

APPENDIX G

Information on Radiation Exposure and Risk

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APPENDIX G INFORMATION ON RADIATION EXPOSURE AND RISK

1. INFORMATION ON RADIATION EXPOSURE

Radiation is the release of energy from radioactive materials. The levels of the energy released vary greatly. The length of time radioactive material continues to release energy also varies greatly, from several seconds to thousand of years. The energy particles released by radioactive material travel in surrounding air and material until the excess energy is dissipated by subatomic collisions. These collisions may have a detrimental effect on biological tissue. A measurement of damage to biological tissues, known as the roentgen-equivalent-man (rem), is the standard used to assess the effects of the energy released from radiation. One millirem, a common subunit of the rem, is 1/1000th of a rem.

Radiation can be broken down into two basic categories: ionizing and non-ionizing. This section deals with ionizing radiation, which has enough energy to change an atom's structure. Low energy radiation given off by devices such as television, radio, or microwave ovens is non-ionizing and is not considered here.

Radiation is present everywhere in the environment in naturally occurring elements and from cosmic sources. These natural sources make up what is known as "background radiation." Humans are also routinely exposed to radiation from medical examinations and sometimes from therapy. Some consumer products, such as smoke detectors, also contain radioactive sources and contribute a small amount to overall exposure. The typical person living in the United States is exposed to about 360 millirem of radiation annually, mostly from natural sources (NAS-NRC 1990). The pie chart in Figure G-1 illustrates the percentage attributed to various sources of radiation.

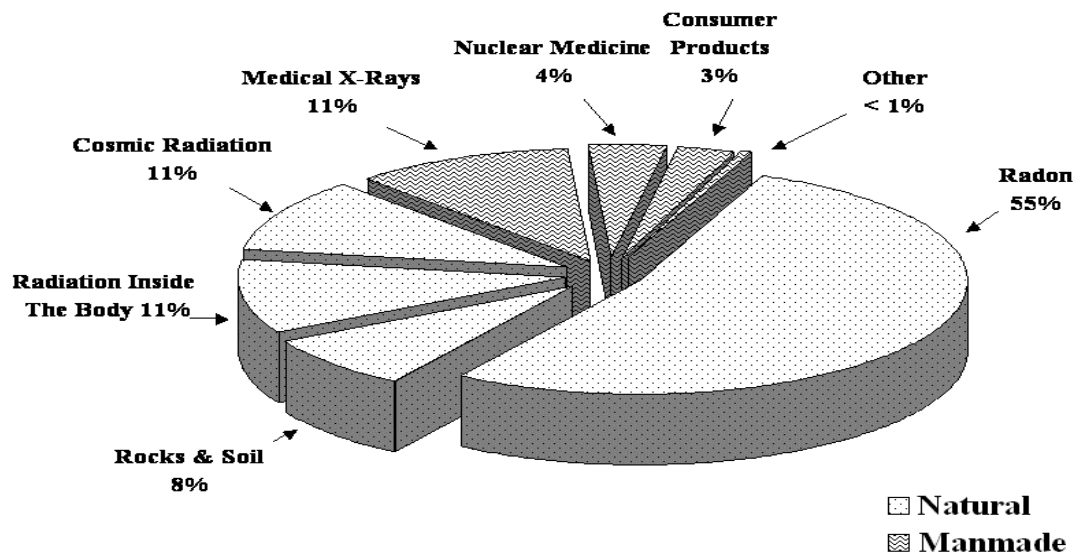


Figure G-1 Contributing Sources of Natural and Manmade Radiation for the Average American

The average person living in the U.S. receives about 295 millirem per year from natural sources and 65 millirem per year from man-made sources. Man-made sources are mostly from medical uses. Radon is by far the largest natural source of exposure (200 millirem per year). It originates below the Earth's

surface in certain geological formations and rises to ground level where people are exposed to it. Radon gas is often trapped and lingers in well-insulated buildings. Also, just being outdoors results in exposure to natural sources of cosmic radiation. A person living in Colorado receives 40 millirem per year more than a person living in New York. A round-trip flight from the U.S. to Europe would result in an additional 10 millirem each way. For comparison with a man-made source, a typical chest x-ray gives a dose of from 10 to 40 millirem.

Since 1974, the Naval Nuclear Propulsion Program (NNPP) has used thermoluminescent dosimeters (TLDs) as the primary means to measure radiation exposure of Navy personnel. It is characteristic of thermoluminescent material that radiation causes internal changes that make the material, when heated, give off an amount of light directly proportional to the radiation dose.

Control of radiation exposure in the NNPP has always been based on the assumption that any exposure, no matter how small, involves some risk; however, exposure within the accepted exposure limits represents a small risk when compared with normal hazards of life. The basis for this statement is presented below.

2. EXPOSURE TO RADIATION MAY INVOLVE SOME RISK

Since the inception of nuclear power, scientists have cautioned that exposure to ionizing radiation in addition to that from natural background may involve some risk. The National Committee on Radiation Protection and Measurements (NCRPM) in 1954 (NCRPM 1954) and the International Commission on Radiological Protection (ICRP) in 1958 (ICRP 1959) both recommended that exposures should be kept as low as practicable and that unnecessary exposure should be avoided to minimize this risk. The ICRP in 1962 (ICRP 1964) explained the assumed risk as follows:

The basis of the Commission's recommendations is that any exposure to radiation may carry some risk. The assumption has been made that, down to the lowest levels of dose, the risk of inducing disease or disability in an individual increases with the dose accumulated by the individual, but is small even at the maximum permissible levels recommended for occupational exposure.

The National Academy of Sciences-National Research Council Advisory Committee on the Biological Effects of Atomic Radiation included similar statements in its reports in 1956-1961 and in 1990 (NAS-NRC 1990). In 1960, the Federal Radiation Council (FRC) stated that its radiation protection guidance did not differ substantially from recommendations of the NCRPM, the ICRP, and the National Academy of Sciences (FRC 1960). This statement was again reaffirmed in 1987 (USEPA 1987).

One conclusion from these reports is that radiation exposures to personnel should be minimized. This is not a new conclusion. It has been a major driving force of the NNPP from its inception.

3. RADIATION EXPOSURE COMPARISONS

The success of the NNPP in minimizing exposures to personnel can be evaluated by making some radiation exposure comparisons. One important measure of NNPP personnel exposure is annual exposure, the amount of exposure an individual receives in a year. Since 1980, no individual has exceeded 2 rem in a year while working in the NNPP. Also, the average exposure per person monitored since 1980 is about 0.043 rem for Fleet personnel and 0.104 rem for Shipyard personnel. The following comparisons give perspective on these individual annual doses in comparison to federal limits and other exposures:

- The maximum individual annual dose of 2 rem is less than the federally allowed individual quarterly dose of 3 rem.
- The maximum individual annual dose of 2 rem is less than one-half the federal annual limit of 5 rem.
- Although no person in the NNPP has exceeded 2 rem in a year since 1980, between 150 and 8,489 workers at NRC-licensed commercial nuclear reactors have exceeded 2 rem in each year over this same period (NRC 2005).
- The average annual exposure of 0.043 rem for Fleet personnel is:
 - less than 1% of the federal annual limit of 5 rem.
 - less than one-fourth of the average annual exposure of commercial nuclear power plant personnel (NRC 2005).
 - about one-fourth of the average annual exposure received by U.S. commercial airline flight crew personnel due to cosmic radiation (NCRPM 1989a).
- The average annual exposure of 0.104 rem for Shipyard personnel is:
 - approximately 2 percent of the federal annual limit of 5 rem.
 - approximately one half of the average annual exposure of commercial nuclear power plant personnel over the same time period (NRC 2005).
 - less than the average annual exposure received by U.S. commercial airline flight crew personnel due to cosmic radiation (NCRPM 1989a).

For additional perspective, the annual exposures for personnel in the NNPP may also be compared to natural background and medical exposures:

- The average annual exposure of 0.043 rem since 1980 for Fleet personnel is:
 - less than 15 percent of the average annual exposure to someone living in the US. from natural background radiation (NCRPM 1987).
 - less than the difference in the annual exposure due to natural background radiation between Denver, Colorado and Washington, D.C. (NCRPM 1987).

Fleet personnel operating nuclear-powered submarines receive less total annual exposure than they would if they were stationed on shore performing work not involving occupational radiation exposure. This exposure is less because of the effectiveness of the shielding aboard ship and because the low natural background radiation in a steel hull submerged in the ocean is less than the natural background radiation from cosmic, terrestrial, and radon sources on shore.

- The average annual exposure of 0.104 rem for Shipyard personnel is:
 - less than one-half of the average annual exposure that someone living in the U.S. would receive from natural background radiation (NCRPM 1987).

- less than the exposure from common diagnostic medical x-ray procedures such as x-rays of the back (NCRPM 1989b).

4. STUDIES OF THE EFFECTS OF RADIATION ON HUMANS

Observations on the biological effects of ionizing radiation began to be made soon after the discovery of x-rays in 1895 (NAS-NRC 1990).

Numerous references are made in the early literature concerning the potential biological effects of exposure to ionizing radiation. These effects have been intensively investigated for many years (Upton 1982). Although there still exists some uncertainty about the exact level of risk, the National Academy of Sciences has stated: "It is fair to say that we have more scientific evidence on the hazards of ionizing radiation than on most, if not all, other environmental agents that affect the general public". (National Academy of Sciences 1980).

A large amount of experimental evidence of radiation effects on living systems has come from laboratory studies on cell systems and on animals. However, what sets our extensive knowledge of radiation effects on humans apart from other hazards is the evidence that has been obtained from studies of human populations that have been exposed to radiation in various ways (National Academy of Sciences 1980). The health effects demonstrated from studies of people exposed to high doses of radiation (that is, significantly higher than current occupational limits) include the induction of cancer, cataracts, sterility, and developmental abnormalities from prenatal exposure. Animal studies have documented the potential for genetic effects.

Near the end of 1993, the Secretary of Energy requested the disclosure of all records and information on radiation experiments involving human subjects performed or supported by Department of Energy or predecessor agencies. The NNPP has never conducted or supported any radiation experiments on humans. As discussed in this report, the NNPP has adopted exposure limits recommended by national and international radiation protection standards committees, such as the NCRPM and the ICRP, and has relied on conservative designs and disciplined operating and maintenance practices to minimize radiation exposure to levels well below these limits.

5. HIGH DOSE STUDIES

The human study populations that have contributed a large amount of information about the biological effects of radiation exposure include the survivors of the atomic bombings of Hiroshima and Nagasaki, x-rayed tuberculosis patients, victims of various radiation accidents, patients that have received radiation treatment for a variety of diseases, radium dial painters, and inhabitants of South Pacific islands that received unexpected doses from fallout due to early nuclear weapons tests. All of these populations received high or very high exposures.

The studies of atomic bomb survivors have provided the single most important source of information on the immediate and delayed effects of whole-body exposure to ionizing radiation. The studies have been supported for over 40 years by the U.S. and Japanese governments and include analysis of the health of more than 90,000 survivors of the bombings. Continued follow up of the Japanese survivors has changed the emphasis of concern from genetic effects to the induction of cancer (NAS-NRC 1990, UNSCEAR 2000).

The induction of cancer has been the major late effect of radiation exposure in the atomic bomb survivors. The tissues most sensitive to the induction of cancer appear to be the blood forming organs, thyroid, and female breast. Other cancers linked to radiation, but with a lower sensitivity, include cancers of the lung,

stomach, colon, bladder, liver and ovary. A wave-like pattern of leukemia induction was seen over time beginning about 2 years after exposure, peaking within 10 years of exposure and generally diminishing to near baseline levels over the next 40 years. For other cancers, statistically significant excess was observed 5 to 10 years or more after exposure, and the excess risk continues to rise slowly with time (UNSCEAR 2000).

While it is often stated that radiation causes all forms of cancer, many forms of cancer actually show no statistically significant increase among atomic bomb survivors. These cancers include chronic lymphocytic leukemia, multiple myeloma, and cancers of the rectum, gall bladder, larynx, pancreas, prostate, cervix and kidney (UNSCEAR 2000).

To understand the impact of cancer induction from the atomic bombings in 1945, it is necessary to compare the number of radiation related cancers to the total number of cancers expected in the exposed group. In studies of 50,000 survivors with doses ranging from 0.5 to over 200 rem, nearly 6,900 cases of solid cancer have been identified as of 1994. Of these, roughly 700 are in excess of expectation (Pierce 2001). Also, within this population, there were 4,565 solid cancer deaths and 176 leukemia deaths as of 1990 (Pierce 1996). Of these, an estimated 376 solid cancer deaths and 78 leukemia deaths are in excess of expectation (Pierce 1996). These studies did not reveal a statistically significant excess of cancer below doses of 6 rem (UNSCEAR 2000). The cancer mortality experience of the other human study populations exposed to high doses (referenced above) is generally consistent with the experience of the Japanese atomic bomb survivors (UNSCEAR 2000).

About 40 years ago the major concern of the effects from radiation exposure centered on possible genetic changes. Ionizing radiation was known to cause such effects in many species of plants and animals. However, intense study of nearly 70,000 offspring of atomic bomb survivors has failed to identify any increase in genetic effects. Based on a recent analysis, humans now appear less sensitive to genetic effects from radiation exposure than previously thought (NAS-NRC 1990).

Radiation-induced cataracts have been observed in atomic bomb survivors and persons treated with very high doses of x-rays to the eye. Based on this observation, potential cataract induction was considered a matter of concern. However, more recent research indicates the induction of cataracts by radiation requires a high threshold dose. The National Academy of Sciences has stated the threshold for a vision-impairing cataract under conditions of protracted exposure is thought to be no less than 800 rem, which greatly exceeds the amount of radiation that can be accumulated by the lens through occupational exposure to radiation under normal working conditions (NAS-NRC 1990).

Radiation damage to the reproductive cells at very high doses has been observed to result in sterility. Impairment of fertility requires a dose large enough to damage or deplete most of the reproductive cells and is close to a lethal dose if exposure is to the whole body. The National Academy of Sciences estimates the threshold dose necessary to induce sterility in either the male or female is about 350 rem in a single dose (NAS-NRC 1990). As in the case of cataract induction, this dose far exceeds the dose that can be received from occupational exposure under normal working conditions.

Developmental abnormalities were observed among children of the atomic bomb survivors that received high prenatal exposure (that is, their mother was pregnant at the time of the exposure). These abnormalities included stunted growth, small head size, and mental retardation. Additionally, recent analysis suggests that during a certain stage of development (the 8th to 15th week of pregnancy) the developing brain is especially sensitive to radiation. A slight lowering of IQ might follow even relatively low doses of 10 rem or more (NAS-NRC 1990).

From this discussion of the health effects observed in studies of human populations exposed to high doses of radiation, it can be seen that the most important of the effects from the standpoint of occupationally exposed workers is the potential for induction of cancer (NAS-NRC 1990).

6. LOW DOSE STUDIES

The cancer causing effects of radiation on the bone marrow, female breast, thyroid, lung, stomach, and other organs reported for the atomic bomb survivors are similar to findings reported for other irradiated human populations. With few exceptions, however, the effects have been observed only at high doses and high dose rates. Studies of populations chronically exposed to low-level radiation have not shown consistent or conclusive evidence of an associated increase in the risk of cancer (NAS-NRC 1990). Attempts to observe increased cancer in human populations exposed to low doses of radiation have been difficult.

One problem in such studies is the number of people needed to provide sufficient statistics. As the dose to the exposed group decreases, the number of people needed to detect an increase in cancer goes up at an accelerated rate. For example, for a group exposed to 1 rem (equivalent to the average lifetime accumulated dose in the NNPP) it would take more than 500,000 people in order to detect an excess in lung cancers based on current estimates of the risk (Shore 1990). This is almost 2 times the number of people that have performed nuclear work in all the Naval shipyards over the last 53 years. Another limiting factor is the relatively short time since large groups of people began receiving low doses of occupational radiation. As discussed previously, data from the atomic bomb survivors indicates a long latency period between the time of exposure and expression of the disease.

There is also the compounding factor that cancer is a generalization for a group of about 300 separate diseases, many being relatively rare and having different apparent causes. It is difficult to analyze low dose study data to eliminate the possibility that some factor other than radiation may be causing an apparent increase in cancer induction. This difficulty is particularly apparent in studies of lung cancer, where smoking is such a common exposure, is poorly documented as to individual habits, and is by far the primary cause of lung cancer. Because cancer induction is statistical in nature, low dose studies are limited by the fact that an apparent observed small increase in cancer may be due to chance alone.

Despite the above-mentioned problems and lack of consistent or conclusive evidence from low dose studies to date, low dose studies fulfill an important function. They are the only means available for eventually testing the validity of current risk estimates derived from data accumulated at higher doses and higher dose rates.

Low dose groups that have been, and are currently being studied include groups exposed as a result of medical procedures, exposed to fallout from nuclear weapons testing, living near U.S. commercial nuclear installations, living in areas of high natural background radiation, and occupationally exposed to low doses of radiation. The National Academy of Sciences has reviewed a number of the low dose studies in NAS-NRC 1980 and NAS-NRC 1990. Their overall conclusion from reviewing these studies was as follows:

Studies of populations chronically exposed to low-level radiation, such as those residing in regions of elevated natural background radiation, have not shown consistent or conclusive evidence of an associated increase in the risk of cancer. (NAS-NRC 1990)

This conclusion has been supported by studies that have been completed since NAS-NRC 1990 was published. For example, in 1990, the National Cancer Institute completed a study of cancer in U.S. populations living near 62 nuclear facilities that had been in operation since before 1982. This study

included commercial nuclear power plants and Department of Energy facilities that used radioactive materials. The conclusion of the National Cancer Institute study was as follows:

There was no evidence to suggest that the occurrence of leukemia or any other form of cancer was generally higher in the (counties near the nuclear facilities) than in the (counties remote from nuclear facilities). (NCI 1990)

At the request of the Three Mile Island Public Health Fund, independent researchers investigated whether or not the pattern of cancer in the 10-mile area surrounding the Three Mile Island nuclear plant had changed after the TMI-2 accident in March 1979 and, if so, whether the change related to radiation releases from the plant. A conclusion of this study was as follows.

For accident emissions, the authors failed to find definite effects of exposure on the cancer types and population subgroups thought to be most susceptible to radiation. No associations were seen for leukemia in adults or for childhood cancers as a group. (Hatch 1990)

Of particular interest to workers in the NNPP are studies of groups occupationally exposed to radiation. A recent survey of radiation worker populations in the U.S. shows there are about 350,000 workers currently under study (Shore 1990). For more than a decade, NNPP personnel, including those at shipyards and in the Fleet, have been included among populations being studied. These studies are discussed below.

In 1978, Congress directed the National Institute for Occupational Safety and Health (NIOSH) to perform a study of workers at the Portsmouth Naval shipyard (PNS). This study was in response to an article in the Boston Globe newspaper describing research by Dr. T. Najarian and Dr. T. Colton, assisted by the Boston Globe staff. The report alleged that Portsmouth workers who were occupationally exposed to low-level radiation suffered twice the expected rate of overall cancer deaths and five times the expected rate of leukemia deaths. Congress also chartered an independent oversight committee of nine national experts to oversee the performance of the study to assure technical adequacy and independence of the results. The following is a summary of the study and its results. NIOSH prepared this summary at the conclusion of their last study phase in February 1986.

In December 1980, NIOSH researchers completed the first report on a detailed study of the mortality among employees of the shipyard. Included in the study were all those who had been employed at PNS since January 1, 1952 (the earliest date that records existed that could identify former employees). In this report it was concluded that 'Excesses of deaths due to malignant neoplasms and specifically due to neoplasms of the blood and blood-forming tissue, were not evident in civilian workers at PNS...' in contrast to the results of the original study conducted by the physician. Later, in an investigation to determine why the physician's study results differed so greatly from the NIOSH study, a number of shortcomings in his original study were found that resulted in incorrect conclusions.

To make more certain that workers who had died from leukemia did not die because of radiation exposures received at the shipyard, a second study was conducted. That study compared the work and radiation histories of persons who died of leukemia, with persons who did not. In this analysis, again, no relationship was found between leukemia and radiation, although the NIOSH researchers were unable to rule out the possibility of other occupational exposures having a role.

In this current and third NIOSH paper, we investigated the role that radiation and other occupational exposures at the shipyard may have had in the development of lung cancer. This study is an outgrowth of an observation made in the 1980 NIOSH study referred to above. The observation was that persons with greater than 1 rem cumulative exposure to radiation had an increase in lung cancer.

In this report entitled “Case Control Study of Lung Cancer in Civilian Employees at the Portsmouth Naval Shipyard,” we compared the work and radiation histories of persons who died of lung cancer with persons who did not. We found that persons with radiation exposures in excess of 1 rem had an excess risk of dying of lung cancer, but the radiation was in all likelihood not the cause. This was because persons with radiation exposure tended also to have exposure to asbestos (a known lung carcinogen) and to welding by-products (suspected to contain lung carcinogens).

Thus, the earlier reports of excess cancer rates among PNS workers exposed to low-level radiation were not substantiated by NIOSH. The NIOSH studies were published in scientific literature (Rinsky 1981; Greenburg 1985; Stern 1986; Rinsky 1988).

In 1991, researchers from the Johns Hopkins University, Baltimore, Maryland, completed a more comprehensive epidemiological study of the health of workers at the six Naval shipyards and two private shipyards that service Naval nuclear-powered ships (Matanoski 1991). This independent study evaluated a population of 70,730 civilian workers, beginning with the first overhaul of the first nuclear-powered submarine, USS NAUTILUS, in 1957 and ending in 1981, to determine whether there was an excess risk of leukemia or other cancers associated with exposure to low levels of gamma radiation.

This study did not show any cancer risks linked to radiation exposure. Furthermore, the overall death rate among radiation exposed shipyard workers was less than the death rate for the general U.S. population. It is well recognized that many worker populations have lower mortality rates than the general population, because the workers must be healthy to perform their work. This study shows that the radiation exposed shipyard population falls in this category.

The death rate for cancer and leukemia among the radiation-exposed workers was slightly lower than that for non-radiation exposed workers and for the general U.S. population. However, an increased rate of mesothelioma, a type of respiratory system cancer linked to asbestos exposure, was found in both radiation exposed and non-radiation-exposed shipyard workers, although the number of cases was small reflecting the rarity of this disease in the general population. The researchers suspect that shipyard worker exposure to asbestos in the early years of the NNPP, when the hazards associated with asbestos were not as well understood as they are today, might account for this increase.

The Johns Hopkins study found no evidence to conclude that the health of people involved in work on U.S. nuclear-powered ships has been adversely affected by exposure to low levels of radiation incidental to this work. Additional studies are planned to investigate the observations and update the study with data beyond 1981.

In 1987, the Yale University School of Medicine completed a study of the health of Navy personnel assigned to nuclear submarine duty between 1969 and 1981 (Ostfeld 1987). This study was sponsored by the U.S. Navy Bureau of Medicine and Surgery to determine if the enclosed environment of submarines had any impact on the health of these personnel. Although not strictly designed as a cancer study of a low dose population, the study did examine cancer mortality as a function of radiation exposure. The study concluded that submarine duty had not adversely effected the health of crew members. Furthermore, there was no correlation between cancer mortality and radiation exposure. These observations were based on comparison of death rates among about 76,000 officers and enlisted submariners (all who served

between 1969 and 1981) against an aged-matched peer group. The results of this study were published in the Journal of Occupational Medicine (Charpentier 1993).

NIOSH published the results of an update to the 1980 study in the July 2004 edition of the Journal of Occupational and Environmental Medicine (Silver 2004). The cohort was expanded by including all Portsmouth Naval Shipyard (PNSY) workers employed through 1992 and included worker vital statistics up to December 1996. The NIOSH study found nothing to conclude that the health of shipyard workers has been adversely affected by low levels of occupational radiation exposure incidental to work on nuclear-powered ships. These findings are generally consistent with previous studies.

The study showed no statistically significant cancer risks linked to radiation exposure, when compared to the general U.S. population. Further, the overall death rate among PNSY occupational radiation workers was less than the death rate for the general U.S. population. Other key conclusions reached in the study include the following:

- The study found a slightly higher death rate for all types of cancer in personnel who were never radiation workers, when compared to the general U.S. population. The study also found an equivalent slightly higher death rate for all types of cancer for those who received occupational radiation exposure when compared to the general U.S. population. Fewer deaths than expected were observed for tuberculosis, diseases of the heart, circulatory system, and digestive system, as well as for accidents.
- Consistent with the 1981 NIOSH study, the current study did not find a statistically significant difference in the death rates for leukemia for shipyard and the general U.S. population. Although NIOSH concludes that the result is not statistically significant, the data suggest the potential for a small increase in the low risk of leukemia for workers receiving occupational radiation exposure. The small number of leukemia cases (34 out of 11,791 workers receiving occupational radiation exposure) reflects the low risk of this disease. The researchers considered this potential relationship of radiation exposure and leukemia to be considerably uncertain and to require additional study before any conclusion can be made.
- The study found a slightly higher death rate for lung cancer for workers that were never radiation workers, when compared to the general U.S. population. The study found a slightly higher death rate for lung cancer for workers receiving occupational radiation exposure, when compared to the general U.S. population. The researchers concluded that the slightly higher rates were accounted for by factors other than radiation exposure; the other factors were smoking, exposure to welding fumes, and asbestos work during the early years covered by the study when the hazard associated with asbestos was not so well understood as it is today.

Several additional analyses of the PNSY data have been performed by NIOSH, and in the December 2005 issue of Radiation Research (Kubale 2005) NIOSH published the results of a case-control study of leukemia mortality and ionizing radiation. The study found that although the overall risk of leukemia mortality for radiation workers was the same as the general population, a small increase in risk was noted with increasing radiation dose. NIOSH estimated that the lifetime risk for leukemia mortality would increase from 0.33% to 0.36% for workers receiving the average lifetime radiation dose from shipyard workers (1.2 rem). The study also found a small increase in leukemia mortality associated with potential solvent exposure (benzene or carbon tetrachloride). NIOSH cautioned that the relatively small number of leukemia cases among radiation workers (34 out of 11,791 workers receiving occupational radiation exposure) makes it difficult to be certain of the findings. However, the risk estimate is consistent with other radiation epidemiologic study results.

7. NUMERICAL ESTIMATES OF RISK FROM RADIATION

One of the major aims of the studies of exposed populations as discussed above is to develop numerical estimates of the risk of radiation exposure. These risk estimates are useful in understanding the hazards of radiation exposure, evaluating and setting radiation protection standards, and helping resolve claims for compensation by exposed individuals.

The development of numerical risk estimates has many uncertainties. As discussed above, excess cancers attributed to radiation exposure can only be observed in populations exposed to high doses and high dose rates. However, the risk estimates are needed for use in evaluating exposures from low doses and low dose rates. Therefore, the risk estimates derived from the high dose studies must be extrapolated to low doses. This extrapolation introduces a major uncertainty. The shape of the curve used to perform this extrapolation becomes a matter of hypothesis (that is, assumption) rather than observation. The inability to observe the shape of this extrapolated curve is a major source of controversy over the appropriate risk estimate.

Scientific committees, such as the National Academy of Science (NAS-NRC 1990), UNSCEAR (UNSCEAR 2000), and the NCRPM (NCRPM 1993) all conclude that accumulation of dose over weeks or months, as opposed to in a single dose, is expected to reduce the risk appreciably. A dose rate effectiveness factor (DREF) is applied as a divisor to the risk estimates at high doses to permit extrapolation to low doses. The National Academy of Sciences (NAS-NRC 1990) suggested that a range of DREF's between 2 and 10 may be applicable and reported a best estimate of 4 based on laboratory animal studies. UNSCEAR 2000 suggested that a DREF of 2 or 3 would be reasonable based on available data. However, despite these conclusions by the scientific committees, some critics argue that the risk actually increases at low doses while others argue that cancer induction is a threshold effect and the risk is zero below the threshold dose. As stated at the beginning of this section, the NNPP has always conservatively assumed radiation exposure, no matter how small, may involve some risk.

In 1972, both the UNSCEAR and the National Academy of Sciences-National Research Council Advisory Committee on the Biological Effects of Ionizing Radiations issued reports (Charpentier 1993 and UNSCEAR 1972) that estimated numerical risks for specific types of cancer from radiation exposure to humans. Since then, national and international scientific committees have been periodically re-evaluating and revising these numerical estimates based on the latest data and information. The most recent estimates are from the same two committees and are contained in their 2000 and 2006 reports, respectively (UNSCEAR 2000, NAS-NRC 2006). Both committees provided risk estimates based on the use of new models for projecting the risk, revised dose estimates for survivors of the Hiroshima and Nagasaki atomic bombs, and additional data on the cancer experience by both atomic bomb survivors and persons exposed to radiation for medical purposes. A risk estimate for radiation induced cancer derived from the most recent analysis (NAS-NRC 1990, UNSCEAR 2000), can be briefly summarized as follows:

In a group of 10,000 workers in the U.S., a total of about 2,000 (20 percent) will normally die of cancer. If each of the 10,000 received over his or her career an additional one rem, then an estimated four additional cancer deaths (0.04 percent) might occur. Therefore, the average worker's lifetime risk of cancer has been increased nominally from 20 percent to 20.04 percent.

The above risk estimate was extrapolated from estimates applicable to high doses and dose rates using a DREF of about 2. This estimate probably overstates the true lifetime risk at low doses and dose rates, because a DREF of 2 is at the low end of probable DREF values. The National Academy of Sciences, in assessing the various sources of uncertainty, concluded that the true lifetime risk may be contained within an interval from zero to about 6 (NAS-NRC 1990). The National Academy of Sciences points out that

the lower limit of uncertainty extends to zero risk because “the possibility that there may be no risks from exposure comparable to external natural background radiation cannot be ruled out.”

8. RISK COMPARISONS

For comparison with risks normally associated with everyday life, Table E-1 illustrates the chance of death occurring from various sources over an individual's lifetime. The risk associated with radiation from NNPP plants was determined from an individual receiving 1 rem of lifetime-accumulated exposure.

Table G-1	
<i>Some Commonplace Lifetime Risks (NNPP 2007b)</i>	<i>Lifetime Risk¹ (Percent)</i>
Tobacco	11.1
Poor Diet/Lack of Exercise	10.7
Infectious Agents	3.0
Accidents (all)	2.7
Firearms	1.5
Motor Vehicle Accidents	1.2
Falls	0.42
Accidental Poisoning	0.39
Drowning	0.09
Fires	0.08
Other Land Transport Accidents	0.03
Radiation exposure associated with Naval Nuclear Propulsion Plants (risk estimate)	0.04
<i>Note:</i> 1. Smoking assumes the population is at risk from 18 to 76.5 (58.5 years). Other risk assumes the population is at risk for a lifetime (76.5 years)	

9. LOW-LEVEL RADIATION CONTROVERSY

A very effective way to cause undue concern about low-level radiation exposure is to claim that no one knows what the effects are on human beings. Critics have repeated this so often that it has almost become an article of faith that no one knows the effects of low-level radiation on humans. The critics are able to make this statement because, as discussed above, human studies of low-level radiation exposure are unable to be conclusive as to whether or not an effect exists in the exposed groups, because of the extremely low incidence of an effect. Therefore, assumptions are needed regarding extrapolation from high-dose groups. The reason low dose studies cannot be conclusive is because the risk, if it exists at these low levels, is too small to be seen in the presence of all the other risks of life.

In summary, the effect of radiation exposures at occupational levels is also extremely small. There are physical limits to how far scientists can go to ascertain precisely the size of this risk, but it is known to be small. Instead of proclaiming how little is known about low-level radiation, it is more appropriate to emphasize how much is known about the small actual effects.

This appendix has been written to give the reader a basic understanding of radiation experienced in everyday life and the extremely small risks associated with exposure to low levels of ionizing radiation. References for citations in this appendix can be found in Chapter 10.

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