for examining whether the basic restriction is exceeded is the maximum exposure field calculated or measured at the torso. To demonstrate the application of the "simple-source" approach, the 10-mA/m^2 criterion is evaluated for the upright human body next to a 60-Hz line source at chest height.

If two different line sources produce equal magnetic fields at the surface of the body ($B_{surface}$), the maximum induced current density in the torso (J_{max}) is dependent on the distance to the source: Because of nonuniformity, the nearer the source, the lower the maximum current density. Figure 3 shows, for an upright human adjacent to a horizontal line source, the maximum internal current density per unit magnetic field at the surface ($J_{max}/B_{surface}$ in mA/m^2/mT) as a function of source distance.

The dependence of $J_{max}/B_{surface}$ on distance shown in Figure 3 is based on dosimetric calculations for a heterogeneous model of an upright human in a uniform field.[134] Stuchly and Zhao computed J_{max} in the torso and head for uniform fields in three orthogonal orientations. The induced maximum current density per unit field for a uniform vertical field (B_z) represents the asymptotic value of $J_{max}/B_{surface}$ for a line source at chest height as its distance from the body increases. Similarly,

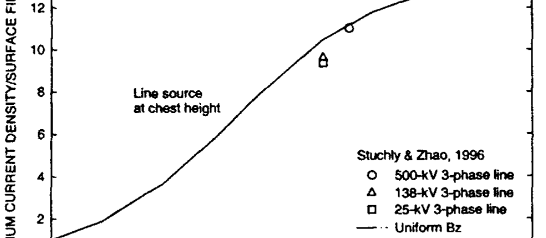


FIGURE 3
Maximum induced current density per unit field (mA/m^2/mT) as a function of distance from line source to surface of the body. Data reported from Stuchly and Zhao.[134]

$J_{max}/B_{surface}$ for uniform horizontal fields (B_x, B_y) represent the asymptotic values for an overhead line source as its height increases.

To account for the nonuniform field in the torso near a source at chest height, an equivalent uniform field through a cross-section of the torso as a function of distance is approximated by the average field across an ellipse, with the major axis parallel to the conductor. The ellipse (semi-major axis = 0.2 m, semi-minor axis = 0.1 m) is in the plane of the conductor. The dependence of the equivalent field on distance is combined with the $J_{max}/B_{surface}$ for the vertical uniform field to produce the curve in Figure 3. A more exact determination of the maximum induced current with distance from a line source can be produced by a systematic variation of the distance to the body in an appropriate dosimetric model.

Stuchly and Zhao[134] also computed the maximum current densities induced by three-phase power lines, with the worker located 0.5 m beyond the outside phases of representative 500-, 138-, and 25-kV overhead lines. The results of this more accurate representation for exposures in realistic nonuniform fields are in reasonable agreement (~12 percent) with those from the approximate method described above (see Figure 3). The difference is due in large part to the reduction in field at the surface of the body by cancellation from the other phases of the power line.

Given the dependence of maximum current density on distance from the source, the surface field necessary to produce current densities above 10 mA/m^2 can easily be determined as a function of distance. The locus of surface-field and source-distance conditions for a maximum induced current density of 10 mA/m^2 is overlaid on the line source characteristics shown in Figure 2. Conditions below the line have maximum current densities less than the basic restriction (<10 mA/m^2) and those above generate current densities that exceed the basic restriction (>10 mA/m^2).

Figure 2 can be used to evaluate exposures from horizontal line sources characterized by PE measurements, survey measurements, or field calculations. All that is needed is the location of the field measurement and the distance from the source to the body surface. For example, the conditions for the three transmission-line exposures considered by Stuchly and Zhao,[134] as shown on Figure 2, are clearly well below the 10 mA/m^2 basic restriction. Figure 2 also shows that, in order for the 138-kV line worker's exposure to reach the basic restriction, an increase of the current to over 2,000 A for the 0.5 m separation, or a decrease in separation to 0.025 m for the 500-A condition, would be required.

Applying the "simple source" approach to electric-field exposures would be difficult because induced electric fields and currents are dependent on the surroundings, posture, and grounding status of the worker, as well as the source voltage and distance. This hampers the definition of general exposure scenarios. Furthermore, sensory perception and indirect effects (contact currents) occur at exposure levels below those where induced-current basic restriction levels are reached. Therefore, extending the "simple-source" approach to electric-field exposures would not be appropriate unless a link to surface fields could be established.

"Field-Ratio" Method for Nonuniform Fields

The "field-ratio" method relies on magnetic-field distributions from calculations or measurements to estimate induced quantities in complex occupational situations. Organ/tissue magnetic fields and whole-body spatial averages of magnetic fields can be derived from computational models in simple situations (e.g., live-line work) or from direct measurements in complex workplace exposure situations.

Given the average field values for specific anatomical sites (B_{organ_avg}) and the whole-body average (B_{body_avg}), we propose that the ratio $B_{organ\_avg}/B_{body\_avg}$ can be used to estimate the induced quantities (dose) under nonuniform field circumstances as follows (see Table VII). If the ratio is greater than 0.75 and less than 1.20, then the average, L99, and maximum induced quantities, as determined for the anatomically correct model under uniform field conditions, approximate the dose under nonuniform conditions. If the ratio is outside these limits, we recommend adjusting the induced field quantity under uniform conditions by that ratio. These rules are based on the analyses of numerical modeling of four exposure scenarios (two postures near transmission lines, plus vault and generator) and uniform field dosimetry.[129,137]

Tables VIII and IX compare the induced electric fields estimated in this way with the induced electric fields calculated for discrete organs in an anatomically correct model for the vault and generator scenarios, respectively. In these scenarios, the estimated dose for most organs is conservative; that is, the predicted value is larger than the modeled value. Only in some cases is the estimated dose less than the modeled value. For example, the maximum (associated with a voxel) may be underestimated by about 10 percent for a highly nonuniform exposure field in the organ, as occurs for the brain in the vault scenario (Table VIII). In this instance, one side of the head is very close to conductors.[128,129] Underestimating the maximum may also occur in distributed tissue, such as muscle or bone marrow in the vault scenario, where arms and legs are in very close proximity to conductors. In such cases, the local exposure of, say, the upper limbs needs to be determined for the purpose of estimating a local dose. The proposed estimation method may also not work well in situations where small organs are exposed to relatively low fields, e.g., testes in the vault scenario. In this instance, the exposure field of the testes is only 0.36 of the whole body average, but testes are a part of the larger volume of the lower abdomen. Thus, for small organs, a more conservative estimate would be not to adjust for exposure field, but to use the whole body or large body part average.

TABLE VII
Nonuniform field adjustments for "field-ratio" method of estimating induced quantities

Ratio R = $B_{organ\_avg}/B_{body\_avg}$	Multiplier for uniform field induced quantity
$0.75 < R < 1.20$	1.0
$R \le 0.75$ or $R \ge 1.20$	$B_{organ\_avg}/B_{body\_avg}$

TABLE VIII
Comparison of estimated induced electric field ($E_{estimate}{}^{A}$) with accurately modeled induced electric field (E_{model}) for selected organs—Vault Scenario

Organ	$B_{organ\_average}/B_{body\_average}$	$E_{estimate}/E_{model}$ Average	L99	Maximum
Bone marrow	0.78	2.04	1.74	0.79
Brain	0.98	1.05	1.06	0.95
Heart	0.74	1.53	1.22	1.15
Kidneys	0.49	1.71	1.45	1.23
Lungs	0.69	1.59	1.28	1.45
Muscle	0.88	1.87	1.98	0.63
Prostate	0.34	1.25	1.38	1.56
Spleen	0.63	2.46	1.89	2.13
Testes	0.36	1.01	1.08	1.67

[A] $E_{estimate}$ is taken for the magnetic flux orientation giving the highest induced measures in a given organ for the uniform magnetic field; for scaling with the ratio $B_{organ\_average}/B_{body\_average}$.

TABLE IX
Comparison of estimated induced electric field ($E_{estimate}{}^{A}$) with accurately modeled induced electric field (E_{model}) for selected organs—Generator Scenario

Organ	$B_{organ\_average}/B_{body\_average}$	$E_{estimate}/E_{model}$ Average	L99	Maximum
Bone marrow	0.91	1.23	1.59	1.55
Brain	1.48	1.07	1.12	1.06
Heart	1.24	1.31	1.28	1.35
Kidneys	1.07	1.24	1.11	0.88
Lungs	1.20	1.27	1.13	1.14
Muscle	0.95	1.13	1.14	1.20
Prostate	0.92	1.44	1.60	1.62
Spleen	1.16	1.10	1.17	1.14
Testes	0.93	1.22	1.20	1.62

[A] $E_{estimate}$ is taken for the magnetic flux orientation giving the highest induced measures in a given organ for the uniform magnetic field; for scaling with the ratio $B_{organ\_average}/B_{body\_average}$.

DISCUSSION

Biological Effects

The various guidelines (e.g., ICNIRP, ACGIH) address safety issues associated primarily with sudden reflex or muscular reactions that result from perception of, or involuntary reaction to, induced currents or fields. Peripheral nerve stimulation is a threshold response perceived as a noxious or painful stimulation. This adverse response occurs at induced electric-field or current density levels below those of other confirmed adverse effects reported in the literature, including stimulation of the heart or skeletal muscle. Therefore, existing data on peripheral nerve stimulation provide one basis for developing magnetic-field exposure guidelines. For electric-field exposures, unpleasant sensory effects at the body surface occur at exposure levels below those associated with neural stimulation from induced electric fields.

There are several other possible effects, independent of overt stimulation, reported below the level of peripheral nerve stimulation. Of these, the evoked-potential effects reported by Silny[57] merit consideration in the setting of guideline limits. Other responses to magnetic fields that may be important in the context of evaluating potential effects of long-term exposure include effects on heart rate and possible effects on heart rate variability and sleep pattern. The available data on potential effects of magnetic-field exposure on memory or attention do not support the existence of any obvious clinically significant effect, but cannot rule out some weak or subtle influence. Although uncertainty has been expressed[6] about the possibility of effects of chronic magnetic-field exposure on childhood and adult leukemia (the latter in occupational settings), at present there is insufficient evidence to support the establishment of a guideline. No guideline, either for the general public or workers, has been based on other chronic disease endpoints that include heart disease, neurodegenerative diseases, neurobehavioral disorders, or cancers other than leukemia.

Typically, the electrical parameter chosen in guidelines as an indicator of dose rate to tissue is induced current density, expressed in terms of current through a bulk tissue reference area. However, biological considerations, including the interaction mechanism for neural stimulation, strongly support the assumption that biological responses of the body to AC magnetic fields (at least at high intensities) are mediated by the induced electric field. Although current density is often treated as if it were synonymous with the induced electric field, the latter is less influenced by the conductivity value and is therefore a more consistent indicator of dose.

In addition to direct field coupling and sensory perception, electric-field exposures can also involve indirect effects through contact with conductors. Such contact can produce conductive currents through the body. Even in the absence of conscious perception, these contact currents can produce fields and current densities in tissue that exceed those associated with EMF at guideline levels. Contact currents usually take hand-to-hand and/or hand-to-foot pathways through the body. Thus, the distributions of fields and current densities in the body due to contact currents are very different than those due to EMF exposures. Corresponding biological effects, if any, are not well investigated.

In general, we should recognize that relatively little research has been conducted on acute human responses to electric fields above 1 kV/m and magnetic fields above 0.1 mT. Because such exposure levels are rare, even in the workplace, epidemiology may not offer the best approach to uncovering potential effects relevant to health. Controlled laboratory experiments on human volunteers offer a viable alternative.

Dosimetric Models

Techniques are now available to calculate the current densities and electric fields induced in bulk anisotropic tissue and organs under a large variety of exposure conditions, including realistic nonuniform fields. Confidence in EMF modeling results has been reinforced by agreement between analytical and computational solutions for simple geometric models and by cross-laboratory agreement.

For magnetic-field dosimetry, the SPFD and impedance methods yield equally accurate results, but IM requires more computational resources. For electric-field dosimetry, the quasistatic FDTD and hybrid methods are more accurate than scaled high-frequency FDTD and FD, when the FD method is used in multiple steps.

Inaccuracies in maximum values for induced quantities, especially at air interfaces, are inherent in computational methods that employ finite voxels to model smooth surfaces. Computational adjustments have been introduced to reduce these inaccuracies.[120] In light of the inaccuracies, the calculated L99 level for tissue electric fields and current densities may present a more realistic benchmark for evaluating basic restrictions on the maximum value in bulk tissue. However, for neural stimulation and other effects where the field in a small volume is important, it is necessary to correct the errors.

In principle, higher resolution models of the human body are feasible. Numerical methods of computation with presently available computers do not restrict voxel size, although enhanced spatial resolution requires extensive computer memory and processing time. High-resolution models are desirable for microdosimetry that targets specific sites and is essential for evaluation of interaction mechanisms. Such models will obviously require improved spatial resolution of conductivity values.

Exposure Assessment

Occupational exposure studies, most intensively conducted within the electric utility industry, have identified certain jobs, working environments, and tasks in which guideline levels are exceeded. These assessments have been essential for identifying work scenarios appropriate for dosimetric analysis in light of the possibility for exceedance of basic restriction. These scenarios inherently involve sources that produce nonuniform exposure fields. Exposures above guideline limits may also occur in the public domain; for example, on high-voltage transmission-line rights-of-way (electric-field exposures) and near certain appliances (magnetic-field exposures).

By assuming uniform field conditions, guidelines take a worst-case approach to setting the investigative field limits at which the basic restrictions might be exceeded. In practice, the fields where guideline limits are exceeded are nonuniform. The "simple-source" and "field-ratio" evaluation approaches described here provide simple means by which such exposures can be realistically evaluated with respect to basic restrictions. By their nature, the simple models are limited to the evaluation of basic restrictions for maximum quantities in the body. To evaluate basic restrictions that may in the future be based on time-weighted average quantities, the use of dosimetric quantities from uniform field modeling is probably appropriate.

Both evaluation methods can easily be extended to other sources, postures, and maximum-level restrictions. For example, if the basic restrictions in guidelines become more targeted to a specific organ or tissue site, then either approach could be applied using dosimetric computations for that location.

The evaluation methods are limited by the accuracy of the dosimetric models. Examples of such limitations are as follows:

- Estimates of maximum current density may include staircase effect errors (~10 percent) inherent in a model that employs voxels to model body surfaces.
- The uncertainties associated with the choice of conductivity model and spatial resolution will be present in the evaluation methods.
- Small organs, distributed organs, and extremities will not be as well-characterized as large organs and the torso, leading to less confidence in the evaluation of basic restriction exceedance for these areas.

To implement the "simple source" method, one needs to know only the measured or computed field at the surface of the body, plus the distance from the source. A set of constant-current curves similar to those in Figure 2 can be generated through a systematic evaluation of induced fields and currents for selected exposure scenarios. A more accurate representation of $J_{max}/B_{surface}$ will result from a computation that relies on an anatomically correct whole-body model for both quantities.

To implement the "field-ratio" method requires measurements or calculations to determine the organ and whole-body average magnetic fields plus a table of induced quantities for uniform field exposures (for example, Table VI). Measurement protocols can be developed to meet the needs of this method.

CONCLUSIONS

For magnetic-field exposures, peripheral nerve stimulation occurs at exposure levels below those of any other confirmed adverse effect and can be the basis for setting magnetic-field exposure limits.

The potential adverse effects of electric fields entail surface stimulation, not internal electric field or currents, unless combined induction effects of EMF are present.

The induced electric field represents a more relevant dose parameter than current density when considering tissue stimulation.

Dosimetric modeling should be an important contributor to guideline development. Modeling has evolved to the point where we have confidence in its accuracy.

The exposure evaluation methods proposed here incorporate the results of computationally intense, anatomically correct dosimetric models into simple methodologies suitable for use in the field by industrial hygienists and others.

RECOMMENDATIONS

Future guidelines will benefit from further investigation of potential effects of mid-to-high-level fields (>1 kV/m; >0.01 mT) on evoked potentials, cardiovascular function as mediated through the autonomic nervous system, and central nervous function, as expressed, for example, by altered sleep patterns. Moreover, further assessment of the sources of uncertainty related to peripheral nerve stimulation is required.

Dosimetric evaluations of contact currents that employ the same approaches as those used for field dosimetry may point the way to identify previously unrecognized potential sites of biological interaction.

By applying an enhanced resolution dosimetry at possible interaction sites, we can better understand and evaluate possible mechanisms of biological effect that serve as the basis for guidelines.

Realistic nonuniform fields deviate significantly from the high-field models used historically in guidelines to establish exposure limits. The simple methods to adjust for field nonuniformity presented here should be expanded and validated for use by industrial hygienists and others.

REFERENCES

1. NRPB (National Radiological Protection Board): Restrictions on Human Exposure to Static and Time Varying Electromagnetic Fields and Radiation: Scientific Basis and Recommendation for Implementation of the Board's Statement. Doc NRPB 4(5):8–69 (1993).
2. ICNIRP (International Commission on Non-Ionizing Radiation Protection): Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (Up to 300 GHz). Health Phys 74:494–522 (1998).
3. EU (European Union): Council Recommendation of 12 July 1999 on the Limitation of Exposure of the General Public to Electromagnetic Fields (0 Hz to 300 GHz)(1999/519/EC). Official J Eur Comm L199:59–70 (1999).

4. ACGIH (American Conference of Governmental Industrial Hygienists): 2000 TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. American Conference of Governmental Industrial Hygienists, Cincinnati, OH (2000).
5. Bailey, W.H.; Su, S.H.; Bracken, T.D.; et al.: Summary and Evaluation of Guidelines for Occupational Exposure to Power Frequency Electric and Magnetic Fields. Health Phys 73(3):433–453 (1997).
6. NIEHS (National Institute of Environmental Health Sciences): Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields. National Institutes of Health, Research Triangle Park, NC (1999).
7. McCann, J.; Kavet, R.; Rafferty, C.N.: Testing Electromagnetic Fields for Potential Carcinogenic Activity: A Critical Review of Animals. Environ Health Perspect 105:(suppl 1):81–103 (1997).
8. Valberg, P.A.; Kavet, R.; Rafferty, C.N.: Can Low-Level 50/60 Hz Electric and Magnetic Fields Cause Biological Effects? Radiat Res 148:2–21 (1997).
9. NIEHS (National Institute of Environmental Health Sciences) Working Group: Assessment of Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields. National Institutes of Health, Research Triangle Park, NC (1998).
10. Boorman, G.A.; Rafferty, C.N.; Ward, J.M.; et al.: Leukemia and Lymphoma Incidence in Rodents Exposed to Low-Frequency Magnetic Fields. Radiat Res 153(5, Pt 2):627–636 (2000).
11. McCann, J.; Kavet, R.; Rafferty, C.N.: Assessing the Potential Carcinogenic Activity of Magnetic Fields Using Animal Models. Environ Health Perspect 108(suppl 1):79–100 (2000).
12. Geddes, L.A.: Handbook of Electrical Hazards and Accidents. CRC Press, Inc., Boca Raton, FL (1995).
13. Asanova, T.P.; Rakov, A.N.: The Health Status of People Working in the Electric Field of Open 400–500 KV Switching Structures. Gig Tr Prof Zabol 10:50–52 (1966).
14. Korobkova, V.P.; Morozov, Y.A.; Stolarov, M.D.; et al.: Influence of the Electric Field in 500 and 750 KV Switchyards on Maintenance Staff and Means for Its Protection. International Conference on Large High Tension Electric Systems, Paris (1972).
15. Roberge, P.F.: Study on the State of Health of Electrical Maintenance Workers in Hydro-Quebec's 735 KV Power Transmission System. Hydro-Quebec, Montreal (1976).
16. Knave, B.; Gamberale, F.; Bergstrom, S.; et al.: Long-Term Exposure to Electric Fields: A Cross-Sectional Epidemiologic Investigation of Occupationally Exposed Workers in High-Voltage Substations. Scand J Work Environ Health 5:115–125 (1979).
17. Broadbent, D.; Broadbent, M.; Male, J.; et al.: Health of Workers Exposed to Electric Fields. Br J Ind Med 42:75–84 (1985).
18. Kouwenhoven, W.B.; Langworthy, O.R.; Singewald, M.L.; et al.: Medical Evaluation of Man Working in AC Electric Fields. IEEE Trans Power App Sys PAS 86:506–511 (1967).
19. Bracken, T.D.; Senior, R.S.; Rankin, R.F.; et al.: Magnetic Field Exposures in the Electric Utility Industry Relevant to Occupational Guideline Levels. Appl Occ Environ Health 12(11):756–768 (1997).
20. Baris, D.; Armstrong, B.G.; Deadman, J.; et al.: A Case Cohort Study of Suicide in Relation to Exposure to Electric and Magnetic Fields Among Electrical Utility Workers. Occ Env Med 53:17–24 (1996).
21. Johansen, C.; Olsen, J.H.: Risk of Cancer Among Danish Utility Workers—A Nationwide Cohort Study. Am J Epid 147:548–555 (1998).
22. NIEHS (National Institute of Environmental Health Sciences) Working Group: Assessment of Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields. National Institutes of Health, Research Triangle Park, NC (1998).
23. Van Wijngaarden, E.; Savitz, D.A.; Kleckner, R.C.; et al.: Exposure to Electromagnetic Fields and Suicide Among Electric Utility Workers: A Nested Case-Control Study. Occ Env Med 57:258–263 (2000).
24. Reichmanis, M.; Perry, F.S.; Marino, A.A.; et al.: Relation Between Suicide and the Electromagnetic Field of Overhead Power Lines. Physiol Chem Phys 11(5):395–403 (1979).
25. Perry, F.S.; Reichmanis, M.; Marino, A.A.; et al.: Environmental Power-Frequency Magnetic Fields and Suicide. Health Phys 41:267–277 (1981).
26. McDowall, M.E.: Mortality of Persons Resident in the Vicinity of Electricity Transmission Facilities. Br J Cancer 53(2):271–279 (1986).
27. Poole, C.; Kavet, R.; Funch, D.P.; et al.: Depressive Symptoms and Headaches in Relation to Proximity of Residence to an Alternating-Current Transmission Line Right-of-Way. Am J Epid 137(3):318–330 (1993).
28. McMahan, S.; Ericson, J.; Meyer, J.: Depressive Symptomatology in Women and Residential Proximity to High-Voltage Transmission Lines. Am J Epid 139(1):58–63 (1994).
29. Verkasalo, P.K.; Kaprio, J.; Varjonen, J.; et al.: Magnetic Fields of Transmission Lines and Depression. Am J Epid 146(12):1037–1045 (1997).
30. Brainerd, G.C.; Kavet, R.; Kheifets, L.I.: The Relationship Between Electromagnetic Field and Light Exposures to Melatonin and Breast Cancer Risk: A Review of the Relevant Literature. J Pineal Res 26(2):65–100 (1999).
31. Graham, C.; Cook, M.R.; Sastre, A.; et al.: Multi-Night Exposure to 60 Hz Magnetic Fields: Effects on Melatonin and Its Enzymatic Metabolite. J Pineal Res 28(1):1–8 (2000).
32. Burch, J.B.; Reif, J.S.; Yost, M.G.; et al.: Reduced Excretion of a Melatonin Metabolite in Workers Exposed to 60 Hz Magnetic Field. Am J Epid 150(1):27–36 (1999).
33. Kaune, W.T.; Guttman, J.L.; Kavet, R.: Comparison of Coupling of Humans to Electric and Magnetic Fields with Frequencies Between 100 Hz and 100 KHz. Bioelectromagnetics 18(1):67–76 (1997).
34. NIEHS (National Institute of Environmental Health Statistics): Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields. National Institutes of Health, Research Triangle Park, NC (1999).
35. Zaffanella, L.E.; Kalton, G.W.: Survey of Personal Magnetic Field Exposure. Phase II: 1000-Person Survey; EMF RAPID Program Engineering Project #6. Lockheed Martin Energy Systems, Inc., Oak Ridge, TN (1998).
36. Graham, C.; Cohen, H.D.: Influence of 60 Hz Fields On Human Behavior Physiology Biochemistry. New York State Power Lines Project; Wadsworth Center for Laboratories and Research, Albany, NY (1985).
37. Deno, D.W.; Zaffanella, L.E.: Field Effects of Overhead Transmission Lines and Stations. In: Transmission Line Reference

Book: 345 KV and Above, pp. 329–419. Electric Power Research Institute, Ed., EPRI, Palo Alto, CA (1982).
38. D'Arsonval, M.A.: Dispositifs Pour La Mesure Des Courants Alternatifs De Toutes Frequences. Comptes Rendus Hebdomadaires des Seances de L'Academie des Sciences 3:450–451 (1896).
39. Lövsund, P.; Oberg, P.A.; Nilsson, S.E.G.; et al.: Magnetophosphenes: A Quantitative Analysis of Thresholds. Med Biol Eng Comp 18:326–334 (1980).
40. Reilly, P.J.: Applied Bioelectricity: From Electrical Stimulation to Electropathology. Springer, New York (1998).
41. Stuchly, M.A.; Dawson, T.W.: Interaction of Low Frequency Electric and Magnetic Fields With the Human Body. Proc IEEE 88:643–664 (2000).
42. Bernhardt, J.H.: The Direct Influence of Electromagnetic Fields on Nerve and Muscle Cells of Man Within the Frequency Range of 1 Hz to 30 MHz. Rad Environ Biophys 16:309–323 (1979).
43. Tucker, R.D.; Schmitt, O.H.: Tests for Human Perception of 60 HZ Moderate Strength Magnetic Fields. IEEE Trans Biomed Eng BME-25:509–518 (1978).
44. Sander, R.; Brinkman, J.; Kuhne, B.: Laboratory Studies on Animals and Human Beings Exposed to 50 Hz Electric and Magnetic Fields. CIGRE, Paris (1982).
45. Cook, M.R.; Graham, C.; Cohen, H.D.; et al.: A Replication Study of Human Exposure to 60-Hz Fields: Effects on Neurobehavioral Measures. Bioelectromagnetics 13(4):261–285 (1992).
46. Graham, C.; Cook, M.R.; Cohen, H.D.; et al.: Dose Response Study of Human Exposure to 60 Hz Electric and Magnetic Fields. Bioelectromagnetics 15:447–463 (1994).
47. Crasson, M.; Legros, J.J.; Scarpa, P.; et al.: 50 Hz Magnetic Field Exposure Influence on Human Performance and Psychophysiological Parameters: Two Double-Blind Experimental Studies. Bioelectromagnetics 20(8):474–486 (1999).
48. Graham, C.; Cook, M.R.; Cohen, H.D.; et al.: Human Exposure to 60-Hz Magnetic Fields: Neurophysiological Effects. Int J Psychophysiol 33(2):169–175 (1999).
49. Dowman, R.; Wolpaw, J.R.; Seegal, R.F.; et al.: Chronic Exposure of Primates to 60-Hz Electric and Magnetic Fields: III. Neurophysiological Effects. Bioelectromagnetics 10:303–317 (1989).
50. Preece, A.W.; Wesnes, K.A.; Iwi, G.R.: The Effect of a 50 Hz Magnetic Field on Cognitive Function in Humans. Int J Radiat Biol 74(4):463–470 (1998).
51. Lai, H.: Spatial Learning Deficit in the Rat After Exposure to a 60 Hz Magnetic Field. Bioelectromagnetics 17(6):494–496 (1996).
52. Lai, H.; Carino, M.A.; Ushijima, I.: Acute Exposure to a 60 Hz Magnetic Field Affects Rats' Water-Maze Performance. Bioelectromagnetics 19(2):117–122 (1998).
53. Sienkiewicz, Z.J.; Haylock, R.G.; Bartrum, R.; et al.: 50 Hz Magnetic Field Effects on the Performance of Spatial Learning Task by Mice. Bioelectromagnetics 19(8):486–493 (1998).
54. Sienkiewicz, Z.J.; Haylock, R.G.; Saunders, R.D.: Deficits in Spatial Learning After Exposure of Mice to a 50 Hz Magnetic Field. Bioelectromagnetics 19(2):79–84 (1998).
55. Siekiewicz, Z.J.; Haylock, R.G.; Saunders, R.D.: Acute Exposure to Power-Frequency Magnetic Fields Has No Effect on the Acquisition of a Spatial Learning Task By Adult Male Mice. Bioelectromagnetics 17(3):180–186 (1996).
56. NIEHS (National Institute of Environmental Health Sciences) Working Group: Assessment of Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields. National Institutes of Health, Research Triangle Park, NC (1998).
57. Silny, J.: Effects of Low Frequency, High Intensity Magnetic Field on the Organism (Meeting Abstract). In: Proceedings of the IEEE International Conference on Electric and Magnetic Fields in Medicine and Biology, London, pp. 103–107. IEEE, Ed., IEEE (1985).
58. Silny, J.: Effects of Low Frequency, High Intensity Magnetic Field on the Organism (Meeting Abstract). In: Proceedings of the IEEE International Conference on Electric and Magnetic Fields in Medicine and Biology, London, p. 104. IEEE. Ed., IEEE (1985).
59. McNeal, D.R.: Analysis of A Model for Excitation of Myelinated Nerve. IEEE Trans Biomed Eng 23:329–337 (1976).
60. Rattay, F.: Analysis of Models for External Stimulation of Axons. IEEE Trans Biomed Eng 33:974–977 (1986).
61. Plonsey, R.; Altman, K.W.: Electrical Stimulation of Excitable Cells—A Model Approach. Proc IEEE 76:1122–1129 (1988).
62. Rattay, F.: Modeling the Excitation of Fiber Under Surface Electrodes. IEEE Trans Biomed Eng 35:199–202 (1988).
63. Reilly, J.P.: Electrical Models for Neural Excitation Studies. Johns Hopkins APL Technical Digest 9:44–59 (1988).
64. Reilly, J.P.: Peripheral Nerve Stimulation by Induced Electric Currents: Exposure to Time-Varying Magnetic Fields. Med Biol Eng Comp 27:101–110 (1989).
65. Cartee, L.A.; Plonsey, R.: The Transient Subthreshold Response of Spherical and Cylindrical Cell Models to Extracellular Stimulation. IEEE Trans Biomed Eng 39:76–85 (1992).
66. Rattay, F.: Analysis of the Electrical Excitation of CNS Neurons. IEEE Trans Biomed Eng 45:766–772 (1998).
67. McIntyre, C.C.; Grill, W.M.: Excitation of Central Nervous System Neurons by Nonuniform Electric Fields. Biophys J 76:878–888 (1999).
68. Barker, A.T.; Freeston, I.L.; Jalinous, R.; et al.: Clinical Evaluation of Conduction Time Measurements in Central Motor Pathways Using Magnetic Stimulation of Human Brain [Letter]. Lancet 1(8493):1325–1326 (1986).
69. Amassian, V.E.; Cracco, R.Q.; Maccabee, P.J.: Focal Stimulation of Human Cerebral Cortex with the Magnetic Coil: A Comparison With Electric Stimulation. Electroencephalogr Clin Neurophysiol 74:401–416 (1989).
70. Bourland, J.D.; Nyenhuis, J.A.; Foster, K.S.; et al.: Threshold and Pain Strength-Duration Curves for MRI Gradient Fields. In: Proc Soc Mag Res Med 5th Ann Meeting, Vancouver, Apr. 12–18, 1994. (1997).
71. Bourland, J.D.; Nuyenhuis, J.A.; Mouchawar, G.A.; et al.: Human Peripheral Nerve Stimulation from Z-Gradients. In: International Society for Magnetic Resonance in Medicine, Proceedings of the 9th Annual Meeting, August 18–24, New York, p. 1157. International Society for Magnetic Resonance in Medicine, Ed., International Society for Magnetic Resonance in Medicine, Berkeley, CA (1990).
72. Schaefer, D.J.; Bourland, J.D.; Nuyenhuis, J.A.; et al.: Effects of Stimulation Gradients Combinations on Human Peripheral Nerve Stimulations Thresholds. In: International Society for Magnetic Resonance in Medicine, Proceedings of the 12th Annual Meeting, Nice, France, p. Poster No. 1220. International Society for Magnetic Resonance in Medicine, Ed., International Society for Magnetic Resonance in Medicine, Berkeley, CA (1995).

73. Budinger, T.F.; Fischer, H.; Hentschel, D.; et al.: Physiological Effects of Fast Oscillating Magnetic Field Gradients. J Comput Assist Tomogr 15(6):909–914 (1991).
74. Cohen, M.S.; Weisshoff, R.M.; Rzedzian, R.R.; et al.: Sensory Stimulation by Time-Varying Magnetic Fields. Magn Reson Med 14:409–414 (1990).
75. Schaefer, D.J.; Bourland, J.D.; Nyenhuis, J.A.; et al.: Determination of Gradient-Induced Human Peripheral Nerve Stimulation Thresholds for Trapezoidal Pulse Trains. In: Soc Mag Res Prod 2nd Annual Meeting, p. 101. Soc Mag Res Prod, San Francisco, CA (1994).
76. Irnich, W.; Schmitt, F.: Magnetostimulation in MRI. Magn Reson Med 33:619–623 (1995).
77. Jefferys, J.G.: Nonsynaptic Modulation of Neuronal Activity in the Brain: Electric Currents and Extracellular Ions. Psych Rev 75(4):689–723 (1995).
78. Korpinen, L.; Partanen, J.: The Influence of 50 Hz Electric and Magnetic Fields on the Extrasystoles of Human Heart. Rev Environ Health 10(2):105–112 (1994).
79. Maresh, C.M.; Cook, M.R.; Cohen, H.D.; et al.: Exercise Testing in the Evaluation of Human Responses to Power Line Frequency Fields. Aviat Space Environ Med 59(12):1139–1145 (1998).
80. Sastre, A.; Cook, M.R.; Graham, C.: Nocturnal Exposure to Intermittent 60 Hz Magnetic Fields Alters Human Cardiac Rhythm. Bioelectromagnetics 19(2):98–106 (1998).
81. Sait, M.L.; Wood, A.W.; Sadafi, H.A.: A Study of Heart Rate and Heart Rate Variability in Human Subjects Exposed to Occupational Levels of 50-Hz Circularly Polarised Magnetic Fields. Med Eng Phys 21(5):361–369 (1999).
82. Gamberale, F.; Olsen, B.A.; Eneroth, P.; et al.: Acute Effects of ELF Electromagnetic Fields: A Field Study of Linesmen Working With 400 KV Lines. Br J Ind Med 46(10):729–737 (1989).
83. Graham, C.; Sastre, A.; Cook, M.R.; et al.: Exposure to Strong ELF Magnetic Fields Does Not Alter Cardiac Autonomic Control Mechanisms. Bioelectromagnetics 21:413–421 (2000).
84. Graham, C.; Sastre, A.; Cook, M.R.; et al.: Heart Rate Variability and Physiological Arousal in Men Exposed to 60-Hz Magnetic Fields. Bioelectromagnetics 21:480–482 (2000).
85. Graham, C.; Cook, M.R.; Sastre, A.; et al.: Cardiac Autonomic Control Mechanisms in Power-Frequency Magnetic Fields: A Multi-Study Analysis. Environ Health Perspect 108:737–742 (2000).
86. Graham, C.; Cook, M.R.: Human Sleep in 60 Hz Magnetic Fields. Bioelectromagnetics 20:277–283 (1999).
87. Olsen, R.G.: Power-Transmission Electromagnetics. IEEE Antennas Propag Mag 35:7–16 (1994).
88. Spiegel, R.J.: High-Voltage Electric Field Coupling to Humans Using Moment Method Techniques. IEEE Trans Biomed Eng 24:466–472 (1977).
89. Shiau, Y.; Valentino, A.R.: ELF Electric Field Coupling to Dielectric Spheriodal Models of Biological Objects. IEEE Trans Biomed Eng 28:429–437 (1981).
90. Kaune, W.T.; McCreary, F.A.: Numerical Calculation and Measurement of 60 Hz Current Densities Induced in an Upright Grounded Cylinder. Bioelectromagnetics 6:209–220 (1985).
91. Kaune, W.T.; Kistler, L.M.; Miller, M.C.: Comparison of the Coupling of Grounded and Ungrounded Humans to Vertical 60 Hz Electric Fields. In: Interaction of Biological Systems with Static and ELF Electric and Magnetic Fields, pp. 185–195. L.E. Anderson; B.J. Kelman; R.J. Weigel, Eds., Pacific Northwest Lab, Richland, WA (1987).
92. Foster, K.R.; Schwan, H.P.: Dielectric Properties of Tissues and Biological Materials: A Critical Review. Crit Rev Biomed Eng 17:24–104 (1989).
93. Hart, F.X.: Numerical and Analytical Methods to Determine the Current Density Distributions Produced in Human and Rat Models by Electric and Magnetic Fields. Bioelectromagnetics Suppl 1:27–42 (1992).
94. Kaune, W.T.; Forsythe, W.C.: Current Densities Measured in Human Models Exposed to 60 Hz Electric Fields. Bioelectromagnetics 6:13–32 (1985).
95. Spiegel, R.J.: Numerical Determination of Induced Currents in Humans and Baboons Exposed to 60 Hz Electric Fields. IEEE Trans Electromagnetic Compatibility 23:382–390 (1981).
96. Chiba, A.; Isaka, K.; Kitagawa, M.: Applications of Finite Element Method to Analysis of Induced Current Densities Inside Human Model Exposed to 60 Hz Electric Field. IEEE Trans Power App Sys 103:1895–1902 (1984).
97. Chen, K.-M.; Chuang, H.-R.; Lin, C.-J.: Quantification of Interaction Between ELF-LF Electric Fields and Human Bodies. IEEE Trans Biomed Eng BME 33:1273–1275 (1986).
98. Dimbylow, P.J.: Finite Difference Calculations of Current Densities in a Homogeneous Model of a Man Exposed to Extremely Low Frequency Electric Fields. Bioelectromagnetics 8:355–375 (1987).
99. Gandhi, O.P.; Chen, J.-Y.: Numerical Dosimetry at Power Line Frequencies Using Anatomically Based Models. Bioelectromagnetics Suppl 1:43–60 (1992).
100. Zubal, I.G.; Harrell, C.R.; Smith, E.O.; et al.: Computerized Three-Dimensional Segmented Human Anatomy. Med Phys 21:299–302 (1994).
101. Gandhi, O.P.: Some Numerical Methods for Dosimetry: Extremely Low Frequencies to Microwave Frequencies. Radio Sci 30:161–177 (1995).
102. Dawson, T.W.; DeMoerloose, J.; Stuchly, M.A.: Comparison of Magnetically Induced ELF Fields in Humans Computed by FDTD and Scalar Potential FD Codes. ACES 11:63–71 (1996).
103. Dawson, T.W.; Caputa, K.; Stuchly, M.A.: Influence of Human Model Resolution of Computed Currents Induced in Organs by 60 Hz Magnetic Fields. Bioelectromagnetics 18:478–490 (1997).
104. Dimbylow, P.J.: FDTD Calculations of the Whole-Body Averaged SAR in an Anatomically Realistic Voxel Model of the Human Body from 1 MHz to 1 GHz. Phys Med Biol 42:479–490 (1997).
105. Baraton, P.; Cahouet, J.; Hutzler, B.: Three-Dimensional Computation of the Electric Fields Induced in a Human Body by Magnetic Fields. Electricite de France, Paris (1993).
106. Hutzler, B.; Baraton, P.; Vicente, J.L.; et al.: Exposure to 50 Hz Magnetic Fields During Live Work. Proc IEEE:1–9 (1994).
107. Gabriel, S.; Lau, R.W.; Gabriel, C.: The Dielectric Properties of Biological Tissues: III. Parametric Models of the Dielectric Spectrum of Tissues. Phys Med Biol 41:2271–2293 (1996).
108. Foster, K.R.; Schwan, H.P.: Dielectric Properties of Tissues. In: Handbook of Biological Effects of Electromagnetic Fields, pp. 25–102. C. Polk; E. Postow, Eds., CRC Press, Boca Raton, FL (1996).

109. Dimbylow, P.J.: Current Densities in a 2 mm Resolution Anatomically Realistic Model of the Body Induced by Low Frequency Electric Fields. Phys Med Biol 45:1013–1022 (2000).
110. Furse, C.M.; Gandhi, O.P.: Calculation of Electric Fields and Currents Induced in a Mm-Resolution Human Model at 60 Hz Using the FDTD Model. Bioelectromagnetics 19:293–299 (1998).
111. DeMoerloose, J.; Dawson, T.W.; Stuchly, M.A.: Application of the Finite-Difference Time-Domain Algorithm to Quasi-Static Field Analysis. Radio Sci 32:329–341 (1997).
112. Dawson, T.W.; DeMoerloose, J.; Stuchly, M.A.: Hybrid Finite-Difference Method for High-Resolution Modeling of Low-Frequency Electric Induction in Humans. J Comput Physics 136:640–653 (1997).
113. Dawson, T.W.; Stuchly, M.A.: Analytic Validation of a Three-Dimensional Scalar-Potential Finite-Difference Code for Low-Frequency Magnetic Induction. ACES 11:72–81 (1996).
114. Dawson, T.W.; Caputa, K.; Stuchly, M.A.: High-Resolution Organ Dosimetry for Human Exposure to Low-Frequency Electric Fields. IEEE Trans Power Delivery 13:366–376 (1998).
115. Dawson, T.W.; Stuchly, M.A.: An Analytic Solution for Verification of Computer Models for Low-Frequency Magnetic Induction. Radio Sci 32:343–367 (1997).
116. Gandhi, O.P.; Ford, J.F.D.: Calculation of EM Power Deposition for Operator Exposure to RF Introduction Heaters. IEEE Trans Electromagnetic Compatibility 30:63–68 (1988).
117. Dimbylow, P.J.: Induced Current Densities from Low-Frequency Magnetic Fields in a 2 Mm Resolution, Anatomically Realistic Model of the Body. Phys Med Biol 43:221–230 (1998).
118. Stuchly, M.A.; Dawson, T.W.; Caputa, K.: Organ Dosimetry for Human Exposure to 60 Hz Uniform Magnetic Fields. Internal Report. University of Victoria, Victoria, BC, Canada (1996).
119. EPRI (Electric Power Research Institute): Evaluation of Occupational Magnetic Field Exposure Guidelines. EPRI, Palo Alto, CA (1998).
120. Potter, M.E.; Okoniewski, M.; Stuchly, M.A.: Low Frequency Finite Difference Time Domain (FDTD) for Modeling of Induced Fields in Humans Close to Line Sources. J Comput Physics 162:82–103 (2000).
121. Dawson, T.W.; Stuchly, M.A.: High Resolution Organ Dosimetry for Human Exposure to Low Frequency Magnetic Fields. IEEE Trans Magnetics 34:1–11 (1998).
122. Stuchly, M.A.; Gandhi, O.P.: Inter-Laboratory Comparison of Numerical Dosimetry for Human Exposure to 60 Hz Electric and Magnetic Fields. Bioelectromagnetics 21(3):167–174 (2000).
123. Dawson, T.W.; Caputa, K.; Stuchly, M.A.: Effects of Skeletal Muscle Anisotropy on Human Organ Dosimetry Under 60 Hz Uniform Magnetic Field Exposure. Phys Med Biol 43:1059–1074 (1998).
124. EPRI (Electric Power Research Institute): Validation of Computational Methods for Evaluation of Electric Fields and Currents Induced in Humans Exposed to Electric and Magnetic Fields. Report TR-111768. EPRI, Palo Alto, CA (1998).
125. Dawson, T.W.; Caputa, K.; Stuchly, M.A.: Magnetic Induction At 60 Hz in the Human Heart: A Comparison Between the In-Situ and Isolated Scenarios. Bioelectromagnetics 20(4):233–243 (1999).
126. Stuchly, M.A.; Dawson, T.W.; Caputa, K.; DeMoerloose, J.: Organ Dosimetry for Human Exposure to 60 Hz Uniform Electric Fields. Internal Report. University of Victoria, Victoria, BC, Canada (1996).
127. Dawson, T.W.; Caputa, K.; Stuchly, M.A.: High-Resolution Magnetic Field Numerical Dosimetry for Live-Line Workers. IEEE Trans Magnetics 35(3 part 1):1131–1134 (1999).
128. Dawson, T.W.; Caputa, K.; Stuchly, M.A.: Organ Dosimetry for Human Exposure to Non-Uniform 60 Hz Magnetic Fields. IEEE Trans Power Delivery 14(4):1234–1239 (1999).
129. Dawson, T.W.; Caputa, K.; Stuchly, M.A.: Numerical Evaluation of 60 Hz Magnetic Induction in the Human Body in Complex Occupational Environments. Phys Med Biol 44(4):1025–1040 (1999).
130. Rankin, R.F.; Bracken, T.D.: Utility Workplace Magnetic-Field Surveys, in Evaluation of Occupational Magnetic-Field Exposure Guidelines. EPRI, Palo Alto, CA (1998).
131. Bracken, T.D.; Rankin, R.F.; Senior, R.S.; et al.: Magnetic-Field Exposures of Cable Splicers in Electrical Network Distribution Vaults. Appl Occ Environ Health 16:369–379 (2001).
132. Lövsund, P.; Oberg, P.A.; Nilsson, S.E.G.: ELF Magnetic Fields in Electro-Steel and Welding Industries. Radio Sci 17(5S):35S–38S (1982).
133. Wenzl, T.B.; Kriebel, D.; Eisen, E.A.; Moure-Eraso, R.: A Comparison of Two Methods for Estimating Average Exposure to Power-Frequency Magnetic Fields. Appl Occ Environ Hygiene 10(2):125–130 (1995).
134. Stuchly, M.A.; Zhao, S.: Magnetic Field-Induced Currents in the Human Body in Proximity of Power Lines. IEEE Trans Power Delivery 11(1):102–109 (1996).
135. Chadwick, P.J.: Occupational Exposure to Electromagnetic Fields: Practical Application of NRPB Guidance. National Radiological Protection Board, Chilton, Didcot, Oxfordshire, UK (1998).
136. ACGIH (American Conference of Governmental Industrial Hygienists): Supplements to the Sixth Edition Documentation of the Threshold Limit Values and Biological Exposure Indices; Supplement: Sub-RF Magnetic Fields; Supplement: Sub-RF and Static Electric Fields. American Conference of Governmental Industrial Hygienists, Cincinnati, OH (1996).
137. Stuchly, M.A.; Dawson, T.W.: Human Body Exposure to Power-Lines: Relation of Induced Quantities to External Magnetic Fields. Health Phys, in press.

Bioelectromagnetics 23:464–474 (2002)

Contact Voltage Measured in Residences: Implications to the Association Between Magnetic Fields and Childhood Leukemia

Robert Kavet[1]* and Luciano E. Zaffanella[2]

[1]*Environment Department, EPRI, Palo Alto, California, USA*
[2]*Enertech Consultants, Lee, Massachusetts, USA*

We measured magnetic fields and two sources of contact current in 36 homes in Pittsfield, MA. The first source, V_{P-W}, is the voltage due to current in the grounding wire, which extends from the service panel neutral to the water service line. This voltage can cause contact current to flow upon simultaneous contact with a metallic part of the water system, such as the faucet, and the frame of an appliance, which is connected to the panel neutral through the equipment-grounding conductor. The second is V_{W-E}, the voltage between the water pipe and earth, attributable to ground currents in the water system and magnetic induction from nearby power lines. In homes with conductive water systems and drains, V_{W-E} can produce a voltage between the faucet and drain, which may produce contact current into an individual contacting the faucet while immersed in a bathtub. V_{P-W} was not strongly correlated to the magnetic field (both log transformed) ($r = 0.28$; $P < 0.1$). On the other hand, V_{W-E} was correlated to the residential magnetic field (both log transformed) ($r = 0.54$; $P < 0.001$), with the highest voltages occurring in homes near high voltage transmission lines, most likely due to magnetic induction on the grounding system. This correlation, combined with both frequent exposure opportunity for bathing children and substantial dose to bone marrow resulting from contact, lead us to suggest that contact current due to V_{W-E} could explain the association between high residential magnetic fields and childhood leukemia. Bioelectromagnetics 23:464–474, 2002. © 2002 Wiley-Liss, Inc.

Key words: exposure assessment; magnetic fields; childhood leukemia; contact voltage

INTRODUCTION

Contact current flows through the body whenever a person touches two conductive surfaces that are at different electrical potentials (voltages). In most cases, the hand serves as the injection point, with the current flowing out of the other hand and/or through the feet. At power frequencies (50/60 Hz), the amount of current flow through the body depends on several factors. These include the magnitude and impedance of the voltage source, the body's electrical resistance, and the resistance of the skin at the points of electrical contact. Once past the skin, body resistance is a function of physical dimension and relative tissue composition (e.g., fat, muscle, blood, and bone). Measurements and modeling estimate an adult's body resistance, once past the skin, to be on the order of 1–2 kΩ, and a young child's to be greater by a factor of 2 to 3, based mainly on a smaller cross sectional area [Reilly, 1998; Dawson et al., 2001]. The skin is highly insulating under dry conditions (> 100 kΩ) and progressively more conductive under increasingly moist and wet conditions. In addition, most shoes and floor materials will provide substantial resistance for hand-to-foot current flow. These factors as well as the characteristics of adult and child body resistance are excellently reviewed [Reilly, 1998].

The scalar potential finite difference method has been used to estimate the electric field due to contact current within the bone marrow of anatomically correct adult- and child-sized models [Dawson et al., 2001]. Increasingly, the electric field in tissue is viewed as a more appropriate measure of dose than current density, because it scales with the potential impressed across the cell membrane, which is the signal transduced if sufficiently large [Dawson et al., 2001]. With the marrow segmented into torso, spine, and upper and

Contract grant sponsor: EPRI; Contract grant number: WO6929-01.

*Correspondence to: Robert Kavet, Environment Department, EPRI, PO Box 10412 Palo Alto, CA 94303.
E-mail: rkavet@epri.com

Received for review 7 September 2001; Final revision received 19 February 2002

DOI 10.1002/bem.10038
Published online in Wiley InterScience (www.interscience.wiley.com).

lower arm, and leg compartments, the electric field in tissue was maximal in the lower arm (below the elbow) of the contacting hand—the segment with the current flowing across the smallest cross sectional area. For a child-sized model, the electric field averaged across the lower arm marrow segment was about 5 millivolts per meter (mV/m) per microampere (μA) of current, and the upper 5% of this tissue had an estimated field of 13 mV/m/μA; for an adult model these values are about 60% less. By comparison, the electric field in the bone marrow of an adult model exposed to a uniform horizontal magnetic field does not exceed about 0.1 mV/m per microTesla (μT) [Dawson et al., 2001]; for a child, the magnetically induced field will scale to a lower value, depending on body size (induction dosimetry for children has not been published).

In a recent risk assessment conducted under the auspices of the National Institute of Environmental Health Sciences, an expert panel [NIEHS Working Group, 1998] concluded that at "internal electric field strengths greater than approximately 1 mV/m. . .numerous well-programmed studies have show strong effects on other endpoints commonly associated with carcinogenic agents. These include significantly increased cell proliferation, disruption of signal transduction pathways, and inhibition of differentiation." Whereas 1 mV/m is not exceeded in bone marrow at uniform magnetic fields less than approximately 10 μT for adults and at higher field strengths for children, the electric field in bone marrow from as little as 1 μA contact current exceeds this 1 mV/m benchmark.

Together with the earth itself, conductive residential water pipes and water mains in the street provide an alternative path to the utility neutral for the load return currents. These "ground currents" occur on both (1) the secondary side of the distribution transformer ("secondary ground currents"), consisting of residential net load currents returning to the transformer serving respective residences, and (2) the primary side of the transformer ("primary ground currents"), consisting of unbalanced primary loads returning to the substation.

This study focuses on two sources of contact current within the residence, both associated with the residential grounding system. The first source, V_{P-W}, is the voltage on the grounding wire, which connects the service panel neutral to the water pipe at the water service entrance; the grounding wire serves as an alternate path for the net load current to return to the distribution transformer serving the residence. This voltage can cause contact current to flow upon simultaneous contact with a metallic part of the water system, such as the faucet, and the frame of an appliance, which is connected to the panel neutral through the equipment-grounding conductor. We described the engineering features of this source in a prior publication [Kavet et al., 2000].

The second source derives from V_{W-E}, the voltage between a home's conductive water pipes and the earth. V_{W-E} may arise from two basic mechanisms: conduction and magnetic field induction. A fraction of the ground currents (described above) returning to the distribution transformer and the substation via the water pipes enters the earth, creating a voltage on the water pipe equal to the current entering the earth multiplied by the resistance between the pipe and earth. This fraction is a function of the relative impedances of the water pipes, the utility neutral, and the earth.

With respect to magnetic field induction, the utility neutral and water pipe system form an extensive network of conductors that can experience an induced electromotive force due to power frequency magnetic fields from nearby high voltage transmission lines or heavily loaded distribution primaries. A simple example is shown in Figure 1, which illustrates calculated magnetic field induction on a network of distribution neutrals near a high voltage transmission line. Because the neutrals and the water system are in electrical contact, the example represents the possibility of induction on water pipes as well. However, an

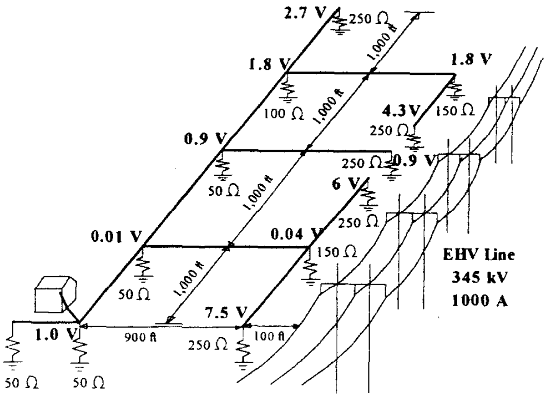


Fig. 1. An example model of induction from a heavily loaded high voltage transmission line on a network of distribution neutrals. The induced neutral to earth voltage can vary greatly depending on a node's location along a path parallel to the line. Induced voltages are lower at intermediate points due to one loop "bucking" an adjacent loop. The induced voltages can be appreciable (≥ 1 V) at distances where a residence would be wire coded according to Wertheimer–Leeper as *very-low-current configuration* (VLCC). At any one point, however, the induced voltage is proportional to the magnetic field.

electromotive force will also be induced on conductive water pipes that are not connected to the utility neutral.

Therefore, in homes not associated with three-phase primary distribution lines (3 Φ DL) or high voltage transmission lines (HVTL), we expect V_{W-E} to arise chiefly from the secondary ground currents in the water pipe (although primary ground currents on single and two-phase primary laterals could also generate a portion of V_{W-E}); in homes near 3-Φ DL, we expect V_{W-E} to be a function of both secondary currents and unbalanced primary ground currents; in homes near HVTL or heavily loaded 3-Φ DL, we expect V_{W-E} to arise from induction as well as from any currents in the primary and secondary ground paths.

Whether through conduction or induction, V_{W-E} produces a voltage between the water pipes and other conductive objects that are embedded in the soil. A metallic drain from a home's sinks and bathtubs to the earth is just such an object. The fraction of V_{W-E} that appears as a voltage from the water pipes to the drain, V_{W-D}, is a function of the pipe and drain resistances to earth and the resistance in the soil between the water pipe and the drain (Fig. 2). A person immersed in a tub of water is in electrical contact with the drain via the tap water. Touching the faucet or spout with a wet hand will complete the circuit, resulting in an exposure to contact current.

The currents considered here, which are continuous power frequency currents while physical contact is maintained, should not be confused with spark discharge from static electricity (e.g., carpet shocks). The latter are discrete self-extinguishing events that occur over tens of microseconds: the discharge characteristics are complex involving capacitive discharge through arm and body as well as conduction into the contacting hand in which the skin impedance at the point of contact changes during the discharge [Reilly, 1998]. While the discharge currents are perceptible, often annoying, the contact currents at issue here are almost exclusively below perception threshold.

The aim of the present study was to develop a protocol for measuring residential sources of contact current and their relationship to residential magnetic fields. Our longer term goal is to apply this protocol to assess whether exposure to contact current could explain the association observed in epidemiologic studies between high residential magnetic fields (>0.3–0.4 μT) and childhood leukemia [Ahlbom et al., 2000; Greenland et al., 2000].

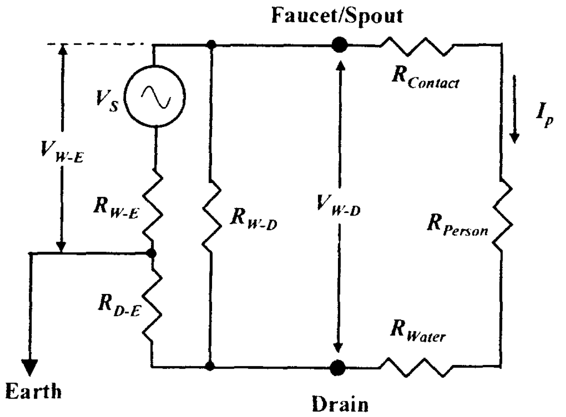


Fig. 2. Circuit description of contact current exposure in a bathtub due to water pipe to earth voltage (V_{W-E}). V_{W-E} arises from (1) primary and secondary ground currents on the water system flowing into the water pipes' resistance to earth, and (2) induction on the grounding network of conductors (neutrals and water lines) from power lines. V_S, the equivalent source voltage of the circuit; V_{W-D}, the open-circuit voltage from water pipe to drain (i.e., in the absence of contact); R_{W-E}, the water pipe resistance to earth; R_{D-E}, the drainpipe's resistance to earth; this resistance is essentially infinite if a part of the drain is plastic and no current will flow; R_{W-D}, the resistance from the water pipe to the drain, usually through the soil; this value will be zero if the two electrodes are shorted in the residence; $R_{Contact}$, the resistance at the point of contact between a hand and the faucet; R_{Water}, the resistance of the bathtub water; R_{Person}, the resistance of a person.

METHODS

House Recruitment

We conducted measurements of contact voltages and associated parameters in a sample of residences in Pittsfield, MA. Pittsfield is an old New England city with an extensive network of conductive plumbing and, thus, a presumed significant amount of ground currents. Most of the residences were selected at random from the telephone book. However, it was desirable to include residences near a HVTL or a large three-phase primary distribution line (3-Φ DL); from previous EMF epidemiology and exposure assessment studies, we knew that complete random selection would result in few such residences [Kheifets et al., 1997]. For this purpose, we conducted a drive-by inspection of several city streets and prepared a list of sites with such houses. The Reverse Address Lookup at www.infospace.com was used to select residences from this list at random.

A solicitation letter was mailed to the residents of detached single houses or duplexes (buildings housing two families) on our selection lists. The letter explained the goals of the study and the need to measure contact voltage in a sample of homes. It further explained our basic requirements, including the need to access the electrical panel, the water pipes where the connection to the grounding wire is located, the kitchen sink and appliances, the laundry appliances, and the bathroom sink, bathtub, and shower. The residents were told that the measurements would last about 1 h and that they would receive a modest cash compensation for their participation. The letter also explained that the individual results would be pooled together and included in a paper without identifying them individually.

A few days after the letters were mailed, a study team member placed calls to the prospective participants. If live contact was made and the resident consented to participate, we made an appointment for a measurement visit. If an answering machine took our call, we left a solicitation message. If the resident refused to participate, did not return our call, or after five or six calls could not be reached, a new residence was selected.

Protocol

The measurement visit protocol included introductory contact with the resident followed by an inspection of the property, using the protocol below. To derive source voltage and source impedance of the contact circuit, the voltage between each pair of electrodes (e.g., appliance frame and water faucet) was measured without and with a 1000 Ω resistor in parallel to the voltmeter. For example, if after the resistor was inserted the voltage went to near zero, this meant that the source impedance was very high (essentially infinite) and the voltage could not produce more than a negligible trickle of current in a person making contact.

The final protocol contained the following elements:

- Introduction to the residents: the measurement team, consisting of two technicians, introduced themselves, explained the logistics of the study and the need to enter various rooms, and entertained any questions from the resident.
- Outdoor inspection: one technician sketched the house including the location of the service entrance, service drop line, general layout of the house in relation to the street, location and type of power line, distance between house and power line, and all the other elements necessary for classifying the house according to the Wertheimer–Leeper wiring code [Kheifets et al., 1997].
- Indoor sketch of the residence: the indoor sketch included the room layout and the locations of the panel and of the water entrance. The length of the ground wire was estimated to $\pm$ 10–15%.
- Ground current measurements: the connection between the water pipe and the grounding wire was inspected. A clamp-on ammeter was inserted alternatively around the water pipe entering the house, the grounding wire, and the water pipe on the house side of the connection between grounding wire and water exit.
- "Basement" measurements: measurements were taken of the voltage between the following electrodes, which were usually located in the basement: neutral connection at the service panel ("panel" for short) to water exit (V_{P-W}); water pipe to drainpipe (V_{W-D}); drainpipe to panel; panel to metallic structure of the house (such as steel column supporting beams).
- Appliance to water pipe: measurements were taken of the voltage between water pipes and the frame of the following appliances: washer, drier, range, refrigerator, and dishwasher (all are measures of V_{P-W}).
- Water pipe (faucet) to drain: measurements were taken of the voltage between faucet and drain of the kitchen sink, bathroom sink, and bathroom tub, and between showerhead and shower drain (all measures of V_{W-D}).
- Outdoor measurements: a metallic stake of about 1 inch (2.5 cm) in diameter was driven about 2 feet (60 cm) deep into the soil at a location at least 20 feet (6.1 m) away from the house. Using long leads the voltages between the following electrodes were measured: panel (or power meter) to earth (V_{P-E}) and water fixture (if available outside the house) to earth (V_{W-E}).
- Magnetic field measurements: the magnetic field was spot-measured near the center of each room of the house at a height of about 1 meter above the floor; the average of these across all measured rooms is B_{avg}. In addition, outdoor measurements were taken at locations away from water lines and service drops. The fields corresponding to the closest and furthest points of the house from the power lines were recorded.
- Occupant interview and payment: the residents were asked a few questions, including the age of the house, their desire to receive a report when the study is completed and their availability for further measurements. Finally a check was given to an adult resident as compensation and gratitude.

The measurements were conducted while a tracer load cycled through three current levels. This technique, introduced previously in a large scale survey of magnetic fields in about 1000 U.S. homes [Zaffanella, 1993], allows the investigator to quantify the change in field value per unit current of added electrical consumption. This paper reports only those data for the low setting, when the tracer load was essentially zero.

Instruments

The following instruments were used for the data acquisition described above: Voltage: FLUKE 89 IV True rms Multimeter (Fluke Corp., Everett, WA); current in ground system: Current Transformer (Clamp-on) FLUKE 801-600; magnetic field: EMDEX SNAP-3-Axis Magnetic Field Survey Meter (Enertech Consultants, Lee, MA); distance of residence to power lines: Optical Tape Measure-Ranging 100 (Ranging Inc., East Bloomfield, NY).

Analysis

The key variables used for the analyses reported in the Results are listed in Table 1. All statistical tests were conducted with JMP 3.1 (SAS, Cary, NC). In some cases, least square regressions and one way ANOVAs were run on log transformed fields and voltages. Nonparametric tests were applied when distributions were unsuitable for parameteric analysis.

RESULTS

General Description of Study Sample

Initial contact was attempted with the occupants of 122 different residences. Roughly half were identified through the phonebook and the remainder through reverse lookup. Of the 96 with whom contact was established, 60 declined participation, mainly due to lack of interest, and 36 went on to participate. Of these, 27 were telephone book selections and the other 9 from the reverse address lookup, chosen because of proximity to a three-phase primary (3-Φ DL) and/or HVTL. All selected residences had an accessible electrical service panel and conductive plumbing connected to the city water main.

Table 2 summarizes the sample with respect to source of access (phone book or reverse lookup), distance of residence from nearby power lines, Wertheimer–Leeper (W–L) wire code category, residence age, and a classification referred to as "Line Type Code." This classification is concerned more with the type of line nearby, rather than with line type combined with distance, which is the basis for the W–L wire code classification method. The Line Type Code categories reflect the magnetic induction and electrical mechanisms that basic principles would suggest are responsible for V_{W-E}. In Type 1 residences (neither 3-Φ DL nor HVTL), we expect V_{W-E} is associated mainly with secondary ground currents; in Type 2's (3-Φ DL, but no HVTL), we expect V_{W-E} to arise from both unbalanced primary ground currents and secondary ground currents; in Type 3's, (HVTL w/ or w/o 3-Φ DL), V_{W-E}, we expect, is due to magnetic field induction, secondary ground currents, and primary ground currents, if present.

Descriptive statistics for key parameters are shown in Table 3. Because of limited outdoor water line accessibility, a direct measurement of V_{W-E} was not available for 10 residences. For these 10 residences, we used V_{P-E} as an estimate of V_{W-E}. We based this substitution on an analysis of 25 residences with both measurements (Fig. 3). After excluding an outlier (circled point) that represented an absolute V_{P-E} (2.4 mV) to V_{W-E} (22.5 mV) difference of about 20 mV, but a full log unit in the graph, log V_{P-E} explained 86% of the variability of log V_{W-E}; moreover the slope of the regression line was 1.00 with an intercept consistent with the origin.

The values of V_{P-W} in Table 3 are similar to the range reported previously in the computer-modeled neighborhood [Kavet et al., 2000]. Here, the 10th to

TABLE 1. Exposure Variables Used in Results

Classification of residence by outdoor power lines	
Wertheimer–Leeper (W–L) wire code	Wiring configuration categories that accounts for kind of line and its distance to residence [e.g., see Kavet et al., 1999]; reduced to three categories for this analysis: Low current configuration (LCC), ordinary high current configuration (OHCC), and very high current configuration (VHCC)
Line Type Code	Classification based on type of line adjacent to residence: Type 1, no 3-Φ primary or HVTL; Type 2, 3-Φ primary, no HVTL; Type 3, HVTL and anything else
Magnetic field	
B_{avg}	Magnetic field averaged across spot measurements in all rooms
Voltage between electrodes	
V_{P-W}	Voltage between neutral at the service panel and the water pipe; equivalent to voltage from appliance frame to nearby water pipe or faucet. Value used in results is average of basement and appliance measurements
V_{W-E}	Voltage between an outdoor water fixture and a stake driven into the Earth, using V_{P-E} as an estimate when direct V_{W-E} measurement not available
V_{W-D}	Voltage between water pipe and drain pipe

TABLE 2. Description of Residences With Contact Voltage Measurements

House	Line Type	HVTL[a]	3-Φ DL	1-2-Φ DL	Secondary	W–L wire code	Line Type Code[b]	Residence age (yr)
	Source	Distance to residence (m)						
1	Telephone book		28		28	OHCC	2	100
2			21		21	OHCC	2	23
3			30		30	OHCC	2	35
4			27		27	OLCC	2	50
5			12		12	VHCC	2	80
6			17		17	OHCC	2	40
7			46		46	OLCC	2	54
8			14		14	VHCC	2	15
9				30	30	OLCC	1	55
10			37		37	OHCC	2	60
11						VLCC	1	110
12				5	5	OLCC	1	73
13					25	OLCC	1	47
14						VLCC	1	39
15						VLCC	1	29
16						VLCC	1	13
17				16	16	OLCC	1	65
18					5.5	OHCC	1	150
19				10	10	OHCC	1	85
20			7.5		7.5	VHCC	2	76
21				8	8	OHCC	1	100
22			30		30	OHCC	2	53
23			30		30	OHCC	2	50
24				24	24	OLCC	1	42
25			23		23	OHCC	2	60
26				18	18	OLCC	1	80
27						VLCC	1	26
28	Reverse lookup	44	14.6		14.6	VHCC	3	45
29		47				VLCC	3	43
30			8			VHCC	2	45
31		47		40	40	OLCC	3	43
32			9		9	VHCC	2	85
33		24	37.5		37.5	OHCC	3	30
34		20		33	33	OHCC	3	37
35		100	14.6		14.6	OHCC	3	43
36		46		27	27	OLCC	3	50

[a]All are 115-kV line.
[b]Type 1, no primary or HVTL; Type 2, primary, but no HVTL; Type 3, HVTL with or without primary.

90th percentile range is 4–111 mV, as compared to 10–90 mV in the model. The voltage measured from water pipe to earth, V_{W-E} spans a range 5–6 times greater than the range spanned by V_{P-W}. The spot measured magnetic field averaged across rooms, B_{avg}, are consistent with those measured in other studies for lines of the same general type [Kavet, 1995; Tarone et al., 1998].

Relation of Exposure Variables to Power Lines

We evaluated the relationship of B_{avg}, V_{P-W}, and V_{W-E} to the W–L wire code split into three categories (VHCC, OHCC, and LCC) and to Line Type Code as defined in Table 2. Standard one-way ANOVA was used for log-transformed B and V quantities. None of the three variables showed a statistically significant ($P < 0.05$) relationship with the W–L code. In contrast, B_{avg} and V_{W-E} were both significantly related to Line Type Code, as shown in Figure 4, which also displays explained variance and their associated P values. V_{P-W} was not significantly related to Line Type Code. Thus, in this small sample, a classification method (i.e., Line Type Code) based on presumed mechanisms of water pipe potentials to earth was more sensitive to high values of B_{avg} and V_{W-E} than the W–L wire code.

TABLE 3. Descriptive Statistics of Key Parameters for Measured Residences ($n = 36$)

Percentile (%)	V_{P-W} (mV)	V_{W-E} (mV)	B_{avg} (μT)
90	111	642	0.379
75	57	316	0.211
50	35	121	0.093
25	18	55	0.044
10	4	21	0.027

Relationships Between Magnetic Fields and Contact Voltages

The relationship between B_{avg} and the two contact voltages, V_{P-W} and V_{W-E}, are shown in Figures 5 and 6. The graphs include symbols that identify the Line Type Code for each data point. We selected B_{avg} because, among our measures, it best represents the time-weighted-average metric used in many epidemiology studies of magnetic fields and childhood leukemia. Figure 5 shows a weak relationship between V_{P-W} and B_{avg}, with higher B_{avg} concentrated among the Line Type Code 3 residences, but no association of Line Type Code with V_{P-W}, as presented earlier. In contrast, Figure 6 shows a stronger and statistically significant relationship between V_{W-E} and B_{avg}, with the noted feature that high V_{W-E} occur almost exclusively in the high field range. The latter group is dominated by Line Type Code 3 category, but not to the complete exclusion of the other two Line Type Code categories.

Relationship Between V_{W-E} and V_{W-D}

As mentioned above, the voltage from the water pipe to the earth, V_{W-E}, is the voltage that drives a

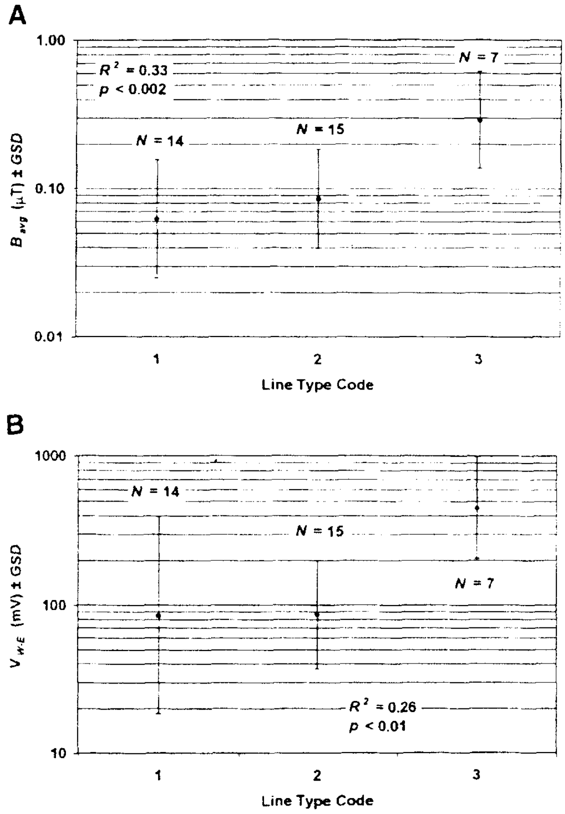


Fig. 4. **A**: B_{avg} versus Line Type Code. **B**: V_{W-E} versus Line Type Code.

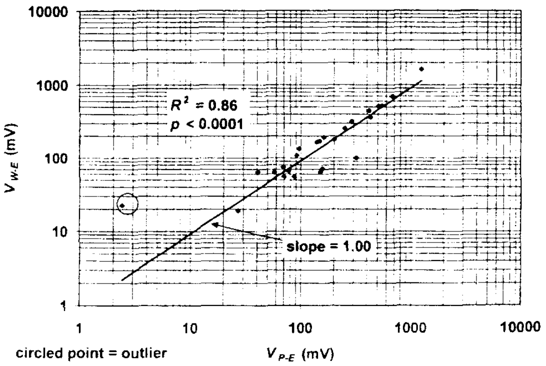


Fig. 3. Measured voltage from water pipe to earth (V_{W-E}) versus measured voltage from service panel neutral to earth (V_{P-E}). Data shown for 25 residences; one residence had a V_{W-E} but not a V_{P-E} reading, and 10 residences lacked a V_{W-E} reading.

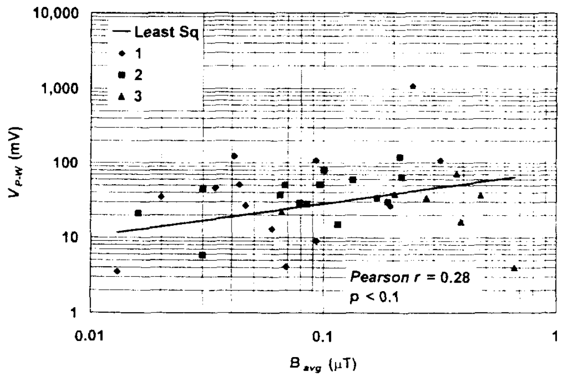


Fig. 5. V_{P-W} versus B_{avg}. The least square regression line is shown. The correlation coefficient and its significance level are indicated. Line Type Code identified in inset.

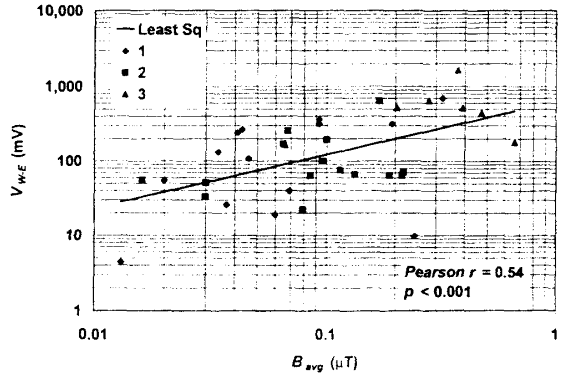


Fig. 6. V_{W-E} versus B_{avg}. The least square regression line is shown. The correlation coefficient and its significance level are indicated. Line Type Code identified in inset.

potential difference from the water pipe to the drain, V_{W-D}. With a continuously conductive metallic drainpipe from the sink or tub to earth, V_{W-D} is the open circuit contact voltage that one would experience from faucet or spout to the drain.

In eight houses, V_{W-D} measurement points were not accessible or we knew the drain was shorted to the pipes. In 16 houses, the drainpipe had a plastic insert, and V_{W-D} is the voltage taken from water pipe to the drainpipe at a point between the plastic and earth (in the basement). In 12 residences, we took readings directly from faucet to drain. In six of these 28 residences, the ratio of V_{W-D} to V_{W-E} was less than 0.01, which we interpreted as an undetected metallic short circuit between the water pipe and the drainpipe. Figure 7 shows the scatter plot of V_{W-E} versus V_{W-D} for the 22 remaining residences. For all points there was a statistically significant correlation (Spearman $r = 0.49$; $P < 0.025$) between the two voltages.

Theoretically, the ratio of V_{W-D} to V_{W-E} is a function of the relative locations of the two electrodes (pipe and drain) in the earth and the resistive properties of the earth. When the water pipe and drain are remote from one another one would expect, from an electrical circuit perspective, that V_{W-D} would be close to V_{W-E}, and that the ratio would diminish with more proximal placement of the two electrodes. Figure 7 distinguishes between these two populations, with the x's representing residences with ratios close to unity and the open circles representing residences with low ratios. In this case, the distinction was straightforward, as there were no residences with V_{W-D} to V_{W-E} ratios between 0.33 and 0.71. Figure 7 also includes the Line Type Code next to each data point, illustrating a mix of Line Type Codes at the higher levels of V_{W-D}. Of the four residences of Line Type Code 3 category, three are in the low V_{W-D} to V_{W-E} ratio category. However, because Line Type 3 has the highest V_{W-E} values even one of those with an open circle is among the higher V_{W-D} residences.

DISCUSSION

Recent assessments and pooled analyses have concluded that there is a positive association between residential power frequency magnetic fields above 0.3–0.4 μT (3–4 mG) and childhood leukemia incidence that cannot be attributed entirely to any known bias, including confounding [NIEHS, 1999; Ahlbom et al., 2000; Greenland et al., 2000; NRPB, 2001]. The odds ratio for this association is roughly between 1.7 and 2.0 [Ahlbom et al., 2000; Greenland et al., 2000]. Despite the association, two factors argue against the magnetic field itself as the etiologic agent: (1) rodent cancer bioassays are almost uniformly negative for cancers of various types and leukemia specifically [Boorman et al., 2000; McCann et al., 2000]; and (2) typical residential levels of magnetic fields, < 1 μT (< 10 mG) away from appliances, produce electric fields in the body well below those believed to affect living systems [NIEHS Working Group, 1998; Kavet et al., 2001].

At a minimum, three conditions need to be satisfied for an exposure to be considered as a possible explanatory factor for the reported associations between magnetic fields and childhood leukemia, given the association is presumed causal: (1) the exposure is associated with the magnetic field; (2) the opportunity for exposure is evident; and (3) the resulting dose can plausibly cause biological effects in relevant tissue sites.

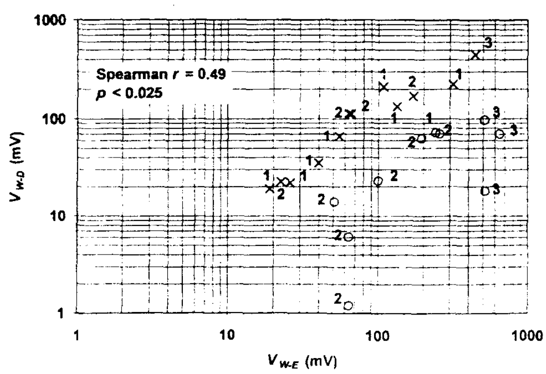


Fig. 7. Measured water pipe to drain voltage (V_{W-D}) versus measured water pipe to earth voltage (V_{W-E}). Line Type is indicated adjacent to each data point. x, the ratio of V_{W-D} to V_{W-E} is ≥ 0.71; o, the ratio of V_{W-D} to V_{W-E} is ≤ 0.33.

TABLE 4. Summary of Mechanisms Responsible for Contact Voltage (V_c)

Basic description	Voltage source	Contact points	Relationships
Magnetic induction in a loop within the residence	B-field from: transmission line, distribution line or grounding system	• Appliance frame to faucet or water pipe (loop includes grounding wire) • Hot to cold faucet (loop includes water pipes) • Water fixtures to drain (loop includes water pipes-to-earth-to-drain)	(V_c) $\propto$ B-field from whatever the source (probably small)
Voltage difference caused by current flow through the ground impedance (often the grounding wire, mainly resistive)	Ground current of index residence plus ground currents from neighbors	Appliance frame to faucet or water pipe	(V_c) $\propto$ B-field due to ground current
Voltage between grounding electrodes (e.g., water pipe) and conductive objects sunk in earth	1. Secondary ground currents—index residence and immediate neighbors 2. Primary ground currents—3-phase feeder or 1–2-phase laterals 3. Transmission line or distribution primary induction on primary neutral or water main	For all three: • Water fixtures to drain • Garden hose fixture to moist/wet ground	1. (V_c) $\propto$ B-field due to ground current in secondary 2. (V_c) to B-field correlation within a primary requires further study; V_c $\propto$ B-field between primary lines 3. (V_c) $\propto$ B-field from transmission line (possibly large)
Unusual or improper wiring			
Ground connection at subpanel	Current in grounding wire originating from subpanel ground connection	Appliance frame to faucet or water pipe	(V_c) $\propto$ B-field due to loop connecting subpanel to main panel
Other improve wiring connections	1. B-field induction from incorrectly wired two-way light switch 2. Interconnected neutrals from appliances at junction box create B-field induction	1. Frame of lighting fixture to frame of properly wired appliance 2. Appliance frame to appliance frame	(V_c) in both cases is relatively small, but $\propto$ B-field due to loop current

The results of this pilot study suggest to us that contact current exposure resulting primarily from the voltage measured between the residential water pipe and earth (V_{W-E}) qualifies as a candidate explanatory factor based on these criteria, as follows:

(1) Association with the field. V_{P-W} and V_{W-E} may each arise through a variety of physical mechanisms, which are summarized in Table 4. Briefly, these voltages arise from either of two generic mechanisms: (a) from the product of current in a segment of the ground path (e.g., the grounding wire, water pipe to earth) and the impedance of that path, or (b) the local magnetic field's induction of an electromotive force in a loop in which the contact electrodes are located. For all magnetic field induction mechanisms, the resulting voltage at a point is linearly related to the magnetic field's time derivative integrated across the loop area. However, as illustrated in Figure 1, the induced voltage along a particular pathway may be quite nonuniform. For the current-by-impedance mechanisms, the resulting contact voltage is generally proportional to the magnetic field associated with that particular current. However, the relationship between the magnetic field and V_{W-E} along the route of a 3-Φ DL has not been characterized through modeling or measurement, although the magnetic field from such a line generally increases with proximity to the substation [King et al., 1997]. As one moves along a primary distribution route, the voltages from neutral-to-earth and water-main-to-earth are functions of the electrical impedances in the neutral, water main, and earth, as well as in the substation's grounding grid to earth. Despite the uncertainty about the correlation of V_{W-E} to the magnetic field *within* a primary route, a heavily loaded primary will have both higher V_{W-E} and higher magnetic fields than an identical system lightly loaded. Thus, we expect the two quantities are correlated *among* different primary lines. Stated differently, at a single point along a primary, V_{W-E} and the magnetic field will likely rise and fall together.

We report a statistically significant relationship between V_{W-E} and B_{avg} both log-transformed (Fig. 6). The seven homes with the highest levels of V_{W-E} (>400 mV) had a B_{avg} of 0.17 μT or greater. Five residences in this group were near HVTL, i.e., Line Type Code 3, while one was near a 3-Φ DL (Line Type Code 2) and one near neither (Line Type Code 1). As indicated above, high V_{W-E} near HVTL likely involves magnetic induction on the conductors of the grounding system, the utility neutral and/or the water main. Visually, Line Type Code 3 exerted an upward influence on the overall relationship between V_{W-E} and B_{avg} (Fig. 6), although the residuals were not significantly related to Line Type Code. After removing these seven residences, the correlation between these two log-transformed quantities, nonetheless, remained suggestive ($r = 0.36$; $P = 0.05$).

Although human contact current exposure in the bathtub scenario would occur upon contact with V_{W-D} (i.e., faucet to drain voltage, see Fig. 2), we chose to emphasize V_{W-E} in this study as a key variable. V_{W-E} serves as a "susceptibility factor" reflecting the interaction between the electric utility distribution and/or transmission system and a residence's electrical grounding system. Theoretically, V_{W-D} may vary from zero to V_{W-E} depending on residence-specific factors, including soil properties under the residence and the relative proximity of the drain to the water system (see R_{W-D} in Fig. 2). In the study population with usable data, V_{W-D} was either greater than roughly 2/3 V_{W-E} (12 houses) or less than about 1/3 of V_{W-E} (10 houses); overall, we reported a positive relationship between V_{W-D} and V_{W-E} (Fig. 7). In some residences V_{W-D} was zero because of a metal short, or was a floating voltage (i.e., an open circuit) because a part (or all) of the drain was nonconductive. If a residence had a drain interrupted with a plastic insert from a repair or renovation, we measured from the remaining conductive section sunk into the soil to estimate the V_{W-D} that would have existed if the drain were conductive along its entire length. Because of the small sample size with usable V_{W-D} measurements in the data set presented here and the bimodal nature of the V_{W-D}-to-V_{W-E} ratio, the correlation between V_{W-D} and B_{avg} was small and not statistically significant ($r = 0.14$; $P > 0.5$). However, if in a much larger study we were to observe a positive relationship between V_{W-E} and B_{avg}, similar to that reported here, then we would also expect a positive, though necessarily weaker, relationship between V_{W-D} and B_{avg}.

On the other hand, V_{P-W} was only weakly related to B_{avg} in our sample (Fig. 5). The prior computer model of a residential neighborhood [Kavet et al., 2000] reported a very high correlation between these two quantities. However, in the computer model, the grounding wire was the sole source of the residential magnetic field, whereas in the real world the field from the grounding wire is "diluted" by other magnetic field sources, most notably outdoor power lines. Also, V_{P-W} was unrelated to either W–L wire code Category or to the simplified Line Type Code category as described in Table 2. This finding is also not unexpected, because the ground currents producing V_{P-W} primarily involve the index residence and possibly neighboring residences in electrical contact through the ground. These phenomena do not appear to be a function of wiring classification of any type.

(2) Opportunity for exposure. With respect to V_{P-W}, exposure opportunity for a small child would be limited, often necessitating a reach from a water fixture to an appliance frame, a reach that could often extend beyond a child's physical dimensions. These factors, added to the high resistance associated with dry skin contact mitigate, in our opinion, the possibility that V_{P-W} may be an important source of contact current exposure, even when contact is made. Single hand contact with an appliance would probably result in negligible current because of the insulating properties of most footwear and flooring materials.

In contrast, a young child's opportunity for exposure to contact current driven by V_{W-D} is possible while bathing, a scenario that can occur hundreds of times per year. Exposure would occur under the conditions that the child contacts the faucet, spout, or the water stream. A wet hand, usually the case in the bathtub, facilitates a good electrical bond with the water system. We are not aware of any studies that describe a child's behavior relevant to this exposure. Thus, we are unable to estimate the amount of seconds or minutes that contact occurs per bath.

(3) Plausible dose. In the 22 residences with valid V_{W-D} measures, the median V_{W-D} was 68 mV with interquartile values of 22 and 113 mV. The median source impedance was 128 Ω, with interquartile values of 0 and 773 Ω. The median values project that for an immersed child of 1000 Ω (R_{Person} in Fig. 2) and child-to-drain resistance through the tub water of 1000 Ω (R_{Water} in Fig. 2), the median (and even 75th percentile) source impedance would be minor. Assuming zero impedance from hand-to-faucet ($R_{Contact}$ in Fig. 2 is zero), a contact at the median voltage would result in a contact current of roughly 30 μA (~68 mV/(1000 + 1000 Ω)). According to dose modeling [Dawson et al., 2001], this current is enough to produce 150 mV/m averaged over the bone marrow in the hand and forearm of a child sized subject, and over 300 mV/m in

5% of this marrow compartment. Tissue doses of this magnitude do not present the biophysical constraints to plausibility that are associated with magnetic fields typical of residential environments.

CONCLUSION

The results shown suggest that exposure to contact current associated with voltage on residential water pipes could lie at the heart of the association between magnetic fields and childhood leukemia. Our data call into question the possible role of HVTL in producing significant levels of V_{W-E} due to magnetic induction on the grounding system. HVTL are not especially prevalent in most epidemiology studies of magnetic fields and childhood leukemia. However, the zone over which a HVTL could affect voltage in the grounding system extends well beyond the distance limits of the W–L wire code categories, and HVTL exposure prevalence could have been underestimated in the epidemiologic literature. Furthermore, we believe the possibility that inductive effects from nearby HVTL could have been an influential factor in the Swedish power line study in which all cases and controls were residents within 300 m of a HVTL [Feychting and Ahlbom, 1993], which deserves further engineering study.

We present our data and comments in the context of a small study in a single locality. As builders and remodelers have shifted to plastic water pipes and drains in recent decades, the population wide opportunity for contact current due to V_{W-D} has likely diminished markedly. Further examination of the existing housing stock, supplemented by computer modeling, could shed light on the extent to which contact voltage associated with traditional wiring, grounding, and plumbing practices may have presented the opportunity for exposure to contact current in previous magnetic field epidemiology studies.

ACKNOWLEDGMENTS

We thank Ms. Jane Fillmore and Mr. Jay Canale for their tireless work in the field, and Prof. Robert Olsen and William H. Bailey, Ph.D. for their expert and thoughtful insight into the issues raised in this paper.

REFERENCES

Ahlbom A, Day N, Feychting M, Roman E, Skinner J, Dockerty J, Linet M, McBride M, Michaelis J, Olsen JH, Tynes T, Verkasalo PK. 2000. A pooled analysis of magnetic fields and childhood leukaemia. Br J Cancer 83:692–698.

Boorman GA, Rafferty CN, Ward JM, Sills RC. 2000. Leukemia and lymphoma incidence in rodents exposed to low-frequency magnetic fields. Radiat Res 153:627–636.

Dawson TW, Caputa K, Stuchly MA, Kavet R. 2001. Electric fields in the human body resulting from 60-hz contact currents. IEEE Trans Biomed Eng 48:1020–1026.

Feychting M, Ahlbom A. 1993. Magnetic fields and cancer in children residing near Swedish high-voltage power lines. Am J Epidemiol 138:467–481.

Greenland S, Sheppard AR, Kaune WT, Poole C, Kelsh MA. 2000. A pooled analysis of magnetic fields, wire codes, and childhood leukemia. Epidemiology 11:624–634.

Kavet R. 1995. Magnetic field exposure assessment. In: Blank M, editor. Electromagnetic fields: biological interactions and mechanisms. (Vol.) Washington, DC: American Chemical Society. pp 191–223.

Kavet R, Ulrich RM, Kaune WT, Johnson GB, Powers T. 1999. Determinants of power-frequency magnetic fields in residences located away from overhead power lines. Bioelectromagnetics 20:306–318.

Kavet R, Zaffanella LE, Daigle JP, Ebi KL. 2000. The possible role of contact current in cancer risk associated with residential magnetic fields. Bioelectromagnetics 21:538–553.

Kavet R, Stuchly MA, Bailey WH, Bracken TD. 2001. Evaluation of biological effects, dosimetric models, and exposure assessment related to ELF electric- and magnetic-field guidelines. Appl Occup Environ Hyg 16:1118–1138.

Kheifets LI, Kavet R, Sussman SS. 1997. Wire codes, magnetic fields, and childhood cancer. Bioelectromagnetics 18:99–110.

King KG, Sullivan TP, Zaffanella LE. 1997. Study of ground currents in proximity of substations. Palo Alto, CA: Electric Power Research Institute, TR-109272.

McCann J, Kavet R, Rafferty CN. 2000. Assessing the potential carcinogenic activity of magnetic fields using animal models. Environ Health Perspect 108(Suppl 1):79–100.

NIEHS. 1999. Health effects from exposure to power-line frequency electric and magnetic fields. National Institute of Environmental Health Sciences, Research Triangle Park, NC: NIH Publication No. 99-4493.

NIEHS Working Group. 1998. Assessment of health effects from exposure to power-line frequency electric and magnetic fields: working group report. Research Triangle Park, NC: National Institute of Environmental Health Sciences.

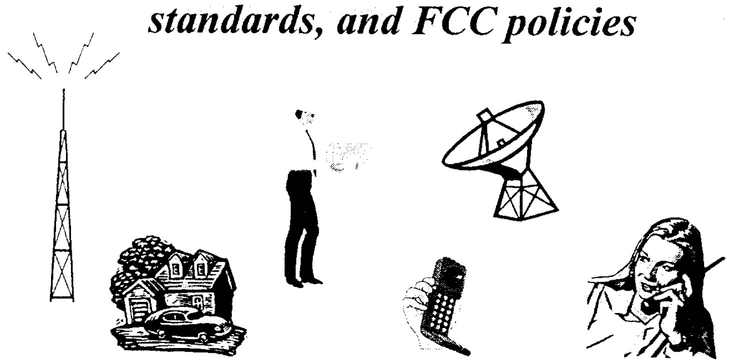
NRPB. 2001. ELF electromagnetic fields and the risk of cancer: report of an advisory group on non-ionising Radiation. (Vol 12), No 1: Chilton: National Radiological Protection Board.

Reilly JP. 1998. Applied bioelectricity: from electrical stimulation to electropathology. New York: Springer-Verlag.

Tarone RE, Kaune WT, Linet MS, Hatch EE, Kleinerman RA, Robison LL, Boice JD, Jr., Wacholder S. 1998. Residential wire codes: reproducibility and relation with measured magnetic fields. Occup Environ Med 55:333–339.

Zaffanella LE. 1993. Survey of residential magnetic field sources. Vol 1–2: Palo Alto, CA: Electric Power Research Institute, TR-102759.

Human Exposure to Radiofrequency Electromagnetic Fields: *biological effects, standards, and FCC policies*



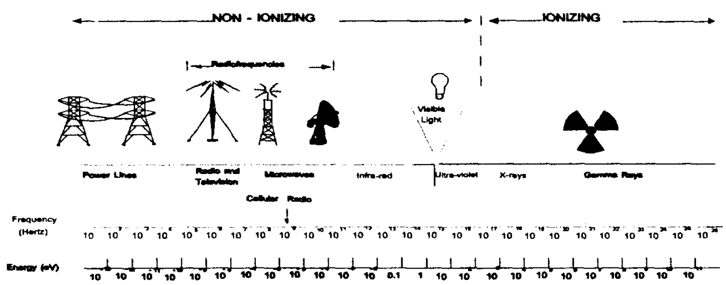
Radiofrequency Radiation or Radiofrequency Energy

- electromagnetic radiation
- "radiofrequency" or "Radio Frequency" = RF
- includes radio waves & microwaves
- "non-ionizing" radiation

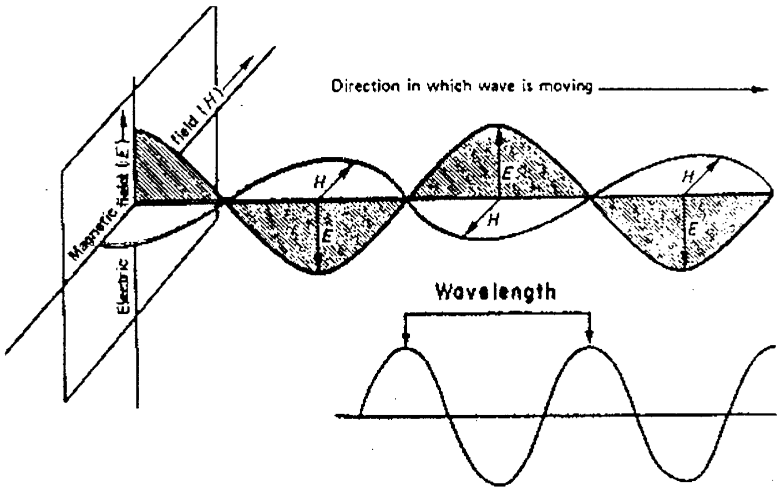
Radiofrequency electromagnetic radiation = *Non-ionizing radiation*

- *Ionizing vs. non-ionizing*
- **ionizing radiation:** ***greater amount of energy & more severe harmful effects (e.g., nuclear radiation, gamma rays)***
- **mechanisms of interaction are different (*ionizing radiation causes breakage of molecular bonds*)**

The Electromagnetic Spectrum



An Electromagnetic Wave



Far-field conditions:

$$S = \frac{E^2}{3770} = 37.7\,H^2$$

where:

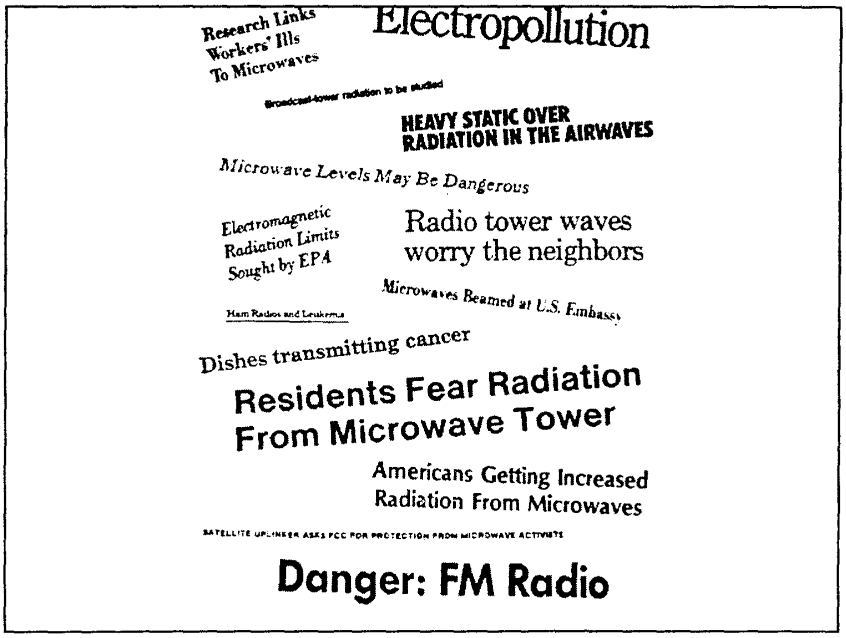
S = power density (mW/cm^2)

E = electric field strength (V/m)

H = magnetic field strength (A/m)

Major uses of radiofrequency energy:

- **Telecommunications**
- **Industrial applications**
- **Medical applications**



HERALD SUN (MELB) 1st Edition
Monday 28 April, 1997 Page 7

Mobile phones link to cancer

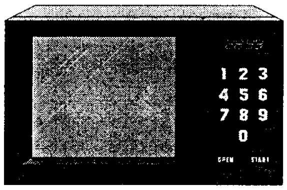
By BARRY HAILSTONE and LORETTA HALL

AN Australian hospital has established a link between the use of digital mobile phones and cancer.

Why is the FCC involved in this health & safety issue?

FCC has legal responsibilities under National Environmental Policy Act (NEPA) to evaluate environmental impact

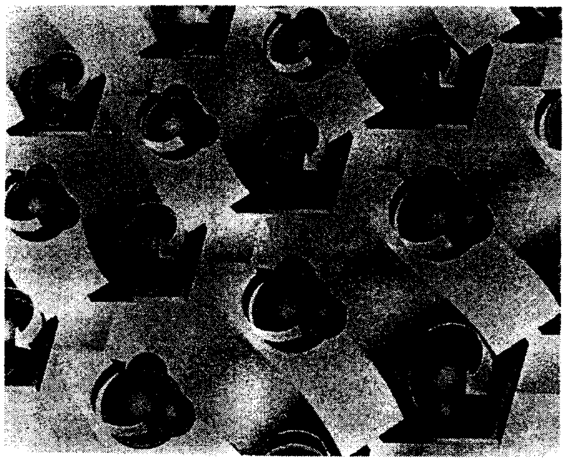
What are the potential biological effects of RF energy?



+

Radiofrequency (RF) Energy (microwaves)

= 



Microwave Heating: **Alternating electromagnetic waves cause electrically dipolar water molecules to spin → friction → heat. Heat is then passed to neighboring molecules.**

How are safe exposure levels determined?

A: mainly through biological experiments (animals, cell cultures) & epidemiologic studies (studies of health status of large groups of people)

<u>Big Issue</u>:

thermal biological effects

vs.

"non-thermal" biological effects

****Also: is an "effect" a hazard?***

Biological Effects of Exposure to RF Fields: *thermal vs. "non-thermal"*

- Thermal
- primarily short-term (acute)
- well-understood
- energy absorption by water molecules in tissue

- "Non-thermal"
- long-term (chronic)
- low-level
- controversial data
- mechanisms not understood
- relevance to health (if any) unknown

Some "Non-thermal" Effects Reported in the Scientific Literature:

- *effects on calcium ions in brain tissue*
- *effects on leakage of blood-brain barrier*
- *certain effects on immune system*
- *breaks in genetic material (DNA)*

*** However, not all effects have been replicated & relevance to human health not known**

FCC adopted original rules regarding RF exposure in 1985 and revised them in 1996

***U.S. Federal Communications Commission**: Policy Concerning Exposure to Radiofrequency Radiation from FCC-Regulated Transmitters*

- **FCC not a health and safety agency**
- **Relies on expert organizations and agencies for advice and guidance**
- **FCC has legal responsibilities under National Environmental Policy Act (NEPA) to evaluate impact on environment and health of its actions**

In 1996, FCC adopted new guidelines for evaluating human exposure to radiofrequency electromagnetic fields

- **1993 Notice of Proposed Rule Making**
- **Comments submitted by public, industry & other Federal agencies**
- **Rules: *47 CFR 1.1307(b), 1.1310, 2.1091, 2.1093.***
- **Final adoption required by 1996 Telecom Act**

Office of Engineering & Technology **RF Safety Program**

- develops policy recommendations
- assist FCC staff in evaluating RF sources
- liaison w/other agencies/organizations
- respond to Congressional/other inquiries
- conduct technical studies/evaluations
- conference presentations/participation
- respond to consumer inquiries

FCC Personnel involved with RF Safety

OET downtown:

- ✓ ***Scientific/technical:***
  - Robert Cleveland, Ed Mantiply
- ✓ ***Consumer issues/public outreach:***
  - Donice Jones, Michael Crowe

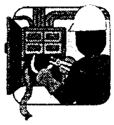
Also:
OET Lab: Kwok Chan, Tim Harrington, Martin Perrine
(portable/mobile device compliance)
EB (Denver): Jerry Ulcek *(enforcement)*

FCC INTERNET SITE for RF Safety: *www.fcc.gov/oet/rfsafety*

- **Frequently asked questions (FAQs)**
- **Information on FCC RF safety activities**
- **FCC RF safety publications**
- **Relevant FCC decision documents**
- **Joint FCC/FDA site on mobile phone safety**
- **Links to other relevant Web sites**

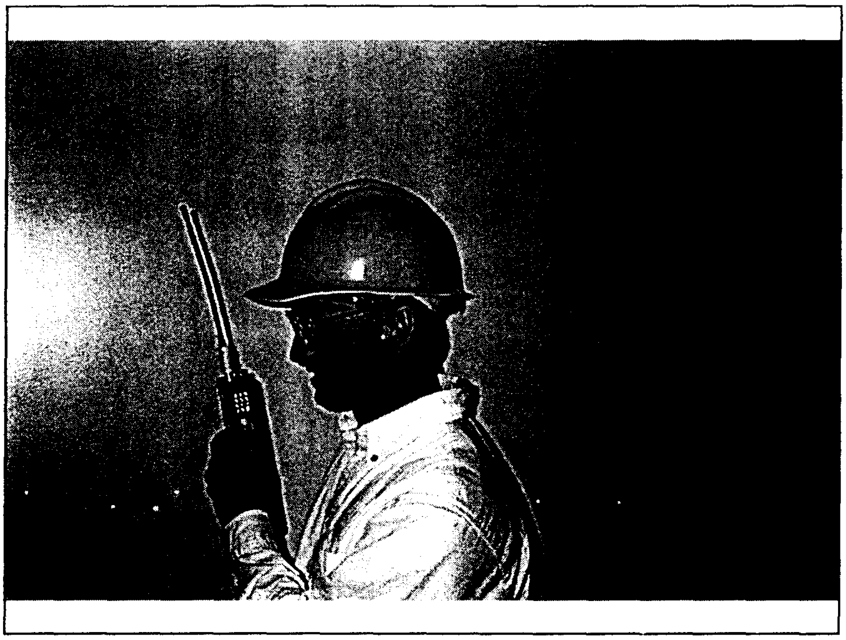
Also: **FCC RF Safety Information Telephone Line: +1-202-418-2464**

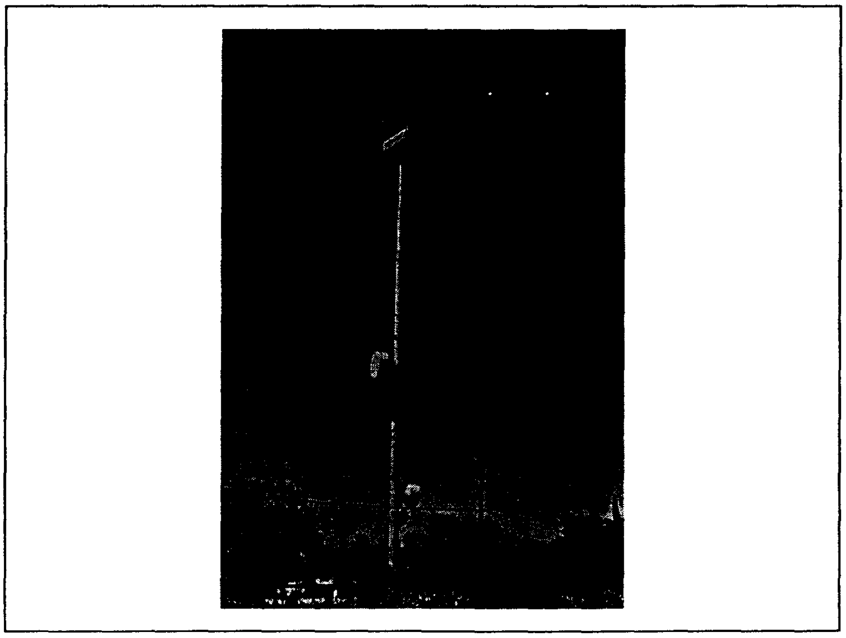
What are the sources of exposure to RF energy?

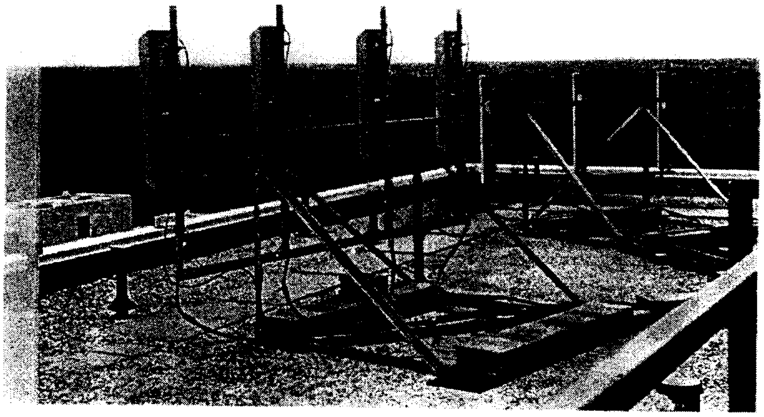


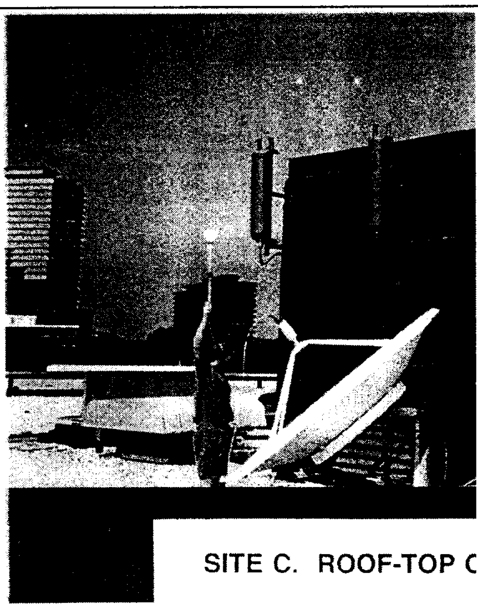
workers

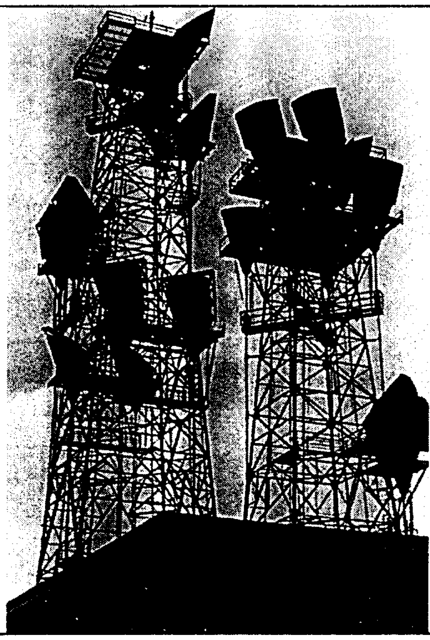
general public/consumers

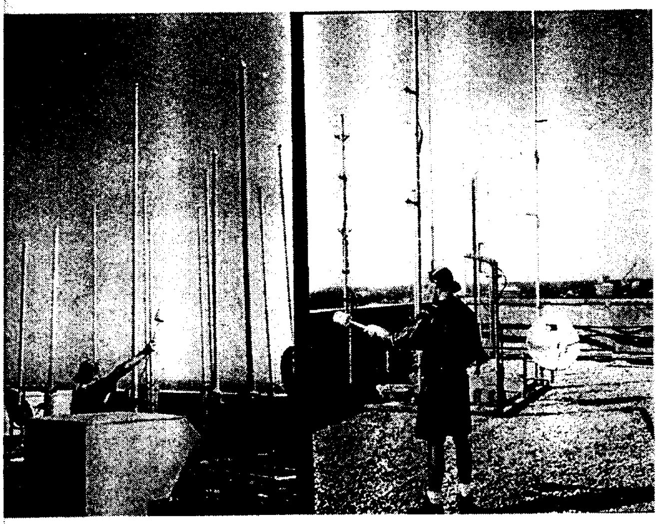


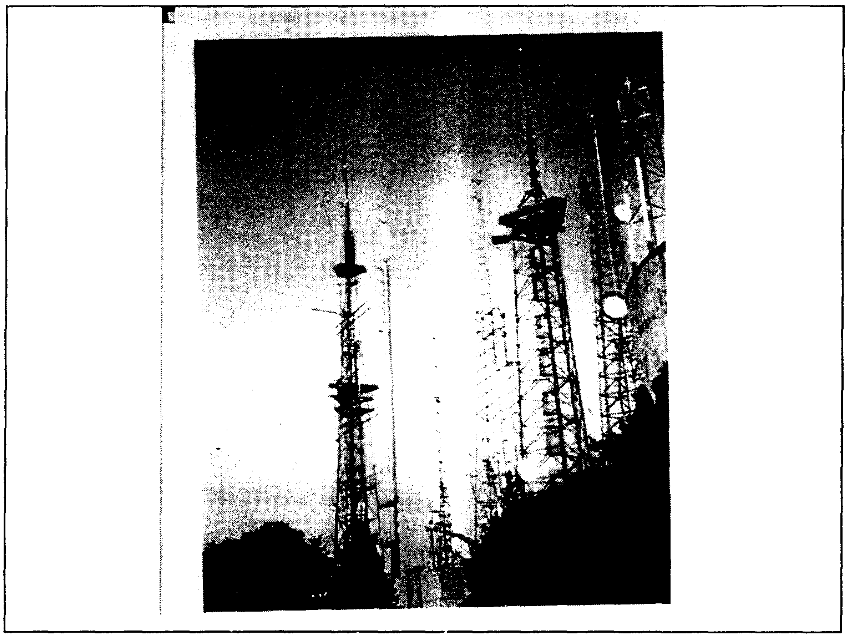


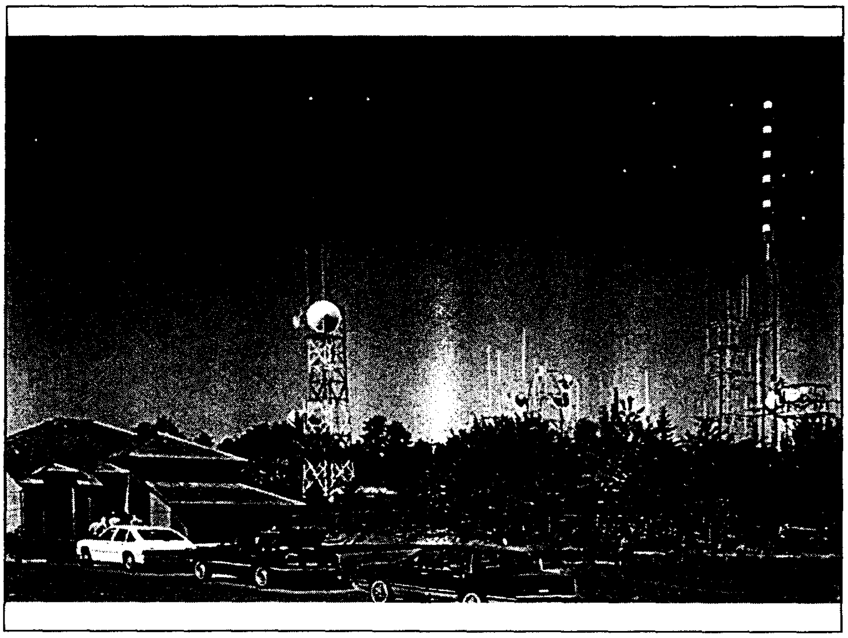


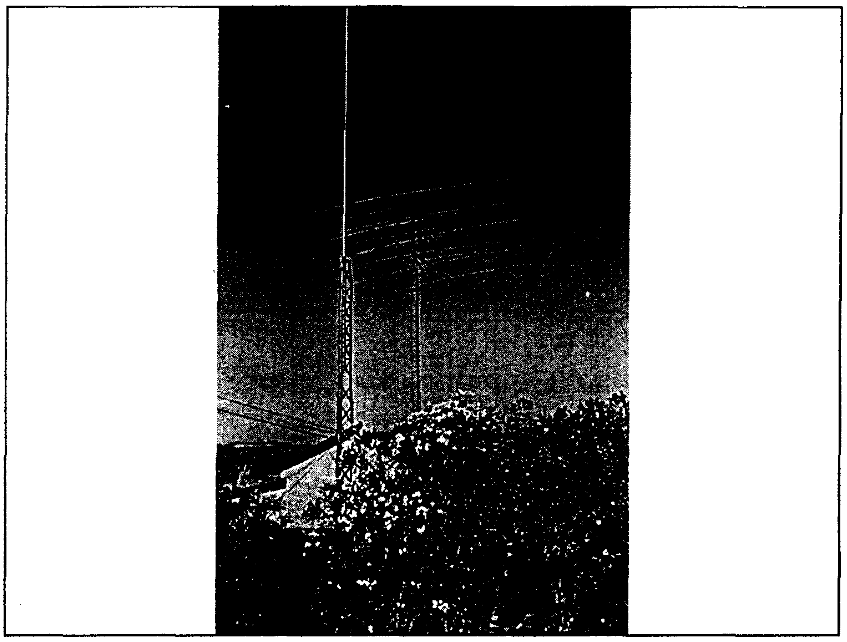

SITE C. ROOF-TOP C

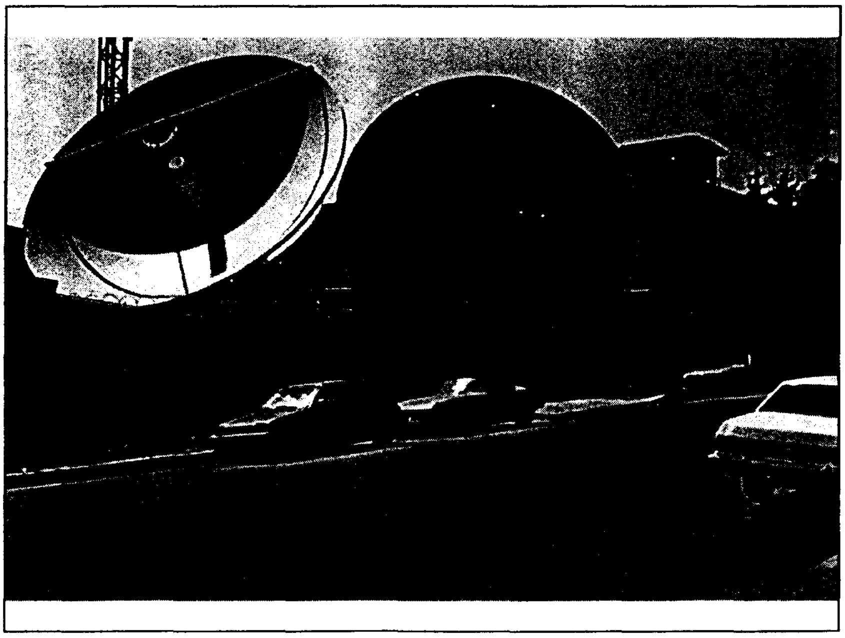


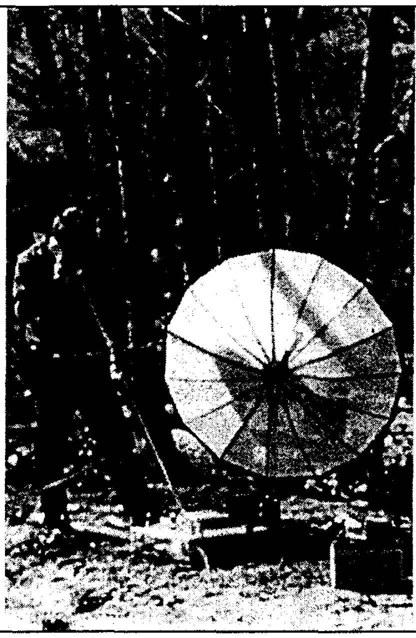












What are the standards for safe exposure?

Global Standards for RF Exposure: principal organizations developing recommended exposure limits

- Institute of Electrical and Electronics Engineers (IEEE)
- International Commission on Non-Ionizing Radiation Protection (ICNIRP)
- National Council on Radiation Protection and Measurements (USA)

Standards for RF Exposure Used in Various Countries

- ✓ USA: NCRP, IEEE
- ✓ Europe (& others): ICNIRP
- ✓ Others (Eastern Europe, China, etc.)

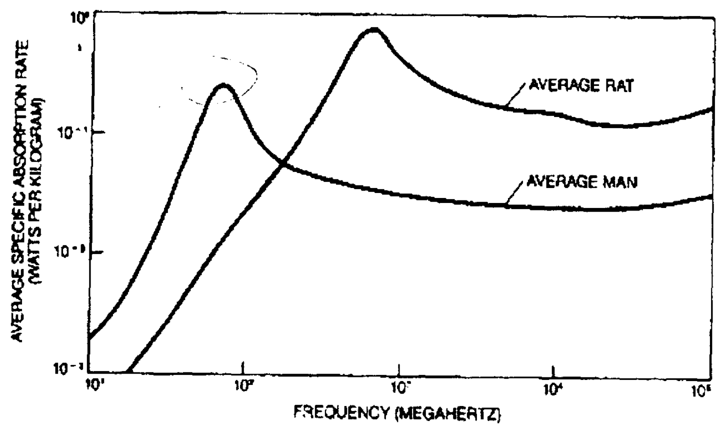
Standards for RF Exposure Used in Various Countries

- IEEE and NCRP exposure limits similar for most frequencies except certain low frequencies and microwave frequencies
- ICNIRP MPE limits also similar, but also some differences for low and high frequencies
- *Significant* differences between IEEE/NCRP and ICNIRP limits for cell phone exposure

Exposure Guidelines Based on *Specific Absorption Rate (SAR)*

- *SAR* = rate energy absorbed per unit mass
- *Units*: watts/kg (W/kg) or milliwatts/gm (mW/g)
- Resonant SAR peaks exist for whole-body SAR (maximum absorption rate)
- Whole-body adult human:
  - Resonant absorption at about 70-100 MHZ

Whole-body SAR is Dependent on Frequency of Incident Radiation



➢Many RF guidelines based on SAR level of 4 watts/kg (*whole body exposure*) as threshold for potentially harmful effects

➢Safety factors are incorporated so that actual exposure is well below this threshold

➢ANSI/IEEE, NCRP, ICNIRP exposure limits all based on this threshold

Recommended limits are <u>*exposure*</u> limits not <u>*emission*</u> limits

This means:

- **➢*Accessibility* (by public or workers) is critical**
- **➢ If no one is present in an RF environment then there is no exposure issue**

FCC Guidelines Based on Recommendations of US Government Health and Safety Agencies

- **✓ *EPA*: Environmental Protection Agency**
- **✓ *FDA*: Food and Drug Administration**
- **✓ *NIOSH*: Natl. Institute for Occupational Safety & Health**
- **✓ *OSHA*: Occupational Safety & Health Administration**

FCC limits have TWO tiers for Maximum Permissible Exposure (MPE)

(1) Occupational/Controlled Limits:

- *apply to workers*

(2) General Population/Uncontrolled Limits:

- *apply to general public (residential exposure, etc.)*

Units, frequencies, etc., used in FCC Guidelines

› **Frequency range: 300 kHz to 100 GHz**

- **exposure limits depend on frequency**

› **Maximum Permissible Exposure (MPE)**

- **power density: mW/cm^2**
- **field strength: V/m or A/m**

Table 1. FCC Limits for Maximum Permissible Exposure (MPE)

(A) *Limits for Occupational/Controlled Exposure*

Frequency Range (MHz)	Electric Field Strength (V/m)	Magnetic Field Strength (A/m)	Power Density (mW/cm^2)	Averaging Time (minutes)
0.3-3.0	614	1.63	(100)*	6
3.0-30	1842/f	4.89/f	($900/f^2$)*	6
30-300	61.4	0.163	1.0	6
300-1500	--	--	f/300	6
1500-100,000	--	--	5	6

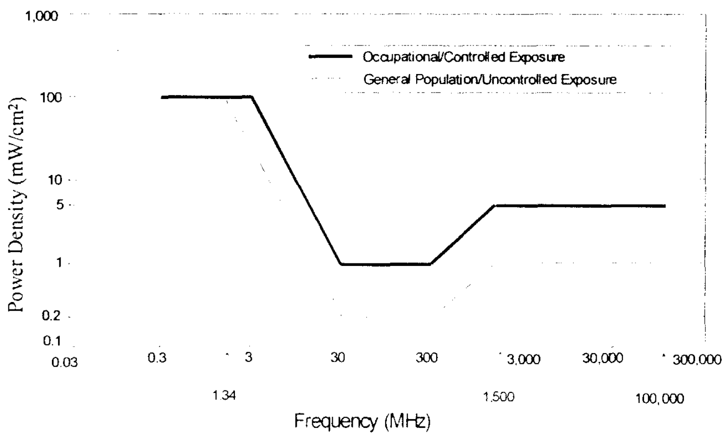
(B) *Limits for General Population/Uncontrolled Exposure*

Frequency Range (MHz)	Electric Field Strength (V/m)	Magnetic Field Strength (A/m)	Power Density (mW/cm^2)	Averaging Time (minutes)
0.3-1.34	614	1.63	(100)*	30
1.34-30	824/f	2.19/f	($180/f^2$)*	30
30-300	27.5	0.073	0.2	30
300-1500	--	--	f/1500	30
1500-100,000	--	--	1.0	30

f = frequency in MHz * = Plane-wave equivalent power density

Figure 1. FCC Limits for Maximum Permissible Exposure (MPE)

Plane-wave Equivalent Power Density



EXPOSURE: *worker vs public*

	WORKER	*PUBLIC*
Potential exposure/week	Usually 40 hours	Up to 168 hours
Knowledge of exposure	Usually well informed	Often not informed
Personal control over exposure	Usually possible	Often not possible
Health status/susceptibility	Generally healthy	May include invalids, shut-ins, infants, pregnant women, etc.
Monitoring of health	Usually good	May be poor

GUIDELINES ARE TIME-AVERAGED

EXAMPLE OCCUPATIONAL EXPOSURE TIMES ALLOWED BY FCC GUIDELINES AT VARIOUS POWER DENSITIES* DURING A SIX-MINUTE PERIOD (for MPE limit of 1 mW/cm^2)

Exposure Level (mW/cm^2)	Exposure Time Allowed	Time Out of RF Field
1.0	6 min	not applicable
1.5	4 min	2 min
2.0	3 min	3 min
3.0	2 min	4 min
5.0	1 min 12 sec	4 min 48 sec
10.0	36 sec	5 min 24 sec

* Plane-wave equivalent power density.

FCC POLICY ON EVALUATION OF MOBILE/PORTABLE DEVICES

•EFFECTIVE DATE: *August 1996*

•TWO CATEGORIES:
- ➢ *"PORTABLE" DEVICES*: used within 20 cm of body
- ➢ *"MOBILE" DEVICES*: not used within 20 cm of body

•EVALUATING PORTABLE DEVICES (ex. cell phones)
- ➢ Specific absorption rate (SAR) limits apply
- ➢ Laboratory procedure

•EVALUATING MOBILE DEVICES
- ➢ Field strength/power density limits apply

How is compliance with the FCC exposure guidelines evaluated?

- **FIXED ANTENNA SITES**
- **PORTABLE DEVICES (cell phones)**

REVISED FCC CATEGORICAL EXCLUSIONS

August 1997

SERVICE TYPE	EVALUATION REQUIRED IF
Experimental Radio Service	P>100 W ERP (164W EIRP)
Multipoint Distribution Service	non-roof: ht <10m & P>1640W EIRP roof: P>1640W EIRP
Paging and Radiotelephone Service	non-roof: ht <10m & P>1000W ERP roof: P>1000W ERP
Cellular Radiotelephone Service	non-roof: ht <10m & P>1000W ERP (all channels) roof: P>1000W ERP (all channels)
Personal Communications Service (Narrowband: P = 1000 W) (Broadband: P = 2000 W)	non-roof: ht <10m & power> P (ERP) roof: power>P (ERP) (P in all channels) non-roof: ht <10m & power>P (ERP) roof: power>P (ERP) (P in all channels)
Satellite Communications	all included
Radio and Television Broadcast	all included
Auxiliary Broadcast, etc.	depends on service
Maritime Radio Services	ship earth stations only
Amateur Radio Service	transmitter output P > (see 47 CFR 97 13)

ALSO ADDED General WCS, Part 26; WCS, Part 27, and LMDS, Part 101

Methods for Evaluating Compliance

- *CALCULATIONS/EXPERIMENTAL METHODS*
- *COMPUTER MODELS*
- *FIELD MEASUREMENTS*
- *PORTABLE/MOBILE DEVICES*

⚠ *FCC RF Safety Publications*

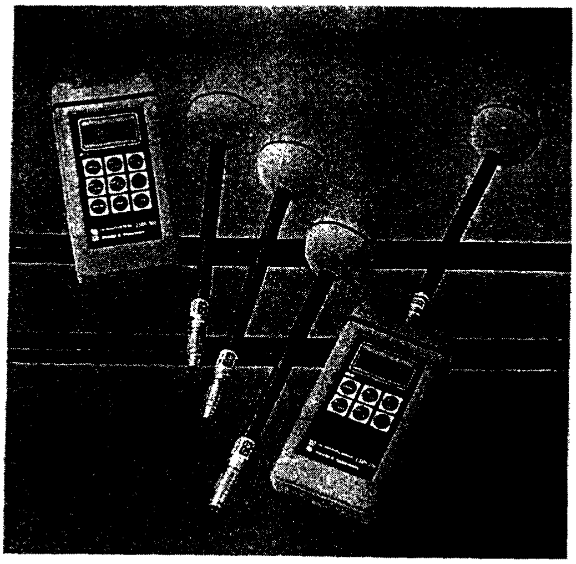
- **OET BULLETIN 56:** ***general information, FAQ's***
- **OET BULLETIN 65: guide for evaluating compliance with FCC RF exposure limits**
- **OET 65 SUPPLEMENTS:**
  - **A: Broadcast**
  - **B: Amateur radio**
  - **C: Mobile & portable devices**
- **LOCAL GOVERNMENT (LSGAC) GUIDE**
- **Others (Cellular/PCS factsheet, public notices, etc.)**

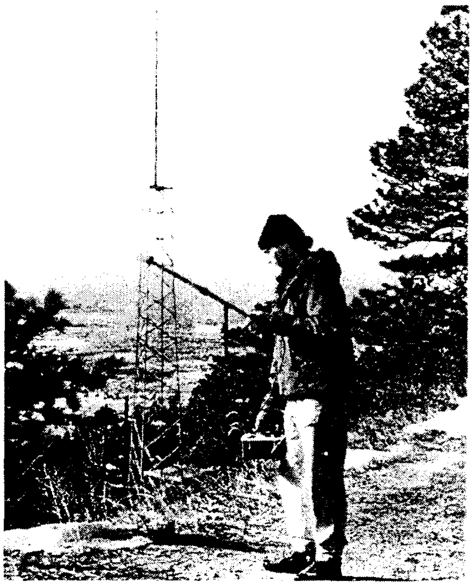
Federal Communications Commission
Office of Engineering & Technology

Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields

OET Bulletin 65
Edition 97-01

August 1997

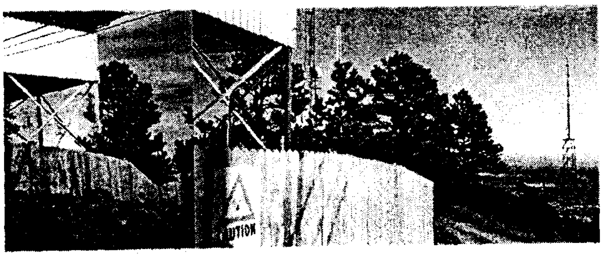


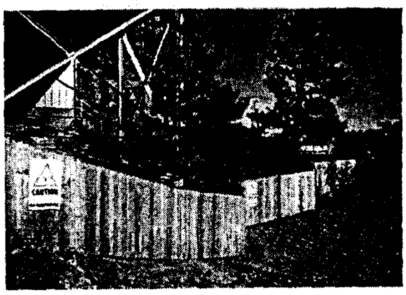


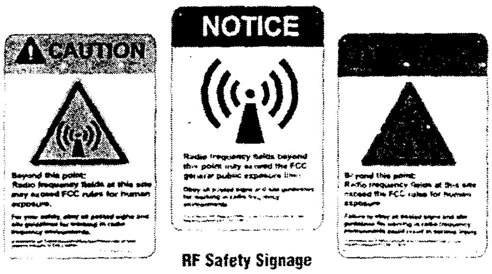
Ways To Control Exposure For Fixed Transmitting Stations

PUBLIC EXPOSURE:

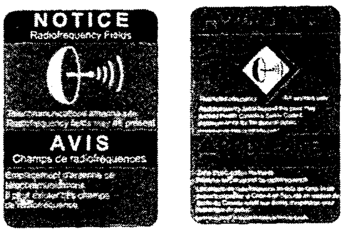
- Restrict access by fencing or other means
- Use warning/alerting signs in restricted areas
- Redesign antenna to selectively reduce RF levels
- Increase antenna height to reduce RF on ground
- Relocate to new site







RF Safety Signage

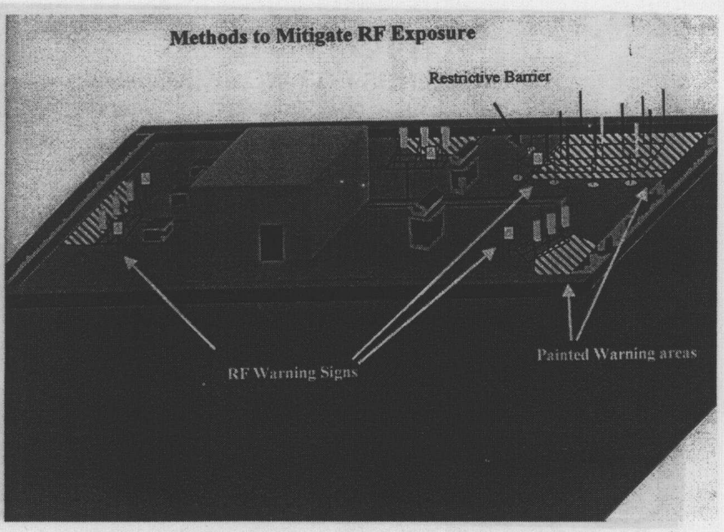


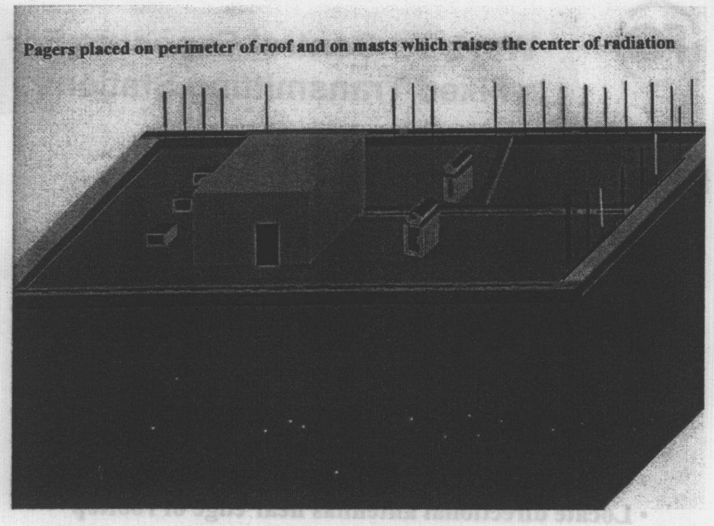
Rf Safety Signage

Ways To Control Exposure For Fixed Transmitting Stations

WORKPLACE EXPOSURE:

- **Educate & train personnel**
- **Develop RF work practices**
- **Limit time of exposure (time averaging)**
- **Use warning/alerting signs & restrict access**
- **Shield RF sources**
- **Reduce power as necessary**
- **Use auxiliary/temporary transmitters**
- **Use protective clothing and personal monitors**
- **Elevate rooftop antennas above roof level**
- **Locate directional antennas near edge of rooftop**





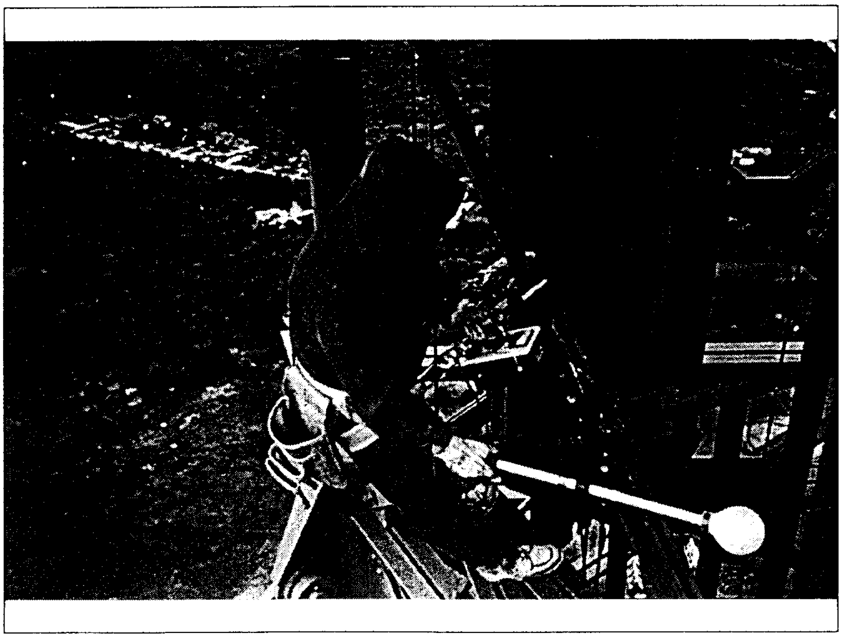
example

⚠ NOTICE ⚠

GUIDELINES FOR WORKING IN RADIOFREQUENCY ENVIRONMENTS

- ⚠ All personnel should have electromagnetic energy (EME) awareness training.
- ⚠ All personnel entering this site must be authorized.
- ⚠ Obey all posted signs.
- ⚠ Assume all antennas are active.
- ⚠ Before working on antennas, notify owners and disable appropriate transmitters.
- ⚠ Maintain minimum 3 feet clearance from all antennas.
- ⚠ Do not stop in front of antennas.
- ⚠ Use personal RF monitors while working near antennas.
- ⚠ Never operate transmitters without shields during normal operation.
- ⚠ Do not operate base station antennas in equipment room.


RF / MICROWAVE
MONITOR
HOLADAY
INDUSTRIES
narda
50%



In the USA: Both FCC and Occupational Safety and Health Administration (OSHA) have regulations concerning workplace exposure to RF radiation

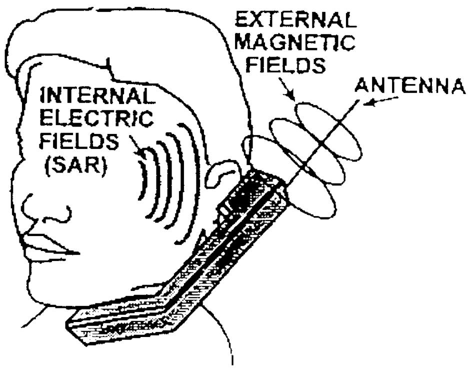
- **OSHA regulations emphasize the development of worker education and training program ("RF Safety Program")**
- **FCC regulations also endorse formal education and training programs**

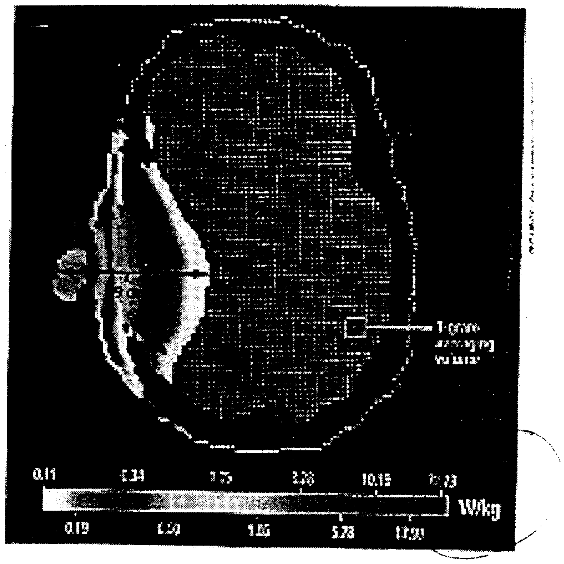
FCC POLICY ON EVALUATION OF MOBILE/PORTABLE DEVICES

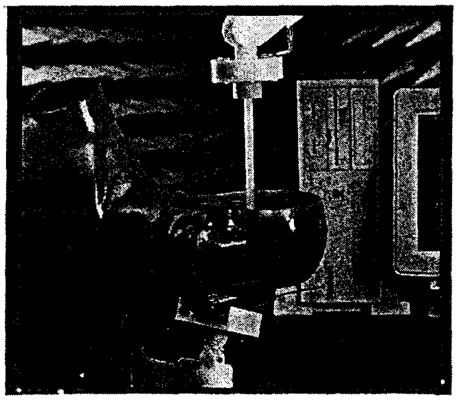
➢ **FCC limit for hand-held devices such as cell phones is SAR level of 1.6 watts per kilogram (1.6 W/kg) avgd over 1 gm**

➢ **OET laboratory is responsible for certifying compliance of portable devices such as cell phones with this limit**

SAR induced in head of user by cell phone is proportional to the internal electric field







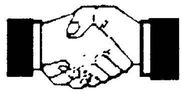
Wireless Facility Siting:
Federal vs Local Jurisdiction

- Sec 704 of Telecomm Act of 1996 amended Sec 332(c) of Communications Act
- Local authority limited to placement, construction, modification of wireless facilities
- Restricts local regulation of wireless facilities based on RF emissions
- LSGAC established to provide advice & information to FCC on local/state concerns
- Web information: www.fcc.gov/wtb/siting

Federal
Communications
Commission

Local and State
Government
Advisory
Committee

A Local Government Official's Guide to Transmitting Antenna RF Emission Safety: Rules, Procedures, and Practical Guidance



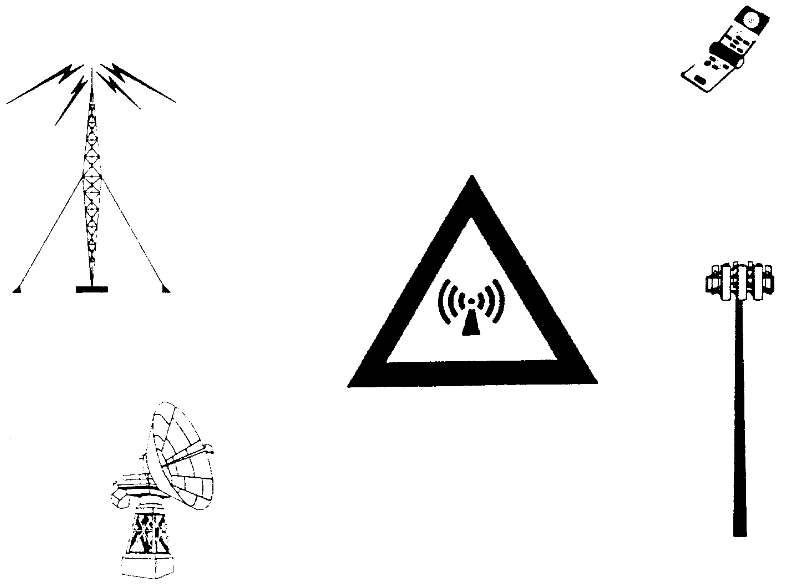
June 2, 2000

Future Developments & Issues

- Results of ongoing research into cell phone safety
- Revision of safety standards
- Adoption of uniform mobile phone test standards
- Completion of international WHO project and recommendations for research and standards development

Federal Communications Commission
Office of Engineering & Technology

Questions and Answers about Biological Effects and Potential Hazards of Radiofrequency Electromagnetic Fields



OET BULLETIN 56
Fourth Edition

August 1999

Questions and Answers about Biological Effects and Potential Hazards of Radiofrequency Electromagnetic Fields

OET BULLETIN 56

Fourth Edition

August 1999

Authors
Robert F. Cleveland, Jr.
Jerry L. Ulcek

Office of Engineering and Technology
Federal Communications Commission
Washington, D.C. 20554

INTRODUCTION

Many consumer and industrial products and applications make use of some form of electromagnetic energy. One type of electromagnetic energy that is of increasing importance worldwide is radiofrequency (or "RF") energy, including radio waves and microwaves, which is used for providing telecommunications, broadcast and other services. In the United States the Federal Communications Commission (FCC) authorizes or licenses most RF telecommunications services, facilities, and devices used by the public, industry and state and local governmental organizations. Because of its regulatory responsibilities in this area the FCC often receives inquiries concerning whether there are potential safety hazards due to human exposure to RF energy emitted by FCC-regulated transmitters. Heightened awareness of the expanding use of RF technology has led some people to speculate that "electromagnetic pollution" is causing significant risks to human health from environmental RF electromagnetic fields. This document is designed to provide factual information and to answer some of the most commonly asked questions related to this topic.[1]

WHAT IS RADIOFREQUENCY ENERGY?

Radio waves and microwaves are forms of electromagnetic energy that are collectively described by the term "radiofrequency" or "RF." RF emissions and associated phenomena can be discussed in terms of "energy," "radiation" or "fields." Radiation is defined as the propagation of energy through space in the form of waves or particles. Electromagnetic "radiation" can best be described as waves of electric and magnetic energy moving together (i.e., radiating) through space as illustrated in **Figure 1.** These waves are generated by the movement of electrical charges such as in a conductive metal object or antenna. For example, the alternating movement of charge (i.e., the "current") in an antenna used by a radio or television broadcast station or in a cellular base station antenna generates electromagnetic waves that radiate away from the "transmit" antenna and are then intercepted by a "receive" antenna such as a rooftop TV antenna, car radio antenna or an antenna integrated into a hand-held device such as a cellular telephone. The term "electromagnetic field" is used to indicate the presence of electromagnetic energy at a given location. The RF field can be described in terms of the electric and/or magnetic field strength at that location.[2]

Like any wave-related phenomenon, electromagnetic energy can be characterized by a wavelength and a frequency. The wavelength (λ) is the distance covered by one complete

---

[1] Exposure to low-frequency electromagnetic fields generated by electric power transmission has also been the subject of public concern. However, because the FCC does not have regulatory authority with respect to power-line electromagnetic fields, this document only addresses questions related to **RF** exposure. Information about exposure due to electrical power transmission can be obtained from several sources, including the following Internet World Wide Web site: **http://www.niehs.nih.gov/emfrapid**

[2] The term "EMF" is often used to refer to electromagnetic fields, in general. It can be used to refer to either power-line frequency fields, radiofrequency electromagnetic fields or both.

electromagnetic wave cycle, as shown in **Figure 1**. The frequency is the number of electromagnetic waves passing a given point in one second. For example, a typical radio wave transmitted by an FM radio station has a wavelength of about three (3) meters and a frequency of about 100 million cycles (waves) per second or "100 MHz." One "hertz" (abbreviated "Hz") equals one cycle per second. Therefore, in this case, about 100 million RF electromagnetic waves would be transmitted to a given point every second.

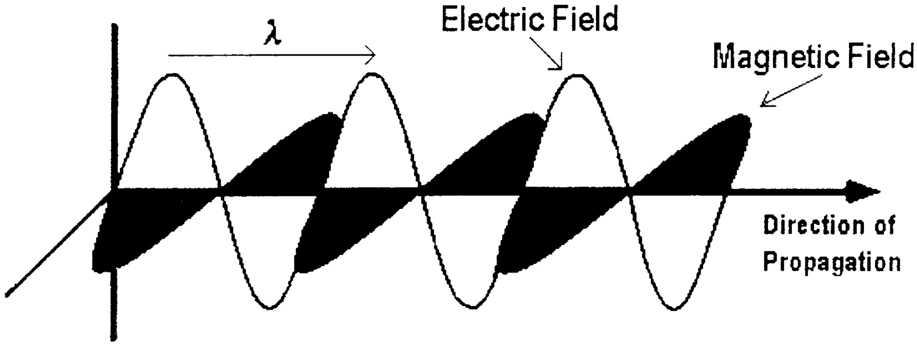


FIGURE 1. *Electromagnetic Wave*

Electromagnetic waves travel through space at the speed of light, and the wavelength and frequency of an electromagnetic wave are inversely related by a simple mathematical formula: frequency (*f*) times wavelength (λ) = the speed of light (*c*), or $f \times \lambda = c$. This simple equation can also be expressed as follows in terms of either frequency or wavelength:

$$f = \frac{c}{\lambda} \quad or \quad \lambda = \frac{c}{f}$$

Since the speed of light in a given medium or vacuum does not change, high-frequency electromagnetic waves have short wavelengths and low-frequency waves have long wavelengths. The electromagnetic "spectrum" (**Figure 2**) includes all the various forms of electromagnetic energy from extremely low frequency (ELF) energy, with very long wavelengths, to X-rays and gamma rays, which have very high frequencies and correspondingly short wavelengths. In between these extremes are radio waves, microwaves, infrared radiation, visible light, and ultraviolet radiation, in that order. The RF part of the electromagnetic spectrum is generally defined as that part of the spectrum where electromagnetic waves have frequencies in the range of about 3 kilohertz to 300 gigahertz. One kilohertz (kHz) equals one thousand hertz, one megahertz (MHz) equals one million hertz, and one gigahertz (GHz) equals one billion hertz. Thus, when you tune your FM radio to 101.5, it means that your radio is receiving signals from a radio station emitting radio waves at a frequency of 101.5 million cycles (waves) per second, or 101.5 MHz.

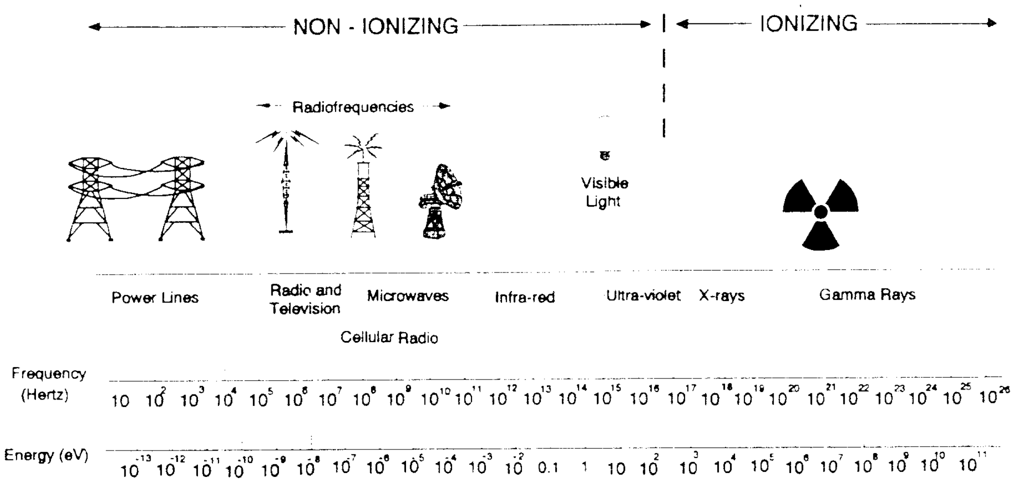


FIGURE 2. *The Electromagnetic Spectrum*

HOW DO WE USE RADIOFREQUENCY ENERGY?

Probably the most important use for RF energy is in providing telecommunications services to the public, industry and government. Radio and television broadcasting, cellular telephones, personal communications services (PCS), pagers, cordless telephones, business radio, radio communications for police and fire departments, amateur radio, microwave point-to-point radio links and satellite communications are just a few of the many applications of RF energy for telecommunications.

Microwave ovens and radar are examples of non-communications uses of RF energy. Also important are uses of RF energy in industrial heating and sealing where electronic devices generate RF radiation that rapidly heats the material being processed in the same way that a microwave oven cooks food. RF heaters and sealers have many uses in industry, including molding plastic materials, gluing wood products, sealing items such as shoes and pocketbooks, and processing food products.

There are a number of medical applications of RF energy, including a technique called *diathermy*, that take advantage of the ability of RF energy to rapidly heat tissue below the body's surface. Tissue heating ("hyperthermia") can be beneficial in the therapeutic treatment of injured tissue and cancerous tumors (*see* References 17 & 18).

WHAT ARE MICROWAVES?

Microwaves are a specific category of radio waves that can be defined as radiofrequency radiation where frequencies range upward from several hundred megahertz (MHz) to several gigahertz (GHz). One of the most familiar and widespread uses of microwave energy is found in household microwave ovens, which operate at a frequency of 2450 MHz (2.45 GHz).

Microwaves are also widely used for telecommunications purposes such as for cellular radio, personal communications services (PCS), microwave point-to-point communication, transmission links between ground stations and orbiting satellites, and in certain broadcasting operations such as studio-to-transmitter (STL) and electronic news gathering (ENG) radio links. Microwave radar systems provide information on air traffic and weather and are extensively used in military and police applications. In the medical field microwave devices are used for a variety of therapeutic purposes including the selective heating of tumors as an adjunct to chemotherapy treatment (microwave hyperthermia).

Radiofrequency radiation, especially at microwave frequencies, efficiently transfers energy to water molecules. At high microwave intensities the resulting energetic water molecules can generate heat in water-rich materials such as most foods. The operation of microwave ovens is based on this principle. This efficient absorption of microwave energy via water molecules results in rapid heating throughout an object, thus allowing food to be cooked more quickly than in a conventional oven.

WHAT IS NON-IONIZING RADIATION?

As explained earlier, electromagnetic radiation is defined as the propagation of energy through space in the form of waves or particles. Some electromagnetic phenomena can be most easily described if the energy is considered as waves, while other phenomena are more readily explained by considering the energy as a flow of particles or "photons." This is known as the "wave-particle" duality of electromagnetic energy. The energy associated with a photon, the elemental unit of an electromagnetic wave, depends on its frequency (or wavelength). The higher the frequency of an electromagnetic wave (and the shorter its corresponding wavelength), the greater will be the energy of a photon associated with it. The energy content of a photon is often expressed in terms of the unit "electron-volt" or "eV".

Photons associated with X-rays and gamma rays (which have very high electromagnetic frequencies) have a relatively large energy content. At the other end of the electromagnetic spectrum, photons associated with low-frequency waves (such as those at ELF frequencies) have many times less energy. In between these extremes ultraviolet radiation, visible light, infrared radiation, and RF energy (including microwaves) exhibit intermediate photon energy content. For comparison, the photon energies associated with high-energy X-rays are billions of times ***more*** energetic than the energy of a 1-GHz microwave photon. The photon energies associated with the various frequencies of the electromagnetic spectrum are shown in the lower scale of **Figure 2**.

Ionization is a process by which electrons are stripped from atoms and molecules. This process can produce molecular changes that can lead to damage in biological tissue, including effects on DNA, the genetic material. This process requires interaction with photons containing high energy levels, such as those of X-rays and gamma rays. A single quantum event (absorption of an X-ray or gamma-ray photon) can cause ionization and subsequent biological damage due to the high energy content of the photon, which would be in excess of 10 eV (considered to be the minimum photon energy capable of causing ionization). Therefore, X-rays and gamma rays are examples of ***ionizing*** radiation. Ionizing radiation is also associated with the generation of nuclear energy, where it is often simply referred to as "radiation."

The photon energies of RF electromagnetic waves are not great enough to cause the ionization of atoms and molecules and RF energy is, therefore, characterized as ***non-ionizing*** radiation, along with visible light, infrared radiation and other forms of electromagnetic radiation with relatively low frequencies. It is important that the terms "ionizing" and "non-ionizing" not be confused when discussing biological effects of electromagnetic radiation or energy, since the mechanisms of interaction with the human body are quite different.

HOW ARE RADIOFREQUENCY FIELDS MEASURED?

Because an RF electromagnetic field has both an electric and a magnetic component (electric field and magnetic field), it is often convenient to express the intensity of the RF field in terms of units specific for each component. The unit "volts per meter" (V/m) is often used to measure the strength ("field strength") of the electric field, and the unit "amperes per meter" (A/m) is often used to express the strength of the magnetic field.

Another commonly used unit for characterizing an RF electromagnetic field is "power density." Power density is most accurately used when the point of measurement is far enough away from the RF emitter to be located in what is commonly referred to as the "far-field" zone of the radiation source, e.g., more than several wavelengths distance from a typical RF source. In the far field, the electric and magnetic fields are related to each other in a known way, and it is only necessary to measure one of these quantities in order to determine the other quantity or the power density. In closer proximity to an antenna, i.e., in the "near-field" zone, the physical relationships between the electric and magnetic components of the field are usually complex. In this case, it is necessary to determine both the electric and magnetic field strengths to fully characterize the RF environment. (Note: In some cases equipment used for making field measurements displays results in terms of "far-field equivalent" power density, even though the measurement is being taken in the near field.) At frequencies above about 300 MHz it is usually sufficient to measure only the electric field to characterize the RF environment if the measurement is not made too close to the RF emitter.

Power density is defined as power per unit area. For example, power density can be expressed in terms of milliwatts per square centimeter (mW/cm^2) or microwatts per square centimeter ($\mu W/cm^2$). One mW equals 0.001 watt of power, and one μW equals 0.000001 watt. With respect to frequencies in the microwave range and higher, power density is usually used to express intensity since exposures that might occur would likely be in the far-field. More details about the physics of RF fields and their analysis and measurement can be found in References 2, 3, 8, 21, 33, 34 and 35.

WHAT BIOLOGICAL EFFECTS CAN BE CAUSED BY RF ENERGY?

A biological effect occurs when a change can be measured in a biological system after the introduction of some type of stimuli. However, the observation of a biological effect, in and of itself, does not necessarily suggest the existence of a biological ***hazard***. A biological effect only becomes a safety hazard when it "causes detectable impairment of the health of the individual or of his or her offspring" (Reference 25).

There are many published reports in the scientific literature concerning possible biological effects resulting from animal or human exposure to RF energy. The following discussion only provides highlights of current knowledge, and it is not meant to be a complete review of the scientific literature in this complex field. A number of references are listed at the end of this document that provide further information and details concerning this topic and some recent research reports that have been published (References 1, 3, 6, 7, 9, 14, 15-19, 21, 25, 26, 28-31, 34, 36, 39-41, 47, 49 and 53).

Biological effects that result from heating of tissue by RF energy are often referred to as "thermal" effects. It has been known for many years that exposure to high levels of RF radiation can be harmful due to the ability of RF energy to heat biological tissue rapidly. This is the principle by which microwave ovens cook food, and exposure to very high RF power densities, i.e., on the order of 100 mW/cm^2 or more, can clearly result in heating of biological tissue and an increase in body temperature. Tissue damage in humans could occur during exposure to high RF levels because of the body's inability to cope with or dissipate the excessive heat that could be generated. Under certain conditions, exposure to RF energy at power density levels of 1-10 mW/cm^2 and above can result in measurable heating of biological tissue (but not necessarily tissue damage). The extent of this heating would depend on several factors including radiation frequency; size, shape, and orientation of the exposed object; duration of exposure; environmental conditions; and efficiency of heat dissipation.

Two areas of the body, the eyes and the testes, are known to be particularly vulnerable to heating by RF energy because of the relative lack of available blood flow to dissipate the excessive heat load (blood circulation is one of the body's major mechanisms for coping with excessive heat). Laboratory experiments have shown that short-term exposure (e.g., 30 minutes to one hour) to very high levels of RF radiation (100-200 mW/cm^2) can cause cataracts in rabbits. Temporary sterility, caused by such effects as changes in sperm count and in sperm motility, is possible after exposure of the testes to high-level RF radiation (or to other forms of energy that produce comparable increases in temperature).

Studies have shown that environmental levels of RF energy routinely encountered by the general public are *far below* levels necessary to produce significant heating and increased body temperature (References 32, 37, 45, 46, 48 and 54). However, there may be situations, particularly workplace environments near high-powered RF sources, where recommended limits for safe exposure of human beings to RF energy could be exceeded. In such cases, restrictive measures or actions may be necessary to ensure the safe use of RF energy.

In addition to intensity, the frequency of an RF electromagnetic wave can be important in determining how much energy is absorbed and, therefore, the potential for harm. The quantity used to characterize this absorption is called the "specific absorption rate" or "SAR," and it is usually expressed in units of watts per kilogram (W/kg) or milliwatts per gram (mW/g). In the far-field of a source of RF energy (e.g., several wavelengths distance from the source) whole-body absorption of RF energy by a standing human adult has been shown to occur at a maximum rate when the frequency of the RF radiation is between about 80 and 100 MHz, depending on the size, shape and height of the individual. In other words, the SAR is at a maximum under these conditions. Because of this "resonance" phenomenon, RF safety standards have taken account of the frequency dependence of whole-body human absorption, and the most restrictive limits on exposure are found in this frequency range (the very high frequency or "VHF" frequency range).

Although not commonly observed, a microwave "hearing" effect has been shown to occur under certain very specific conditions of frequency, signal modulation, and intensity where animals and humans may perceive an RF signal as a buzzing or clicking sound. Although a number of theories have been advanced to explain this effect, the most widely-accepted hypothesis is that the microwave signal produces thermoelastic pressure within the head that is perceived as sound by the auditory apparatus within the ear. This effect is not recognized as a health hazard, and the conditions under which it might occur would rarely be encountered by members of the public. Therefore, this phenomenon should be of little concern to the general population. Furthermore, there is no evidence that it could be caused by telecommunications applications such as wireless or broadcast transmissions.

At relatively low levels of exposure to RF radiation, i.e., field intensities lower than those that would produce significant and measurable heating, the evidence for production of harmful biological effects is ambiguous and unproven. Such effects have sometimes been referred to as "non-thermal" effects. Several years ago publications began appearing in the scientific literature, largely overseas, reporting the observation of a wide range of low-level biological effects. However, in many of these cases further experimental research was unable to reproduce these effects. Furthermore, there has been no determination that such effects might indicate a human health hazard, particularly with regard to long-term exposure.

More recently, other scientific laboratories in North America, Europe and elsewhere have reported certain biological effects after exposure of animals ("*in vivo*") and animal tissue ("*in vitro*") to relatively low levels of RF radiation. These reported effects have included certain changes in the immune system, neurological effects, behavioral effects, evidence for a link between microwave exposure and the action of certain drugs and compounds, a "calcium efflux" effect in brain tissue (exposed under very specific conditions), and effects on DNA.

Some studies have also examined the possibility of a link between RF and microwave exposure and cancer. Results to date have been inconclusive. While some experimental data have suggested a possible link between exposure and tumor formation in animals exposed under certain specific conditions, the results have not been independently replicated. In fact, other studies have failed to find evidence for a causal link to cancer or any related condition. Further research is underway in several laboratories to help resolve this question.

In general, while the possibility of "non-thermal" biological effects may exist, whether or not such effects might indicate a human health hazard is not presently known. Further research is needed to determine the generality of such effects and their possible relevance, if any, to human health. In the meantime, standards-setting organizations and government agencies continue to monitor the latest experimental findings to confirm their validity and determine whether alterations in safety limits are needed in order to protect human health.

WHAT RESEARCH IS BEING DONE ON RF BIOLOGICAL EFFECTS?

For many years research into possible biological effects of RF energy has been carried out in government, academic and industrial laboratories all over the world, and such research is continuing. Past research has resulted in a very large number of scientific publications on this topic, some of which are listed in the reference section of this document. For many years the U.S. Government has sponsored research into the biological effects of RF energy. The majority of this work has been funded by the Department of Defense, due, in part, to the extensive military interest in using RF equipment such as radar and other relatively high-powered radio transmitters for routine military operations. In addition, some U.S. civilian federal agencies responsible for health and safety, such as the Environmental Protection Agency (EPA) and the U.S. Food and Drug Administration (FDA), have sponsored and conducted research in this area in the past, although relatively little civilian-sector RF research is currently being funded by the U.S. Government. At the present time, much of the non-military research on biological effects of RF energy in the U.S. is being funded by industry organizations such as Motorola, Inc. In general, relatively more research is being carried out overseas, particularly in Europe.

In 1996, the World Health Organization (WHO) established a program (the International EMF Project) designed to review the scientific literature concerning biological effects of electromagnetic fields, identify gaps in knowledge about such effects, recommend research needs, and work towards international resolution of health concerns over the use of RF technology. (*see* Reference 40) The WHO and other organizations maintain Internet Web sites that contain additional information about their programs and about RF biological effects and research (see list of Web sites in **Table 3** of this bulletin). The FDA, the EPA and other federal agencies responsible for public health and safety are working with the WHO and other organizations to monitor developments and identify research needs related to RF biological effects. For example, in 1995 the EPA published the results of a conference it sponsored to assess the current state of knowledge of RF biological effects and to address future research needs in this area (Reference 53).

WHAT LEVELS ARE SAFE FOR EXPOSURE TO RF ENERGY?

Development of Exposure Guidelines

Exposure standards and guidelines have been developed by various organizations and countries over the past several decades. In North America and most of Europe exposure standards and guidelines have generally been based on exposure levels where effects considered harmful to humans occur. Safety factors are then incorporated to arrive at specific levels of exposure to provide sufficient protection for various segments of the population.

Not all standards and guidelines throughout the world have recommended the same limits for exposure. For example, some published exposure limits in Russia and some eastern European countries have been generally more restrictive than existing or proposed recommendations for exposure developed in North America and other parts of Europe. This discrepancy may be due, at least in part, to the possibility that these standards were based on exposure levels where it was believed no biological effects *of any type* would occur. This philosophy is inconsistent with the approach taken by most other standards-setting bodies which base limits on levels where recognized hazards may occur and then incorporate appropriate safety margins to ensure adequate protection.

In the United States, although the Federal Government has never itself developed RF exposure standards, the FCC has adopted and used recognized safety guidelines for evaluating RF environmental exposure since 1985. Federal health and safety agencies, such as the Environmental Protection Agency (EPA), the Food and Drug Administration (FDA), the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) have also been actively involved in monitoring and investigating issues related to RF exposure. For example, the FDA has issued guidelines for safe RF emission levels from microwave ovens, and it continues to monitor exposure issues related to the use of certain RF devices such as cellular telephones. NIOSH conducts investigations and health hazard assessments related to occupational RF exposure.

In 1971, a federal RF radiation protection guide for workers was issued by OSHA based on the 1966 American National Standards Institute (ANSI) RF exposure standard. However, the OSHA regulation was later ruled to be advisory only and not enforceable. Presently, OSHA enforcement actions related to RF exposure of workers are undertaken using OSHA's "general duty clause," which relies on the use of widely-supported voluntary "consensus" standards such as those discussed below.[3]

U.S. federal, state and local governmental agencies and other organizations have generally relied on RF exposure standards developed by expert non-government organizations such as ANSI, the Institute of Electrical and Electronics Engineers (IEEE) and the National Council on Radiation Protection and Measurements (NCRP).[4] For example, in 1966, 1974, and 1982, ANSI issued protection guides for RF exposure developed by committees of experts. These earlier ANSI standards recommended limits for exposure of the public that were the same as those recommended for exposure of workers.

In 1986, the NCRP issued exposure criteria for the workplace that were the same as the 1982 ANSI recommended levels, but the NCRP also recommended more restrictive limits for exposure of the general public. Therefore, the NCRP exposure criteria included ***two*** tiers of recommended limits, one for the general population and another for occupational exposure. In 1987, the ANSI committee on RF exposure standards (Standards Coordinating Committee 28) became a committee of the IEEE, and, in 1991, revised its earlier standard and issued its own two-tiered standard that had been developed over a period of several years.

---

[3] For information about OSHA RF-related activities and RF protection programs for workers, see the OSHA Internet Web site (case sensitive): www.osha-slc.gov/SLTC/ (select subject: "radiofrequency radiation").

[4] ANSI is a non-profit, privately funded, membership organization that coordinates development of voluntary national standards. The IEEE is a non-profit technical and professional engineering society. The NCRP is a non-profit corporation chartered by the U.S. Congress to develop information and recommendations concerning radiation protection. Several government agencies, including the FCC, and non-government organizations have established relationships with NCRP as "Collaborating Organizations."

The ANSI/IEEE standards have been widely used and cited and have served as the basis for similar standards in the United States and in other countries. Both the NCRP and ANSI/IEEE guidelines were developed by scientists and engineers with a great deal of experience and knowledge in the area of RF biological effects and related issues. These individuals spent a considerable amount of time evaluating published scientific studies relevant to establishing safe levels for human exposure to RF energy.

In addition to NCRP and ANSI/IEEE, other organizations and countries have issued exposure guidelines. For example, several European countries are basing guidelines on exposure criteria developed by the International Committee on Nonionizing Radiation Protection (ICNIRP, Reference 25). The ICNIRP guidelines are also derived from an SAR threshold of 4 W/kg (for adverse effects) and are similar to the 1992 ANSI/IEEE and NCRP recommendations with certain exceptions. For example, ICNIRP recommends somewhat different exposure levels in the lower and upper frequency ranges and for localized exposure due to such devices as hand-held cellular telephones. Many, but not all, countries have based exposure recommendations on the same general concepts and thresholds as those used by the NCRP, ANSI/IEEE and ICNIRP. Because of differences in international standards, the World Health Organization (WHO), as part of its EMF Project (discussed earlier), has initiated a program to try and develop an international framework for RF safety standards.

FCC Exposure Guidelines

In 1985, the FCC adopted the 1982 ANSI guidelines for purposes of evaluating exposure due to RF transmitters licensed and authorized by the FCC. This decision was in response to provisions of the National Environmental Policy Act of 1969 requiring all Federal Government agencies to evaluate the impact of their actions on the "quality of the human environment."[5] In 1992, ANSI adopted the 1991 IEEE standard as an American National Standard (a revision of its 1982 standard) and designated it ANSI/IEEE C95.1-1992.[6]

In 1993, the FCC proposed to update its rules and adopt the new ANSI/IEEE guidelines. After a lengthy period to allow for the filing of comments and for deliberation the FCC decided, in 1996, to adopt a modified version of its original proposal.[7] The FCC's

[5] The National Environmental Policy Act of 1969, 42 USC Section 4321, *et seq.*

[6] ANSI/IEEE C95.1-1992 (originally issued as IEEE C95.1-1991), "IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz," (Reference 3).

[7] *See Report and Order* and *Second Memorandum Opinion and Order and Notice of Proposed Rulemaking*, ET Docket 93-62, (References 55 and 56). In 1997, the FCC released a technical bulletin entitled, "Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields," OET Bulletin 65 (Reference 57) that contains detailed information on methods for compliance with FCC guidelines. These documents can be accessed at the FCC's Web site: **http://www.fcc.gov/oet/rfsafety.**

action also fulfilled requirements of the Telecommunications Act of 1996 for adopting new RF exposure guidelines.[8]

The FCC considered a large number of comments submitted by industry, government agencies and the public. In particular, the FCC considered comments submitted by the EPA, FDA, NIOSH and OSHA, which have primary responsibility for health and safety in the Federal Government. The guidelines the FCC adopted were based on the recommendations of those agencies, and they have sent letters to the FCC supporting its decision and endorsing the FCC's guidelines as protective of public health.

In its 1996 Order, the FCC noted that research and analysis relating to RF safety and health is ongoing and changes in recommended exposure limits may occur in the future as knowledge increases in this field. In that regard, the FCC will continue to cooperate with industry and with expert agencies and organizations with responsibilities for health and safety in order to ensure that the FCC's guidelines continue to be appropriate and scientifically valid.

The FCC's guidelines are based on recommended exposure criteria issued by the NCRP and ANSI/IEEE. The NCRP exposure guidelines are similar to the ANSI/IEEE 1992 guidelines except for differences in recommended exposure levels at the lower frequencies and higher frequencies of the RF spectrum. Both ANSI/IEEE and NCRP recommend two different tiers of exposure limits. The NCRP designates one tier for occupational exposure and the other for exposure of the general population while ANSI/IEEE designates exposure tiers in terms of "environments," one for "controlled" environments and the other for "uncontrolled" environments. Over a broad range of frequencies, NCRP exposure limits for the public are generally one-fifth those for workers in terms of power density.[9]

The NCRP and ANSI/IEEE exposure criteria identify the same threshold level at which harmful biological effects may occur, and the values for Maximum Permissible Exposure (MPE) recommended for electric and magnetic field strength and power density in

---

[8] The Telecommunications Act of 1996, enacted on February 8, 1996, required that: "Within 180 days after the enactment of this Act, the Commission shall complete action in ET Docket 93-62 to prescribe and make effective rules regarding the environmental effects of radio frequency emissions." *See* Section 704(b) of the Telecommunications Act of 1996, Pub. L. No. 104-104, 110 Stat. 56 (1996).

[9] The FCC adopted limits for field strength and power density that are based on Sections 17.4.1 and 17.4.2, and the time-averaging provisions of Sections 17.4.1.1 and 17.4.3, of "Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields," NCRP Report No. 86, for frequencies between 300 kHz and 100 GHz (Reference 34). With the exception of limits on exposure to power density above 1500 MHz, and limits for exposure to lower frequency magnetic fields, these MPE limits are also based on the guidelines developed by the IEEE and adopted by ANSI. *See* Section 4.1 of ANSI/IEEE C95.1-1992, "Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz" (Reference 3).

both documents are based on this threshold level.[10] In addition, both the ANSI/IEEE and NCRP guidelines are frequency dependent, based on findings (discussed earlier) that whole-body human absorption of RF energy varies with the frequency of the RF signal. The most restrictive limits on exposure are in the frequency range of 30-300 MHz where the human body absorbs RF energy most efficiently when exposed in the far field of an RF transmitting source. Although the ANSI/IEEE and NCRP guidelines differ at higher and lower frequencies, at frequencies used by the majority of FCC licensees the MPE limits are essentially the same regardless of whether ANSI/IEEE or NCRP guidelines are used.

Most radiofrequency safety limits are defined in terms of the electric and magnetic field strengths as well as in terms of power density. For lower frequencies, limits are more meaningfully expressed in terms of electric and magnetic field strength values, and the indicated power densities are actually "far-field equivalent" power density values. The latter are listed for comparison purposes and because some instrumentation used for measuring RF fields is calibrated in terms of far-field or plane-wave equivalent power density. At higher frequencies, and when one is actually in the "far field" of a radiation source, it is usually only necessary to evaluate power density. In the far field of an RF transmitter power density and field strength are related by standard mathematical equations.[11]

The exposure limits adopted by the FCC in 1996 expressed in terms of electric and magnetic field strength and power density for transmitters operating at frequencies from 300 kHz to 100 GHz are shown in **Table 1**. The FCC also adopted limits for localized ("partial body") absorption in terms of SAR, shown in **Table 2**, that apply to certain portable transmitting devices such as hand-held cellular telephones.[12]

---

[10] These exposure limits are based on criteria quantified in terms of specific absorption rate (SAR). SAR is a measure of the rate at which the body absorbs RF energy. Both the ANSI/IEEE and NCRP exposure criteria are based on a determination that potentially harmful biological effects can occur at an SAR level of 4 W/kg as averaged over the whole-body. Appropriate safety factors have been incorporated to arrive at limits for both whole-body exposure (0.4 W/kg for "controlled" or "occupational" exposure and 0.08 W/kg for "uncontrolled" or "general population" exposure, respectively) and for partial-body (localized SAR), such as might occur in the head of the user of a hand-held cellular telephone. The new MPE limits are more conservative in some cases than the limits specified by ANSI in 1982. However, these more conservative limits do not arise from a fundamental change in the SAR threshold for harm, but from a precautionary desire to add an additional margin of safety for exposure of the public or exposure in "uncontrolled' environments.

[11] See OET Bulletin 65 (Reference 57) for details.

[12] These guidelines are based on those recommended by ANSI/IEEE and NCRP. *See* Sections 4.2.1 and 4.2.2 of ANSI/IEEE C95.1-1992 and Section 17.4.5 of NCRP Report No. 86. For purposes of evaluation, the FCC has designated these devices as either "portable" or "mobile" depending on how they are to be used. Portable devices are normally those used within 20 centimeters of the body and must be evaluated with respect to SAR limits. Mobile devices are normally used 20 centimeters or more away from the body and can be evaluated in terms of either SAR or field intensity. Detailed information on FCC requirements for evaluating portable and mobile devices can be found in OET Bulletin 65 and in the FCC's Rules and Regulations, 47 CFR 2.1091 and 2.1093.

Time Averaging of Exposure

The NCRP and ANSI/IEEE exposure criteria and most other standards specify ***"time-averaged"*** MPE limits. This means that it is permissible to exceed the recommended limits for short periods of time as long as the ***average*** exposure (over the appropriate period specified) does not exceed the limit. For example, Table 1 shows that for a frequency of 100 MHz the recommended power density limit is 1 mW/cm^2 with an averaging time of six minutes (any six-minute period) for occupational/controlled exposure.

The time-averaging concept can be illustrated as follows for exposure in a workplace environment. The sum of the product (or products) of the actual exposure level(s) multiplied by the actual time(s) of exposure must not be greater than the allowed (average) exposure limit times the specified averaging time. Therefore, for 100 MHz, exposure at 2 mW/cm^2 would be permitted for three minutes in any six-minute period as long as during the remaining three minutes of the six-minute period the exposure was at or near "zero" level of exposure. Therefore, in this example:

$$\mathbf{(2\ mW/cm^2)\ X\ (3\ min.) + (0\ mW/cm^2)\ X\ (3\ min.) = (1\ mW/cm^2)\ X\ (6\ min.)}$$

Of course, other combinations of power density and time are possible. It is *very important* to remember that time averaging of exposure is only necessary or relevant for situations where temporary exposures might occur that are *in excess of* the absolute limits for power density or field strength. These situations usually only occur in workplace environments where exposure can be monitored and controlled. For general population/uncontrolled exposures, say in a residential neighborhood, it is seldom possible to have sufficient information or control regarding how long people are exposed, and averaging of exposure over the designated time period (30 minutes) is normally not appropriate. For such public exposure situations, the MPE limits normally apply for continuous exposure. In other words, as long as the absolute limits are not exceeded, indefinite exposure is allowed.

Induced and Contact Currents

In addition to limits on field strength, power density and SAR, some standards for RF exposure have incorporated limits for currents induced in the human body by RF fields. For example, the 1992 ANSI/IEEE standard (Reference 3), includes specific restrictions that apply to "induced" and "contact" currents (the latter, which applies to "grasping" contact, is more related to shock and burn hazards). The limits on RF currents are based on experimental data showing that excessive SAR levels can be created in the body due to the presence of these currents. In its 1996 Order adopting new RF exposure guidelines the FCC declined to adopt limits on induced and contact currents due primarily to the difficulty of reliably determining compliance, either by prediction methods or by direct measurement. However, the FCC may reconsider this decision in the future because of the development of new instrumentation and analytical techniques that may be more reliable indicators of exposure.

Table 1. ***FCC Limits for Maximum Permissible Exposure (MPE)***

(A) Limits for Occupational/Controlled Exposure

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.3-3.0	614	1.63	(100)*	6
3.0-30	1842/f	4.89/f	$(900/f^2)$*	6
30-300	61.4	0.163	1.0	6
300-1500	--	--	f/300	6
1500-100,000	--	--	5	6

(B) Limits for General Population/Uncontrolled Exposure

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.3-1.34	614	1.63	(100)*	30
1.34-30	824/f	2.19/f	$(180/f^2)$*	30
30-300	27.5	0.073	0.2	30
300-1500	--	--	f/1500	30
1500-100,000	--	--	1.0	30

f = frequency in MHz *Plane-wave equivalent power density

NOTE 1: Occupational/controlled limits apply in situations in which persons are exposed as a consequence of their employment provided those persons are fully aware of the potential for exposure and can exercise control over their exposure. Limits for occupational/controlled exposure also apply in situations when an individual is transient through a location where occupational/controlled limits apply provided he or she is made aware of the potential for exposure.

NOTE 2: General population/uncontrolled exposures apply in situations in which the general public may be exposed, or in which persons that are exposed as a consequence of their employment may not be fully aware of the potential for exposure or can not exercise control over their exposure.

Table 2. *FCC Limits for Localized (Partial-body) Exposure*

Specific Absorption Rate (SAR)	
Occupational/Controlled Exposure (100 kHz - 6 GHz)	**General Uncontrolled/Exposure (100 kHz - 6 GHz)**
< 0.4 W/kg whole-body **≤ 8 W/kg partial-body**	**< 0.08 W/kg whole-body** **≤ 1.6 W/kg partial-body**

WHY HAS THE FCC ADOPTED GUIDELINES FOR RF EXPOSURE?

The FCC authorizes and licenses devices, transmitters and facilities that generate RF and microwave radiation. It has jurisdiction over all transmitting services in the U.S. except those specifically operated by the Federal Government. However, the FCC's primary jurisdiction does not lie in the health and safety area, and it must rely on other agencies and organizations for guidance in these matters.

Under the National Environmental Policy Act of 1969 (NEPA), the FCC has certain responsibilities to consider whether its actions will "significantly affect the quality of the human environment." Therefore, FCC approval and licensing of transmitters and facilities must be evaluated for significant impact on the environment. Human exposure to RF radiation emitted by FCC-regulated transmitters is one of several factors that must be considered in such environmental evaluations.

Major RF transmitting facilities under the jurisdiction of the FCC, such as radio and television broadcast stations, satellite-earth stations, experimental radio stations and certain cellular, PCS and paging facilities are required to undergo routine evaluation for RF compliance whenever an application is submitted to the FCC for construction or modification of a transmitting facility or renewal of a license. Failure to comply with the FCC's RF exposure guidelines could lead to the preparation of a formal Environmental Assessment, possible Environmental Impact Statement and eventual rejection of an application. Technical guidelines for evaluating compliance with the FCC RF safety requirements can be found in the FCC's OET Bulletin 65 (Reference 57).

Low-powered, intermittent, or inaccessible RF transmitters and facilities are normally "categorically excluded" from the requirement for ***routine*** evaluation for RF exposure. These exclusions are based on calculations and measurement data indicating that such transmitting stations or devices are unlikely to cause exposures in excess of the guidelines under normal conditions of use.[13] The FCC's policies on RF exposure and categorical exclusion can be found in Section 1.1307(b) of the FCC's Rules and Regulations.[14] It should be emphasized, however, that these exclusions are ***not*** exclusions from compliance, but, rather, only exclusions from routine evaluation. Furthermore, transmitters or facilities that are otherwise categorically excluded from evaluation may be required, on a case-by-case basis, to demonstrate compliance when evidence of potential non-compliance of the transmitter or facility is brought to the Commission's attention [*see* 47 CFR §1.1307(c) and (d)].

The FCC's policies with respect to environmental RF fields are designed to ensure that FCC-regulated transmitters do not expose the public or workers to levels of RF radiation that are considered by expert organizations to be potentially harmful. Therefore, if a transmitter and its associated antenna are regulated by the FCC, they must comply with provisions of the FCC's rules regarding human exposure to RF radiation. In its 1997 Order, the FCC adopted a provision that all transmitters regulated by the FCC, regardless of whether they are excluded from routine evaluation, are expected to be in compliance with the new guidelines on RF exposure by September 1, 2000 (Reference 56).

In the United States some local and state jurisdictions have also enacted rules and regulations pertaining to human exposure to RF energy. However, the Telecommunications Act of 1996 contained provisions relating to federal jurisdiction to regulate human exposure to RF emissions from certain transmitting devices.. In particular, Section 704 of the Act states that, "No State or local government or instrumentality thereof may regulate the placement, construction, and modification of personal wireless service facilities on the basis of the environmental effects of radio frequency emissions to the extent that such facilities comply with the Commission's regulations concerning such emissions." Further information on FCC policy with respect to facilities siting is available in a factsheet from the FCC's Wireless Telecommunications Bureau.[15]

---

[13] The Council on Environmental Quality, which has oversight responsibility with regard to NEPA, permits federal agencies to categorically exclude certain actions from routine environmental processing when the potential for individual or cumulative environmental impact is judged to be negligible (40 CFR §§ 1507, 1508.4 and "Regulations for Implementing the Procedural Provisions of NEPA, 43 Fed. Reg. 55,978, 1978).

[14] 47 Code of Federal Regulations 1.1307(b).

[15] "Fact Sheet 2", September 17, 1997, entitled, "*National Wireless Facilities Siting Policies*," from the FCC's Wireless Telecommunications Bureau. This factsheet can be viewed and downloaded from the bureau's Internet World Wide Web Site: http://www.fcc.gov/wtb/.

ARE EMISSIONS FROM RADIO AND TELEVISION ANTENNAS SAFE?

Radio and television broadcast stations transmit their signals via RF electromagnetic waves. There are currently approximately 14,000 radio and TV stations on the air in the United States. Broadcast stations transmit at various RF frequencies, depending on the channel, ranging from about 550 kHz for AM radio up to about 800 MHz for some UHF television stations. Frequencies for FM radio and VHF television lie in between these two extremes. Operating powers ("effective radiated power") can be as little as a few hundred watts for some radio stations or up to millions of watts for certain television stations. Some of these signals can be a significant source of RF energy in the local environment, and the FCC requires that broadcast stations submit evidence of compliance with FCC RF guidelines.

The amount of RF energy to which the public or workers might be exposed as a result of broadcast antennas depends on several factors, including the type of station, design characteristics of the antenna being used, power transmitted to the antenna, height of the antenna and distance from the antenna. Since energy at some frequencies is absorbed by the human body more readily than energy at other frequencies, the frequency of the transmitted signal as well as its intensity is important. Calculations can be performed to predict what field intensity levels would exist at various distances from an antenna.

Public access to broadcasting antennas is normally restricted so that individuals cannot be exposed to high-level fields that might exist near antennas. Measurements made by the FCC, EPA and others have shown that ambient RF radiation levels in inhabited areas near broadcasting facilities are typically well below the exposure levels recommended by current standards and guidelines (References 32, 46, 48, 51, 52). There have been a few situations around the country where RF levels in publicly accessible areas have been found to be higher than those recommended by applicable safety standards (e.g., see Reference 50). But, in spite of the relatively high operating powers of many stations, such cases are unusual, and members of the general public are unlikely to be exposed to RF levels from broadcast towers that exceed FCC limits. Wherever such situations have arisen corrective measures have been undertaken to ensure that areas promptly come into compliance with the applicable guidelines.

In cases where exposure levels might pose a problem, there are various steps a broadcast station can take to ensure compliance with safety standards. For example, high-intensity areas could be posted and access to them could be restricted by fencing or other appropriate means. In some cases more drastic measures might have to be considered, such as re-designing an antenna, reducing power, or station relocation.

Antenna maintenance workers are occasionally required to climb antenna structures for such purposes as painting, repairs, or beacon replacement. Both the EPA and OSHA have reported that in these cases it is possible for a worker to be exposed to high levels of RF energy if work is performed on an active tower or in areas immediately surrounding a radiating antenna (e.g., see Reference 42, 43, 45, and 51). Therefore, precautions should be taken to ensure that maintenance personnel are not exposed to unsafe RF fields. Such precautions could include temporarily lowering power levels while work is being performed, having work performed only when the station is not broadcasting, using auxiliary antennas while work is performed on the main antenna, and establishing work procedures that would specify the minimum distance that a worker should maintain from an energized antenna.

HOW SAFE ARE MICROWAVE AND SATELLITE ANTENNAS?

Point-to-Point Microwave Antennas

Point-to-point microwave antennas transmit and receive microwave signals across relatively short distances (from a few tenths of a mile to 30 miles or more). These antennas are usually rectangular or circular in shape and are normally found mounted on a supporting tower, on rooftops, sides of buildings or on similar structures that provide clear and unobstructed line-of-sight paths between both ends of a transmission path or link. These antennas have a variety of uses such as transmitting voice and data messages and serving as links between broadcast or cable-TV studios and transmitting antennas.

The RF signals from these antennas travel in a directed beam from a transmitting antenna to a receiving antenna, and dispersion of microwave energy outside of the relatively narrow beam is minimal or insignificant. In addition, these antennas transmit using very low power levels, usually on the order of a few watts or less. Measurements have shown that ground-level power densities due to microwave directional antennas are normally a thousand times or more below recommended safety limits. (e.g., *see* Reference 38) Moreover, as an added margin of safety, microwave tower sites are normally inaccessible to the general public. Significant exposures from these antennas could only occur in the unlikely event that an individual were to stand directly in front of and very close to an antenna for a period of time.

Satellite-Earth Stations

Ground-based antennas used for satellite-earth communications typically are parabolic "dish" antennas, some as large as 10 to 30 meters in diameter, that are used to transmit ("uplinks") or receive ("downlinks") microwave signals to or from satellites in orbit around the earth. The satellites receive the signals beamed up to them and, in turn, retransmit the signals back down to an earthbound receiving station. These signals allow delivery of a variety of communications services, including long distance telephone service. Some satellite-earth station antennas are used only to ***receive*** RF signals (i.e., just like a rooftop television antenna used at a residence), and, since they do not transmit, RF exposure is not an issue.

Since satellite-earth station antennas are directed toward satellites above the earth, transmitted beams point skyward at various angles of inclination, depending on the particular satellite being used. Because of the longer distances involved, power levels used to transmit these signals are relatively large when compared, for example, to those used by the microwave point-to-point antennas discussed above. However, as with microwave antennas, the beams used for transmitting earth-to-satellite signals are concentrated and highly directional, similar to the beam from a flashlight. In addition, public access would normally be restricted at station sites where exposure levels could approach or exceed safe limits.

Although many satellite-earth stations are "fixed" sites, portable uplink antennas are also used, e.g., for electronic news gathering. These antennas can be deployed in various locations. Therefore, precautions may be necessary, such as temporarily restricting access in the vicinity of the antenna, to avoid exposure to the main transmitted beam. In general, however, it is unlikely that a transmitting earth station antenna would routinely expose members of the public to potentially harmful levels of microwaves.

ARE CELLULAR AND PCS TOWERS AND ANTENNAS SAFE? WHAT ABOUT CAR PHONES AND HAND-HELD PHONES?

Base Stations

Cellular radio systems use frequencies between 800 and 900 megahertz (MHz). Transmitters in the Personal Communications Service (PCS) use frequencies in the range of 1850-1990 MHz. The antennas for cellular and PCS transmissions are typically located on towers, water tanks or other elevated structures including rooftops and the sides of buildings. The combination of antennas and associated electronic equipment is referred to as a cellular or PCS "base station" or "cell site." Typical heights for free-standing base station towers or structures are 50-200 feet. A cellular base station may utilize several "omni-directional" antennas that look like poles, 10 to 15 feet in length, although these types of antennas are becoming less common in urban areas.

In urban and suburban areas, cellular and PCS service providers now more commonly use "sector" antennas for their base stations. These antennas are rectangular panels, e.g., about 1 by 4 feet in dimension, typically mounted on a rooftop or other structure, but they are also mounted on towers or poles. The antennas are usually arranged in three groups of three each. One antenna in each group is used to transmit signals to mobile units (car phones or hand-held phones), and the other two antennas in each group are used to receive signals from mobile units.

The FCC authorizes cellular and PCS carriers in various service areas around the country. At a cell site, the total RF power that could be transmitted from each transmitting antenna at a cell site depends on the number of radio channels (transmitters) that have been authorized and the power of each transmitter. Typically, for a cellular base station, a maximum of 21 channels per sector (depending on the system) could be used. Thus, for a typical cell site utilizing sector antennas, each of the three transmitting antennas could be connected to up to 21 transmitters for a total of 63 transmitters per site. When omni-directional antennas are used, up to 96 transmitters could be implemented at a cell site, but this would be unusual. While a typical base station could have as many as 63 transmitters, not all of the transmitters would be expected to operate simultaneously thus reducing overall emission levels. For the case of PCS base stations, fewer transmitters are normally required due to the relatively greater number of base stations.

Although the FCC permits an ***effective radiated power*** (ERP) of up to 500 watts per channel (depending on the tower height), the majority of cellular base stations in urban and suburban areas operate at an ERP of 100 watts per channel or less. An ERP of 100 watts corresponds to an ***actual*** radiated power of about 5-10 watts, depending on the type of antenna used (ERP is not equivalent to the power that is radiated but, rather, is a quantity that takes into consideration transmitter power and antenna directivity). As the capacity of a system is expanded by dividing cells, i.e., adding additional base stations, lower ERPs are normally used. In urban areas, an ERP of 10 watts per channel (corresponding to a radiated power of 0.5 - 1 watt) or less is commonly used. For PCS base stations, even lower radiated power levels are normally used.

The signal from a cellular or PCS base station antenna is essentially directed toward the horizon in a relatively narrow pattern in the vertical plane. The radiation pattern for an omni-directional antenna might be compared to a thin doughnut or pancake centered around the antenna while the pattern for a sector antenna is fan-shaped, like a wedge cut from a pie. As with all forms of electromagnetic energy, the power density from a cellular or PCS transmitter decreases rapidly (according to an inverse square law) as one moves away from the antenna. Consequently, normal ground-level exposure is much less than exposures that might be encountered if one were very close to the antenna and in its main transmitted beam.

Measurements made near typical cellular and PCS installations, especially those with tower-mounted antennas, have shown that ground-level power densities are well below limits recommended by RF/microwave safety standards (References 32, 37, and 45). For example, for a base-station transmitting frequency of 869 MHz the FCC's RF exposure guidelines recommend a Maximum Permissible Exposure level for the public ("general population/uncontrolled" exposure) of about 580 microwatts per square centimeter ($\mu W/cm^2$). This limit is many times greater than RF levels found near the base of typical cellular towers or in the vicinity of lower-powered cellular base station transmitters, such as might be mounted on rooftops or sides of buildings. Measurement data obtained from various sources have consistently indicated that "worst-case" ground-level power densities near typical cellular towers are on the order of 1 $\mu W/cm^2$ or less (usually significantly less). Calculations corresponding to a "worst-case" situation (all transmitters operating simultaneously and continuously at the maximum licensed power) show that in order to be exposed to levels near the FCC's limits for cellular frequencies, an individual would essentially have to remain in the main transmitting beam (at the height of the antenna) and within a few feet from the antenna. This makes it extremely unlikely that a member of the general public could be exposed to RF levels in excess of these guidelines due to cellular base station transmitters. For PCS base station transmitters, the same type of analysis holds, except that at the PCS transmitting frequencies (1850-1990 MHz) the FCC's exposure limits for the public are 1000 $\mu W/cm^2$. Therefore, there would typically be an even greater safety margin between actual public exposure levels and recognized safety limits.

When cellular and PCS antennas are mounted at rooftop locations it is possible that ambient RF levels greater than 1 $\mu W/cm^2$ could be present on the rooftop itself. However, exposures approaching or exceeding the safety guidelines are only likely to be encountered very close to or directly in front of the antennas. For sector-type antennas RF levels to the side and in back of these antennas are insignificant.

Even if RF levels were higher than desirable on a rooftop, appropriate restrictions could be placed on access. Factoring in the time-averaging aspects of safety standards could also be used to reduce potential exposure of workers who might have to access a rooftop for maintenance tasks or other reasons. The fact that rooftop cellular and PCS antennas usually operate at lower power levels than antennas on free-standing towers makes excessive exposure conditions on rooftops unlikely. In addition, the significant signal attenuation of a building's roof minimizes any chance for persons living or working within the building itself to be exposed to RF levels that could approach or exceed applicable safety limits.

Vehicle-Mounted Antennas

Vehicle-mounted antennas used for cellular communications normally operate at a power level of 3 watts or less. These cellular antennas are typically mounted on the roof, on the trunk, or on the rear window of a car or truck. Studies have shown that in order to be exposed to RF levels that approach the safety guidelines it would be necessary to remain very close to a vehicle-mounted cellular antenna for an extended period of time (Reference 20).

Studies have also indicated that exposure of vehicle occupants is reduced by the shielding effect of a vehicle's metal body. Some manufacturers of cellular systems have noted that proper installation of a vehicle-mounted antenna is an effective way to maximize this shielding effect and have recommended antenna installation either in the center of the roof or the center of the trunk. With respect to rear-window-mounted cellular antennas, a minimum separation distance of 30-60 cm (1 to 2 feet) has been suggested to minimize exposure to vehicle occupants that could result from antenna mismatch.

Therefore, properly installed, vehicle-mounted, personal wireless transceivers using up to 3 watts of power result in maximum exposure levels in or near the vehicle that are well below the FCC's safety limits. This assumes that the transmitting antenna is at least 15 cm (about 6 inches) or more from vehicle occupants. Time-averaging of exposure (as appropriate) should result in even lower values when compared with safety guidelines.

Mobile and Portable Phones and Devices

The FCC's exposure guidelines, and the ANSI/IEEE and NCRP guidelines upon which they are based, specify limits for human exposure to RF emissions from hand-held RF devices in terms of *specific absorption rate (SAR)*. For exposure of the general public, e.g., exposure of the user of a cellular or PCS phone, the FCC limits RF absorption (in terms of SAR) to 1.6 watts/kg (W/kg), as averaged over one gram of tissue. Less restrictive limits, e.g., 2 W/kg averaged over 10 grams of tissue, are specified by guidelines used in some other countries (Reference 25).

Measurements and computational analysis of SAR in models of the human head and other studies of SAR distribution using hand-held cellular and PCS phones have shown that the 1.6 W/kg limit is unlikely to be exceeded under normal conditions of use (References 4, 16, 27). The same can be said for cordless telephones used in the home. Lower frequency (46-49 MHz) cordless telephones operate at very low power levels that could not result in exposure levels that even come close to the 1.6 W/kg level. Higher frequency cordless phones operating near 900 MHz (near the frequencies used for cellular telephones) operate with power levels similar to or less than those used for cell phones. They are also unlikely to exceed the SAR limits specified by the FCC under normal conditions of use.

In any case, compliance with the 1.6 W/kg safety limit must be demonstrated before FCC approval can be granted for marketing of a cellular or PCS phone. Testing of hand-held phones is normally done under conditions of maximum power usage. However, normal power usage is less since it depends on distance of the user from the base station transmitter. Therefore, typical exposure to a user would actually be expected to be less than that indicated by testing for compliance with the limit.

In recent years, publicity, speculation, and concern over claims of possible health effects due to RF emissions from hand-held wireless telephones prompted industry-sponsored groups to initiate research programs to investigate whether there is any risk to users of these devices. Organizations such as Wireless Technology Research (funded by the cellular radio service industry) and wireless equipment manufacturers, such as Motorola, Inc., have been investigating potential health effects from the use of hand-held cellular telephones and other wireless telecommunications devices.

In 1994, the U.S. General Accounting Office (GAO) issued a report that addressed the status of research on the safety of cellular telephones and encouraged U.S. Government agencies to work closely with industry to address wireless safety issues (Reference 59). In that regard, the Federal Government has been monitoring the results of ongoing research through an inter-agency working group led by the EPA and the FDA's Center for Devices and

Radiological Health. In a 1993 "Talk Paper," the FDA stated that it did not have enough information at that time to rule out the possibility of risk, but if such a risk exists, "it is probably small" (Reference 58). The FDA concluded that there is no proof that cellular telephones can be harmful, but if individuals remain concerned several precautionary actions could be taken, including limiting conversations on hand-held cellular telephones and making greater use of telephones with vehicle-mounted antennas where there is a greater separation distance between the user and the radiating antennas.

HOW SAFE ARE FIXED AND MOBILE RADIO TRANSMITTERS USED FOR PAGING AND "TWO-WAY" COMMUNICATIONS?

"Land-mobile" communications include a variety of communications systems which require the use of portable and mobile RF transmitting sources. These systems operate in narrow frequency bands between about 30 and 1000 MHz. Radio systems used by the police and fire departments, radio paging services and business radio are a few examples of these communications systems. They have the advantage of providing communications links between various fixed and mobile locations.

As with cellular and PCS communications, there are three types of RF transmitters associated with land-mobile systems: base-station transmitters, vehicle-mounted transmitters, and hand-held transmitters. The antennas used for these various transmitters are adapted for their specific purpose. For example, a base-station antenna must radiate its signal to a relatively large area, and, therefore, its transmitter generally has to use much higher power levels than a vehicle-mounted or hand-held radio transmitter.

Although these base-station antennas usually operate with higher power levels than other types of land-mobile antennas, they are normally inaccessible to the public since they must be mounted at significant heights above ground to provide for adequate signal coverage. Also, many of these antennas transmit only intermittently. For these reasons, such base-station antennas have generally not been of concern with regard to possible hazardous exposure of the public to RF radiation. However, studies at rooftop locations have indicated that high-powered paging antennas may increase the potential for exposure to workers or others with access to such sites, e.g., maintenance personnel (Reference 12). This could be a concern especially when multiple transmitters are present. In such cases, restriction of access or other corrective actions may be necessary.[16]

Transmitting power levels for vehicle-mounted land-mobile antennas are generally less than those used by base-station antennas but higher than those used for hand-held units. As with cellular transmitters, some manufacturers recommend that users and other nearby

---

[16] Methods and techniques for controlling exposure are discussed in OET Bulletin 65 (Reference 57).

individuals maintain a minimum distance (e.g., 1 to 2 feet) from a vehicle-mounted antenna during transmission or mount the antenna in such a way as to provide maximum shielding for vehicle occupants. Studies have shown that this is probably a conservative precaution, particularly when the "duty factor" (percentage of time an antenna is actually radiating) is taken into account since safety standards are "time-averaged." Unlike cellular telephones, which transmit continuously throughout a call, two-way radios normally transmit only when the "press-to-talk" button is depressed. The extent of any possible exposure would also depend on the actual power level and frequency used by the vehicle-mounted antenna. In general, there is no evidence that there would be a safety hazard associated with exposure from vehicle-mounted, two-way antennas when the manufacturer's recommendations are followed.

Hand-held "two-way" portable radios such as walkie-talkies are low-powered devices used to transmit and receive messages over relatively short distances. Because of the relatively low power levels used (usually no more than a few watts) and, especially, because of the intermittency of transmissions (low duty factor) these radios would normally not be considered to cause hazardous exposures to users. As with vehicle-mounted mobile units, time averaging of exposure can normally be considered when evaluating two-way radios for compliance with safety limits, since these units are "push to talk.". Laboratory measurements have been made using hand-held radios operating at various frequencies to determine the amount of RF energy that might be absorbed in the head of a user. In general, the only real possibility of a potential hazard would occur in the unlikely event that the tip of the transmitting antenna were to be placed directly at the surface of the eye, contrary to manufacturers' recommended precautions, or if for some reason continuous exposure were possible over a significant period of time, which is unlikely. If hand-held radios are used properly there is no evidence that they could cause hazardous exposure to RF energy (References 5, 11, 13, and 27).

ARE RF EMISSIONS FROM AMATEUR RADIO STATIONS HARMFUL?

There are hundreds of thousands of amateur radio operators ("hams") worldwide. Amateur radio operators in the United States are licensed by the FCC. The Amateur Radio Service provides its members with the opportunity to communicate with persons all over the world and to provide valuable public service functions, such as making communications services available during disasters and emergencies. Like all FCC licensees, amateur radio operators are expected to comply with the FCC's guidelines for safe human exposure to RF fields. Under the FCC's rules, amateur operators can transmit with power levels of up to 1500 watts. However, most hams use considerably less power than this. Studies by the FCC and others have shown that most amateur radio transmitters would not normally expose persons to RF levels in excess of safety limits. This is primarily due to the relatively low operating powers used by most amateurs, the intermittent transmission characteristics typically used and the relative inaccessibility of most amateur antennas. As long as appropriate distances are maintained from amateur antennas, exposure of nearby persons should be well below safety limits. This has been demonstrated by studies carried out by the FCC and others (Reference 54). If there were any opportunity for significant RF exposure, it would most likely apply to the amateur operator and his or her immediate household. To help ensure compliance of amateur radio facilities with RF exposure guidelines, both the FCC and American Radio Relay League (ARRL) have developed technical publications to assist operators in evaluating compliance of their stations (References 23 and 57).

CAN IMPLANTED ELECTRONIC CARDIAC PACEMAKERS BE AFFECTED BY NEARBY RF DEVICES SUCH AS MICROWAVE OVENS OR CELLULAR TELEPHONES?

Over the past several years there has been concern that signals from some RF devices could interfere with the operation of implanted electronic pacemakers and other medical devices. Because pacemakers are electronic devices, they could be susceptible to electromagnetic signals that could cause them to malfunction. Some allegations of such effects in the past involved emissions from microwave ovens. However, it has never been shown that signals from a microwave oven are strong enough to cause such interference.

The FDA requires pacemaker manufacturers to test their devices for susceptibility to electromagnetic interference (EMI) over a wide range of frequencies and to submit the results as a prerequisite for market approval. Electromagnetic shielding has been incorporated into the design of modern pacemakers to prevent RF signals from interfering with the electronic circuitry in the pacemaker. The potential for the "leads" of pacemakers to be susceptible to RF radiation has also been of some concern, but this does not appear to be a serious problem.

Recently there have been reports of possible interference to implanted cardiac pacemakers from digital RF devices such as cellular telephones. An industry-funded organization, Wireless Technology Research, LLC (WTR), working with the FDA, sponsored an investigation as to whether such interference could occur, and, if so, what corrective actions could be taken. The results of this study were published in 1997 (*see* Reference 24), and WTR and the FDA have made several recommendations to help ensure the safe use of wireless devices by patients with implanted pacemakers. One of the primary recommendations is that digital wireless phones be kept at least six inches from the pacemaker and that they not be placed directly over the pacemaker, such as in the breast pocket, when in the "on" position. Patients with pacemakers should consult their physician or the FDA if they believe that they may have a problem related to RF interference.

WHICH OTHER FEDERAL AGENCIES HAVE RESPONSIBILITIES RELATED TO POTENTIAL RF HEALTH EFFECTS?

Various agencies in the Federal Government have been involved in monitoring, researching or regulating issues related to human exposure to RF radiation. These agencies include the Food and Drug Administration (FDA), the Environmental Protection Agency (EPA), the Occupational Safety and Health Administration (OSHA), the National Institute for Occupational Safety and Health (NIOSH), the National Telecommunications and Information Administration (NTIA) and the Department of Defense (DOD).

By authority of the Radiation Control for Health and Safety Act of 1968, the Center for Devices and Radiological Health (CDRH) of the FDA develops performance standards for the emission of radiation from electronic products including X-ray equipment, other medical devices, television sets, microwave ovens, laser products and sunlamps. The CDRH established a product performance standard for microwave ovens in 1971 limiting the amount of RF leakage from ovens. However, the CDRH has not adopted performance standards for other RF-emitting products. The FDA is, however, the lead federal health agency in monitoring the latest research developments and advising other agencies with respect to the safety of RF-emitting products used by the public, such as cellular and PCS phones.

The FDA's microwave oven standard is an ***emission*** standard (as opposed to an ***exposure*** standard) that allows leakage (measured at five centimeters from the oven surface) of 1 mW/cm^2 at the time of manufacture and a maximum level of 5 mW/cm^2 during the lifetime of the oven.[17] The standard also requires ovens to have two independent interlock systems that prevent the oven from generating microwaves the moment that the latch is released or the door of the oven is opened. The FDA has stated that ovens that meet its standards and are used according to the manufacturer's recommendations are safe for consumer and industrial use.

The EPA has, in the past, considered developing federal guidelines for public exposure to RF radiation. However, EPA activities related to RF safety and health are presently limited to advisory functions. For example, the EPA now chairs an Inter-agency Radiofrequency Working Group, which coordinates RF health-related activities among the various federal agencies with health or regulatory responsibilities in this area.

OSHA is responsible for protecting workers from exposure to hazardous chemical and physical agents. In 1971, OSHA issued a protection guide for exposure of workers to RF radiation [29 CFR 1910.97]. The guide, covering frequencies from 10 MHz to 100 GHz, stated that exposure of workers should not exceed a power density of ten milliwatts per square centimeter (10 mW/cm^2) as averaged over any 6-minute period of the workday. However, this guide was later ruled to be only advisory and not mandatory. Moreover, it was

---

[17] 21 Code of Federal Regulations 1030.10.

based on an earlier (1966) American National Standards Institute (ANSI) RF protection guide that has been superseded by revised versions in 1974, 1982 and 1992 (see previous discussion of standards). OSHA personnel have recently stated that OSHA uses the ANSI/IEEE 1992 guidelines for enforcement purposes under OSHA's "general duty clause" (see OSHA's Internet Web Site, listed in Table 3, for further information).

NIOSH is part of the U.S. Department of Health and Human Services. It conducts research and investigations into issues related to occupational exposure to chemical and physical agents. NIOSH has, in the past, undertaken to develop RF exposure guidelines for workers, but final guidelines were never adopted by the agency. NIOSH conducts safety-related RF studies through its Physical Agents Effects Branch.

The NTIA is an agency of the U.S. Department of Commerce and is responsible for authorizing Federal Government use of the RF electromagnetic spectrum. Like the FCC, the NTIA also has NEPA responsibilities and has considered adopting guidelines for evaluating RF exposure from U.S. Government transmitters such as radar and military facilities.

The Department of Defense (DOD) has conducted research on the biological effects of RF energy for a number of years. This research is now conducted primarily at the DOD facility at Brooks Air Force Base, Texas. In addition, the DOD uses the ANSI/IEEE 1992 standard as a guide for protecting military personnel from excessive exposure to RF electromagnetic fields.

WHERE CAN I OBTAIN INFORMATION ON RF EXPOSURE AND HEALTH EFFECTS?

Although relatively few offices or agencies within the Federal Government routinely deal with the issue of human exposure to RF fields, it is possible to obtain information and assistance on certain topics from the following federal agencies. Most of these agencies also have Internet Web sites.

FDA: For information about radiation from microwave ovens and other consumer and industrial products contact: Center for Devices and Radiological Health (CDRH), Food and Drug Administration, Rockville, MD 20857.

EPA: The Environmental Protection Agency's Office of Radiation and Indoor Air is responsible for monitoring potential health effects due to public exposure to RF fields. Contact: Environmental Protection Agency, Office of Radiation and Indoor Air, 401 M Street, S.W., Washington, D.C. 20460.

OSHA: The Occupational Safety and Health Administration's (OSHA) Health Response Team (1781 South 300 West, Salt Lake City, Utah 84165) has been involved in studies related to occupational exposure to RF radiation. OSHA also maintains an Internet World

Wide Web site that may be of interest. The URL (case sensitive) is: http://www.osha-slc.gov/SLTC/ (select subject: radiofrequency radiation).

NIOSH: The National Institute for Occupational Safety and Health (NIOSH) monitors RF-related safety issues as they pertain to the workplace. Contact: NIOSH, Physical Agents Effects Branch, Mail Stop C-27, 4676 Columbia Parkway, Cincinnati, Ohio 45226. Toll-free number: 1-800-35-NIOSH (1-800-356-4674).

DOD: Questions regarding Department of Defense activities related to RF safety and its biological research program can be directed to the Radio Frequency Radiation Branch, Air Force Research Laboratory, Brooks Air Force Base, TX 78235.

FCC: Questions regarding potential RF hazards from FCC-regulated transmitters can be directed to the RF Safety Program, Office of Engineering and Technology, Technical Analysis Branch, Federal Communications Commission, 445 Twelfth Street, S.W., Washington, D.C. 20554. The telephone number for inquiries on RF safety issues is: 1-202-418-2464. Calls for routine information can also be directed to the FCC's toll-free number: 1-888-CALL-FCC (225-5322). Another source of information is the FCC's RF Safety Internet Web site (http://www.fcc.gov/oet/rfsafety) where FCC documents and notices can be viewed and downloaded. Questions can also be sent via e-mail to: rfsafety@fcc.gov.

In addition to government agencies, there are other sources of information and possible assistance regarding environmental RF energy. Some states also maintain non-ionizing radiation programs or, at least, some expertise in this field, usually in a department of public health or environmental control. The list of references at the end of this bulletin can be consulted for detailed information on specific topics, and **Table 3** provides a list of some relevant Internet Web sites.

TABLE 3. ***INTERNET WEB SITES FOR FURTHER INFORMATION***

Note: All Internet addresses below preceded by "http://".
Also, some URL's may be case sensitive

American Radio Relay League: www.arrl.org

American National Standards Institute: www.ansi.org

Bioelectromagnetics Society: www.bioelectromagnetics.org

COST 244 (Europe): www.radio.fer.hr/cost244

DOD: www.brooks.af.mil/AFRL (*select radiofrequency radiation)*

European Bioelectromagnetics Association: www.ebea.org

Electromagnetic Energy Association: www.elecenergy.com

Federal Communications Commission: www.fcc.gov/oet/rfsafety

ICNIRP (Europe): www.icnirp.de

IEEE: www.ieee.org

IEEE Committee on Man & Radiation: www.seas.upenn.edu/~kfoster/comar.htm

International Microwave Power Institute: www.impi.org

Microwave News: www.microwavenews.com

J.Moulder, Med.Coll.of Wisc.: www.mcw.edu/gcrc/cop/cell-phone-health-FAQ/toc.html

National Council on Radiation Protection & Measurements: www.ncrp.com

NJ Dept Radiation Protection: www.state.nj.us/dep/rpp (*select non-ionizing radiation)* *Richard Tell Associates*: www.radhaz.com

US OSHA: www.osha-slc.gov/SLTC *(select subject: radiofrequency radiation)*

Wireless Industry (CTIA): www.wow-com.com

Wireless Industry (PCIA): www.pcia.com

World Health Organization EMF Project: www.who.ch/peh-emf

ACKNOWLEDGEMENTS

The assistance of the following individuals in reviewing a draft of this bulletin is gratefully acknowledged: Q. Balzano, M. Swicord, J. Welch (all Motorola, Inc.); R. Bromery, J. Burtle, K. Chan, R.Dorch, B. Franca (all FCC); J. Elder, N. Hankin (U.S. Environmental Protection Agency); J. Healer, F. Matos (both NTIA, U.S. Dept. of Commerce); G. Lotz (National Institute for Occupational Safety and Health); R. Owen (U.S. Food and Drug Administration), R. Petersen (Lucent Technologies).

REFERENCES

This list is not meant to be a complete bibliography, but, rather it provides a selection of some of the more relevant and recent references and publications related to this topic.

Reports with NTIS Order Numbers are U.S. Government publications and can be purchased from the National Technical Information Service, U.S. Department of Commerce, (800) 553-6847

1. Adey, W.R., "Tissue Interactions with Non-ionizing Electromagnetic Fields." *Physiological Reviews*, 61: 435-514 (1981).

2. American National Standards Institute (ANSI), "*Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields - RF and Microwave.*" ANSI/IEEE C95.3-1992. Copyright 1992, The Institute of Electrical and Electronics Engineers, Inc. (IEEE), New York, NY 10017. For copies contact the IEEE: 1-800-678-4333 or 1-908-981-1393.

3. American National Standards Institute (ANSI), "*Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz,*" ANSI/IEEE C95.1-1992 (previously issued as IEEE C95.1-1991). Copyright 1992 by the Institute of Electrical and Electronics Engineers, Inc. (IEEE), New York, N.Y. 10017. For copies contact the IEEE: 1-800-678-4333 or 1-908-981-1393.

4. Balzano, Q., Garay O. and Manning, T.J. "Electromagnetic energy exposure of simulated users of portable cellular telephones," *IEEE Transactions on Vehicular Technology*, Vol. 44 (3), pp. 390-403 (1995).

5. Balzano Q., Garay O., and F.R. Steel, "Energy Deposition in Simulated Human Operators of 800-MHz Portable Transmitters." *IEEE Trans. Veh. Tech.*, VT-27(4):174 (1978).

6. Carpenter, D.O. and S. Ayrapetyan, eds., "*Biological Effects of Electric and Magnetic Fields*, Vol. 2, J. Elder: "*Thermal, Cumulative, and Life Span Effects and Cancer in Mammals Exposed to Radiofrequency Radiation.*" Academic Press, San Diego, (1994).

7. Chou, C.K. et al., "Long-term, Low-level Microwave Irradiation of Rats." *Bioelectromagnetics*, 13:469-496 (1992).

8. Chou, C.K. et al., "Radiofrequency Electromagnetic Exposure: Tutorial Review on Experimental Dosimetry." *Bioelectromagnetics*, 17: 195-208 (1996).

9. Chou, C.K., Guy, A.W. and R. Galamboo, "Auditory Perception of Radiofrequency Electromagnetic Fields." *J. Acoust. Soc. Amer.*, 71: 1321-1334 (1982).

10. Cleary, S. F., "Microwave Radiation Effects on Humans," *BioScience*, 33(4): 269 (1983).

11. Cleveland, Jr. R.F., and T.W. Athey, "Specific Absorption Rate (SAR) in Models of the Human Head Exposed to Hand-Held UHF Portable Radios." *Bioelectromagnetics* 10:173 (1989).

12. Cleveland, Jr., D.M. Sylvar, J.L. Ulcek and E.D. Mantiply, "*Measurement of Radiofrequency Fields and Potential Exposure from Land-mobile Paging and Cellular Radio Base Station Antennas.*" Abstracts, Seventeenth Annual Meeting, Bioelectromagnetics Society, Boston, Massachusetts, p. 188 (1995).

13. Dimbylow, P.J. and S.M. Mann, "SAR Calculations in an Anatomically Realistic Model of the Head for Mobile Communication Transceivers at 900 MHz and 1.8 GHz," *Phys. Med. Biol.* 39(12): 1537-1553 (1994).

14. Foster, K.R., and A.W. Guy, "The Microwave Problem," *Scientific American*, 255(3): 32 (September 1986).

15. Frei, M.R. et al., "Chronic Exposure of Cancer-prone Mice to Low-level 2450 MHz Radiofrequency Radiation." *Bioelectromagnetics*, 19: 20-31 (1998).

16. Gandhi, O.P., G. Lazzi and C.M. Furse, "EM Absorption in the Human Head and Neck for Mobile Telephones at 835 and 1900 MHz," *IEEE Trans. on Microwave Theory and Techniques*, 44 (10), pp.1884-1897 (1996).

17. Gandhi, O.M. (ed.), *Biological Effects and Medical Applications of Electromagnetic Fields*, Prentice-Hall, Englewood Cliffs, NJ (1990).

18. Gandhi, O.P., "Biological Effects and Medical Applications of RF Electromagnetic Fields," *IEEE Transactions on Microwave Theory and Techniques*, 30(11):1831 (1982).

19. Gandhi, O.P. (ed.), "Biological Effects of Electromagnetic Radiation." *IEEE Engineering in Medicine and Biology*, 6(1): 14-58 (1987).

20. Guy, A.W., and C.K. Chou (1986). "Specific Absorption Rates of Energy in Man Models Exposed to Cellular UHF-mobile-antenna Fields." *IEEE Trans. Microwave Theory and Tech.*, MTT-34(6): 671 (1986).

21. Hammett, W.F., *"Radio Frequency Radiation, Issues and Standards."* McGraw-Hill, New York (1997).

22. Hankin, N., *"The Radiofrequency Radiation Environment: Environmental Exposure Levels and RF Radiation Emitting Sources,"* U.S. Environmental Protection Agency, Washington, D.C. 20460. Report No. EPA 520/1-85-014 (1986).

23. Hare, Ed, *RF Exposure and You.* Published by the American Radio Relay League (ARRL), Newington, CT 06111, USA (1998).

24. Hayes, D.L. et al., "Interference with Cardiac Pacemakers by Cellular Telephones." *New England J. or Medicine*, 336: 1473-1479 (1997).

25. International Commission on Non-Ionizing Radiation Protection (ICNIRP), "Guidelines for Limiting Exposure to Time-varying Electric, Magnetic, and Electromagnetic Fields (Up to 300 GHz)," *Health Physics* 74: 494-520 (1998).

26. Klauenberg, B.J., Grandolfo, M. and D.N. Erwin (eds.), *Radiofrequency Radiation Standards, Biological Effects, Dosimetry, Epidemiology and Public Health Policy.* NATO ASI Series A: Life Sciences, Plenum Press (1994).

27. Kuster, N., Q. Balzano and J. Lin, Eds., *Mobile Communications Safety*, Chapman and Hall, London, (1997).

28. Lai, H. and N.P. Singh, "Single- and Double-strand DNA Breaks in Rat Brain Cells After Acute Exposure to Radiofrequency Electromagnetic Radiation." *Intl. J. Radiation Biology*, 69: 513-521 (1996).

29. Lai, H. and N.P. Singh, "Acute Low-Intensity Microwave Exposure Increases DNA Single-strand Breaks in Rat Brain Cells." *Bioelectromagnetics*, 16:207-210 (1995).

30. Malyapa, R.S. et al., "Measurement of DNA Damage Following Exposure to 2450 MHz Electromagnetic Radiation." *Radiation Research*, 148: 608-617 (1997).

31. Malyapa, R.S. et al., "Measurement of DNA Damage Following Exposure to Electromagnetic Radiation in the Cellular Communications Frequency Band (835.62 and 847.74 MHz)." *Radiation Research*, 148: 618-627.

32. Mantiply, E.D., "Summary of Measured Radiofrequency Electric and Magnetic Fields (10 kHz to 30 GHz) in the General and Work Environment." *Bioelectromagnetics*, 18: 563-577 (1997).

33. National Council on Radiation Protection and Measurements (NCRP), "*Radiofrequency Electromagnetic Fields; Properties, Quantities and Units, Biophysical Interaction, and Measurements*," NCRP Report No. 67 (1981). Copyright NCRP, Bethesda, MD 20814, USA. For copies contact: NCRP Publications at 1-800-229-2652.

34. National Council on Radiation Protection and Measurements (NCRP), "*Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields*," NCRP Report No. 86. (1986). Copyright NCRP, Bethesda, MD, 20814, USA. For copies contact NCRP Publications: 1-800-229-2652.

35. National Council on Radiation Protection and Measurements (NCRP), "*A Practical Guide to the Determination of Human Exposure to Radiofrequency Fields*," NCRP Report No. 119, (1993). Copyright NCRP, Bethesda, MD 20814. For copies contact: NCRP Publications at: 1-800-229-2652.

36. Petersen, R.C., "Bioeffects of Microwaves: A Review of Current Knowledge." *Journal of Occupational Medicine*, 25(2): 103 (1983).

37. Petersen, R. and P. Testagrossa, "Radio-Frequency Electromagnetic Fields Associated with Cellular-Radio Cell-Site Antennas." *Bioelectromagnetics*, 13:527 (1992).

38. Petersen, R.C., "Electromagnetic Radiation from Selected Telecommunications Systems." *Proceedings IEEE*, Vol. 68, No. 1, p. 21-24 (1998).

39. Repacholi, M.H., A. Basten, et. al., "Lymphomas in Eμ-Pim1 Transgenic Mice Exposed to Pulsed 900 MHz Electromagnetic Fields." *Radiation Research*, 147:631-640 (1997).

40. Repacholi, M.H., "Low-Level Exposure to Radiofrequency Electromagnetic Fields: Health Effects and Research Needs." *Bioelectromagnetics*, 19: 1-19 (1998).

41. Schwan, H.P., "Biological Effects of Non-ionizing Radiation: Cellular Properties and Interactions." *Ann. Biomed. Eng.* 16: 245-263 (1988).

42. Tell, R.A., "*A Measurement of RF Field Intensities in the Immediate Vicinity of an FM Broadcast Station Antenna*," Technical Note ORP/EAD-76-2, U.S. Environmental Protection Agency, Las Vegas, NV (1976). NTIS Order No. PB 257698.

43. Tell, R.A., "*Electric and Magnetic Fields and Contact Currents Near AM Standard Broadcast Radio Stations*," Richard Tell Associates, Inc., Las Vegas, NV. Project performed under contract for Federal Communications Commission (FCC), Office of Engineering and

Technology, Washington, D.C. 20554. FCC Report No. OET/RTA 89-01 (1989). NTIS Order No. PB 89-234850.

44. Tell, R.A., "*Induced Body Currents and Hot AM Tower Climbing: Assessing Human Exposure in Relation to the ANSI Radiofrequency Protection Guide,*" Richard Tell Associates, Inc., Las Vegas, NV. Project performed under contract for Federal Communications Commission (FCC), Office of Engineering and Technology, Washington, D.C. 20554. FCC Report No. OET/RTA 91-01 (1991). NTIS Order No. PB 92-125186.

45. Tell, R.A., "*Engineering Services for Measurement and Analysis of Radiofrequency (RF) Fields,*" Richard Tell Associates, Inc., Las Vegas, NV. Project performed under contract for Federal Communications Commission (FCC), Office of Engineering and Technology, Washington, D.C. 20554. FCC Report No. OET/RTA 95-01 (1995). NTIS Order No. PB 95-253829.

46. Tell, R. A. and E. D. Mantiply, "Population Exposure to VHF and UHF Broadcast Radiation in the United States," *Proceedings of the IEEE*, Vol. 68(1), pages 6-12 (1980).

47. Toler, J.C. et al., "Long-term Low-level Exposure of Mice Prone to Mammary Tumors to 435 MHz Radiofrequency Radiation." *Radiation Research*, 148: 227-234 (1997).

48. U.S. Environmental Protection Agency, authors Tell, R. A., and E. D. Mantiply, "*Population Exposure to VHF to UHF Broadcast Radiation in the United States,*" Technical Note ORP/EAD 78-5 (1978). NTIS order No. PB 284 637.

49. U.S. Environmental Protection Agency, "Biological Effects of Radiofrequency Radiation," Report No. EPA- 600/8-83-026F (1984). NTIS Order No. PB85-120848.

50. U.S. Environmental Protection Agency, Electromagnetics Branch, Las Vegas, NV 89114. "*An Investigation of Radiofrequency Radiation Levels on Lookout Mountain, Jefferson County, Colorado,*" (1987).

51. U.S. Environmental Protection Agency, Office of Radiation Programs, "*Radiofrequency Electromagnetic Fields and Induced Currents in the Spokane, Washington Area,*" EPA Report No. EPA/520/6-88/008 (1988). NTIS Order No. PB88-244819/AS.

52. U.S. Environmental Protection Agency, Office of Radiation Programs, "*Electric and Magnetic Fields Near AM Broadcast Towers,*" EPA Report No. EPA/520/6-91/020, (1991). NTIS Order No. PB92-101427.

53. U.S. Environmental Protection Agency, Office of Air and Radiation and Office of Research and Development, "*Summary and Results of the April 26-27, 1993 Radiofrequency Radiation Conference.*" Vol. 1: Analysis of Panel Discussions, EPA Report No. 402-R-95-009, (1995); Vol. 2: Papers, EPA Report No. 402-R-95-011, (1995).

54. U.S. Federal Communications Commission (FCC), Office of Engineering and Technology, "*Measurements of Environmental Electromagnetic Fields at Amateur Radio Stations*," FCC Report No. FCC/OET ASD-9601, February 1996, Washington, D.C. 20554. NTIS Order No. PB96-145016. Copies can also be downloaded from OET's Home Page on the World Wide Web at: http://www.fcc.gov/oet/.

55. U.S. Federal Communications Commission (FCC), "Guidelines for Evaluating the Environmental Effects of Radiofrequency Radiation," *Report and Order*, ET Docket 93-62, FCC 96-326, adopted August 1, 1996, 61 Federal Register 41006 (1996).

56. U.S. Federal Communications Commission (FCC), "Guidelines for Evaluating the Environmental Effects of Radiofrequency Radiation," *Second Memorandum Opinion and Order and Notice of Proposed Rule Making*, ET Docket 93-62 (WT Docket 97-192), FCC 97-303, adopted August 25, 1997, 62 Federal Register 47,960, 49,557 and 61,447 (1997).

57. U.S. Federal Communications Commission, Office of Engineering and Technology, "*Evaluating Compliance with FCC-Specified Guidelines for Human Exposure to Radiofrequency Radiation*," OET Bulletin 65, Edition 97-01, August 1997, Washington, D.C. 20554 [NTIS Order No. PB86-127081]. Three supplements to this bulletin have also been issued: Supplement A (additional information for radio and television broadcasters), Supplement B (additional information for amateur radio operators), and Supplement C (additional information for evaluating mobile and portable RF devices). Copies of the bulletin and supplements can be obtained by contacting the FCC's RF Safety Program at: (202) 418-2464 or by downloading from the OET Internet Web site: http://www.fcc.gov/oet/rfsafety.

58. U.S. Food and Drug Administration, Rockville, MD 20857. "*FDA Talk Paper, Update on Cellular Phones*." FDA Ref. No. T93-7, February 4, 1993.

59. U.S. General Accounting Office, "*Status of Research on the Safety of Cellular Telephones*." Report No. GAO/RCED-95-32 (1994). Available from GAO, P.O. Box 6015, Gaithersburg, MD 20884-6015, 1-202-512-6000.

ehp Environmental Health PERSPECTIVES
ehponline.org
Journal of the National Institute of Environmental Health Sciences

Reprinted from:

June 2003

VOLUME 111 | NUMBER 7

The National Institute of Environmental Health Sciences
National Institutes of Health
U.S. Department of Health and Human Services

of culture are not created. Additionally, the community has lost a primary source of protein and other nutrients such as iron, calcium, zinc, and essential omega-3 fatty acids due to the avoidance of contaminated foods, further exacerbating chronic, diet-related health problems in the community, such as diabetes and cardiovascular disease (Akwesasne Task Force on the Environment 1997; Arquette et al. 2002; Tarbell and Arquette 2000).

References

ATSDR. 2000. Toxicological Profile for Polychlorinated Biphenyls (Update). Atlanta, GA:Agency for Toxic Substances and Disease Registry.

Akwesasne Task Force on the Environment. 1997. Superfund clean-up at Akwesasne: a case study in environmental justice. Int J Contemp Sociol 34:267–290.

American Council on Science and Health. 1997. Position paper of the American Council on Science and Health: public health concerns about environmental polychlorinated biphenyls (PCBs). Ecotoxicol Environ Saf 38:71–84.

Arquette M, Cole M, Cook K, LaFrance B, Peters M, Ransom J, et al. 2002. Holistic risk-based environmental decision making: a Native perspective. Environ Health Perspect 110:259–264.

Brock JW, Burse VW, Ashley DL, Najam AR, Green VE, Korver MP, et al. 1996. An improved analysis for chlorinated pesticides and polychlorinated biphenyls (PCBs) in human and bovine sera using solid-phase extraction. J Anal Toxicol 20:528–536.

Brouwer A, Longnecker MP, Birnbaum LS, Cogliano J, Kostyniak P, Moore J, et al. 1999. Characterization of potential endocrine-related health effects at low-dose levels of exposure to PCBs. Environ Health Perspect 107:639–649.

Brown JF Jr. 1994. Determination of PCB metabolic, excretion, and accumulation rates for use as indicators of biological response and relative risk. Environ Sci Technol 28:2295–2305.

Bush B, Snow J, Koblintz R. 1984. Polychlorobiphenyl (PCB) congeners, *p,p'*-DDE, hexachlorobenzene in maternal and fetal cord blood from mothers in upstate New York. Arch Environ Contam Toxicol 13:517–527.

Carpenter DO, Arcaro KF, Bush B, Niemi WD, Pang S, Vakharia DD. 1998. Human health and chemical mixtures: an overview. Environ Health Perspect 106:1263–1270.

Centers for Disease Control and Prevention. 2000. Blood lead levels in young children—United States and selected states, 1996–1999. Morb Mortal Wkly Rep 49:1133–1137.

———. 2001. Epi Info. (6). Atlanta, GA:Centers for Disease Control and Prevention.

Chiarenzelli J, Pagano J, Scrudato R, Falanga L, Migdal K, Hartwell A, et al. 2001. Enhanced airborne polychlorinated biphenyl (PCB) concentrations and chlorination downwind of Lake Ontario. Environ Sci Technol 35:3280–3286.

Cohen AC. 1950. Estimating the mean and variance of normal populations from singly truncated and doubly truncated samples. Ann Math Stud 21:557–569.

———. 1959. Simplified estimators for the normal distribution when samples are singly censored or truncated. Technometrics 1:217–237.

Curtis SA. 1992. Cultural relativism and risk-assessment strategies for federal projects. Hum Organ 51:65–70.

DeCaprio A, Tarbell AM, Bott A, Wagemaker DL, Williams RL, O'Heir CM. 2000. Routine analysis of 101 polychlorinated biphenyl congeners in human serum by parallel dual-column gas chromatography with electron capture detection. J Anal Toxicol 24:403–420.

DeKoning EP, Karmaus W. 2000. PCB exposure *in utero* and via breast milk: a review. J Expo Anal Environ Epidemiol 10:285–293.

DeVoto E, Fiore BJ, Millikan R, Anderson HA, Sheldon L, Sonzogni WC, et al. 1997. Correlations among human blood levels of specific PCB congeners and implications for epidemiologic studies. Am J Ind Med 32:606–613.

Duarte-Davidson R, Wilson SC, Jones KC. 1994. PCBs and other organochlorines in human tissue samples from the Welsh population. II. Milk. Environ Pollut 84:79–87.

Ecology and Environment, Inc. 1992. Phase 1, Grasse River: River and Sediment Investigation. Lancaster, NY:Ecology and Environment, Inc.

Fitzgerald EF, Deres DA, Hwang S-A, Bush B, Yang B-Z, Tarbell A, et al. 1999. Local fish consumption and serum PCB concentrations among Mohawk men at Akwesasne. Environ Res 80:S97–S103.

Fitzgerald EF, Hwang S-A, Brix KA, Bush B, Cook K, Worswick P. 1995. Fish PCB concentrations and consumption patterns among Mohawk women at Akwesasne. J Expo Anal Environ Epidemiol 5:1–19.

Fitzgerald EF, Hwang S-A, Bush B, Cook K, Worswick P. 1998. Fish consumption and breast milk PCB concentrations among Mohawk women at Akwesasne. Am J Epidemiol 148:164–172.

Forti A, Bogdan KG, Horn E. 1995. Health Risk Assessment for the Akwesasne Mohawk Population from Exposure to Chemical Contaminants in Fish and Wildlife. Albany, NY:New York State Department of Health.

George-Kanentiio D. 1995. Iroquois population in 1995. Akwesasne Notes 1:61.

Goran MI, Kaskoun M, Johnson R, Martinez C, Kelly B, Hood V. 1995. Energy expenditure and body fat distribution in Mohawk children. Pediatrics 95:89–95.

Greizerstein HB, Gigliotti P, Vena J, Freudenheim J, Kostyniak PJ. 1997. Standardization of a method for the routine analysis of polychlorinated biphenyl congeners and selected pesticides in human serum and milk. J Anal Toxicol 21:558–566.

Greizerstein HB, Stinson C, Mendola P, Buck GM, Kostyniak PJ, Vena JE. 1999. Comparison of PCB congeners and pesticide levels between serum and milk from lactating women. Environ Res 80:280–286.

Grinde D, Johansen B. 1995. Ecocide of Native America: Environmental Destruction of Indian Lands and Peoples. Santa Fe, NM:Clear Light Publishers.

Gupta AK. 1952. Estimation of the mean and standard deviation of a normal population from a censored sample. Biometrika 39:260–273.

Hald A. 1949. Maximum likelihood estimation of the parameters of a normal distribution which is truncated at a known point. Skand Aktuar Tidskr 32:119–134.

Hansen LG. 1998. Stepping backward to improve assessment of PCB congener toxicities. Environ Health Perspect 106:171–189.

———. 2001. Identification of steady state and episodic PCB congeners from multiple pathway exposures. In: PCBs: Recent Advances in Environmental Toxicology and Health Effects (Robertson LW, Hansen LG, eds). Lexington, KY:University Press of Kentucky, 48–56.

Harris S, Harper B. 1997. A Native American exposure scenario. Risk Anal 17:789–795.

Hess P, de Boer J, Cofino WP, Leonards PEG, Wells DE. 1995. Critical review of the analysis of non- and mono-ortho-chlorobiphenyls. J Chromatogr 703:417–465.

Hild C. 1998. Cultural concerns regarding contaminants in Alaskan local foods. Circumpolar Health 57:S61–S66.

Karmaus W, DeKoning EP, Kruse H, Witten J, Osius N. 2001. Early childhood determinants of organochlorine concentrations in school-aged children. Pediatr Res 50:331–336.

Lacetti G. 1993. Public health assessment. General Motors/Central Foundry Division. Albany, NY:New York State Department of Health.

Liem A, Furst P, Rappe C. 2000. Exposure of populations to dioxins and related compounds. Food Addit Contam 17:241–259.

Matthews HB, Dedrick RL. 1984. Pharmacokinetics of PCBs. Annu Rev Pharmacol Toxicol 24:85–103.

Mazhitova Z, Jensen S, Ritzen M, Zetterstrom R. 1998. Chlorinated contaminants, growth and thyroid function in shoolchildren from the Aral Sea region in Kazakhstan. Acta Paediatr 87:991–995.

McFarland VA, Clarke JU. 1989. Environmental occurrence, abundance, and potential toxicity of polychlorinated biphenyl congeners: considerations for a congener-specific analysis. Environ Health Perspect 81:225–239.

Nawrot TS, Staessen JA, Den Hond EM, Koppen G, Schoeters G, Fagard R, et al. 2002. Host and environmental determinants of polychlorinated aromatic hydrocarbons in serum of adolescents. Environ Health Perspect 110:583–589.

Osius N, Karmaus W, Kruse H, Witten J. 1999. Exposure to polychlorinated biphenyls and levels of thyroid hormones in children. Environ Health Perspect 107:843–849.

Palinkas LA, Russell J, Downs MA, Petterson JS. 1992. Ethnic differences in stress, coping, and depressive symptoms after the Exxon Valdez oil spill. J Nerv Ment Dis 180:287–295.

Patandin S, Dagnelie PC, Mulder PG, Op de Coul E, van der Veen JE, Weisglas-Kuperus N, et al. 1999. Dietary exposure to polychlorinated biphenyls and dioxins from infancy until adulthood: a comparison between breast-feeding, toddler, and long-term exposure. Environ Health Perspect 107:45–51.

Patandin S, Koopman-Esseboom C, Weisglas-Kuperus N, Sauer PJJ. 1997. Birth weight and growth in Dutch newborns exposed to background levels of PCBs and dioxins. Organohalogen Compounds 34:447–450.

Ramil CM, Pereiro IR, Cela TR. 2002. Determination of polychlorinated biphenyl compounds in indoor air samples. J Chromatogr A 963:65–71.

RMT, Inc. 1986. Draft Remedial Investigation (Task 10). Report for Remedial Investigation/Feasibility Study at GM-CFD Massena, New York. Madison, WI:Engineering and Environmental Services, RMT, Inc.

Safe SH. 1994. Polychlorinated biphenyls (PCBs): Environmental impact, biochemical and toxic responses, and implications for risk assessment. Crit Rev Toxicol 24:87–149.

SAS Institute. 2001. Statistical Analysis System. Version 8.1. Cary, NC:SAS Institute.

Schecter AJ, Stanley J, Boggess K, Masuda Y, Mes J, Wolff M, et al. 1994. Polychlorinated biphenyl levels in the tissues of exposed and nonexposed humans. Environ Health Perspect 102(suppl 1):149–158.

Schell LM. 1999. Human physical growth and exposure to toxicants: lead and polychlorinated biphenyls. In: Human Growth in Context (Johnston FE, Eveleth PB, Zemel BS, eds). London:Smith-Gordon, 221–238.

Seegal RF. 1996. Epidemiological and laboratory evidence of PCB-induced neurotoxicity. Crit Rev Toxicol 26:709–737.

Skinner L. 1992. Chemical Contaminants in the Wildlife from the Mohawk Nation at Akwesasne and the Vicinity of the General Motors Corporation/Central Foundry Division, Massena, NY Plant. Albany, NY:New York State Department of Environmental Conservation.

Sloan R, Jock K. 1990. Chemical contaminants in fish from the St. Lawrence River drainage on lands of the Mohawk nation at Akwesasne and near the General Motors Corporation/Central Foundry Division, Massena, NY plant. Albany, NY:New York State Department of Environmental Conservation.

SPSS. 2001. Statistical Package for the Social Sciences. Version 10.1.4. Chicago:SPSS, Inc.

Staessen JA, Nawrot T, Hond ED, Thijs L, Fagard R, Hoppenbrouwers K, et al. 2001. Renal function, cytogenetic measurements, and sexual development in adolescents in relation to environmental pollutants: a feasibility study of biomarkers. Lancet 357:1660–1669.

Stehr-Green PA. 1989. Demographic and seasonal influences on human serum pesticide residue levels. J Toxicol Environ Health 27:405–421.

Swanson GM, Ratcliffe HE, Fischer LJ. 1995. Human exposure to polychlorinated biphenyls (PCBs): a critical assessment of the evidence for adverse health effects. Regul Toxicol Pharmacol 21:136–150.

Tarbell AM, Arquette M. 2000. Akwesasne: a Native American community's resistance to cultural and environmental damage. In: Reclaiming the Environmental Debate: The Politics of Health in a Toxic Culture (Hofrichter R, ed). Cambridge, MA:MIT Press, 93–111.

U.S. EPA. 1984. Hazardous Waste Sites: Descriptions of Sites on the Current National Priorities List. Washington, DC:US Environmental Protection Agency Remedial Response Program.

———. 1997a. Mercury Study Report to Congress, Volume 1: Executive Summary. Research Triangle Park, NC:U.S. Environmental Protection Agency.

———. 1997b. Mercury Study Report to Congress, Volume 7: Characterization of Human Health and Wildlife Risks from Mercury Exposure in the United States. Research Triangle Park, NC:U.S. Environmental Protection Agency.

———. 1998. Guidance for Data Quality Assessment. Practical Methods for Data Analysis. Washington, DC:Environmental Protection Agency.

Woodward-Clyde Associates. 1991. Final feasibility study report for Reynolds Metals Company St. Lawrence reduction plant. Plymouth Landing, PA:Woodward-Clyde Associates.

Childhood Leukemia: Electric and Magnetic Fields as Possible Risk Factors

Joseph D. Brain,[1] Robert Kavet,[2] David L. McCormick,[3] Charles Poole,[4] Lewis B. Silverman,[5] Thomas J. Smith,[1] Peter A. Valberg,[6] R. A. Van Etten,[7] and James C. Weaver[8]

[1]Department of Environmental Health, Harvard School of Public Health, Boston, Massachusetts, USA; [2]EMF Health Assessment, Electric Power Research Institute, Palo Alto, California, USA; [3]Life Sciences, IIT Research Institute, Chicago, Illinois, USA; [4]Department of Epidemiology, University of North Carolina, Chapel Hill, North Carolina, USA; [5]Pediatric Hematology-Oncology, Children's Hospital, Dana Farber Cancer Institute, Boston, Massachusetts, USA; [6]Health Risk Assessment, Gradient Corp, Cambridge, Massachusetts, USA; [7]Department of Genetics, Center for Blood Research, Boston, Massachusetts, USA; [8]Harvard–MIT Division of Health Sciences and Technology, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

Numerous epidemiologic studies have reported associations between measures of power-line electric or magnetic fields (EMFs) and childhood leukemia. The basis for such associations remains unexplained. In children, acute lymphoblastic leukemia represents approximately three-quarters of all U.S. leukemia types. Some risk factors for childhood leukemia have been established, and others are suspected. Pathogenesis, as investigated in animal models, is consistent with the multistep model of acute leukemia development. Studies of carcinogenicity in animals, however, are overwhelmingly negative and do not support the hypothesis that EMF exposure is a significant risk factor for hematopoietic neoplasia. We may fail to observe effects from EMFs because, from a mechanistic perspective, the effects of EMFs on biology are very weak. Cells and organs function despite many sources of chemical "noise" (e.g., stochastic, temperature, concentration, mechanical, and electrical noise), which exceed the induced EMF "signal" by a large factor. However, the inability to detect EMF effects in bioassay systems may be caused by the choice made for "EMF exposure." "Contact currents" or "contact voltages" have been proposed as a novel exposure metric, because their magnitude is related to measured power-line magnetic fields. A contact current occurs when a person touches two conductive surfaces at different voltages. Modeled analyses support contact currents as a plausible metric because of correlations with residential magnetic fields and opportunity for exposure. The possible role of contact currents as an explanatory variable in the reported associations between EMFs and childhood leukemia will need to be clarified by further measurements, biophysical analyses, bioassay studies, and epidemiology. ***Key words:*** **childhood leukemia, contact currents, contact voltages, electric and magnetic fields, EMF, review.** ***Environ Health Perspect*** **111:962–970 (2003). doi:10.1289/ehp.6020 available via** ***http://dx.doi.org/*** **[Online 25 February 2003]**

Whether health risks result from exposure to power-line electric or magnetic fields (EMFs) remains unclear. Epidemiologic studies have repeatedly shown small associations between measures of residential power-line magnetic fields and childhood leukemia. The possibility that these associations are caused by bias or confounders, however, cannot be ruled out (Savitz 2003). In addition, extensive investigations in animals at much higher levels of EMFs have not demonstrated adverse effects (Boorman et al. 2000). Recently, the International Agency for Research on Cancer (IARC 2002) designated EMFs as a class 2B carcinogen ("possibly carcinogenic"), based on "consistent statistical associations of high-level residential magnetic fields with a doubling of the risk of childhood leukemia." The California Department of Health Services (CADHS 2002) recently issued a report concluding that "EMFs can cause some degree of increased risk of childhood leukemia, adult brain cancer, Lou Gehrig's disease, and miscarriage." Hence, the question of whether electric-power use has a possible role in childhood leukemia risk remains in the forefront of concern.

To assess past research and suggest future directions in the area of childhood leukemia and EMFs, the Electric Power Research Institute and the Harvard School of Public Health sponsored a workshop titled "Childhood Leukemia: Added Risk from the Use of Electricity?" on 8 November 2001, in Lexington, Massachusetts. This workshop brought together a number of experts.

The epidemiologic associations reported between EMFs and childhood leukemia remain unexplained. Integrating all the lines of evidence presents a challenge to accurately evaluating potential health effects from EMFs. Epidemiologic results, when available, often predominate over rodent bioassay and other laboratory data in hazard identification and risk assessment. However, the epidemiology studies of EMFs and childhood leukemia, all of case–control design, pose several issues, and the link between EMFs and leukemia has not been supported by laboratory data. In many of the epidemiology studies, the small proportion of the study population classified as receiving high exposure levels limits the precision of the effect estimate. In addition, confounding and differential selection and participation of controls by attributes associated with exposure can lead to biased effect estimates (Ahlbom et al. 2000; Hatch et al. 2000). Finally, the relevant exposure metric is not known; thus, it has not been possible for epidemiologists to quantify EMF exposure appropriately in the study populations. Experimental approaches also have limitations, such as *a*) requiring high-dose to low-dose extrapolation, *b*) requiring interspecies extrapolation, *c*) using "pure" EMF signals of specific frequency and field strength that may not mimic real human exposures, and *d*) being subject to practical and logistic bounds on study size (statistical power). Epidemiologists have been hampered because experimental studies of EMFs have not identified biologic mechanism(s) that could serve as the basis for designing new studies. The goal of the workshop described here was to review the science and consider new directions for EMF research in the areas of epidemiology, exposure metrics, animal studies, and biophysics.

Childhood Leukemia and EMFs

A major focus of EMF research during the past 20 years has been to determine whether, and how, EMFs might increase the risk of cancer, particularly childhood leukemia. The rationale for investigating EMFs stems from the original observation that childhood leukemia correlated with the proximity of overhead utility lines (Wertheimer and Leeper 1979). Early research focused on quantifying EMF exposure by electrical wiring configurations ("wire codes") and determining whether wire codes were accurate surrogates for magnetic-field exposure. More recently, however, magnetic-field exposure itself ("spot" and 24-hr average) has become the focus of investigation (Ahlbom et al. 2001; Greenland et al. 2000).

If typical residential magnetic fields are used as the exposure metric, then adverse EMF effects are not expected to occur. In a review of the EMF literature, the National Institute of Environmental Health Sciences (NIEHS 1999) identified 1 mV/m as a tissue electric field that could plausibly be associated

Address correspondence to P.A. Valberg, Gradient Corp., 238 Main St., Cambridge, MA 02142 USA. Telephone: (617) 395-5000. Fax: (617) 395-5001. E-mail: pvalberg@gradientcorp.com

The workshop was made possible through support from EPRI contract WO2964 and the Harvard School of Public Health.

The authors declare they have no conflict of interest.

Received 25 September 2002; accepted 25 February 2003.

with a biologic effect. At 5 µT (equivalent to 50 mG), which is roughly five times higher than the highest average field recorded in the "1,000-home study" (Zaffanella 1993), the induced-electric-field level in human tissues, including bone marrow, remains below this 1 mV/m "benchmark" dose (Kavet et al. 2001). Nonetheless, when Greenland et al. (2000) pooled the epidemiology studies of childhood leukemia, they found evidence of increased risk at the upper-end magnetic field levels to which a small proportion of U.S. residents are exposed. The authors estimated a relative risk (RR) of 1.7 [95% confidence interval (CI), 1.2–2.3] for exposures above 0.3 µT (3 mG), and a population attributable fraction of 3% (95% CI, –2% to > 8%) for exposures above 0.05 µT. Another pooled analysis by Ahlbom et al. (2000) produced similar results for a 0.4-µT cut point. The data from the 1,000-home study (Zaffanella 1993) show that 4.7% of residences in the United States have average spot measurements (point-in-time measurements averaged across available rooms) ≥ 0.3 µT, and 2.6% have fields ≥ 0.4 µT.

Interpretation of the associations between childhood leukemia and EMFs rests on understanding several lines of evidence: *a*) clinical data on etiology and pathogenesis of childhood leukemia; *b*) results from EMF-exposed laboratory animals; *c*) survey data on EMF levels present in households and whether the intensity is sufficient to induce biologic effects; and *d*) consideration of alternative EMF exposure metrics.

Biology of Childhood Leukemia

Leukemia is a cancer of blood progenitor cells that arises in the bone marrow, where stem cells normally differentiate into lymphoid and myeloid progenitor cells. Lymphoid progenitor cells form mature B cells or T cells. Myeloid progenitor cells yield neutrophils, monocytes, or eosinophils. Marrow precursor cells also produce red blood cells and platelets. Leukemia can be classified according to the presumed cell of origin (myeloid or lymphoid) as well as its clinical course (chronic or acute). Chronic lymphocytic leukemia and chronic myelogenous leukemia, which likely originate in primitive stem cells, are characterized by protracted, subacute disease. Acute lymphoblastic leukemia (ALL) and acute myelogenous leukemia (AML) refer to cancer of lymphoid or myeloid progenitor cells, with rapid onset and deterioration without aggressive therapy. Most childhood leukemia is either ALL or AML. Leukemia can be further subclassified according to morphology, genetic alterations, cell surface markers, and other characteristics (Table 1).

Childhood leukemogenesis is likely a multistep process. For ALL, specific oncogene-associated translocations and other abnormalities have been identified in 45% of cases, and random translocations in an additional 25%; but in 30% of the children with ALL, specific genetic alterations have not been identified (Look 1997). Factors predisposing to the development of leukemia in children include underlying genetic disorders, family history, ionizing radiation, chemotherapeutic agents, and possibly infection or environmental chemicals. The underlying genetic disorders associated with an increased risk of developing childhood leukemia include Down syndrome (overall 15-fold increase in risk), defects in DNA repair (Bloom syndrome, Fanconi anemia), congenital marrow failure (Kostmann syndrome, Diamond-Blackfan anemia, and Schwachman-Diamond syndrome), neurofibromatosis type I, and Li-Fraumeni syndrome (Miller 1967; Robison and Neglia 1987).

Family history is a risk factor for the development of childhood leukemia. In identical twins, there is a 25% concordance rate, which is highest in infancy. However, if the diagnosis is made in one sibling after 7 years of age, leukemia risk does not appear to be increased in the other sibling (Miller 1967).

Few environmental or exogenous agents are known to cause the development of childhood leukemia. Postnatal ionizing radiation is a contributing factor. Survivors living within 1,000 meters of the atomic bomb blast in Japan showed a 20-fold increase in leukemia rates; however, children exposed to these bombs *in utero* did not exhibit an increased risk of leukemia (Miller 1967). Pediatric patients given therapeutic irradiation exhibit higher leukemia rates. Similarly, after certain kinds of chemotherapy, there is an increased risk of developing AML (Pui et al. 1989; Tucker et al. 1987).

In contrast to these few known agents, the number of suspected risk factors is much greater. Sources of radiation from prenatal exposure, nearby nuclear plants, or natural background have all been considered as risk factors, as well as radon from groundwater or indoor sources. Investigation into causal factors has included chemical exposures from maternal or child medications, pesticides, parental smoking, or parental occupation. Factors associated with pregnancy and early development, such as maternal pregnancy history, maternal age, birth weight, birth order, and breast-feeding, have also been considered as potential risk factors. A role for infections in childhood leukemogenesis has been proposed from two perspectives. Greaves and colleagues (Greaves 1997; Greaves and Alexander 1993) suggest that unusual timing of postnatal infections could provoke recruitment and proliferation of undifferentiated B cells or T cells with preleukemic translocations. Kinlen (1995, 1997) has proposed that common infections can occasionally trigger a leukemic response, and that an increased leukemia risk is evident when comparing leukemia rates of populations with unusually large influxes of new residents,

Table 1. Childhood leukemia types, subtypes, and features.

Type (%)	Subtype (%)	Morphology	Common genetic abnormalities (%)	Characteristics
ALL (74)	B progenitor (80–85)	L1, L2	t(12;21) (20) t(9;22) (4) 11q23 translocations (6) t(1;19) (5)	Precursor B-cell markers on cell surface, no surface immunoglobulin, ploidy abnormal in 35% of cells
	T cell (10–15)		7q35/TCRβ (3) 14q11/TCRαg (4) 9p deletions	T-cell markers on cell surface, higher median age of patients, higher white blood cell count, bulky disease, male predominance
	Mature B cell (1–2)	L3	t(8;14), t(2;8), or t(8;22) (2)	Surface immunoglobulin, same as Burkitt's lymphoma
AML (19)	Undifferentiated (2)	M0	Monosomy 5/7	
	Myeloblastic (45)	M1, M2	t(8;21)	
	Promyelocytic (10)	M3	t(15;17)	DIC (bleeding)
	Myelomonocytic (20)	M4	11q23/MILL	Infants, chloromas, secondary AML
	Myelomonocytic with eosinophilia[a]	M4Eo	Inversion 16	
	Monocytic (17)	M5	11q23 translocations	Infants, chloromas, secondary AML
	Erythroleukemia (1)	M6		Exceedingly rare in children
	Megakaryocytic (5)	M7	t(1;22)	Down syndrome, infants, myelofibrosis

DIC, disseminated intravascular coagulation.
[a]Percent not available.

potentially bringing in pathogens, to rates among stable populations.

Epidemiology of Childhood Leukemia

Although cancer in childhood (younger than 20 years) is rare, childhood leukemia is the most common form of childhood cancer and represents about one-third of the total childhood cancers in the United States (Linet et al. 1999). For children 0–20 years old, leukemia rates average around 2–3 per 100,000 person-years, but the rate peaks at two or three times this level in 0–4-year-olds. ALL constitutes about three-fourths of U.S. cases of childhood leukemia. Each year, about 2,400 new cases of childhood ALL are reported, with an incidence of approximately 3 per 100,000. Age-specific incidence rates are slightly higher in whites than in blacks at most ages, but between 3–4 years of age, white children show a dramatic peak in rates not seen in black children. Male:female ratios show slightly higher risk for males (1.2:1.0 for all ages), except between 15 and 19 years of age, when the male:female ratio is 2:1. AML constitutes about one-fifth of U.S. cases of childhood leukemia. In contrast to ALL, AML rates do not show a peak at younger ages, and marked gender differences are not apparent at any age.

Childhood leukemia rates vary by geographic locale and ethnicity. In general, ALL rates are the highest in the United States (whites only) and Europe, intermediate in India and China, and the lowest in North Africa and the Middle East. Great Britain reports similar rates and patterns as the United States (Draper 1991). Internationally, however, ALL leukemia rates exhibit a 4-fold range, from about 2 cases per 100,00 person-years in Bangalore, India, to about 8 cases per 100,000 person-years in Costa Rica, in 0–4-year-olds (Parkin et al. 1998). In Africa, T-cell and mature B-cell leukemias are more frequent than is the B-cell progenitor subtype, which may be due to the high incidence of Burkitt's lymphoma associated with AIDS. For AML, the higher incidences are reported in Asia, with lower rates in North America and India.

In the United States, childhood leukemia incidence rates differ by race within geographic areas, but they are similar for the same race among different geographic areas (NCI 2003). In general, leukemia rates are the highest for white children from higher social classes. For black children, the 0–4-year-old ALL case rates per 100,000 person-years are 2.4 (Greater Delaware Valley), 2.5 (Los Angeles), 2.8 [SEER (Surveillance, Epidemiology and End Results) areas], and 2.9 (New York State); for white children, the rates are 5.9 (Greater Delaware Valley), 6.9 (Los Angeles), 6.2 (SEER areas), and 6.2 (New York State) for the same age group.

In the United States, the overall incidence for childhood leukemia has been declining over the past several decades (NCI 2003). Data from 1973 through 1994 show 10.5–13.3% decreases in leukemia incidence, depending on age group. Advances in treatment have led to even more dramatic declines in leukemia mortality, with corresponding increases in 5-year survival rates.

Some have suggested that investigations of childhood leukemia "clusters" might provide clues to the association between childhood leukemia and environmental agents, such as EMFs. Apparent clustering may arise for etiologic, statistical, or sociologic reasons. One U.S. childhood leukemia cluster was reported in Woburn, Massachusetts. Local residents from the east side of Woburn identified a transient, approximate doubling, of the childhood leukemia incidence rate. This area had been highly industrialized since the 1700s, and polluted well water was detected in the 1970s. In an extensive follow-up analysis, the Massachusetts Department of Public Health (1997) confirmed 19 cases of childhood leukemia but found little or no association with children drinking the polluted water (RR = 1.2; 95% CI, 0.3–5.0). An exceedingly imprecise result was reported for pregnant mothers drinking the polluted water, with a 95% CI covering a 100-fold range (RR = 8.3; 95% CI, 0.7–94.7). The extreme imprecision is attributed to the small sample size, which is a problem in most cluster investigations. For comparison, in EMF studies (Greenland et al. 2000) even the smallest leukemia case group was twice as large as the case group in the Woburn study. Although clusters are often the focus of media attention, the examination of cluster studies has not been particularly informative in elucidating additional factors in the development of childhood leukemia or other diseases (Gawande 1999).

Pathogenesis of Acute Leukemia

The multistage process in the development of acute leukemias includes an initial event, a survival or proliferation advantage that causes clonal expansion, additional genetic or epigenetic events that promote escape from programmed cell death or block cell differentiation, and finally, functional bone marrow failure with clinical disease. As discussed above, some of the initiating events are chromosomal translocations. For example, treatment of patients having solid tumors with inhibitors of topoisomerase II, such as etoposide, can induce translocations involving the *Mll* gene on chromosome 11q23, leading to AML or ALL.

In cases where genetic alterations constitute a critical component of the disease process, use of transgenic mice can provide valuable information on pathogenesis. The mutations induced by chromosomal translocations in human leukemias can be introduced into laboratory mice, and leukemogenicity can be assessed in distinct target cells. In one model, altered DNA is introduced *in vitro* to a fertilized mouse egg. The genetically altered egg is implanted into a foster mother. One of her progeny will then carry the altered genes and can be bred to generate additional mice for experimental studies. A major disadvantage of this system is that the transgene is present in all tissues, not just the bone marrow. Alternatively, bone marrow can be harvested from donor mice, altered genetic material introduced *in vitro*, and the transduced bone marrow transplanted into irradiated syngeneic (genetically identical) recipient mice. However, this model system is labor intensive, and experimental variability does occur.

Using these model systems, several aspects of acute leukemia pathogenesis have been elucidated:

- Translocation-induced leukemia oncogenes often confer disease specificity (see Table 1).
- Leukemia-specific oncogenes are insufficient as single agents to induce an acute leukemia phenotype in mice (Higuchi et al. 2002).
- In contrast to acute leukemias, chronic myelogenous leukemia is likely the consequence of a single genetic event (Philadelphia chromosome translocation) (Li et al. 1999).
- Cellular context determines the response of the hematopoietic system to leukemia oncogenes (Li et al. 1999).
- Continued expression of some leukemia translocation oncogenes is required for maintenance of the leukemia phenotype (Huettner et al. 2000).
- Disruption of the ARF/p53 tumor suppressor pathway is a major step in the progression of acute leukemia (Eischen et al. 1999; Unnikrishnan et al. 1999).

Further studies of EMF effects on hematopoietic cell lines should be based on B-lymphoid development and could be useful for identifying pathways that might be complemented in a mouse model. Mouse models, however, may be insensitive to weak EMF effects. For example, in p53 knockout mice, inactivation of both alleles for p53 greatly increases the percentage of lymphomas and decreases the survival time of affected animals, but residential EMF exposure may not be strong enough to inactivate the second allele (Jacks et al. 1994).

Animal Carcinogenicity Studies with EMFs

Epidemiologic studies are often inconclusive and may report associations in the absence of a causative link. In such situations, well-designed and controlled studies using experimental model systems can provide critical data for human hazard assessments. Three approaches have been used to evaluate the cancer risk from exposure to 60-Hz magnetic fields: *a*) chronic oncogenicity bioassays, *b*) oncogenicity bioassays in genetically engineered (transgenic or knockout) mice, and *c*) multistage (co-carcinogenesis or tumor promotion) studies.

Chronic oncogenicity evaluations. The advantages of chronic oncogenicity bioassays include their use of standardized models and study designs that are widely accepted by regulatory agencies. Two-year oncogenicity studies in rodents are supported by a large historical database assembled for numerous chemical and physical agents. These assessments have demonstrated value for predicting human responses. Disadvantages of the animal studies include the need for interspecies extrapolations of organ-specific effects and the common requirement to extrapolate data from high-dose experimental exposures to low-dose human exposures.

Three large-scale, long-term studies of EMF exposure have been conducted in rats (Boorman et al. 1999; Mandeville et al. 1997; Yasui et al. 1997) and two in mice (Babbitt et al. 2000; McCormick et al. 1999). Descriptions and findings from these investigations are summarized in Table 2. Using identical study designs and exposure protocols, McCormick, Boorman, and co-workers examined the tumorigenic effect of EMFs in rats and in mice. The authors evaluated hematopoietic neoplasias and other putative target tissues (breast, brain) for solid tumors. Male rats exposed intermittently to 1,000 µT (10 G) exhibited a statistically significant decrease in leukemia incidence; no significant effects occurred in female rats or in other groups of males. In female mice exposed intermittently to 1,000 µT, a statistically significant decrease in malignant lymphoma was observed; no effects occurred in male mice or in other groups of females. For both rats and mice, the authors reported no significant differences in the incidence of breast or brain tumors in any group. Using different exposure protocols, Yasui et al. (1997) reported no differences in leukemia or lymphoma incidences in rats exposed to either 500 µT or 5,000 µT (5 or 50 G). Likewise, Mandeville et al. (1997) reported no effects on the incidence of leukemia in female rats exposed to 2, 20, 200, or 2,000 µT (0.02, 0.2, 2, or 20 G). Finally, Babbitt et al. (2000) saw no differences in total hematopoietic neoplasms or lymphomas in female mice exposed to 1,400 µT (14 G) (circularly polarized) EMFs.

Evaluations in genetically altered mice. The advantages of using transgenic mice are that weak effects can be magnified and effects occurring only in sensitive subpopulations can be detected. Relevant mechanisms of action may also be identified in sensitive animal models. However, if the historical database is small or nonexistent, there is limited context with which to interpret the data. Also, for many of these sensitive-animal models, their ability to predict human responses is unknown.

Two models have been developed in transgenic mice and applied to the investigation of EMF effects. In the first model, Berns et al. (1994) developed a transgenic mouse carrying the *pim-1* oncogene. After a single dose of *N*-ethyl-*N*-nitrosourea, lymphoma develops within 4–6 months; neoplastic cells show T-cell markers. If no carcinogen is given, spontaneous T-cell and B-cell lymphomas develop within 15–18 months. Animals die shortly after lymphoma is apparent, and therefore, survival is a useful indicator of disease progress. This model has been used in two studies investigating the

Table 2. Oncogenicity studies in animals exposed to EMF over a lifetime.

Species	Group size	Exposure	Percent incidence of hematopoietic neoplasia		Reference
Rats (F344)	100/both sexes/		Leukemia male	Leukemia female	Boorman et al (1999)
	exposure group	Sham control	50	20	
		10 G (continuous)	50	25	
		10 G (intermittent, 1 hr on/off)	36*	22	
		2 G (continuous)	47	24	
		0 02 G (continuous)	44	18	
		60 Hz, 18 5 hr/day			
Rats (F344)	48/both sexes/		Leukemia male	Leukemia female	Yasui et al (1997)
	exposure group	Sham control	10	16	
		50 G	8	14	
		5 G	8	12	
			Lymphoma. male	Lymphoma female	
		Sham control	0	0	
		50 G	0	2	
		5 G	0	2	
		50 Hz, 22 6 hr/day			
Rats (F344)	50 female/		Leukemia		Mandeville et al (1997)
	exposure group	Sham control	10		
		20 G	10		
		2 G	6		
		0 2 G	18		
		0 02 G	8		
		60 Hz, 20 hr/day			
Mice	100/both sexes/		Lymphoma male	Lymphoma female	McCormick et al (1999)
(B6C3F1)	exposure group	Sham control	8	32	
		10 G (continuous)	7	26	
		10 G (intermittent)	6	20*	
		2 G (continuous)	4	22	
		0 02 G (continuous)	7	31	
		60 Hz, 18 5 hr/day			
Mice	190 or 380 female/		Total hematopoietic neoplasms		Babbitt et al (2000)
(C57BL/6)	exposure group	Sham control	56		
		14 G (circularly polarized)	59		
			Lymphoma		
		Sham control	35		
		14 G (circularly polarized)	37		
		60 Hz, 18 hrs/day			

*$p < 0.05$ versus sham control

effects of EMF exposure (Harris et al. 1998; McCormick et al. 1998). Survival and lymphoma incidence were unaffected in several different EMF exposure formats (Table 3). In the second model (Donehower 1996), one (hemizygous) or both copies of the *p53* gene are deleted from the germ line. McCormick et al. (1998) evaluated lymphoma incidence in TSG-*p53* mice exposed to 1,000 µT (10 G) continuous EMFs (Table 3). EMF exposure had no effect on survival and lymphoma incidence.

Multistage (promotion) studies. Multistage study designs have the potential to identify weak effects and thus have increased sensitivity. They are useful for identifying nongenotoxic effects or effects that occur only in populations exposed to other agents. Their primary disadvantage relates to their unknown accuracy for predicting human responses.

Two promotional studies have investigated the response of mice to EMFs in conjunction with ionizing radiation (Babbitt et al. 2000) or dimethylbenz[*a*]anthracene (Shen et al. 1997). The study design and findings are summarized in Table 4. No increases in lymphoma incidence due to the EMF exposure occurred in these two studies.

EMFs and Interactions with Matter

If power-line EMFs initiate or modulate the onset of disease in humans, then it should be possible to identify a mechanism by which EMFs alter molecules, chemical reactions, cell membranes, or biologic structures in a functionally significant manner. An "electric field" is produced by electrically charged objects, such that the size and direction of the electric field predicts the size and direction of force on electric charges. Likewise, a "magnetic field" is produced by moving charges, and the magnetic field predicts force on moving charges. Therefore, any EMF bioeffects must solely and ultimately be the result of forces; there are no other actions of EMFs. The plausibility of a biologic effect depends on whether EMF forces can significantly modify biologic processes having electrically responsive elements [e.g., ions, charged proteins, neural electric currents, magnetic molecules (free radicals), and magnetic particles].

The measurement units used for EMFs reflect the force exerted. The unit of measure for electric fields is volts per meter (V/m), which is identical to newtons per coulomb (N/C), where the newton is the metric unit for force, and the coulomb is the metric unit for quantity of electric charge; that is, the electric field gives the force per unit charge. The unit of measure for magnetic field is the tesla (T); typical environmental fields are in the microtesla (µT) range, which is one-millionth of a tesla. A metric unit, the tesla is identical to newtons/ampere-meter (N/A-m), and therefore, the magnetic field gives force per unit length (meter) of unit current (ampere).

Next, one can ask how the forces and energies conveyed by EMF exposure compare with forces and energies endogenous to biologic systems. As discussed below, the energies and forces exerted by environmental, 60-Hz EMFs seem well below those present in biologic systems. That is, normal living cells operate under conditions of energy and force "noise" such that 60-Hz EMF effects will be lost in this background. Theoretically, one could postulate that a low-noise, multicellular organ system might respond to feeble EMF influences and separate them from noise, similar to what happens in a manmade electronic circuit that responds to 60-Hz EMFs. However, the construction of a biologic system capable of responding to 60-Hz EMFs imposes severe size, averaging time, temperature stability, and conductivity constraints. Although sharks can respond to extremely weak, slowly changing electric fields in seawater, their sensor organ (*ampulla* of Lorenzini) is complex, containing a large number (~10,000) of receptor cells, in which small interactions are integrated to generate a change that stands out against noise (Adair 2001; Adair et al. 1998). Aside from such specialized sensory systems, fundamental force and energy considerations appear to preclude disruption of biology by weak EMFs. Table 5 lists mechanisms by which EMFs might alter biologic function, but the strengths of EMF interaction energies and forces are found to be small compared with the endogenous energies

Table 3. EMF studies in genetically engineered mice.

Species	Group size	Exposure	Percent incidence of lymphoma		Reference
Mice (*pim-1*)	30/both sexes/ exposure group		Male	Female	McCormick et al. (1998)
		Sham control	49	47	
		10 G (continuous)	23*	47	
		10 G (intermittent)	57	53	
		2 G (continuous)	43	45	
		0.02 G (continuous)	47	45	
		60 Hz, 18.5 hr/day, for 26 weeks			
Mice (*pim-1*)	100 female/ exposure group		T-cell	B-cell	Harris et al. (1998)
		Sham control	5	23	
		10 G (continuous)	8	22	
		10 G (intermittent)	7	28	
		1 G (continuous)	8	18	
		0.01 G (continuous)	4	25	
		50 Hz, 20 hr/day, up to 18 months			
Mice (TSG-*p53*)	30/both sexes/ exposure group		Male	Female	McCormick et al. (1998)
		Sham control	3	3	
		10 G (continuous)	0	7	
		60 Hz, 18.5 hr/day, for 26 weeks			

*$p < 0.05$ versus sham control.

Table 4. Multistage oncogenicity studies with EMF.

Species	Group size	Exposure	Percent incidence of lymphoma			Reference
Mice (C57BL/6)	380 female/ exposure group	X-ray:	3.0 Gy	4.0 Gy	5.1 Gy	Babbitt et al. (2000)
		Sham control	41	38	53	
		14 G	34	41	47	
		(circular) 60 Hz, 18 hr/day, lifetime				
Mice (Swiss Webster)	155–165/ exposure group	Dimethylbenz[*a*]anthracene:				Shen et al. (1997)
		Sham control		24		
		10 G		22		
		50 Hz, 3 hr/day, 5 days/week, for 16 weeks				

and forces characteristic of the living system (Valberg et al. 1997).

Table 5 shows that, in terms of energy or force at the whole-body scale or at the molecular scale, the effect of "large" EMFs is many orders of magnitude below the typical forces and energies that accompany life processes. For example, x-rays can produce significant molecular damage even when the total energy deposited in the body is small. However, the energy of a 60-Hz EMF photon is vastly less than that of x-rays and is too weak to alter molecular structures. The intensity of the electric field per se could be increased to levels where it accelerates individual free electrons to electron-volt energies, exceeding those needed to break a chemical bond (e.g., in corona discharge). However, the level of electric-field intensity required for this type of molecular damage is far above what a person is exposed to in environmental, power-line EMFs.

Likewise, EMF forces on biologic structures can be calculated easily, but the force required to distort the shape of complex biologic molecules—for example, DNA or enzymes—is far larger than what the electric component of EMFs can provide. However, the magnetic component of EMFs will act on magnetic particles or with single-molecule magnetic dipole (e.g., free radicals). Although magnetite particles are plausible geomagnetic field sensors (Kirschvink et al. 1992, 2001), functional biogenic ferromagnetic material has been established only in a limited number of organisms (e.g., magnetotactic bacteria). In these organisms, the magnetic interaction provides sensory guidance and is not likely to lead to internal malfunctions. Although magnetic forces may be adequate to twist ferromagnetic particles, the response of the particles to EMFs is limited by the reversal of the power-line magnetic field direction 120 times every second. That is, the net twist over any 1/60th of a second will be zero, and because of the viscosity of biologic materials, only a tiny amount of twist will take place during the 1/120th of a second that the magnetic field points in a given direction.

Coupling of EMFs to biologic effects. Most theoretical analyses of EMF actions have emphasized physical parameters and have analyzed models of individual cells or subsystems of single cells (mainly membranes and magnetosomes) (Adair 1991, 1994; Kirschvink et al. 2001; Polk 1992, 1994; Weaver and Astumian 1990). The shark provides an example of how a multicellular system can detect weak electric fields (described above), and the possibility that some multicellular structures may amplify electric fields has been considered (Fear and Stuchly 1998; Gowrishankar and Weaver 2003). The importance of biologic system size also has been emphasized in a model for the biologic detection of small magnetic field differences (Weaver et al. 2000). Multicellular system models begin with the recognition that EMFs are physical, not chemical, agents, as illustrated in the following causal chain (Weaver 2002):

$$\text{EMFs} \rightarrow \text{Physics} \rightarrow \text{Chemistry} \rightarrow \text{Biology}$$

A necessary condition for biologic activity is that EMF-induced changes must exceed chemical changes from natural or background influences. Changes in biology are coupled to EMFs through changes in biochemistry, which in turn must have an ongoing, metabolically driven chemical process (reaction or transport rate) that is sensitive to EMFs. The assumption behind predicting the "weakest" detectable field is that this limit is determined by the ability of weak fields to alter the biochemistry, but it is not limited by the ability of a small number of molecules to alter the biologic system.

A key consideration is the size of the EMF-induced chemical change relative to naturally occurring changes in the same chemical process, which can be thought of as a chemistry-based signal-to-noise (S/N) ratio. For example, the signal (S) can be the EMF-induced, accumulated change in an ionic or molecular flux (Astumian et al. 1995), or the change in the average number of receptor-bound ligands (Weaver et al. 2000). But the accumulated change in flux or receptor-bound number also varies because of other natural processes, which constitute a generalized chemical noise (N), including the sources listed in Table 6. The totality of the sources of competing chemical change on Table 6, ($N_{\Delta N} + N_{\Delta T} + N_{\Delta C} + N_{\Delta M} + N_{\Delta E}$), can be expected to be much larger for humans *in vivo* than for cellular preparations studied *in vitro* (Weaver et al. 1999). Therefore, for the intact organism, the overall chemistry-based signal-to-noise ratio can be written symbolically as

$$\left(S_{\text{EMF}}/N_{\text{overall}}\right) = \frac{S_{\text{EMF}}}{N_{\Delta N} + N_{\Delta I} + N_{\Delta C} + N_{\Delta M} + N_{\Delta E}}$$

The question of how to add the various competing chemical changes has not been fully addressed. If the competing changes can be regarded as random (and independent), then each of the competing changes can be added as the sum of their magnitudes squared (Weaver et al. 1999). In summary, the *in vivo* human biochemical environment exhibits considerable noise. This inherent, background noise must be quantitatively reconciled with the relatively small levels of 60-Hz EMF "signal" if one is to predict alteration of ongoing biochemical processes by EMFs. The effect threshold for voltage-gated channels in single, long cells is predicted to be about 50 V/m, which in a human-sized organism corresponds to the electric field induced by a magnetic field of about 1 T (10,000 G) (Weaver et al. 1999). If temperature noise is ignored, the threshold electric field is about 0.1 V/m, which corresponds to a magnetic field of 6,000 μT (60 G) (Weaver et al. 1999). As system size increases, fundamental noise tends to increase at a slower rate than does the induced EMF signal. Hence, the constraint that signal should exceed noise ($S/N > 1$) is more likely to be met in a large, multicellular system rather than in individual, isolated cells (Weaver et al. 2000).

Another difficulty in coupling EMFs to biologic effects has been assessing perturbations in membrane transport systems. An improved approach for evaluating molecular transport has been developed that might have application to predicting EMF effects on cell function (Gowrishankar and Weaver 2003), which uses a multicellular model based on elementary transport models that can be assembled into both membranes and bulk electrolyte. The model can predict voltages, currents, dissipated power density, and chemical changes throughout the system. Simulation of the bone marrow by the lattice transport model may be particularly appropriate in testing the hypothesis that contact currents are a potential causal link between EMFs and childhood leukemia. Marrow within bone is mechanically protected from

Table 5. Biologic process strength compared with EMF interaction strength.

Interaction process	Interaction strength in living system	Interaction strength for typical "large" EMF levels[a]
Heating	Basal metabolism ~100 W	Absorbed 60-Hz EMF energy = ~0.00001 W (i.e., 10 μW is 10,000,000-fold below basal metabolism)
Photon absorption	Chemical bond energies of ~0.1–5 eV	60-Hz EMF photons = ~0.000001 eV (i.e., EMF ~1 μeV, vs. x-rays ~500–5,000 eV)
Force (electrical)	Biologic forces ~1–100 pN	Molecule with electric charge of ±100 = ~0.0002 pN (pN = 10^{-12} N = 0.000000000001 N)
Force (magnetic)	Biologic forces ~1–100 pN	Twisting force on microscopic ferromagnetic particles (acting like compass needles), ~2 pN, but EMF force alternates direction every 1/120th sec, and averages to zero
Biochemistry	Free-radical recombination lifetimes ~2 nsec	Free-radical chemistry requires larger fields, and any effects occur over nanoseconds, so 60-Hz field with period of 17 msec appears same as static field

[a]e.g., E = 1,000 V/m and M = 100 μT (or 1,000 mG)

motion [a source of generalized noise, ($N_{\Delta M}$) (Vaughan and Weaver 1998)], and should also partially attenuate biologically generated electric fields, potentially decreasing background field noise, ($N_{\Delta E}$).

Contact Currents as a Possible Explanatory Exposure

A "contact current" occurs at home or in the workplace when a person touches two conductive surfaces that are at different electrical voltages. Typically, these currents may flow from hand to hand or from a hand through the feet, depending on how the contact with the conductive surfaces is made. Sensory reactions to contact current depend on the level of current, the physical dimensions and anatomical features of the exposed individual, the size of the contact area (e.g., touch or grip), and unspecified sensitivity factors unique to that individual (reviewed in Reilly 1998). For example, adult men experience sensory thresholds at electric currents between 100 and 500 µA, with progressively lower thresholds for women and children due to their smaller size; a child's lower perception threshold is about 50 µA.

Associations between residential magnetic fields and the risk of childhood leukemia have been observed, but the magnetic fields per se appear to be too weak to cause biologic effects, and leukemia bioassays in rodents are uniformly negative. It is conceivable that the magnetic field measurements are acting as a surrogate for some other exposure. An exposure, such as contact currents, could be an explanatory factor for the observed epidemiologic associations if three conditions are satisfied: *a*) an association is present between contact current exposure and the measured power-line magnetic field level, *b*) levels of contact current expected in a home are sufficient to deliver an adequate dose to the bone marrow, and *c*) a target population (i.e., small children) has the opportunity to encounter contact currents.

Association between magnetic fields and contact voltages. In a computer model, two sources of contact voltage were considered, which appear either between the electrical panel (*P*) and the water line entering the house (*W*), or between the water line (*W*) and the earth ground (*E*) (Kavet et al. 2000). The first source, V_{P-W}, occurs in the grounding conductor that connects the neutral wire at the electrical service panel (fuse or breaker box) to the water line entering the house (as required by the National Electrical Code). The grounding conductor carries a fraction of a home's net load current producing an ohmic voltage across the conductor's length. Because appliance frames also are connected via the third or "green" wire in the power cord to the service panel neutral, an individual can be exposed to V_{P-W} when simultaneously touching an appliance frame and a water fixture.

The second source arises from the voltage between the water pipes and the earth, V_{W-E}. This voltage results from ground currents in the primary and secondary electrical distribution circuits that flow from the water pipes into the earth. V_{W-E} also can result from induction caused by magnetic fields from heavily loaded power lines that may be nearby. V_{W-E} produces a voltage between water pipes and the drainpipe (V_{W-D}), because the drainpipe is sunk into the soil and therefore becomes a component in the earth return pathway. Exposure to a contact voltage could occur to a person bathing while contacting a water fixture or the water stream. If any segment of the water supply or drainpipe is nonconductive, exposure does not occur. Basic engineering principles suggest that, across large populations, V_{W-E} and the residential magnetic field should be associated with each other (Kavet and Zaffanella 2002).

In a computer-modeled neighborhood, Kavet et al. (2000) observed that V_{P-W} is highly correlated to the magnetic field attributable to the ground current within a particular residence. In a pilot study of 36 residences (Kavet and Zaffanella 2002), the degree of correlation between contact voltages and magnetic field measurements varied. V_{P-W} was poorly correlated to spot-measured magnetic fields (B_{avg}) (both log-transformed). This discrepancy is due most likely to the effects of magnetic fields from nearby lines, which may have "swamped" the fields from the ground path. On the other hand, V_{W-E} was significantly ($p < 0.001$) correlated to B_{avg} (both log-transformed) with the highest levels of V_{W-E} (> 400 mV) associated with proximity to high voltage transmission lines (i.e., probably due to magnetic field induction). V_{W-D}, however, was not significantly correlated with B_{avg} (22 valid data points). The results suggest a positive association between magnetic field exposure and contact voltage due to V_{W-E}, but a more precise description of the relation between V_{W-D} and B_{avg} will require a larger sample. V_{W-E} is the source voltage for V_{W-D}, and V_{W-D} is some fraction of V_{W-E}, but the fraction varies from house to house. Kaune et al. (2002) failed to find an association between ground currents and case versus control status for childhood cancer, but because of large variations in the conductivity of water pipes, ground currents may not correlate with contact voltages.

Sufficient dose to tissue. Biologic response to an environmental exposure requires sufficient dose as a necessary but not sole condition. A key difficulty with attributing a causal interpretation to the association between childhood leukemia and magnetic fields has been the low dose to target tissue associated with ambient magnetic fields. For example, residential fields away from appliances rarely exceed 1 µT, and studies using anatomically representative computer models report that a 5-µT 60-Hz magnetic field fails to induce even 1 mV/m (the minimum "benchmark" dose for biologic effects; NIEHS 1999) in an adult's bone marrow, with lower values expected for children because of their smaller size (Kavet et al. 2001).

Studies examining contact current dosimetry report that the bone marrow of a child-sized model's lower arm experiences an average of 5 mV/m per µA of contact current into the hand, and 5% of the tissue achieves 13 mV/m per µA (Dawson et al. 2001). Modeled adults experience roughly 40% of the values of the modeled child. Because exposure in the bathtub scenario (summarized above) can reach 30 µA or more, electric fields in a child's marrow of up to 500 mV/m (0.5 V/m) are conceivable, exceeding by several-fold the above 1 mV/m "benchmark dose."

Opportunity for exposure. Although V_{P-W} can technically cause contact current to flow, it is most likely a minor source of exposure, especially to children. Simultaneous contact with an appliance and a water fixture is probably not common and the reach may be beyond a child's physical dimensions. In addition, most appliance contact is with a dry hand, which means the contact resistance can exceed 100 K ohms, resulting in a relatively low current. In contrast, contact with the water fixture in a bathtub involves a wet hand that essentially short-circuits the insulating outer layer of the skin. Moreover, if children bathe several hundred times per year, then ample opportunity exists for some level of contact, although such behaviors have not been studied.

Table 6. Noise processes that compete with EMF interaction strength.

Noise process	Symbol	Source of competing chemical changes
Stochastic chemical noise	$N_{\Delta N}$	Randomizing collisions and fluctuations inherent to an aqueous biological environment
Temperature variations	$N_{\Delta T}$	Environmental and metabolic temperature fluctuations coupling to significant biochemical temperature dependence
Concentration variations	$N_{\Delta C}$	Physiological processes leading to variations in concentrations of ions and molecules
Mechanical noise	$N_{\Delta M}$	Motion of tissues leading to possible mechanical interference with ongoing processes
Background electric fields	$N_{\Delta E}$	Neuromuscular electrical activity and motion-created streaming potentials that lead to background electric fields

Summary of the contact–current metric. Because the three conditions, association between exposures, sufficient dose, and exposure opportunity, have not been refuted in modeled analyses, the contact-voltage explanation remains viable. However, the key exposure parameters have not yet been characterized in a large-sample study. Furthermore, no bioassay or *in vitro* model of childhood leukemogenesis has been studied with controlled applications of contact current, but molecular models of childhood leukemia in molecular engineered mice can provide insight on the possible role of 60-Hz bone marrow electrical fields. The use of transgenic mice allows characterization of the initial genetic alteration that can be applied to the investigation of subsequent epigenetic factors such as 60-Hz currents through the bone marrow. Thus, although some theoretical models support additional inquiry, the lack of definitive data showing magnetic fields to be a surrogate for exposure to contact voltages adds uncertainty as to the direction of future research.

Summary

In children, ALL represents approximately 75% of the total leukemia types. In acute leukemia, initiating events tend to be genetic in origin and commonly are represented by chromosomal translocations. There are known and suspected risk factors, and epidemiologic associations between EMFs and childhood leukemia have made EMFs a suspected risk factor. Animal data on the effects of EMF exposure, however, are overwhelmingly negative regarding EMF exposure per se being a significant risk for hematopoietic neoplasia. We may fail to observe laboratory effects from EMF exposure because typical power-line EMFs do not give a "dose" detectable above the many sources of "noise" in biologic systems. We may fail to detect EMF effects in bioassay systems because EMFs themselves are not the causal exposure in the epidemiologic associations. "Contact voltages" have been proposed as a novel exposure metric, and they meet three plausibility conditions: association with residential EMF levels, biologic effective dose, and opportunities for exposure. If replicable laboratory findings indicate that contact voltages are important in leukemia risk, then epidemiology studies might be designed to explore this proposal further.

References

Adair RK 1991 Constraints on biological effects of weak extremely-low-frequency electromagnetic fields Phys Rev A 43 1039–1048

——— 1994 Constraints of thermal noise on the effects of weak 60-Hz magnetic fields acting on biological magnetite Proc Natl Acad Sci USA 91 2925–2929

——— 2001 Simple neural networks for the amplification and utilization of small changes in neuron firing rates Proc Natl Acad Sci USA 98·7253–7258

Adair RK, Astumian RD, Weaver JC 1998 On the detection of weak electric fields by sharks, rays and skates Chaos 8.576–587

Ahlbom A, Cardis E, Green A, Linet M, Savitz D, Swerdlow A 2001. Review of the epidemiologic literature on EMF and health Environ Health Perspect 109(suppl 6)·911–933

Ahlbom A, Day N, Feychting M, Roman E, Skinner J, Dockerty J, et al. 2000 A pooled analysis of magnetic fields and childhood leukaemia Br J Cancer 83·692–698

Astumian RD, Weaver JC, Adair RK 1995 Rectification and signal averaging of weak electric fields by biological cells. Proc Natl Acad Sci USA 92 3740–3743

Babbitt JT, Kharazi AI, Taylor JM, Bonds CB, Mirell SG, Frumkin E, et al 2000. Hematopoietic neoplasia in C57BL/6 mice exposed to split-dose ionizing radiation and circularly polarized 60 Hz magnetic fields Carcinogenesis 21:1379–1389.

Berns A, van der Lugt N, Alkema M, van Lohuizen M, Domen J, Acton D, et al 1994 Mouse model systems to study multistep tumorigenesis Cold Spring Harb Symp Quant Biol 59 435–447.

Boorman GA, McCormick DL, Findlay JC, Hailey JR, Gauger JR, Johnson TR, et al 1999 Chronic toxicity/oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in F344/N rats. Toxicol Pathol 27·267–278

Boorman GA, Rafferty CN, Ward JM, Sills RC 2000. Leukemia and lymphoma incidence in rodents exposed to low-frequency magnetic fields Radiat Res 153 627–636.

CADHS. 2002 An Evaluation of the Possible Risks from Electric and Magnetic Fields (EMF) from Power Lines, Internal Wiring, Electrical Occupations and Appliances. Oakland, CA:California Department of Health Services, California EMF Program Available http //www.dhs ca.gov/ehib/emf/RiskEvaluation/riskeval html [accessed 19 February 2003]

Dawson TW, Caputa K, Stuchly MA, Kavet R 2001. Electric fields in the human body resulting from 60-Hz contact currents. IEEE Trans Biomed Eng 48·1020–1026

Donehower LA 1996 The p53-deficient mouse a model for basic and applied cancer studies. Semin Cancer Biol 7:269–278

Draper GJ. (ed) 1991 The Geographical Epidemiology of Childhood Leukaemia and Non-Hodgkin Lymphomas in Great Britain, 1966–83. Studies on Medical and Population Subjects, No. 53. London.Her Majesty's Stationery Office.

Eischen CM, Weber JD, Roussel MF, Sherr CJ, Cleveland JL. 1999 Disruption of the ARF-Mdm2-p53 tumor suppressor pathway in Myc-induced lymphomagenesis. Genes Dev 13 2658–2669

Fear EC, Stuchly MA 1998 Biological cells with gap junctions in low frequency electric fields IEEE Trans Biomed Eng 45 856–866

Gawande A 1999. The cancer-cluster myth. New Yorker. 8 February, 34–37

Gowrishankar TR, Weaver JC. 2003 A new approach to electrical modeling of single and multiple cells Proc Natl Acad Sci USA 100.3203–3208

Greaves MF 1997 Aetiology of acute leukaemia. Lancet 349.344–349

Greaves MF, Alexander FE 1993 Review an infectious etiology for common acute lymphoblastic leukemia in childhood? Leukemia 7.349–360

Greenland S, Sheppard AR, Kaune WT, Poole C, Kelsh MA. 2000. A pooled analysis of magnetic fields, wire codes, and childhood leukemia. Childhood Leukemia-EMF Study Group Epidemiology 11·624–634

Harris AW, Basten A, Gebski V, Noonan D, Finnie J, Bath ML, et al 1998 A test of lymphoma induction by long-term exposure of E mu-Pim1 transgenic mice to 50 Hz magnetic fields Radiat Res 149 300–307

Hatch EE, Kleinerman RA, Linet MS, Tarone RE, Kaune WT, Auvinen A, et al 2000 Do confounding or selection factors of residential wiring codes and magnetic fields distort findings of electromagnetic fields studies? Epidemiology 11 189–198

Higuchi M, O'Brien D, Kumaravelu P, Lenny N, Yeoh EJ, Downing JR 2002 Expression of a conditional AML1-ETO oncogene bypasses embryonic lethality and establishes a murine model of human t(8,21) acute myeloid leukemia. Cancer Cell 1.63–74

Huettner CS, Zhang P, Van Etten RA, Tenen DG 2000 Reversibility of acute B-cell leukaemia induced by *BCR-ABL1* Nat Genet 24 57–60.

IARC. 2002 Non-ionizing radiation, part 1 static and extremely low-frequency (ELF) electric and magnetic fields IARC Monogr Eval Carcinog Risks Hum 80 1–429

Jacks T, Remington L, Williams BO, Schmitt EM, Halachmi S, Bronson RT, et al. 1994 Tumor spectrum analysis in *p53*-deficient mice. Curr Biol 4 1–7

Kaune WT, Dovan T, Kavet RI, Savitz DA, Neutra RR 2002 Study of high- and low-current-configuration homes from the 1988 Denver Childhood Cancer Study Bioelectromagnetics 23:177–188

Kavet R, Stuchly MA, Bailey WH, Bracken TD 2001. Evaluation of biological effects, dosimetric models, and exposure assessment related to ELF electric- and magnetic-field guidelines Appl Occup Environ Hyg 16 1118–1138

Kavet R, Zaffanella LE. 2002. Contact voltage measured in residences: implications to the association between magnetic fields and childhood leukemia. Bioelectromagnetics 23.464–474

Kavet R, Zaffanella LE, Daigle JP, Ebi KL. 2000 The possible role of contact current in cancer risk associated with residential magnetic fields. Bioelectromagnetics 21 538–553

Kinlen LJ. 1995. Epidemiological evidence for an infective basis in childhood leukaemia Br J Cancer 71 1–5

———. 1997 High-contact paternal occupations, infection and childhood leukaemia five studies of unusual population-mixing of adults. Br J Cancer 76:1539–1545

Kirschvink JL, Kobayashi-Kirschvink A, Woodford BJ 1992 Magnetite biomineralization in the human brain Proc Natl Acad Sci USA 89:7683–7687

Kirschvink JL, Walker MM, Diebel CE. 2001 Magnetite-based magnetoreception: a review Curr Opin Neurobiol 11.462–467.

Li S, Ilaria RL, Million RP, Daley GQ, Van Etten RA 1999 The P190, P210, and P230 forms of the *BCR/ABL* oncogene induce a similar chronic myeloid leukemia-like syndrome in mice but have different lymphoid leukemogenic activity J Exp Med 189·1399–1412

Linet MS, Ries LA, Smith MA, Tarone RE, Devesa SS 1999 Cancer surveillance series· recent trends in childhood cancer incidence and mortality in the United States J Natl Cancer Inst 91·1051–1058

Look AT. 1997 Oncogenic transcription factors in the human acute leukemias. Science 278(5340) 1059–1964

Mandeville R, Franco E, Sidrac-Ghali S, Paris-Nadon L, Rocheleau N, Mercier G, et al 1997. Evaluation of the potential carcinogenicity of 60 Hz linear sinusoidal continuous-wave magnetic fields in Fischer 344 rats FASEB J 11.1127–1136

Massachusetts Department of Public Health 1997 Woburn Childhood Leukemia Follow-up Study. Final Report. Boston, MA:Massachusetts Department of Public Health

McCormick DL, Boorman GA, Findlay JC, Hailey JR, Johnson TR, Gauger JR, et al. 1999. Chronic toxicity/oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in B6C3F1 mice Toxicol Pathol 27·279–285.

McCormick DL, Ryan BM, Findlay JC, Gauger JR, Johnson TR, Morrissey RL, et al 1998 Exposure to 60 Hz magnetic fields and risk of lymphoma in PIM transgenic and TSG-p53 (p53 knockout) mice. Carcinogenesis 19:1649–1653

Miller RW. 1967. Persons with exceptionally high risk of leukemia Cancer Res 27:2420–2423

NCI. 2003. Surveillance, Epidemiology and End Results (SEER). Finding Cancer Statistics. Bethesda, MD:National Cancer Institute Available: http://surveillance.cancer gov/statistics/ [accessed 19 February 2003]

NIEHS 1999. Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields NIH Publication 99-4493. Research Triangle Park, NC·National Institute of Environmental Health Sciences

Parkin DM, Kramárová E, Draper GJ, Masuery E, Michaelis J, Neglia J, et al. (eds). 1998 International Incidence of Childhood Cancer, Vol 2 IARC Publications, No. 144 Lyon, France·International Agency for Research on Cancer

Polk C 1992 Counter ion polarization and low frequency, low electric field intensity biological effects Bioelectrochem Bioenerget 28:279–289

——— 1994 Effects of extremely-low-frequency fields on biological magnetite limitations on physical models Bioelectromagnetics 15.261–270

Pui C-H, Behm FG, Raimondi SC, Dodge RK, George SL, Rivera GK, et al 1989 Secondary acute myeloid leukemia in children treated for acute lymphoid leukemia New Engl J Med 321 136–142

Reilly JP 1998 Applied Bioelectricity. From Electrical Stimulation to Electropathology. New York Springer-Verlag.

Robison LL, Neglia JP 1987 Epidemiology of Down syndrome and childhood acute leukemia Prog Clin Biol Res 246 19–32

Savitz DA. 2003. Health effects of electric and magnetic fields: are we done yet? Epidemiology 14:15–17.
Shen YH, Shao BJ, Chiang H, Fu YD, Yu M. 1997. The effects of 50 Hz magnetic field exposure on dimethylbenz(alpha)anthracene induced thymic lymphoma/leukemia in mice. Bioelectromagnetics 18:360–364.
Tucker MA, Meadows AT, Boice JD Jr, Stovall M, Oberlin O, Stone BJ, et al. 1987. Leukemia after therapy with alkylating agents for childhood cancer. J Natl Cancer Inst 78:459–464.
Unnikrishnan I, Radfar A, Jenab-Wolcott J, Rosenberg N. 1999. p53 mediates apoptotic crisis in primary Abelson virus-transformed pre-B cells. Mol Cell Biol 19:4825–4831.
Valberg PA, Kavet R, Rafferty CN. 1997. Can low-level 50/60-Hz electric and magnetic fields cause biological effects? Radia Res 148:2–21.
Vaughan TE, Weaver JC. 1998. Molecular change due to biomagnetic stimulation and transient magnetic fields: mechanical interference constraints on possible effects by cell membrane pore creation via magnetic particles. Bioelectrochem Bioenerget 46:121–128.
Weaver JC. 2002. Understanding conditions for which biological effects of nonionizing electromagnetic fields can be expected. Bioelectrochemistry 56:207–209.
Weaver JC, Astumian RD. 1990. The response of cells to very weak electric fields: the thermal noise limit. Science 247:459–462.
Weaver JC, Vaughan TE, Astumian RD. 2000. Biological sensing of small field differences by magnetically sensitive chemical reactions. Nature 405:707–709.
Weaver JC, Vaughan TE, Martin GT. 1999. Biological effects due to weak electric and magnetic fields: the temperature variation threshold. Biophys J 76:3026–3030.
Wertheimer N, Leeper E. 1979. Electrical wiring configurations and childhood cancer. Am J Epidemiol 109:273–284.
Yasui M, Kikuchi T, Ogawa M, Otaka Y, Tsuchitani M, Iwata H. 1997. Carcinogenicity test of 50 Hz sinusoidal magnetic fields in rats. Bioelectromagnetics 18:531–540.
Zaffanella LE. 1993. Survey of Residential Magnetic Field Sources. EPRI Report TR-102759, Vols 1 and 2. Palo Alto, CA:Electric Power Research Institute.

English | **Español** | **Franç**

World Health Organization

Search OK

Home
Countries
Health topics
Publications
Research tools
WHO sites
EMF Home
EMF Project
Research
Standards
About Electro Magnetic Fields
EMF Publications & Information resources
Meetings

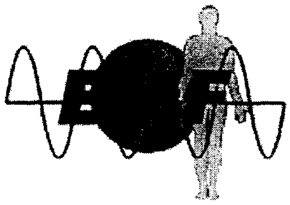
The International EMF Project (EMF)

About Us | Contact Us | Publications

Location: **WHO** > **WHO sites** > **EMF Home**

International **EMF** *Project*

"...through its International EMF Project, the World Health Organization is pooling resources and knowledge concerning health effects of exposure to EMF."



ON THIS SITE, YOU WILL BE ABLE TO FIND DETAILS ON THE FOLLOWING QUESTIONS:

- What is the International EMF Project?
- What research on the health effects of EMF is being done?
- What are the standards and guidelines on exposure to EMF?
- What are electromagnetic fields?
- What WHO publications are available on this topic?
- What meetings are of interest?

If you have any comments on this site please email emfproject@who.int.

WHAT'S NEW

New RF rese agenda - Jul
More informa

WHO respon to inquiries ab Epidemiologic Around Base
More informa

Precautiona Framework: on WHO's A
More informa 7KB]

Precautiona Framework Health Prote
We invite pub comment on Please addres comments to emfproject@w
Full report [PD

QUICK LINKS SITE

The EMF Sta Worldwide D
More informa

EMF Fact Sh Press Releas
More informa

EMF Researc Database
More informa

FAQs
More Informa

NEXT EMF ME

3rd Internat Seminar in C new date
13 - 17 Octob Guilin - China
More informa

Internationa Conference

WHO website

MICRO WAVE NEWS

Vol. XXIII No. 1 — *A Report on Non-Ionizing Radiation* — *January/February 2003*

INSIDE...

HIGHLIGHTS pp.2-8

Brillouin Precursor Theory Draws More Fire
Albanese: At the Center of the Storm
NAS Panel on PAVE PAWS Seeks More Data
FDA's View of MW–Cancer Link in 1993
Australians Admit Error in Cancer–Transgenic Mouse Paper; Explanation Baffles Skeptics
Eye on Europe:
Tower Epi Studies • COST281 To Investigate Genotoxic Effects • EU Occupational Limits • Germans Explain Support for Precaution • Wireless Lobby in U.K. • Tower Information in Portugal • German Tutorial on a CD

EMF NEWS pp.8-10

Chemicals and EMFs Can Act Synergistically In the Development of Brain Cancer
IEEE Rebuffs Appeals on ELF Standard
Industry Lobby Glosses Over Leukemia Risk
NEMA Statement on EMFs and Cancer
Catholics Seek To Muzzle Power Line Critic
Excerpt: Former IARC Head Backs Precaution

FROM THE FIELD pp.11-14

Hot New Papers: GSM Degrades DNA
Letter: Nonthermal Effects in Inorganic World
2003 Conference Calendar (Part II)
Meeting Notes: Precaution • Brazil • China
Across the Spectrum
Flashback: 5, 10, 20 Years Ago

UPDATES pp.15-18

Phones in Pockets • Circadian Rhythms & Cancer • "Consumer Reports" on Cell Phone Safety • Precautionary Principle • People in the News • Second Look at Secondhand Radiation • Phoning and Driving • Exposures on Sailing Ships
Keeping Current: Follow-Up on the News

VIEWS ON THE NEWS p.19

Swedish Study Must Be Followed Up

Swedes Find GSM Radiation Causes Nerve Damage at Very Low Doses

Leakage Through the Blood-Brain Barrier

In a new paper that is sure to reignite concerns over the safety of mobile phones, Drs. Leif Salford and Bertil Persson have shown that extremely low doses of GSM radiation can cause brain damage in rats.

Salford, a neurosurgeon, and Persson, a biophysicist, both at Sweden's University of Lund, report that they see nerve damage following a single two-hour exposure at a specific absorption rate (SAR) of 0.002 W/Kg. The effect becomes statistically significant at 0.02 W/Kg. These nonthermal levels are a hundred to a thousand times lower than the 2 W/Kg exposure standard recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

Salford and Persson first showed that low-level microwave radiation can cause leakage through the blood-brain barrier (BBB) over ten years ago (see *MWN*, J/F92 and J/A92). In this latest work, they again show that microwave

(continued on p.19)

1993 FDA Memo

Data "Strongly Suggest" Microwaves Can Promote Cancer

In the spring of 1993 at the height of public concern over cell phone–brain tumor risks, Food and Drug Administration (FDA) biologists concluded that the available data "strongly suggest" that microwaves can "accelerate the development of cancer." This assessment is in an internal agency memo recently obtained by *Microwave News* under the Freedom of Information Act.

"Of approximately eight chronic animal experiments known to us, five resulted in increased numbers of malignancies, accelerated progression of tumors, or both," wrote Drs. Mays Swicord and Larry Cress of FDA's Center for Devices and Radiological Health (CDRH) in Rockville, MD. They also pointed to other evidence from laboratory (*in vitro*) studies that supported a cancer risk.

Yet, in its public statements at that time, the agency played down these findings. For instance, in a Talk Paper issued in early February, the FDA stated that there was "limited evidence that suggests that lower levels [of microwaves] might cause adverse health effects."

"A few studies suggest that [microwave] levels [from cellular phones] can accelerate the development of cancer in laboratory animals," the FDA added, "but there is much uncertainty among scientists about whether these results apply to the use of cellular phones."

(continued on p.5)

SECONDHAND RADIATION

Phones in Railway Cars... Japan's Dr. Tsuyoshi Hondou caused quite a stir last year when he predicted that a railroad car full of mobile phone users could result in unhealthy exposures to RF/MW radiation (see *MWN*, M/J02 and J/A02). A number of observers immediately issued statements denouncing his model. Now, two research groups with ties to the wireless industry have published their criticisms. "It seems highly improbable that ICNIRP basic restrictions or even reference levels could be exceeded" in an enclosed space, Nokia's Dr. Anssi Toropainen concludes in the January 2003 issue of *Bioelectromagnetics* (*24*, pp.63-65). Toropainen contends that every passenger in a commuter rail car would need to have four or five 900MHz GSM phones operating at full power (250mW) to exceed the ICNIRP ambient limit of $450\,\mu W/cm^2$, while each passenger would have to be using 16 phones in order to exceed the SAR limit of 0.08 W/Kg. Hondou's arguments are also the subject of an exchange in the December issue of the *Journal of the Physical Society of Japan*, (*71*, p.3100-3102, 2002), where he originally published his concerns. Drs. Axel Kramer, Jürg Fröhlich and Niels Kuster of IT'IS in Zurich contend that even in a worst-case scenario—with many people using phones at full power—"exposure can never reach 25% of the...SAR safety limits for environmental exposure." Closed spaces "do not impose safety issues other than those in any other location." Hondou, who is at Tohoku University in Sendai, responds that the IT'IS calculations are wrong because they assume that radiation will be absorbed equally by each passenger. The criticisms are "based on naïve implicit assumptions which are neither relevant nor valid," he writes.

Keeping Current: Follow-Up on the News

◆ Half of all 14- to 20-year-olds in the U.S. will own a cellular phone by the end of the year, according to the Zelos Group, a research and consulting firm based in San Francisco. And Student Monitor, another data group, estimates that 70% of the 5.6 million full-time college students in the U.S. now own cell phones, the *New York Times* reports (January 20).

◆ As expected, the Australian Communications Authority (ACA) has released draft standards to regulate radiation emissions to protect the public and workers. The objective is to ensure that exposures are below the ICNIRP limits (see *MWN*, N/D02). The deadline for comments is February 20. The proposals are available at: <www.aca.gov.au/standards/emr/draftemrstd.htm>.

◆ Coming soon from ICNIRP: The report on health risks posed by radiation from anti-theft devices, funded by the EC's Fifth Framework research program (see *MWN*, M/A00), is now in press. And guidance on judging compliance of pulsed and complex non-sinusoidal waveforms below 100kHz with ICNIRP's limits will appear in the March 2003 issue of *Health Physics* and soon afterwards at <www.icnirp.org>.

◆ The appeal in the Newman cell phone–brain tumor case was filed by the Peter Angelos law firm on January 21 in the U.S. Court of Appeals for the Fourth Circuit in Richmond, VA (see *MWN*, S/O02 and N/D02). The reply from the defense team is due February 24.

◆ The first issue of *EHP Toxicogenomics*, dated January 2003, is out. The journal is a quarterly supplement to *Environmental Health Perspectives*, which is published by NIEHS. The print edition is free for the first year for qualified subscribers. For more information, go to: <ehp.niehs.nih.gov/txg>. And the IEEE Power Engineering Society has inaugurated a new bimonthly magazine, *IEEE Power & Energy*.

◆ Two years ago, U.K. researchers argued that teenagers were substituting mobile phone use for smoking (see *MWN*, N/D00). Now, a group in Finland has found contrary evidence among 10,000 Finnish teenagers. In a letter to the *British Medical Journal* (January 18), the Finns allow that their results may not apply to other countries "where parents do not help pay for their children's mobile phone costs as much as they do in Finland."

BEMS

Excellentia Supra Omnia

Twenty-Fifth Annual Meeting
Technical Program & Registration

1978-2003
25 Years of Excellence

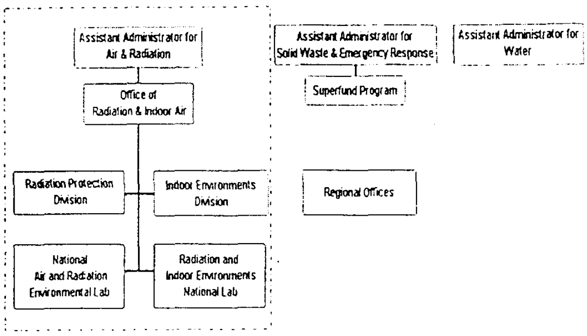
Wailea Marriott, an Outrigger Resort
Wailea, Maui, Hawaii
June 22 - 27, 2003

Environmental Protection Agency

Radiation Protection Program

Briefing for International Visitors

Organizational Framework



2

EPA's Niche in Radiation Protection

EPA has unique set of expertise for dealing with radiation in the environment

- Regulation and policy development and implementation
- Science/technical information and studies
- Radioanalytical and policy support to other agency offices
- Emergency response

3

Key Players and Stakeholders
Federal Agencies

- EPA
  - Issues standards to limit exposure
  - Measures radiation in environment and assesses effects on people and environment
  - Informs people about risks and promotes actions that reduce exposure
- NRC
  - Implements EPA's and its own standards
  - Regulates civilian uses of nuclear materials
- DOE
  - Manages materials from nuclear weapons production
- HHS/FDA - Center for Devices and Radiological Health
  - Key role in emergency response
  - Standards for x-ray machines and other products

4

Regulation and Policy Development and Implementation

- Waste Management
  - Yucca Mountain, NV
    - Fuel from power plants
    - EPA sets standard to be implemented by NRC & DOE
    - Proposal: August, 1999; Final: Summer, 2000
  - Waste Isolation Pilot Project, NM
    - Weapons waste
    - Certified safe operation of the facility, approves sites to ship waste to WIPP
  - Low Activity Mixed Waste Rule
    - Combined radioactive and hazardous wastes
    - To provide safe disposal options for waste generators

continued

Regulation and Policy Development and Implementation

(Continuation)

- Waste Management (cont'd)
  - TENORM - Technically Enhanced Naturally Occurring Radioactive Material
    - Assessing sources and risks
  - MARSSIM - Multi-Agency Radiation Survey and Site Investigation Manual
    - Guidance for radiation site surveys: planning, conducting, evaluating, and documenting
    - Training in Kazakhstan in September 2000
  - MARLAP - Multi-Agency Radiation Laboratory Protocols Manual
    - Guidance and framework for radioanalytical labs
    - Complements MARSSIM

continued

Regulation and Policy Development and Implementation

(Continuation)

- Federal Guidance
  - Sets principles and policies for other U.S. agencies to follow when developing their radiation policies
- Air Standards
  - Limit radioactive air emissions from government facilities, uranium mills, uranium mill tailings disposal piles, phosphogypsum
- Capability Development
  - Demonstrations, training and technology transfer to other U.S. Feds, Regions, States and tribes, and other countries
- Public Information

7

Science and Technical Information and Studies

- Risk Assessment
  - Methods /scientific bases for exposure, dose & risk assessments
  - Support for development of policy, guidance, and rule makings for radiation protection and risk management
- Federal Guidance Technical Reports
  - Provide current scientific and technical information
  - Used by regulators to assess dose and risk
- BEIR VII Biological Effects of Ionizing Radiation
  - Assessing viability of Linear No Threshold (LNT) hypothesis

Continued

8

Science and Technical Information and Studies

(Continuation)

- Environmental Radiation Ambient Monitoring System (ERAMS)
  - National radiation monitoring network
  - 200+ stations
  - Monitors air, precipitation, drinking water and milk
- Environmental Analysis
  - Radiochemical and mixed waste analysis (supports Agency decisions at contaminated sites)
  - Lab and field measurement, sampling and QA
  - Mobile labs

9

Emergency Response

- Preparation and Response
  - Establish guidelines for protecting the public from radiation
  - Monitor and assess radioactivity in the environment
  - Coordinate the Federal response to an emergency if a nuclear accident occurs in a foreign country
- Mobile Laboratories and Field Support
  - Full radioanalytical capability
  - On site radioanalysis and assessment
  - Environmental monitoring and sampling at the site
- Orphan Sources
  - National program for identifying and managing uncontrolled sources

10

Radioanalytical and Policy Support to Other Agency Offices

- Contaminated Site Clean Up
  - Largest U.S. sites have radiation contamination
  - Provide technical support for radionuclide cleanups
    - Site sampling and analysis
    - Technology evaluation
- Support to EPA Regions
  - Decontamination and decommissioning (help assess environmental implications at nuclear power plants and fuel facilities)
  - Analytical data and technical assistance to support Agency decisions

11

Statutory Authorities for EPA's Radiation Program

- Atomic Energy Act (AEA)
  - Generally applicable standards: rad materials outside the fence
  - Federal Guidance: advise President on national rad protection guidance for Federal and State agencies
- Nuclear Waste Policy Act (NWPA) and Amendments (NWPAA)
  - Yucca Mountain: authority to set procedures for spent nuclear fuel and high level waste repositories
- Waste Isolation Pilot Plan Land Withdrawal Act (WIPP LWA)
  - WIPP oversight: regulatory authority over DOE

continued

12

Statutory Authorities for EPA's Radiation Program

(Continuation)

- Clean Water Act (CWA) and
  Safe Drinking Water Act (SDWA)
  - Drinking water: mandate to protect current and future sources
  - Maximum Contaminant Levels (MCLs)
- Comprehensive Environmental Response Compensation and Liability Act (CERCLA)
  - Superfund: authority to clean up radioactively contaminated sites
- Clean Air Act (CAA)
  - National Emission Standards for Hazardous Air Pollutants: air emissions of radionuclides
- ER Directives
  - Several Federal-level directives defining our roles in emergencies

13

Non-Ionizing Program

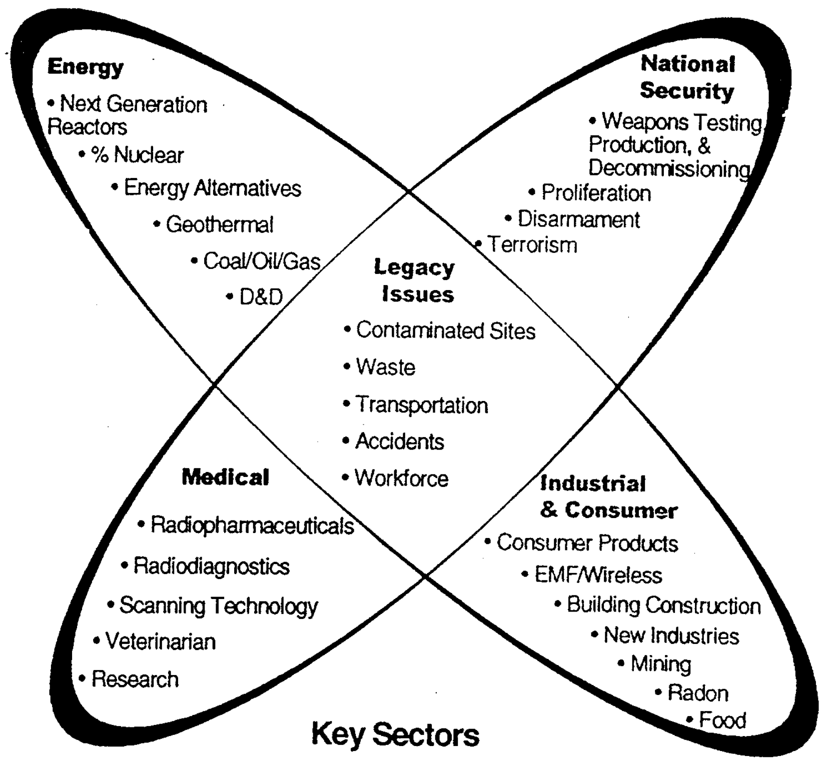
(Continuation)

- Recently transferred to our program
- Strategy and Policy still being formed
  - Science and Research
  - Policy
  - Analyses
  - Information and communications
- Short-term, obvious role seems to be education and providing information
  - Acknowledge and explain uncertainties
  - Explain possibilities of risk without undue alarm
  - Keep current on research
  - Advise people on how to scrutinized media reports and studies
  - Factsheets and webpages

14

APPENDIX B - KEY SECTORS WITH EXAMPLES OF CHALLENGES

The Future of Radiation Protection



PRINCIPLES FOR GUIDING ACTION
PROJECT ON THE FUTURE OF RADIATION PROTECTION

Pollution/Exposure Prevention

Pollution Prevention involves adopting practices that reduce at the source the amount of any hazardous substances or pollutants being released into the environment. It includes processes that eliminate the use of hazardous materials or increase the efficiency of their use. Exposure prevention involves adopting practices that reduce exposures to any hazardous substances that are released.

Pollution prevention approaches include substitution of materials, technology innovations, process modifications, redesign of products, improvements in training, and mass balance measurement to assess progress in reducing emissions. Exposure prevention includes inventory control, isolation and storage, and improvements in maintenance and housekeeping. Pollution/exposure prevention often saves money by reducing waste and health-related costs. Even where costs are substantial, it is justifiable to eliminate or reduce the use of hazardous materials and reduce exposures to them if the risks of damage to human health or the environment are high.

Public Right-to-Know

Right-to-Know involves assuring easy public (and public manager) access to complete and up-to-date information on the state of chemicals and radiation in the environment.

Actions to foster this principle include:

- Providing high quality, credible information;
- Filling in important information gaps with monitoring and research;
- Providing information in understandable, usable forms;
- Integrating information on chemical and radiation exposures into community-specific formats;
- Providing guidance to the public in interpreting data;
- Eliminating unnecessary secrecy;
- Integrating information on radiation into environmental databases;
- Integrating information from different Federal agencies.

Total Accounting

Total Accounting involves assessing the full cradle to grave costs and benefits of decisions, including impacts on human health and natural systems.

Challenges that arise in applying this principle include:

- Building agreement on methods;
- Doing life cycle analyses (cradle-to-grave, and cross-generational where appropriate);
- Valuing environmental resources and ecosystem services in doing environmental accounting;
- Assessing social costs to individuals and society as well as costs to the bottom line;
- Dealing with uncertainties and lack of data.

Risk Harmonization/ Cumulative Risk Assessment

This principle involves harmonizing approaches to radiation and chemicals based on a careful crosswalk between chemical and radiation models, parameters, risk calculations, and measurement techniques. It also requires a focus on understanding risks posed by cumulative exposures and interactions between hazardous agents.

Many of the major environmental risks we face require the simultaneous evaluation and control of both radiological and chemical risks, yet separation of the two persists along legal, regulatory, programmatic, training and operational lines. An additional complexity is the possible interaction between hazardous agents. Risk harmonization is necessary to allow us to evaluate cumulative risk and evolve beyond today's inadequate carcinogen by carcinogen approach to public health.

Inclusive Science

Inclusive Science involves bringing a wide range of disciplines and viewpoints to bear in research related to important issues of public policy.

Sound, rigorous scientific methods that can stand up to public and peer scrutiny are essential in all areas of research dealing with health and environmental risks. In many research areas related to public policy debates it is also essential to take an inclusive approach, drawing as appropriate on disciplines within the social sciences as well as the physical and biological sciences. Parties with views that are currently non-mainstream in character should have a role in the formulation of research agendas if their views are an important aspect of particular policy debates and their overall approach is evidence-oriented rather than ideological. Where apropos, an inclusive approach may employ alternative dispute resolution techniques to foster agreement on questions and methods for research.

Place-Based Tailoring

Place-based tailoring involves deliberate efforts to adapt policies to fit local or regional circumstances, and to encourage experimentation.

While uniform national policies and regulations are justified in many circumstances, they are sometimes adopted merely for bureaucratic convenience. As a result, "one size fits all" approaches sometimes fit no one. Place-based tailoring requires adopting a grass roots perspective as well as a national perspective. It also requires encouraging local and regional participation in the formulation of policies and regulations. Where appropriate, research can be tailored to address local questions, and information should be organized so that communities can look at local end exposures across media and disciplines.

Stewardship

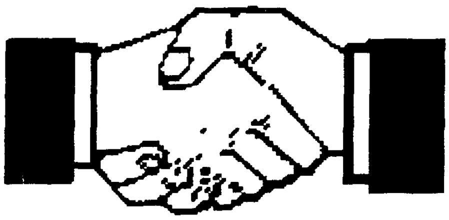
Stewardship involves taking responsibility for providing the expertise and resources to maintain across generations an adequate level of protection to human well being, health and the environment. Stewardship can be viewed as a "master principle" that encompasses all the others.

Stewardship is to hold something in trust for another. Historically, it was a means to protect a kingdom while the king was away or to govern for the sake of an underage king. Stewardship in today's context is willingness to choose service to the next generation over immediate self-interest. It is accepting accountability and providing leadership to assure the success of future generations. Stewardship is closely related to the concept of *sustainability*. Sustainable development is development that meets current needs without compromising the ability of future generations to meet their own needs.

Federal
Communications
Commission

Local and State
Government
Advisory
Committee

A Local Government Official's Guide to Transmitting Antenna RF Emission Safety: Rules, Procedures, and Practical Guidance



June 2, 2000

A Local Government Official's Guide to Transmitting Antenna RF Emission Safety: Rules, Procedures, and Practical Guidance

Over the past two years, the Federal Communications Commission (FCC) and its Local and State Government Advisory Committee (LSGAC) have been working together to prepare a voluntary guide to assist state and local governments in devising efficient procedures for ensuring that the antenna facilities located in their communities comply with the FCC's limits for human exposure to radiofrequency (RF) electromagnetic fields. The attached guide is the product of this joint effort.

We encourage state and local government officials to consult this guide when addressing issues of facilities siting within their communities. This guide contains basic information, in a form accessible to officials and citizens alike, that will alleviate misunderstandings in the complex area of RF emissions safety. This guide is not intended to replace OET Bulletin 65, which contains detailed technical information regarding RF issues, and should continue to be used and consulted for complex sites. The guide contains information, tables, and a model checklist to assist state and local officials in identifying sites that do not raise concerns regarding compliance with the Commission's RF exposure limits. In many cases, the model checklist offers a quick and effective way for state and local officials to establish that particular RF facilities are unlikely to exceed specific federal guidelines that protect the public from the environmental effects of RF emissions. Thus, we believe this guide will facilitate federal, state, and local governments working together to protect the public while bringing advanced and innovative communications services to consumers as rapidly as possible. We hope and expect that use of this guide will benefit state and local governments, service providers, and, most importantly, the American public.

We wish all of you good luck in your facilities siting endeavors.

William E. Kennard, Chairman
Federal Communications Commission

Kenneth S. Fellman, Chair
Local and State Government
Advisory Committee

A LOCAL GOVERNMENT OFFICIAL'S GUIDE TO TRANSMITTING ANTENNA RF EMISSION SAFETY: RULES, PROCEDURES, AND PRACTICAL GUIDANCE

A common question raised in discussions about the siting of wireless telecommunications and broadcast antennas is, "Will this tower create any health concerns for our citizens?" We have designed this guide to provide you with information and guidance in devising efficient procedures for assuring that the antenna facilities located in your community comply with the Federal Communication Commission's (FCC's) limits for human exposure to radiofrequency (RF) electromagnetic fields.[1]

We have included a checklist and tables to help you quickly identify siting applications that do not raise RF exposure concerns. Appendix A to this guide contains a checklist that you may use to identify "categorically excluded" facilities that are unlikely to cause RF exposures in excess of the FCC's guidelines. Appendix B contains tables and figures that set forth, for some of the most common types of facilities, "worst case" distances beyond which there is no realistic possibility that exposure could exceed the FCC's guidelines.

As discussed below, FCC rules require transmitting facilities to comply with RF exposure guidelines. The limits established in the guidelines are designed to protect the public health with a very large margin of safety. These limits have been endorsed by federal health and safety agencies such as the Environmental Protection Agency and the Food and Drug Administration. The FCC's rules have been upheld by a Federal Court of Appeals.[2] As discussed below, most facilities create maximum exposures that are only a small fraction of the limits. Moreover, the limits themselves are many times below levels that are generally accepted as having the potential to cause adverse health effects. Nonetheless, it is recognized that any instance of noncompliance with the guidelines is potentially very serious, and the FCC has therefore implemented procedures to enforce compliance with its rules. At the same time, state and local governments may wish to verify compliance with the FCC's exposure limits in order to protect their own citizens. As a state or local government official, you can play an important role in ensuring that innovative and beneficial communications services are provided in a manner that is consistent with public health and safety.

This document addresses only the issue of compliance with RF exposure limits established by the FCC. It does not address other issues such as construction, siting, permits, inspection, zoning, environmental review, and placement of antenna facilities within communities. Such issues fall generally under the jurisdiction of states and local governments, within the limits imposed for personal wireless service facilities by Section 332(c)(7) of the Communications Act.[3]

---

[1] This guide is intended to complement, but not to replace, the FCC's OET Bulletin 65, "Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields," August 1997. Bulletin 65 can be obtained from the FCC's Office of Engineering and Technology (phone: 202-418-2464 or e-mail: rfsafety@fcc.gov). Bulletin 65 can also be accessed and downloaded from the FCC's "RF Safety" website: http://www.fcc.gov/oet/rfsafety.

[2] See *Cellular Phone Taskforce v. FCC*, 205 F.3d 82 (2d Cir. 2000).

This document is not intended to provide legal guidance regarding the scope of state or local government authority under Section 332(c)(7) or any other provision of law. Section 332(c)(7)[4] generally preserves state and local authority over decisions regarding the placement, construction, and modification of personal wireless service facilities,[5] subject to specific limitations set forth in Section 332(c)(7). Among other things, Section 332(c)(7) provides that "[n]o State or local government or instrumentality thereof may regulate the placement, construction, and modification of personal wireless service facilities on the basis of the environmental effects of radio frequency emissions to the extent that such facilities comply with the [FCC's] regulations concerning such emissions." The full text of Section 332(c)(7) is set forth in Appendix C.

State and local governments and the FCC may differ regarding the extent of state and local legal authority under Section 332(c)(7) and other provisions of law. To the extent questions arise regarding such authority, they are being addressed by the courts. Rather than address these legal questions, this document recognizes that, as a practical matter, state and local governments have a role to play in ensuring compliance with the FCC's limits, and it provides guidance to assist you in effectively fulfilling that role. The twin goals of this document are: (1) to define and promote locally-adaptable procedures that will provide you, as a local official concerned about transmitting antenna emissions, with adequate assurance of compliance, while (2), at the same time, avoiding the imposition of unnecessary burdens on either the local government process or the FCC's licensees.

First, we'll start with a summary of the FCC's RF exposure guidelines and some background information that you'll find helpful. Next, we'll review the FCC's procedures for verifying compliance with the guidelines and enforcing its rules. Finally, we'll offer you some practical guidance to help you determine if personal wireless service facilities may raise compliance concerns. Note, however, that this guide is only intended to help you distinguish sites that are unlikely to raise compliance concerns from those that may raise compliance concerns, not to identify sites that are out of compliance. Detailed technical information necessary to determine compliance for individual sites is contained in the FCC's OET Bulletin 65 (see footnote 1, above).

---

[3] 47 U.S.C. § 332(c)(7). Under limited circumstances, the FCC also plays a role in the siting of wireless facilities. Specifically, the FCC reviews applications for facilities that fall within certain environmental categories under the National Environmental Policy Act of 1969 (NEPA), *see* 47 C.F.R. § 1.1307(a). Antenna structures that are over 200 feet in height or located near airport runways must be marked or lighted as specified by the Federal Aviation Administration and must be registered with the FCC, *see* 47 C.F.R. Part 17.

[4] Section 332(c)(7) of the Communications Act is identical to Section 704(a) of the Telecommunications Act of 1996.

[5] "Personal wireless services" generally includes wireless telecommunications services that are interconnected with the public telephone network and are offered commercially to the public. Examples include cellular and similar services (such as Personal Communications Service or "PCS"), paging and similar services, certain dispatch services, and services that use wireless technology to provide telephone service to a fixed location such as a home or office.

Before we start, however, let's take a short tour of the radiofrequency spectrum. RF signals may be transmitted over a wide range of frequencies. The frequency of an RF signal is expressed in terms of cycles per second or "Hertz," abbreviated "Hz." One kilohertz (kHz) equals one thousand Hz, one megahertz (MHz) equals one million Hz, and one gigahertz (GHz) equals one billion Hz. In the figure below, you'll see that AM radio signals are at the lower end of the RF spectrum, while other radio services, such as analog and digital TV (DTV), cellular and PCS telephony, and point-to-point microwave services are much higher in frequency.

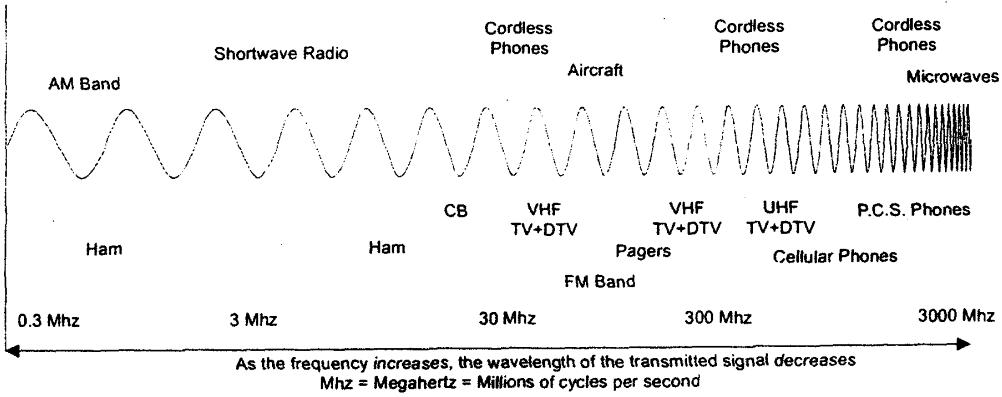


Illustration 1

The FCC's limits for maximum permissible exposure (MPE) to RF emissions depend on the frequency or frequencies that a person is exposed to. Different frequencies may have different MPE levels. Later in this document we'll show you how this relationship of frequency to MPE limit works.

I. The FCC's RF Exposure Guidelines and Rules.

Part 1 of the FCC's Rules and Regulations contains provisions implementing the National Environmental Policy Act of 1969 (NEPA). NEPA requires all federal agencies to evaluate the potential environmental significance of an agency action. Exposure to RF energy has been identified by the FCC as a potential environmental factor that must be considered before a facility, operation or transmitter can be authorized or licensed. The FCC's requirements dealing with RF exposure can be found in Part 1 of its rules at 47 C.F.R. § 1.1307(b). The exposure limits themselves are specified in 47 C.F.R. § 1.1310 in terms of frequency, field strength, power density and averaging time. Facilities and transmitters licensed and authorized by the FCC must either comply with these guidelines or else an applicant must file an Environmental Assessment (EA) with the FCC as specified in 47 C.F.R. § 1.1301 *et seq.* An EA is an official document required by the FCC's rules whenever an action may have a significant environmental impact (see discussion below). In practice, however, a potential environmental RF exposure problem is typically resolved before an EA would become necessary. Therefore, compliance with the FCC's RF guidelines constitutes a *de facto* threshold for obtaining FCC approval to construct or operate a station or transmitter. The FCC guidelines are based on exposure criteria recommended in 1986 by the National Council on Radiation Protection and Measurements (NCRP) and on the 1991 standard developed by the Institute of Electrical and Electronics Engineers (IEEE) and later adopted as a standard by the American National Standards Institute (ANSI/IEEE C95.1-1992).

The FCC's guidelines establish separate MPE limits for "general population/uncontrolled exposure" and for "occupational/controlled exposure." The general population/uncontrolled limits set the maximum exposure to which most people may be subjected. People in this group include the general public not associated with the installation and maintenance of the transmitting equipment. Higher exposure limits are permitted under the "occupational/controlled exposure" category, but only for persons who are exposed as a consequence of their employment (*e.g.*, wireless radio engineers, technicians). To qualify for the occupational/controlled exposure category, exposed persons must be made fully aware of the potential for exposure (*e.g.*, through training), and they must be able to exercise control over their exposure. In addition, people passing through a location, who are made aware of the potential for exposure, may be exposed under the occupational/controlled criteria. The MPE limits adopted by the FCC for occupational/controlled and general population/uncontrolled exposure incorporate a substantial margin of safety and have been established to be well below levels generally accepted as having the potential to cause adverse health effects.

Determining whether a potential health hazard could exist with respect to a given transmitting antenna is not always a simple matter. Several important factors must be considered in making that determination. They include the following: (1) What is the frequency of the RF signal being transmitted? (2) What is the operating power of the transmitting station and what is the actual power radiated from the antenna? [6] (3) How long will someone be exposed to the RF signal at a given distance from the antenna? (4) What other antennas are located in the area, and what is the exposure from those antennas? We'll explore each of these issues in greater detail below.

For all frequency ranges at which FCC licensees operate, Section 1.1310 of the FCC's rules establishes maximum permissible exposure (MPE) limits to which people may be exposed. The MPE limits vary by frequency because of the different absorptive properties of the human body at different frequencies when exposed to whole-body RF fields. Section 1.1310 establishes MPE limits in terms of "electric field strength," "magnetic field strength," and "far-field equivalent power density" (power density). For most frequencies used by the wireless services, the most relevant measurement is power density. The MPE limits for power density are given in terms of "milliwatts per square centimeter" or mW/cm^2. One milliwatt equals one thousandth of one watt (1/1000 of a watt).[7] In terms of power density, for a given frequency the FCC MPE limits can be interpreted as specifying the maximum rate that energy can be transferred (*i.e.*, the power) to a square centimeter of a person's body over a period of time (either 6 or 30 minutes, as explained

[6] Power travels from a transmitter through cable or other connecting device to the radiating antenna. "Operating power of the transmitting station" refers to the power that is fed from the transmitter (transmitter output power) into the cable or connecting device. "Actual power radiated from the antenna" is the transmitter output power minus the power lost (power losses) in the connecting device plus an apparent increase in power (if any) due to the design of the antenna. Radiated power is often specified in terms of "effective radiated power" or "ERP" or "effective isotropic radiated power" or "EIRP" (see footnote 14).

[7] Thus, by way of illustration, it takes 100,000 milliwatts of power to fully illuminate a 100 watt light bulb.

below). In practice, however, since it is unrealistic to measure separately the exposure of each square centimeter of the body, actual compliance with the FCC limits on RF emissions should be determined by "spatially averaging" a person's exposure over the projected area of an adult human body (this concept is discussed in the FCC's OET Bulletin 65).

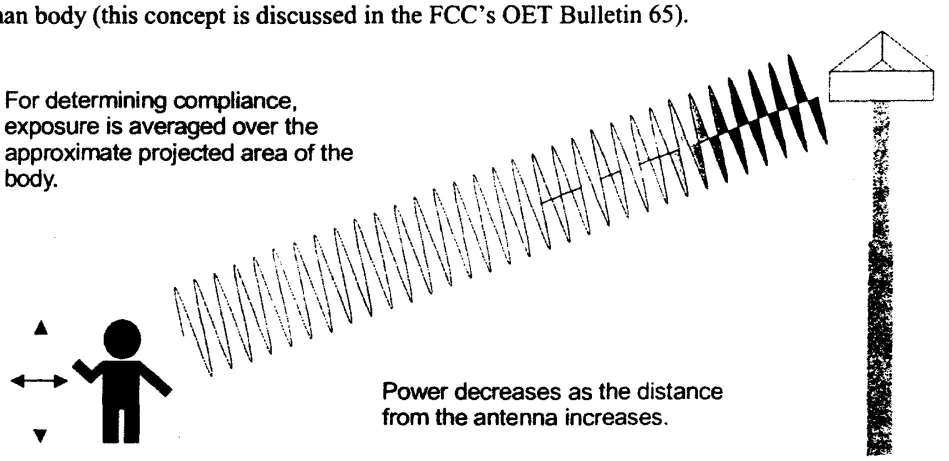


Illustration 2

Electric field strength and magnetic field strength are used to measure "near field" exposure. At frequencies <u>below</u> 300 MHz, these are typically the more relevant measures of exposure, and power density values are given primarily for reference purposes. However, evaluation of far-field equivalent power density exposure may still be appropriate for evaluating exposure in some such cases. For frequencies <u>above</u> 300 MHz, only one field component need be evaluated, and exposure is usually more easily characterized in terms of power density. Transmitters and antennas that operate at 300 MHz or lower include radio broadcast stations, some television broadcast stations, and certain personal wireless service facilities (*e.g.*, some paging stations). Most personal wireless services, including all cellular and PCS, as well as some television broadcast stations, operate at frequencies above 300 MHz. (See Illustration 1.)

As noted above, the MPE limits are specified as time-averaged exposure limits. This means that exposure can be averaged over the identified time interval (30 minutes for general population/uncontrolled exposure or 6 minutes for occupational/controlled exposure). However, for the case of exposure of the general public, time averaging is usually not applied because of uncertainties over exact exposure conditions and difficulty in controlling time of exposure. Therefore, the typical conservative approach is to assume that any RF exposure to the general public will be continuous. The FCC's limits for exposure at different frequencies are shown in Illustration 3, below:

Illustration 3. ***FCC Limits for Maximum Permissible Exposure (MPE)***

(A) Limits for Occupational/Controlled Exposure

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.3-3.0	614	1.63	(100)*	6
3.0-30	1842/f	4.89/f	$(900/f^2)$*	6
30-300	61.4	0.163	1.0	6
300-1500	--	--	f/300	6
1500-100,000	--	--	5	6

(B) Limits for General Population/Uncontrolled Exposure

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.3-1.34	614	1.63	(100)*	30
1.34-30	824/f	2.19/f	$(180/f^2)$*	30
30-300	27.5	0.073	0.2	30
300-1500	--	--	f/1500	30
1500-100,000	--	--	1.0	30

f = frequency in MHz *Plane-wave equivalent power density

NOTE 1: Occupational/controlled limits apply in situations in which persons are exposed as a consequence of their employment provided those persons are fully aware of the potential for exposure and can exercise control over their exposure. Limits for occupational/controlled exposure also apply in situations when an individual is transient through a location where occupational/controlled limits apply provided he or she is made aware of the potential for exposure.

NOTE 2: General population/uncontrolled exposures apply in situations in which the general public may be exposed, or in which persons that are exposed as a consequence of their employment may not be fully aware of the potential for exposure or cannot exercise control over their exposure.

Finally, it is important to understand that the FCC's limits apply cumulatively to all sources of RF emissions affecting a given area. A common example is where two or more wireless operators have agreed to share the cost of building and maintaining a tower, and to place their antennas on that joint structure. In such a case, the total exposure from the two facilities taken together must be within the FCC guidelines, or else an EA will be required.

A. Categorically Excluded Facilities

The Commission has determined through calculations and technical analysis that due to their low power or height above ground level, many facilities by their very nature are highly unlikely to cause human exposures in excess of the guideline limits, and operators of those facilities are exempt from routinely having to determine compliance. Facilities with these characteristics are considered "categorically excluded" from the requirement for routine environmental processing for RF exposure.

Section 1.1307(b)(1) of the Commission's rules sets forth which facilities are categorically excluded.[8] If a facility is categorically excluded, an applicant or licensee may ordinarily assume compliance with the guideline limits for exposure. However, an applicant or licensee must evaluate and determine compliance for a facility that is otherwise categorically excluded if specifically requested to do so by the FCC.[9] If potential environmental significance is found as a result, an EA must be filed with the FCC.

No radio or television broadcast facilities are categorically excluded. Thus, broadcast applicants and licensees <u>must</u> affirmatively determine their facility's compliance with the guidelines before construction, and upon every facility modification or license renewal application. With respect to personal wireless services, a cellular facility is categorically excluded if the total effective radiated power (ERP) of all channels operated by the licensee at a site is 1000 watts or less. If the facility uses sectorized antennas, only the total effective radiated power in each direction is considered. Examples of a 3 sector and a single sector antenna array are shown below:

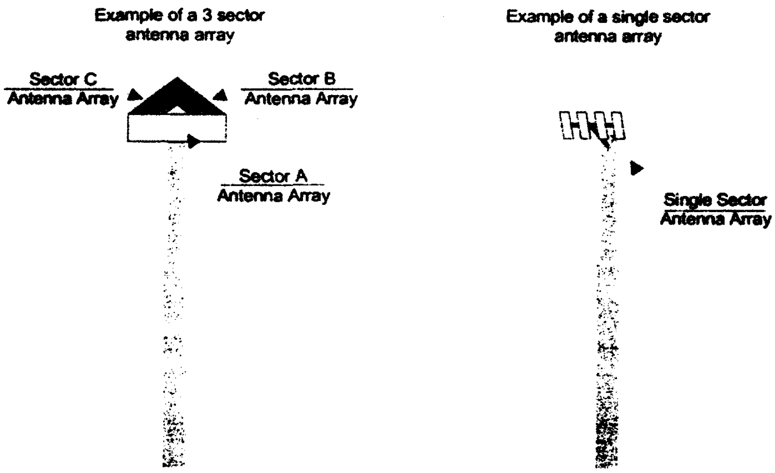


Illustration 4

[8] "The appropriate exposure limits . . . are generally applicable to all facilities, operations and transmitters regulated by the Commission. However, a determination of compliance with the exposure limits . . . (routine environmental evaluation), and preparation of an EA if the limits are exceeded, is necessary only for facilities, operations and transmitters that fall into the categories listed in table 1 [of §1.1307], or those specified in paragraph (b)(2) of this section. All other facilities, operations and transmitters are categorically excluded from making studies or preparing an EA . . ."

[9] See 47 C.F.R §1.1307(c) and (d).

In addition, a cellular facility is categorically excluded, regardless of its power, if it is not mounted on a building and the lowest point of the antenna is at least 10 meters (about 33 feet) above ground level. A broadband PCS antenna array is categorically excluded if the total effective radiated power of all channels operated by the licensee at a site (or all channels in any one direction, in the case of sectorized antennas) is 2000 watts or less. Like cellular, another way for a broadband PCS facility to be categorically excluded is if it is not mounted on a building and the lowest point of the antenna is at least 10 meters (about 33 feet) above ground level. The power threshold for categorical exclusion is higher for broadband PCS than for cellular because broadband PCS operates at a higher frequency where exposure limits are less restrictive. For categorical exclusion thresholds for other personal wireless services, consult Table 1 of Section 1.1307(b)(1).[10]

For your convenience, we have developed the checklist in Appendix A that may be used to streamline the process of determining whether a proposed facility is categorically excluded. You are encouraged to adopt the use of this checklist in your jurisdiction, although such use is not mandatory.

B. What If An Applicant Or Licensee Wants To Exceed The Limits Shown In Illustration 3?

Any FCC applicant or licensee who wishes to construct or operate a facility that, by itself or in combination with other sources of emissions (*i.e.*, other transmitting antennas), may cause human exposures in excess of the guideline limits must file an Environmental Assessment (EA) with the FCC. Where more than one antenna is collocated (for example, on a single tower or rooftop or at a hilltop site), the applicant must take into consideration all of the RF power transmitted by all of the antennas when determining maximum exposure levels. Compliance at an existing site is the shared responsibility of all licensees whose transmitters produce exposure levels in excess of 5% of the applicable exposure limit. A new applicant is responsible for compliance (or submitting an EA) at a multiple-use site if the proposed transmitter would cause non-compliance and if it would produce exposure levels in excess of 5% of the applicable limit.[11]

An applicant or licensee is not permitted to construct or operate a facility that would result in exposure in excess of the guideline limits until the FCC has reviewed the EA and either found no significant environmental impact, or pursued further environmental processing including the preparation of a formal Environmental Impact Statement. As a practical matter, however, this process is almost never invoked for RF exposure issues because applicants and licensees normally undertake corrective actions to ensure compliance with the guidelines before submitting an application to the FCC.

Unless a facility is categorically excluded (explained above), the FCC's rules require a licensee to evaluate a proposed or existing facility's compliance with the RF exposure guidelines and to

[10] Table 1 of §1.1307(b)(1) is reproduced in Appendix A to this guide.

[11] For more information, see OET Bulletin 65, or see 47 CFR §1.1307(b)(3).

determine whether an EA is required. In the case of broadcast licensees, who are required to obtain a construction permit from the FCC, this evaluation is required before the application for a construction permit is filed, or the facility is constructed. In addition, if a facility requires the filing of an EA for any reason other than RF emissions, the RF evaluation must be performed before the EA is filed. Factors other than RF emissions that may require the filing of an EA are set out in 47 C.F.R. § 1.1307(a). Otherwise, new facilities that do not require FCC-issued construction permits should be evaluated before they are placed in operation. The FCC also requires its licensees to evaluate existing facilities and operations that are not categorically excluded if the licensee seeks to modify its facilities or renew its license. These requirements are intended to enhance public safety by requiring periodic site compliance reviews.

All facilities that were placed in service before October 15, 1997 (when the current RF exposure guidelines became effective) are expected to comply with the current guidelines no later than September 1, 2000, or the date of a license renewal, whichever is earlier.[12] If a facility cannot meet the September 1, 2000, date, the licensee of that facility must file an EA by that date. Section 1.1307(b) of the FCC's rules requires the licensee to provide the FCC with technical information showing the basis for its determination of compliance upon request.

II. How the FCC Verifies Compliance with and Enforces Its Rules.

A. Procedures Upon Initial Construction, Modification, and Renewal.

The FCC's procedures for verifying that a new facility, or a facility that is the subject of a facility modification or license renewal application, will comply with the RF exposure rules vary depending upon the service involved. Applications for broadcast services (for example, AM and FM stations, and television stations) are reviewed by the FCC's Mass Media Bureau (MMB). As part of every relevant application, the MMB requires an applicant to submit an explanation of what steps will be taken to limit RF exposure and comply with FCC guidelines. The applicant must certify that RF exposure procedures will be coordinated with all collocated entities (usually other stations at a common transmitter site or hill or mountain peak). If the submitted explanation does not adequately demonstrate a facility's compliance with the guidelines, the MMB will require additional supporting data before granting the application.

The Wireless Telecommunications Bureau (WTB) reviews personal wireless service applications (for cellular, PCS, SMR, etc.). For those services that operate under blanket area licenses, including cellular and PCS, the license application and renewal form require the applicant to certify whether grant of the application would have a significant environmental impact so as to require submission of an EA. The applicant's answer to this question covers all of the facilities sites included within the area of the license.

For those services that continue to be licensed by site (*e.g.*, certain paging renewals), the WTB requires a similar certification on the application form for each site. To comply with the FCC's rules, an applicant must determine its own compliance before completing this certification for

[12] Prior to October 15, 1997, the Commission applied a different set of substantive guidelines.

every site that is not categorically excluded. The WTB does not, however, routinely require the submission of any information supporting the determination of compliance.

B. Procedures For Responding To Complaints About Existing Facilities.

The FCC frequently receives inquiries from members of the public as to whether a particular site complies with the RF exposure guidelines. Upon receiving these inquiries, FCC staff may ask the inquiring party to describe the site at issue. In many instances, the information provided by the inquiring party does not raise any concern that the site could exceed the limits in the guidelines. FCC staff will then inform the inquiring party of this determination.

In some cases, the information provided by the inquiring party does not preclude the possibility that the limits could be exceeded. Under these circumstances, FCC staff may ask the licensee who operates the facility to supply information demonstrating its compliance. FCC staff may also inspect the site to determine whether it is accessible to the public, and examine other relevant physical attributes. Usually, the information obtained in this manner is sufficient to establish compliance. If compliance is established in this way, FCC staff will inform the inquiring party of this determination.

In some instances, a licensee may be unable to provide information sufficient to establish compliance with the guideline limits. In these cases, FCC staff may test the output levels of individual facilities and evaluate the physical installation. Keep in mind, however, that instances in which physical testing is necessary to verify compliance are relatively rare.

If a site is found to be out of compliance with the RF guidelines, the FCC will require the licensees at the site to remedy the situation. Depending on the service and the nature and extent of the violation, these remedies can include, for example, an immediate reduction in power, a modification of safety barriers, or a modification of the equipment or its installation. Actions necessary to bring a site into compliance are the shared responsibility of all licensees whose facilities cause exposures in that area that exceed 5% of the applicable MPE limit. In addition, licensees may be subject to sanctions for violating the FCC's rules and/or for misrepresentation.

The FCC is committed to responding fully, promptly, and accurately to all inquiries regarding compliance with the RF exposure guidelines, and to taking swift and appropriate action whenever the evidence suggests potential noncompliance. To perform this function effectively, however, the FCC needs accurate information about potentially problematic situations. By applying the principles discussed in this guide about RF emissions, exposure and the FCC's guidelines, state and local officials can fulfill a vital role in identifying and winnowing out situations that merit further attention.

III. Practical Guidance Regarding Compliance.

This section is intended to provide some general guidelines that can be used to identify sites that should not raise serious questions about compliance with FCC RF exposure guidelines. Sites that don't fall into the categories described here may still meet the guidelines, but the determination of compliance will not be as straightforward. In such cases, a detailed review may be required. The tables and graphs shown in Appendix B are intended only to assist in distinguishing sites that should not raise serious issues from sites that may require further inquiry. They are not intended for use in identifying sites that are out of compliance. As noted above, the factors that can affect exposure at any individual site, particularly a site containing multiple facilities, are too numerous and subtle to be practically encompassed within this framework.

Applying the basic principles discussed in this guide should allow you to eliminate a large number of sites from further consideration with respect to health concerns. You may find it useful to contact a qualified radio engineer to assist you in your inquiry. Many larger cities and counties, and most states, have radio engineers on staff or under contract. In smaller jurisdictions, we recommend you seek initial assistance from other jurisdictions, universities that have RF engineering programs, or perhaps the engineer in charge of your local broadcast station(s).

We'll exclude any discussion of broadcast sites. As explained before, broadcast licensees are required to submit site-specific information on each facility to the FCC for review, and that information is publicly available at the station as long as the application is pending. The focus in this section is on personal wireless services, particularly cellular and broadband PCS, the services that currently require the largest numbers of new and modified facilities. Many other personal wireless services, however, such as paging services, operate in approximately the same frequency ranges as cellular and broadband PCS.[13] Much of the information here is broadly applicable to those services as well, and specific information is provided in Appendix B for paging and narrowband PCS operations over frequency bands between 901 and 940 MHz.

Finally, this section only addresses the general population/uncontrolled exposure guidelines, since compliance with these guidelines generally causes the most concern to state and local governments. Compliance with occupational/controlled exposure limits should be examined independently.

A. Categorically Excluded Facilities.

As a first step in evaluating a siting application for compliance with the FCC's guidelines, you will probably want to consider whether the facility is categorically excluded under the FCC's rules from routine evaluation for compliance. The checklist in Appendix A will guide you in making this determination. Because categorically excluded facilities are unlikely to cause any exposure in excess of the FCC's guidelines, determination that a facility is categorically excluded should generally suffice to end the inquiry.

B. Single Facility Sites.

If a wireless telecommunications facility is not categorically excluded, you may want to evaluate potential exposure using the methods discussed below and the tables and figures in Appendix B.

[13] The major exception is fixed wireless services, which often operate at much higher frequencies. In addition, some paging and other licensees operate at lower frequencies

If you "run the numbers" using the conservative approaches promoted in this paper and the site in question does not exceed these values, then you generally need look no further. Alternately, if the "numbers" don't pass muster, you may have a genuine concern. But remember, there may be other factors (*i.e.*, power level, height, blockages, etc.) that contribute to whether the site complies with FCC guidelines.

Where a site contains only one antenna array, the maximum exposure at any point in the horizontal plane can be predicted by calculations. The tables and graphs in Appendix B show the maximum distances in the horizontal plane from an antenna at which a person could possibly be exposed in excess of the guidelines at various levels of effective radiated power (ERP).[14] Thus, if people are not able to come closer to an antenna than the applicable distance shown in Appendix B, there should be no cause for concern about exposure exceeding the FCC guidelines. The tables and graphs apply to the following wireless antennas: (1) cellular omni-directional antennas (Table B1-1 and Figure B1-1); (2) cellular sectorized antennas (Table B1-2 and Figure B1-2); (3) broadband PCS sectorized antennas (Table B1-3 and Figure B1-3);[15] and (4) high-power (900 MHz-band) paging antennas (Table B1-4 and Figure B1-4). Table B1-4 and Figure B1-4 can also be used for omni-directional, narrowband (900 MHz) PCS antennas. Note that both tables and figures in Appendix B have been provided. In some cases it may be easier to use a table to estimate exposure distances, but figures may also be used when a more precise value is needed that may not be listed in a table.

It's important to note that the predicted distances set forth in Appendix B are based on a very conservative, "worst case" scenario. In other words, Appendix B identifies the furthest distance from the antenna that presents even a remote realistic possibility of RF exposure that could exceed the FCC guidelines. The power levels are based on the approximate maximum number of channels that an operator is likely to operate at one site. It is further assumed that each channel operates with the maximum power permitted under the FCC's rules and that all of these channels are "on" simultaneously, an unlikely scenario. This is a very conservative assumption. In reality, most sites operate at a fraction of the maximum permissible power and many sites use fewer than the maximum number of channels. Therefore, actual exposure levels would be expected to be well below the predicted values. Another mitigating factor could be the presence of intervening structures, such as walls, that will reduce RF exposure by variable amounts. For all these reasons, the values given in these tables and graphs are considered to be quite conservative and should over-predict actual exposure levels.

---

[14] ERP is the apparent effective amount of power leaving the transmit antenna. The ERP is determined by factors including but not limited to transmitter output power, coaxial line loss between the transmitter and the antenna, and the "gain" (focusing effect) of the antenna. In some cases, power may also be expressed in terms of EIRP (effective isotropically radiated power). Therefore, for convenience, the tables in Appendix B also include a column for EIRP. ERP and EIRP are related by the mathematical expression: (1.64) X ERP = EIRP.

[15] Because broadband PCS antennas are virtually always sectorized, no information is provided for omni-directional PCS antennas.

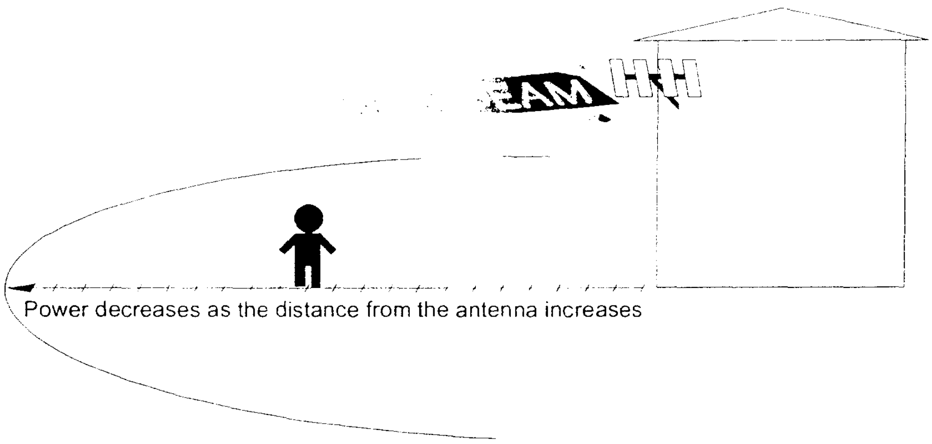


Illustration 5

Personal wireless service antennas typically do not emit high levels of RF energy directed above or below the horizontal plane of the antenna. Although the precise amount of energy transmitted outside the horizontal plane will depend upon the type of antenna used, we are aware of no wireless antennas that produce significant non-horizontal transmissions. Thus, exposures even a small distance below the horizontal plane of these antennas would be significantly less than in the horizontal plane. As discussed above, the tables and figures in Appendix B show distances in the horizontal plane from typical antennas at which exposures could potentially exceed the guidelines, assuming "worst case" operating conditions at maximum possible power levels. In any direction other than horizontal, including diagonal or straight down, these "worst case" distances would be significantly less.

Where unidirectional antennas are used, exposure levels within or outside the horizontal plane in directions other than those where the antennas are aimed will typically be insignificant. In addition, many new antennas are being designed with shielding capabilities to minimize emissions in undesired directions.

C. Multiple Facility Sites.

Where multiple facilities are located at a single site, the FCC's rules require the total exposure from all facilities to fall within the guideline limits, unless an EA is filed and approved. In such cases, however, calculations of predicted exposure levels and overall evaluation of the site may become much more complicated. For example, different transmitters at a site may operate different numbers of channels, or the operating power per channel may vary from transmitter to transmitter. Transmitters may also operate on different frequencies (for example, one antenna array may belong to a PCS operator, while the other belongs to a cellular operator). A large number of variables such as these make the calculations more time consuming, and make it difficult to apply a simple rule-of-thumb test. See the following illustration.

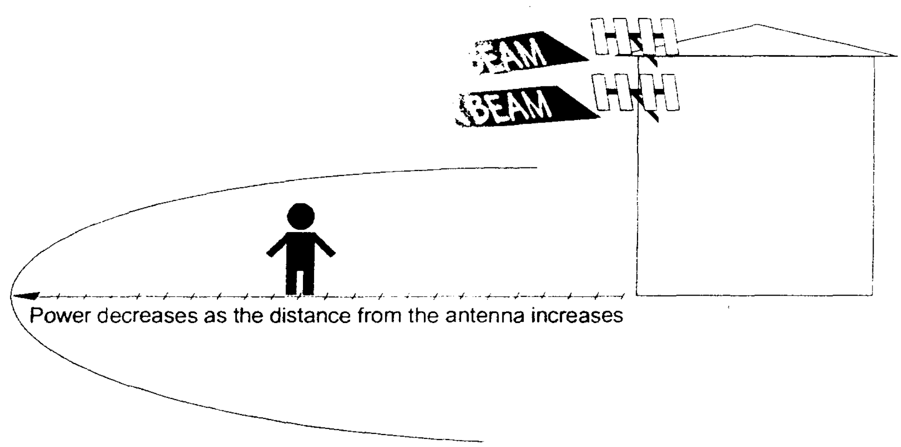


Illustration 6

However, we can be overly conservative and estimate a "worst case" exposure distance for compliance by assuming that the total power (e.g., ERP) of all transmitting antennas at the site is concentrated in the antenna that is closest to the area in question. (In the illustration above, this would be the antenna that is mounted lower on the building.) Then the values in the tables and graphs in Appendix B may be used as if this were the only antenna at the site, with radiated power equal to the sum of the actual radiated power of all antennas at the site. Actual RF exposure at any point will always be less than the exposure calculated using these assumptions. Thus, if people are not able to come closer to a group of antennas than the applicable distance shown in Appendix B using these assumptions, there should be no cause for concern about exposure exceeding the FCC guidelines. This is admittedly an extremely conservative procedure, but it may be of assistance in making a "first cut" at eliminating sites from further consideration.

IV. Conclusion.

We've highlighted many of the most common concerns and questions raised by the siting of wireless telecommunications and broadcast antennas. Applying the principles outlined in this guide will allow you to make initial conservative judgments about whether RF emissions are or should be of concern, consistent with the FCC's rules.

As we have explained, when first evaluating a siting application for compliance with the FCC's guidelines, you will probably want to consider whether the facility is categorically excluded under the FCC's rules from routine evaluation for compliance. The checklist in Appendix A will guide you in making this determination. Because categorically excluded facilities are unlikely to cause any exposure in excess of the FCC's guidelines, determination that a facility is categorically excluded should generally suffice to end the inquiry.

If a wireless telecommunications facility is not categorically excluded, you may want to evaluate potential exposure using the methods discussed in Part III of this paper and the tables and figures in Appendix B. If the site in question does not exceed the values, then you generally need look no further. Alternately, if the values don't pass muster, you may have a genuine concern. But remember, there may be other factors (*i.e.*, power level, height, blockages, etc.) that contribute to whether the site complies with FCC guidelines.

If you have questions about compliance, your initial point of exploration should be with the facilities operator in question. That operator is required to understand the FCC's rules and to know how to apply them in specific cases at specific sites. If, after diligently pursuing answers from the operator, you still have genuine questions regarding compliance, you should contact the FCC at one of the numbers listed below. Provision of the information identified in the checklist in Appendix A may assist the FCC in evaluating your inquiry.

General Information: Compliance and Information Bureau, (888) CALL-FCC

> Concerns About RF Emissions Exposure at a Particular Site: Office of Engineering and Technology, RF Safety Program, phone (202) 418-2464, FAX (202) 418-1918, e-mail rfsafety@fcc.gov
>
> Licensing and Site Information Regarding Wireless Telecommunications Services: Wireless Telecommunications Bureau, Commercial Wireless Division, (202) 418-0620
>
> Licensing and Site Information Regarding Broadcast Radio Services: Mass Media Bureau, Audio Services Division, (202) 418-2700
>
> Licensing and Site Information Regarding Television Service (Including DTV): Mass Media Bureau, Video Services Division, (202) 418-1600

Also, note that the RF Safety Program Web site is a valuable source of general information on the topic of potential biological effects and hazards of RF energy. For example, OET recently updated its OET Bulletin 56 ("Questions and Answers about Biological Effects and Potential Hazards of Radiofrequency Electromagnetic Fields"). This latest version is available from the program and can be accessed and downloaded from the FCC's web site at:

http://www.fcc.gov/oet/rfsafety/

APPENDIX A

Optional Checklist for Determination

Of Whether a Facility is Categorically Excluded

Optional Checklist for Local Government
To Determine Whether a Facility is Categorically Excluded

Purpose: The FCC has determined that many wireless facilities are unlikely to cause human exposures in excess of RF exposure guidelines. Operators of those facilities are exempt from routinely having to determine their compliance. These facilities are termed "categorically excluded." Section 1.1307(b)(1) of the Commission's rules defines those categorically excluded facilities. This checklist will assist state and local government agencies in identifying those wireless facilities that are categorically excluded, and thus are highly unlikely to cause exposure in excess of the FCC's guidelines. Provision of the information identified on this checklist may also assist FCC staff in evaluating any inquiry regarding a facility's compliance with the RF exposure guidelines.

BACKGROUND INFORMATION

1. Facility Operator's Legal Name: ______
2. Facility Operator's Mailing Address: ______
3. Facility Operator's Contact Name/Title: ______
4. Facility Operator's Office Telephone: ______
5. Facility Operator's Fax: ______
6. Facility Name: ______
7. Facility Address: ______
8. Facility City/Community: ______
9. Facility State and Zip Code: ______
10. Latitude: ______
11. Longitude: ______

continue →

Optional Local Government Checklist (page 2)

EVALUATION OF CATEGORICAL EXCLUSION

12. Licensed Radio Service (see attached Table 1): ______
13. Structure Type (free-standing or building/roof-mounted): ______
14. Antenna Type [omnidirectional or directional (includes sectored)]: ______
15. Height above ground of the lowest point of the antenna (in meters): ______
16. ☐ Check if all of the following are true:
    (a) This facility will be operated in the Multipoint Distribution Service, Paging and Radiotelephone Service, Cellular Radiotelephone Service, Narrowband or Broadband Personal Communications Service, Private Land Mobile Radio Services Paging Operations, Private Land Mobile Radio Service Specialized Mobile Radio, Local Multipoint Distribution Service, or service regulated under Part 74, Subpart I (see question 12).
    (b) This facility will not be mounted on a building (see question 13).
    (c) The lowest point of the antenna will be at least 10 meters above the ground (see question 15).

If box 16 is checked, this facility is categorically excluded and is unlikely to cause exposure in excess of the FCC's guidelines. The remainder of the checklist need not be completed. If box 16 is not checked, continue to question 17.

17. Enter the power threshold for categorical exclusion for this service from the attached Table 1 in watts ERP or EIRP* (note: EIRP = (1.64) X ERP): ______
18. Enter the total number of channels if this will be an omnidirectional antenna, or the maximum number of channels in any sector if this will be a sectored antenna:
19. Enter the ERP or EIRP per channel (using the same units as in question 17): ______
20. Multiply answer 18 by answer 19: ______
21. Is the answer to question 20 less than or equal to the value from question 17 (yes or no)?

If the answer to question 21 is YES, this facility is categorically excluded. It is unlikely to cause exposure in excess of the FCC's guidelines.

If the answer to question 21 is NO, this facility is not categorically excluded. Further investigation may be appropriate to verify whether the facility may cause exposure in excess of the FCC's guidelines.

---

*"ERP" means "effective radiated power" and "EIRP" means "effective isotropic radiated power

TABLE 1: TRANSMITTERS, FACILITIES AND OPERATIONS SUBJECT TO ROUTINE ENVIRONMENTAL EVALUATION

SERVICE (TITLE 47 CFR RULE PART)	EVALUATION REQUIRED IF:
Experimental Radio Services (part 5)	power > 100 W ERP (164 W EIRP)
Multipoint Distribution Service (subpart K of part 21)	non-building-mounted antennas: height above ground level to lowest point of antenna < 10 m and power > 1640 W EIRP building-mounted antennas: power > 1640 W EIRP
Paging and Radiotelephone Service (subpart E of part 22)	non-building-mounted antennas: height above ground level to lowest point of antenna < 10 m and power > 1000 W ERP (1640 W EIRP) building-mounted antennas: power > 1000 W ERP (1640 W EIRP)
Cellular Radiotelephone Service (subpart H of part 22)	non-building-mounted antennas: height above ground level to lowest point of antenna < 10 m and total power of all channels > 1000 W ERP (1640 W EIRP) building-mounted antennas: total power of all channels > 1000 W ERP (1640 W EIRP)

TABLE 1 (cont.)

SERVICE (TITLE 47 CFR RULE PART)	EVALUATION REQUIRED IF:
Personal Communications Services (part 24)	(1) Narrowband PCS (subpart D): non-building-mounted antennas: height above ground level to lowest point of antenna < 10 m and total power of all channels > 1000 W ERP (1640 W EIRP) building-mounted antennas: total power of all channels > 1000 W ERP (1640 W EIRP) (2) Broadband PCS (subpart E): non-building-mounted antennas: height above ground level to lowest point of antenna < 10 m and total power of all channels > 2000 W ERP (3280 W EIRP) building-mounted antennas: total power of all channels > 2000 W ERP (3280 W EIRP)
Satellite Communications (part 25)	all included
General Wireless Communications Service (part 26)	total power of all channels > 1640 W EIRP
Wireless Communications Service (part 27)	total power of all channels > 1640 W EIRP
Radio Broadcast Services (part 73)	all included

TABLE 1 (cont.)

SERVICE (TITLE 47 CFR RULE PART)	EVALUATION REQUIRED IF:
Experimental, auxiliary, and special broadcast and other program distributional services (part 74)	subparts A, G, L: power > 100 W ERP subpart I: non-building-mounted antennas: height above ground level to lowest point of antenna < 10 m and power > 1640 W EIRP building-mounted antennas: power > 1640 W EIRP
Stations in the Maritime Services (part 80)	ship earth stations only
Private Land Mobile Radio Services Paging Operations (part 90)	non-building-mounted antennas: height above ground level to lowest point of antenna < 10 m and power > 1000 W ERP (1640 W EIRP) building-mounted antennas: power > 1000 W ERP (1640 W EIRP)
Private Land Mobile Radio Services Specialized Mobile Radio (part 90)	non-building-mounted antennas: height above ground level to lowest point of antenna < 10 m and total power of all channels > 1000 W ERP (1640 W EIRP) building-mounted antennas: total power of all channels > 1000 W ERP (1640 W EIRP)

TABLE 1 (cont.)

SERVICE (TITLE 47 CFR RULE PART)	EVALUATION REQUIRED IF:
Amateur Radio Service (part 97)	transmitter output power > levels specified in § 97.13(c)(1) of this chapter
Local Multipoint Distribution Service (subpart L of part 101)	non-building-mounted antennas: height above ground level to lowest point of antenna < 10 m and power > 1640 W EIRP building-mounted antennas: power > 1640 W EIRP LMDS licensees are required to attach a label to subscriber transceiver antennas that: (1) provides adequate notice regarding potential radiofrequency safety hazards, *e.g.*, information regarding the safe minimum separation distance required between users and transceiver antennas; and (2) references the applicable FCC-adopted limits for radiofrequency exposure specified in § 1.1310 of this chapter.

APPENDIX B

Estimated "Worst Case" Distances that Should be Maintained from Single Cellular, PCS, and Paging Base Station Antennas

Table B1-1. Estimated "worst case" horizontal* distances that should be maintained from a single, omni-directional, **cellular base-station** antenna to meet FCC RF exposure guidelines

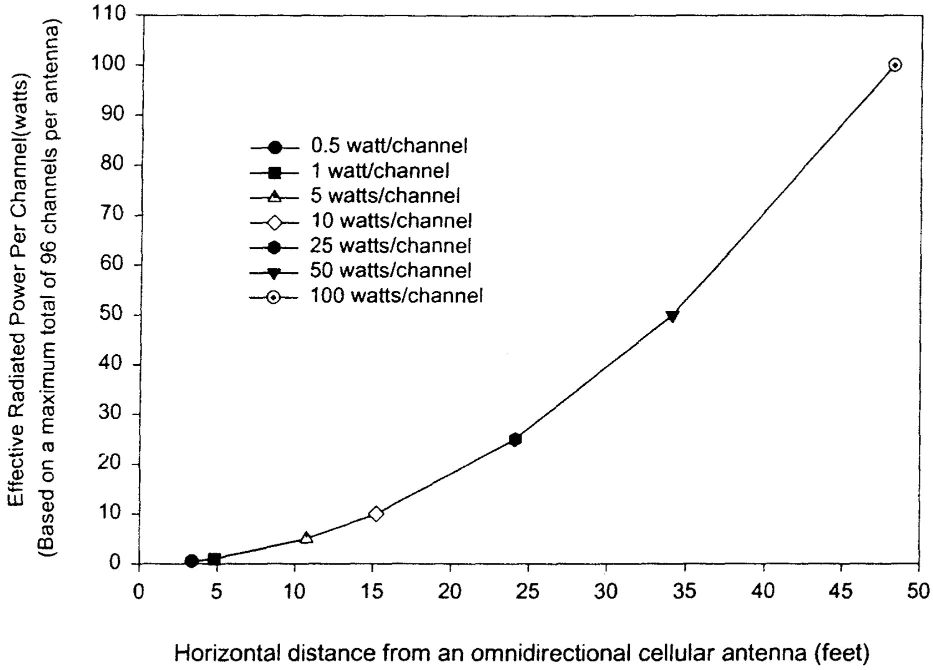
Effective Radiated Power (watts) per channel based on maximum total of 96 channels per antenna	Effective Isotropic Radiated Power (watts) per channel based on a maximum total of 96 channels per antenna	Horizontal* distance (feet) that should be maintained from a single omni-directional cellular antenna
0.5	0.82	3.4
1	1.6	4.8
5	8.2	10.8
10	16.4	15.2
25	41	24.1
50	82	34.1
100	164	48.2

For intermediate values not shown on this table, please refer to the Figure B1-1

*These distances are based on exposure at same level as the antenna, for example, on a rooftop or in a building directly across from and at the same height as the antenna.

Note: These estimates are worst case, assuming an omnidirectional antenna using 96 channels. If the systems are using fewer channels, the actual horizontal distances that must be maintained will be less. Cellular omnidirectional antennas transmit more or less equally from the antenna in all horizontal directions and transmit relatively little energy directly toward the ground. Therefore, these distances are even more conservative for "non-horizontal" distances, for example, distances directly below an antenna.

Figure B1-1. Estimated "worst case" horizontal* distances that should be maintained from a single omni-directional **cellular base station** antenna to meet FCC RF exposure guidelines



* These distances are based on exposure at same level as antenna, for example, on a rooftop or in a building directly across from and at the same height as the antenna.

Note: These estimates are worst case, assuming an omnidirectional antenna using 96 channels. If the systems are using fewer channels, the actual horizontal distances that must be maintained will be less. Cellular omnidirectional antennas transmit more or less equally from the antenna in all horizontal directions and transmit relatively little energy directly toward the ground.

Table B1-2. Estimated "worst case" horizontal* distances that should be maintained from a single, sectorized, **cellular base-station** antenna to meet FCC RF exposure guidelines

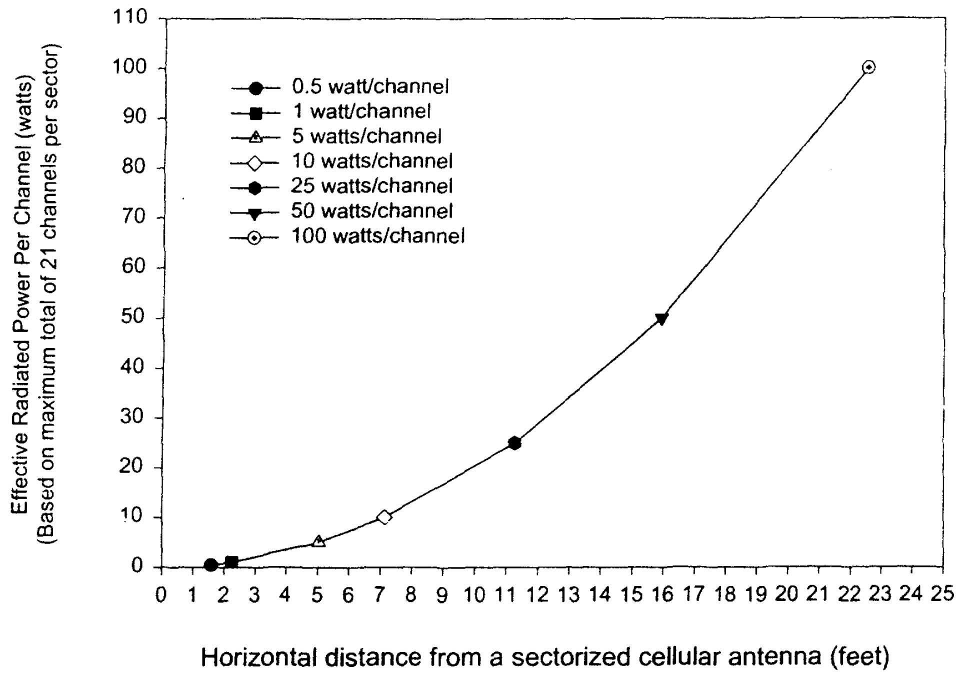
Effective Radiated Power (watts) per channel based on maximum total of 21 channels per sector	Effective Isotropic Radiated Power (watts) per channel based on maximum total of 21 channels per sector	Horizontal* distance (feet) that should be maintained from a single sectorized cellular antenna
0.5	0.82	1.6
1	1.6	2.3
5	8.2	5
10	16.4	7.1
25	41	11.3
50	82	16
100	164	22.6

For intermediate values not shown on this table, please refer to the Figure B1-2

*These distances are based on exposure at same level as the antenna, for example, on a rooftop or in a building directly across from and at the same height as the antenna.

Note: These estimates are "worst case," assuming a sectorized antenna using 21 channels. If the systems are using fewer channels, the actual horizontal distances that must be maintained will be less. Cellular sectorized antennas transmit more or less in one direction from the antenna in a horizontal direction and transmit relatively little energy directly toward the ground. Therefore, these distances are even more conservative for "non-horizontal" distances, for example, distances directly below an antenna.

Figure B1-2. Estimated "worst case" horizontal* distances that should be maintained from a single sectorized, **cellular base station** antenna to meet FCC RF exposure guidelines



* These distances are based on exposure at same level as antenna, for example, on a rooftop or in a building directly across from and at the same height as the antenna.

Note: These estimates are "worst case", assuming a sectorized antenna using 21 channels. If the systems are using fewer channels, the actual horizontal distances that must be maintained will be less. Cellular sectorized antennas transmit more or less in one direction from the antenna in a horizontal direction and transmit relatively little energy directly toward the ground.

Table B1-3. Estimated "worst case" horizontal* distances that should be maintained from a single sectorized **Broadband PCS base station** antenna to meet FCC RF exposure guidelines

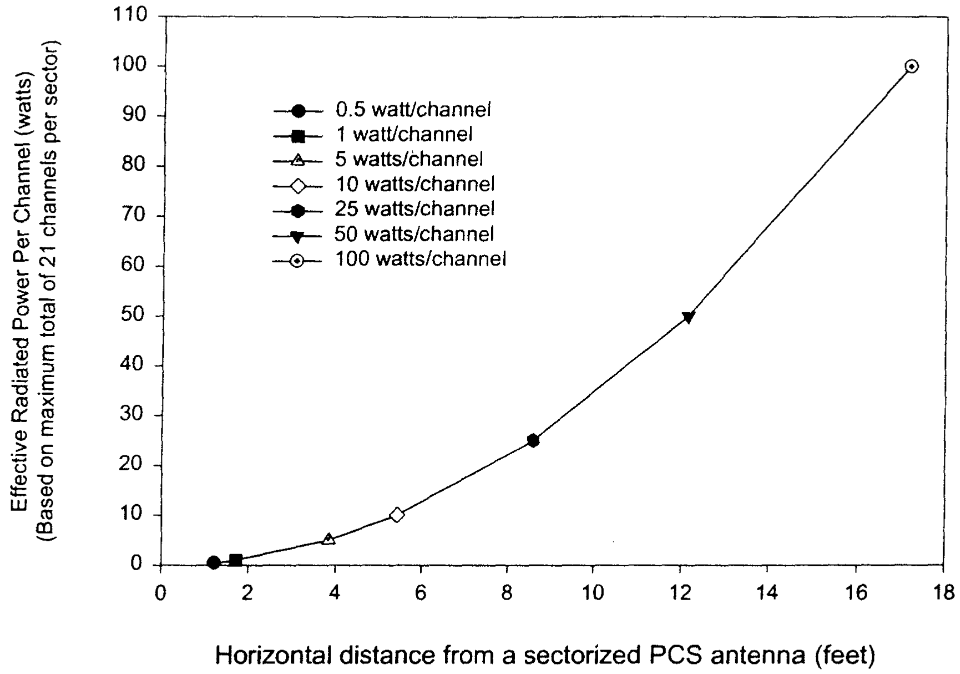
Effective Radiated Power (watts) per channel based on maximum total of 21 channels per sector	Effective Isotropic Radiated Power (watts) per channel based on maximum total of 21 channels per sector	Horizontal* distance (feet) that should be maintained from a single sectorized Broadband PCS antenna
0.5	0.82	1.2
1	1.6	1.7
5	8.2	3.8
10	16.4	5.4
25	41	8.6
50	82	12.1
100	164	17.2

For intermediate values not shown on this table, please refer to the Figure B1-3

*These distances are based on exposure at same level as the antenna, for example, on a rooftop or in a building directly across from and at the same height as the antenna.

Note: These estimates are "worst case," assuming a sectorized antenna using 21 channels. If the system is using fewer than 21 channels, the actual horizontal distances that must be maintained will be less. PCS sectorized antennas transmit more or less in one direction from the antenna in a horizontal direction and transmit relatively little energy directly toward the ground. Therefore, these distances are even more conservative for "non-horizontal" distances, for example, distances directly below an antenna.

Figure B1-3. Estimated "worst case" horizontal* distances that should be maintained from a single sectorized, **PCS base station** antenna to meet FCC RF exposure guidelines



* These distances are based on exposure at same level as antenna, for example, on a rooftop or in a building directly across from and at the same height as the antenna.

Note: These estimates are "worst case", assuming a sectorized antenna using 21 channels. If the systems are using fewer channels, the actual horizontal distances that must be maintained will be less. PCS sectorized antennas transmit more or less in one direction from the antenna in a horizontal direction and transmit relatively little energy directly toward the ground.

Table B1-4. Estimated "worst case" horizontal* distances that should be maintained from a single omnidirectional **paging** or **narrowband PCS** antenna to meet FCC RF exposure guidelines. Note: this table and the associated figure only apply to the 900-940 MHz band; paging antennas at other frequencies are subject to different values.

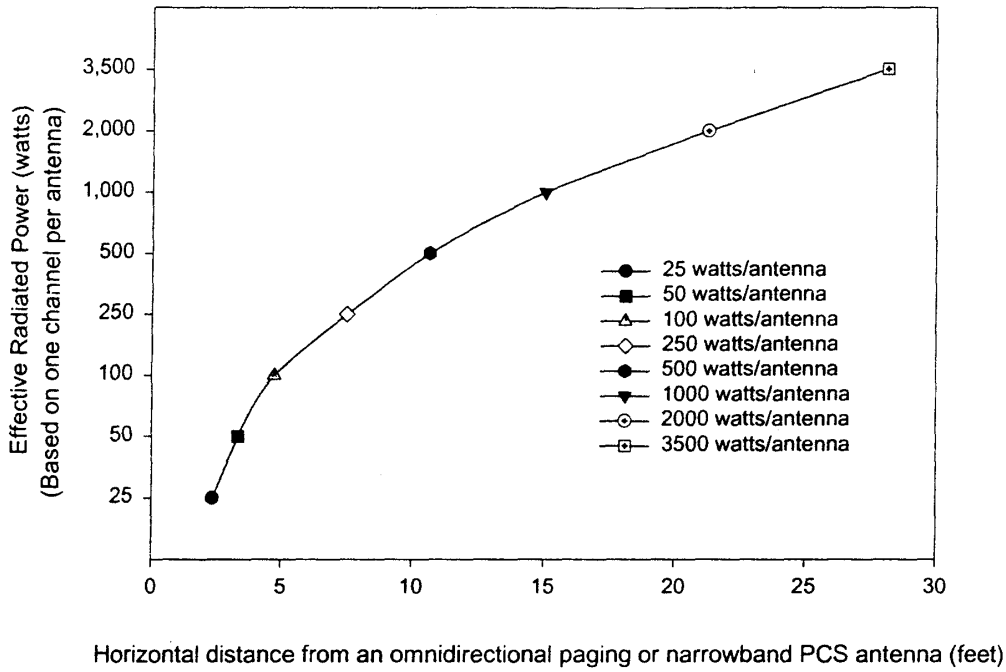
Effective Radiated Power (watts) based on one channel per antenna	Effective Isotropic Radiated Power (watts)	Horizontal* distance (feet) that should be maintained from a single omnidirectional paging or narrowband PCS antenna
50	82	3.4
100	164	4.8
250	410	7.5
500	820	10.6
1,000	1,640	15.1
2,000	3,280	21.3
3,500	5,740	28. 2

For intermediate values not shown on this table, please refer to the Figure B1-4

*These distances are based on exposure at same level as the antenna, for example, on a rooftop or in a building directly across from and at the same height as the antenna.

Note: These distances assume only one frequency (channel) per antenna. Distances would be greater if more than one channel is used per antenna. Omnidirectional paging and narrowband PCS antennas transmit more or less equally from the antenna in all horizontal directions and transmit relatively little energy toward the ground. Therefore, these distances are even more conservative for "non-horizontal" distances, for example, distances directly below an antenna.

Figure B1-4. Estimated "worst case" horizontal* distances that should be maintained from a single omnidirectional **paging** or **narrowband PCS** antenna to meet FCC RF exposure guidelines. Note: this figure and the associated table only apply to the 900-940 MHz band; paging antennas at other frequencies are subject to different values



* These distances are based on exposure at the same level as the antenna, for example, on a rooftop or building directly across from and at the same height as the antenna.

Note: These distances assume only one frequency (channel) per antenna. Distances would be greater if more than one channel is used per antenna. Omnidirectional paging and narrowband PCS antennas transmit more or less equally from the antenna in all horizontal directions and transmit relatively little energy towards the ground.

APPENDIX C

Text of 47 U.S.C. § 332(c)(7)

(7) PRESERVATION OF LOCAL ZONING AUTHORITY.

(A) GENERAL AUTHORITY. Except as provided in this paragraph, nothing in this Act shall limit or affect the authority of a State or local government or instrumentality thereof over decisions regarding the placement, construction, and modification of personal wireless service facilities.

(B) LIMITATIONS.

(i) The regulation of the placement, construction, and modification of personal wireless service facilities by and State or local government or instrumentality thereof (I) shall not unreasonably discriminate among providers of functionally equivalent services; and (II) shall not prohibit or have the effect of prohibiting the provision of personal wireless services.

(ii) A State or local government or instrumentality thereof shall act on any request for authorization to place, construct, or modify personal wireless service facilities within a reasonable period of time after the request is duly filed with such government or instrumentality, taking into account the nature and scope of such request.

(iii) Any decision by a State or local government or instrumentality thereof to deny a request to place, construct, or modify personal wireless service facilities shall be in writing and supported by substantial evidence contained in a written record.

(iv) No State or local government or instrumentality thereof may regulate the placement, construction, or modification of personal wireless service facilities on the basis of the environmental effects of radio frequency emissions to the extent that such facilities comply with the Commission's regulations concerning such emissions.

(v) Any person adversely affected by any final action or failure to act by a State or local government or any instrumentality thereof that is inconsistent with this subparagraph may, within 30 days after such action or failure to act, commence an action in any court of competent jurisdiction. The court shall hear and decide such action on an expedited basis. Any person adversely affected by an act or failure to act by a State or local government or any instrumentality thereof that is inconsistent with clause (iv) may petition the Commission for relief.

(C) DEFINITIONS. For purposes of this paragraph

(i) the term "personal wireless services" means commercial mobile services, unlicensed wireless services, and common carrier wireless exchange access services;

(ii) the term "personal wireless service facilities" means facilities for the provision of personal wireless services; and

(iii) the term "unlicensed wireless service" means the offering of telecommunications service using duly authorized devices which do not require individual licenses, but does not mean the provision of direct-to-home satellite services (as defined in section 303(v)).