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PUBLIC SERVICE COMMISSION

COMMONWEALTH OF KENTUCY
BEFORE THE PUBLIC SERVICE COMMISSION
CASE NO. 2013-00291

HAROLD BARKER;	)	
ANN BARKER; and	)	
BROOKS BARKER,	)	
COMPLAINANTS	)	
	)	**COMPLAINANTS' INFORMATION**
V.	)	**REQUESTS TO EAST KENTUCKY**
	)	**POWER COOPERATIVE, INC.**
EAST KENTUCKY POWER	)	
COOPERATIVE, INC.,	)	
DEFENDANT	)	

* * * * * * * * * *

East Kentucky Power Cooperative, Inc. ("EKPC"), pursuant to the Order dated April 7, 2014 which set the Procedural Schedule in Case No. 2013-00291, is requested to file responses to the following requests for information by June 23, 2014, with copies to the Commission and to all parties of record, and in accordance with the following instructions:

1. Please provide written responses, together with any and all exhibits pertaining thereto, in one or more bound volumes, separately indexed and tabbed by each response.

2. If any request appears confusing, please request clarification directly from Complainants or their attorney.

3. The responses provided should first restate the question asked and also identify the person(s) supplying the information.

4. Please answer each designated part of each information request separately. If you do not have complete information with respect to any information request, so state and give as much information as you do have with respect to the matter inquired about, and identify each person whom you believe may have additional information with respect thereto.

5. To the extent that the specific document, work paper or information does not exist as requested, but a similar document, work paper or information does exist, provide the

similar document, work paper, or information.

6. To the extent that any request may be answered by way of a computer printout, please identify each variable contained in the printout which would not be self-evident to a person not familiar with the printout.

7. If you object to any request on the grounds that the requested information is proprietary in nature, or for any other reason, please notify the Complainant's or their attorney as soon as possible.

8. For any document withheld on the basis of privilege, state the following: date; author; addressee; indicted or blind copies; all persons to whom distributed, shown, or explained; and, the nature and legal basis for the privilege asserted.

9. "Document" means the original and all copies (regardless of origin and whether or not including additional writing thereon or attached thereto) of memoranda, reports, books, manuals, instructions, directives, records, forms, notes, letters, notices, confirmations, telegrams, pamphlets, recordings, notations of any sort concerning conversations, telephone calls, meetings or other communications, bulletins, transcripts, diaries, analyses, summaries, correspondence investigations, questionnaires, surveys, worksheets, and all drafts, preliminary versions, alterations, modifications, revisions, changes, amendments and written comments concerning the foregoing, in whatever form, stored or contained in or on whatever medium, including computerized memory or magnetic media. A request to identify a document means to state the date or dates, author or originator, subject matter, all addressees and recipients, type of document (e.g., letter, memorandum, telegram, chart, etc.), code number thereof, or other means of identifying it and its present location and custodian. If any such document was, but is no longer in your possession or subject to your control, state what

disposition was made of it, including the date of such disposition.

10. "Study" means any written, recorded, transcribed, taped, filmed, or graphic matter, however produced or reproduced, either formally or informally, considering or evaluating a particular issue or situation, in whatever detail, whether or not the study of the issue or situation is in a preliminary stage, and whether or not the study discontinued prior to completion.

11. "Person" means any natural person, corporation, professional corporation, partnership, association, joint venture, proprietorship, firm, or other business enterprise or legal entity. A request to identify a natural person means to state his or her full name and residence address, his or her present last known position and business affiliation at the time in question. A request to identify a person other than a natural person means to state its full name, the address of its principal office, and the type of entity.

12. "And" and "or" should be considered to be both conjunctive and disjunctive, unless specifically stated otherwise. "Each" and "any" should be considered to be both singular and plural, unless specifically stated otherwise. Words in the past tense should be considered to include the present, and words in the present tense include the past, unless specifically stated otherwise. "You" or "your" means the person whose filed testimony is the subject of these interrogatories and, to the extent relevant and necessary to provide full and complete answers to any request, "you" or "your" may be deemed to include any person with information relevant to any information request who is or was employed by or otherwise associated with the witness or who assisted, in any way, in the preparation of the witness' testimony.

13. "PSC" or "Commission" means the Kentucky Public Service Commission.

Respectfully submitted,

M. ALEX ROWADY, ESQ.
BLAIR & ROWADY, P.S.C.
212 South Maple Street
Winchester, Kentucky 40391
(859) 744-3251
ATTORNEY FOR COMPLAINANTS

CERTIFICATE OF SERVICE

This is to certify that a true copy of the foregoing Complainants' Information Requests to East Kentucky Power Cooperative, Inc. was sent by first-class mail to David S. Sanford, Esq., Goss Samford, PLLC, Attorneys for Defendant 2365 Harrodsburg Road, Suite B235, Lexington, Kentucky 40504, this 12th day of June, 2014.

M. ALEX ROWADY, ESQ.

INFORMATION REQUESTS

1. Does the Certificate of Public Convenience and Necessity ("CPCN") process afford affected parties a greater opportunity to address health and safety issues (and other concerns) than the abbreviated process employed in replacing the Smith-Hunt-Sideview 69kV transmission line?

2. Does the Kentucky eminent domain law provide affected parties any opportunity to litigate health and safety concerns?

a. Is the eminent domain law designed exclusively to award monetary damages for condemnation of real property?

3. Are Mary Jane Warner, Paul Dolloff or Benjamin Cotts registered professional engineers in Kentucky or elsewhere?

4. What is the difference in cost to EKPC between applying for a CPCN to undertake a transmission line project versus utilizing the statute's safe harbor provisions?

a. What is the difference in the amount of time required to complete the CPCN process versus the safe harbor?

5. Regarding the previous 69kV transmission line, please state:

a. whether it was still in service during construction of the new 345kV/138kV line;

b. the date it was removed from service and decommissioned; and

c. the date when it was physically removed, line and poles.

6. Please state when construction of the new 345kV/138kV transmission line began.

7. Was the transmission crossing the Barkers' property designed as a 345kV/138kV line?

8. In what capacity was Thad Mumm associated with EKPC on November 10, 2005, the date of the open house?

a. Detail the use made of his notes taken at the open house, particularly those of his discussions with the Barkers.

9. From EKPC's standpoint, what was the significance of the October 26, 2005 letter from the PSC to Mr. Sherman Goodpaster, counsel for EKPC?

10. Please explain how KRS 278.020(2) exempts utility-owned real property from the CPCN process.

11. LEGISLATIVE RESEARCH COMMISSION, Siting of Electric Transmission Lines Research Report No. 348, Chapter 2 Kentucky's Certification Process for Electric Transmission Lines states:

"In 2004, Senate Bill 246 amended KRS 278.020 ....."

"Senate Bill 246 also provided for a forum in which individuals affected by the proposed construction can play an active role in the CPCN process. Individuals can request that PSC hold a public hearing in the county where the line would be located. If an individual wishes to play a more formal role, he or she can request to intervene in the case, which grants the person full rights of a party in the case."

Chapter 3, Page 31 and 32:

"Public Participation

Before 2004, individual landowners potentially affected by new electric transmission lines could not necessarily intervene when the lines were proposed. This was because they were not considered "interested persons" in an application for a CPCN under the case Satterwhite v. Public Service Commission (474 S.W. 2d 287, Ky. 1971).

That has changed. KRS 278.020(8) states that "any interested person, including a person over whose property the proposed transmission line will cross, may request intervention, and the commission shall, if requested, conduct a public hearing...." An interested person also includes a landowner whose land may be crossed, even if such crossing is not definitely known when the transmission owner files an application to build a new line Commonwealth of Kentucky. Public Statement. Section 8)."

Do you agree the above quotation indicates that one of the Sitings/CPCN process purposes is to provide individuals affected by the proposed construction with an opportunity to participate actively in the CPCN process?

12. In reference to the above LRC Report No 348 please consider the above in answering the following questions:

a. On Page 3 of Ms. Warner's report it states "whether (1) a CPCN is required for an entire transmission line project when one or more segments that equal or exceed one mile in length are not replacements or upgrades;"

b. On Page 3 of Ms. Warner's report it states "or (2) a CPCN is only required for those segments of a transmission line project which equal or exceed one mile in length that are not replacements or upgrades;"

Since one of the primary purposes of the CPCN process is to give individuals such as the Barkers an opportunity to participate, would you not agree that limiting the definition to the above would had a chilling effect on this purpose?

13. Please define the following terms:

a. existing electric transmission line "replacement" as stated in KRS 278.020(2);

b. existing electric transmission line "upgrading" as stated in KRS 278.020(2); and

c. existing electric transmission line "deviation".

14. On p. 11, lines 15-18, of Ms. Mary Jane Warner's testimony, she states: "The proximity of a deviation in right-of-way to the pre-existing right-of-way is one factor that could be taken into account in determining whether a project is a replacement and upgrade project or a whole new construction project, but that cannot be the sole determinative factor."

a. Please list the other factors used to distinguish a "replacement and upgrade" project from "a whole new construction" project.

b. What is the source of those factors?

c. Were those factors employed in the Smith-Hunt-Sideview project?

15. Please refer to p. 11, lines 21-23, through p. 12, line 1, of Ms. Mary Jane Warner's testimony. How was it determined that only 559 feet of the 6,975 feet of deviation at the Hunt Substation was not a replacement or upgrade?

a. How much of this 6,975 feet required new right-of-way for the new transmission line?

b. Did any of the 6,975 feet cross property owned by more than one land owner?

c. Was this 6,975 feet relocated for the benefit of one land owner?

16. Beginning on line 15 of Ms. Mary Jane Warner's testimony, she estimates the cost of the two options suggested by Mr. Pfeiffer for moving the segment crossing the Barkers' property to be $69,000 and $72,000, respectively. Please provide a detailed breakdown of how those figures were derived.

17. Regarding the amended and restated transmission line easements signed by the Gravett and Foley property owners on March 15, 2006 which allowed for the Clark substation on Jackson Ferry Road:

a. When EKPC diverted the centerline for the new 345kV transmission line, was it moved approximately 1029 feet to the east?

b. When EKPC diverted the centerline for the new transmission line, did this diversion cross both the Foley and Gravett lands?

c. Was the diverted centerline for the new transmission line across the Foley and Gravett properties moved 6,975 feet?

d. Was anyone at the PSC informed of this diversion? If not, why not?

18. Members of EKPC's staff have made statements at various times about the length of the new right-of-way associated with the Smith-Hunt-Sideview replacement project, as follows:

a. October 7, 2005 letter from Mr. Sherman Goodpaster to the PSC stating that there were two deviations totaling less than **4,000** feet;

b. EKPC letter to U.S. Fish and Wildlife Service on March 1, 2006 stating "As you are aware, the vast majority (approximately 92%) of this project involves rebuilding of an existing transmission line." [18 miles x .08 (100%-92% x 5,280 = **7,603** feet]

c. Gilpin Report states on page 18:

Stearns, Reffett, & Sword	= 3,751 feet
Foley & Shearer Estates	= 6,969 feet
Haggard, Bower & EKPC	= 3,977 feet
Total	= **14,697** feet

d. Answer and Motion to Dismiss by East Kentucky Power Cooperative, Inc. dated October 13, 2013 on pp. 3-4 stating:

"Other than 'bending' the centerline to accommodate the structures referred to in the Staff Opinion request letter, a total of three adjustments to the centerline of the Project were undertaken through the course of development. First, at the request of one property owner who owned land adjacent to the Hunt substation, EKPC rerouted the portion of the transmission line around the Hunt substation. The new centerline amounted to a deviation of approximately 8,000 feet, but it was contained entirely within the property owned by the requesting landowner."

"The second and third deviations were necessary to bring the 345 kV circuit into EKPC's newly constructed North Clark Switching Station while allowing the 69 kV circuit to continue along the existing centerline into the nearby and existing Sideview substation. To accomplish this, EKPC acquired an easement for approximately 2,800 feet from the property owners adjacent to EKPC's North Clark switching station property. The remainder of that portion of the line, approximately 2,400 feet, is on North Clark Switching property itself."

North Clark Switch Station	= 2,800 feet
North Clark Switch Station	= 2,400 feet *
Hunt Substation diversion	= 8,000 feet
Total	**13,240 feet**

*2,400 feet claimed to be on EKPC property but this property was purchased for this project.

e. EKPC's November 21, 2013 Responses to PSC Request for Information, p. 1:

"The first deviated area was around the Hunt Substation...was reported to be 8,000 feet, when in fact this distance is actually 6,975 feet."

"The second and third deviated areas were near the North Clark Substation and were reported to be 2,800 feet and 2,400 feet respectively. These distances are actually 1,875 feet and 1,880 feet."

"These errors in calculation were due to the use of an incorrect coordinate system that was referenced in EKPC's GIS mapping system for the project."

This version can be summarized as follows:

8,000 feet became	6,975 feet
2,800 feet became	1,875 feet
2,400 feet became	1,880 feet
Total	**10,730 feet**

i. Please state when these errors were found?

ii. Please state how many times before this Project was the GIS mapping system used?

iii. Please state whom EKPC uses as a registered Land Surveyor in the state of Kentucky as being responsible for the location of the centerline of the Project?

f. On page 6 of Ms. Mary Jane Warner's testimony the following lengths of new transmission line are claimed.

North Clark Switch Station	= 3,755 feet
Hunt Substation	= 559 feet
Total	= **4,314 feet**

Summary Of Centerline Lengths

October 7, 2005	Official EKPC Request	<4,000 Feet
March 1, 2006	Official EKPC Request	7,603 Feet
May 2006	Gilpin Report	14,697 Feet
October 10, 2013	Answer and Motion to Dismiss	13,240 Feet
November 21, 2013	Sworn Statement	10,739 Feet
June 2, 2014	Sworn Statement	4,313 Feet

i. Why is there such a variation in the lengths of the centerline?

19. Please provide the size, type, manufacturer, cost per foot and ampacity of each different type of electric conductor used on the 345kV/138kV transmission line crossing the Barker property. Please describe the function of each type of conductor and the maximum temperature rating of each conductor type.

20. Please provide the size, manufacturer and specifications of the H-frame poles UT-78 and UT-80.

21. Please provide a list of all materials, with manufacturer and part number that make up each type of insulator string utilized on poles UT-78 and UT-80.

22. Please provide the sag calculations for the section of transmission lines crossing the Barkers' property, beginning and ending at the dead end/horizontal tension points on each side of the Barkers' property.

23. Please provide the "ruling span" calculation for the above mentioned line segment.

24. Please provide the maximum rating in amps under emergency and normal conditions for the line crossing the Barkers' property.

25. Please provide the minimum ground clearance between each line and the ground for the sections of line crossing the Barkers' property under normal and emergency line operating conditions.

26. Please state EKPC's standards for transmission line conductor design maximum capacity as a function of actual conductor maximum capacity as stated by the conductor's manufacturer.

27. Page 24, lines 22-23, of Ms. Mary Jane Warner's testimony discusses the elimination of pole UT-79. Please provide the engineering costs to redesign this section of the transmission line.

28. At the February 5, 2014 informal hearing before the PSC, the attorney for EKPC indicated that the estimated cost of redesigning the transmission lines to reposition them 200 feet away from the Barkers' house would be nearly "$1,000,000". Please define in detail the cost analysis for such a figure.

29. Please state Dr. Dolloff's employment history with dates for each engagement.

30. Please state the various transmission lines where Dr. Dolloff has performed detail design.

31. Please state the various electrical distribution systems Dr. Dolloff has analyzed.

32. Please state the various projects where Dr. Dolloff has performed sag calculations.

33. On p. 5, line 22, of his testimony, Dr. Dolloff states: "Yes, I later returned to the Barkers' home and took magnetic field readings.":

a. Please provide the date of those readings.

b. Please provide all magnetic field test data collected for the 345kV/69kV line crossing the Barkers' property.

c. Please provide mva, mw, mvar and amp data for both the 69kV and 345kV lines during the time span the tests were performed.

d. Please provide the manufacturer and model number of the instrument used to measure magnetic fields during the above referenced testing.

34. Was Dr. Dolloff aware on December 5, 2008 that at least one state in the United States had power line EMF standards?

a. Did he advise the Barkers at that time that he knew of no states with EMF standards?

b. If the answer to both of the foregoing questions is yes, who at EKPC directed him to make such an assertion to the Barkers?

35. The electrical data for the new 345kV/138kV transmission line provided to John Pfeiffer by Dr. Dolloff on February 27, 2012 was as follows:

69kV - Dale				sum of 2 phases
Date/Time	MW	MVAR	MVA	Amps
19-Jan-12 07:00:00	29.72816	-3.303750515	29.91117	**750.8357881**
19-Jan-12 07:01:00	29.69754	-3.323134661	29.88289	**750.1259025**
19-Jan-12 07:02:00	29.66692	-3.342518806	29.85463	**749.4164011**
19-Jan-12 07:03:00	29.63631	-3.361902952	29.82638	**748.7073801**
19-Jan-12 07:04:00	29.60569	-3.38128686	29.79815	**747.9987926**
19-Jan-12 07:05:00	29.57507	-3.400671005	29.76994	**747.290641**
19-Jan-12 07:06:00	29.54445	-3.420055151	29.74175	**746.5828786**
19-Jan-12 07:07:00	29.51384	-3.439439297	29.71357	**745.8756015**
69kV - Dale				
Date/Time	MW	MVAR	MVA	Amps
06-Feb-12 07:00:00	18.49824	-1.689943552	18.575277	**466.2800511**
06-Feb-12 07:01:00	18.52166	-1.696624279	18.59920476	**466.8806901**
06-Feb-12 07:02:00	18.54507	-1.703305006	18.62313171	**467.481309**
06-Feb-12 07:03:00	18.56849	-1.709985852	18.64706167	**468.0820033**
06-Feb-12 07:04:00	18.59191	-1.716666579	18.67099081	**468.6826769**

06-Feb-12 07:05:00	18.61532	-1.723347425	18.69492294	**469.2834257**
06-Feb-12 07:06:00	18.63874	-1.730028152	18.71885424	**469.8841537**
06-Feb-12 07:07:00	18.66215	-1.736708999	18.74278853	**470.4849566**
06-Feb-12 07:08:00	18.68557	-1.743389726	18.76672198	**471.0857385**

69kV - Dale

Date/Time	MW	MVAR	MVA	Amps
07-Feb-12 07:00:00	20.18166	-1.270856738	20.22163	**507.6072**
07-Feb-12 07:01:00	20.16913	-1.280587912	20.20974	**507.3087**
07-Feb-12 07:02:00	20.1566	-1.290319204	20.19785	**507.0103**
07-Feb-12 07:03:00	20.14407	-1.300050497	20.18597	**506.7121**
07-Feb-12 07:04:00	20.13154	-1.30978179	20.1741	**506.414**
07-Feb-12 07:05:00	20.11901	-1.319513083	20.16223	**506.116**
07-Feb-12 07:06:00	20.10647	-1.329244256	20.15036	**505.8182**
07-Feb-12 07:07:00	20.09394	-1.338975549	20.13851	**505.5205**
07-Feb-12 07:08:00	20.08141	-1.348706841	20.12665	**505.223**
07-Feb-12 07:09:00	20.06888	-1.358438134	20.1148	**504.9256**

345kV – North Clark

Date/Time	MW	MVAR	MVA	Amps
1/19/12 7:00	9.56	26.78	28.44	**142.78**
1/19/12 7:01	11.71	26.09	28.60	**143.59**
1/19/12 7:02	15.92	25.41	29.98	**150.53**
1/19/12 7:03	22.36	24.09	32.87	**165.01**
1/19/12 7:04	33.96	22.77	40.89	**205.28**
1/19/12 7:05	35.10	22.10	41.48	**208.24**
1/19/12 7:06	44.01	21.69	49.07	**246.33**
1/19/12 7:07	41.99	21.88	47.35	**237.70**
1/19/12 7:08	41.43	22.24	47.02	**236.06**

345kV – North Clark

Date/Time	MW	MVAR	MVA	Amps
2/6/12 7:00	190.98	-3.36	191.01	**958.93**
2/6/12 7:01	178.22	-2.29	178.23	**894.82**
2/6/12 7:02	182.25	-2.10	182.26	**915.02**
2/6/12 7:03	178.62	-1.96	178.63	**896.82**
2/6/12 7:04	187.87	-1.73	187.88	**943.24**
2/6/12 7:05	183.14	-1.49	183.15	**919.49**
2/6/12 7:06	183.17	-1.25	183.17	**919.61**
2/6/12 7:07	188.88	-4.62	188.93	**948.53**
2/6/12 7:08	198.66	-4.08	198.70	**997.56**

345kV – North Clark

Date/Time	MW	MVAR	MVA	Amps
2/7/12 7:00	240.76	-8.29	240.91	**1209.46**
2/7/12 7:01	240.85	-8.82	241.01	**1209.97**

2/7/12 7:02	234.51	-8.12	234.65	**1178.05**
2/7/12 7:03	230.35	-7.74	230.48	**1157.13**
2/7/12 7:04	252.91	-10.61	253.13	**1270.83**
2/7/12 7:05	270.21	-13.00	270.52	**1358.14**
2/7/12 7:06	274.75	-14.60	275.14	**1381.33**
2/7/12 7:07	280.55	-15.28	280.97	**1410.58**
2/7/12 7:08	281.04	-15.26	281.45	**1413.02**
2/7/12 7:09	271.90	-14.44	272.28	**1366.96**

With respect to the bolded data shown above (which are presumptively inaccurate), please indicate:

a. Who made the calculation of amps?

b. How were the amps calculated?

c. Is it not correct that amps are calculated using the following formula: VA = $\sqrt{3}$ V_{LINE} x I_{LINE}?

d. Does 28.44 mVA represent a current of 142.78 Amps @ 345 kV?

e. Is it true that the basic equation "VA = $\sqrt{3}$ V_{LINE} x I_{LINE}" is a very basic electrical equation that is fundamental to electrical engineering?

f. Why did Dr. Dolloff submit inaccurate data to John Pfeiffer?

36. On p. 28, lines 15-17, of his testimony, Dr. Dolloff states "neither of the transmission lines in question will ever be loaded to maximum capacity and the conductors will never reach maximum operating temperature under normal operating conditions."

a. Please identify the operating procedures that limit transmission line operating capacities.

b. Please provide the maximum operating capacities of EKPC transmission lines in terms of percent full load of normal conductor limits that transmission lines are allowed to operate.

c. Please define who in EKPC has the authority to exceed the above stated operating conditions.

37. Please state Dr. Cotts' employment history with dates for each engagement.

38. Please state the various transmission lines where Dr. Cotts has performed detail design.

39. Please state the various electrical distribution systems Dr. Cotts has analyzed.

40. Please state the various projects where Dr. Cotts performed sag calculations.

41. Page 1 of Dr. Cotts' report describes the "underbuilt" transmission line as a 69kV line.

a. Please state all public references in which the new underbuilt line is described as a 69kV line.

b. Please state all locations in design drawings and specifications which show that the underbuilt line is rated as only up to 69kV.

42. Page 12 of Dr. Cotts' report states: "All comparative model configurations are evaluated using the conductor height at minimum ground clearance (taking into account both conductor sag and terrain change). The conductor sag is calculated based upon maximum temperature (212 degrees Fahrenheit). In order to compare the similar scenarios, the 69-kV transmission line was modeled at an estimated average load of 150 amperes (A) for all configurations and the 345-kV transmission line was modeled at an average load of 300 A."

a. Please state the rationale for using 150 A and 300 A respectively.

b. Please state the minimum and maximum current levels for each circuit of this transmission line since the transmission line was placed into service prior to the date of these questions and answers.

43. Please provide the sag calculations used for each circuit.

44. Please state the reason for using 69 kV for the underbuilt line when this circuit was designed and installed as a 138 kV line?

45. Please provide all test data collected for the 345kV/69kV line crossing the Barkers' property.

46. Please provide mva, mw, mvar and amp data for both the 69kV line and 345kV line during the time span of tests performed on May 22, 2014.

47. Please provide the elevation of the 69kV and 345kV lines at the point of the tests on the Bert T. Combs Mountain Parkway.

48. Please provide the elevation of the 69kV and 345kV lines at the point of the tests on the Barkers' property.

49. Please provide the elevations of the ground level changes at the Barkers' home for each measurement point.

50. Please explain how it is possible to compare measurement results if measurements of EMF are taken at two different points on a transmission line and no line elevation measurements were made.

51. Please provide the ambient temperature at the time of all measurements at the Barker parker property and at the test site at the Bert T. Combs Mountain Parkway.

52. Table 4 of page 34 of Dr. Cotts' report lists measurements made during testing at the Barker house. Please describe the measurement technique.

53. Please identify all EKPC personnel involved in the planning and designing stages of the Smith-North Clark project, indicate each person's role and the date each became aware of the critical situation associated with the Barkers' property.

54. According to EKPC's letter dated October 7, 2005, to the PSC, there were six locations mentioned where property owners had constructed residences and other structures immediately adjacent to the existing right-of-way. Please identify the owners and locations of the properties, the distance from the original 100-foot right-of-way, the date the structure was built and type of structure involved, the date EKPC became aware of the structures' proximity to the line, and indicate the final resolution for each situation.

55. On p. 5, lines 2-3, of her testimony Ms. Mary Jane Warner states, "The structure and lower circuit are designed with the necessary clearances to operate at 138kV, if the need should ever arise for such a change." Why was this not stated in EKPC's letter to the PSC dated October 7, 2005?

56. According to the Gilpin Report dated May 2006, page 40, table 8.6a, there are three houses located 0-100 feet from the right-of-way of the proposed route. Please identify the location of these three houses and the final resolution for each situation.

57. According to EKPC's open house attendee list dated November 10, 2005, there were approximately four additional concerned property owners that were not mentioned in EKPC November 21, 2013 sworn responses to the Commission Staff's Initial Request for Information. Ron Blackburn, Danny Shimfessel, John Flynn and Jerry Jessie voiced concerns regarding EMF and proximity of structures to right-of-way. What provisions, if any, were made for each of these property owners?

58. Regarding the five distinct routes from the original 166 alternative routes generated by the EPRI-GTC Siting Method, please identify with maps those five routes and the

project team that performed the impact evaluations for each. What solutions were generated specifically for the critical proximity involving the Barkers' property.

59. EKPC's response dated November 21, 2013 to the Commission's Request for Information dated November 7, 2013 indicates that an incorrect coordinate system was used which resulted in a significant change in calculating the centerline lengths. Please show the measurements based on the original incorrect coordinate system used and also show the corrected measurements based on the Kentucky State Plane, South Zone System. Please identify at what time during the planning, design and construction of the Smith-Hunt-Sideview replacement project did EKPC begin using the correct Kentucky State Plane, South Zone System?

60. Please describe how adjusting the centerline/easement to avoid the Barker residence is not the best option when constructing a double circuit transmission line rated at 345kV/138kV knowing the health and safety concerns created by a line of this magnitude.

61. Please explain why EKPC did not apply the total net savings of $143,200.00 from the diversions made on the Foley and Hunt Substation properties and the North Clark property to adjusting the centerline/easement on the Barkers' property 200 to 300 feet east as proposed by Pfeiffer Engineering?

62. In the Complainants' response to EKPC's Request For Data dated May 12, 2014, refer to question 7 that states the two poles identified as UT78 are not 140 feet tall. What is the difference in cost now that it is understood that the two poles identified as UT78 are actually 130 feet tall?

63. Does EKPC believe that it exercised good judgment in constructing a 345kV/138kV transmission line so close that it encroaches upon the Barkers' residence and creates an electric shock from vehicles in their driveway when EKPC knew the high levels of electric/magnetic fields associated with a line of this size? Does EKPC believe it followed the guidelines set forth in KRS 278.020(8) regarding this project which specifically include landowners directly impacted by the line routing in the review process, and also require the specific path of the line to be identified in the application for a CPCN?

64. Refer to the direct testimony of Ms. Mary Jane Warner in response to the second question on page 21. This response incorrectly characterizes the Barkers' statements on p. 11 of their direct testimony. The Barkers actually stated "EKPC indicated that 1880 ft. of the diversion in North Clark Line is located on EKPC's substation property. This substation did not preexist nor did they own the land prior to the construction of the new 345kv/138kv line/easement. Therefore the entire length of 3755 ft. was all new ROW and easement." The Barkers still maintain that their statement is correct. On p. 4 of EKPC's Answer and Motion to Dismiss dated October 10, 2013, it states "[w]ork on the Project began in March of 2006 and concluded in 2007." Refer to response 2, page 11 and 12 of the Barkers' direct testimony dated April 25, 2014 and page 22 of Pfeiffer Engineering Investigation Report dated April 24, 2014.

65. Please explain why EKPC did not move the transmission line to the east at the Barker's property during the discussions about removing UT79 and adjusting UT80 which ultimately left an encroachment of 3 feet on the carport and an encroachment of 6 feet on the garage?

66. Does EKPC believe that the 138kV transmission line circuit constructed in the Smith-Hunt Sideview project is unnecessary or wasteful since it is not being operated at 138kV?

67. Were there any charges, increases, rate changes or other adjustments passed on to any co-op/customer resulting from the construction of this 345kV/138kV transmission line project or associated substations?

68. Please refer to Ms. Mary Jane Warner's testimony on pp. 15 and 16. Where in KRS 278.020(2) does it mention anything about a segment or section of a transmission line project governing the requirements involved in issuing a CPCN for a transmission line project? Did EKPC request funding through RUS for this 345kV/138kV transmission line as one construction project or as several segments or sections? (Construction work plans historically have always been treated as one construction project and cooperatives have historically financed construction work plans as one project.)

69. Please provide all letters, memos, e-mails, documents and correspondence from EKPC or their counsel to the PSC and the PSC to EKPC or their counsel related to case 2013-00291.

70. Please provide all proposals, inter office memos, maps, letters, e-mails, documents and correspondence pertaining to the Barker's property regarding the original 69kV transmission line and the 345kV/138kV transmission line from Mary Jane Warner, Rick Drury, Bill Sharp and Mike Wells, Dan McNichol.

71. Please provide copies of letters, e-mails, memos, correspondence and inter office mail EKPC received during or after the open house on November 10, 2005 pertaining to issues, concerns and comments regarding what was presented at the open house.

72. Please indicate if any other electric utility in Kentucky has ever constructed a 345kV/138kV transmission line without the requirement for a CPCN?

73. What was Dominic Ballard's position with EKPC in 2006?

74. What were Mr. Ballard's duties?

75. Please furnish copies of all e-mails, memos, inter office correspondence, letters, and notes from conversations between Mr. Ballard and the Barkers or their counsel.

76. Please provide the date Mr. Ballard became aware that the original 69kV transmission line supposedly encroached on the Barkers' residence.

a. Was this discovered by Mr. Ballard himself or by someone else at EKPC. If by a person other than Mr. Ballard, please identify whom.

77. When did Mr. Ballard become aware of the route of the new 345kV/138kV transmission line, the size of the line and the location on the Barkers' property?

78. Why were negotiations not pursued with Mr. Farris with regards to the adjustment of the easement being requested on the Barkers' property?

79. On page six of the direct testimony of Gabor Mezei he indicates that the long term average magnetic field levels in the center of the Barkers' residence as a result of the nearby transmission line is anticipated to be approximately 3.3mG. What would be the approximate mG reading 35 feet CLOSER to the transmission line using the same modeling?

80. On p. 13 of Dr. Dolloff's testimony please explain why it took ten months to return to the Barkers' residence for the purpose of taking magnetic field measurements. Why were the Barkers not informed of this visit and why were the results of the measurements taken never supplied and explained to the Barkers?

81. Does Dr. Dolloff agree that on December 5, 2008 that the Barkers' emf meter was compared to Dr. Dolloff's emf meter at the edge of the house at the exact same time and both meters were displaying the same value of measurements of magnet field.

82. Does Dr. Dolloff agree that the Barkers' emf/elf meter due to its single axis design cannot overstate a magnetic field reading when taking measurements but actually could only UNDERSTATE a reading based upon the position/orientation of the meter to the field generating source?

83. Does Dr. Dolloff agree that all statements, data and information given to the Barkers at their December, 2008 meeting by him are correct?

The remaining questions are to be answered by Dr. Mezei and please refer to the article entitled Human Health Effects of Non-ionizing Electromagnetic Fields, attached hereto:

84. On page 7 you state ""[b]ased on a recent in-depth review of the scientific literature, the WHO concluded that current evidence does not confirm the existence of any health consequences from exposure to low level electromagnetic fields." However the same document states"A number of epidemiological studies suggest small increases in risk of childhood leukemia with exposure to low frequency magnetic fields in the home." Based on this evidence, as well as your confirmation on page 14 that the International Agency for Research on Cancer (IARC) has declared ELF EMF to be Group 2B, possible human carcinogens, why is it not reasonable and indeed responsible for the Barker family to demand that they not be subjected to exposure to elevated magnetic fields in their home? Should anyone demand absolute proof of harm before applying the Precautionary Principle so as to reduce their exposure to an agent for which there is evidence of harm even though it may fall short of absolute proof?

85. On page 11 and the following pages you discuss the IARC considerations in establishing carcinogenicity. As I have served on IARC panels I am aware that they consider three factors: a) human epidemiological studies; b) animal studies and c) mechanistic studies. It is true that chemical carcinogens are almost always found to cause cancer in animals if they cause cancer in humans, based on equivalent exposures based on body weight. As stated in the WHO information sheet referenced above, "Low-frequency magnetic fields induce circulating currents within the human body." However as was well documented by Kaune and Phillips in 1980 (Bioelectromagnetics 1: 117-129: 1980) the current induced in the human body are much larger than those induced by the same applied EMF in smaller and four-legged animals. Thus unlike the situation with a chemical exposure, it is not correct to require the same results from whole animal exposures as those in humans. Clearly animals do not respond to EMFs in the same fashion as humans. In the 2007 WHO Environmental Health Criteria document on ELF EMFs, there is the statement "Resolving the conflict between epidemiological data (which show an association between ELF magnetic field exposure and an increased risk of childhood leukemia and experimental and mechanistic data w(which do not support this association) is the highest research priority in this fields." You acknowledge these findings on page 15. Given these statements and the statistically significant evidence for elevations in leukemia in both children and adults in the meta-analyses that have been done, why do you (as well as many of the national and international organizations such as SCENIHR) insist on treating EMFs in the same manner as chemical carcinogens, when they do not act in a similar manner?

86. Your own studies and meta-analyses show small but statistically significant associations between leukemia and brain cancer in adults in relation to ELF EMF exposure. Even your own pooled analysis of childhood leukemia shows associations with ELF EMF, although

weaker and not statistically significant associations. In the light of your own studies how can you in good conscience argue that the Barkers have no reason to be concerned about operation of a power line so close to their home that it causes significant elevations in their exposure to magnetic fields? Is it because you are paid to draw that conclusion?

87. Again with your recent publication on ELF EMF and Alzheimer's Disease, you acknowledge that your own analysis shows "a moderate association between Alzheimer's disease and estimated magnetic field levels", but then you pass it off as possibly being due to publication bias (page 26). As above how can you ethically report these associations, even if more research needs to be done, and then argue that the Barker family has no reason to be concern about the increased exposure they will experience from operation of this high voltage power line?

88. Your critique of my report is flawed for many of the reasons discussed above. There is no question but that the evidence for harm from ELF EMFs is to a degree "limited". That alone is sufficient reason for the Barkers to oppose the operation of this power line adjacent to their home. The essence of the Precautionary Principle is that one doesn't wait to have absolute, causal proof of associations before taking responsible action to reduce one's exposure to an agent. As documented by many reports, including the reviews found in the Bioinitiative Report as well as your own publications, there is evidence for associations between ELF EMF exposure and various human diseases. One does not need to report every negative study when the weight of evidence from the human studies is clear. As documented above, animal studies are not directly relevant to human studies of EMFs, in contrast to the situation with chemical carcinogens. Why do you not accept your own work to draw appropriate public health interventions to reduce risk of human disease?

CHAPTER ONE HUNDRED

Human Health Effects of Nonionizing Electromagnetic Fields

David O. Carpenter, M.D.

1 INTRODUCTION

Electromagnetic waves are packets of energy that have no mass. Visible light is an example of electromagnetic waves. As every school child learns, electromagnetic waves all travel at "the speed of light" and are sine waves of various frequencies. The colors humans can distinguish are a result of differences in the wave lengths of the photons of light, with blues and purples being of shorter wave lengths than reds. Our eyes have photoreceptors that are able to distinguish different colors of light based on the ability of the visual pigments to absorb specific wavelengths. The energy in the shorter wave length colors (blue and purple) is greater than that of the longer wave length colors (reds), and this energy is transmitted to the photoreceptors that are designed to detect the specific color. Since the speed of light is a universal constant, the wave length (distance traveled for one complete sine wave) is inversely related to the frequency. Thus, the energy in an electromagnetic wave is a direct function of the frequency.

Figure 100.1 shows the electromagnetic spectrum (1). The most energetic portion (cosmic rays, gamma rays, and X-rays) has sufficient energy to directly break chemical bonds and is therefore considered to be ionizing radiation. While exposure to ionizing electromagnetic radiation is not as damaging to biological tissues as is particulate ionizing radiation (alpha particles that are helium nuclei, beta particles that are electrons, protons, neutrons, or larger fission nuclei), they do have sufficient energy to directly damage DNA, causing mutations that can lead to cancer and birth defects. Ultraviolet electromagnetic waves have lower energy and longer wavelength. Ultraviolet radiation causes skin cancer and suppression of the immune system. Visible light has less energy and longer wavelengths than does ultraviolet. Obviously, life on earth would not be possible without visible light, and therefore it is hard to think of visible light as being dangerous. Below visible light are infrared electromagnetic waves. These are the energy coming from the sun that heats the earth, without which life on earth would not be possible. The sun also generates lower frequency electromagnetic waves.

The major subject of this chapter is that portion of the electromagnetic spectrum that has lower energy and longer wavelengths than the infrared. The energies in these ranges of frequency are not sufficient to directly break chemical bonds, and the question to be examined is whether they have sufficient energy to cause human disease by other mechanisms, particularly at intensities that do not cause measureable heating. Known as nonionizing electromagnetic fields (EMFs), they range from microwaves at the high energy end to the low frequency electric and magnetic fields produced by electricity. The latter are frequently described as "extra low frequency" (ELF) electromagnetic fields, although more commonly the term "EMF" is used to indicate power line frequency fields in contrast to "RF" (radiofrequency) for all of the communication frequencies. Because all forms of electromagnetic waves have energy, at sufficient intensity electromagnetic waves cause tissue heating. This is the principle of the microwave oven, where energy in transmitted to water molecules such that one can bake a potato. At lower intensities and with varying wavelengths microwaves are also used for communication. This is the basis of radar and mobile phones. At still lower frequencies electromagnetic waves are used for television

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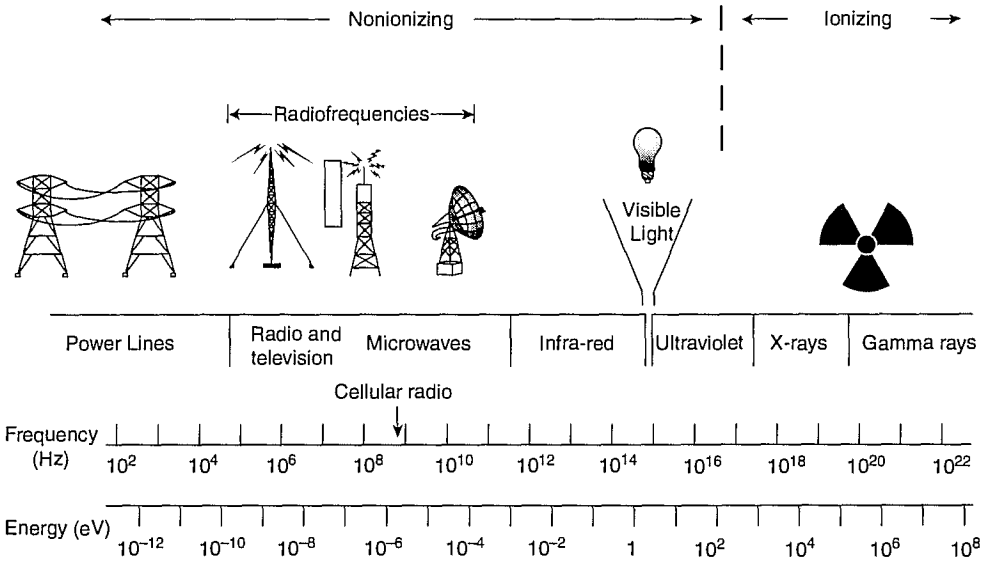

Figure 100.1. The electromagnetic spectrum. Reproduced with permission from Ref (1).

and radio transmission signals. The extralow frequencies (usually considered to be the range between 3 Hz–3 kHz) include those associated with electricity, which is at 50 Hz in much of the world but at 60 Hz in North America. At these low frequencies, there are coupled electric and magnetic fields, each of which has distinct properties. Table 100.1 lists the sources and uses of EMFs of various frequencies.

Table 100.1. Sources of EMFs

Frequency	Purpose	Additional EMFs	Maximal Power
DC	Earth's magnetic field		
3–30 Hz	Movement through DC		
50/60 Hz	Electricity	Harmonics up to 500 Hz Ground currents Contact currents High frequency transients	
535–1605 KHz	AM Radio		
3–30 MHz	Amateur radio		
88–108 MHz	FM Radio	(reflected waves, standing waves)	
54–216 MHz	Television		
470–806 MHz	High definition TV		
27–806 MHz	Cable TV, radio		
800–900 MHz	Early mobile phones		1–15 W
900–1800 MHz	GSM mobile phones		1–2 W
1800–1900 MHz	DECT cordless phones		0.25 W
1900–2200 MHz	UMTS mobile phones		2 W
Microwave bands:			
1–2 GHz	L-band		
2–4 GHz	S-band		
4–8 GHx	C-band		
8–12 GHz	X-band		
6–100 MHz plus			
Pulsed plus			
Static DC			
Magnetic Field	MRI		

Definitions: GSM: Global System for Mobile Communications; DECT: Digital enhanced Cordless Telecommunication; UMTS: Universal Mobile Telecommunications System; MRI: Magnetic resonance imaging.

2 THE PHYSICS OF ELECTRIC, MAGNETIC, AND RADIOFREQUENCY FIELDS

Planck's law ($E = h\nu$) provides the relationship between energy and wavelength for all forms of electromagnetic fields, where E is photon energy in joules, h is Planck's constant, 6.624×10^{-34} J s, and ν is in Hertz, cycles per second. While ionizing radiation is usually characterized by energy and visible light is usually specified by wavelength, the nonionizing EMF fields are most commonly described by frequency. The term "microwave" is usually used for radiofrequency fields of several hundred megahertz (MHz) up to 1000 MHz (1 gigahertz, GHz) and higher. The RF portion of the EMF spectrum is usually considered to be the range between 3 kiloHertz (kHz) and 300 GHz.

At lower frequencies, including some of the lower RF fields, electric and magnetic fields are distinguished. The electric field (**E**) is related to voltage, and expressed as volts/meter (V/m). This is the field that one charged particle exerts on another, and is what one has in a capacitor, where there is a charge between two plates. Thus, the electric field can be considered to be stored energy. Magnetic field (**H**) is a function of current flow, and is expressed as amperes per meter (A/m). Moving charged particles will feel a force in the presence of a magnetic field. The magnetic field is usually expressed as magnetic flux density, **B**, where $\mathbf{B} = \mu_0 \mathbf{H}$, where $\mu_0 = 4\pi \times 10^{-7}$. Both electric and magnetic fields are vectors that fall off with distance from the source. While the electric field is easily shielded, magnetic fields penetrate building materials and biologic systems readily. The international unit for magnetic field is Tesla (**T**), although in the United States magnetic field is often expressed as Gauss (**G**), where $1\,\text{G} = 100\,\mu\text{T}$.

The earth has both a static electric and magnetic field (2). The electric field varies with weather, and is about 100 V/m. The magnetic field varies over the surface of the earth, but is less dependent on weather. The magnetic field is large compared to that generated by power lines, being about 60–70 μT (0.6–0.7 G). However, a moving person will be exposed to fluctuations in these fields because of interferences with objects.

Electric and magnetic fields decrease with distance from their source as the inverse square of the distance from point sources, like an appliance, or as the inverse of the distance from a power line or cable. High-voltage power lines will have electric fields on the order of 8–10 kV/M in the right of way, whereas the magnetic field in the right of way can be on the order of 70 μT (0.7 G). Both will fall off with distance. The electric field around a distribution line is lower since these lines operate at a lower voltage. However, the magnetic field around distribution lines can be significant, varying with the current flow. Since all appliances that use electricity will also generate electric and magnetic fields, for many individuals these will be a major source of exposure and levels will vary depending on how close to the appliance one is in a residence or an office (3). Figure 100.2 shows measurements of the magnetic field in a typical office.

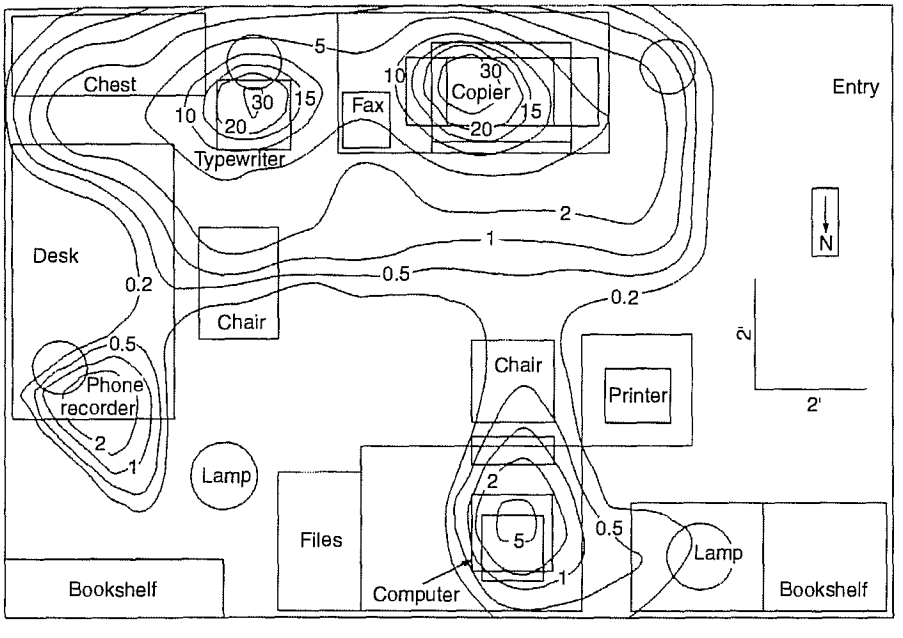

Figure 100.2. Spatial distribution of magnetic field levels in a real estate office. Note the general background field in most of the area is well below 0.1 μT (1 mG). The highest fields are at the copier, typewriter, and computer. Contours are shown for 0.1, 0.5, 1, 2, 5, 10, 15, 20, and 30 mG. Reproduced with permission from Ref. (2).

The amount of energy absorbed by RF radiation depends upon the frequency, intensity, and duration of exposure. The specific absorption rate (SAR) is a measure of the rate of energy absorption per unit mass, and is expressed in terms of watts per kilogram (W/kg). This is an important measurement with regard to tissue heating upon RF exposure, but is increasingly being used for RF exposures that are presumed to not cause measureable heating.

The sources of RF are varied (1, 4) and operate at different frequencies as shown above in Table 100.1. AM radio antennas use frequencies between 535 and 1605 kHz, and the entire tower structure serves as a radiator, with the RF projected at 365°. Amateur radio operates usually between 3 and 30 MHz. FM radio uses frequencies between 88 and 108 MHz, television between 54 and 216 MHz or UHF frequencies between 470 and 806 MHz. All, especially FM broadcast antennas, can cause significant exposure at ground level. Satellite earth base stations use high-power densities, but exposure outside the main beam is usually not great. Higher microwave frequencies are used for other telecommunication systems, including mobile phones, cable television, cellular radio, and often operate in the range of 27–806 MHz. Mobile (cellular) telephones used to operate at frequencies between 800 and 900 MHz. This was followed by the Global System for Mobile Communications (GMS) that operates at 900–1800 MHz and is the dominant system in Europe and parts of Asia at present. The Advanced Wireless Services (AWS-1) is a communication spectrum band approved by the U.S. Federal Communications Commission in 2006 for mobile voice and data services, video, and messaging, and operates at two frequencies, from 1710 to 1755 MHz and from 2110 to 2155. The Universal Mobile Telecommunications System (UMTS) operates in Europe at frequencies between 1.9 and 2.2 GHz, and allows Internet browsing, video telephony, and music downloads. Cordless telephones use the Digital Enhance Cordless Telecommunication (DECT) system, which operates at 1880–1900 MHz worldwide. WiFi operates in the range of 2400–5000 MHz, and is widely used for broadband wireless access, for computers, PDAs, pocket PCs, and cell phones. Microwave ovens operate at 2450 MHz. Radar operates at greater than 3600 MHz.

In our modern world, we are all bathed in a sea of EMFs coming from electricity and wireless communications, as well as from natural sources. If one can use a mobile phone or turn on to a radio station or TV channels, this is an indication that RF signals are all around you. The fact that everyone is exposed complicates the search for the answer to the question of whether there are serious adverse health effects resulting from exposure, as no one is unexposed. We now have WiFi in almost every McDonald's restaurant, in Starbucks coffee shops, and in many homes and offices, and some cities are going wireless as well. The use of mobile phones has grown exponentially, and there are now some 4 billion mobile phone subscribers worldwide (5).

3 SOURCES OF HUMAN EXPOSURE TO EMFs

While it is traditional to consider ELF and RF as two distinct sources of exposure, in reality exposure to most EMF sources is much more complex. RF fields (112–438 kHz) commonly occur with ELF fields (6). Electricity-generated EMFs are described as 50 or 60 Hz, and RF is expressed as a designated frequency. However, electricity-induced fields include harmonics of the base frequency, as well as high-voltage transient fields when currents are turned on and off (7). Ground currents are common, usually a result of wiring flaws and magnetic induction from nearby power lines (8). Contact currents, found in household plumbing as a result of multigrounded neutrals, may result in currents of tens of microamperes when a person touches the plumbing (9). In addition, there are also some low-intensity RF fields coming from power lines, although their origin is uncertain (6). RF fields are often superimposed upon a carrier frequency, and are often modulated or pulsed. Thus, while the information is carried by the designated frequency, humans' exposure is to a much more complex variety of EMFs (4).

In the past the urban RF environment was primarily a result of radio and television transmission, but that has changed in the era of contemporary communications. Frei et al. (10) reported on RF exposure of 166 Swiss volunteers who wore an exposimeter for 1 week. They found that mean weekly exposure to all RF-EMF was 0.13 mW/m^2 (range 0.014–0.881 mW/m^2). Of this 32% was due to the mobile phone base stations, 29% from mobile phone handsets, and 23% due to DECT cordless phones. Exposures were greatest when on trains, in airports, or on buses. The relatively very large contribution from the mobile phone base stations is somewhat of a surprise, and may have very important public health implications. Burch et al. (11) performed a somewhat similar investigation in the United States and note that in addition to distance, elevation and line-of-sight visibility to transmitter facilities and base stations is an important variable in predicting RF exposure. It must be noted that health effects resulting from exposure to RF from base stations has not been systematically studied in many human health investigations to date, and the results of Frei et al (10) raise the possibility that this is an even greater source of average exposure for a significant portion of the population than is the use of a mobile phone.

Exposure to EMFs results in currents induced in the body. The electric fields within the body are much smaller than those applied externally, but for magnetic field the body does not perturb the field (12). The size and shape of a body greatly influences the currents that are induced by an applied magnetic field (Figure 100.3). These induced currents may play a significant role in health outcomes. This is one factor that makes extrapolation of animal data to humans very difficult. It is also important to understand that many of the cells of the

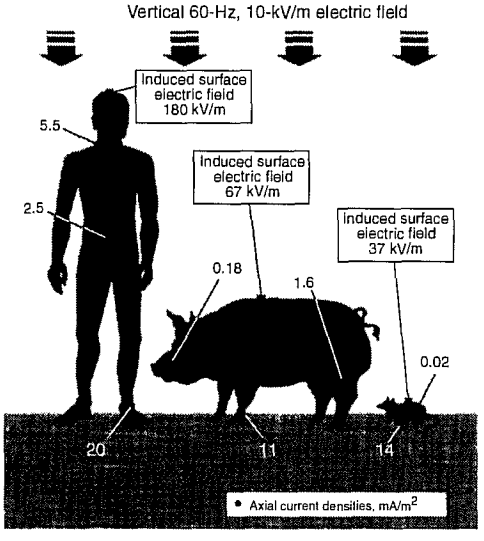

Figure 100.3. Electric field interactions and induced currents in humans, pigs, and rodents. Current densities vary according to body size, shape, and orientation to the field. Adapted from Ref. (13).

body, especially neurons and muscle, are electrically excitable and produce rapid action potentials as well as slower synaptic and other potentials (14), all of which are associated with local fields and currents.

4 HEALTH EFFECTS OF POWER LINE FIELDS

4.1 Childhood Leukemia

In 1979, Wertheimer and Leeper (15) reported that children living in homes in Denver, Colorado, in which the magnetic field was elevated because of proximity to distribution power lines, were more likely to develop cancer than were children living in homes that did not have elevated magnetic fields. They did not directly measure magnetic fields in the homes of the children, but rather deduced relative levels by development of what they called a "wiring configuration." The categorization of homes was based on measurements from various types of power lines. They found that measured magnetic fields were low over buried power lines, and homes with buried lines became their comparison group. They then distinguished "high-current configuration" homes from "low-current configuration" homes, based on proximity to aboveground lines, whether they were primary or secondary lines, and proximity to transformers coming from the primary lines. While this initial report of an association between exposure to magnetic fields and childhood cancer was greeted with skepticism, the observation was essentially replicated for childhood leukemia in a series of follow-up studies in Denver (16), Los Angeles (17), and Sweden (18).

A number of other studies followed Wertheimer and Leeper, primarily focused on childhood leukemia. Three meta-analyses have been published that evaluate the results of all studies up to year 2000. Wartenberg (19) identified 11 childhood cancer studies with some measure of magnetic field exposures of children and with complete data. He found a significantly elevated risk of childhood leukemia whether using a fixed effects model (odds ratio (OR) = 1.48, 95% Confidence Interval (CI) = 1.18–1.85) or a random effects model (OR = 1.52; 1.08–2.14). He noted that the ORs were consistently higher in studies using wire configuration codes than in those that directly measured magnetic field intensities in homes and that evidence for a clear dose–response relationship was not strong. Ahlbom et al. (20) pooled results from nine primary studies of childhood leukemia and either calculated or measured magnetic field, and obtained an OR of 2.0 (1.27–3.13) for magnetic field exposures greater than 0.4 μT (4 mG). For acute lymphocytic leukemia they found an OR = 2.08 (1.30–3.33). They did not find significant differences between results from measured compared to calculated magnetic fields. Greenland et al. (21) obtained original data from 15 childhood leukemia studies with either measured magnetic fields or wire codes and found a summary OR of 1.7 (1.2–2.3) for magnetic fields greater than 0.3 μT (3 mG). They, like Ahlbom et al. (20), did not find any significant difference between measured magnetic fields and wire code studies.

Studies performed since 2000 have generally yielded results that are similar to the earlier ones. Foliart et al. (22) explored long-term survival among children with leukemia in relation to their exposure to magnetic fields, and found a significantly greater risk of not surviving among children living in homes with magnetic fields greater than 0.3 μT (3 mG). Draper et al. (23) demonstrated that children who live within 200 m of a high-voltage power line had an OR of 1.69 (1.13–2.53) for development of leukemia, compared to those living beyond 600 m, whereas those living between 200 and 600 m had an OR = 1.23 (1.02–1.49). Mizoue et al. (24) performed a similar study of residence close to high-voltage power lines in Japan and found an insignificant elevation in risk of childhood leukemia. Schüz et al. (25) used the same studies in the pooled analysis by Ahlbom et al. (20) to examine whether nighttime bedroom magnetic fields were related to childhood leukemia more strongly than 24 or 48 h measurements. They found essentially no difference, replicating the previous results with significantly elevated risk by measuring when the magnetic field was either 0.4 μT (4 mG) or more. Kabuto et al. (26) measured magnetic fields in homes of 312 Japanese children newly diagnosed with acute lymphoblastic leukemia (ALL) or acute myelocytic leukemia (AML) compared to 603 matched controls. They found an OR = 2.6 (0.76–8.6) for AML plus ALL, and OR = 4.7

(1.15–19.0) for ALL only. Feizi and Arabi (27) reported significant elevations of childhood leukemia among residents of Iran living close to high-voltage power lines with magnetic fields of more than 0.45 μT (4.5 mG). One of the few convincingly negative studies is that of the United Kingdom Childhood Cancer Study Investigators (27a), who studied the homes of 473 children with various malignant neoplasms and did not find a significant relationship between residential magnetic field and any type of childhood cancer.

There is some evidence for particularly vulnerable populations. Mejia-Arangure et al. (28) reported that for children with Down's syndrome the OR for leukemia from magnetic fields greater than 0.6 μT (6 mG) was 3.7 (956% CI = 1.05–13.1. Infante-Rivard and Deadman (29) reported that maternal occupational exposure to magnetic fields greater than or equal to 0.4 μT (4 mG) increased the risk that the child would develop leukemia (OR = 2.5; 1.2–5.0). Yang et al. (30) have reported that children who had a particular polymorphorism of one of the DNA repair enzymes and lived within 100 m of a power line with high magnetic fields showed an interaction OR = 4.31 (1.54–12.08). This result suggests that certain individuals may be more genetically vulnerable to exposure to magnetic fields than others.

These studies indicate a consistent pattern of elevated risk of leukemia in children at magnetic field levels greater than 0.3 or 0.4 μT (3 or 4 mG). There is uncertainty as to what is the threshold level for increased risk. Some studies have demonstrated significant elevations in childhood leukemia when comparing children living in homes with 0.2 μT (2 mG) to those in homes with 0.1 μT (1 mG) (18). A German study has shown significantly reduced survival of children with acute lymphocytic leukemia if living in a home with magnetic fields between 1 and 2 μT (1 and 2 mG) (31). Since no one is unexposed, at present there is no reason to believe that there is a threshold of exposure below which risk of cancer is not elevated, although the evidence for the relationship at 0.4 μT (4 mG) and above is by far the strongest.

If magnetic fields cause childhood leukemia, as the above studies suggest, one would expect that exposure to magnetic fields from appliances and household wiring would also increase risk. Several studies have shown small but statistically significant elevations in leukemia incidence in relation to use of appliances, particularly electric blankets (17, 32, 33). This is in spite of the great difficulty in accurately measuring exposure from appliances over long periods of time. Prenatal electric blanket used by pregnant women appears to elevate risk of the child developing leukemia as well (32, 33).

4.2 Other Forms of Childhood Cancer

Evidence for a relationship between exposure to ELF and other forms of cancer in children is much weaker than for leukemia. The original Wertheimer and Leeper (15) study suggested elevations in all kinds of cancer. Savitz et al. (16) reported significant elevations in rates of brain cancer and nonsignificant elevations with lymphoma and soft tissue cancers, but Feychting and Ahlbom (18) found significant relationships only with leukemia. The relationship between childhood ELF exposure and brain cancer has been reviewed by Miller et al. (34) and Kheifets et al. (35). Both conclude that the evidence for an association is weak and inconsistent among studies. There have, however, been two studies that suggest that parental EMF exposures increase risk of brain tumors in children. Johnson and Spitz (36) found statistically significant elevations in rates of childhood brain cancer in children of male electricians, while De Roos et al. (37) reported a nonsignificant elevation in neuroblastoma in children whose fathers were occupationally exposed to more than 0.4 μT (4 mG). Li et al. (38) reported statistically significant elevations in the risk of brain cancer in children whose mothers were occupationally exposed to EMFs, with ORs varying between 1.5 and 2.3.

4.3 Adult Exposure to Magnetic Fields and Cancer

There have been both residential and occupational studies designed to determine whether exposure to EMFs is associated with elevated rates of adult cancer. While the strength and consistency of relations observed are not as strong as those for childhood leukemia, most studies have demonstrated elevations in adult leukemia in occupational EMF studies in spite of obvious limitations in exposure assessment, which is usually done only by job title. The association between adult leukemia and occupational EMF exposure was reviewed by Savitz and Calle in 1987 (39), and they reported statistically significant elevations in total leukemias, acute lymphocytic and acute myelogenous leukemias based on analysis of 11 publications. Kheifets et al. (40) compared results from five major studies of electric utility workers and concluded that results suggest a small elevated risk of leukemia. Lowenthal et al. (41) reported a case–control study of 854 patients with lymphoid or myeloid leukemias, ages 0–94 years, and found that living within 300 m of a high-voltage power line for the first 15 years of life resulted in an OR = 3.23 (1.26–8.29). Villeneuve et al. (42) reported highly statistically significant elevations in the risk of leukemia in electric utility workers, but found that while exposure to magnetic fields showed only nonsignificant elevations in risks, exposure to electric fields showed stronger and more significant relations.

One major limitation in most studies of EMFs and cancer is that the exposure assessment is done for only one source of EMF, either residence or occupation. Feychting et al. (43) investigated both residential and occupational exposures for leukemia and brain tumors among Swedish adults living within 300 m of transmission lines. For leukemia both residential and occupational exposures, considered alone, showed no significant relationships. However, when the

combined exposures were considered a risk ratio (RR) = 3.7 (1.5–9.4) was found. For brain cancer the combined exposures gave a higher but still nonsignificant RR.

Kheifets et al. (44) conducted a meta-analysis of occupational exposure to EMFs and brain cancer, and found a 10–20% statistically significant elevated risk in a broad group of electrical occupations that was consistent across several different analysis models. Villeneuve et al. (45) studied occupational exposure to magnetic fields and brain cancer in Canadian men, and found a nonsignificantly increased risk of brain cancer in men who had ever held a job with an average magnetic fields of 0.6 μT (6 mG) or greater, but a highly statistically significant elevation in men with glioblastoma multiforme (OR = 5.36; 1.16–24.78), and with risk related to a time-weighted index score. Others have either found (46, 47) or not found (48–50) elevated risks in occupationally exposed cohorts. In summary, results are suggestive of a small elevated risk of brain cancer, but the lack of consistency limits confidence in concluding that the associations are real. In a study of electric appliance use and brain cancer, Kleinerman et al. (51) reported that the use of hair dryers increased risk of glioma (OR = 1.7; 1.1—2/5) and that male use of electric shavers increased risk (OR = 10.9; 2.3–50).

There have been a number of studies of breast cancer and EMFs. Erren (52) performed a meta-analysis that reviewed 43 publications. For women, he calculated a pooled risk ratio of 1.12 (1.09–1.14), while for men the risk ratio (RR) was 1.37 (1.11–1.71). He comments that the results from individual studies are variable and sometimes contradictory, but in sum the studies suggest that there is a small but real association between exposure and disease. London et al. (53) studied 743 cases and 699 controls in Los Angeles County, California, and found no relationship between wire configuration or measured magnetic fields and risk of breast cancer. Kliukiene et al. (54) reported a significant elevation in breast cancer risk in Norwegian women living near a high-voltage power line (OR = 1.58; 1.30–1.92) and a nonsignificantly elevated risk upon occupational exposure.

Other cancers have not been well studied. Tynes et al. (55) found a significant elevation in the risk of malignant melanoma upon considering both residential and occupational exposure to 50 Hz magnetic fields. Håkansson et al. (56) reported elevations in risks of kidney, liver, and pituitary gland cancers in Swedish men occupationally exposed in industries using resistance welding. Baumgardt-Elms et al. (57) reported nonsignificant elevation of testicular cancer in relation to residential proximity to high-voltage powerlines, but no association was found between exposure and prostate cancer (58) or endometrial cancer (59). Villeneuve et al. (60) did not find any relationship between non-Hodgkin's lymphoma and 60 Hz exposure to magnetic fields, but did find a relationship with electric fields of 10 and 40 V/m. This is one of the few studies to report association with electric fields.

4.4 Animal Studies of ELF and RF EMF and Cancer

Animal studies have generally not demonstrated that exposure to 50/60 Hz EMFs results in elevated rates of cancer in animals, whether or not the EMF exposure is superimposed on another carcinogen, although in a 2 year exposure study done by the National Toxicology Program there was a significant elevation in thyroid adenomas, but only in males and only in Fischer 344/N rats (61). The results of these earlier animal studies are reviewed in detail by the NIEHS Working Group Report (62). The one interesting positive report is that of Reif et al. (63). They performed a hospital-based case–control study of canine lymphoma at the Colorado State University Veterinary Teaching Hospital and categorized the dogs' homes on the basis of the Wertheimer and Leeper (15) wire configuration code. They found that dogs that lived in very high-current code homes had an OR = 6.8 (1.6–28.5) compared to those living in homes with buried, very low, or low wiring configurations.

Studies since this report was issued are generally in agreement with the conclusion that rodents exposed to various intensities of 50 or 60 Hz magnetic fields do not result in increased incidence of any cancer (64), acute myeloid leukemia (65), or lymphoma (66). Bernard et al. (67) did not find that EMF exposure altered the development of nitrosourea-induced leukemia in rats. Neither did Chung et al. (68) find the 60 Hz EMF exposure increased ethylnitrosourea-induced brain tumors nor did Negishi et al. (69) find that 50 Hz magnetic fields altered lymphoma/leukemia in mice induced with DMBA. As indicated in Figure 100.3, the fact that induced currents in rodents are very different from those in human may explain the failure of animal models to confirm the results from human studies.

For RF exposures the situation is very similar, although a number of early studies did suggest elevations in various cancers (70). Repacholi et al. (71) reported that transgenic mice exposed to 900 MHz RF fields showed an increased risk of developing lymphoma, but these results were not replicated in either the same strain (72) or a different strain of mice (66).

4.5 Mechanisms whereby 50/60 Hz EMFs may Cause Cancer

The effects or lack thereof of 50/60 Hz EMF on chromosomes and genes have also been extensively reviewed in the NIEHS Working Group Report (62). The conclusion up to that time was that while there have been many studies, no consistent pattern of response has been found in studies of DNA, chromosomal damage, or gene induction. There are a number of changes that have been detected in multiple studies that focus on various signaling pathways such as protein kinase C, calcium homeostasis and flux, cell

proliferation, and enzyme synthesis and activity. However, replication has often not been possible and the studies have not shown a clear pattern of reproducible effects. In addition, most of the *in vitro* studies have been at field intensities significantly greater than those reported in the epidemiological investigations reporting elevated rates of cancer.

There have been numerous studies since 1998 that fail to find evidence of DNA damage (73–75) or consistent and reproducible effects on gene expression (76–78). However, Lai and Singh (79) exposed rats acutely to 0.1–0.5 mT (100–500 mG) and found increases in DNA single- and double-strand breaks in rat neurons. The report of Yang et al. (30) mentioned above is important in this regard, which says that children with a particular genetic polymorphorism of a DNA repair gene have elevated risk of developing childhood leukemia.

Lin et al. (80) and Goodman and Blank (81) have reported increased transcript levels for specific genes in response to low-frequency EMFs. They particularly found elevation in heat shock protein 70 (HSP70). Di Carlo et al. (82) exposed chick embryos to chronic 60 Hz EMFs and report that this resulted in a decrease in expression of HSP70. These observations were replicated by Tokalov and Gutzeit (83) in human cells at intensities as low as 10 μT (100 mG), but not by Coulton et al. (84). In *Salmonella*, Williams et al. (85) did not find DNA breaks on exposure to a 14.6 mT (146,000 mG), 60 Hz EMF, but did find evidence of induction of stress proteins. Lupke et al. (86) have reported expression of 986 genes involved in metabolism, cellular physiology, signal transduction, and immune responses upon exposure of human monocytes to 1.0 mT (10,000 mG) 50 Hz EMFs. Ivancsits et al. (85) reported DNA strand breaks induced by 1000 μT (10,000 mG) Hz EMFs applied intermittently. In a later study, Ivancsits et al. (87, 87a) assayed DNA damage in cultured human fibroblasts by the comet assay, and found DNA damage with intermittent 50 Hz EMF at intensities as low as 35 μT (350 mG). In a recent review, Blank (88) has proposed that EMFs act by causing charge movements of proteins and DNA and that the resulting conformational changes alter a variety of cellular functions. Clearly, most of these positive studies report significant effects only at much higher field strengths than those reported to result in human disease.

There is evidence that magnetic field exposure alters the normal circadian rhythm of the pineal hormone, melatonin (89), and some have proposed that this alteration might be a factor in the risk of childhood leukemia (90).

In total, these reports do not allow one to conclude what might be the mechanism of the elevation in rates of cancer seen in humans exposed to magnetic fields. The cellular and animal studies are not consistently positive, and even those that are positive are often with higher intensities than are experienced by humans. Replication in different laboratories is a problem as well. While there is some indication of mechanisms that may explain the EMF–cancer connection (especially gene induction, DNA damage, and HSP70 induction), at present there is not a clear consensus that any of these mechanisms is the basis of the observed associations.

4.6 Neurodegenerative Diseases

There is reasonably strong and consistent evidence that lifetime occupational exposure to EMFs greater than 0.2 μT (2 mG) is associated with an increased risk of Alzheimer's disease. García et al. (91) have published a meta-analysis of 14 studies (9 case–control and 5 cohort studies) that followed standardized criteria for diagnosis of Alzheimer's disease and obtained a pooled OR = 2.03 (1.38–3.00) for the case–control studies and OR = 1.62 (1.16–2.27) for the cohort studies.

Two studies have appeared since this meta-analysis was published, and both support an association between magnetic field exposure and Alzheimer's disease. Röösli et al. (92) investigated more than 20,000 Swiss railway employees where they compared diseases in highly exposed train drivers, who had a mean exposure of 21 μT (210 mG), with station masters whose mean exposure was 1 μT (10 mG). The train drivers had an OR of 1.96 (0.98–3.92) for senile dementia and OR = 3.15 (0.90–11.04) for Alzheimer's disease. For every 10 years of cumulative exposure, the senile dementia mortality increased by 5.7% (1.3–10.4) and Alzheimer's disease increased by 9.4% (2.7–16.4). Huss et al. (93) reported on Alzheimer's disease in the 4.7 million persons in the Swiss National Cohort. The adjusted hazard ratio (HR) for Alzheimer's disease was 1.24 (0.80–1.92) among persons living within 50 m of a 220–380 kV power line, compared to those who lived 600 m or more away from the line. In those living at least for 5 years within 50 m of the line the HR = 1.51 (0.91–2.51), and the HR increased to 1.78 (1.07–2.96) after 10 or more years of residence within 50 m of the line.

The cause of Alzheimer's disease is still uncertain, and thus it is not surprising that the mechanism whereby EMFs might increase risk is not well understood. Alzheimer's brains have two specific abnormalities, amyloid plaques and neurofibulatory tangles. The plaques are formed from deposits of amyloid β, while the tangles are deposits of tau protein. Both are normal proteins that behave abnormally in this disease, but it is still unclear whether these deposits cause Alzheimer's or are rather indications of some other etiologic process. Noonan et al. (94) found that there was a positive but not statistically significant relationship between magnetic field exposure and levels of amyloid β in electric utility workers, and postulated that this might be the explanation of the relationship between magnetic field exposure and Alzheimer's disease. They further suggest that the hormone, melatonin, may have a role. Melatonin biosynthesis is

reduced by magnetic field exposure (89), and there is evidence that melatonin reduces the expression of amyloid β (95).

Amyotrophic lateral sclerosis (ALS), in which upper and lower motoneurons are lost, is another neurodegenerative disease. The relationship of ALS to EMF exposure is complex and somewhat uncertain at present. Ahlbom (96) published a review in which he pooled results from seven investigations of the relationship between EMF and ALS. For all seven studies, the RR = 1.5 (1.2–1.7), while for the three clinical and ALS society-based studies RR = 3.3 (1.7–6.7), for two mortality registry and census-based studies RR = 1.3 (1.1–1.6), and for two utility-based studies RR = 2.7 (1.4–5.0). Studies since this time have been mixed in results. Håkansson et al. (97) found an RR = 2.2 (1.0–4.7) in a study of over 700,000 Swedish engineering industry workers. In a study of almost 5 million Swedish residents, no relationship was found between EMF exposure and ALS (98), but an elevated risk of ALS was found among "electrical and electronics work" (RR = 1.4 (1.1–1.9)). This led the authors to suggest that the etiologic factor was related to electric shocks, not EMFs. A similar conclusion was made by Noonan et al. (99), who studied case-referent sets of male deaths in Colorado. ALS was significantly associated with employment in electrical occupations (OR = 2.30, 1.29–4.09), but not with magnetic field exposure, estimated by job–exposure matrix. Johansen (100) reported on 31,000 Danish utility employees and found a significant elevation in rates of motor neuron diseases (SIR = 1.89, 1.16–2.93), and also suggested that this may be secondary to electric shock rather than EMF. The study of Swiss railway employees (92) reported a nonsignificant elevated risk of ALS, but that from the Swiss National Cohort (93) did not detect any relationship. Thus, it remains unclear whether there is a significant elevation of ALS as a function of EMF exposure, or whether it is electrical shocks that increase risk by some unknown mechanism. It is interesting that no relation between EMF exposure has been seen with Parkinson's disease (92, 98, 101), another neurodegenerative disease.

While it is not a neurodegenerative disease, there is some evidence for a relationship between magnetic field exposure and risk of suicide. Ahlbom (96) has reviewed 11 publications that examined depression and suicide, and finds the results to be inconsistent albeit with some studies showing statistically significant elevations. Van Wijngaarden et al. (102), in a study not included in the Ahlbom (96) review, reported a case–control of suicide mortality in electric utility workers, and found statistically significant elevations in risk of suicide with years of employment as an electrician or lineman, and a dose–response gradient with exposure to magnetic fields (OR=1.70; 1.00–2.90). Further studies of possible associations between increased exposure to magnetic fields and depression are needed.

4.7 Effects of Power Line EMFs on Other Organ Systems

Many effects of EMFs on other organ system functions have been reported, although questions remain as to whether these are of major health concern and/or whether they occur at intensities commonly experienced by humans. Some of these are certainly real biologic effects that even have clinical utility, for example, the promotion of bone healing by applied electric and magnetic fields (103). All cells, but especially nerve and muscle, utilize electrical signals in normal physiology, and growth and regeneration are influenced by externally applied DC electric fields (104, 105). Migration of many species of animals is dependent upon their ability to detect the earth magnetic field through specific receptors (106), while other species use perturbations of magnetic field to detect and catch prey (107). The pineal gland, a structure that plays a central role in regulation of circadian rhythms through the hormone, melatonin, is affected by DC and possible 60 Hz magnetic fields (89). It has been suggested that magnetic fields may increase risk of breast cancer via alteration of melatonin rhythms (108). Various effects on the cardiovascular system have been reported, although it is unclear whether they constitute harm (109).

A number of effects on the nervous system have been reported, although most were at high-intensity field strength. Various groups have reported changes in brain neurotransmitters, including dopamine (110, 111), glutamate (112), and acetylcholine (113). It has long been known that application of magnetic fields stimulates release of calcium from brain tissue (114), but the physiologic significance is still unclear. Adverse effects of magnetic fields on rodent learning have been reported (115, 116), but these also were found only at field intensities considerably larger than usually found in the ambient environment.

5 SUMMARY OF HUMAN HEALTH EFFECTS COMING FROM POWER LINE FREQUENCY EMFs

Although EMFs have been demonstrated to cause a number of different biologic effects, the major concerns relevant to human health with power line frequency EMFs are cancer, especially leukemia, and the neurodegenerative diseases, especially Alzheimer's disease. The evidence of association of EMF exposure and leukemia is strong and consistent in almost every study of childhood leukemia and in the majority of studies of adult leukemia, in spite of poor exposure assessment. There remains some debate as to which component of the EMFs is responsible for the association, but even the most skeptical persons acknowledge the consistency of the association. From the point of view of public health, it does not really matter whether the cause is the aggregate magnetic field, electrical shocks, voltage transients, harmonics, or some other feature. There remains some concern that

animal models have not been found to develop leukemia, but this does not change the nature of the results of human studies. While the specific mechanism responsible is not known, several biologic effects that might be responsible have been identified.

6 HEALTH EFFECTS OF RF

6.1 Cancer and AM/FM Radio or Mobile Phone (Cell) Towers

Several studies have reported elevated rates of cancer among people living in close proximity to radio or television transmission towers, although others have not found such a relationship. Dolk et al. (117) reported a statistically significant elevation of adult leukemia that declined with distance from an FM and TV transmission facility. Michelozzi et al. (118) studied childhood and adult leukemia as a function of distance from Vatican Radio, and reported a significant elevation in mortality from leukemia in both adult males and children. Both decreased with distance from the transmitter. Park et al. (119) used Korean death certificates over the period of 1994–1995 and studied death rates in 10 RF-exposed areas, defined as AM radio towers of over 100 kW power, as compared to control areas. They found a significantly elevated all-cancers mortality in the exposed areas, with elevated mortality from leukemia especially elevated in children ages 0–14 years (MRR=2.29, 1.05–5.98) and in young adults aged 15–29 (MRR = 2.44, 1.07–5.24). Ha et al. (120) did a case–control study of Korean children with leukemia ($n = 1928$) or brain cancer ($n = 956$) using controls ($n = 3082$) with respiratory illnesses. They found OR = 2.15 (1.00–4.67) for all types of leukemia among children living within 2 km of the nearest AM radio transmitter compared to those living more than 20 km away, but no elevation in risk of brain cancer. However, Merzenich et al. (121) studied German children with leukemia ($n = 1959$) and 5848 controls and did not find any elevation in risk of leukemia among children living within 2 km of the nearest broadcast transmitter.

Further study of these possible relationships is necessary, particularly because the studies to date have only used distance from the broadcast tower as an exposure metric. Burch et al. (11) have found that many factors in addition to distance are important in determining what the RF exposure is inside a home. While the results to date are somewhat inconsistent, the fact that leukemia in both children and adults appears to be the cancer of greatest concern is important since this is also the cancer showing the most consistent elevations upon exposure to 50–60 Hz EMFs.

There has been little study of possible relations between residential proximity to mobile phone towers and cancer incidence beyond the report by Eger et al. (122), who reported a significant threefold excess in overall rates of new cancers among individuals who lived within 400 m of a mobile phone tower for 10 years or more, compared to those living further away (OR = 3.38; 99% CI = 1.05–10.91).

6.2 Electrical Hypersensitivity and Neurobehavioral Effects of EMFs

There are numerous reports of individuals who demonstrate a syndrome of ill health when they are in the presence of EMFs of various frequencies (especially RF), and this syndrome has been labeled "electromagnetic hypersensitivity." This subject has been reviewed by Seitz et al. (123) and Röösli (124). In spite of the fact that some 1.5–10% of the population in various countries report that they are electrosensitive, both reviews conclude that the evidence to date is insufficient to document that this is a real disorder. The symptoms reported include headache, fatigue, dizziness, numbness and tingling, sleep disturbances, concentration and memory problems, and loss of appetite. With the use of a mobile phone, some people report burning sensations on the skin and headaches (125). Several reports have indicated that these symptoms are more common among individuals living close to mobile phone towers (126–128).

While the symptoms are very disabling in some persons, most if not all attempts to demonstrate unusual sensitivity to RF-EMFs in a controlled setting have not been successful. Rubin et al. (129) reviewed 31 studies of electrosensitive subjects and found that in the great majority of studies these individuals could not distinguish the presence of fields in a double-blind provocation study. Similar conclusions have been drawn in recent studies (130, 131). However, other studies of sensitive individuals report elevated levels of arousal on exposure to some RF signals (132), as well as a reduced intracortical facilitation when measured by application of transcranial magnetic stimulation compared to controls (133). Dahmen et al. (134) performed a study to determine whether individuals reporting electrosensitivity showed differences from controls in various clinical tests. They found significant differences between levels of thyroid stimulating hormone and the liver enzymes, ALT/AST, between cases and controls, and suggested that thyroid, liver, and kidney dysfunction may characterize electrosensitive individuals. These results have not been confirmed.

There have also been studies of perceived well-being among individuals living close to mobile phone base stations, and these have been reviewed by Kundi and Hutter (135). While a few studies have shown elevated prevalence of neuropsychiatric complaints among residents living close to these base stations (128), most studies have not been able to either confirm or deny effects on well-being and performance (126, 136, 137). In an experimental study of 10 healthy young adults, Hung et al. (138) demonstrated a delay in sleep latency after exposure to pulse-modulated microwaves and suggest that this is a consequence of the ELF modulation frequency at 8 Hz.

Neurobehavioral studies have been done in both humans and animals after RF exposure. Barth et al. (139) performed a meta-analysis of human studies with GSM mobile phone exposures and concluded that there were small effects on both attention and working memory. Divan et al. (140) surveyed parents of over 13,000 Danish children, and after adjustment for potential confounders found an OR=1.80 (1.45–2.23) for more overall behavioral problems among children with both prenatal and postnatal exposure to mobile phones. There is some evidence that mobile phone RF exposure alters cerebral blood flow in humans (141) and has some effects on sleep EEG (142, 143). These effects on sleep may be secondary to RF-induced changes in melatonin levels (144). It is not clear, however, that these alterations are permanent or necessarily harmful. Experimental studies of spatial memory in mice, tested using the Morris water maze, has demonstrated deficits in spatial information after exposure to GSM 900 MHz radiation at SAR values ranging from 0.41 to 0.98 W/kg (145, 146).

6.3 Effects of RF EMF Exposure on Brain Structure and Function

Since microwave radiation generates heat, at certain intensities the brain is damaged because of the heat generated. Most national and international standards for mobile phone and other sources of microwave radiation are designed to protect against heat-caused damage. There are, however, a number of studies that report damage to the blood–brain barrier (BBB) or neuronal damage at intensities that are presumed not to cause significant heating.

Nittby et al. (147) have reviewed animal studies on the effects of RF and ELF fields on the BBB, and find that some demonstrate damage to the BBB at nonthermal intensities, whereas others do not. The inconsistent findings occur over a range of SAR values and over a range of frequencies. Permeability of the BBB to albumin and various dyes is clearly increased at intensity levels sufficient to cause a rise in brain temperature, and there is the possibility that the shape of the skull actually will focus the microwaves to cause a very localized heating. While there have been limited BBB studies on humans, Söderqvist et al. (148) have reported that the blood–cerebrospinal fluid barrier in humans shows increased permeability to transthyretin after use of either mobile or cordless phones.

Because humans are regularly subjected to magnetic resonance imaging (MRI) that includes a high-intensity static field, a radiofrequency field, and a time-varying magnetic field, there has been significant study of MRI exposures to blood–brain barrier permeability. Results of rodent studies have been inconsistent, with some research groups regularly reporting increases in BBB permeability whereas others find no effect. A similar lack of consistency is characteristic of studies of mobile phone frequency studies.

Morphologic studies of rodent brains after RF exposure also have resulted in inconsistent reports of damage. Sanford et al. (149) found that a 2 h exposure of young rats to GMS RF fields caused significant neuronal loss in several areas of brain after 50 days, and the degree of neuronal damage increased with SAR. Grafström et al. (150), from the same research group, exposed old rats to GSM-900 radiation for 55 weeks and did not find any histological changes.

6.4 Use of Mobile (Cell) Phones and Cancer

Perhaps the most pressing question today regarding possible health effects of EMFs is whether the use of a mobile phone increases risk of brain and other cancers. The use of mobile phones is a relatively recent practice, but has quickly become something that most people use whether they live in developed or developing countries. Many developing countries have given up on landlines, and mobile phones are the only means of communication. Among the younger generation, life without daily use of a mobile phone seems impossible. An added problem is that the mobile phone technology has changed rapidly, and therefore exposure metrics today are quite dissimilar from what they were only a few years ago. In addition the latency for development of brain tumors following environmental exposure is expected to be long, which along with the technological changes makes it difficult to determine what is the degree of risk of current mobile phone use.

There have been several meta-analyses on the subject of mobile phone use and development of various kinds of cancer. Kundi et al. (151) reported on nine studies from five countries, and found significant relative risks between 1.3 and 4.6, with the highest overall risk for acoustic neuroma and uveal melanoma, and with risk increasing with latency and duration of mobile phone use. Kundi (152) updated this review on the basis of 33 studies, most of which dealt with brain cancer. He reported combined OR = 1.5 (1.2–1.8) for glioma, 1.3 (0.95–1.9) for acoustic neuroma, and 1.1 (0.8–1.4) for meningioma, respectively. Hardell et al. (153) reviewed 10 studies of glioma and determined that the use for a period of 10 years or more resulted in an OR = 2.0 (1.2–3.4) for ipsilateral use, but OR = 1.1 (0.6–2.0) for contralateral use. For nine studies of acoustic neuroma, they found OR = 2.4 (1.1–5.3) for ipsilateral use and OR = 1.2 (0.7–2.2) for contralateral use of 10 years or more. Results for seven studies of meningioma did not show any significant elevations in the risk. Khurana et al. (154) reviewed publications in peer-reviewed journals that reported effects of mobile phone use for 10 or more years and concluded that the use of a mobile phone for 10 or more years approximately doubles the risk of being diagnosed with an ipsilateral glioma or acoustic neuroma, but not meningioma. Myung et al. (155) performed another meta-analysis of 23 case–control studies. They found no overall relationship between mobile phone use and brain tumor risk, but found that in 15 of the 23 studies there was no

blinding. In the 13 studies where there was blinding, there was a significant elevation in the risk of tumors with 10 or more years of use of a mobile phone (OR = 1.18; 1.04–1.34). Therefore, there is relative consistency among these various meta-analyses in indicating elevated risk of gliomas and acoustic neuromas ipsilateral to mobile phone use but only after a latency of 10 years or more.

The long-awaited INTERPHONE Study (156) has not answered many of the questions regarding mobile phone use and brain cancer (157). While this is a large (2765 glioma cases, 2425 meningioma cases, and 7658 controls) study conducted in 13 countries, it led to the surprising result that ever use of a mobile phone gave ORs significantly less than 1.0 for both glioma and meningioma. This observation seems unlikely to be real, and may imply a bias in the study design. There was, however, an elevation in ORs with long-term (>10 years) use, more striking for glioma than for meningioma and more pronounced on the ipsilateral than contralateral side of the head. While this study has some results that appear to be problematic, the overall results are not inconsistent with previous reports. If as expected the lower ORs with short-term use reflect a flaw in the study design, it is possible, and indeed likely, that the elevated ORs with long-term use are underestimations of the actual risk. However, the concern that there were major flaws in the study design reduces confidence in the results. Nonetheless, the evidence from the INTERPHONE Study and other research on the possible relationship between mobile phone use and brain cancer led to a World Health Organization expert panel to recommend that mobile phones be rated as "possibly carcinogenic to humans" in May, 2011. While the mechanisms resulting in cancer are still not known, a 2011 report from the National Institutes of Health (157a) showing increased glucose metabolism in the brains of healthy volunteers exposed to muted mobile phone radiation convincingly disproves the assertions of skeptics that radiofrequency radiation cannot have biologic effects on the human brain.

Other results suggest that the problem of brain tumors may become more serious in the future. Hardell and Carlberg (158) examined risk of brain tumors as a function of the age at which a person began to use a mobile phone. For ipsilateral risk of a grade I–IV astrocytoma, they report a significantly increased risk even after 1 year of use (OR = 2.0; 1.5–2.5) among 663 cases and 2162 controls. The OR increased with 10 or more years of use (OR = 3.3; 2.0–5.4). If a person began the use under the age of 20 years, the OR for more than 1 year of use was OR = 7.8 (2.3–22), between the ages of 20–40, OR = 2.1 (1.5–2.9), whereas between 50–80 years, OR = 1.8 (1.3–2.5). This suggests that the younger brain is considerably more vulnerable to RF radiation. Moreover, they also found that cordless phones, which have not been studied in most other reports of RF exposure, were equally associated with elevated risk of astrocytomas as were mobile phones. Thus, the total population of exposed persons is considerably greater than just mobile phone users, even when not considering exposure to RF from mobile phone base stations.

There are at least two reasons that may explain a greater vulnerability of children to brain tumors from mobile phone use. Figure 100.4 shows the penetration of RF radiation into the model of heads of a child at two ages and an adult (159). Because the skull is thinner in a child and the brain is smaller, the RF penetrates further. In addition, there is a large body of evidence that children are generally more vulnerable to a variety of environmental exposures than adults due to the fact that their organs are growing and their metabolism is greater (160). Children are known to be more at risk than adults of development of cancer secondary to exposure to ionizing radiation (161), for example.

If the use of mobile phones results in elevated risks of glioma and acoustic neuroma, one might expect to see the incidence of these cancers increasing significantly over time. Data from Scandinavia has not shown any significant change over the period of 1998–2003 (162). But since the latency between exposure and development of diseases like brain cancer is usually believed to be 10–30 years, it may be that the use of mobile phones has not been sufficiently common for a period of time long enough for a change in overall rate to be apparent. There continues to be an increase in the incidence of childhood cancer in the United States, however (Figure 100.5) (163). The two major cancers of childhood are leukemia and brain cancer, the cancers most related to EMF exposure.

Other cancers have not been as well studied. Sadetzki et al. (164) reported elevated risk of benign and malignant parotid gland tumors with ipsilateral mobile phone use among frequent users (OR = 1.58; 1.11–2.24). No evidence has been found for elevated risk of pituitary tumors (165), non-Hodgkin lymphoma (166), or testicular cancer (167). Early reports suggest an elevated incidence of female breast cancer among Norwegian radio and telegraph operators (168), but there has been little more recent study of a possible relationship with RF fields. Eger et al. (122) report elevations in rates of breast cancer in German residents living within 400 m of a mobile phone tower.

There has been considerable discussion concerning possible sources of bias in these studies of mobile phone use and cancer. Exposure assessment is weak in almost all studies to date, usually dependent on self-reported use of a mobile phone in the distant past or records of the individual who owns the mobile phone. There have been two reports coming from the INTERPHONE group that examined recall bias (169) and selection bias (170). They conclude that while recall errors are large, there is little evidence for differential recall bias that would alter results. With regard to selection bias, refusal to participate appeared to be related to less use of a mobile phone, which could in fact result in a downward bias of about 10%.

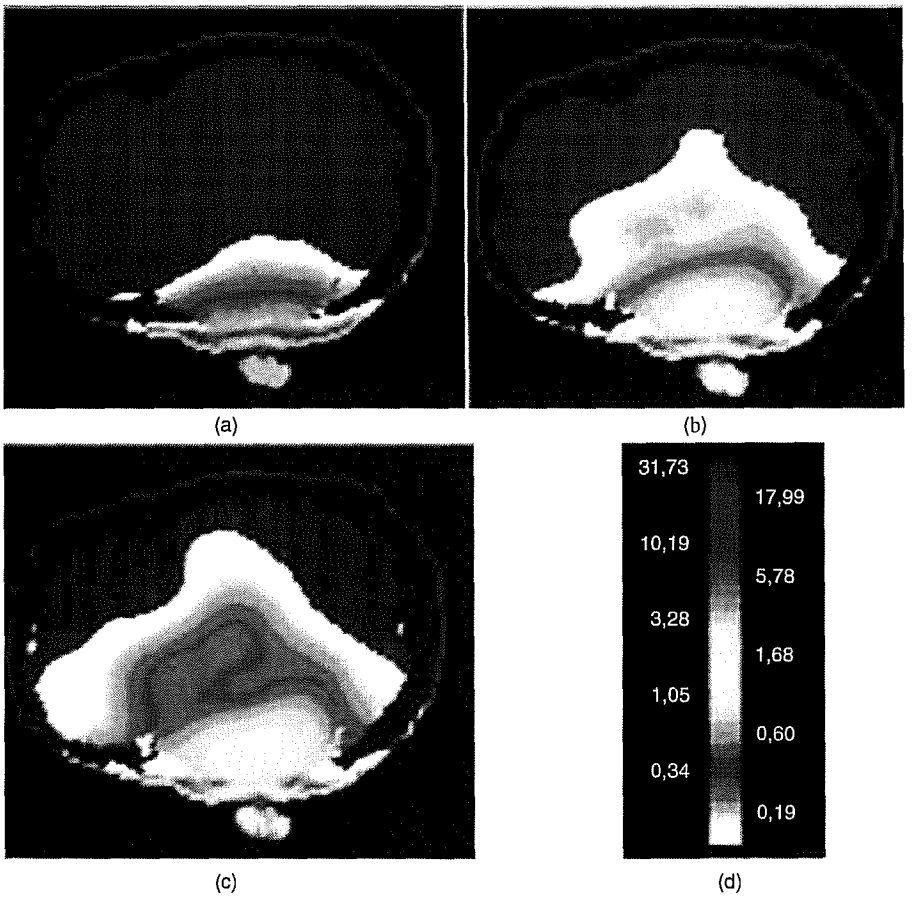

Figure 100.4. The SAR distributions for layer no. 34 for models of an adult male and 10 year and 5 year old children (a)–(c). (d) Scale in W/kg. This layer contains the feed point and is two cells lower than the cross-sectional plane passing through the top of the ear for each of the models. Frequency: 835 MHz; radiated power: 600 mW. Reproduced with permission from Ref. (159).

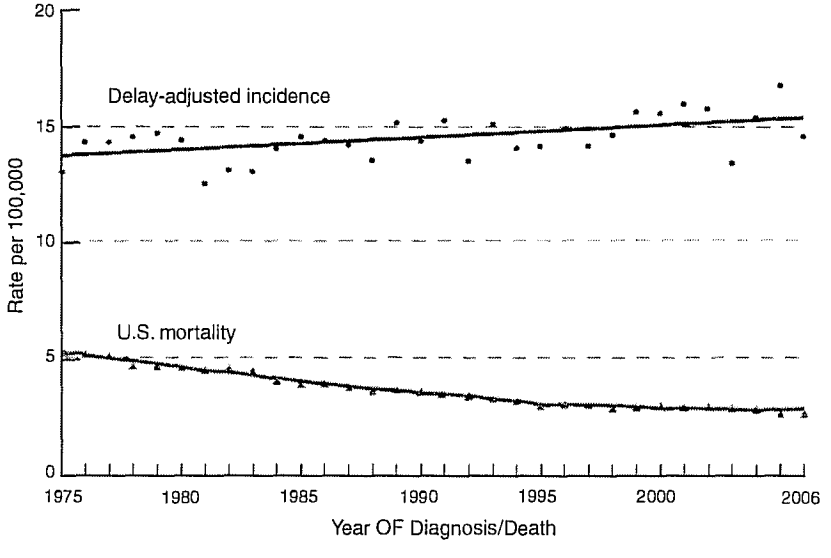

Figure 100.5. SEER Delay-adjusted incidence and U.S. mortality for all childhood cancers, under 20 years of age for both sexes and all races, 1975–2006 (Data from Ref. (163)).

7 ELF, RF, AND MOBILE PHONE USE AND DAMAGE TO SPERM

Baste et al. (171) investigated rates of 1 year infertility among 10,497 Norwegian Navy personnel in relation to self-reported frequency of work close of RF EMFs, and reported an OR = 1.86 (1.46–2.37) for infertility among men working close to high-frequency aerials compared to men who did not, after adjustment for exposure to organic solvents, welding, and lead. They also found a significant dose-dependent relationship for "high," "some," and "low" exposures. Wdowiak et al. (172) evaluated 304 men from an infertility clinic in Poland and found that regular use of a mobile phone was associated with a decrease in sperm motility, an observation confirmed in a study by Agarwal et al. (173) from the United States. These effects may be secondary to the practice of many men who wear their mobile phones on their belt, thus exposing their pelvis.

De Iuliis et al. (174) studied the effects of mobile phone radiation (1.8 GHz, SAR 0.4–27.5 W/kg) on isolated human spermatozoa. They found that RF-EMF exposure enhanced mitochondrial reactive oxygen species (ROS) generation and that the formation of ROS resulted in decreased motility and vitality of sperm.

There has been less study of ELF field effects on infertility, but Li et al. (175) reported a study of healthy sperm donors who were equipped with a meter for measurement of magnetic fields, 40–1000 Hz, for a period of 64–78 days. They found that men whose exposure was in the highest 90th percentile (<0.16 μT (1.6 mG)) showed a significant elevated risk of having poor sperm quality (OR = 2.0, 1.0–4.0) compared to men whose exposure was less than or equal to 0.16 μT (1.6 mG), after adjustment for season, age, education, and marital status. Furthermore, there was a significant test for tread based on the number of hours spent in magnetic fields greater than 0.16 μT (1.6 mG). While this is a single study, it suggests that 50/60 Hz fields have similar effects to those of RF fields.

8 MECHANISMS OF ACTION OF RF HEALTH EFFECTS

A major factor in the skepticism that the reported elevations in risk of cancer from both ELF and RF-EMF exposures are real arises from the perception that since there is not sufficient energy in this part of the electromagnetic spectrum to cause direct damage to DNA, EMF could not possible cause cancer. This attitude is based on the erroneous perception that all carcinogens are directly mutagenic. This is, in fact, very clearly not the case since only 54% of 149 carcinogen chemicals studied by the National Cancer Institute and National Toxicology Program were mutagenic, and 23% of mutagenic substances were not carcinogens (176).

DNA damage may, however, occur indirectly through generation of ROS, as demonstrated by Luukkonen et al. (177) and Campisi et al. (178) or by other mechanisms. Diem et al. (179) demonstrated nonthermal single- and double-strand DNA breakage in human fibroblasts and rat granulosa cells in response to 1800 MHz mobile phone radiation exposure (SAR 1.2 or 2 W/kg). Markovà et al. (180) and Belyaev et al. (181) have shown that nonthermal microwaves affect chromatin conformation and ability of DNA repair in human lymphocytes. Of special interest is the conclusion of Markovà et al. (180) that the damage was more dependent upon the carrier frequency than the GSM signal. Their most recent study (182) reports that DNA double-strand breaks and their misrepair is much more pronounced in mesenchymal stem cells than in fibroblasts.

Gene induction is a likely basis for EMF-induced cancers, although the literature is full of both negative (183, 184) and positive (185, 186) reports. This subject has been reviewed by McNamee and Chauhan (187). Zhao et al. (188) reported the gene expression profile of rat neurons exposed to 1800 MHz RF fields and found that of the 1200 candidate genes, 24 were upregulated and 10 downregulated by exposure. As is the case for ELF exposure, several studies have implicated heat shock proteins as the response triggers for other effects (189). Simkó et al. (190) reported elevated HSP70 expression after RF exposure of human Mono Mac 6 cells, associated with ROS release. Sanchez et al. (191) reported a 3–5 week delayed heat shock protein response of cultured keratinocytes.

Two recent studies have demonstrated altered protein synthesis in cultured human cells (192) and intact human skin (193). In the latter study, 10 volunteers were exposed to RF (SAR = 1.3 W/kg) and protein expression changes determined in skin punch biopsies. Eight proteins were identified that were affected significantly, 2 of which were present in all 10 individuals. The Gerner et al. (192) study looked at protein expression changes in three types of cells. While there was no altered expression with short-term RF exposure (2 W/kg of GSM 1800), after an 8 h exposure there was a significant increase in protein synthesis in Jurkat T cells, human fibroblasts, and activated human mononuclear cells, but not in quiescent mononuclear cells. Because the increase in temperature was less than 0.15°C, the authors interpret these changes to be nonthermal.

Blank and Goodman (194) have recently proposed a mechanism to explain how EMFs effect on DNA to initiate transcription. They suggest that EMFs displace electrons in DNA, which causes transient charging of small groups of base pairs. At charged sites disaggregation forces overcome H-bonds, and this enables transcription. They note that not every cell type responds to EMF, and the variability among cell types is clearly demonstrated in the studies described above by Gerner et al. (192). Blank and Goodman (194) suggest that this mechanism applies to both ELF and RF effects on gene induction.

9 INTERNATIONAL AND NATIONAL STANDARD OF EXPOSURE

Table 100.2 provides some international standards for magnetic field exposure at ELF frequencies, and also magnetic field standards for magnetic field exposures at the edge of right of ways on transmission lines for the only two U.S. states that have such values established. The level in New York State of 200 mG was determined in the 1980s by measurement of the magnetic field levels at various high-voltage power lines in the state and using the largest value measured as the new standard so as to assure that the situation would not get worse with construction of new power lines. Clearly, these standards were not based on any consideration of the evidence of adverse effects on human health. Most international organizations and states also have electric field limits, but these also are not based on human health considerations.

For RF exposures there is an assumption by the Institute of Electrical and Electronics Engineers (195), the American National Standards Institute (196), the National Council on Radiation Protection and Measurements (193), and the International Radiation Protection Association (IRPA), now known as the International Commission on Non-Ionizing Radiation Protection (197), that the threshold for potentially harmful effects is in the range of an SAR of 4 W/kg, an exposure that will result in measureable tissue heating. Building in a safety factor, this has led to a standard for "safe" exposure of 0.4 W/kg for occupational exposures and 0.08 W/kg for general public exposures (1). The exposure limit adapted by the Federal Communications Commission (FCC) in the United States is based entirely on the assumption that tissue heating is the only adverse effect of RF exposure (198).

Table 100.3 lists some standards for RF. More detail on the standards proposed by the International Commission on Non-Ionizing Radiation Protection can be found in their recent review (200). Figure 100.6 shows exposure standards by country for exposure from cell phone frequencies (201) and demonstrates how great the variability is among countries.

Table 100.2. ELF Magnetic Field Standards

International Commission on Non-Ionizing Radiation Protection (ICNIRP)	= 1000 mG
Institute of Electrical and Electronics Engineers (IEEE)	= 9040 mG
Australian Radiation Protection and Nuclear Safety Agency (ARPANSA)	= 3000 mG
UK Health Protection Agency	
Occupational	= 5000 mG
Public	= 1000 mG
State of Florida	500 kV Lines
	200 mG at the edge of ROW
	250 mG at edge of ROW for double circuit
	230 kV Lines
	150 mG at edge of ROW
State of New York	All High Voltage Powerlines
	200 mG at edge of ROW

Table 100.3. Some National and International RF Standards

Federal Communications Commission: SAR from wireless phones < or equal to 1.6 W/kg
583 μW/cm^2 at 875 MHz
1000 μW/cm^2 for 1800–1950 MHz

ICNIRP (for the general public) (199)

Frequency	Current density (head, trunk) (mA/m^2)	Whole-body SAR (W/kg)	Localized SAR (head and trunk) (W/kg)	Localized SAR (limbs) (W/kg)
Up to 1 Hz	8	–	–	–
1–4 Hz	8/f	–	–	–
4 Hz–1 kHz	2	–	–	–
1–100 kHz	f/500	–	–	–
100 kHz–10 MHz	f/500	0.08	2	4
10 MHz–10 GHz	–	0.08	2	4

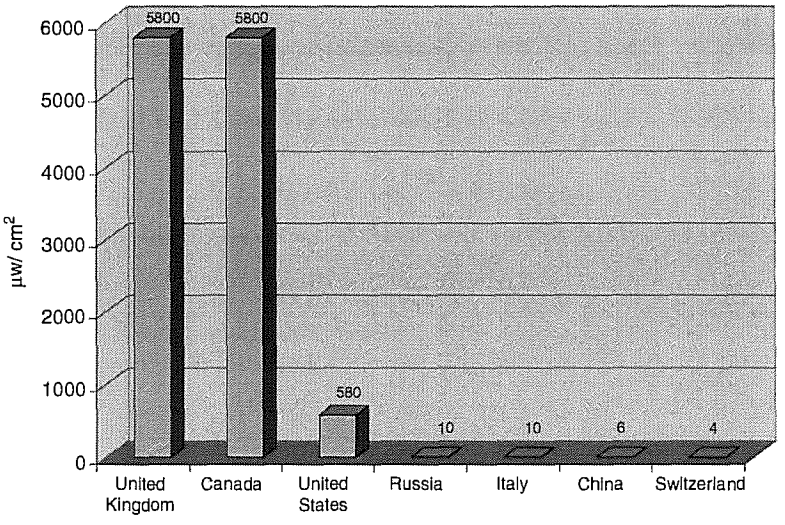

Figure 100.6. International exposure standards (µW/cm2) at cell phone frequencies (800–900 MHz). Modified from Ref. (201).

Unfortunately, international standards for exposure to ELF and RF EMFs are at present insufficient to protect the health of the public, based on the evidence of harm presented above. The existing standards for both ELF and RF appear to have no relationship to the documentation of adverse human health effects resulting from EMF exposures. These standards have been established primarily by engineers and physicists, and effectively ignore the evidence documenting adverse human health effects at EMF exposure levels that do not cause tissue heating. The evidence from human studies is dismissed primarily because of the lack of a reproducible animal model and a single documented mechanism of action, neither of which in this author's opinion is justified, based on the reasoning presented above. In the first place, there is no satisfactory animal model of leukemia (202) and as shown in Figure 100.3 animals do not respond to applied EMF fields as do humans. In the second place, we do not know a single mechanism for most kinds of cancer, and there is no reason why the lack of such a mechanism for EMF should be a reason to discount the direct evidence for human disease. The evidence of human harm from excessive exposure to both ELF and RF is strong and consistent for cancer. While there is poor reproducibility and consistency for some of the other proposed health outcomes, this indicates only the need for more research with better exposure assessment.

Standards that would prevent human disease have been proposed (202, 203). They are 0.1 µT (1 mG) for ELF and 0.1 µW/cm2 for RF. Because exposures at these levels are very common in the ambient environment, it is unrealistic to impose these at present as regulatory standards, but they are reasonable goals that can be accomplished by a combination of technological developments and behavioral changes. Certainly, more research is needed. However the evidence that excessive exposure to both power line frequency and RF increases risk of cancer is strong and consistent, and society ignores this evidence at its peril.

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