UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
PENNSYLVANIA POWER & LIGHT COMPANY	)	
	)	
and	)	Docket Nos. 50-387
	)	50-388
ALLEGHENY ELECTRIC COOPERATIVE, INC.	)	
	)	
(Susquehanna Steam Electric Station, Units 1 and 2)	)	

APPLICANTS' TESTIMONY OF ROGER E. LINNEMANN ON HEALTH EFFECTS OF RADIOACTIVE EMISSIONS FROM THE SUSQUEHANNA STEAM ELECTRIC STATION (CONTENTIONS 1, 2, AND 9)

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TESTIMONY OF ROGER E. LINNEMANN ON HEALTH EFFECTS OF RADIOACTIVE EMISSIONS FROM THE SUSQUEHANNA STEAM ELECTRIC STATION (CONTENTIONS 1, 2 and 9)

1. I am Roger E. Linnemann, M.D. and my business address is Suite 400, 3508 Market Street, Philadelphia, Pennsylvania. I am President of Radiation Management Corporation and also Associate Clinical Professor of Radiology at the University of Pennsylvania School of Medicine.

2. My testimony will cover the medical effects of radiation, sources of radiation to which our population is now exposed, and estimated risks to the population from the operation of the Susquehanna Steam Electric Station ("Susquehanna"). Specifically, it will address the health effects associated with the uranium fuel cycle (Contention 1); those resulting from radioactive releases from Susquehanna, including cesium-137 and cobalt-60 (Contention 2); and those attendant to the decommissioning of the Susquehanna facility (Contention 9).

3. Radiation can induce cancer. Radiation can induce genetic mutations. Both are true statements. However, an important characteristic of all biological systems is their ability to react to physical or chemical insults with a graded response to increasing doses. Consequently, any discussion of radiation effects must include a discussion of the dose and dose rate.

Exposure from Nuclear Power Reactors

4. As of December 1, 1980 there were 75 power reactors licensed to operate in the United States. (1) */ The estimated average dose to the entire U.S. population from power reactors is approximately 0.001 millirem per year. (2) To people living within the vicinity of a reactor the doses vary from a few millirem per year to the closest residents to an average of 0.04 millirem per year to individuals living within fifty miles. (2) The annual offsite exposure design objectives set down by the Nuclear Regulatory Commission in Appendix I to 10 C.F.R. Part 50 for operation of a nuclear power plant are 5 millirem per year total body radiation and 15 millirem per year to the thyroid gland to any individual offsite per unit. An annual average total body dose to an individual living within fifty miles of Susquehanna would be less than 0.005 millirem. (1)(3) The maximum an individual would receive from all pathways is an annual total body dose of less than 5 millirem. The maximum annual adult thyroid dose would be 0.5 millirem. The maximum dose to any organ from all pathways would be to the

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*/ References are listed at the end of my testimony.

thyroid of an infant, and would be under 6 millirem for one year. All these are per unit doses. (1)(3). See also, Affidavit of Frazier L. Bronson In Support of Summary Disposition of Contention 2 (Radioactive Doses) ("Bronson Affidavit"), paras. 14, 22 and 23 and Exhibits "B", "C" and "E" through "H" thereto.

Biological Effects

5. Prior to the discovery of the x-ray in 1895 by Konrad Wilhelm Roentgen in Germany, the world was unaware that ionizing radiation existed. Since that time radiation has been studied longer, in greater detail, and by more prominent, international scientists than any other potential hazard in our working or living environments. There are over 80,000 articles in the scientific literature devoted to biological effects of ionizing radiation. Since the 1940's the U.S. government estimates that it has funded over $2 billion studying the effects of radiation in both animal and human populations. (4) In 1928 the first international committee, the International Committee on Radiation Protection (ICRP), was established to collate and review the world's literature on the effects of radiation with the objective of establishing standards for its use. In 1929 our own National Council on Radiation Protection (NCRP) was formed to accomplish the same objectives for the United States. Today these two bodies are still in existence and have the longest continuous experience in the review of radiation effects and standard setting. The members on these two august bodies are chosen from a wide variety of radiation-related sciences, from a variety of both government and non-government agencies (research institutions, universities, etc.). They were chosen because of their depth of knowledge and prominence in the field and the esteem they have received from colleagues throughout the world. Their careful deliberations and recommendations are reviewed on many levels before they are promulgated to national governing bodies and the general public.

6. Some thirty years ago the NCRP recommended a permissible body burden for radium deposited in the body. This was established on the basis of information that existed in the 1930's and that remains valid today. Similar review bodies have been formed on national and international scales on both an ad hoc basis and a permanent basis. In 1955 the General Assembly of the United Nations founded the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) "to make yearly progress reports and to develop a summary of reports received on radiation levels and radiation effects on man and his environment". (5) Since that time, this committee has conducted its own independent reviews of radiation effects. Unlike ICRP and NCRP this committee, however, does not suggest standards. Their most recent comprehensive report was made in 1977. (6)

7. Because of its leadership in the use of peaceful and military uses of radiation, the United States has convened many ad hoc committees, in addition to the NCRP, to review radiation effects. One of these was formed in 1956 by the National Academy of Sciences and was the Committee on the Biological Effects of Atomic Radiation (BEAR). (7) This BEAR Committee issued six reports reviewing and updating the knowledge of radiation, particularly large-scale animal experiments which were initiated in the 1940's. This BEAR Committee first came up with a concept of regulating average population dose on the basis of genetic risk to future generations. In 1959 the Federal Radiation Council was formed to advise the Executive branch on proper standards for radiation workers in the various government agencies.

8. Because of the increasing number of nuclear reactors and the demand for a review and public information, the National Academy of Sciences established the BEIR Committee (Biological Effects of Ionizing Radiation). The Committee's first report, "The Effects on the Populations of Exposure to Low Levels of Ionizing Radiation", was published in 1972. (8).

It was the first major report to quantify risks of very low level radiation. In 1973, the BEIR Committee was asked to develop a health/benefit cost analysis for activities involving ionizing radiation and its alternatives. The result of this effort was published in 1977 as "BEIR II" (9). Because of increasing public anxiety about radiation effects, in 1978 the President directed the Department of Health, Education and Welfare to conduct its own independent review of radiation effects. (10) Finally, in 1980 the BEIR Committee published a third report, BEIR-III, which reported on a comprehensive review of information gathered since its 1972 report was published. (11)

9. Prior to 1970 major reviews of radiation research and effects were conducted about once every ten years. Since 1970 eight major reviews have been conducted by both permanent and ad hoc committees. In addition to those mentioned above, these include: NCRP, 1971; NCRP, 1980; British Medical Research Council, the United Kingdom Radiological Protection Board, and ad hoc committees of the American Medical Association. The conclusions and recommendations of all of these reviews are remarkably similar.

ICRP Report

10. The ICRP Report 26 (1977) (12) emphasized the stochastic and nonstochastic effects of radiation. The nonstochastic effects of radiation are essentially threshold effects (effects that increase in severity with an increasing dose), for example, cataracts, infertility, and aging. The stochastic effects (cancer and genetic effects), on the other hand, increase in frequency as a population is exposed to increasing doses of radiation. This is sort of an "all or none" phenomena, and severity of effect is not a function of dose. In the absence of direct observations at low doses the ICRP established

a linear non-threshold relationship down to zero exposure in order to describe and quantify the stochastic effect in a population. The ICRP stated that this most conservative theoretical approach required a number of assumptions, as well as extrapolation from high dose and high dose rates. The report states that below 100 rad the evidence for cancer induction is less convincing in human populations than above 100 rad. The report also states that there are no observations of genetic effects in humans exposed to any level of radiation, including the Japanese experience at Hiroshima and Nagasaki. In determination of cancer risk the absorbed dose to the specific organ is more important than the total body radiation. As a result of its extensive review, the ICRP 1977 Committee found that the genetic risk on a population is about 40% of that for the cancer risk at any dose. In averaging the risks for both sex and age the report gives an upper limit leukemia risk of 20 per million per rad and a total cancer risk of 5 times this, or 100 per million per rad. They also estimated that the number of fatal cancers/rad is equal to the number of nonfatal cancers/rad. In succeeding reports of 1978 (13) and 1980 (14) the ICRP found no new evidence to change their 1977 review or to suggest a change in the standards.

UNSCEAR Report

11. The UNSCEAR 1977 report contains a massive compilation of all data in the literature relevant to the induction of cancer and genetic effects of radiation both in experimental animals and humans. This Committee stresses the possible conservatism in their estimates obtained by linear extrapolation of radiation effects measured at high doses and dose rates, stating: "While the rate [of late radiation effects] per rad from doses of a few rad is unlikely to be higher than [these linear estimates], it might be

substantially lower". (15)

12. The Committee evaluates, for those malignancies known to be induced by radiation, the estimated number that could occur in a population of one million people per rad of radiation dose received by the members of this population. The highest estimates, averaged over all age groups, are given for two cancer types: thyroid cancer and breast cancer. For each of these cancers the upper limit incidence rate is given as approximately 100 cases per million per rad. Because of the low fatality rate of thyroid cancers, the lifetime risk of these cancers is about ten times lower, whereas the mortality risk of breast cancer is roughly two times lower than the incidence rates, i.e., equal to approximately 50 per million per rad. Other cancers demonstrate lower rates: leukemia, 20; lung cancer, 25 to 50; bone tumors, 2 to 5 cases per million per rad. The best available estimate for all malignancies averaged over both sexes and all ages, is given as 100 per million per rad, i.e., equal to the ICRP estimate given above.

NCRP Report

13. The NCRP's review and update of radiation data were completed in 1980 and submitted as Report No. 64. (16) The findings, although similar to other reports, concentrated heavily on the radiobiological research in animals and human epidemiological studies that bear on the question of effects of low level, low-LET (Linear Energy Transfer, the concentration of energy deposition along the path of the ray as it goes through tissue), and low dose rate radiation, the type of radiation that the population would encounter in the environment. They concluded that the linear non-threshold model for estimating effects of low level radiation overestimates these effects by a factor of 2-10 for doses less than 20 rads and for dose rates of 5 rad/year or less. They did not attempt to quantify effects.

BIER-III Report

14. BEIR-III report (1980) did a comprehensive evaluation of the data accumulated since 1972. The report is important in that its evaluation placed great emphasis on dose/response relationship for less than 100 rad, including many of the controversial studies that have been reported since 1972. The report is important in that many of the long-term studies have an additional eight year followup, particularly the effects on the populations in Hiroshima and Nagasaki and the effects of the patients treated with radiation for ankylosing spondylitis.

15. The report is also important in that their review showed that the expression of risk is probably for the lifetime of the individual, rather than only for a 30-year risk plateau as had been assumed in earlier reports. Also, it appears that in general the female carries a slightly greater risk for cancer induction from radiation than the male. The major radiation induced cancers are: breast, thyroid, bloodforming organs, lung, GI tract and bone. As with other previous reports the BEIR-III committee struggled with the best model to use for estimating effects of low LET, low dose and low dose rate radiation in absence of observed data. The consensus of the committee was the linear quadratic model, which in effect gives an estimate of dose/response relationships that is between the linear model, which the Committee feels is the upper estimate of risk, and the pure quadratic model which is the lower estimate of risk. This linear quadratic model, therefore, reduced the cancer risk estimates of the 1972 BEIR report, which were based on linear non-threshold model, by about one-half. Like the ICRP and NCRP, the report concluded that cancer risk is greater than the genetic risk; that the solid tumor risk is greater than the leukemia risk, about 10 times, versus 5 times by the ICRP. They concluded that the risk for cancer death for 1 rad exposure to 1 million people would result in 77 to 226 extra cases of cancer death. This is lower

than BEIR-I by a factor of about 2 or 3. Stating it another way using the linear quadratic model, they concluded that a 10 rad exposure to a population would increase the risk over normal cancer frequency from 0.25% to 1.4% and 1 rad per year would increase the normal cancer risk by 3-8% using the linear quadratic model. The linear model would say the latter risk is 6-16%.

16. The review of genetic information, which the BEIR-III Committee states must come from animal data since there are no observed data on genetic effects from human populations exposed to ionizing radiation, concludes that in spite of more data available and better methods of calculation, the risk estimates are no different from those of the BEIR-I report. One rem (1000 millirem) of parental exposure would lead to 5-75 additional serious disorders per million liveborn in the first generation, which is compared to a 10% (107,000) normal genetic disorder without radiation. Like the ICRP the Committee concluded that the genetic effect is about 40% of the cancer effect rate.

17. The Committee considered in great detail several controversial studies showing effects at less than 100 rem and studies that purported to show a risk that is greater than linear at low dose and low dose rate. The Committee concluded that these studies are not conclusive; that they are inconsistent with the large body of confirmed data; that they suffer from inadequate sample size, and in some cases, have used inadequate statistical analyses. As a result, the Committee concluded that these studies did not justify any changes in the BEIR-III estimates. Specifically, the studies by Najarian (17) and Bross (18) produced inconsistent and unconfirmed results. The Mancuso study (19) on the cancer risk of radiation workers at the Hanford, Washington nuclear complex was also reviewed in great detail. BEIR-III Committee found it lacked in statistical importance and the reported results were in contrast to results of more substantive study on larger populations exposed to larger doses. One

indication of the problems with the Mancuso study is that an increase in the incidence of leukemia among these workers was not seen, whereas it is usually the first cancer detected in irradiated populations.

18. In spite of the number and extensiveness of reviews by various national and international bodies in the past 10 years, all of the studies are remarkably similar in their conclusions, and in particular in their estimates of risk at low levels of ionizing radiation exposure. Table I summarizes the results of these estimates. They all conclude that the risk is a statistical risk which can only be applied to a large population, that is, it is impossible to predict a risk on an individual basis. Taken together, all reviews estimate a cancer risk for 1 rem exposure to 1 million people of 100 excess cancers in addition to the 167,000 cancers that would normally occur. The reviews show that the genetic effect is about 40% of the cancer effect, i.e., 1 rem exposure to a parental generation with 1 million livebirths would result in about 5-75 genetic disorders in the first generation, compared to the 107,000 that normally occur in one million livebirths, and 60-1100 disorders at equilibrium a few generations downstream; i.e., a point where the number of new mutations appearing equals the number of those that are eliminated from the population's gene pool. The cancer and genetic effect a 1 rem could also be zero.

Cancer

19. Cancer is a common but complex disease. One out of every four people can expect to develop cancer during his or her lifetime, and if present mortality rates continue, one out of every seven people will die from this disease. Cancer is primarily a disease of the younger and older age groups. The mechanism of cancer induction is not well understood. The induction of cancer is more probably a multi-gate phenomena. These gates may open sequentially or simultaneously in order for any one of billions of cells to start an

uncontrolled growth. One gate may be a genetic predisposition or inherited genetic defect in a cell. A second gate may be a defect in the immunological mechanism that controls cellular growth. A third gate may be a virus infection of the cell. There is ample evidence in animals that viruses play a role in the development of leukemia. There is indirect evidence to suspect viruses as one of the factors in human cancer development. Finally, a fourth factor is environmental agents, among these: chemical agents (arsenic, coal tar, chemical dye intermediates, etc.) and physical agents (ionizing radiation, heat, ultraviolet light). It has been estimated that there are 1500 of these chemical and physical agents in our environment and about 500 have been demonstrated to induce cancer in controlled animal studies. (20) Ionizing radiation is but one of these agents and, comparatively speaking, it is probably the least potent carcinogen; it is the one carcinogen about which we have the most information.

20. Cancer is not only age-related, but also sex related and its virulency is a function of the tissue involved. For example, breast cancer and thyroid cancer are more prevalent in women. Some cancers are more easily induced by one agent than another, and some cancers are highly curable with, relatively speaking, less impact on the individual and society. Two of these are skin cancer and thyroid cancer. There are some 400,000 skin cancers diagnosed in this country each year. The cure rate is close to 100%. Attempting to establish a cause-and-effect relationship for cancer is difficult because there is a relatively long latent period between the exposure to an agent and the development of cancer.

21. A cell cannot distinguish one type of radiation from another. All radiation, regardless of the type or source, eventually does the same thing--it deposits energy in the cell. From this initial physical insult a series of chemical changes take place resulting in: 1) death of

the cell; or 2) repair and recovery of this damage, particularly if the energy deposition was "low enough and slow enough"; or 3) permanent damage which is retained in the cell during future divisions. In the latter case, the cell may retain the damage for a lifetime without clinical manifestations or this damage may later express itself as a cancer or a genetic disorder. In either case the expression of this latent damage is highly dependent on the total dose (amount of energy deposited) and the dose rate (time period over which dose is experienced). Of all cancers leukemia is the one that is most easily identified among populations exposed to sufficiently high doses of radiation. It has relatively low normal incidence; its cause and effect relationship has been demonstrated in multiple studies; it has a short latent period (about 5 years versus 15 years for solid tumors); and its period of expression (the time during which a person is at risk) is shorter (about 25 years versus lifetime for solid tumors), thus allowing for shorter followup period in order to determine the full risk. Solid tumors (lung and breast) are only now beginning to manifest themselves in the survivors of Hiroshima and Nagasaki. On an individual basis it is impossible to assign a cause and effect relationship to any single agent, because no carcinogenic agent results in a specific cancer and many agents can induce a similar cancer. The lower the exposure to one agent, the less likely it was a significant factor in the development of cancer.

22. That radiation can be a major factor in the induction of cancer has been well demonstrated in both animal and human studies. The overwhelming majority of the available hard data is from studies in which human populations have been exposed to high doses and high dose rates. The most significant human studies in this regard are the followup of some hundred thousand survivors of Hiroshima and Nagasaki (21) and 14,000 patients with ankylosing spondylitis who were treated with x-rays. (22) Other human

studies that support the conclusions of these latter two are the followup of radium dial painters, (23) early radiologists (24) and infants who received head and neck irradiation. (25) The most conclusive evidence that radiation is a significant factor in the induction of cancer lies above exposures of about 100 rad (100,000 millirad) and generally for exposures that occur over a very short period of time. In Nagasaki the leukemia excess is seen at 100 rad and above. In Hiroshima, the excess can be seen in the range of 20 to 50 rad. The early radiologists were exposed to hundreds of thousands and millions of millirads. Bone sarcomas in radium dial painters resulted after tens of thousands of millirad. Ankylosing spondylitis patients received an average exposure of 380,000 millirad.

23. Except for the in utero exposures to direct x-rays, there are no convincing human observations that radiation is a carcinogenic agent below about 20 rad (20,000 millirad). There have been many studies recently that have purported to show an effect; but these studies have been carefully reviewed by the major scientific bodies cited above and have been rejected because the data failed to support the conclusions. Since an effect decreases with decreasing dose and dose rate, it is unlikely that effects will ever be demonstrated at background levels of radiation, diagnostic medical, or environmental exposures.

24. From an epidemiological point-of-view, the problems of finding effects of low level radiation (below 20,000 millirad) are threefold: 1) ever increasing populations are needed as the dose decreases; 2) with lower exposures, longer followup periods (lifetime in many cases) are required to demonstrate an effect; 3) as the dose decreases, other carcinogenic agents, e.g., chemicals become more important.

25. It can be estimated from known effects at high doses and high dose rates that at 1 millirad of exposure, one would need an experiment of at least 8 billion mice to statistically demonstrate an effect. As for human populations, an exposure of 5000 millirads would require the followup of about 7,000,000 people for a lifetime to obtain the proper statistics to detect an effect. One can conclude that the effects at low exposures are indeed minute if such large populations are needed for their detection.

26. In the absence of definitive information at low doses and low dose rates, it has been customary by all national and international bodies concerned with the hazards of radiation to set standards by making some assumptions without direct evidence concerning the effects of low level radiation. In setting standards, the linear nonthreshold model is used as the most conservative assumption. With this model it is possible to calculate maximum cancer risks in order for society to judge the ultimate benefit of a radiation-using device or for workers to judge the potential hazard of radiation work compared to other work. According to this risk model, 1 rad (1000 millirad) exposure to 1 million people would result in 100 excess cancer deaths over and above the 167,000 normally expected in this size population. In other words the risk for an individual exposed to 1000 millirad is one chance in 10,000 of dying of cancer as a result of this exposure, whereas his normal risk is one chance in seven.

Genetic Effects

27. There is no human evidence that radiation has caused genetic disorders. All of the information on genetic effects of radiation comes from carefully controlled animal experiments, and there is every reason to believe that radiation causes genetic disorders in the human species as well. The genetic disorders from radiation were first discovered by Dr. Mueller (26) who

in the 1920's showed that radiation can cause genetic abnormalities in the fruit fly. His studies at relatively high doses also showed that there was a linear relationship where twice the effect was seen with twice the dose. Based on his observations and other information at the time, there was a stimulus to organize the first radiation protection committees. Genetic studies in humans are among the most difficult and elusive studies from which to gather meaningful data. The reasons are: 1) a relatively high incidence of normal genetic disorders (approximately 10% of all livebirths have some genetic disorder with about 3% showing obvious gross disorders); 2) the requirement for extremely large irradiated populations in order to make any small increase in the genetic disorders statistically apparent; 3) understanding and controlling all other causes that produce similar genetic disorders. For example, it is estimated that 50% of livebirth disorders are due to maternal influences, diet, smoking, drugs, etc.

28. Genetic effects in general may be expressed on two levels: those effects that manifest themselves in the immediate offspring of irradiated individuals and those that affect society as a whole. The input parameter is a radiation dose received by the gonads of parents before reproduction. Radiation damage to the genetic material, which is contained in the chromosomes of the germ cells, may take two forms: gene mutations and chromosome aberrations. Both of these phenomena occur "spontaneously" in the population. Chromosome aberrations usually result in abnormalities seen in the offspring of the first generation. They are usually not compatible with life and, therefore, are not passed on. Gene mutations can cause effects which are not necessarily manifested in the first generation but may be seen in many generations hence (e.g., diabetes) and can affect the overall health of society.

29. The most extensive work in radiation genetics has been conducted by Dr. Russell (27)(28) since the 1940's. He has irradiated hundreds of thousands of mice under various conditions to determine the dose/response effect for total dose as well as dose rate. About 50,000 millirad is the lowest total dose where one can statistically determine a small increase in genetic mutations with a reasonable experimental population design. Russell also carried out important work on the effect of dose rate and found that in the female mouse there is a dose rate, about 9 millirad per minute, below which no further increase in genetic effects are seen. He found that as the dose rate is lowered, the increase in genetic effects gets smaller than one would predict on the linear model. Further evidence of repair of genetic material in the female was seen when female mice were given large doses of radiation, approximately 400,000 millirad, and were allowed to breed at intervals of time following the exposure. If this interval were seven weeks or more, the increase in genetic mutations disappeared. In another attempt to assess the affect of repeated exposures for many generations, Spalding (29) irradiated 70 generations of mice, each generation to a dose of about 300,000 millirad. He found that there was no deterioration in the species as regards litter size and health. The only human study that sheds light on the question and tends to support the evidence from animal work is the followup of the first generation of children born to parents who were irradiated in Japan. (30) The study consisted of about 71,000 babies born to parents who were in Hiroshima and Nagasaki at the time of the bombing and a control group of 71,000 children of parents from other parts of Japan. The four major parameters which would indicate genetic disorders by radiation were: the frequency of stillbirths, miscarriages, obvious physical and mental defects and growth and development abnormalities. There was no difference in the frequencies of these parameters between the irradiated group and the control group.

30. A few general statements regarding radiation genetics can be made. Radiation in sufficiently high doses can induce genetic disorders. As with a cancer risk, the risk of genetic disorders decreases as the dose decreases and the dose rate decreases. The genetic disorders induced by radiation are of similar nature to those that occur spontaneously. From evidence at high dose and dose rates, it would appear that the incidence is small enough that to detect an effect of 3 millirem per year parental exposure, one would need to follow 700,000,000 people for 3 generations in order to get a statistically significant result. (31) Risk estimates from the BEIR-I and BEIR-III reports indicate that a parental exposure of 1 rem (1000 millirem) to 1,000,000 people would cause in the first generation 5-75 additional disorders and at equilibrium a few generations later would increase the disorders by 60-1100. This is small, compared to the natural disorder rate which is about 100,000 per million livebirths. It is important to note that the genetic harm to a population is primarily dependent on the average dose received by members of that population, irrespective of how the exposure is distributed among the members of the population. In other words, if 1% of one million people receive 5000 millirem the eventual effect will be the same as if all had received 50 millirem. There are no isotopes released from a nuclear power plant which are known to significantly concentrate in the gonads once they are ingested through drinking or eating contaminated foods. Gonadal exposures from environmental radiation are essentially the same as the exposure to the total body.

Other Sources of Radiation

31. From time immemorial the human race has been bathed in an envelope of radiation emanating from the sky, the ground, the food we eat and from within our own bodies. On the East Coast of the United States this amounts to approximately an average of 100 millirems per year, and

in the area of the Susquehanna Steam Electric Station about 74 millirem per year. Annually the radiation from the sky (cosmic) contributes about 35 millirem to this natural exposure; the buildings we live in add another 24 millirem; the air we breathe, 5 millirem; the radiation from the ground, about 11 millirem; and the food we eat, about 25 millirem. The latter is chiefly from radioactive potassium and carbon-14 which is in both water and food. This background radiation varies considerably around the world. For example, in Denver due to higher elevation and increased radioactivity in the mountains the population is exposed to approximately 175 millirem per year. In some areas of France the annual exposure is 350 millirem; in India, 1500 millirem; Egypt, 400 millirem; and some areas of Brazil, 13,000 millirem. For the United States, Oakley (32) calculated the average annual dose from cosmic and terrestrial radiation at 84 millirem per year. Different regions, however, vary widely in their annual dosage. The coastal region of Florida shows an average annual dose of about 64 millirem. In Pennsylvania the average is about 97 millirem per year. A number of studies have been done to assess cancer and genetic effects in the various background levels of radiation. To date these studies have been negative. One of the most recent was a study reported out of China (33) where 73,000 people were evaluated for chromosomal aberrations, hereditary disorders, congenital deformities, abortion rate, cancer, growth and development abnormalities in backgrounds that vary by as much as 125 millirem. There was no evidence of association of these parameters with radiation. Though this does not rule out induction of these disorders by radiation, it does indicate that at these levels and with these large populations the disorders are not detectable.

32. With the increasing use of radiation in medicine, research and industry, man has added radiation to his environment. By far the largest

contribution (95%) is from the use of radiation in medicine. The average citizen in this country receives about 100 millirem per year from this source. In any one year approximately 160,000,000 people in the United States receive at least one x-ray. The average dose to the bone marrow from x-rays, depending upon the type of x-ray and the part of the body x-rayed, varies from about 1 millirem to about 200 millirem per film. There are approximately 10 million nuclear medicine procedures done in this country where radioisotopes are deliberately given to a patient orally or by injection to study the function and anatomy of internal organs. The average bone marrow dose is about 300 millirem per procedure. Other sources to which the population is exposed include fallout, approximately 2-3 millirem annually; television sets, watches, etc. add about 1 millirem annually; and the 35,000,000 people who fly averaged about 3 millirem per year. (34)

Radiation Risks

33. In the absence of any observed effects at very low doses and in the interest of assisting the lay community in weighing the risks and benefits of a technology, it is customary to extrapolate from observed effects at high doses to possible effects at low doses. Consequently, to guard the public's health to the maximum, conservative assumptions are incorporated into the derivation of mathematical formulas for estimating low dose effects. As I discussed above, most committees have used the linear nonthreshold model in order to estimate effects. However, the most recent reviews and material indicate that this is probably high and conservative by a factor of 2-10. (35)(36)

34. The U.S. population exposure from present day operations of nuclear power reactors is about 0.001 millirem per year. This is some tens of thousands of times below levels from which effects have been observed in humans. A safety factor of this magnitude is considerable. In other areas of environmental hazards, industrial hazards or medical treatment procedures, safety factors of 10 or less are common and often difficult to achieve.

35. According to the most recent estimates by the BEIR-III committee using the linear quadratic dose/effect relationship, an annual exposure of 0.001 millirem to the population of the United States could result in about 10 extra cancer deaths during the lifetime of the total population, 218 million. Normally, there will be about 32 million cancer deaths during the lifetime of 218 million people. If the linear nonthreshold hypothesis is used, the excess cancer deaths from this exposure would be 20 over the lifetime of the total population. On the other hand, if a pure quadratic relationship were used, the excess cancer deaths would be 1. Genetic disorders at equilibrium resulting from this exposure would be about 10-20. Normally about 21 million genetic disorders would be expected in livebirths during the reproductive lifetime of this population (218 million). In other words, if radiation is harmful at these low doses, it appears that the worst we could expect is less than one extra cancer death and less than one genetic disorder each year as a result of the normal operations of nuclear power plants.

36. An upper estimate of the numerical risk for the low level discharges from normal operations of the Susquehanna Steam Electric Station would show that for both cancer deaths and genetic disorders, even the theoretical risk is too small to be measurable during the entire lifetime of the plant. It can have no affect on the cost/benefit balance. This is even so with respect to persons particularly susceptible to cancer. For example, the maximum exposure to an individual offsite is about 5 millirem per year. (1) The maximum lifetime risk that he/she would die of cancer induced by this exposure is 1 chance in 20,000 (linear) and 1 chance in 40,000 (linear quadratic). His/her normal risk of dying of cancer from other causes

not associated with this plant during his/her lifetime is 1 in 7. Because of the I-131 released from the plant and its specificity for the thyroid gland, an estimate for this particular cancer can also be made. The risk has been calculated for an adult who would receive maximum dose to his/her thyroid gland from I-131. The "maximum" adult would receive a dose of 0.5 millirem per year. The lifetime risk using the linear model is about 1 in 10 million that a person would develop cancer of the thyroid; the normal risk is about 1 in 1000. Considering the estimated population within fifty miles of Susquehanna by the year 2000, 1.6 million people (1), one would not expect to see even one extra cancer of the thyroid during the entire lifetime of the plant. The radiation dose to the maximum exposed infant's thyroid would be less than 11 millirem (assuming both units in operation) for the one year he/she is an infant and less as he/she grows older. The resultant risk for his/her exposure between infancy and 15 years of age is about one chance in 1 million that this infant would eventually develop cancer of the thyroid.

37. Genetic harm as a result of exposure to the population from the operation of Susquehanna is also insignificant. Assuming that 1.6 million people reproduce themselves over a lifetime and they receive an average of 0.005 millirem per year, the additional genetic disorders at equilibrium from this exposure would be about 0.01 to 0.15. Normally this population would experience about 100,000 genetic disorders in the first generation. If both parents received the maximum individual dose, 5 millirem per year for their 30-year reproductive life, they would have about 1 chance in 1 million of having an offspring with a genetic disorder due to the plant exposure. The normal risk is 1 chance in 10.

Management of Spent Nuclear Fuel (Back End of Nuclear Fuel Cycle)

38. As set forth in the Affidavit of Dr. Morton I. Goldman in

Support of Partial Summary Disposition of Contention 1 (Fuel Cycle Doses), the risk equivalent total body dose commitment to the world population for radionuclides potentially released from the back end of the fuel cycle attributable to both Susquehanna units, computed over a period of 100 years, is 42,240 person-rem for the (limiting) reprocessing mode; to this amount one must add approximately 10 person-rem as the total body dose attributable to Technetium-99 ("Tc-99") over the same period of time. See Testimony of Richard W. Englehart on the Tc-99 portion of Contention 1. This gives an upper bound of 42,250 person-rem (total body) as the 100-year limiting dose attributable to the back end of the fuel cycle. Based on these values and the above discussed rates of 100 excess cancer deaths and 50 genetic disorders per million total body person-rem, I estimate the upper limit to the health effects from the back end of the fuel cycle for Susquehanna to be 0.042 excess cancer deaths per year and 0.021 excess genetic disorders.

39. Similarly, the limiting long-term Tc-99 doses, as computed by Dr. Englehart, would be 0.11 person-rem/year total body over the first 10,000 years, dropping to 0.03 person-rem/year total body during the following 90,000 years. The health effects from such small doses would be negligible, on the order of .11 total excess cancer deaths in the first 10,000 years and .27 total excess cancer deaths in the following 90,000.

Danville Resident Exposure

40. The release of cesium-137 and cobalt-60 into the Susquehanna River and potential health effects on the 9000 inhabitants of Danville, PA have been analyzed. As set forth in the Bronson Affidavit, the collective annual dose to each Danville resident from these radionuclides is 4.1×10^{-4} millirem per year, or a collective dose of 3.7×10^{-3} person-rem. Theoretically

this dose could result in less than 4×10^{-7} extra cancer deaths per year among this 9000 population. Normally this population will experience about 10-15 cancer deaths per year. The individual cancer death risk is also incalculably small -- less than one chance in a billion that in any one year he/she would die of cancer as a result of this exposure. The normal cancer death risk is one chance in 600 per year.

41. Considering the discussion regarding radiation effects in this testimony, these doses are trivial and will not materially impact on the health of the residents of Danville and will not affect the cost/benefit ratio.

Decommissioning

42. As set forth in the testimony of Albert Weinstein on Contention 9, the estimated occupational exposures for decommissioning the Susquehanna facility would be 3690 person-rem to workers for immediate dismantlement with lesser exposures for entombment and safe storage. Population doses for a population of 3.5 million within a 50 mile radius of the site are 0.05 person-rem (immediate dismantlement), 3×10^{-4} person-rem (preparation for safe storage) and 0.04 person-rem (entombment). The "maximum" individual would receive a much smaller dose than from routine plant operations.

Based on these values I would estimate the health effect as follows:

Population	Dose	Cancer Deaths	Genetic Disorders
Worker	3690	0.4	0.2
General	0.09	0.00001	0.000004

43. As shown by the above computations, the health effects of the radiation exposures associated with decommissioning of Susquehanna will be negligible even among workers engaged in decommissioning activities.

TABLE I

CANCER DEATH RISKS

Normal	167,000#
ICRP	100*
UNSCEAR	100*
NCRP	10-50*
BEIR I	117-621*
BEIR III	77-226*

*per million/rad

#per million population

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