BEFORE THE STATE OF NEW YORK PUBLIC SERVICE COMMISSION

CASES 26529 AND 26559—Common Record Hearings on Health and Safety of 765 kV Transmission Lines.

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Q. Would you state your name and business address?

A. My name is Andrew A. Marino. My business address is the Veterans Administration Hospital, Irving Avenue, Syracuse, New York.

Q. Would you summarize your educational and professional background?

A. I received a bachelor's degree in physics from St. Joseph's College, Philadelphia, Pa., in June 1962. I received my master's and doctorate in physics from Syracuse University in 1965 and 1968 respectively. My field of specialization is biophysics. Since September 1964 I have been employed full time by the VA Hospital as a research biophysicist. Our laboratory is devoted to the study of the interaction of electricity and biological organisms. During the course of my employment, I have co-authored approximately 20 scientific publications I graduated from the College of Law of Syracuse University in May 1974, and was subsequently admitted to the practice of law in New York.

Q. Why are you testifying in this proceeding?

A. We were contacted by The PSC and were asked to examine the then current status of evidence in Case 26559 in the area of biological effects of electric and magnetic fields. Our review of the evidence submitted by the applicants on the issue of the possible biological effects of the proposed transmission lines indicated that it was less than adequate. For example, on the subject of electric field effects, the expert for the applicants testified that cows grazing under a transmission line were happily grazing, based on his observation that their tails were wagging. We therefore accepted the invitation of the PSC to testify in the present proceeding.

Q. What is the purpose of your testimony?

A. I will describe the biological effects of extremely low frequency (ELF) electric fields which have been reported in the literature. 1 will discuss the biological effects which we have observed in rats and mice at 60 hertz (Hz), On the basis of these results, I will propose a tentative safety level for chronic exposure to electric fields at 60 Hz of 1.5

volts/cm. On the basis of the research discussed above I will advise against construction of the transmission line as proposed.

Q. Would you describe any reports which deal with biological effects of very low frequency fields?

A. In 1968, McElhaney, Stalnaker and Bullard (1) reported the effect of electric fields of 3 Hz and 30 Hz on rat femurs. They placed insulated metal plates over and under the right leg bones of rats and held them in place by means of a plaster cast. Wires were brought out through the cast and connected to voltage sources. At each frequency an electric field of approximately 70 volts/cm was applied to the animal s leg in situ. The rats were given the electric field treatment for one hour every twelve hours for 28 days, after which they were sacrificed and the right and left femurs were removed and studied. The left femurs were not immobilized. Six sham immobilized rats, six rats exposed at 3 Hz, and five rats exposed at 30 Hz survived the experiment and were evaluated to determine the effect of the electric field. It was found that all five of the 30 Hz rats developed tumors (as did two of the six 3 Hz rats). No tumors were seen on the sham immobilized legs and none were seen on non-immobilized legs. Unfortunately, the nature of the reported tumors was not described and this point has not yet been resolved. Further, the data seemed to suggest that the electric field at 30 Hz lessened the osteoporotic effect of immobilization.

Also, in 1968, Hamer (2) showed that electric fields of 004 volts/cm at frequencies in the range of 2 to 12 Hz can effect human reaction time performance. Employing 27 human volunteers, each being tested at two frequencies in the range, he showed that the average period of time for the subjects to respond to an audio cue was shorter at the higher of the two frequencies. The result shows that not only does the presence of the weak electric field affect the human subject’s ability to organize a response to its environment, but also that this phenomenon is frequency sensitive. In work extending over twenty years, Konig (3) has found similar results in the 3–10 Hz range. He has described relationships between atmospheric and artificially produced ELF electric fields, and the reaction time of humans. In both cases, reaction time is inversely proportional to the frequency of the ELF electric field.

In 1971 a Soviet group described the effect 50 Hz electric fields of 200 volts/cm had on the rate of division of cells in the eye and the liver of mice(4). Prior to electric field exposure, 12 mice were injected with a substance which suspends the process of cell division after it has begun. Half the mice were then exposed to the electric field for four hours Following which all 12 mice were sacrificed. The percentage of cells in the liver and corneal epithelium of each mouse that were in the suspended state of division was determined. It was found that, on the average, there were three times as many suspended-state cells in the experimentals as in the controls. This indicates that the tissue from the exposed mice was three times more active than that of the control mice.

A recent demonstration of the effect of ELF fields on biological systems is the work of Bassett et al. (5). They attached circuits to the legs of dogs which had undergone fibular osteotomies (surgically performed bone fractures). The dogs were divided into two groups; 20 in the first, and 19 in the second. The first group were all exposed to pulses of I millisecond duration repeating at 1 Hz. This arrangement produced a peak field within the dogs of 0.002 volts/cm. The second group of dogs were exposed to pulses of 130 microseconds repeating at 65 Hz. This arrangement produced a peak field within the dogs of 0.020 volts/cm. The authors found a decidedly beneficial effect in the second group of exposed dogs. After 28 days of continuous exposure, the organization and strength. of the repair process in the fractures had increased significantly. That is, the 65 Hz circuit was found to augment bone repair. The biological effect described by Bassett et al. was produced by subjecting the animals to a time varying magnetic field, which in turn induced an electric field. That is, both fields were simultaneously present in the animals, and it is therefore not possible to state categorically that the effect was due solely to the electric field. Kruger et al. (6), exposed egg-laying hens to a maximum full-body electric field of 16 volts/cm at 60 Hz for 16 weeks. During the first and second four week period, egg production by the exposed hens was significantly lower than that of the controls. During the third and fourth four week period there were no significant differences. The results suggest that while the long-term (greater than 16 weeks) egg laying capacity of the hens was not altered, some presently unknown physical process resulted in a decrease in production over the short term (less than 8 weeks). Earlier work by the same group suggested that continuous exposure for 28 days to 35 volts/cm electric fields at 45 Hz and 60 Hz depressed the growth rate of one day old chicks by about 5% (7).

The effect of 60 Hz electric fields on regeneration in *Dugesia* was studied by Marsh (8). *Dugesia* (flatworms) possess differentiated anterior (head) and posterior (tail) ends. If the animal is cut into three roughly equal segments, the middle segment has the intrinsic ability to regenerate a new head at the anterior surface, and a new tail at the posterior surface. Marsh found that this normal regeneration pattern (head anterior, tail posterior) was altered by 60 Hz electric fields of 3.1 to 4.2 volts/cm. In a significant number of the animals exposed, biopolarity was produced. That is, the animal regenerated a head at both the anterior and posterior surface. Bipolarity can be produced in flatworms by a variety of chemical and mechanical techniques. The phenomenon per se is therefore of little interest for our present purposes. It is significant, however, that bipolarity can be caused by an ELF electric field, thereby indicating that such fields can be biologically active.

Gann and LaFrance (9) exposed mammalian cells in culture to electric fields at 60 Hz. They found that at 2000 volts/cm, there was no observable effect on cell morphology or regeneration rate. At 6000 volts/cm however, all cells died within one week after exposure was initiated. The possibility that the observed lethal effect was due to artifacts such as corona, ozone or toxic contaminants was excluded. The observation substantiate the thesis that ELF electric fields can cause biological effects.

Friend, Finch and Schwan (10) studied the effect of electric fields of various frequencies and strengths on the shape of amoebas. They found at field strengths of less than 10 volts/cm, amoebas exposed in the range of 1 Hz to 100 Hz extended pseudopodia perpendicularly to the field and exhibited other visible changes. When the field was removed, the amoebas resumed their normal shape. These effects could be repeated many times without apparent damage to the amoebas. At higher electric fields, cell damage was observed. There are two ways to explain the observed effects. One approach would focus on the physical forces involved, and would describe the effects in terms of passive cell properties such as dielectric constant and conductivity. Cell function that is, the fact that the cell is alive—would not be regarded as primarily significant. A second approach invokes the biological nature of the object being studied. The cell would be regarded as sensing the imposed electric field and subsequently adapting in such a manner that its ability to tolerate the field is optimized. The authors gave a heuristic argu ment in support at the first approach and concluded that dielectric forces may be important in the production of the observed effects. It remains equally possible however, that the living nature of the organism studied played some role in the observed effects, particularly at the lower field strengths. In this event, the work of Friend et al. would be supportive of the thesis that low frequency electric fields can cause a biological (as opposed to a purely physical) effect in amoebas.

Watson, De Haas, and Hauser (11) studied the effect of electric fields on the growth rate of embryonic chick tibiae *in vitro*. They concluded that there is present in the embryonic bone a transducer mechanism which allows the electric field to interact directly and modify the growth rate. The authors removed the tibiae (leg bones) of 8–9 day old embryos and placed them in plastic dishes containing suitable growth media. It is well known that in such a system the tibiae will continue to develop for a certain period, much as they would have developed if left in the undisturbed embryo. From each embryo, one tibia was allowed to grow and develop in culture as a control. The dish containing the matched tibia was subjected to an electric field of 1000 volts/cm which varied as a square wave with a 1:10 mark-space ratio at a rep rate of 1 Hz. The increase in length of each tibia after 9 days in culture was measured. After studying 41 matched pairs of tibiae, it was found that the increase in length of the experimental tibiae exceeded that of the control tibiae by an average of 12%. The authors found no macroscopic or microscopic pathologies in the tibiae studied. The motivation for this work, and other similar work, is discussed subsequently in my testimony. Regardless of the theoretical framework which one may choose in an attempt to understand the mechanisms involved, it is clear that the work shows at a low frequency electric field can alter the growth of chick tibiae in culture, that is, can cause a biological effect.

Prompted by considerations of occupational safety, Blanchi et al. (12), investigated the biological affects of electric fields. They found cardiovascular effects in mice and rats subjected to an electric field of 1000 volts/cm at 50 Hz. Twelve experimental mice were housed in plastic cages maintained between metal electrodes. They were chronically exposed to an electric field (9 hours on, 3 hours off) for a total exposure of 1000 hours. A parallel group of control animals was maintained under identical conditions except for the absence of the impressed field. After 1000 hours of exposure it was found that the normal distribution of white blood cells has been altered in the experimental mice. The percentages of neutrophils and eosiniphils in the exposed mice showed average increases of 99% and 44% respectively in comparison with the controls while the lymphocytes decreased by 17%. Analogous changes in the white blood cell distribution were observed in rats which were subjected to an acute exposure et 6 hours. In this case, the proportions off white blood cell types usually came back to normal about a week after the field was removed. The authors took electrocardiograms (EKG) on all the experimental and control mice, and found that after 1000 hours of exposure, those of the exposed mice were significantly altered. In particular, on the average there was a lengthening of PR interval (19.5%), R wave s duration (23%), and of QRS complex duration (19.5%). The authors also described some qualitative changes in the brain electrical activity (EEG) of guinea pigs following exposure to the electric field, but gave no statistical date to support their observations.

Lott and McCain (13) conducted a study to determine if a mammal, the rat, was aware of changes in its external electric field, and also to determine if the posterior hypothalamus was specifically electrosensitive. To record hypothalmic activity, microelectrodes were stereotaxically implanted in the posterior hypothalmus of one group of rats. Scalp electrodes were applied to a second group to record the EEG. The rats were anesthetized and subjected to a pulsed inhomogeneous electric field of 0.4 volts/cm maximum, 640 Hz. Total brain activity was measured for each rat before, during, and after field exposure with a total measuring time of about 90 minutes. The average (9 rats) brain activity recorded from the scalp electrodes showed a marginal increase when the electric field was applied, and returned to control levels upon cessation of exposure. The average (9 rats) hypothalmic activity showed a significant and sustained increase during the exposure period. Again, recovery occurred when the field was removed. No significant changes were observed in the respiration, temperature, or EKG in any of The animals. The possibility that the observed effects were due to the induction artifacts was ruled out. It was concluded that the electric field altered the brain activity, indicating that rats are aware of changes in their external electric field. It should be noted that the changes in brain activity described above occurred immediately upon exposure to the electric field, and were observed in anesthetized animals. In the anesthetized state, brain activity is depressed and is therefore less likely to be affected by external factors.

Warnke studied the effect of 50 Hz electric fields on the behavior of bees (14). Bee hives were placed on grounded metal plates, and slightly above the hive a cable was strung and connected to a high voltage generator. Employing a total of nine hives, Warnke found that the electric field caused grossly abnormal behavior in the bees. At 110 volts/cm, the bees exhibited great restlessness as recorded by temperature change. The bees on the hive or on the metal plate exhibited a characteristic pose in which the wings were spread, and the flying bees exhibited abrupt movements. The degree of defense of social territory was abnormally increased, and some bees, including the queen bee, were herded together and stung to death. Honey and pollen was no longer stored, and cells which were already filled with honey were emptied. Hives which had been established a short time prior to initiation of field exposure were abandoned a few days after exposure was begun. When the experimenter prevented the queen bee from leaving the hive, the swarm departed without her. In hives which had been well established prior to the initiation of field exposure, all apertures were closed off by the bees, resulting in death of the entire swarm due to lack of oxygen.

Spittka et al. (15) studied the effect of electric fields (50 Hz, 500–700 volts/cm) on the drinking behavior of trained rats in a series of three experiments which involved a total of 35 rats. Each time a rat pressed a lever a drop of water was released. The rate of pressing and the total number of times the lever was pressed were measured. The authors found that on the average there was a significant decrease in the lever pressing rate when the electric field was turned on. They concluded that their study proved that the 50 Hz electric field does affect rats, although the specific mechanism of action remains unknown. A subsequent study by the same group (16) showed that if given a choice between a region in which there exists a 50 Hz, 500 volt/cm electric field, and a region in which that field is absent, the rats prefer the field-free region. A similar phenomenon was observed by Altman (17) in mice at much lower field strengths. In longer term experiments, it was also reported that the pattern of locomotor activity of rats is affected by the electric field (16).

Q. Are there any reports of ELF fields causing cancer or causing death?

A. There are no reports linking ELF electric fields and cancer, however there is a Soviet report which described the exposure of mice and insects to very high electric fields (5000 volts/cm) at the Soviet power frequency of 50 Hz (18). The mice and insects died after several hours of such exposure. The authors took pains to point out that the lethal effect was no due to artifacts such as ionization, corona, or spark discharge.

Q. What do you conclude on the basis of the reports described above (1–18)?

A. I conclude that ELF electric fields can affect biological systems. That is, the older view that such an interaction is impossible, or that it has nor been shown to occur, is incorrect. This conclusion is significant for the following reason. Power lines have heretofore been designed under the assumption that their electric fields could have no such biological impact. If ELF fields can affect biological systems, then a detailed inquiry into the nature and extent of such effects, as are likely to be associated with the particular transmission system design, must be initiated, and the results thereof must be taken into account here at the design stage of the power line.

Q. Granted that ELF electric fields can influence biological systems, will the electric fields of the proposed transmission lines cause such effects?

A. The short answer is in my opinion, probably yes. Before discussing this point however, I would like continue to describe the reports dealing with the reported biological effects of ELF electric fields. I will now describe a series of reports related to the proposed Naval communications system known as Project Sanguine. As proposed several years ago, Project Sanguine envisioned a large buried antenna which would operate continuously in the 45–75 Hz range. The maximum electric and magnetic fields (at ground level over the antenna) were to be 0.0007 volts/cm and 0.13–0.20 gauss respectively (33). To facilitate its study of the possible environmental impacts to the proposed system, the Navy contracted for a number of studies involving the effect of Sanguine strength fields on various biological systems. Subsequently, most of the scientific studies performed under contract have found biological effects due to either the electric field, or to both electric and magnetic fields in concert.

Goodman, Marron and Greebebaum (19) examined the effects on Physarum polycephalum (slime mould) of phased, crossed electric and magnetic fields at 45 Hz, 60 Hz and 75 Hz. The field strengths employed were 0.007 volts/cm and 2.0 gauss. At all three frequencies the authors observed delays in the mitotic cycle of the slime mould, and retardation in protoplasmic streaming.

Physarum polycephalum may be maintained indefinitely in shake-flask cultures as separate microscopic organisms (microplasmodia). Stationary macroplasmodia are obtained by allowing an aliquot of the microplasmodia to coalesce on a suitable substrate, if growth media is then added, the stationary culture undergoes naturally synchronous mitoses. That is, the entire culture of about a thousand million nuclei simultaneously undergoes mitoses, permitting accurate observation of cycle timing. Experimental shake-flask cultures were exposed to the fields for more than 600 days. Control cultures, identical in all respects except for the absence of the fields, were also maintained. Periodically, aliquots were withdrawn from the experimental and control cultures to produce stationary macroplasmodia. *Physarum* undergo three mitoses in the twenty-four hour period following the addition of the growth media, and the time required to reach metaphase of the second mitotic division was measured for each macroplasmodia. After a culture had been in the 60 Hz fields for 80–100 days, a significant mitotic delay became evident. The same effect took 100–120 days in the 75 Hz fields and 14 days in the 45 Hz fields, The induced delays which ranged from 0.5 to 2 hours were found to be reversible, and vanished 30–60 days after the experimental cultures were removed from the fields. No delays were seen in cultures exposed to fields five times weaker than those described above. Coincidental with, and at 75 Hz prior to, the appearance of the mitotic delay, there appears an increase in the shuttle streaming period of 7–17%, depending on the particular frequency. The mitotic delay and the retardation of shuttle streaming therefore indicate that the applied fields cause a slow down in the metabolism of Physarum, the significance of which is presently unknown. Recently, similar effects have been observed at 75 Hz with only the electric field present. The authors conclude the ELF fields can influence biological systems.

Southern (20) studied the effect of electric and magnetic fields (0.5 gauss, 0.002 volts/cm, 45–76 Hz) on the orientation of 3–9 day old ring-billed gull chicks. Cages were centered on the ground directly over the buried antenna which produced the fields. A gull chick was released in the center of the cage by means of a rope and pulley arrangement operated by observers concealed behind blinds. A trial was terminated when either the bird had reached the edge of the cage or 2 minutes had elapsed. Each individual chick was used in only one trial. It was found that in 255 trials under control conditions (antenna turned off) the gull chicks showed a directional preference for the southeast. In 642 trials with the antenna energized, it was found that the birds dispersed randomly within the cage (no mean bearing). Southern concluded that the fields employed were sufficient to disrupt orientation.

Graue (21)conducted pilot studies to determine whether the Sanguine fields at the Wisconsin Test Facility could affect the orientation of homing pigeons. He found that headings, while the pigeons were in the vicinity of the antenna, were slightly altered.

Durfee et al. (22), studied the influence of electric fields (60–75 Hz 0.01 36 volts/cm) upon hatchability and early development of chicks, and upon the in vitro growth rate of chick embryo cells (60–75 Hz, 0.01–0.10 volts/cm). No significant effects were seen in the former study, however in the latter study, growth inhibition and growth acceleration were both seen, depending on the particular field strength and frequency employed. McCleave et al. (23), studied the effect on fish of extremely weak electric fields in the range of 0.0007 to 0.000007 volts/cm at 60 Hz and 75 Hz. They found that the American eel and probably the Atlantic salmon are sensitive to such fields when they are applied perpendicularly to the fish body axis. The authors employed the method of classically conditioned cardiac deceleration (an accepted technique in fish sensory perception studies). Electrodes which permitted continuous recordings of heart activity were implanted in each fish. The fish were gently constrained within a water tank and were presented with the ELF electric field (conditioned stimulus) for two or three consecutive heart beats, followed by a momentary shock (unconditioned stimulus) The change in heart rate following application of the ELF electric field was measured. In the range of 0.O007 to 0.00007 volts/cm, it was found that 24% of the 70 fish studied showed conditioned cardiac deceleration (slowed heart beat rate) to the perpendicular ELF electric field. No effect was seen in 10 fish subjected to an electric field of 0.000007 volts/cm or in 23 fish subjected to a parallel ELF electric field in the range of 0.0007 to 0.000007 volts/cm. Even though the ELF electric field could be perceived by the fish studied, it was found that the field did not affect their normal behavior. That is, there was no change in total activity during periods of application of the ELF electric field, nor in the pattern of such activity.

Perhaps the most significant aspect of the report described above is that it demonstrates the remarkable sensitivity to ELF electric fields which can be exhibited by some biological organisms Gavalas-Medici and Magdaleno (24) exposed trained monkeys to a variety of electric fields (7–75 Hz, 0.0035–0.35 volts/cm). They found shortened interresponse times throughout the frequency range, with the effect occurring as low as 0.035 volts/cm at 7 Hz. At 0.2 volts/cm, both 7 Hz and 75 Hz electric fields produced large and statistically significant reductions in interresponse times. At 60 Hz, the effect was of borderline significance (P<0.1). Since the difference observed however was in the same direction as those observed at other frequencies, the authors concluded that this observation indicates that the threshold for the effect at 60 Hz is higher (*but very little higher*) than the maximum level employed in the study (0.35 volts/cm).

In another Sanguine related study, Riesen et al. (25), studied the effect of 60 Hz electric fields on mitochondria from brain and liver cells. The ability of the subcellular organelles to function biochemically in the presence of the electric field was measured. It was found that an electric field of 1.55 volts/cm caused complete loss of biochemical function in brain mitochondria after 40 minutes. At 0.063 volts/cm, normal biochemical function remained in liver and brain mitochondria after 60 minutes of exposure.

I would now like to describe the work of the German scientists (26, 27, 28) who have studied the biological effect of excluding the normal atmospheric electric fields, and the effect of simulating such fields via the addition of an ELF electric field of 10 Hz. All measurable human and animal biological variables exhibit daily periodicities. For instance such variables as activity, body temperature potassium excretion, and ability to estimate time exhibit daily maxima and minima which are intimately related to the change between day and night. These changes are called biological rhythms, and they are synchronized to one another and to the 24 hour period of the natural environment. Biological rhythms have been tested under conditions artificially held constant without any environmental time cues such as the light/dark cycle. It was found that the rhythms persisted but with a period slightly different from 24 hours. This slight deviation of the period from the duration or one day when measured under constant conditions has led to the name circadian rhythms. For the past decade, Wever (26) has devoted himself to the study of which parameters of circadian rhythms, if any, are influenced by electromagnetic fields. Wever has studied circadian rhythms in man using an elaborately constructed underground bunker which provided complete isolation from all environmental time cues. One of the two experimental suites in the bunker was shielded against all electric and magnetic fields of terrestrial or atmospheric origin. In addition, the room contained built-in facilities for introducing a range of artificial fields. In the second experimental suite, the earth’s natural fields were continuously present. The rooms were built in such a way that the subjects could not distinguish between them. Human subjects were isolated in the bunker for three to eight weeks, and their circadian rhythms such as activity and body temperature were recorded. Wever found that 34 subjects who lived in the non-shielded room had a body temperature rhythm with a mean period of 24.87–0.44 hours while 50 subjects who lived in the shielded room had a body temperature rhythm of 25.26–0.85 hours. The difference was statistically significant at $P<0.01$. Thus, the total of the natural electromagnetic fields had a significant effect on human circadian rhythms, namely it shortened their period. Another, possibly more important effect of these fields was also observed. In 15 subjects who lived in the shielded room, internal desynchronization occurred. That is, while the body temperature rhythm continued to maintain a circadian rhythm near 25 hours, the period of the activity rhythm changed its value remarkably, sometimes lengthening and then sometimes shortening. Thus, the normal synchronization between the rhythms was destroyed. Internal desynchronization was not observed in the non-shielded room in which the natural fields of the earth were present. Thus Wever showed that the natural electromagnetic fields of the earth influence the interaction between the activity rhythm and the body temperature rhythm.

Having shown that the total of the earth s electromagnetic fields have a significant effect on human circadian rhythms, Wever next studied the question of which component or these fields caused the effect. In 10 subjects an artificial electric field (10 Hz, 0.025 volts/cm) was switched and off in changing temporal sequence. No subject knew when he was being exposed to the field, and each subject acted as his own control. Wever found that the presence of the artificial electric field reversed the effects found previously. That is, with the field present, the 10 subjects showed lower values of the period of the body temperature rhythm, and in no case did internal desynchronization occur when the electric field was switched on. Moreover, when the field was switched on with the subject in a state of internal desynchronization, the desynchronization was stopped. Wever concluded that the artificial electric field on one hand, and the total of the natural electromagnetic fields on the other, influence human circadian rhythms similarly in each respect investigated. He interpreted his results as indicating that the natural electromagnetic fields can affect human beings, and, that artificial electric fields of 10 Hz, 0.025 volts/cm, can influence human circadian rhythms.

Wever's equipment does not permit study of the high intensity electric fields such as are associated with transmission lines. Moreover his technique of measuring subtle changes in human rhythms has the great disadvantage of allowing only about 8 experiments per year. Thus, many interesting and relevant questions such as the existence of a threshold, the effect of increasing intensity, and the effect of frequency are likely to remain unanswered for the foreseeable future.

Altman and Soltau (27) studied the effect of electric fields on the blood of guinea pigs. Animals were exposed under ambient conditions (the normal ambient atmospheric electric fields), Faraday conditions (the absence of normal ambient atmospheric electric fields), or to an artificially imposed 10 Hz electric field of 2.4 volts/cm. When the animals were shielded from all atmospheric electric fields, statistically significant changes were seen in the hematocrit and in the distribution of blood proteins as compared to the animals exposed under normal conditions after 13 days. When the Faraday caged animals were subjected to the artificial electric field, the parameters measured returned to normal. That is, the artificial electric field created a physiological response identical to that associated with the normal conditions. Thus, both Altman (27) and Wever (26) have shown by entirely different methods that the absence of atmospheric electric fields causes a measurable biological effect, and that the effect can be eliminated via the addition of an ELF electric field. This phenomenon has also been described by Lang (28), who found that when mice were maintained under Faraday conditions, their body water content became elevated after 14 days, and remained elevated at 35 days into the experimental period. At 56 days into the experimental period the difference was not significant. Blood hemoglobin and blood sodium, as measured in the pooled blood, followed a similar time sequence. All effects were eliminated by the application of a 10 Hz electric field of 35 volts/cm.

Moos (29) exposed mice to an average field of 10 volts/cm at 60 Hz and studied the effect on their activity. The data appears to show that the mice were more active when the field was turned on, and the author stated that no definite conclusions were possible but that it appears that a trend had been established.

Knickerbocker et al. (30), exposed mice intermittently to an ELF electric field (1600 volts/cm, 60 Hz) over a 10½ month period, and studied them both at the gross and histological level over several generations. The results of the study were largely negative, except that the male progenies of the exposed mice were slightly smaller in weight.

Q. In your own research have you studied the effect of electric fields on biological systems?

A. Yes.

Q. What is the purpose of your electric field research?

A. The basic purpose of our laboratory is to elucidate the physical basis by which a biological organism controls its growth processes. The ultimate aim is to restore the ability to regenerate limbs in those species, such as man, which have lost that capability during the course of evolution. We believe that electrical factors are crucial in growth phenomena. Many publications have emanated from our laboratory on this subject. In one such publication, the ability of electric currents to grow bone in dogs was described (34). This experiment has since been repeated by others and it is now possible to grow bones in humans. When the results are analyzed in detail however, it is impossible to determine whether the effects are due to the actual current that flows, the electric field that causes the current, or whether the effects are related to chemical species that are created at the implanted metallic electrodes. Therefore the decision was made to design experiments to study each physical process separately. This was the motivation for our electric field experiments.

Q. Would you describe your electric field experiments?

A. I shall describe two studies. In the first study (31) comprised of ten experiments, 21–24 day old Sprague Dawley rats were exposed continuously to a 60 Hz electric field of 150 volts/cm for one month. A variety of biological effects were found including depressed body weights, serum corticoids, and water consumption. The observations have been tentatively interpreted to indicate that a power frequency electric field is a biological stressor.

In the second study (32), Ha/ICR mice were allowed to mate, gestate, deliver and rear their offspring for three successive generations while being continuously exposed to 60 Hz electric fields. Mice exposed to vertical electric fields exhibit decreased body weights at 35 days postpartum and increased mortality rates for three successive generations. Mice exposed to horizontal electric fields exhibit decreased body weights for two successive generations.

Q. Would you describe both studies in further detail?

A. Male Sprague-Dawley rats, 21–24 days old, were continuously exposed to a 60 Hz electric field for approximately one month. The field was nominally 150 rms.-volts/cm, and was applied across plastic cages with a variety of grounded metal tops as shown in

Figure 1 of Exhibit E-4 (AAM-1).*

All rats were purchased from commercial breeders. Except where noted, they were 1–2 days in transit and were held 1–2 days after arrival prior to initiation of field exposure. All rats placed on study were free of any recognizable diseases or defects. Occasionally, respiratory infections occurred during exposure and in such cases the animal was destroyed. All rats were maintained in a single room of a government accredited, standard (i.e., not pathogen free) animal care facility and were fed and water ad libitum. Environmental conditions were 23°C, 50% relative humidity, with a light/dark cycle of 12:12.

Following exposure, the rats were weighed and then sacrificed by decapitation. The serum was recovered and frozen until analyzed. In the first four experiments the experimental rats were housed in individual cages similar to that shown in Figure 1, and Type A cage tops were employed. Control rats were housed three per cage in larger cages with metal tops. In addition to final body we measured serum hydroxycorticosterone (corticoids) and serum proteins in the pooled sera of all rats within each of the experimental and control groups. In the remaining experiments every rat was caged individually, and vibration isolation pads were added. The pads reduced the electric field induced vibration in the vicinity of the cages from 2.5 x 10 cm/sec. to 1.0 x 10^{-3} cm/sec. (Normal background vibration was 2.8 x 10 cm/sec.) One of three types of cage tops was employed, depending on the particular experiment (Figure 1). The food and water consumed by every rat were measured as were the final body weights, and the final weights of the pituitary and adrenal glands. Serum corticoids were measured in sub-pools of 2–3 rats, and serum glutamic oxaloacetic transaminase (SGOT) was measured in the pooled sera of all rats within each group. Corticoids were measured fluorometrically and total proteins were measured by the Biuret method corrected for hemolysis. Percent albumin was determined by electrophoresis on cellulose acetate, with planimetric integration. SGOT was measured in a clinical laboratory by autoanalyzer.

In Experiment 1, the rats exposed to the electric field exhibited depressed body weights and altered concentrations of serum corticoids and albumin. In the first replicate study, (Experiment 2, Table 1), the exposed rats again showed depressed serum corticoids and elevated serum albumin , however the body weights were not significantly different (at 5%). In the second replicate study (Experiment 3, Table 1), results similar to Experiment 2 were observed. In the first three experiments, the experimental serum corticoids were depressed by a grand mean of 31.7%, with a standard error of 2.4%. The corresponding values for the increase in albumin were 28.2% and 9.1%. The data also suggested that the average body weight was lower in the experimental groups (by a grand mean of 6.6% with a standard error of 4.37%), but a 5% level of confidence within each experiment was achieved only in Experiment 1.

Experiment 4 was performed to determine whether the observed disturbances in the adrenal-pituitary system would prevent the exposed rats from responding to a known stress. As previously, the rats, were exposed for one month, and weighed. A lower average body weight in the exposed group ($P<0.05$) was observed. Immediately after weighing, the rats were subjected to a cold stress (−13°C for one hour), and sacrificed. The serum corticoids in both groups rose markedly (Table 1), indicating that the exposed rats remained capable of responding to a cold stress in the predictable fashion. In Experiment 5, after one month of electric field exposure, the experimental rats consumed less water, had enlarged pituitaries, and showed depressed levels of serum corticoids (Table 2). In Experiment 6, the experimental rats drank less water, exhibited depressed body weights, and showed enlarged adrenals and pituitaries.

In Experiment 7, the allotted period of acclimatization to the laboratory environmental conditions following arrival was increased to four days, after which time exposure was commenced. We found that water consumption was depressed as previously, but that the body and organ weights were normal. Similar results were observed in Experiment 8, wherein an acclimatization period of three days was provided.

In Experiments 9 and 10, we exposed rats obtained from a different source. The animals were purchased locally (shipment time, two hours), and acclimatized for three days prior to exposure.

In Experiment 9 we found the water consumed, pituitary weights, and serum corticoids were significantly different in the exposed rats In Experiment 10, food consumption was the only parameter significantly affected. Values of SGOT are shown in Table 2. The concentration in the experimental sera was marginally higher in some cases (Experiments 5, 7, and 9), and substantially higher in others (Experiments 6, 8, and 10).

The observed pattern of water consumption was consistent from experiment to experiment, and deserves some comment. In all experiments in which it was measured, the cumulative water consumed by the experimental and control groups, when compared statistically after 1, 3, showed no significant differences. In all cases (except Experiment 10), the comparison of water consumed during the last half of the exposure period showed significant differences, with the experimental group exhibiting depressed consumption. The differences remained significant (at 5%) even when the comparisons were extended to include the entire exposure period (Table 2). This data is considered particularly important in that it indicates that microcurrents produced in the rats during the act of drinking were not significant determiners of the experimental results. If either perceptible or subliminal microcurrents were significant factors, alterations in the drinking pattern of the experimental rats would have been apparent from the start of the experiment.

No specific effects were detected in the entire series of experiments that could be ascribed to the different types of field configuration produced by the three types of grounded cage tops. Questions concerning the relative effect of uniform versus non-uniform fields require further experimentation. Throughout these studies, which involved a total of 174 experimental rats and 199 control rats, an additional 11 experimental and 5 control rats died during the exposure period. In each of the 10 experiments one or more measured parameters were significantly different in the experimental animals compared to the control animals. In general, these results indicate that exposure to a 150 volts/cm 60 Hz electric field is productive of a physiological stress response. The physiological response has been shown to be not attributable to such secondary effects as the field induced mechanical vibration or the occurrence of microcurrents produced by drinking, and we conclude that the field itself is the responsible agent.

While there are apparent inconsistencies in the data, to the extent that the same measured parameters are not always statistically significant from one experiment to the next, there are no inconsistencies in the data that would mitigate against the general conclusion reached. It is generally agreed that stressors are additive when assayed by the physiological response. This phenomena has been manifested as the accentuation of a pre-existing, sub-clinical pathological condition by exposure to low frequency magnetic fields. In the present series of experiments, as in all animal experimentation other than that involving totally germ free animals in a rigidly controlled environment, the multitude of factors productive of minor stress responses are impossible to completely control. This is evidenced by the disparate results obtained in Experiments 9 and 10. In both experiments we attempted to mitigate the stressful effect of shipment from a distant supplier to the laboratory. The animals were purchased locally so that prolonged transit time was avoided and a period of several days acclimatization was afforded prior to the initiation of exposure. Despite these precautions Experiment 9 demonstrated measurable differences between experimental and control animals in three parameters, while in Experiment 10 only one parameter was so influenced. In a sense, this is an advantageous situation in that the circumstances of our experiments approximate much more closely the real world in which all organisms including man are continually subjected to some variable degree of stress, and our results are similarly transferable to this real world situation.

In addition to the microcurrents described above which occurred only during eating and drinking, the exposed rat continuously experienced induced currents because of the presence of the electric field. To establish the non-thermal nature of the effects described here, we measured the induced current in the rats and found that 0.68 ma/cm was induced at 150 volts/cm, with a corresponding current density of about 11.1 ma/cm. If we assume the rat to be a uniform mass with a resistivity of l00‰-cm, then the total power dissipated is about 2.3 x 10^{-12}; watts, which is obviously too low to produce heating. In conclusion, one month’s exposure to power frequency electric fields produced quantifiable biological changes in rats. The changes produced in at least some experiments were depressed water consumption, depressed body weight, increased adrenal and pituitary weights, and altered serum concentrations of albumin, hydroxycorticosterone, and SGOT. The observed changes are consistent with, but do not categorically establish, the hypothesis that a power frequency electric field is a biological stressor. To assess the potential hazards of such exposure, further work wherein larger groups of animals might be studied at different exposure times and at different field strengths appears desirable.

In the second study, mature male and female Ha/ICR mice were purchased commercially and split into horizontal, vertical, and control groups. Mice in the horizontal group were allowed to mate, gestate, deliver, and rear their offspring in a horizontal 60 Hz electric field of 100 volts/cm. At maturity, randomly selected individuals from the first generation were similarly allowed to mate, gestate, deliver and rear their offspring while being continuously exposed. Randomly selected individuals from the second generation were then mated to produce the third and final generation. A parallel procedure was followed for the vertical group wherein three generations were produced in the ambient electric field. Breeding was accomplished by allowing two females and one male to occupy a single cage. Pregnancy was determined by abdominal palpation. Pregnant females were placed in individual cages and remained with their offspring until weaning, at about three weeks after birth. The number of offspring in each litter was determined daily, beginning on the day of birth. After weaning, the mice were separated by sex and their body weights were measured periodically up to thirty-five days after birth, except in the case of the second generation which was weighed up to ten weeks postpartum. During the study, all mice were housed in a room having a temperature of 23°C, a relative humidity of 50% and a light-dark cycle of 12:12. Plastic cages (15 x 30 x 15 cm) with metal cage tops were employed, except for the horizontal group which had plastic cage tops. The mice had continuous access to water via a water bottle with a metal straw which protruded about 5 cm downward from the cage top. Continuous access to food was provided via a trough which protruded downward from the cage top about 7 cm In each case, the trough was constructed of the same material as the cage top. The vertical electric field was generated by grounding the metal cage top and applying the appropriate voltage to an insulated metal plate which was placed under the plastic cage. The horizontal electric field was generated by employing a suitably mounted capacitor in which neither the energized plate nor the grounded plate made physical contact with the plastic cage. The relatively high strength vertical and horizontal electric fields employed resulted in electric field induced vibration in the vicinity of the cages of about 2.5×10^{-3} cm/sec., which was smaller than the ambient vibration in the absence of the electric fields. The results are given in Table 3. In the first generation, males and females reared in both the horizontal and vertical electric field were significantly smaller than the controls when measured at 35 days postpartum. Larger depressions in average body weight were seen in the second generation at 35 days postpartum, while at ten weeks postpartum the differences between the experimental and control weights had narrowed considerably. A very large mortality rate in the vertical field mice during the 8-35 day postpartum period was also noted. A large mortality was again seen in the vertical groups in the third generation, however the only group whose body weights were significantly affected were the males exposed to the vertical electric field. The mice exposed to the electric fields demonstrated obvious effects compared to the equivalent control mice. The most severe effects were seen in the males and females exposed to the vertical field, possibly due to the greater intensity of the vertical field. Alternatively, a direction-dose factor may be involved. In the vertical field experiments, a relatively constant dorsiventral exposure vector existed particularly for the central nervous system, regardless of the movement of the mice. In the horizontal field, the relationship between the mice and the field direction was constantly changing as a result of their movement. The increased severity in the vertically exposed mice may therefore indicate the existence of a directionally sensitive sensing mechanism within the mouse which initiates a response proportional to the time the electric field is along a certain axis. The vertically exposed mice experienced (after weaning) microcurrents of the order of 5 a when eating or drinking, because both acts necessitated touching grounded conductors. The horizontally exposed mice experienced much less microcurrent because their entire cage was constructed of plastic. The possibility must therefore be considered that the greater weight depressions and the increased mortality in the vertical mice may be related to the grounding microcurrents.

Long term exposure to altered environmental conditions may lead to adaption via a variety of mechanisms including exclusion of susceptible individuals from the genetic pool by death prior to maturity or by favoring the survival of those genetically constituted to better resist the altered circumstances. The elevated 8–35 days mortality rate in the second generation, and the decreased severity of the weight differentials between the experimental and control mice in the third generation may be interpreted as evidence for such a mechanism. On the other hand, the elevation of the 8–35 day mortality rate in the third generation is some evidence to the contrary. More extensive studies are necessary to explore this possibility, as well as to explore the basic causative factors for the effects described herein.

Vibration measurements referred to in both studies were performed by Dr. Daniel A. Driscoll, New York State Department of Environmental Conservation.

Q. Have any of the reports described above (1–32) been repeated by other investigators with contradictory results?

A. No.

Q. What do you conclude from the reports cited and described above (1-32)?

A. My first and most fundamental conclusion is that ELF electric fields can affect biological systems. There can no longer be any doubt on this point. The predicate therefore exists for an inquiry into whether such effects will be caused by the proposed 765 kV transmission lines.

Q. Will the proposed transmission lines cause biological effects?

A. In my opinion, probably yes. I can not be more definite because never in history has any free-world company, organization, or government conducted a systematic study of the question. With minor exceptions, the research in the literature cited above was performed by investigators for reasons other than evaluating the safety of transmission lines. The problem of safety of transmission lines did not influence the design of such experiments and in most cases the results were not related to transmission lines by the individual investigators. Nevertheless, it is possible to analyze the literature and to inquire into its implications for the issue of the safety of the proposed transmission lines. This I have done, and my conclusion above is so based. I do not find it possible however, to go beyond this conclusion and say that specific effects are scientifically certain to occur. I also do not find a scientific base to answer in any definitive way the myriad of very specific questions that can be asked once it is accepted that the presently proposed trans mission lines will probably cause biological effects i.e., will a farmer be adversely affected by the proposed transmission lines if he passed under such a line once a day, three days a week, thirty-two weeks a year, except on holidays, in a tractor with tires four feet in diameter made of carbonized rubber, traveling at five miles per hour; if so, how so?

Q. Are you saying that what you call specific information will come only from studies appropriately designed to furnish it?

A. Yes.

Q. Will the probable effects be hazardous?

A. I cannot reply substantively because the question calls for medical expertise (see testimony of Dr. Robert O. Becker). It is obvious, however, even to one who is not a medical expert that many of the reported biological effects of ELF electric fields are highly undesirable, while in other cases it is not possible to say whether an effect is harmful or not. (19, 26)

Q. Would you explain why you believe that the proposed transmission lines will probably cause biological effects?

A. The reports I have cited describe behavioral effects (2, 3, 4, 14, 15, 16, 17, 20. 21, 23, 24, 29); and the effects on growth and physiology (1, 5, 6, 7, 8, 10, 12, 13, 18, 19, 22, 26, 27, 28, 30, 31, 32). The great majority of these effects ere observed between 45–75 Hz, at electric field strength comparable to or below that which would occur on the right-of-way of the proposed transmission lines. Any one report may involve a mechanism or describe a result or process which could occur under the proposed transmission lines. In view of the number and diversity of such reports, it is probable that some situations involving the transmission line electric field will be associated with biological effects.

Q. What do you mean by some situations?

A. The whole range of different kinds of interactions are possible between the transmission line fields and people and the environment. They vary from a single brief encounter, to chronic exposure such as occurs for individuals living very close to a transmission line. The lesson of the literature is that some situations will probably result in biological effects.

Q. How do you know that in some situations there will probably be no biological effects?

A. Because there are some ELF electric field biologica1 studies which so indicate. For instance, in connection with Project Sanguine, deLorge has conducted many behavioral, studies in monkeys (35) and has found no ELF electric field biological effects. The logical conclusion that flows from all such null or negative reports is that some situations involving the interaction of the transmission line fields, and people and the environment, will probably not result in biological effects.

Q. Then you find no contradiction between the positive literature you described (1–32), and the null or negative reports such as those of deLorge?

A. Certainly not. As I indicated the literature shows that some situations involving the transmission lines will probably result in biological effects, and other situations probably will not do so. Obviously. both conclusions can be true simultaneously and the truth of one does not imply the falsity of the other. For example, deLorge's studies do not vitiate the work of Gavalas-Medici (24) who performed a related type of study under materially different conditions (higher electric field strength, different tasks) and observed the behavioral effect.

Q. Are there other studies which describe negative effects?

A. Yes, there are some studies I connection with Project Sanguine (36, 37, 38). Mittler (36) exposed male *Drosophila* (flies) to ELF fields (45–75 Hz, 0.1 volts/cm, 1 gauss) for five days, and found no genetic aberrations in their offspring. Marr et al. (37), found that the ELF fields (45–75 Hz, 0–1 volts/cm, 0.1–2 gauss) did not affect the behavior of pigeons or rats. Coate, et al. (38), conducted a series of nine pilot studies, some of which showed no ELF biological effect. Perhaps the most well known study of this type is the clinical study published in 1967 (45), which I will discuss shortly.

Q. Would you summarize your conclusions regarding the implications of the literature?

A. Some studies indicate that the electric field of the proposed transmission lines will cause biological effects in some situations. Other studies indicate that transmission lines will not cause biological effects in some situations. The positive reports (1–32) do not contradict the negative reports, and conversely. The positive reports cannot be generalized to prove that the transmission line fields will cause a biological effect in every situation. Similarly the negative reports cannot be generalized to prove that the transmission line electric fields will result in a biological effect in no situation. Moreover there are no contradictory reports in the literature. If contradictory results are subsequently reported (either by a null experiment being duplicated with positive results, or a positive experiment being duplicated with null results) then the implications of that particular experimental protocol for the transmission line situation would be in conflict or doubt.

Q. Have there been any studies in the effects of ELF fields on plants?

A. Very little (39, 40, 41, 42). Work has been done, and only at Sanguine level field strengths. No one can say whether the proposed transmission lines will harm vegetation because so little work has been done.

Q. Have there been any studies of the effects of ELF fields on organisms living in the soil?

A. Again, very little has been done. It can, however, be said with certainty that the soil anthropods in the vicinity of the Sanguine Wisconsin Test Facility No. 4 were not affected by whatever Sanguine level fields they happened to experience (43).

Q. Is more research into the area of ELF electric field biological effects needed?

A. Research is necessary at the specific level. It is not realistic to expect that answers to very specific questions will be deducible from the general literature. Appropriately designed experiments must be funded and conducted so as to refine and detail the existing knowledge. Both epidemiological and laboratory studies should be conducted.

Q. Have any epidemiological studies been performed?

A. A study was published in 1970 by a French scientist, in which he examined the number of visits to physicians in two groups of employees (44). The non-exposed group (74 men) lived and worked at more than 125 meters from a transmission line, while the exposed group (70 men) lived and worked at not more than 25 meters from a transmission line. The lines were between 60 kV and 400 kV. No significant differences in number of visits to a physician between the two groups were seen and no differences were seen between the wives and children in each group.

The French report is a modest beginning in the epidemiological study of ELF biological effects. In view of the large population at risk due to exposure to power frequency electric fields, and the poorly defined end points of such risk, epidemiological surveys should be conducted so as to assess the existing hazards to man. Various groups within the population at risk, based on criteria such as age and employment, should be identified and compared with appropriate controls.

Q. Isn't the Electric Power Research Institute (EPRI) conducting biological research in ELF area?

A. Yes, however there are some other problems with looking to EPRI for a solution. From the point of view of output, EPRI research has not produced any finished reports in the ELF biological effects area, with the single exception of the *in vitro* study described earlier (9), which ironically does not apply to transmission lines. In fact, with two additional exceptions (30, 45), the entire American electric utility industry since its inception has not produced a published report in the area of biological effects of ELF fields. There is some EPRI funded work in progress, however it is unlikely that it will supply answers to many specific questions, because much of the work in progress involves experimental protocols similar to those of work already published.

Q. Are you saying that the on-going EPRI research of which you are aware cannot provide answers to specific questions of transmission line safety?

A. Yes.

Q. Are there any on-going epidemiological studies, by EPRI or by any other group?

A. No.

Q. What sort of research program would be required?

A. It is instructive to examine Project Sanguine in this regard. The Navy proposed to build a smile antenna system which would inject into the environment electric and magnetic fields whose maximum strength would be 0.0007 volts/cm and 0.13–0.20 gauss. Under Federal law, the Navy was required to determine the probable environmental effects of the antenna and of its associated fields prior to construction of the final system. Since the biological and environmental impact of the low level Sanguine fields had never been systematically studied, the Navy funded a variety of research projects at considerable cost. The studies were aimed at determining whether a specific piece of Navy hardware with specific operating characteristics would cause adverse environmental effects. It seems reasonable that a research program of comparable scope should be conducted in full view of the scientific community, dealing with the specific effects of transmission lines such as those presently proposed. In view of the potentially vast environmental impact of transmission lines such as those presently proposed, in contrast to the impact of Sanguine, it is difficult to justify doing less.

Q. What is the situation within the Soviet Union regarding the safety of high voltage transmission lines such as those presently proposed?

A. In the Soviet Union it is recognized by the government that ELF electric fields due to transmission lines do cause undesirable biological effects in exposed workers. Consequently, the Soviet government in 1970, promulgated nationwide Rules and Regulations governing the nature and extent of the permissible exposure (46).

Q. What is the substance of the Rules and Regulations?

A. According to the Rules, working conditions are not limited or controlled where the electric field is less than or equal to 50 volts/cm. If the electric field is greater than 250 volts/cm, all work must be done with the worker protected by screening or some other device. For fields between the two values, the permissible duration of field exposures without protective measures is limited as follows. At 250 volts/cm, 5 minutes; at 200 volts/on 10 minutes; at 150 volts/cm, 90 minutes; at 100 volts/cm, 180 minutes. Thus for instance, after spending 90 minutes in an electric field of 150 volts/cm, the worker must spend the remaining portion of the 24-hour period in an electric field of less than 50 volts/cm.

Q. With reference to its biological effects, is the electric field associated with high voltage transmission lines a design parameter in the Soviet Union?

A. Yes (47). The Soviets believe that the electric field affects people, that the reaction is non-specific, and that it can develop after comparatively long exposures (2–5 months). They further believe that the effects of exposure are cumulative, dose-related, and depend strongly on individual physiological differences. Such effects include disturbances of the cardiovascular system, the central nervous system, blood composition, and lower sexual capability (47, 48, 49, 50) The current generation of transmission facilities are therefore being designed to minimize these problems (47).

Q. Do the Rules apply only to maintenance personnel?

A. Yes. Similar standards for agriculture workers and for the general population are being developed (47).

Q. Do the Soviets believe that infrequent or non-systematic exposure of the general population constitutes a health hazard?

A. They believe that the consequences of such exposure can practically be disregarded (47).

Q. What is the Soviet view or the effect of the voltage transmission line electric fields on the flora, fauna, and the ecological balance of the area along the right-of-way?

A. Research in this area is practically non-existent, and therefore that careful laboratory and field studies should be conducted (47).

Q. What is the basis of the Soviet Rules and Regulations? That is, what prompted them?

A. They were prompted in part by medical and physiological studies (48, 49, 50). In the medical study (48), the Soviet investigators studied the state of health of 45 persons (including 4 women) who worked in 400 kV and 500 kV switchyards. Each worker was exposed to the fields from 2 to 5 hours per day, and the average exposure period was about 4 years per worker. The Soviet investigators performed complete clinical studies of peripheral blood, x-rays of the chest, and electrocardiography, in addition to general physical examinations and histories. Of the 45 subjects, 41 presented some type of subjective disorder most frequently neurological and cardiovascular, occurring during and shortly after field exposure. Symptoms subsided some hours after exposure ceased, and in general the severity of the symptoms were proportional to the length of time of exposure. Approximately 30% of the male subjects reported decreased sexual vigor. The authors believed that the reported symptoms were due to autonomic nervous system dysfunction. Physical examination, while failing to show any organic pathology, did reveal instability of the pulse and blood pressure, tremors of the extremities and hyperhidrosis. Accompanying this, the EKG showed bradycardia in 14 subjects and slowed atrioventricular conduction in 10 subjects, while laboratory studies of the peripheral blood showed only mild changes from normal (except for marked spherocytosis found in 17 of 28 subjects in whom this examination was done). The

Soviet investigators concluded that their observations gave leave to assume that being in a high voltage electric field of commercial frequency is an adverse influence upon the working person. This is manifest by disorders of the functional state of the nervous and cardiovascular systems. The Soviet medical study of switchyard personnel (48) led to a physiological study of the work conditions in 400 kV and 500 kV open switchyards (49). Two groups of operating personnel were formed for purposes of study. Group I was composed of persons working under electric field exposure of not more than two hours daily. Group II contained persons exposed not less than five hours daily. In all, 54 persons were studied by the following tests: temperature, pulse, blood pressure, critical flicker fusion frequency (CFF), speech and motor performance error (determined by reaction time testing) and the strength-duration curve and optical stimulation frequency of the adductor pollicis. Essentially, no differences were noted between Groups I and II in body temperature, pulse, arterial blood pressure and CFF. Changes were, however, noted in the strength-duration curves or motor function, with Group II showing an increase in excitability at the end of the field exposure period, and an increase in the latent time in the reaction time tests. Error in speech and motor performance increased with exposure in both Groups, but more so in Group II. The author concluded from the data that the electric field influenced primarily the autonomic nervous system, and that the extent of functional changes was directly related to the duration of the exposure.

Q. Were there other Soviet studies which led to their Rules?

A. The question cannot presently be answered. Other studies may have been done and not published, and studies might have been published but not translated in English. There is no agency or organization which systematically translates the Soviet literature in this area and makes it generally available. Literature becomes available only when some agency or organization becomes interested in a specific study, translates it, and chooses to disseminate it. Soviet literature inn the field is therefore available only on a random or haphazard basis.

Q. What reception have the Soviet studies and the Soviet Rules received in the U.S.?

A. I would characterize the response to the Soviet studies, at least by those individuals in industry and government with whom I have spoken, as skeptical. The Rules have not been adopted in any form anywhere in the U.S.

Q. Why have the Soviet studies been received skeptically?

A. One reason is the studies, or at least the available translations thereof, contain some unscientific terminology as judged by Western standards. Also pertinent data is sometimes omitted. Another reason is that a roughly comparable American study (45) performed about the same time, reached conclusions diametrically opposite to the Soviet results.

Q. Would you describe the American study?

A. The effects of 345 kV, 60 Hz fields on 11 linemen were studied over 42 months (45). The linemen were periodically given very complete physical examinations which included hematological studies and blood chemical studies. The authors found no significant changes of any kind in the general physical examination. The men remained healthy. No malignancies were found and there were no significant changes in any of the clinical laboratory studies. No disease states were round which could be related in any way to the transmission line exposure. The psychiatrist could not detect any significant changes in emotional status in any of the men that could be related to transmission line exposure. There are some difficulties with the report. No data was given, nor were any controls employed. For each physical examination there is given only the unsubstantiated opinion of a physician that the individual was normal. The average exposure period was 6 hr./week/lineman, as compared to the Soviet study of 2–5 hr./day/worker. In neither study was the actual or effective or average electric field strength given to which the individuals were exposed. It is clear from the American study (51) (45) that none of the 11 linemen studied developed recognizable illnesses or diseases in the 42-month period during which they were occupationally exposed which were attributable to such exposure. All 11 men were pronounced healthy at the beginning and end of the exposure period.

Q. Did the American investigators do a follow-up their 11 subjects?

A. A follow-up was published in 1973, the men remained healthy (52). It should be pointed out however, that 8 men had become supervisors, and 1 man had quit. Notwithstanding the fact that the American study (45) has been contested by the Soviet studies (48, 49) it is often cited to prove that high voltage transmission lines are safe (51). Little attention is also given to the fact the study involved only controlled clinical observations, whereas in virtually every scientific study cited here, the tests and techniques employed were considerable more sensitive.

Q. What do you conclude from the Soviet and American studies?

A. There is some conflict in the conclusions to which they lead concerning whether the health of occupationally exposed individuals is jeopardized by high voltage transmission lines. None of the studies commands acceptance on its merits to the exclusion of the others.

Q. If the known Soviet literature is not conclusive on the issue of worker safety in power frequency electric fields, then of what significance are their Rules?

A. I think that the very existence of the Rules is most significant even though I have been unable to find a compelling scientific basis therefor in the Soviet literature. The Rules were promulgated after the American study was published, and it is certain the Soviets were aware of it. I assume that the Soviets are not unintelligent, scientifically backward, or prone to needlessly interfere with their industrial progress. It follows therefore that sufficient evidence exists, in the Soviet view, to warrant measures to protect workers notwithstanding the American study. Since the Rules were promulgated prior to the great majority of the reports which were cited above to show that the proposed transmission line will probably cause biological effects, they could not have been part of the basis of the Soviet decision. I therefore conclude that there is merit in the argument that there exists data and information within the Soviet Union which indicated that the presently proposed transmission lines might be a biological hazard.

Q. Can you briefly describe the role of the Federal government in the area of the potential biological hazard of power frequency electric fields?

A. The Federal government has not entered the field to any substantial degree.

Q. Do you mean that the Federal government is not now supporting any research to determine whether high voltage transmission line electric fields are safe?

A. Yes.

Q. Is there any Federal research currently underway regarding the biological effects ELF electric fields other than power frequency electric fields? That is, is there work being done at other frequencies?

A. Yes. As I indicated previously, the Navy has an extensive research program underway in connection with Project Sanguine. The information being developed there is useful in relation to the power line problem, however, it can hardly be considered to be conclusive thereon.

Q. Why not?

A. The Sanguine electric field is about one million times weaker than that of the proposed transmission lines. Most of the Sanguine research projects performed under contract have found biological effects at fields comparable to those of Sanguine. Obviously, if an effect exists at a given field strength, then arguably some version of that effect will exist at field strengths one million times greater. On the other hand, if no effect exists at a given field strength, then it cannot reasonably be argued that none will exist at field strengths one million times greater.

Q. Hasn't the Office of Telecommunications Policy (OTP) been conducting a program in this area?

A. In 1971, the OTP initiated a five-year program (53) called Program for Control of Electromagnetic Pollution of the Environment: The Assessment of Biological Hazards of Nonionizing Electromagnetic Radiation. This program is intended to coordinate the biological research of all the Federal agencies which 12 have some interest in the spectrum (0 to 10 Hz). In its first annual report on this program, priorities were set; and the ELF area was given the lowest priority (53). Subsequently, no biological research has been done in the ELF area except for project Sanguine.

Q. Why was the ELF area given the lowest priority?

A. According to OTP, ELF fields affect lesser numbers of people than do higher frequency fields such as radar and radio.

Q. How many Federal agencies participate in this program?

A. Twenty-two (54,55). It is my understanding that each agency designs its own research program, consistent with its mission and responsibilities. OTP seeks to coordinate these effects and eliminate duplucation (54, 55).

Q. Isn't the Environmental Protection Agency doing any research in the ELF area?

A. No. Presently they are only doing mobile surveillance (55). That is, they drive a truck from place to place and measure the ambient levels of electromagnetic pollution.

Q. Is it conceivable that OTP is unaware of the potential health hazard of power frequency electric fields?

A. OTP had notice that others thought that there was a problem. Certainly it was aware that the Soviet Union has been studying this area since 1962. Furthermore, a specific recommendation was made in 1973 to the Electromagnetic Radiation Management Council (ERMAC), which is an advisory body formed by OTP to assist it by advising on side effects and the adequacy of control of electromagnetic radiation. The recommendation concerned the danger to the public health from exposure to power frequency electric fields, and was made by the Ad Hoc Committee for the Review of Biomedical and Ecological Effects of ELF Radiation (56).

Q. What is this Committee?

A. A group of experts in the field, formed by the Navy to review its research program on the biological ecological effects of ELF fields. Dr. Becker was a member of that Committee and can supply other pertinent facts concerning it. Briefly, the Committee reviewed research results then available concerning project Sanguine. Many research projects in various stages of completion were discussed. The areas of investigation reviewed included human exposure studies, behavioral studies, physiological and biorhythms studies, and studies involving genetics, ecology and growth and development. In each area the Committee found some apparent biological effect, and called for more research. The Committee made many specific recommendations. The recommendation pertinent here is (56):9. This Committee went on record to recommend that the Electromagnetic Radiation Management Advisory Council (ERMAC) be apprised of the positive findings evaluated by this Committee and their possible significance, should they be validated by future studies, to the large population at risk in the United States who are exposed to 60 Hz fields from power lines and other 60 Hz sources.

Q. Are you saying that OTP was aware of the problem of the potential health hazard of power frequency electric fields?

A. Yes, in the sense that they had notice of it. I infer notice from (1) the literature (1–32), (2) the activities within the Soviet Union, and (3) the specific recommendation by the Ad Hoc Committee. This is not to say that the OTP agrees that there is a problem.

Q. What is the attitude or position of the OTP?

A. I think that its position can be ascertained from the following quote which appeared in OTP's 3 Annual Report (55): *Other Electrical Power and Electrical Safety*: 1974 witnessed a significant increase in interest over the possible hazards associated with increasingly high voltage electrical power transmission lines (e.g., ±500 kV) and their associated fields. The trend toward higher voltage transmission has resulted in public concern and efforts to block these high power lines because the biological effects are not well known, Fragmentary research evidence suggesting injurious or undesirable effects is cited in this regard. For example, hearings are now pending in New York State which will consider the matter of biological safety with reference to the operation of two 765 kV lines which have been contested. This is among a growing number of such cases.

Q. What is your opinion of OTP's position in the ELF area?

A. OTP is the agency of the Federal government with the overall responsibility to advise the government on matters involving the biological risks of nonionizing radiation, a mandate which includes the ELF area. OTP has never published a comprehensive review of the ELF area, taken a position with respect to the merits of the literature therein, or even taken cognizance that the literature exists, It has never taken official cognizance of the Soviet literature or the Soviet Work Rules, and it has assigned the lowest priority to the ELF area for a most dubious reason. Consequently, the ELF area has been ignored by the Federal government, except for the area of military application. I believe therefore that OTP should be more active in the ELF area.

Q. What is a magnetic field?

A. It is a region of space in which a force would be exerted on a charged particle which moved through it. The field can arise from atomic currents, as from a magnet, or from currents moving in a wire. With reference to the latter case, the frequency of the magnetic field would be the same as that of the current in the wire which creates it.

Q. Can magnetic fields affect biological organisms, and if so, would you please describe these effects? (57, 58)

A. Magnetic fields can have biological effects. That much is clear. This area is however, in its infancy and the reports tend to be preliminary. This is particularly true if the question is restricted to magnetic fields of low strength and frequency comparable to that associated with the transmission line. For this reason, and because of the demands made upon my time, I have not thoroughly researched the literature in this area. There is however, one series of experiments which I will describe because of their potentially great significance.

In 1973 Beischer and his colleagues described the effect of exposure of human subjects to magnetic fields alternating at 43 Hz (59). A total of 13 volunteers were involved in the study. All were confined to a specially constructed platform for one week, during which ten subjects were exposed to a magnetic field of 1 gauss for up to 22.5 hours. A large battery of physiological and psychophysiological tests were given throughout the confinement period. The results were negative with one exception; a significant increase of serum triglycerides was observed 1 to 2 days after exposure in 9 out of 10 men exposed to the magnetic field. Similar trends were not seen in the five control subjects. This phenomenon was induced by a magnetic field of magnitude and frequency comparable to that associated with the presently proposed transmission lines. That is, the magnetic field near ground level is less than a factor of 10 smaller than Beischer's field everywhere on the transmission line right-of-way (60). Directly under the transmission lines the factor is less than 2 (60). Dr. Beischer has indicated to me that his only reservations concerning the validity of the triglyceride effect is the relatively small number of subjects involved.

In his report (59) he states in summary, "The results of this pilot study suggest that an alternating magnetic field of 45 Hz and 1 gauss strength may cause a time-delayed increase of serum triglyceride in man. It should be emphasized that the number of subjects was small and that a final assessment depends on establishment of the threshold for* the effect and the field strength biological effect relationship." The medical significance of elevated serum triglycerides will be discussed by Dr. Becker, however it can be stated that the phenomena is evidence of a potentially harmful condition.

*This statement assumes that the line is operating at 4000 amperes.

The credibility of Beischer's observations is greatly accented by observations made at the Naval Research Unit No. 4 on personnel who had been working near the Sanguine Wisconsin Test Facility, where elevated triglycerides were found in six of eight subjects (56). The fact that identical observations were made by the Navy under different research protocols, at different times and places, with different subjects, lends credence to their validity. The phenomema of magnetic field induced elevations in human serum triglycerides unquestionably deserves further attention. Evidence thus far adduced appears to indicate that the magnetic field of the presently proposed transmission lines should at least be considered.

Q. What was the recommendation of the Ad Hoc Committee For the Review of Biomedical and Ecological Effects of ELF Radiation concerning the elevated triglycerides?

A. The Committee urged that the highest priority be attached to the study of this phenomenon ("Priority 1Urgent and Absolutely Necessary"), and stated: (56)

The reports of elevated triglycerides in humans exposed to experimental ELF magnetic fields for short periods of time as well as in individuals working at or near the Sanguine Wisconsin Test Facility cause this area to have the highest priority for future allocation of scarce research resources, Most emphasis should be placed on controlled laboratory studies. Detailed animal experiments on triglyceride levels should be undertaken simultaneously with a continuation of the human experimentation.

Q. Was this recommendation implemented?

A. Construction of animal exposure facilities was begun, and exposure of monkeys was initiated in November 1975. No further human experimentation has been conducted.

Q. Almost all of the literature you have cited to establish that ELF fields can affect biological organisms is recent. Why is that so?

A. The effects described are generally subtle, and therefore easily missed. Also the reports describing ELF biological effects correspond roughly to the time frame in which the relationship of man to his environment, both natural and artificial, is being re-examined.

Q. What has been the basis or reason for asserting that no ELF field biological effects exist?

A. The argument has been: For an external electric field to affect an organism, it must penetrate into the organism. It is easily shown that only a small percentage of the applied electric fields actually penetrates into the organism. Based on our present understanding of how biological systems work, fields this small can't cause any specific effects (like causing neurons to fire). Also, the small electric field that does penetrate the organism will cause only a very small induced current. These currents are so small, that they may be considered harmless. Thus, based on our present knowledge of the effects of applying electric current to an organism via contact electrodes, ELF electric fields would not be predicted as being capable of affecting biological systems.

Q. How would you respond to the argument that calculations show that ELF fields can't cause specific biological effects, i.e., that it is impossible?

A. Invariably such arguments are based on a simplistic view of the biological system, and on the assumption of specific values for its electrical characteristics. Such arguments can be useful, but obviously when they contradict experimental fact they must be rejected. For instance, Schwan (61) has argued that ELF electric fields cannot trigger synapses, and therefore that it is impossible that they can modify behavior or affect the central nervous system. It has been pointed out that Schwan's biological model is too simple (24), and many investigators have reported the very effects which Schwan argued can't exist (2,3,4,14,15,16,17,20,21,23,24,29). Mathematical models and theoretical analyses and predictions of what will occur are useful in the absence of experimental research, but when elements of such an approach contradict what actually occurs, their usefulness is obviously severely limited. Clearly we now need a biological model which predicts that both electric and magnetic fields can have functional and physiological effects.

Q. How would you respond to the argument that the levels of induced current inside organisms due to ELF electric fields are incapable of producing a biological effect?

A. The argument is very weak. In most of the cited ELF electric field research, the animal or organism was exposed in toto to an ELF electric field. In rat experiments for example, the rat experiences induced currents at every point within its body, i.e., its heart, lung, eyes, gonads, etc. Moreover, since the electrical conductivity of tissues vary, the actual strength of the induced currents will vary. Nowhere within the rat is there no induced current. On the other hand, in work aimed at determining safe levels of electric current, such current is applied over a limited surface area at one point (say the hand), and is allowed to exit over a limited surface area at another point (say the foot). In every such measurement, parts of the organism are uninvolved. It is therefore not possible to extrapolate from results and observations in which currents are locally administered with any realistic hope of being able to predict what the biological impact of full body ELF electric field exposure will be. The point is that ELF electric field exposure, and ELF electric current exposure are distinct, not identical problems from the point of view of their biological consequences.

There are other fundamental reasons why the electric field and not the resulting induced currents must be treated as the dependent variable for purposes of analysis and experimentation. Electric field exposure is the vastly more common environmental hazard. The electric field is a much more general and much more practical variable for purpose of experimental study, as is illustrated by Warnke's study of bees (14), Wever's study of human circadian rhythm (26), and our study of the effect of chronic exposure of rats (31). ELF electric field exposure and electric current exposure are quite different at the surface or skin of the exposed animal, even when the internal electric field produced by each modality is the same. Specific effects may therefore be associated with one modality, and not the other.

Q. Suppose that no complaints of physical injury or harm had been received by any power company regarding the electric or magnetic fields of its 765 kV transmission line. Does the absence of such complaints indicate that such fields are not a health hazard?

A. The absence of complaints would be a kind of low level indication that the transmission line is not obviously hazardous. Even though most people probably don't know what electric or magnetic fields are, if very gross sorts of things happened to people or animals in the vicinity of the transmission line, then surely a connection between them and the line would be made and complaints would be heard. When one entertains the idea of more subtle effects occurring, the absence of complaints is not unreasonable. By way of example, if the absence of citizen complaints indicated the absence of subtle hazard then a paucity of complaint by the public concerning the depletion of atmospheric ozone, or concerning contamination of the watershed by chlorinated hydrocarbons, could be viewed as evidence that these phenomena are not occurring. I find such an argument unreasonable.

Q. You have confined your testimony to effects reported within a narrow frequency range. Would you explain why?

A. Transmission lines operate in the extremely low frequency region of the electromagnetic spectrum generally defined as less than 100 Hz. Also my experience is in this area. Therefore, I do not consider the higher frequency data relevant, nor am I competent to discuss it.

Q. The biological effects due to electric fields which you have described have occurred at low frequencies below 100 Hz, but for the most part not at exactly 60 Hz which is the frequency of the proposed line. Does this fact tend to reduce their significance?

A. Scientists generally study electrical effects by class of frequencies. That is, we speak of microwaves or infrared or X-rays or radio waves or visible light. Each is a band of frequencies within the electromagnetic spectrum. Since the physical mechanism underlying the effects which I have discussed is unknown, the most reasonable premise under which to operate would be to assume that the effects could be observed by employing any frequency near the chosen frequency.

Q. Is there a generally accepted scientific theory which could explain the biological effects of electric fields at very low frequencies and very low strengths at the molecular or cellular level?

A. No. It is only recently that such effects have been described and no coherent theory has yet evolved. Perhaps some history of the field will be helpful. The older view of the interaction of electricity with biological organisms generally does not take into consideration the fact that the organism is alive. For instance, radiation of sufficient energy to produce ionization in muscle tissue will do so regardless of whether the animal is alive or not. In this view, any effects due to energy which could not produce ionization because the frequency was too low, were attributable to heating of the animal tissue. There is now a competing viewpoint, one which we happen to accept as correct. In this latter view (62, 63), cells in the body exist in equilibrium with their immediate electrical microenvironment. Certain changes in this microenvironment result in an information transfer into the cell which is capable of controlling the cell function. Thus, in this view, a given cell may be triggered to differentiate, or build bone, or increase protein synthesis, or decrease its hormone output. The environmental change can be exceedingly small because its function is to convey information to the cell, which is itself the source of the energy for the process. Thus, in theory, a heretofore considered small electrical stimulation, could produce a biological effect.

Q. Could you particularize this theory to a more concrete biological situation?

A. Yes. I will describe the application with which I am personally involved. Piezoelectricity is a property of some materials by which, when these materials are squeezed, they generate a voltage, The property is well-known to physicists. It turns out that many tissues in the human body are piezoelectric (64), including bone and other tissues. (65) We have a working hypothesis that the voltages generated during walking or other movements may control the function of the cells of bone (66). That is, the changes in the normal voltages that appear on the bone surface may trigger cells to build or resorb bone, depending on their magnitude and polarity.

Q. Assuming that this control system exists, could it be affected by 60 Hz electric fields?

A. Yes, 60 Hz fields could interact with cells directly, or they could affect cells indirectly. Every material that is piezoelectric also exhibits the converse piezoelectric effect. That is, when a voltage is applied to it, it becomes strained, thereby creating a surface charge. This surface charge may convey or transmit information to cells: thereby affecting, or controlling their function. Thus in theory. electric fields applied to a living system may affect that system. McElhaney's experiment discussed above (1) was predicated on this theory, as was that of Watson (11). Norton's work on bone explants in tissue culture (67), and in vivo (68) is also based on this idea. All these investigators have described biological effects.

Q. Is it possible to compute a safety level for chronic exposure to 60 Hz electric fields?

A. Compared to the pervasiveness of 60 Hz fields in the environments, only a very modest amount of research has been performed, It is therefore not possible to establish a safety factor with the desirable precision. It is possible, however, to make a reasonable beginning. We believe that it is reasonable to employ a safety factor of 100 to 1 in evaluating permissible chronic human exposure to 60 Hz electric fields. Since there are ELF biological effects at 150 volts/cm (31, 32) the utilization of the 100 to 1 safety factor with respect to this field strength would yield a proposed tentative safety level of 1.5 volts/cm at 60 Hz.

Q. How does the proposed tentative safety level compare with the electric field strength to which the general public is exposed normally?

A. I have made no measurements personally; however, the following values are listed in the Fact Sheet for the Sanguine System (33).

Appliance	Electric Field*
Incandescent Light Bulb	0.02 volts/cm
Electric range	0.04 volts/cm
Clock radio	0.15 volts/cm
Color Television set	0.30 volts/cm
Hair dryer	0.40 volts/cm
Food mixer	0.50 volts/cm
Refrigerator	0.60 volts/cm

Phonograph	0.90 volts/cm
Broiler	1.30 volts/cm
Electric blanket	2.50 volts/cm
*Measured 30 cm from device	

Based on these values, it appears that the ambient electric field at 60 Hz is considerably less than the proposed safety level.

Q. What width of the ROW of the proposed 765 kV transmission lines would insure that the electric field would not be greater than 1.5 volts/cm at any point beyond?

A. At points where the line is 50 feet above the ground, the ROW would have to be roughly 870 feet wide.

Q. Isn't a safety factor of 100 extraordinarily high in engineering applications?

A. It depends on how the safety factor is being applied. If one envisions the appropriate safety factor for the thickness of the wall of a steam vessel so as to insure that it doesn't rupture, or the appropriate thickness of a strut on a transmission line tower so as to insure that the tower doesn't collapse, then a safety factor of 1.5 to 5 would be typical. Such engineering safety factors are relatively low because they rest on a certain informational base, namely the known physical properties of the materials. On the other hand, biological safety factors are necessarily higher because our data base concerning the properties or responses of biological objects is not nearly as certain. Clearly when we speak of a safety factor to protect against involuntary exposure of the general population to the electric fields of the presently proposed transmission lines, we are talking of a biological safety factor.

Q. On what do you base your choice of a safety factor of 100?

A. In evaluating the safe-in-use of food additives, a safety factor of 100 has been explicitly chosen by the federal government (69). The federal rule seeks to balance the desire of a manufacturer to gain an economic advantage with the desire of the government to protect the public health. The numerical value of 100 was chosen as the appropriate balance point, and it is therefore significant as a precedent when a similar balance must be struck. I am not urging that the safety factor for food additives be adopted, but rather that the policy considerations underlying the adoption of a safety factor of 100 for food additives are also present in connection with involuntary exposure of the general population to power line electric fields, and therefore that the same numerical value should be adopted.

In further analyzing the question of the appropriate numerical value of the safety factor for permissible electric field exposure, I think that the value of 100 should be viewed as the starting point because it is a precedent, with the appropriate question being, why not a safety factor of 100? The balance described above could then be re-examined.

Q. Are you personally attempting to balance the economic gain and the danger to public health associated with the proposed transmission lines?

A. I certainly am not. I am identifying a situation which is presented to the Public Service Commission, and recommending that since it is confronted with a similar qualitative situation as that which led the federal government to adopt a safety factor of 100 that therefore the Public Service Commission should also adopt the safety factor of 100 as a starting point. This level could then be raised or lowered depending on the particular weight that the Public Service Commission chooses to give to the economic considerations and the public health considerations in the particular case.

Q. What are some other safety factors, and how were they set?

A. The Occupational Safety and Health Administration has promulgated an occupational safety standard for permissible microwave exposure of 10 mW/cm^2 (70). This standard is based on the known ability of microwaves to cause heating in biological tissue at levels ten times higher (71). Therefore the implicit safety factor is 10.

Q. Why didn't you pick this safety factor?

A. A safety factor that is appropriate for occupational exposure is inappropriate for the general population (72). The general population is uncontrolled. It contains the old, the young, the healthy, the sick and all variations thereof. Additionally, the whole range of exposure periods is possible, from occasional to chronic. This is to be contrasted with the occupational setting in which it is presumed that the employees are healthy, and wherein their exposure can be controlled and monitored by the employer (72).

Q. What is the Russian safety factor for microwave exposure?

A. The Soviet and East European safety factor is 10,000 (0.01 mW/cm^2).

Q. What are some other safety factors, and what are their bases?

A. The safety factor for new microwave ovens is 100 (1.0 mW/cm^2). (73) It is based on the rationale described above (72) (i.e., more protection for an uncontrolled population) and on the possibility that the Soviet standard and not the American standard is the correct one (72). The safety factor for carcenogenic substances is infinite (74). That is, if the substance causes cancer in animals it cannot be used in food.

Q. Do you conclude therefore that 100 is the appropriate level?

A. Putting aside the special cases (carcenogenic substances, for which the safety factor is infinite; occupational exposure, for which the safety factor is 10), the precedent is well established that a safety factor of 100 is the appropriate numerical value with relation to the public at large when a balance must be struck between economic advantage and the public health, unless there is evidence to justify a different value.

Q. Would you recommend construction of the 765 V line as proposed by the applicant?

A. I would recommend against construction as proposed. The level of the electric field which would be produced at points beyond the right-of-way would exceed what I believe is a reasonable safety level. Also, the level of the magnetic field on right-of-way may cause biological effects in people exposed to these fields. In my opinion, common wisdom dictates that these effects should be studied further.

Q. Do the conclusions you have proffered apply to transmission lines whose voltage is less thin 765 kV?

A. They apply proportionately. That is, if one lowers the current that flows, one lowers the magnetic field associated with it. If the voltage is lowered, then the electric field at any point in space is lowered by the same factor. Regardless of how a company designs or operates its transmission lines, I do not think reasonably arrived at safety levels for electric and magnetic emanations should be chronically exceeded.

Q. Would you state for the record whether the conclusions you have reached apply equally to a 400 kV d-c overhead transmission line or an underground 345 kV transmission system with the same power transfer capability as the proposed line?

A. I have not analyzed the d-c case and therefore cannot comment on it. With reference to an underground power system, elementary laws of physics show that it is possible to shield a conductor which is carrying a voltage so that the electric and magnetic fields at points beyond the shield are greatly reduced. The biological hazard would then be reduced proportionately.

Q. Does this conclude your testimony?

A. Yes.

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Cases 26529 and 26559 Exhibit °E-4°° (AAM-1) Page 1 of 4

FIGURE 1. APPARATUS EMPLOYED TO GENERATE THE POWER FREQUENCY ELECTRIC FIELD. A metal plate was permanently mounted between two sheets of plywood, with provisions for applying and measuring the working voltage vibration isolation pads which supported the cage, were glued to the upper wood surface. Three designs were employed for the grounded cage top: (1) an all stainless steel top (Type A), (2) a modification of Type A in which the metal feed trough was replaced with one of

plastic (Type B), (3) a modification of Type B in which a stainless steel lid covering the plastic feed trough was added (Type C). The approximate electric field profiles corresponding to each type of cage top are shown. Perturbing effects due to the presence of the various dielectric materials, and due to the water bottle, have been neglected.