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INTRODUCTION

The public generally accepts the premise that exposure to radiation can have an undesirable effect. Furthermore, it believes that as the radiation dose increases, the magnitude of the effect will increase. On the other hand, while the background radiation dose varies from a few hundred millirem/year (a few millisieverts/yr) in some places to a few thousand millirem/yr (tens of millisieverts/yr) in others, researchers have been unable to find a correlation between the level of background radiation and incidence of cancer or other maladies attributable to radiation.

No one is sure of the exact relationship between a low dose of radiation and its effect on living things. Several relationships have been proposed and three have been investigated and discussed at some length. They are referred to as the linear-nonthreshold (LNT), threshold, and hormetic models. The LNT relationship is the one that has been adopted by national and international regulatory bodies for use in developing radiation protection guidelines and regulations.[1] It is the most conservative of the three and is based on the assumption that exposure to any radiation above zero dose will have some effect. The threshold relationship was developed on the assumption that the human body can tolerate some amount of radiation without negative effects. More accurately, the assumption is that cells are able to repair damage done by radiation as long as the damage is limited. The Environmental Protection Agency (EPA) uses a threshold model

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1. Ronald L. Kathren, *Historical Development of the Linear Nonthreshold Dose-Response Model as Applied to Radiation Protection*, 1 Pierce L. Rev. 5 (2003); Ronald L. Kathren, *Pathway to a Paradigm: The Linear Nonthreshold Dose-Response Model in Historical Context: The American Academy of Health Physics 1995 Radiology Centennial Hartman Oration*, 70 Health Physics 621 (1996).

to predict health effects resulting from exposure to hazardous chemicals. Under the assumptions in the hormetic relationship, small amounts of radiation are thought to be healthful, perhaps as a result of the radiation stimulating the cell's repair mechanisms, which then repair damage done by radiation and other agents. Some examples of substances that are thought to have healthful effects at low doses and negative effects at higher ones include selenium and red wine.

Effects of radiation on living things are obviously independent of the model that human beings use to predict those effects. However, the model selected is important. It becomes the basis for regulations that dictate what dose members of the public may receive. The smaller that dose must be, the more expensive operation of any facility using radioactive material becomes. Wall thickness must be greater, more backup systems to minimize releases of radioactive material must be incorporated into the facility design, and at contaminated sites, more earth must be moved to ensure that the site is clean enough to meet standards. Some question whether it is efficient or even ethical to spend billions of dollars to reduce radiation doses to very low levels to prevent one or two postulated deaths when those dollars could be used to save many thousands of lives through immunizations, better sanitation, wider distribution of existing medicines, medical research, and so on.[2]

Because there is considerable controversy about the relationship between radiation dose and its effects, i.e., the shape of the curve, and because use of the LNT model does lead to standards that can be expensive to meet, national and international organizations periodically review the evidence related to the shape of the curve and issue recommendations on the shape that regulatory agencies should use. The National Council on Radiation Protection (NCRP) released its latest review in June 2001.[3] In its report, the NCRP concluded that there was not sufficient evidence to justify changing from the LNT model to another. The target release date for a report by the National Academy of Sciences on the biological effects of ionizing radiation (BEIR-VII) is October 2003.[4]

The papers in this issue of *Pierce Law Review* explore the potential impact of the shape of the dose-response curve, if any, on society. This paper focuses on the impact dose response curves have on public acceptance, including nuclear energy. Use of nuclear technology, as is true of

2. Zbigniew Jaworowski, *Radiation Risk and Ethics*, 9 Physics Today 24 (1999).

3. National Council on Radiation Protection and Measurements, *Evaluation of the Linear-Nonthreshold Model for Ionizing Radiation* (2001).

4. National Academy of Sciences, *Project: Health Risks from Exposure to Low Levels of Ionizing Radiation (BEIR VII – Phase 2)* <http://www4.nas.edu/webcr.nsf/5c50571a75df494485256a95007a091e/ bcfab2307a0344bb85256774004aa611?OpenDocument> (last updated May 11, 1999).

almost all technologies, offers benefits to society and presents some problems. Whether society chooses to take advantage of the benefits and deal with the problems or chooses to ban the technology often depends, in large measure, on public acceptance of that technology.

WHAT IS THE PUBLIC'S ATTITUDE TOWARD NUCLEAR TECHNOLOGY AND RADIATION?

The public's attitude toward nuclear technology depends on the specific technology being considered. As a tool for medical diagnosis and treatment, radiation is frequently used and generally accepted. A number of surveys have shown that the public believes nuclear power should be kept as an electricity generation option, although when asked whether more nuclear power plants should be built, most people are less positive. The use of radiation to sterilize food is controversial. There is not much discussion of the widespread use of radiation in scientific research, manufacturing processes, and routine non-destructive testing procedures – probably because the public is generally unaware of these uses. Nuclear weapons are at the end of the public acceptance spectrum with some people viewing them as a necessary evil in today's world and others insisting that they are just plain evil.

The root of the public concern about nuclear technology is fear of radiation. Two of the greatest concerns members of the public voice about nuclear power are the potential for catastrophic accidents or attacks at the power plants, which they believe may release large amounts of radioactive material, and management of high-level radioactive waste. The high-level waste is a two-fold concern. First, the public believes there is the potential for an accident that releases radioactive material while the waste is being transported. Second, even though the high-level waste is going to be buried deep in the ground and isolated from people and the environment, it will continue to emit radiation for tens of thousands of years, and the public is concerned that some of the radioactive material may escape over the millennia.

Since everyone is exposed daily to small doses of background radiation, the public has little choice but to accept those doses as a part of life, and most do so without comment. However, some make a distinction between small doses from "natural" sources and equally small doses from "man-made" sources. Natural sources include radioactive Carbon-14, Potassium-40, Uranium-235 and -238 and their progeny, and cosmic rays reaching the Earth from outer space. Man-made sources include medical and dental x-rays, fallout from nuclear weapons testing, tiny amounts of radioactive materials used in consumer products such as smoke detectors, and doses from normal operations of nuclear power plants and nuclear waste facilities. The characteristics of ionizing radiation and its effects on living things are the same whether the radiation is from a natural or a man-made source. However, the level of acceptance of radiation from natural and man-made sources can vary widely.

WHAT SHAPES THE PUBLIC'S ATTITUDE?

Public attitudes toward, and acceptance of, the various nuclear technologies are shaped by many factors. These include personal experience, formal and informal education, and information available through print, broadcast, and electronic media. Another important factor, often overlooked, is the atmosphere created by the body of laws, regulations, and guidelines that govern the operation of nuclear facilities and the use of radioactive materials.

Nearly one-third of all people who are admitted to a hospital receive some diagnostic or treatment procedure using radioactive material. Most of those people, their families, and perhaps close friends, develop their attitudes toward nuclear medical technologies as a result of this personal experience. If the technology has been beneficial to them, they are likely to accept it as a positive factor in their environment. People who work at nuclear facilities, and their families, generally accept nuclear technology as a positive influence on their lives. The nuclear facility provides jobs and pays local taxes. In addition, employees of nuclear facilities are usually well-versed in nuclear science and radiation protection, which gives them a feeling that they understand and have some control over the way the nuclear technology will affect them. At facilities where employees have learned that they were exposed to certain sources of radiation without their knowledge or were misled about the size of the radiation dose they received, the employees may be angry with the organization that misled them but not necessarily less acceptant of nuclear technology.

While some people have first-hand experience with nuclear technology or have an opportunity to learn about it in formal or informal classes, most people receive their information through the print, broadcast, or electronic media. In the past, public attitudes toward, and acceptance of, nuclear technology depended heavily on the sources consulted by the media and how the writers and editors chose to portray those sources. Sources included anti-nuclear activists, elected officials, government agencies, scientific organizations and publications, and the nuclear industry. Today, with approximately 40% of the households in the United States connected to the internet, people who are interested in learning about nuclear technology may select their source of information. Print and broadcast media are ubiquitous and still have significant influence, but organizations wishing to speak to the public directly may do so through websites.

Formal education in the United States does little to improve the public's understanding of radiation. The subject is often treated inadequately, or inaccurately, in text books, leaving students with a poor understanding of radiation and its effects. Such a small number of high school and college students take advanced science courses that the more detailed information available in those courses reaches very few people. In addition, supposedly well-informed nuclear scientists publicly disagree on the effects of radiation. Media that provide informal education such as books, movies, television programs, and even comics, often contribute to misunderstanding by portraying radiation as a powerful, mysterious, and dangerous force but providing no factual details. Movie and television personalities, most of whom have little training in nuclear science, occasionally reinforce that characterization of radiation in their pronouncements. Faced with so much negative information and with lack of consensus among scientists, members of the public are certain to develop a healthy skepticism about radiation.

Finally, the laws and regulations that govern the use of nuclear technologies shape the public's attitude toward radiation. For decades, those regulations have been based on the LNT model which indicates that any dose above zero has a negative effect, and the larger the dose, the greater the effect. Use of the LNT model also leads to the conclusion that a collective dose resulting from a very small dose to each of a very large number of people will result in the same number of deaths or illnesses as a relatively large dose to each of a small number of people. As a result of the regulations based on LNT, applications for licenses to construct or operate nuclear facilities must demonstrate that the radiation released from the proposed facility under normal or accident conditions will be below very low levels prescribed in the regulations and, in addition, will be as far below those levels as "reasonably achievable." News stories about hearings on the applications and discussions of the new facilities all carry the underlying message that any radiation is dangerous and should be avoided.

WHAT IMPACT WILL THE SHAPE OF THE DOSE-RESPONSE CURVE HAVE ON PUBLIC ATTITUDES?

The shape of the dose-response curve is likely to have little or no direct affect on public attitudes toward or acceptance of nuclear technology. Most people are not even aware that a dose-response curve exists, don't care about its shape, and wouldn't be prepared to interpret it if they saw it. The primary effect on public attitudes will be through indirect means. If the shape of the dose-response curve used to estimate effects of radiation on living things and as a basis for regulations governing nuclear facilities changes from the current LNT model, that change will begin to appear over time in a number of ways. The discussion of the effects of radiation in textbooks will be revised. Health professionals and radiation protection specialists will begin to give their patients and clients different advice on what radiation dose is acceptable. The regulations specifying allowable releases of radioactive materials, circumstances requiring evacuation of an area, allowable residual contamination at Superfund sites, and so on may be modified. The media may run stories on the new dose-response curve and implications of its adoption. How the change in the shape of the dose-response curve affects the attitudes of the general public will depend, in large measure, on how it is treated by these intermediaries.

The impact of a new dose-response curve on public attitudes toward radiation and nuclear technology will also depend on why, or under what circumstances, the new curve is adopted. In evaluation of the LNT Model for Ionizing Radiation, NCRP Report No. 136, the NCRP said:

> In keeping with previous reviews by the NCRP (1980; 1993b; 1997), the council concludes that there is no conclusive evidence on which to reject the assumption of a linear-nonthreshold dose-response relationship for many of the risks attributable to low-level ionizing radiation although additional data are needed (NCRP, 1993c). However, while many, but not all, scientific data support this assumption (NCRP,1995), the probability of effects at very low doses such as are received from natural background (NCRP, 1987) is so small that it may never be possible to prove or disprove the validity of the linear-nonthreshold assumption.

If the shape of the curve is changed without compelling evidence for the new shape, there will be lingering controversy. Proponents of the LNT model and any other shapes not selected will continue to argue that their model is more accurate. The decision will be perceived by some to be political or a result of pressure by special interest groups. It will be a very long time before the new curve's shape can override the LNT model's effect on public attitudes over the past half century.

If, on the other hand, a change in the shape of the dose-response curve is recommended on the basis of compelling scientific evidence, corresponding changes in public attitudes will come faster. The NCRP document quoted above indicates that the NCRP has some reservations about whether there will ever be compelling evidence for any dose-response curve shape. However, with the current focus on biological research and the rapidly improving techniques in that field, laboratory experiments that are impossible now could be routine in a matter of years. Verified, indisputable evidence of the effects (or lack of effects) of low doses of radiation on living things should bring about consensus among scientists and relatively quick changes in regulations. These would be newsworthy events and the public would be made aware of them. Changes in public attitudes would follow.

Compelling scientific evidence that the LNT model is accurate could also have an impact on public attitudes, although it is difficult to say what impact. One of the reasons much of the public is confused and frightened about radiation is that the experts do not agree on the effects of low doses. If the experts agreed on the effects, they would be more likely to agree on the level of protection required, and the public would be more likely to accept that opinion. If the public was convinced that the required level of shielding and security could and would be provided, its fear of radiation might subside, leading to greater acceptance of nuclear technology. On the other hand, the costs of such shielding and security are also likely to be well-known, and if they are too high, the public could decide that the costs outweigh the benefits, resulting in a rejection of the technology.

SUMMARY

While much of the public may be unaware of the existence of a curve that shows the relationship between low radiation doses and a body's response to them, public acceptance of the use of radioactive materials and nuclear power is affected by that curve. The shape of the curve influences requirements for radiation protection, health care professionals' advice to patients on the use of radiation, and textbook discussions of radiation and the uses of radioactive materials. As long as the shape of the curve is unknown, there will be debate among professionals about the effects of low doses of radiation, and the public will continue to have a nagging uncertainty about whether nuclear technology can be safely utilized. If a compelling case can be made for a particular shape to the dose-response curve, and the vast majority of scientists support the selection, then the public will be in a position to make its decision about whether to accept nuclear technology. A compelling case for a threshold or hormetic model is likely to lead to greater acceptance. A compelling case for the LNT model would probably lead to a public consensus on each of several nuclear technologies. That consensus could be either greater acceptance or rejection of a technology, depending upon the relative costs associated with protecting the public health and the perceived benefits of the technology.