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Public Policy and the Health Effects of Radiation at Low Doses

An Interactive Qualifying Project Report

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by

Glenn S. Barnett

Brian Bunten

Matt Linnemann

Date: December 17th, 1999

Approved: Douglas W. Woods

Professor Douglas W. Woods, Major Advisor

James B. Muckerheide, Co-Advisor

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Abstract

This project will examine the controversy surrounding the health effects of radiation at low doses. Guidelines based on the questionable conclusion that there is no lower threshold to such effects currently impede the progress of several nuclear-related industries. Working from literature and interviews, we will assess the appropriateness of the current and proposed guidelines, discuss the parties involved in the regulation process, and examine the potential benefits and detriments to adapting a new model for policy implementation.

Introduction

Synopsis

Regulations based on the questionable conclusion that there is no lower threshold to the effects of irradiation on human health currently impede the progress of several industries employing nuclear technology. This conclusion, which employs what is known as the Linear Non-Threshold model, is supported by a number of national and international organizations. However, many professionals and organization believe that a threshold model is more appropriate and effective in policymaking decisions. This paper will describe the essentials of the physics and biology behind the debate between the threshold radiation model and the linear model, and examine the use of these models to define regulatory guidelines. This paper will also examine these models' effects on several industries, including nuclear power, transportation of nuclear waste, and the irradiation of food for disease prevention. The major parties involved in the regulation process will be discussed, and the suitability of the current guidelines will be assessed as well as the proposed alternatives. This paper will also examine the potential benefits and costs to adopting a new model for policymaking in industries employing nuclear technologies. Currently, progress in these industries is being impeded by disagreements as to the general nature of low level radiation effects: specifically, whether or not a threshold level exists at which radiation starts to do noticeable damage to the human body. The goal of our project is to determine whether or not the concept of a threshold model is valid for regulatory and policy-making guidelines.

History of Radiation Policy

The first standards for radiation protection were established in 1934 by the National Council on Radiation Protection and Measurement (NCRP). After World War II, data became available regarding A-bomb victims in Japan and irradiated laboratory animals. These data indicated that very high doses (500+ rem) of radiation were fatal, while smaller doses (<50 rem) left no detectable short-term damage, where a rem is a standardized unit of measurement of human exposure to radiation. However, it was presumed that negative health effects were present even in those small doses, and that they would manifest themselves later in the subject's life. The government, choosing to err on the side of safety, adopted a linear model for radiation. This model essentially states that at any amount of irradiation, no matter how small, has detrimental effects on the human body, even though they may not be detectable by current technology. As the level of the dose rises, so does the harm to the individual. This linear model has come to be known as the "Linear No-Threshold" model, or the LNT model. This model has led to policies which aim for a radiation level "as low as reasonably achievable" (Muckerheide & Rockwell).

Many agencies are involved in the establishment of radiation protection standards in the United States. The Environmental Protection Agency (EPA) and the Nuclear Regulatory Commission (NRC) are involved in policy establishment, as are the Department of Energy (DOE), the Food and Drug Administration (FDA), and several other Federal agencies in the United States. These agencies all have large programs for research, analysis, and examination of the health effects of radiation. These agencies policy decisions are largely influenced by independent scientific groups such as the Biological Effects of Ionizing Radiation (BIER) Committee and the National Council on Radiation Protection and Measurements (NCRP). These groups are responsible for setting models and policies which federal agencies then enforce.

International groups also contribute to policymaking in the area of radiation protection. Two major international groups are the International Commission on Radiological Protection (ICRP) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). These groups' findings are taken into consideration by federal agencies and organizations, and also used in international projects.

The state of public policy relative to low levels of irradiation has not changed significantly since World War II. Despite conflicting evidence, the major policymaking groups continue to maintain the notion that any amount of irradiation, no matter how small, is detrimental to human health. Our project will examine the suitability of that policy, including supporting evidence, conflicting evidence, and the industries that stand to be affected by it.

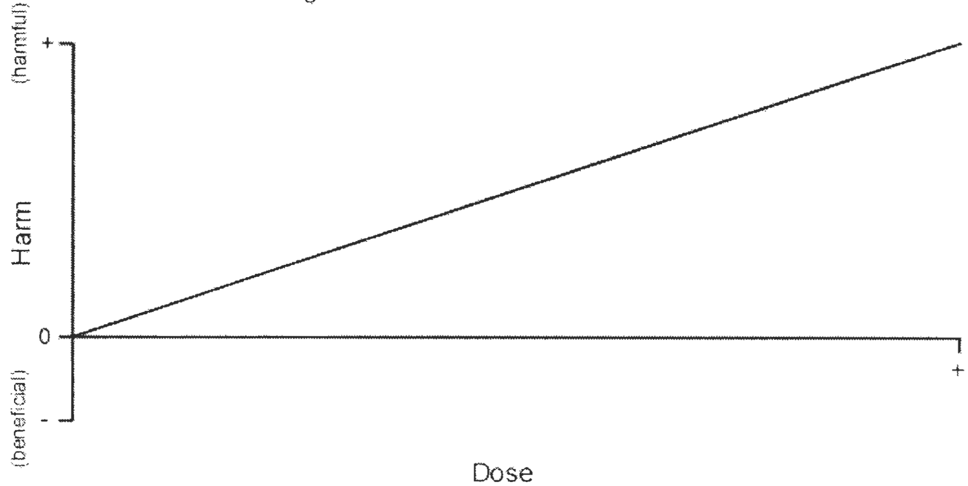
The Threshold Controversy

Introduction to the Controversy

At the center of the low-level radiation controversy is a debate regarding the correlation between radiation dosage and human harm. The government, various agencies it funds, and several other organizations have taken a stance in support of what is known as the "Linear Non-Threshold" model. Many radiation experts, however, disagree with the LNT model. They support what is known as the "Linear Threshold Hypothesis". As we illustrate below, should the LNT model be replaced with a form of the threshold concept for regulatory, risk-assessment and policymaking purposes, several beneficial nuclear technologies could be made available to the public. Additionally, substantial savings could be obtained by not spending billions on measures that reduce radiation by insignificant amounts.

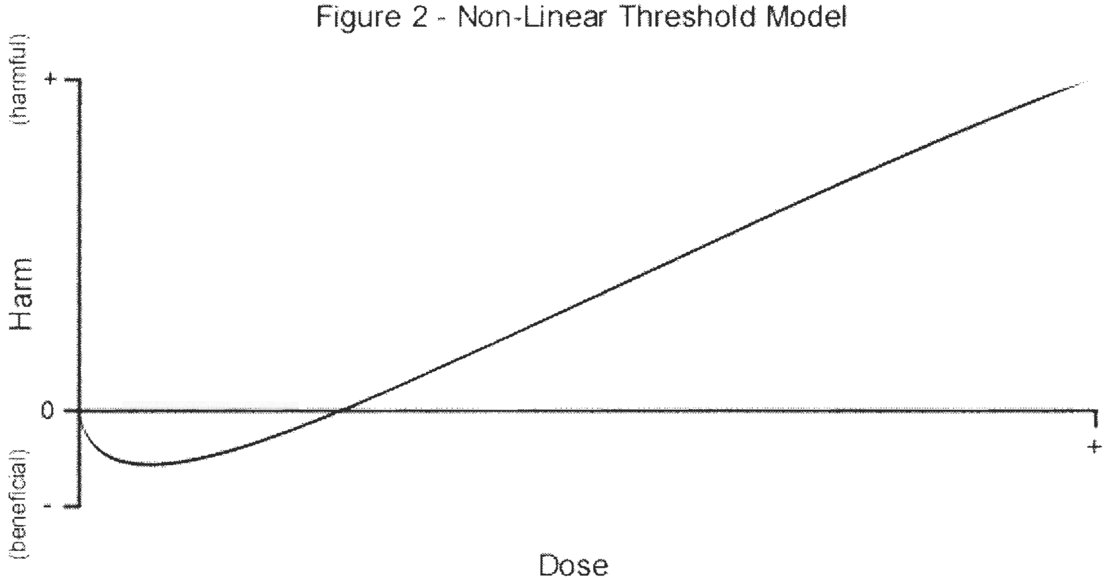
The Linear Non-Threshold model states that as the intensity of a radiation dose increases from 0, the harm caused increases in a linear fashion (Figure 1).

Figure 1 - Linear Non-Threshold Model



However, many leading experts in the field of radiation disagree with this approach. They feel that significant evidence exists to support the concept of a Non-Linear Threshold Model. This model indicates that as dosage increases from zero, the harm effect does not increase until a certain threshold. Additionally, various data indicates that the harm effect actually starts off in the negative direction, with negative harm equaling a benefit of some kind (Figure 2).

Figure 2 - Non-Linear Threshold Model



While the threshold model indicates that not only is there a threshold at low levels where no harm is done and potential benefits exist, the LNT model maintains that any amount of radiation is bad, and thus the government policies based on the LNT prevent the use of many potentially beneficial technologies.

The LNT model first rose to acceptance after World War II. Data taken from A-bomb victims and irradiated laboratory animals indicated that a dose of radiation greater than

500 rem was fatal, while smaller doses of about 40 or 50 rem left no detectable damage. However, it was presumed that negative health effects were present even in those small doses, and that they would probably manifest themselves later in the subject's life. The government, erring on the side of safety, adopted the LNT model, which aimed for a radiation level "as low as reasonably achievable" (Muckerheide & Rockwell). In the view of some experts, this somewhat ambiguous phrase has provided millions of research dollars and caused billions of cleanup and prevention costs to be spent on radiation-lowering procedures that reduced radiation so insignificantly that exposed life forms would notice no health differences. Some professionals place the estimate of occupational safety and health costs at more than $8.5 billion, with negligible benefits gained (Hahn and Hird 1991).

The Biological Arguments

The biological arguments used to justify the LNT model depend on the basic characteristics of DNA damage in cells hit by irradiation which can cause the beginnings of cancer development (Roth 1998). The induction of cancer is considered to be a stochastic effect, meaning the effect is random in nature. When the ionizing radiation hits the cell, there is a small chance that DNA damage will occur. If this damaged DNA is unrepaired or misrepaired, the presumption is that this damage will lead to a tumor in the cell that progresses through the multistep process that leads to cancer. When larger amounts of radiation are hitting a cell there exist more chances for that cell to become cancerous, but under this theory of radiation effects, even a single radiation hit has the possibility, albeit slim, of causing cancer in a cell (Sinclair 1997).

The argument against this position from the threshold standpoint involves the concepts of adaptive response, biological defense mechanisms (BDM), and apoptosis. Adaptive response means that when the body is exposed to an amount of radiation, it automatically improves the body's BDMs. BDMs are the body's process for the constant repair of DNA and cellular damage. Studies have shown that at very low doses, our BDM is improved by exposure to irradiation. At high doses, however, it is unable to combat the cumulative effects of irradiation (Cohen 1998). Apoptosis means that as cells are injured by ionizing radiation, they are programmed to "commit suicide" to prevent cancer. It is theorized that as the dose rate increases, BDMs and apoptosis can no longer keep up with the irradiation, and thus the threshold is broken and a net increase in damage occurs (Cameron 1998, Kondo 1996).

The LNT supporters believe that the intensity of doses significant to trigger BDM are too large to be of consideration. They believe, based on human data from early radiologists, that repeated doses of 150 mGy are required to trigger and maintain the body's biological defense mechanisms. They also believe that the body would initially be more resilient to ionizing radiation by way of the body's defense, but eventually the defensive effect would go away, lasting only somewhere between a few days and several weeks. To keep a body's BDM active would require repeated doses of 150+ mGy, which would definitely cause deterministic effects like cancer (Strom 1998).

Another foundation of the LNT model is the premise that radiation damage is not repairable. Since the damage done by radiation is supposedly cumulative, it would make sense that the larger the dose, the greater the amount of harm that can potentially be done on the body. However, there exist examples of radiation damage that is indeed repairable in at least some scenarios (Mossman 1998). Therefore, while repair has been demonstrated to an extent in cellular and even some human epidemiological studies, its importance is still largely unknown, and thus a greater understanding is required before repair is included in calculation of risk from radiation (Mossman 1998).

Many substances we encounter and/or consume are harmful in large quantities, however our bodies require them in smaller doses for normal function. For example, oxygen, vitamins and even sunlight help the body carry out normal function and produce nutrients at normal levels. Meanwhile the normal use of oxygen by the body causes a large amount of cellular damage constantly, but this damage is constantly being repaired. It is approximated by the discover of cancer causing genes, Michael Bishop, that every single gene in our cells has undergone $10^\wedge10^{th}$ mutations, almost all of which are repaired before developing into problems. This idea of low level benefits carries over to ionizing radiation, the breaks in DNA are exactly the same as normal oxidative breakages (Pollycove 1998). The repair mechanisms are used constantly to repair damage from many "mutagens" which are present even in normal diets and are due to the body's metabolic activities. These damaging events are thought to occur several thousand times a day, but most are repaired before causing any serious problems in healthy individuals.

An example of this immune system response and subsequent repair is given in the following figure presented by Makinodan and James (1990) and used in the presentation entitled Molecular Biology, Epidemiology, and the Demise of the Linear No-Threshold(LNT) Hypothesis (1998) by Myron Pollycove, M.D. In the experiment they irradiated mouse spleen cells with from zero to two Gray in vitro, and from zero to seven Gray in vivo. The in vitro results showed an 80 percent raised immune response up to roughly 0.38 Gy after which it was lowered, finally dropping below the normal level at about 0.63 Gy and following a curve downward to baseline (no immunity remaining). A similar course was seen in vivo, however the critical points were attained at higher Gy doses.

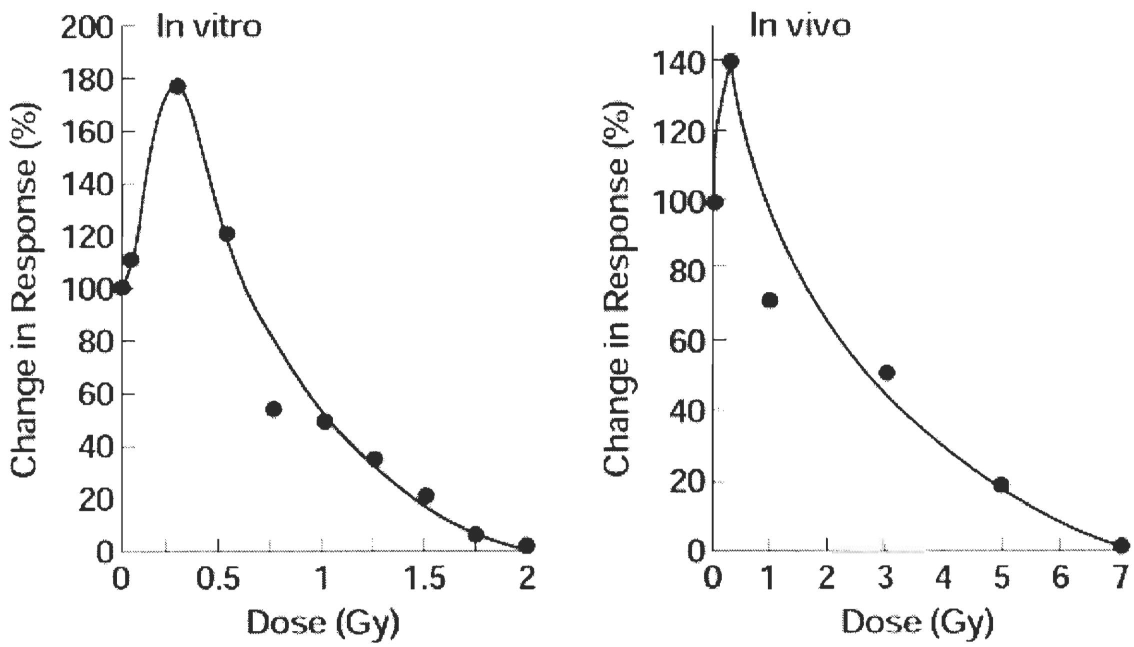


Figure 3 – Immune system response to radiation. Mouse splenic cells primed with antigenic sheep red blood cells. Makinodan T, James SJ 1990.

According to studies by Dr. Lawrence Grossman at Johns Hopkins University, the health of the individual plays a greater role in the repair of damage than the exposure itself. He found that patients with a common form of skin cancer showed a decreased ability to repair cell damage, leading to the hypothesis that if a person has lowered repair ability they have an increased risk of problems such as cancers that would have been stopped early in their growth otherwise.

In 1979 T.D. Luckey published Radiation Hormesis which reviewed literature exposing exceptions to the idea of radiation at low doses being a negative force. He discovered many reports of benefits due to low level exposure on animals, such as a strengthened immune system leading to decreased infection rates, and longer lives. He wrote in The Health Physics Society's Newsletter in December of 1990, "Future health physicists should be concerned less about probing for minimum exposures and become active in promulgating ways to provide safe supplementation, (20 to 100 mGy y-1.) Except for persons with genetic inability to repair DNA, this is well below harmful effects of chronic, whole-body exposures, estimated to be over 1,000 mGy y-1 for low-LET radiation."

Laboratory groups at The Gray Laboratory Cancer Research Trust in England performed experiments to determine the mechanisms involved in cellular response to radiation. They utilized a radiosensitive cell line from patients with Ataxia Telangiectasia (AT), a disease impairing DNA repair, while the control was of normal radio-resistant cells. Forty five minutes after exposure to ionizing radiation, certain genes known to play a role in cell repair after damaging stresses on cells were upregulated (allowed to operate at a higher rate) in the normal cells, but not in the AT cells, meaning that the cell “recognized” a problem and focused its energies into repair. More assays were performed, notably with protein levels, and altered cell division points were performed which will lead to future experiments. This experiment demonstrates that the body employs protective defensive mechanisms when exposed to irradition (Gray 1998).

A study headed by John Y.H. Chan of the Chinese University of Hong Kong titled “Cell-Cycle Regulation of DNA Damage-Induced Expression of the Suppressor Gene PML” explores radiation effects on cell growth and particularly expression of the promyelocytic leukemia (PML) gene. This gene arrests cell growth in the G1 phase after DNA damage, allowing for repair mechanisms to take effect, or to trigger cell lysis, the killing of the cell, should the damage be too extreme. The cells used were the human HeLa variety, a continuous cell line that can go through infinite generations outside of the body (Chan et al 1997).

In part of this study the cells were irradiated with 20 Gy of ionizing radiation inducing DNA damage. Immunoflourescent antibodies to the PML protein showed greatly increased activity at 8 and 24 hours, measured by the increased glow as the cells expressed the PML gene. Western blots, which detect antibodies present with a PML protein, also showed an increase in PML up to 8 hours, with production tailing off after 24 hours determined by directly measuring the amounts of the gene produced. Computerized flow cytometry showed which stage of development the cell was in after experiments. The cell phases are S where DNA is synthesized, G1 and G2 are cell growth, G0 is resting, and M is cell division. The normal un-radiated cells had 40.6

percent of the DNA paused for repair procedures in the G1 phase, under 10 Gy it was raised to 73.8 percent paused for repair, and after 20 Gy it went up to 92.1 percent of DNA paused for repair. To further increase the production, wild type human p53 was transfected into the HeLa cells through the Ad5CMV-p53 vector, which inserts the p53 gene into the cell DNA. This insertion led to a 2-5 fold increase in PML production over the previous experiment. These results showed the upregulation of the PML protein which allowed for increased cell repair by slowing cell growth in critical periods. It has been found that cells can withstand higher doses of radiation in the S phase than in the G2 and M, also showing that a slowdown of the cycle in the G1 phase, which immediately precedes S, will lead to improved survivability (Chan et al 1997).

The Epidemiological Argument

A primary reason for the LNT controversy is the lack of complete, modern population studies. The main sources for data are typically studies at relatively high doses, i.e. survivors of the bombings in Japan, various occupational exposures (miners, etc), medically exposed individuals, and weapons and facility releases. Several studies on natural background sources (radon, radium, etc) exist, but their significance is disputed in the radiation community. Laboratory studies on animal populations, cellular and molecular studies, and natural radioactivity studies also provide useful radiation data. Since irradiated populations are often rare and of uncontrolled origin, incomplete or incorrect studies have many times been conducted and accepted.

Japanese Atomic Bomb Survivors

The population data most used in radiation science is the Japanese atomic bomb survivors. Data for this study was obtained by the Radiation Effects Research Foundation (RERF), data that unfortunately is not freely available to researchers. LNT supporters claim that a linear relationship between dose and harm is the correct interpretation of the data. However, Dr. Kondo and several other researchers have produced reports on the RERF data that identify beneficial health effects at low to medium doses (Muckerheide 1998). Dr. Cohen also mentions that a 30 percent probability of decreasing risk of tumors can be found with increasing dose from zero up to 20 cSv. The regulatory limit for radiation protection is far lower than that, around 0.01 cSv (Cohen 1998). The newly released BIER V report refers almost exclusively to the

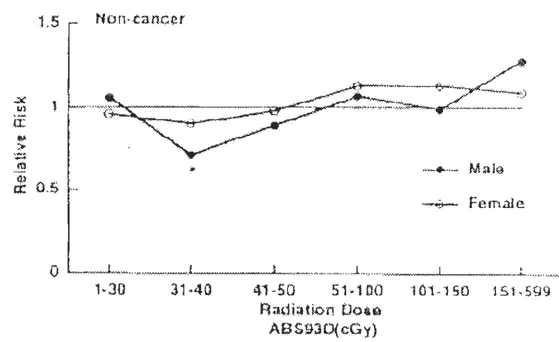
Japanese data, producing as an end result a policy based on the linear model. However, the BIER V report mentions several times that low-dose data is lacking in many respects and is insufficient for policymaking by itself. The report goes on to mention how the Japanese data must be combined with laboratory animal studies and what we know about carcinogenesis to produce usable policy data. The report discusses in no uncertain terms how a better understanding of low level radiation and more low-dose data is needed before a definitive model can be produced (BIER V).

Before presenting epidemiological evidence, important aspects of radiation must be defined and explained to help the reader more easily understand the data. The radiation effects that will be described depend on the quantity (dose or exposure) and the quality (type of particle) of radiation. The radiation quality is determined by a number called the Relative Biological Effectiveness (RBE). When examining health effects in humans, the effectiveness is referred to as the Quality Factor (QF). A 200 KVP x-ray is used as a standard (QF=1). Every thing else is relative to this standard. (Shrivastava 1980).

A quantity, called the Dose Equivalent, gives the net effect of the dose and QF, which is an estimate of the radiation hazard. The unit for the Dose Equivalent is the "rem" (radiation equivalent man). An equivalent unit is the sievert (Sv) for which one Sv equals 100 rems. For a large population, the radiation hazard is expressed in "person rems". (1 rem to 2000 persons vs. 2 rems to 1000 persons = 2000 person rems). (Shapiro 1978). "Rem" is equivalent to dose in rads times the QF. A "rad" is the unit for absorbed dose.

An equivalent unit is the Gray (Gy) for which 1 Gy equals 100 rads. One "rad" is equal to 100 ergs: absorbed energy per gram of tissue. (NEA 1987).

Statistics emerging from studies done on Japanese survivors of the atomic bombs are able to show quite clearly, a contradiction with the linear non-threshold theory. A report released in 1997 by Dr. Y. Okumura and Dr. Mine of the Atomic Bomb Disease Institute, Nagasaki University of Medicine shows that the Relative Risk (ratio of the number of exposed persons affected by the exposure, to the number of persons not exposed at all) (NEA 1987) from non-cancer deaths of atomic bomb survivors, who received between 31-40 cGy was significantly less than those who had not been exposed. This data was generated from 100,000 registered survivors.



The relative risk of death from non-cancer

Figure 4 – Relative risk of death from non-cancer

The mortality from non-cancerous diseases was lower in exposed males than age-matched, unexposed males. It also showed that at even a low level of 1 cGy (exposed) compared to less than 0.5cGy (non-exposed), the mortality rate was lower for the exposed population of males and females from ages 30 to 80+ than those that were not exposed. (Okumura, Mine 1997)

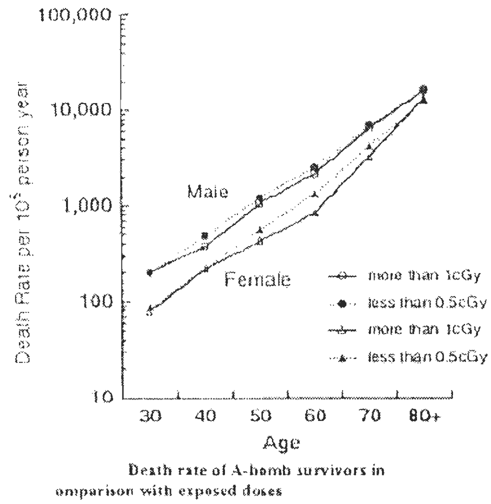


Figure 5 – Death rate of A-Bomb survivors in comparison with exposed doses

A report from 1994 by Dr. Sadao Hattori, quite clearly shows a beneficial relationship between low level exposure of approximately 8-10 cGy and the Leukemia death rate (during 35 years) of persons from Hiroshima and Nagasaki exposed to A-bomb radiation. With the normal death rate per 10^5 non-exposed persons being approximately 110, the rate decreases to approximately 40 persons per 10^5 when exposed to 8 cGy. (Hattori 1994).

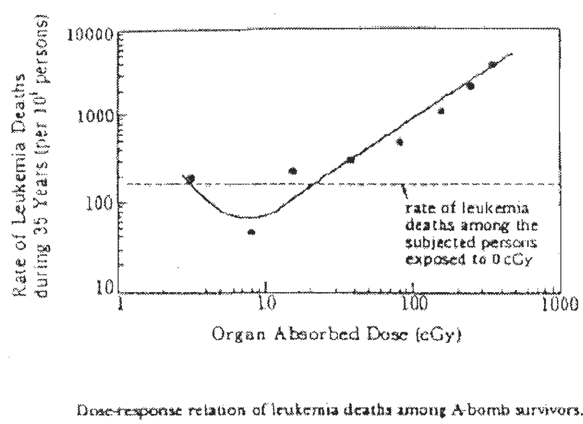


Figure 6 – Dose-reponse relation of leukemia deaths among A-Bomb survivors.

Similarly, Prof. Emeritus Dr. Sohei Kondo, of Kinki University reports (1993) that 23,321 A bomb survivors, between 1950-1985, exposed to 1-9 rad had lower death rates (0.16 percent) from leukemia and all cancers as well, compared to 34,272 zero rad, non-exposed survivors (0.17 percent). The reduction in death frequency differs only by a 1-3 hundredths of a percent, which may not be enough to constitute a beneficial result, but certainly suggests that Low Level exposure does not have any harmful effect. The size of the population used in this study is adequate to give these results valid statistical significance. A direct comparison to an extrapolation of the LNT relationship reveals contradictory results. The LNT theory predicts a 0.17 percent increase in cancer deaths in those exposed to 5 rad, but as we can see, the data shows that this exposure had no effect on number of cancer deaths. (Kondo 1993)

Table 3.5 Numbers of subjects and cancer deaths, 1950-85, among atomic bomb survivors classified by DS86 dose

Dose (rad)[a]	Number of Subjects	Leukemia No.	Leukemia Frequency(%)	All other cancers No.	All other cancers Frequency(%)
0	34,272	58	0.17	2,443	7.13
1-9	23,321	38	0.16	1,655	7.10
100-199	1,946	23	1.20	221	11.4

(constructed from data of Shimizu et al., 1989)

Estimates of excess cancer deaths (%) at low doses of radiation by no-threshold linear extrapolation from data on high doses

Dose (rad)[a]	All cancers	Leukemia	Other cancers
1	0.035	0.007	0.029
5	0.17	0.03	0.14

a Shielded kerma values

Figure 7 – Number of subjects and cancer deaths 1950-85 among A-Bomb survivors.

A 1996 report by Drs. J. Alvarez and F. Seiler analyzes similar data on approximately 65 thousand Japanese A-bomb survivors and shows that for exposure to doses from 0.004 seiverts (Sv) even up to 0.19 Sv, the effect on death rates due to tumor cancers and

Leukemia ranges from no effect to a decrease in death rate. Between these two values the mortality ratio (actual deaths divided by expected deaths) was below unity by 0.01-0.06 percent for solid tumor cancers and 0.28-0.59 percent for Leukemia.(Alvarez, Seiler 1996).

1.2.1.1 Japanese Atomic Bomb Survivors - Cancer/Leukemia

Table 1. Solid Tumor Cancers. Solid tumor data from Shimizu et al. (15) with additional uncertainty information and confidence intervals of difference from the expected background cancer rate.

Dose Range (Sv)	Average Dose (Sv)	Number of Subjects	Number of Expected Background Cancer Deaths	Number of Observed Cancers Deaths	Mortality Ratio	Number of Excess Cancers	Excess Fractional BG Uncertainty	Fractional 90% confidence of difference
0-0.009	0.004	36132	2725.8	2562	0.94	-163.9	-3.1	-1.7
0.01-0.05	0.02	19518	1408.1	1394	0.99	-14.1	-0.4	-0.2
0.06-0.09	0.07	4113	336.5	341	1.01	4.5	0.2	0.1
0.10-0.19	0.13	5209	412.8	410	0.99	-2.8	-0.1	-0.1
0.20-0.49	0.31	6218	499.9	529	1.06	29.1	1.3	0.7
0.50-0.99	0.69	2829	214	273	1.23	59.0	4.0	1.9
1.0-1.99	1.38	1380	101.8	158	1.55	56.2	5.5	2.4
2.0-2.99	2.34	361	20.4	37	1.81	16.6	3.7	1.3
3.0-3.99	3.51	147	9.3	20	2.15	10.7	3.5	1.1
4.0 +	4.41	84	5.5	10	1.82	4.5	1.9	0.8

Table 2. Leukemia Data. Leukemia data from Shimizu et al. (15) with additional uncertainty information and confidence intervals of difference from the expected background cancer rate.

Dose Range (Sv)	Average Dose (Sv)	Number of Subjects	Number Expected Background Cancer Deaths	Number of Observed Cancers Deaths	Mortality Ratio	Number of Excess Cancers	Excess Fractional BG Uncertainty	Fractional 90% confidence of difference
0-0.009	0.004	35280	89.9	61	0.68	-28.9	-3.0	-1.6
0.01-0.05	0.02	19740	51.6	33	0.64	-18.6	-2.6	-1.3
0.06-0.09	0.07	4059	12.1	5	0.41	-7.1	-2.0	-0.9
0.10-0.19	0.13	5210	15.2	11	0.72	-4.2	-1.1	-0.5
0.20-0.49	0.32	6375	18.6	23	1.24	4.4	1.0	0.4
0.50-0.99	0.69	3042	8.6	24	2.79	15.4	5.3	1.5
1.0-1.99	1.39	1579	4.5	24	5.33	19.5	9.2	2.0
2.0-2.99	2.38	412	1	15	15.0	14.0	14.0	1.8
3.0-3.99	3.44	130	0.3	2	6.67	1.7	3.1	0.4
4.0 +	4.61	166	0.4	4	10.0	3.6	5.7	0.7

Figures 8 and 9 – Solid Tumor and Leukemia data

Occupational Exposures

Occupational exposures are another established segment of the radiation data available. Studies focus primarily on weapons plant workers, nuclear shipyard workers, nuclear power plant workers, coal miners, and other professions which have at some point come into contact with significant amounts of irradiation. In this area, studies have shown a linear model can be abstracted from the data, but typically these studies focus on higher doses. As more data emerges involving human effects at low doses, non-harmful and beneficial effects from irradiation at low doses become more evident.

In 1987, a million-dollar study of nuclear shipyard workers was conducted by the DOE and Johns Hopkins University, which examined nuclear shipyard workers and their counterparts at conventional shipyards. This study drew from a database of almost 700,000 shipyard workers, with nearly 108,000 nuclear shipyard workers with exposures occurring from 1960 to 1981. From this population, three main groups were extracted: 33,352 non-nuclear workers, 10,462 workers with a working lifetime dose equivalent of less than 5 mSv, and 28,542 nuclear workers with a working lifetime dose equivalent of 5 or more mSv. Five mSv is approximately equal to the sea-level background radiation one would receive in 1.5 years (Muckerheide 1998). Professor Myron Pollycove from the University of California at San Francisco observed that the nuclear workers "had a lower death rate from all causes, leukemia, and LHC than the non-nuclear workers." He went on to point out that these seemingly beneficial effects from the low doses of radiation were consistent with the increased longevity and decreased mortality and cancer death rates that could be found in western states with high natural background radiation. The study was not recognized by the BIER V report, even though the chairman of the study's Technical Advisory Panel was the chairman of the BIER V (Muckerheide & Rockwell).

A study of 36,000 nuclear weapons plant workers conducted by Dr. T. D. Luckey of the University of Missouri at Columbia found that those exposed to a lifetime dose of 25 cSv had less cancer mortality than a comparison group that was exposed to a lifetime dose of 13 cSv. This would suggest an optimum lifetime dose of 25 cSv or greater. The data used was over a period of 19 years, indicating an optimum dose of greater than 1 cSv per year. The lung cancer mortality rate appeared to decrease with increasing dose, although only those workers with a lifetime dose of 20 cSv or more were found to have a statistically significant decrease. The leukemia mortality rate of exposed nuclear weapons workers compared to that of unexposed workers is statistically identical. (Luckey 1994, Muckerheide 1998)

Data taken from another study by Dr. Luckey detailing 20 years of operation at a Canadian energy plant operation found that the 4,000 exposed workers with an average exposure of 70 mSv had a lower cancer mortality rate than 21,000 unexposed workers. Worth noting is that the unexposed workers mortality rate matched precisely that of the general population of Ontario males. (Muckerheide 1998)

Environmental Background Radiation Studies

In the 1980s, Dr. Bernard Cohen conducted a study that compared area radon levels to lung cancer rates. By using 300,000 radon measurements taken from state departments and the EPA itself, the study produced results in strict contrast with the LNT model (Figure 3), indicating that people living in higher radiation areas are significantly less likely to contract lung cancer. The data used in the study represents 90 percent of the total U.S. population and over half of all U.S. counties. The figure below shows plots of age-adjusted and smoking-adjusted lung cancer mortality rates for both males and females. The points are not per-county, but rather the counties with close radon levels are grouped together (and displayed along the bottom of the chart). This study has not been taken into consideration for policymaking because it is considered to be an ecological study, and it is the belief of the EPA that ecological studies have trouble establishing a dose-response model. Dr. Cohen protests that the weaknesses do not affect the results and that the professed ecological shortcomings are irrelevant to the study's ability to establish a non-linear dose-response model, but to date the EPA has still ignored the data (Cohen 1998, Muckerheide & Rockwell).

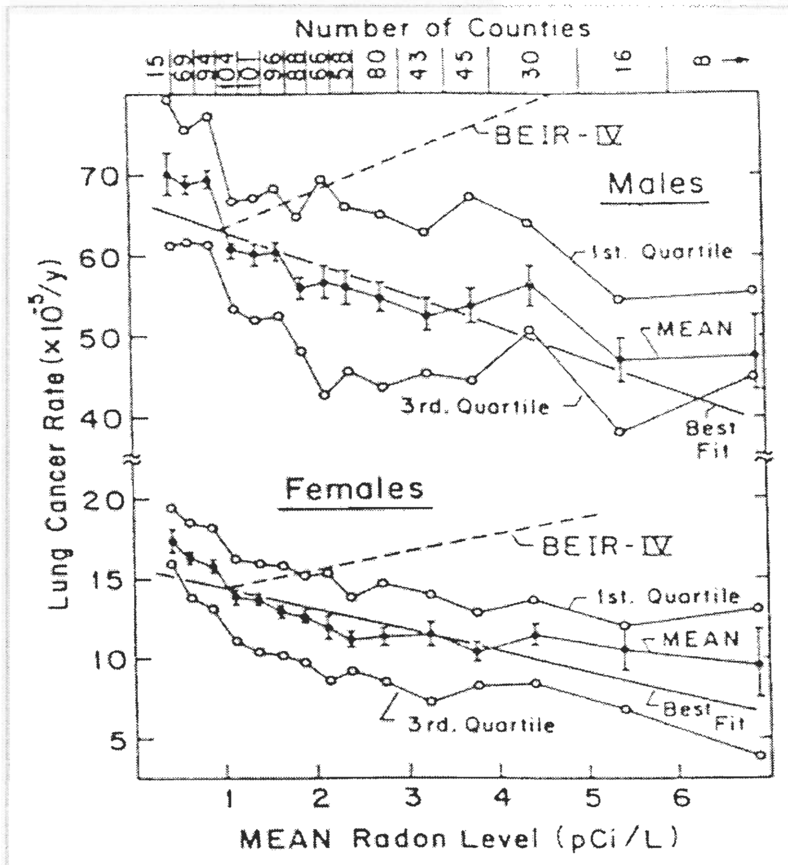
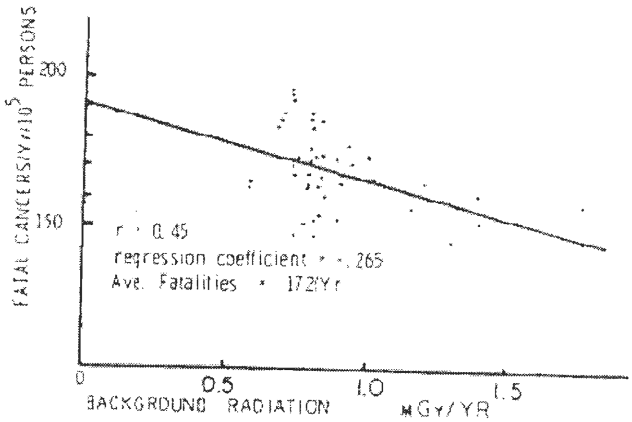


Figure 10 – Relationship between Radon Level and Lung Cancer Rate

Another study conducted about the correlation between geographical radiation levels and observed cancer effects is John Jagger's 1998 study. Jagger uses data from NCRP reports to determine the average natural background radiation (NBR) levels of the Rocky Mountain states and the Gulf Coast states and compares those levels to the average cancer death rates in the same areas. NCRP studies find the NBR levels of Rocky Mountain states to be 3.2 times the amount of NBR found in Gulf Coast states. American Cancer Society data shows an age-adjusted overall cancer death in Gulf Coast states is 1.26 times higher than in Rocky Mountain states. When these data are paired, the difference from the expectation that the cancer death rate might be proportional to NBR is a factor of 4 (3.2 * 1.26), which shows plainly a negative correlation between NBR and overall cancer death. (Jagger)

A report from Prof. Dr. Don Luckey (1991) tells us of a study by Firgerio in 1973 of 163 metropolitan areas in the 48 contiguous states that attempted to create a proportional relationship between background radiation and cancer mortality. But the findings showed the opposite, that with increased background radiation (from 0 to 1.5 mGy per year), there were less cancer moralities. (Luckey 1994).



Age-adjusted leukemia mortality rates and background radiation levels of the 48 contiguous U.S. show a strong inverse correlation.[148,296,297]

Figure 11 – Age-adjustec leukemia mortality rates and background radiation levels

Prof. Jaworowski, a member of UNSCEAR, reports that the 74 thousand people of Yangjiang county, China with a high background level of radiation (5.5 mSv per year) had a 14.6 percent lower cancer mortality rate than two low background counties of 77 thousand people, which received (2.1 mSv per year). In the high background county, the people received a 70 year lifetime dose of 385 mSv which is 5.5 times higher than the dose limit proposed in the EPA (Environmental Protection Act). In an age group of 10-79 years, the general cancer mortality rate was 14.6 percent lower in the high-background county than the low background counties. The leukemia mortality rate was 15 percent lower for males and 60 percent lower for females. (Jaworowski 1994).

Animal Experiments

Our disproof of the existence of any safe dose or rate of radiation, with respect to human cancer, relies completely on human epidemiological evidence. And we also know that evidence from other species, while holding true for their species, can mislead us about humans. Only results from humans can send us in a clear direction as to the effects of LLR, but since humans cannot be the subjects of future LLR studies, we must look to the alternative.

Experiments conducted on laboratory animals are an important step in the analysis of the effects of Low Level Radiation. One experiment, reported by Dr. Lorenz during the Manhattan Project exposed laboratory animals to different levels of radiation per day to show a relationship between dose and survival time. The animals used were mice, rabbits and guinea pigs. Doses of 8.8 rem, 4.4 rem, 2.2 rem, 1.1 rem, and 0.11 rem where given to subjects for eight hours a day until death. The results of this experiment showed that the animals exposed to 0.11 rem per day outlived those that were not exposed. The average survival time for non-exposed mice was 703 days compared to 761 days for those exposed to the 0.11 rem per day and 1400 day for non-exposed guinea pigs compared to 1457 days to those exposed to 0.11 rem per day (Muckerheide & Rockwell 1997, Lorenz 1954).

We can see a similar trend in an experiment by Spalding and Associates at LANL (1982) where lab mice where exposed to different levels for different amounts of time. Their survival percentage was compared to that of control mice. "The average lifespan of the irradiated groups tended to be longer that that of sham irradiated mice. Note that the lowest dose rate for these healthy mice, 7 mGy / day, is about 800 times greater than that recommended for humans, 5 mGy / day."(Dr. T.D. Luckey 1995)

Other studies show increases in longevity for animals irradiated with low levels of radiation. Dr. Harold Boxenbuam's experiment of irradiating wild chipmunks with a single dose of 200 or 400 Roentgens gamma radiation, showed that compared to a control group, they survived longer ."(Dr. T.D. Luckey 1995). (Spaulding 1982).

The trends seen by the data in these reports are that of a Hormesis model. When something is hormetic, it is harmful at high doses while being beneficial at low doses. Some common examples of hormetic substances would be salt or iodine. All of the evidence supports the idea that exposure to very low levels of radiation do not cause any detrimental health effects, but in fact perhaps provide beneficial effects. This type of evidence needs to be more heavily considered when assessing the risk of Low Level radiation, which could lead to a significant change in cost in radiation reduction plans and technology.

Data Supporting a Linear Model

Not all radiation studies refute the LNT theory. From a study of the experience of British workers involved in the preparation of instrument dials made luminous with radium, Baverstock reported highly significant proof of breast cancer induction by gamma radiation in young female workers who applied the radium-226 to the instruments. The total breast dose accumulated by the young women was 40 rads (cGy). The dose rate of external gammas to the breasts was, by measurement, 0.5 rad (cGy) per week or less. For a 40 hour week, this represents a dose of 0.1 rad per 8 hours (per day). Among the women whose average age was twenty years at the time of first employment, breast cancer was observed at twice the expected rate during a limited follow up period. (Gofman 1990) These dose rates, however, are much higher than the above studies that dispute the validity of the LNT. LNT supporters believe that while the dial-painter study appears to be a high-dose study, it demonstrates the inability of the body to adequately repair damage after exposure to low-level radiation.

Before continuing with further evidence that supports the LNT theory, a description of what "safe dose or dose rate" means will be given. A "safe dose or dose rate" is when all exposed persons are safe as the exposure occurs, and all are safe afterwards. No fraction will be killed later by radiation induced cancer. In contrast, "no safe dose or dose rate" means that no one is safe as the exposure occurs, and after, some fraction of the exposed persons will die from radiation induced cancer and the rest will be safe from it.

In the Nova Scotia Fluoroscopy Study, Myrden and Hiltz studied 243 women who had chest fluoroscopies with the beam traveling from front to back. The estimated absorbed breast dose was 7.5 rads per fluoroscopy. Time between fluoroscopies was days or weeks. The total breast dose accumulation per woman was about 1,221 rads when the therapy was bilateral and about 741 when it was unilateral. The average breast dose in these women was about 850 rads. Breast cancer was observed at more than six times the expected rate during a limited follow-up period. (Gofman 1990). Such a low one-time dose of 7.5 rads resulting in a 6-fold rate of breast cancer seems like a significant find, but the very high total dose (thousands of rads) is most likely responsible for the increased cancer rate.

A study in Modan, Israel examined the scalp-irradiation of over 10 thousand Israeli children who received X-irradiation for ringworm of the scalp. The estimated thyroid dose per child was a single dose of 9.0 rads. Thyroid cancer was observed at four times the expected rate during a limited follow-up period. The expected rate is derived from a control group which was matched by age, sex, and demographics, and a second control group of unirradiated siblings. However, recent developments indicate that radiation delivered to the scalp might also have affected the pituitary gland, which could indirectly contribute to the incidence of thyroid cancer. These affects are yet to be fully clarified by the authors of the study, and the case continues to be examined. (Gofman 1990).

In an In-Utero study performed by Stewart and co-workers, the X-ray histories (maternal) for children who died of cancer or leukemia was compared to that of matched controls who had no malignant diseases. The best estimated dose to the fetus (third trimester) was 0.5 rad per obstetric examination. A 0.3 rad per film exposure has been suggested. It was shown by comparison of the groups that diagnostic X-rays during pregnancy, irradiating the fetus-in-utero, provoked about a 50 percent increase in the frequency of childhood cancer and leukemia. The estimated relative risk of cancer associated with obstetric radiography is now about 1.94. (Gofman 1990).

Much of the evidence cited as proof of harm from low-dose exposures are actually at comparitively high doses, especially when compared to background radiation or typical modern-day exposure rates. Others are plagued by confounding factors, such as the pituitary gland affects in the Modan study. These supposed low-dose studies attempt to disprove studies like Cohen's radon vs. cancer incidence and Jagger's NBR vs. observed cancer effects. However, the problems mentioned above fail them from doing so.

Ultimately, it seems that for all existing populations, insufficient data exists at the lower dose levels to allow for a comprehensive understanding on which to base a thorough and efficient risk-assessment model. A general consensus exists that more data at low doses and a greater understanding of the nature of radiation is necessary before a universal conclusion can be reached (Strom, BIER V).

Financial Justifications vs. Public-Safety

A primary reason as to why the LNT model has been accepted for so many years is because of its easy justification to the public. Since it errs on the side of safety, people have no problem accepting the idea that the government is trying to reduce all possible amounts of radiation. They feel the model is suitable for policymaking in this sense. However, when informed of the price of enforcing these regulations when compared to the benefits which they bring, the public may be willing to set policy standards to a new, less conservative model.

The debate may come down to the concept that society as a whole is not willing to spend an unlimited amount of money to save a human life. The regulatory powers need to reconsider the spending of billions of dollars on protective measures. These measures have not been proven to prevent any deaths directly, or even to indirectly prevent deaths. The only cause of death directly attributable to regulated U.S. radiation sources is that of radiation poisoning. There have been no recorded deaths of this type in 40 years (Cohen 1990). Meanwhile, other public-health-preserving programs are noted for their reductions in yearly deaths. For instance, automobiles claim tens of thousand of lives per year. It is indisputable that putting more money into government transportation programs, improving roads and so on, would reduce the yearly death toll. But instead, the government spends billions of dollars on protective measures at nuclear power plants, reducing the radiation level of the plant from that of the natural radiation levels of Denver to those of Boston. At the same time, power providers are forced to choose the alternative of coal plants because of the prohibitive cost of nuclear power, yet each coal plant is blamed for 3,000 human deaths over the lifetime of the plant. If a less restrictive model and policy were adopted by the regulatory powers that be, billions of so-called public health measures could be spent in other public health programs at a much greater yield. (Cohen 1990)

With so much controversy and evidence against it, it seems strange that the LNT model is not only used for government policy decisions and public education, but that it is still vigorously defended. If the effect of radiation on the body, while harmful at higher doses, may be beneficial at low doses, the argument of erring on the cautious side by reducing radition exposure to a minimum loses its validity. The policy question then becomes what is the level of radiation that maximizes benefit and minimizes disease and mortality. It seems only natural and logical to take a close, unbiased look at the models suggested, the data at hand, and the relative costs of safety, and adjust relevant policies accordingly.

References:

Cameron, John R.

Argument against the motion that the LNT model is appropriate for the estimation of risk from low-level (less than 100mSv/year) radiation, **Medical Physics** Vol. 25, No. 3, March 1998

Calvert Cliffs' Coordinating Committee v. Atomic Energy Commission

146 U.S.App.D.C. 33, 449 F.2d 1109, 1111 (1971).

Chan, John Y.H.; Li, Li: Fan, Yu-Hung; Mu, Zhao-Mei; Zhang, Wei-Wei; Chang, Kun-Sang

Cell-Cycle Regulation of DNA Damage-Induced Expression of the Suppressor Gene PML, **Biochemical and Biophysical Research Communications** Vol. 240, pp 640 - 646, October 1997 Article No. RC977692

Cohen, Bernard L.

Argument against that motion that low levels of radon in homes should be considered harmful, **Medical Physics** Vol. 25, No. 3, March 1998

Cohen, Bernard L.

The Nuclear Energy Option: An Alternative for the 90s, Plenum Press 1990

Gofman, John W.

Radiation-Induced Cancer From Low-Dose Exposure: An Independent Analysis, First Edition. (Committee for Nuclear Responsibility Books, San Francisco, California.) 1990.

Hahn, R.W. and Hird, J.A.

"The costs and benefits of regulation: Review and synthesis, Yale J. Regulation 8, 233-278 (1991)

Jagger, John

Natural Background Radiation and Cancer Death in Rocky Mountain States and Gulf Coast States, **Health Physics**, Vol. 75, No. 4, October 1998

Kondo, S.

Tissue-repair error model for radiation carcinogenesis, Proc. 12th Int. Congr. Photobiol (1996)

Mossman, Kenneth L.

Where do we go from here?, **Medical Physics** Vol. 25, No. 3, March 1998

Muckerheide, Jim

Nuclear News September 1995, The Health Effects of Low-Level Radiation

Muckerheide, Jim

Low-Level Radiation Health Effects: a Compilation of Data and Programs, Revision 4, March 14, 1998

Muckerheide Jim and Rockwell, Ted

21st Century Fall1997, Nuclear Report

NRC's Committee on the Biological Effects of Ionizing Radiations

BIER V Report

Roth, Eike

The Brittle Basis of Linearity, 1998, IAEA-CN-67/6

Sinclair, Warren K.

The linear no-threshold response: Why not linearity?, **Medical Physics** Vol. 25, No. 3, March 1998

Strom, Daniel J.

Argument for Both Motions, **Medical Physics** Vol. 25, No. 3, March 1998

Interview Methodology and Discoveries

Methodology

For this project we conducted interviews with several experts in the field in person, via telephone, and via the Internet. Several issues were taken into consideration beforehand so as to allow for the most productive interview session possible. These issues dealt with the selection of suitable experts in various nuclear related fields that would be able to provide useful perspectives that would help us towards our final conclusions on our research.

For a given interviewee, we first needed their background information, which was provided by Mr. Muckerheide. From this information we decided on which areas to direct our questions for each interviewee, avoiding irrelevant or unanswerable questions during the interview.

Secondly, we prepared a well thought-out list of questions. We operated under the assumption that our discoveries in interviews would be primarily in the form of personal judgements in each expert's areas, as opposed to straight "numerical" data that is obtainable through other sources.

During the interview, we advanced our questions from general to specific, choosing the direction of the interview based on previous questions and the expert’s own background.

However, our primary goal was to uncover pertinent information, and if the conversation drifted too far away from our objectives, we attempted to reroute the interview back to the correct direction.

The form of interview was the in-depth qualitative interview as described by Professor Doyle in the *Introduction to Interviewing Techniques* chapter of the IGSD IQP Handbook. This format allowed us to adjust our questions based on how the interview proceeded through the questioning, following up on the ideas and facts revealed to maximally clarify the subject. The interview style is unstructured and conversational, consisting of open-ended questions that allow the interviewee to follow whatever lines they feel are appropriate. This allowed the interviewees to best show their knowledge and specific point of view.

We felt this method of interviewing was the most appropriate given our objectives and resources. Other methods, such as focus groups and standardized interviews would be inappropriate or non-optimal considering the goals of our paper and the nature of the field and its state of debate.

The ultimate goal of these interviews was to complement the knowledge we had gained from literature and publications with the insight and very current relevancy that only a professional in the field can contribute. A large part of our study is based on the conflicting opinions of various factions; these interviews presented us with the opportunity to directly understand the arguments of one side versus another and to confront the resulting thoughts and counter-arguments that surround each issue.

Because of the fierce debates surrounding the issues we investigated, we made sure to have a well-rounded assortment of interviewees. To give our project a comprehensive scope, we included opinions from all sides of the debate. Optimally, we could base questions in later interviews based on information gained in earlier interviews, where opposing opinions would come into contact to expose the essence of the debate.

Finally, we tape recorded the interviews, so that we could be more concerned with interviewing than note-taking during the interview, and so that we could have an exact record of what was said when it came time to analyze the data that we have gained.

We presented ourselves in a professional manner to the interviewees so as to avoid the impression that we were wasting their time. In that vein, our questions were made to be as pertinent as possible in order to keep the meeting moving at a quick pace; however, we took steps not to rush the interview in any way. During the interview, we were prepared to offer follow-up questions when appropriate, as this provided valuable in-depth data directly relevant to the project that we might not find elsewhere.

James K. Doyle

Chapter 11: Introduction to Interviewing Techniques, Prepared for the Interdisciplinary and Global Studies Division IQP Handbook, Worcester Polytechnic Institute http://www.wpi.edu/Academics/Depts/IGSD/IQPHbook/ch11.html

Interview 1: Dr. Ed Calabrese

The first interview we conducted was with Dr. Ed Calabrese, of the University of Massachusetts at Amherst. The summary of the interview follows.

Starting off the conversation, we asked if Dr. Calabrese felt that a linear dose-response model is appropriate for risk estimation of radiation at low doses.

He stated that the model is appropriate as a start. It deals only with protection, and for that cause he felt that it was adequate, for any error would be on the side of safety. He went on to explain that the government's main objective with this policy is to eliminate public fears. If the public knows that they will be protected to the fullest extent by the policy, then the policy is adequate.

Following up, we asked what evidence he would site to back up his standpoint. He felt that more significant than biological or epidemiological evidence was the social and political climate of today concerning radiation. There is much fear and mistrust of radiation, he believes, and this policy best alleviates those fears.

When we went on to ask if he felt there was significant data on which to alter policy, he quickly stated that too much is unknown about radiation at this point to change policy.

Concerning exactly what type of data would be significant on which to alter policy, i.e. epidemiological or biological, he felt that because we cannot precisely measure the effects of irradiation at low levels, a further understanding of the biological functions behind irradiation and its effects would be necessary.

When the topic of reparation of DNA damaged by irradiation came up, Dr. Calabrese quickly stated that he believed DNA repair to undoubtedly take place and contribute to the body's defenses against irradiation. He cited a large issue that recently appeared in the *Journal of Science*, and implied that the discoverers of DNA repair could very well be candidates for a Nobel Prize in the near future.

In closing up the interview, Dr. Calabrese went on to reiterate the point that the whole debate was entangled in politics, and discussed that politicians only hear the "squeaky wheel" - the loud protesters. Until society is more enlightened regarding the effects of radiation on human health, especially at low doses, politicians will be unwilling to make changes that would favor nuclear technology and industries.

We next Dr. Calabrese if he felt that current policy model was in the best overall interests of the public's health. We put forth the conjecture that money saved in the nuclear regulatory industry could be used towards the public health in other fields, for example transportation safety and medical research. Dr. Calabrese stood by his earlier statements, saying that the current policy model serves its purpose: it protects the people. He felt that more money than necessary is probably spent as a result of this policy, but getting things changed will require a better understanding of radiation, because as the public now sees it, without this policy they are at risk.

When asked what changes he would suggest to the current model for risk estimation, he stated that he felt no changes were necessary at this point.

Interview 2: Dr. Richard Wilson

Our next interview was with Dr. Richard Wilson of Harvard University. This interview was conducted via E-Mail on 2/11/99. A full transcript follows. Our questions are in italics, Dr. Wilson's responses are in plain text.

Do you feel that a linear dose-response model is appropriate for risk estimation of radiation at low doses?

Yes, provided that it is considered to be a precautionary principle and applied in a similar way to all societal pollutants.

What evidence would you site to back up your standpoint?

See the list of references carefully collected in http://phys4.harvard.edu/~wilson/lowdose.html

1. The RERF data fit a linear model
2. The cancers produced are similar to background cancers and under these circumstances a small increase of radiation is expected to add linearly to

background (see Crump, Guess and Peto in 1975 and Crawford and Wilson in 1995/6)

How valuable is epidemiological evidence when debating the LNT theory?

Not much good below 10 Rems lifetime dose.

Have there been any recent advances in epidemiological studies?

The Preston, Pierce Mabuchi analyses of RERF data use superior statistical techniques which push the limit down to perhaps 10 Rems from 20 Rems.

I do not know what to make of Cohen's "ecological" studies of radon.

Do you feel there is significant data on which to alter policy?

Yes. Because policy has not used the linear theory [correctly]. We should spend to reduce exposure: $10-$100 per person-Rem occupational exposure, $2,000 per person-Rem public exposure and NO MORE.

What are you feelings on the reparation of DNA damaged by irradiation?

I have none.

What changes would you suggest to the current model for risk estimation?

None

Is there a general protocol that must be followed before any type of transport or disposal is possible?

DOT policies should be followed and [the] public hearing [should be] abbreviated to no more than six weeks.

How has policy on nuclear waste disposal changed over the last 2 decades, and where do you see it heading in the future?

Two decades ago the US government (AEC) had a plan (Lyons Kansas). Now the plan is [to] do nothing and spend $5 billion a year talking about it. [The issue of nuclear waste disposal is headed] nowhere unless legal action is taken. See for example the Skull Valley Goshutes who want nuclear waste in their own back yard. We must fight to let them have their own way.

Interview 3: Dr. Michael Fox

Our next interview was with Dr. Michael Fox, retired, formerly of the Pacific Northwest lab at Hanford. This interview was conducted via telephone on 2/15/99. The format of the transcript is the same as the previous interview.

Do you feel that a linear dose-response model is appropriate for risk estimation of radiation at low doses?

No. On this planet, where I and everyone else live, there is a sea of radiation, and the sea varies a lot. There are very few people that have relatively high doses of natural radioactivity, and I'm here in eastern Washington and just 135 miles to the north east of us is Smokehead County. Smokehead county, according to Washington state data averages, the average annual dose to residents is 1500 mRem a year from radon alone. If you're living in an average natural background area, which will depend on the altitude, we get maybe a total of 350-360 mRem a year; 200 of that is radon. But Smokehead county is getting 1500 mRem from radon alone and so I've looked up all cancer data from the state of Washington, and there aren't any excess cancers, including lung cancers, which is what we call the "critical organ". Because you inhale radon gas when you breathe.

Do you feel there is significant data on which to alter policy?

There are tremendous amounts of information. What's happening is [with] the cell metabolism. A lot of people are now able to analyze the metabolites quite specifically on a cellular level, which is a huge advance in analytical chemistry. They've been able to determine the amounts of metabolites that are not only in each cell of the 48 billion cells in our body, but also from a variety of studies, they know how many metabolites are formed in various radiation fields. And the radiation fields that have any application to us are from power plant operations or standard operations for cleanup activity. These are so low, in terms of doses that the load itself is at 100mrad per year exposure which is 1 ten millionth of the metabolite load that is there already, naturally. If you consider the actual measurement and the standard deviation on that number of metabolites in the cell, it's going to be a 5 percent variation. It will absolutely swamp any effect caused by a radiation field and you'll never measure it, therefore you'll never see any adverse health effects.

If the critics were correct, if their Linear theory was correct, then the cancer rate in Smokehead county would be three times what they are here because the lung exposure is at least three times higher. So you look up the cancer mortality data and you don't see that at all. Therefore the linear theory is wrong.

Why do you think the policy-making agencies are still using a linear model at low levels?

That's pretty easy. The policy is driven by fear, it's not driven by science. It's driven by fear and advocacy and I know for a fact you have anti-[nuclear activists] running the show. You have Dan Riker who is one of the founding fathers of the NRDC, he's secretary there. You have Bob Alvarez who works in the office of the secretary [of the U.S. Department of Energy]. They are in a position to make policy and to fund those particular groups that might have something adverse to say about it. It's a real mess. When you have policy such as radiation exposure standards that are not based on science but are based on fear, it in fact has cost millions and millions of dollars. I happen to know quite a bit about the relative cost of a power plant for example. In China they have 400 Megawatt, huge power plants and they were built in 53-54 months and they cost 1.3 billion dollars each. Now that's at least a third the cost of what it would cost in the US and it was built in half the time. That means in China they will have a low cost of electricity.

How valuable is epidemiological evidence when debating the LNT theory?

Well, epidemiological studies are a problem because even epidemiologists admit they are a fairly blunt instrument. And it's easy to "fudge" the numbers especially when they're in front of a press conference or in front of a group who are not familiar with statistics and whatnot. All in all, you really have to pay attention to the author, that's one thing I do. So if I see certain names, I don't even read it anymore. Because they're dishonest….they have MD's, PHD's, but they are dishonest.

I'm cursed with a very strong scientific background and one of my favorite people in science was a Nobel prize winner, Richard Feiman, and he says wonderful things. One of them was that "a scientists first obligation is to try to prove himself wrong." You should not be an advocate of a particular hypothesis or theory, you should be willing to look at it, challenge it, and examine all corners of it's application. They are 1st rate lawyers and 4th rate scientists. Regrettably, when it comes to policy making you can have trouble getting recognition. It's really hard for our country because we spend so much of our resources chasing small risks such as protecting our society from small doses of radiation, most of which are exceed by natural exposures.

Discoveries

In summary, there was much disagreement in opinion among our interviewees. We had a fairly diverse representation of the radiation policymaking community.

Dr. Wilson tended to take the opinion of the linear-model supporters, typically proposing wide-sweeping bureaucratic solutions to the problems (such as his per person-Rem payments to reduce exposure).

Dr. Fox took the opposite side, believing that the linear model is horribly inappropriate at low levels. He feels that data exists today that would facilitate changes in policy if the regulatory field were not so tied up in politics and bureaucratics.

Dr. Calabrese often took a middle-of-the-road approach. He believes that ultimately the linear model will be found to be incorrect, but in the meantime it offers safety, security, and at least a partially legitimate way to make policy.

The interviewees did not agree on the appropriateness of the linear dose-response model for risk estimation at low doses. The supporters (Calabrese and Wilson) claimed that since it errs on the side of safety, the regulations will be adequate. Professor Fox, however, strongly disagrees, using radon epidemiological studies as his proof that at low levels, there is a definate non-linear dose-response pattern.

The interviewees also disagreed on whether or not there was significant data on which to alter policy. Calabrese felt that too much is unknown about radiation to change policy, while Wilson felt that we should spend fixed amounts to reduce exposure: $10-100 per person-Rem occupational, and $2,000 per person-Rem public exposure, and no more than that figure. Even he feels that we are in danger of, if not already overspending on radiation protection. Fox feels that significant biological and epidemiological data exists to alter policy to a nonlinear model.

In discussing the usefulness of epidemiological studies, Fox feels that the numbers are too easily fudged to rely on too heavily. He feels that well-documented, objective studies are unquestionably helpful in policymaking, but unfortunately too many studies are conducted by special-interest groups that are looking to prove that their theories are right and their interests protected.

Wilson feels that certain studies push the "questionable level" of low radiation down as low as 10 Rems. He admits that he doesn't know what to make of Cohen's "ecological" (his use of quotes) studies of radon.

The consensus on why the linear model is still used seems to be that the motives behind policymakers are political and fear-driven. Societal education on the myths and realities of radiation will surely help to eliminate this over time.

Both Wilson and Calabrese felt that no changes should be made to the current model for risk estimation at this time. They believe that a greater understanding is needed before that happens.

Industries Affected by Radiation Policy

The Nuclear Power Industry

America's power needs are served today primarily by coal, gas, oil and nuclear power. These sources, while providing adequate power for the present, will need to be expanded in the years to come. As more and more nuclear plants exceed their life span and are decommissioned, we are forced to rely more and more heavily on coal, gas and oil. These three types of power generation release immense amounts of carbon and other pollutants into the air, causing a wide variety of undesirable effects, like acid rain, air pollution, and global warming. A potentially beneficial alternative to the future of American power is Nuclear Energy.

Nuclear power's advantages over its competitors are numerous. Firstly, nuclear power produces no harmful air pollutants, unlike coal-fired and oil-fired power plants. CO_2, one such pollutant, is blamed with causing global warming, which could have severe consequences to coastal areas. Pollution from coal and oil-fired plants also has harmful effects on human health, as well as contributing to acid rain, which is very harmful to nearby environs including plant life and animal life, particularly fish. In December of 1997, more than 160 countries met to negotiate binding limits for greenhouse gas emissions for developed nations. The result of this summit was the Kyoto Protocol, which aims for an overall reduction of 5.2 percent relative to 1990 emissions. This protocol has not yet been ratified by the United States government, and our nation's coal, gas, and oil plants continue to emit vast amounts of carbon (EIA 1999).

Nuclear power also has an advantage in that there is an abundance of fuel available, and more advanced methods of nuclear power production, such as breeder plants, extend the life of fuel exponentially more. Coal and especially oil are much scarcer, and oil in particular is used for many other applications besides power production. Global conflict has erupted over control of precious non-renewable resources -- conflict that could be avoided with nuclear power.

Nuclear power plants are perceived today as prohibitively expensive to build and operate. While it's true that the billion dollar startup cost of a nuclear plant is very expensive, in the long run, nuclear power is far less expensive due to the small amount of fuel required for energy, the abundance of that fuel, and the cleanliness of the process. Per kilowatt-hour, as of 1990 nuclear power competes with coal as the most efficient fuel for power production [figure 12] (NEI 1998). However, some predict that in the future, these figures will change quite distinctly in some regions [figure 13] (OECD/IEA NEA 1998).

Fuel	Cost (cents/kWh)
Oil	4.14
Gas	3.38
Nuclear	1.91
Coal	1.83

Figure 12: 1990 Electricity Costs by Source (NEI 1998)

Country	Nuclear	Coal	Gas
France	3.22	4.64	4.74
Russia	2.69	4.63	3.54
Japan	5.75	5.58	7.91
Korea	3.07	3.44	4.25
Spain	4.10	4.22	4.79
USA	3.33	2.48	2.33-2.71
Canada	2.47-2.96	2.92	3.00
China	2.54-3.08	3.18	-

Figure 13: 1998 Projected Costs of Generating Electricity (OECD/IEA NEA 1998)

(US 1997 cents/kWh, Discount rate 5% for nuclear & coal, 30 year lifetime, 75% load factor.)

A large concern about nuclear power in the mind of the public is the safety factor. With what happened at Chernobyl and Three Mile Island still fresh in the minds of the public, it is difficult to alleviate the public's fears of nuclear power. The reactions to these two accidents, however, are typically disproportionate to the actual risk involved.

What the public fails to recognize about the Chernobyl disaster is the inherent differences between the type of reactor used in the Chernobyl plant and a typical early-generation American reactor. All reactors rely on what is known as a moderator to allow the efficient usage of less-pure fuels. This moderator acts as a catalyst of sorts in propagating the reaction. If the moderator is removed, the reaction would slow down and eventually stop. Early in the history of nuclear power, there were two schools of thought on which type of moderator to use.

One possible moderator is pure graphite because it is very effective in getting a highly efficient result out of less-than optimal fuels. The alternative to pure graphite is water, which is less effective in producing a reaction. However, if the fuel is enriched to a small extent, water proves to be an acceptable moderator.

The Russians opted for the graphite moderator approach, because of better yields without enrichment, and the ability to easily extract substances to be used in nuclear weapons. The Americans chose to use water as a catalyst, which prevents extraction of nuclear weapons material, but which ends up being a much better choice nonetheless.

In all reactions, extremely high amounts of heat are produced, and some sort of cooling system is needed. In systems where graphite is used as the moderator, water runs through the graphite rods, drawing the heat out of the rods and into the cooling system. In this type of configuration, the water actually acts as a "poison" to the reaction, slowing it down. Water is also used to cool American reactors, but should the flow of water somehow stop, the reaction would slow down and stop because of the lack of a moderator.

Knowing this, it is easy to see how an accident like the Chernobyl disaster could happen. If something happens to go wrong with the cooling system, and water is prevented from reaching the reactor, the reactor overheats dramatically, and furthermore since water was acting as a "poison" to the reaction and is no longer reaching the reactor, the reaction speeds up. At this point, the reaction is uncontrolled and uncooled, and a disaster is essentially guaranteed to happen. If an American reactor were denied of its water flow, the reactor would heat up, but without a moderator the reaction itself would gradually die down.

Furthermore, the nature of the Russian reactor's easily-accessible fuel rods, which allow for the extraction of plutonium for weapons, prevent the reactors from using a containment structure like the American reactors have. The containment structures used in U.S. reactors have immense steel and concrete walls that, should a meltdown ever occur, would keep everything within the confines of the containment (Cohen 1990).

As is plainly evident, a nuclear disaster like Chernobyl would be nearly impossible in even obsolete American reactors because of fundamental differences in design and operation.

The Three Mile Island incident is no more indicative of weaknesses in American nuclear power than the Chernobyl disaster. However, the difference with the TMI incident is more due to overreaction by the media and various groups on the left. Chernobyl was undeniably a disaster of large proportions. The Three Mile Island incident, while being costly for the utilities involved, was a relatively insignificant occurrence with respect to health effects. It was given supposed importance because of its location here in the United States and because of vehement protests by several activist groups.

In the Three Mile Island accident, a loss-of-coolant accident (LOCA) occurred because a valve failed to close. The operators at the plant misinterpreted instrument readings and believed the valve to be closed. Eventually, the problem was discovered, and a simple solution was implemented.

Had the error gone undetected for large amounts of time, a reactor meltdown could have happened at TMI. But since U.S. reactors have among other safety measures containment structures, the accident would have been contained, and no damage to human health or the environment would have occurred (Cohen 1990).

While neither of these accidents indicated any instabilities in the operation of modern nuclear plants, socially they have had a great impact on the public's perception and fear of nuclear power.

Risks created by nuclear plants would be further lessened because of research and experience in the field. Much of Europe and Asia are now relying on nuclear reactors as their primary source of power, and the art has reached a concrete state of sorts, with standards for designing and constructing power plants. With more experienced construction crews and a seasoned operations staff, these modular modern-day reactors would operate predictably and reliably.

The primary obstacle the industry needs to overcome is that of the transportation and disposal of nuclear waste. Nuclear waste emits considerable amounts of radiation for years after it is "spent", or done being used for power. Current methods for storing waste center mainly around putting it deep underground, but it is difficult to implement this sort of thing because of the "not in my backyard" philosophy most people have. Many other countries, such as France, Japan, and Germany have been using a process called "reprocessing". This allows some new fuel to be extracted from the waste, while the rest is disposed of underground. The United States has postponed both the development of reprocessing facilities and the development of nuclear waste depositories due to political pressure from various agencies and organizations. Currently, all nuclear waste is being stored in temporary cooling tanks at the power plants. The waste is safe here, but once the plants run out of cooling tanks, more must be built to avoid shutdown of the plants (Cohen 1990). Clearly, if nuclear power is to continue to be used, the waste issue must be solved.

Another major concern with nuclear power plants is that of external radiation to the nearby area. Studies have shown that the radiation output to the areas surrounding a power plant are minimal, and would pale in comparison to, for example, the natural radiation emitted by a mountain. The public fear of radiation emitted by a power plant is unwarranted. Moving from a house at a low altitude to a property next to a nuclear power plant would be equivalent to simply moving to a higher altitude such as Colorado. And since nuclear power plants are built at least 40 miles away from major population areas, the danger of irradiation from standard operation is insignificant.

Current radiation protection policy, however, does not take these factors into account. The linear non-threshold model used for policymaking maintains that even the smallest amount of radiation is dangerous, and that the agencies need to strive for an amount "as low as reasonably achievable" (Muckerheide & Rockwell). By this way of thinking, no nuclear plants should be built at all, because they do increase the amount of radiation in an area, even though that amount is insignificant compared to natural levels. This policy forces the use of alternative sources of power, like coal, gas, and oil. Unfortunately, oil is very precious, is used in many other industries, and is a source of global conflict. Coal is abundant, but emits carbon monoxide, which causes air pollution, acid rain, and global warming. Nuclear power has none of these problems, yet policy still blocks the way.

Another deterrent to the building of nuclear power plants is the long and arduous licensing process required to build these plants. While many precautionary measures must be taken before building a plant, the process today takes much longer than it should, and opposing groups can easily block the process for years at the cost of billions to the power companies, and through them to the citizens. New regulations by the NRC and other committees promises a more stable and predictable licensing process which will not see the billion-dollar roadblocks that previous attempts have led to.

Another perceived drawback to nuclear power is the danger in extracting fuel. This as well is an unfounded fear, as the same dangers lie in the mining of coal and the extraction of natural gases. In China in 1993-1994, the normalized death rate due to nuclear fuel extraction was estimated to be 3.5 man $(GW_e^a)^{-1}$, while the normalized death rate due to coal mining was 20 man $(GW_e^a)^{-1}$(Pan et al 1997).

A case can be made that nuclear fuel is in proportionally short supply, and at our current rates we would go through the available fuel in about 40 years. However, special reactors called breeder reactors can more efficiently utilize the fuel, allowing for 100 times more energy than today's reactors to be extracted from a given amount of fuel. With this technology, we would have sufficient fuel for thousands of years.

The future holds potential for nuclear power. As non-renewable resources become more scarce, driving the price higher, the United States will have to adopt alternatives to remain competitive. While hydroelectric, wind, and solar power offer perfectly clean methods of energy acquisition, they will probably never be cost-effective nor widespread enough to provide a base source of energy for the nation. Breeder plants, while not yet developed, would allow for getting much more use out of nuclear fuel than is currently possible. And an Integral Fast Reactor (IFR), essentially a breeder reactor with an on-site reprocessing facility, would allow for minimal exposure of spent fuels to the outside world.

With government support of the technology and research, nuclear energy can serve our country well into the next millennia.

References:

The Nuclear Energy Option: An Alternative for the 90s by Bernard L. Cohen, 1990

Preliminary Research of Health and Environmental Impacts from Coal-Fired Power and Nuclear Power Chains in China by Pan Ziqiang et al., April 1997

The Hazards of U.S. Policy on Low-level Radiation by Jim Muckerheide and Ted Rockwell, 21st Century Fall 1997

Strategic Plan for Building New Nuclear Power Plants by the U.S. Nuclear Energy Industry, Final Report, May 1998

1998 World Energy Outlook by the International Energy Agency, 1998

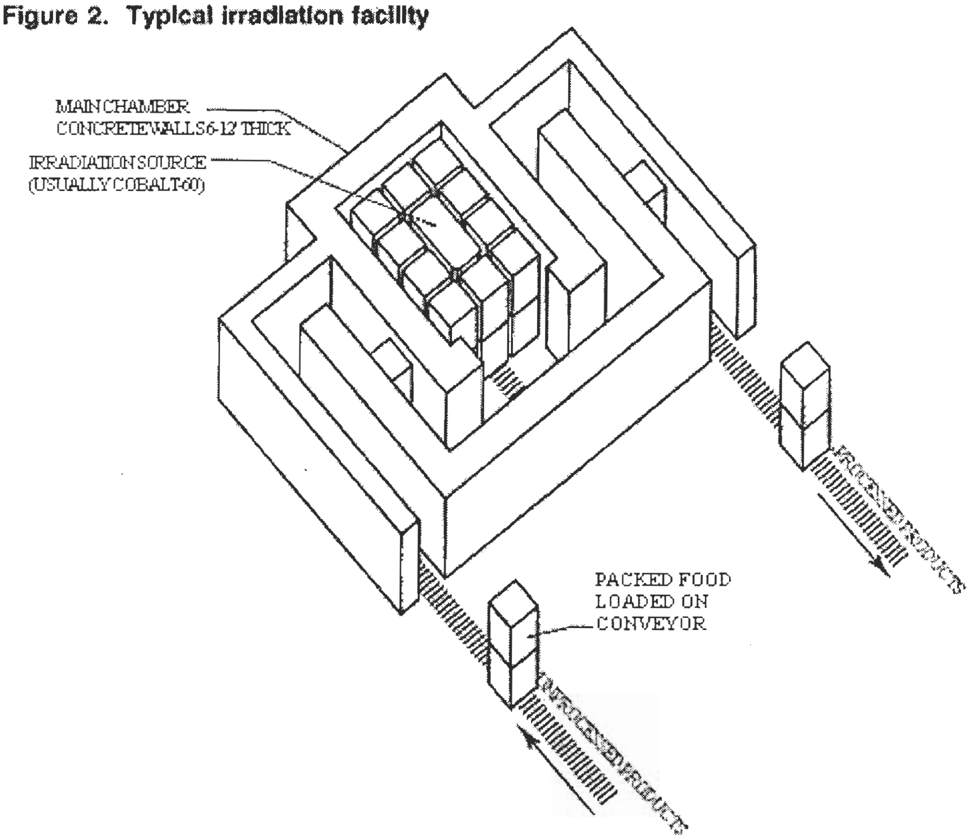
Annual Energy Outlook 1999 by the Energy Information Administration, February 1999

Food Irradiation

An area where radiation has the possibility to positively impact quality of life is the area of food irradiation. The process has been used to some extent on foodstuffs since the 60's, but hasn't gained widespread popularity. This area of nuclear energy usage is one that conflicts with other regulatory practices we have been studying in that irradiation is supported by such government agencies as the FDA, which is pushing for its expanded use. Irradiation should benefit consumers with improved product safety and freshness. One point that was strongly emphasized in the literature was that treated foods still needed to be handled properly because the irradiation only killed off contaminants at the time of treatment, but they could still be infected later. Irradiation is an extra precautionary step in the processing of food that increases safety beyond normal, but doesn't change the food in a positive or negative manner besides that protection.

To irradiate food, the radiation from Cobalt- 60 and Cesium-137 is used to kill bacteria and parasites in food supplies. It is performed by placing pallets of the material onto a conveyor belt which snakes through a lead shielded room containing the radiation source within stainless steel casings. The gamma rays from the source then irradiate the pallets as they travel along the conveyor belt (figure 14). The radiation source never comes into direct contact with the irradiated items, and the items are exposed to very low doses of irradiation. The speed of the belt determines the amount of radiation received.

Figure 2. Typical irradiation facility



Source: Radiation Technology, Inc., Rockaway, NJ. Adapted FDA Consumer, July/August 1986, p. 14-15.

Figure 14 – A Typical Irradiation Facility

There were many benefits given for irradiation by the FDA on their web-site for foods, listed below:

1. Food irradiation can extend the shelf life of many fresh foods. This may be done through preventing sprouting, deactivating mold, and killing spoilage bacteria. With these contaminants eliminated before shipping, they will not damage the food unless re-contaminated later, so the items will have a lengthened shelf life when compared to normally prepared foods.

2. Food irradiation can improve world food supplies. There could be less food waste through reduction of post-harvest losses. The United Nations estimates that over 25 percent of the world's harvest is lost to spoilage and waste. Irradiation could allow many food items that now spoil quickly to be shipped to other countries, or to be grown, irradiated and stored in other countries where they will last longer with less spoilage.

3. Food irradiation could replace fumigants and other pesticides, This will result in a reduction of chemical residues in food because these methods of preserving food attempt to achieve the same result of irradiation, that is, to destroy contaminants, but when chemicals are added to foods, they remain with the food unless thoroughly cleaned, while irradiation is a one shot then gone procedure.

4. Food irradiation can improve food safety by destroying microorganisms Organisms that can be on food can cause foodborne illness and diseases. Consumers who have a high risk for foodborne illness, such as the elderly, the very young, and those with compromised immune systems, would especially benefit from irradiated food in this area.

5. Food irradiation causes little change in the food. The 'fresh' characteristics of foods that are irradiated are unchanged because the process raises the temperature of foods very little, if at all, at the doses used. In fact, it can extend the fresh shelf life of items and make it possible to keep foods longer and in better condition.

Below is a timeline with radiation limits and purpose, which shows the progression of regulations allowing irradiation of foods by the FDA since 1963.

Table from National Food Safety Database

Summary of Approved Food Irradiation Processes

Date	Food/Product	Dose (kGy)	Purpose
1963			
	Wheat and wheat flour	0.2 - 0.5	Disinfestation of insects
1964, 1965			
	White potatoes	0.05 - 0.15	Inhibit sprouting (and extend shelf life)
1983			
	Spices and dry seasonings	30 max	Disinfestation of insects and decontamination
1985			
	Pork (carcasses or fresh, non-heat processed cuts)	0.3 - 1.0	Control of Trichinella spiralis
1985, 1986			
	Dry or dehydrated enzymes	10 max	Control of insects and/or microorganisms
1986			
	Fruit	1 maximum	Delay of maturation (ripening) and disinfestation
1986			
	Fresh vegetables	1 maximum	Disinfestation of insects
1986			
	Herbs	30 maximum	Control of microorganisms (decontamination)
1986			
	Spices	30 maximum	Control of microorganisms
1986			
	Vegetable seasonings	30 maximum	Control of microorganisms
1990			
	Poultry, fresh or frozen	3 maximum	Control of microorganisms (including Salmonella)
1995			
	Meat, frozen and packaged (solely for use by NASA)	44 min	Sterilization (destruction of microorganisms)
1995			
	Animal feed and pet food	2 - 25	Control of Salmonella
1997			
	Red meat, raw, chilled	4.5 max	Control of microorganisms
	Red meat, frozen	7.0 max	

The 1997 irradiation of meats sold to the public was pushed through following Arkansas-based Hudson Foods' Inc. decision to voluntarily recall 25 million pounds (out of an average 8 billion per year consumed) of hamburger suspected of containing E. coli O157:H7, which according to the FDA causes about 20,000 illnesses and 500 deaths a year. Similar legislation is being pursued in Canada, headed by the Canadian Cattlemen's Association, seeking to increase the safety of their products.

The FDA went through a long process in deciding to pass this regulation, following the normal accepting review. Irradiation has been officially termed a "food additive under section 201(s) of the Federal Food, Drug, and Cosmetic Act. Section 409 [c][3][a] of the Act stipulates that food additives cannot be approved unless a fair evaluation of the evidence shows it to be safe for it's specified use. This does not mean that an additive has to be safe in excessive uses, only when used to normal levels. The "petition" or goal of this regulation is to reduce bacterial contamination, however, there is no requirement in the petition that positive health effects are caused by the additive, only that it has no negative effects under normal use. The FDA cites a report, "Evaluation of the Health Aspects of Certain Compounds Found in Irradiated Beef," prepared by the Life Sciences Research Office of the Federation of American Societies for Experimental Biology under contract with the U.S. Army that studied the minute effects of irradiating frozen beef in a vacuum at 56 kGy. Sixty-five active radiolytic products were identified, most of which originated from the lipid fraction. They found that these 65 radiolytic products were identical or structurally similar to substances found in normally prepared foods, and that these radiolytic products were found in very small amounts of about 1 to 700 parts per billion of irradiated beef, even at a radiation dose eight times higher than the highest dose desired by the petition.

When irradiated food is sold in stores, the FDA requires that it be labeled with either "treated with radiation" or "treated by irradiation" along with the international symbol for irradiation. This doesn't apply if certain ingredients of a product were irradiated. FDA studies show that irradiation reduces E.coli 0157:H7, along with the bacterias Salmonella (4 million illnesses, 1,000 deaths) and Campylobacteria (6 million illnesses, 75 deaths).

Currently the major problems associated with food irradiation are that the large food processing companies are concerned that consumers will not purchase such foods, and that there are currently few large-scale irradiation facilities, and none that can handle the amount of approved foods produced.

The Food and Drug Administration in approving recent additions of red meats to the list of irradiation treatable foods used a LNT type model, they stated the following in their Final Ruling on the matter of "Irradiation in the Production, Processing and Handling of Food": "With respect to dose, the amounts of radiolytic products generated in a particular food have been shown to be directly proportional to the radiation dose (Refs. 7, 8, and 9). Thus, it is entirely sound to extrapolate from data obtained at high radiation doses to draw conclusions regarding the amounts of radiolytic products expected to be generated at lower doses." This reasoning is distinct from that of radiation's effects on living tissue due to the lack of repair mechanisms in dead meat. The references they note are the following :

7. Merritt, C., Jr., ``Qualitative and Quantitative Aspects of Trace Volatile Components In Irradiated Foods and Food Substances," Radiation Research Reviews, 3:353-368, 1972.

*8. Morehouse, K. M., ``The Quantitative Determination of Radiolytically Generated Hydrocarbons in Meats," final report for U.S. Army, Natick Research Development and Engineering Center, Sustainability Directorate, under Interagency Agreement FDA 224-93-2448.

9. Merritt, C., Jr., et al., ``Effect of Radiation Parameters on the Formation of Radiolysis Products in Meat Substances," Journal of Agricultural and Food Chemistry, 26:29-35, 1978.

The temperature of the food has also been found to have an effect on radiolytic byproducts. A variety of radiolytic products derived from lipids have been identified, including fatty acids, esters, aldehydes, ketones, alkanes, alkenes, and other hydrocarbons. All of these products found in irradiated food are also found in food that has undergone normal processing and cooking. Freezing foods reduces the available motion of the free radicals allowing them to return to their normal substance without affecting surrounding areas, and irradiating in low oxygen reduces the amount of free radicals. Thus it is preferable to irradiate food in frozen and low oxygen environments to reduce the chances of altering the final makeup of the food in any way while still raising the safety of the food.

Food irradiation is presently limited more by societal prejudices than policy. The FDA and other regulatory bodies are beginning to loosen restrictions on irradiation. However, the public's perception of radiation is still negative, partly because of the government's model of linear dose-response. The reconsideration of that policy on the part of the government would surely lead to a wider acceptance of food irradiation in the future.

Summary

The nuclear community is clearly divided on the issue of human health effects of low levels of irradiation. Both sides feel that they have the evidence to support their viewpoint, and that the other side's evidence is bias-influenced or irrelevant.

Epidemiological studies support both sides of the debate, but bias can play a large role in the findings uncovered by these studies, and most are not comprehensive enough to resolve the matter one way or another. Some exceptions exist however: specifically, the background radiation vs. cancer incidence studies conducted by Cohen and Jagger. These studies are based on current, official data over large populations, and show that low levels of radiation are not only harmless, but can even be beneficial in some respects.

Current understanding of the specific nature of the biological effects of irradiation is sketchy at best. Some evidence exists of DNA repair stimulated by low levels of radiation, but insufficient evidence is currently available to clearly show the complete effects of irradiation.

It is clear, however, that exceedingly large amounts of money are being spent to enforce the linear non-threshold model. The phrase "as low as reasonably achievable", combined with large budgets, has led to grossly excessive spending.

Current regulatory policy, while erring on the side of safety, has too loose of an interpretation and needs to be more rigorously defined. By setting reasonable numerical limits on acceptable levels of radiation, the objective of public protection could be achieved while impeding the progress of nuclear-related fields, specifically nuclear power and food irradiation.

Politics also play a large role in current nuclear policy. Both the pro-nuclear and anti-nuclear sides take uncompromising stances on various issues, and the end result is that progress is stagnated by indecision. This is especially true when dealing with the construction and subsequent regulation of nuclear power plants and nuclear waste disposal. Without a more compromising approach to regulation of these fields, problems are sure to remain exactly as they are.

Equally important is the public perception of radiation and its risks. Current policy implies that any amount of radiation can kill you, and the majority of the public is justifiably scared of anything having to do with radiation. This is another major obstacle blocking advancement in the nuclear power and food irradiation industries. Even if no policy changes are made, the government needs to more thoroughly educate the public as to the real effects of radiation.

The issue of the beneficial effects of low levels of radiation is even more controversial. While there appears to be considerable evidence in support of this conclusion, significant uncertainty remains. However, if nothing else, the fact that low levels of radiation could even potentially be beneficial should cast serious doubt on the current state of radiation policy.

In conclusion, it is our opinion that sufficient data and knowledge of effects at low levels does indeed exist to alter policy from the current linear method of risk assessment. Current policy is too liberal in its protection, and needs to take a more enlightened, cost-effective approach to dealing with the effects of radiation. The government need only conduct a study of background levels vs. cancer incidence to see for themselves the fallacy of current policy.