FACT SHEET

Radiation Safety at Nuclear Power Plants: Studies Look at Public, Workers

February 2008

Key Facts

■ Workers at U.S. facilities that use radioactive materials incur a small occupational health risk. The U.S. Nuclear Regulatory Commission sets standards to ensure their safety. The agency limits worker doses to no more than five rems[1] per year and requires that occupational doses be kept "as low as reasonably achievable."

■ Occupational doses in the U.S. nuclear energy industry averaged only 140 millirems (mrems) per worker in 2006[2]—a 6.4 percent decrease from 2005. The average nuclear plant worker is exposed to less than one-fifth of the 900 mrems per-year dose of cosmic radiation received by airline pilots and cabin crews who regularly fly the high-altitude New York-Tokyo route.

■ People living near a nuclear power plant receive only a tiny amount of radiation exposure from the facility. Less than 1 percent of the average person's total exposure comes from nuclear power plants.

■ Radiation is detected easily and is one of the most studied and best understood forms of energy. Many organizations and scientists in the United States and internationally have extensively studied the health effects of radiation exposure. The results of these studies form the scientific basis for radiation safety standards used to protect workers and the public.

■ A study released by the International Agency for Research on Cancer (IARC) in 2005 found that the risk of health effects from exposure to low levels of radiation is small. IARC also concluded that current radiation protection standards for workers and the public remain valid.

■ The National Academy of Sciences (NAS) in June 2005 released its report from the Biological Effects of Ionizing Radiation Committee VII (BEIR VII), "Health Risks From Exposure to Low Levels of Ionizing Radiation." The study provides strong confirmation that the risk of health effects from exposure to low levels of radiation is small. It also concludes that current radiation protection standards for workers and the public remain valid. The BEIR VII report is the updated scientific basis for radiation safety standards in the United States for the next decade.

■ Among organizations chartered to conduct ongoing studies are the United Nations Scientific Committee on the Effects of Atomic Radiation, the National Academy of Sciences/National Research Council, the International Agency for Research on Cancer and the National Cancer Institute. Further studies will continue to expand the knowledge base on radiation health effects.

National Academy Reviews Radiation Risk

The BEIR VII report is the updated scientific basis for radiation safety standards in the United States. NAS last addressed this topic in the BEIR V report, issued in 1990. NAS formed the BEIR VII committee in 2000 to review the large body of scientific research on radiation health effects that has accumulated

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[1] Exposure to radiation is called a "dose" and is expressed in the measures rem and millirem. A rem measures the effect of radiation on the human body. It takes into account both the amount of radiation deposited in body tissues and the type of radiation. A millirem (mrem) is a thousandth of a rem. The average person receives about 20 millirem from a chest X-ray.

[2] "Occupational Radiation Exposure at Commercial Nuclear Power Reactors," NUREG-0713, Vol. 28, Table 4-3, U.S. Nuclear Regulatory Commission, November 2007. The 140 mrem figure is rounded from 137.3 mrem.

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over the past 15 years.[3] "In general, BEIR VII supports previously reported risk estimates for cancer and leukemia, but the availability of new and more extensive data have strengthened our confidence in these estimates," said Dr. Richard Monson, chairman of the BEIR VII committee and associate dean at the Harvard School of Public Health.

The study found that 1 percent of individuals receiving a dose of 10 rems would be expected to develop cancer, compared with the 42 percent likely to develop cancer from other causes. A 10,000-millirem dose is twice the NRC's annual occupational limit.

The BEIR VII committee said it is difficult to estimate cancer risk from radiation doses of 10 rems or less. However, the committee said the BEIR VII study continues to support the "linear-no-threshold model" for radiation exposure. The model holds that risk declines commensurate with lower radiation exposures; very low exposures mean that the risk to an individual is very low but cannot be assumed to be zero. "The preponderance of information indicates that there will be some risk, even at low doses, although the risk is small," Monson said.

Studies of children whose parents were exposed to radiation have found no adverse health effects that could be attributed to radiation. The committee said that the failure to observe such effects in human studies probably reflects that the genetic risks are very small.

Radiation Health Effects On Public Near Plants

Although nuclear power plants represent one of the smallest sources of radiation exposure to the public, a large number of scientific studies have focused on ensuring that they are not a risk to people living nearby.

Several uncertainties are inherent in any study of the effects of radiation. First, it is extremely difficult to identify an appropriate control group of unexposed individuals who are otherwise identical to the exposed population. Second, there are likely to be "confounding variables" among the exposed population—such as exposure to chemicals or cigarette smoke—that are linked to health problems and therefore complicate data interpretation. Third, it often is difficult to determine the exact radiation doses to individuals in the exposed group. For these reasons, it is necessary to carefully scrutinize the methodology of studies whose conclusions deviate from the general scientific consensus about the effects of radiation. Scientific studies include the following:

National Cancer Institute Study. In September 1990, the National Cancer Institute (NCI) of the National Institutes of Health announced that a large-scale study found no increased incidence of cancer mortality for people living near 62 nuclear installations in the United States. The research, which evaluated mortality from 16 types of cancer, showed no increase in the incidence of childhood leukemia mortality in the study of surrounding counties after start-up of the nuclear facilities.

In 1987, the NCI initiated the broadest study of its kind ever conducted, partly in response to a study by the United Kingdom's Office of Population Censuses and Surveys (see below). The NCI surveyed 900,000 cancer deaths in counties near nuclear facilities that had operated for at least five years prior to the start of the study—the minimum time considered sufficient for related health effects to appear.

British Studies. A study by the U.K. Office of Population Censuses and Surveys (OPCS) showed no rise in cancer near nuclear installations in England and Wales—either for young persons or adults—even when focusing on types of cancer particularly associated with exposure to ionizing radiation, such as leukemia, bone cancer and multiple myeloma.

Investigators analyzed 8 million separate occurrences of cancer from 1959 to 1980, taking into account the distances from nuclear facilities. A fol-

[3] The academy's BEIR VI report addressed radiation exposure from radon.

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low-up analysis of the OPCS data by Sir Richard Doll of Oxford University confirmed nearly all of the initial findings but detected a small excess of childhood leukemia and Hodgkin's disease near older U.K. nuclear sites.

The Oxford researchers attributed the apparent excess to comparisons with control areas that had particularly low cancer mortality, but they suggested additional study.

French Study. A study by two French researchers—reported in the Oct. 25, 1990, issue of Nature—found no increase in childhood leukemia near six nuclear installations in France between 1968 and 1987. The facilities included four nuclear power plants and the nuclear fuel reprocessing plants at La Hague and Marcoule.

Canadian Study. A study released in 1991 by the Ontario Cancer Treatment and Research Foundation, commissioned by Canada's Atomic Energy Control Board, found no statistically significant increase in leukemia among children born to mothers living near five nuclear sites in Ontario province.

Researchers examined data for 1,894 children, aged 14 years or younger, who died from leukemia between 1950 and 1987 and who lived within 15 miles of five Canadian nuclear facilities. The facilities were Ontario Power Generation's Pickering and Bruce Power's Bruce nuclear power plants, the Elliot Lake uranium mines and mills, Atomic Energy of Canada Ltd.'s Chalk River nuclear laboratories, and a former 20-megawatt nuclear station at Rolphton. Near the Chalk River laboratories, childhood leukemia was one-third of the expected rate. Near the Pickering power station, there were 33 childhood leukemia deaths between 1971 and 1987, more than the 25 statistically expected. However, the rate also was elevated during the 20 years before the station entered service.

West Valley Study. A study by doctors at the University of Buffalo Medical School found no increase in cancer incidence among people living in seven towns near a former nuclear fuel reprocessing plant at West Valley in western New York. In fact, the doctors observed a slight reduction in cancer incidence. The study covered 1973 to 1983.

Pennsylvania Department of Health Studies. Two studies issued in 1991 by the Pennsylvania State Department of Health show no rise in cancer incidence among people living near the Three Mile Island nuclear plant. One study involved 31,000 people living within a five-mile radius of the plant. While 943 cases of cancer had been expected to have occurred among the group from 1982 to 1989, only 813 were recorded, the study showed. The second study involved 5,292 women of childbearing age living within a 10-mile radius of the plant. Among this group, 36 cases of cancer had been expected; 35 were recorded. The state study found no association between radiation and cancer and no association between psychological stress and cancer.

TMI Health Fund Study. A study by researchers at Columbia University, released in 1990, found no association between the release of radiation during the 1979 Three Mile Island accident and leukemia, or childhood cancer in general. The study requested by public stakeholder groups near the plant and funded by the Three Mile Island Public Health Fund examined cancer incidence among 159,684 people living within 10 miles of the plant.

More than a dozen other major health studies have found no link between cancer and radiation released from TMI during the accident. The only health effect linked to the accident was stress.

Pilgrim Study. In 1990, the Massachusetts Department of Public Health (MDPH) published a study (the "Southeastern Massachusetts Health Study") of leukemia incidence for 22 towns in the southeastern area of the state. The purpose of the study was to determine if the incidence of leukemia could be associated with exposure to

radiation from the Pilgrim nuclear power plant. The population studied consisted of people aged 13 years and older who were diagnosed between 1978 and 1986 with any type of leukemia, excluding one type known not to be associated with radiation.

The report's findings included the following:

- Individuals with the highest potential for exposure to radiation emissions from Pilgrim (i.e., those who lived and/or worked the longest and closest to the plant) had almost four times the incidence of leukemia as those having the lowest potential for exposure (i.e., those who lived and/or worked the least amount of time and farthest from the plant).
- The study found an association between radiation released from the Pilgrim plant and leukemia incidence only among those cases diagnosed before 1984.
- No apparent relationship with the plant was observed for cases diagnosed between 1984 and 1986.

A review of the study, released in October 1992, found serious problems with the study's methods and conclusions. The 16-month-long analysis was the work of an independent review panel, composed of six experts in epidemiology, appointed by MDPH and Boston Edison Co., which owned the Pilgrim plant.

Among the most serious flaws in methodology, according to the panel, were the following:

- It was very inconsistent with other radiation studies. There was a large disparity between the number of excess leukemia cases reported by the study (47) and the number expected using data from other radiation studies (0.52).
- The study failed to document, from vital records, any excess leukemia deaths during the study period, compared with leukemia mortality before the Pilgrim plant opened.
- The study failed to include towns on Cape Cod that were within the study area.
- In estimating how much radiation exposure that people living near the plant received, the study should have used alternative models of how radiation is dispersed.

The panel called for "a carefully designed new study" to address the concerns raised in its report.

Greenpeace Study. Greenpeace and Ernest Sternglass, an anti-nuclear activist, released "Nuclear Power, Human Health and the Environment: The Breast Cancer Warning in the Great Lakes Basin" in 1995. The study claims that women in 81 counties in the Great Lakes region, where there are 36 U.S. and Canadian nuclear power plants, have an increased risk of breast cancer mortality. It also claims the 1990 National Cancer Institute study and other studies that found no cancer-nuclear power connection failed to look at a sufficiently broad radius around the plants.

The study's findings and methodology have drawn widespread criticism among scientists and in the news media:

- It provides no evidence that women in the 81 Great Lakes counties live closer to nuclear power plants, or that women were exposed to significantly higher levels of radiation, than women in nearby counties that Greenpeace did not choose to study.
- The study offers no detail on important characteristics of the women in those 81 counties, such as urbanization, ethnicity or socioeconomic profile, which would help evaluate whether "selection bias" is present. (The risk of dying from breast cancer is higher in urban areas and among certain ethnic groups.)
- Results can depend on the method that researchers use to compare data. Greenpeace chose to combine the data for all women in all 81 counties and compare the total with the U.S. average. The result was 3.2 excess cancer

deaths per 100,000 women—an extremely small increase. But if Greenpeace had looked at data from each of the 81 Great Lakes counties individually, it would have found something different: In slightly more than half of the counties, the breast cancer death rates are somewhat lower than the U.S. average, and in slightly less than half of them, the death rates are somewhat higher than the U.S. average. With this method, there is no consistent increase in the breast cancer death rates in all of the 81 counties.

- The reason the NCI did not extend its study to a 100-mile radius around each plant—as Greenpeace claims was necessary—is that radioactive emissions from nuclear power plants are virtually nonexistent at that radius. The nearest plant neighbor gets less than one millirem of radiation exposure from the plant annually. This is less than the average person gets annually from watching television.

***Livermore National Laboratory Study*.** The California Department of Health Services released a study in 1995 comparing cancer rates in children and young adults living near the Lawrence Livermore National Laboratory in Livermore, Calif., with those throughout the rest of Alameda County. The federal Centers for Disease Control and Prevention commissioned the study.

Although the study did not find an overall excess of cancer, including leukemia or non-Hodgkin's lymphoma, young people near Livermore had two to six times as many malignant melanomas (a form of skin cancer), as expected over the 30-year period of the study (1960–91).

The researchers acknowledge that "differences in community characteristics or health behaviors" might explain this apparent excess. These include the possibility that Livermore residents screened more actively for skin cancer, the fact that the study made no adjustment for socioeconomic status and the fact that Livermore averages more days of sunlight than other areas of the county. (Greater sunlight exposure is thought to be associated with higher risk of melanoma.)

The study does not assess whether melanoma cases had any connection with the Lawrence Livermore National Laboratory.

***Wing Re-examination of TMI Data*.** In 1997, University of North Carolina researcher Steven Wing published a controversial re-evaluation of the data used in the 1990 TMI study, which found no effect on cancer incidence around the plant. Wing claimed that the accident released more radiation than had been reported previously, resulting in many accident-related cancers within 10 miles of the plant. The authors of the 1990 study, as well as other epidemiologists and the Pennsylvania Department of Health, have criticized Wing's findings and methodology.

Radiation Health Effects On Nuclear Workers

***U.K. Study*.** The January 1992 issue of the British Medical Journal published the results of the U.K.'s National Radiological Protection Board's (NRPB) study of 95,000 nuclear workers. The purpose of the study was to assess the effects of low occupational exposure to radiation.

Researchers found that death rates from cancer did not exceed those in the general population. The results of this study were consistent with data from survivors of the atomic bombs at Hiroshima and Nagasaki, which remain the most important reference for assessing the health effects of radiation. For that reason, the U.K. study was generally believed to confirm the International Commission on Radiation Protection's system of radiation protection. When it released its findings, the NRPB announced plans to do a second study, using a larger study population and longer follow-up.

***Gardner Study*.** The February 1990 British Medical Journal published the results of a five-year study conducted by Martin Gardner, an epidemiologist

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and medical statistician at the University of Southampton, England. Gardner identified a possible association between childhood leukemia in Seascale, England, and the fathers' preconception exposure to radiation while working at the Sellafield nuclear fuel reprocessing plant.

He observed that of 74 cases of childhood leukemia in West Cumbria, 10 of the children had parents who worked at Sellafield. The study also suggested a possible association between the incidence of childhood leukemia in West Cumbria and paternal employment in farming and steelmaking, two occupations that involve exposure to chemicals.

The Gardner study's findings are inconsistent with scientific understanding about radiation. For example, studies of 7,400 children of male Hiroshima and Nagasaki survivors, whose average radiation exposure was four times that of the Sellafield workers, show no evidence of an increase in leukemia or other cancers.

Numerous studies since 1990 failed to support a radiation-cancer link.

A 1996 report by the U.K.'s Committee on Medical Aspects of Radiation in the Environment, which spent more than 10 years examining the Sellafield data, said epidemiologists could stop looking for Gardner's hypothetical radiation-childhood leukemia link at Seascale. "We conclude that the level of risk is inconsistent with the radiation doses actually received via occupational exposure and current estimates of genetic risk," the report said.

The results of a study examining the Gardner hypothesis were published in the May 1999 issue of the British Medical Journal. In it, the authors concluded that "overall, the findings suggest that the incidence of cancer and leukemia among children of nuclear industry employees is similar to that in the general population."

Canadian Study. Because of the Gardner findings, a study was conducted in Canada to determine if there was an association between childhood leukemia and the occupational exposure of fathers to radiation prior to the time of the child's conception.

The study was conducted by the Ontario Cancer Treatment and Research Foundation, the University of Toronto and the University of British Columbia for the Atomic Energy Control Board. It was published in August 1992. The conclusion: "No association between childhood leukemia and the occupational exposures of fathers to ionizing radiation prior to the time of conception."

The report also noted that "the findings of this study in Ontario are not consistent with the hypothesis that childhood leukemia is associated with the occupational exposure of fathers to radiation prior to conception, as was found in the case control study at Sellafield in the United Kingdom by Gardner."

Newcastle Study. An independent study by Professor Alan Craft and Dr. Louise Parker of the Newcastle University Medical School, released in 1992, also contradicted the Gardner study's theory. It found that the geographical distribution of Sellafield employees does not match the geographical distribution of childhood leukemia. This refutes the suggestion that excess leukemia cases in Seascale are the result of preconception exposure of the Sellafield fathers. The study also showed that in West Cumbria (outside Seascale), where many more children had fathers with higher preconception doses than in Seascale, no excess of childhood leukemia existed.

Kinlen Studies. Two studies published in the British Medical Journal in 1993 by Leo Kinlen of the University of Oxford also found "no significant association with paternal preconception exposure to radiation as reported by Gardner and colleagues." Kinlen faulted Gardner on several points. First, although the excess cancers were concentrated in Seascale, in West Cumbria, most of the workers at the nearby Sellafield facility lived outside the parish. Second, excess cancers were not limited—as Gardner had

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thought—to young victims born in Seascale, but also occurred among young Seascale residents who had not been born there. Kinlen believes a more probable cause of the Seascale cancers was "an infectious epidemic promoted by unusual population mixing in an isolated area."

Health and Safety Executive Study. In 1993, the U.K.'s Health and Safety Executive announced the findings of its three-year investigation of leukemia and non-Hodgkin's lymphoma in the children of men employed at Sellafield from 1950 to 1989. This study, broader and more detailed than Gardner's, found "little evidence to suggest that a father's high preconception radiation dose increases the risk of leukemia and non-Hodgkin's lymphoma for his children." While the study found a childhood leukemia cluster in Seascale, it limited its focus almost entirely to children whose fathers started work at Sellafield before 1965. The study said it could not attribute this excess to any one cause, but it called for serious consideration of the Kinlen theory of population mixing.

Doll Review. British epidemiologist Sir Richard Doll dismissed the Gardner hypothesis in a 1994 issue of Nature. The Gardner hypothesis had prompted two families to sue British Nuclear Fuels plc, the company that operates Sellafield. They lost the suit in 1993. In his review of the evidence available to the court, Doll said Gardner's theory of radiation-damaged sperm did not accord with what is known about radiation genetics or childhood leukemia. He noted that offspring of Japanese atomic bomb survivors showed no abnormal genetic activity, even though the Japanese survivors had received much higher radiation doses than the Sellafield workers.

Oak Ridge Study. A study conducted for the Oak Ridge Associated Universities by Steven Wing of the University of North Carolina was published in 1991. The study looked at the 1,524 deaths from all causes among the 8,318 white males hired at Oak Ridge National Laboratory between 1943 and 1972. When compared with all U.S. white males, the Oak Ridge workers had lower than average mortality risks for most causes of death. The study identified 346 cancer deaths among the workers, whereas 438 normally would be expected. The exception was leukemia: Oak Ridge workers were at a 63 percent higher risk of death than all white males. There were 28 deaths from leukemia, whereas 17 normally would be expected.

The same workers had been the subject of an earlier study, which found no increased leukemia risks and no association between cancer mortality and occupational exposures to radiation and other substances. The researchers had no explanation for the difference between the studies. The study does observe an apparent statistical association, but there was insufficient data to conclude that low-level radiation exposure caused the higher than anticipated deaths from leukemia. The study did not take into account possible exposures to hazardous materials, smoking habits or lifestyles.

Navy Shipyard Workers. A study by researchers at The Johns Hopkins University, released in 1991, found no evidence that the workers who serviced nuclear-powered ships for the U.S. Navy between 1957 and 1981 were harmed by their on-the-job exposure to low levels of radiation.

Commissioned by the U.S. Department of Energy, the study examined the records of 70,000 civilian male workers employed at two private and six naval shipyards. The group included 38,220 workers who were exposed to low levels of radiation while on the job, and 32,510 nonexposed workers. The cancer death rate among the radiation-exposed shipyard workers (most of whom accumulated exposures of greater than 500 rems) was lower than among the nonexposed workers and slightly lower than the rate for the U.S. white male population.

The rate for leukemia, specifically, was slightly lower than

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expected—both among the exposed and nonexposed shipyard workers. In addition, the overall death rate among radiation-exposed shipyard workers was significantly lower than the rate for U.S. white males.

The last finding is not unexpected, since worker populations in general tend to have below-average mortality rates. This is because workers must be healthy to be hired, and they must remain healthy to continue their employment.

Stewart-Kneale Studies. British epidemiologists Alice Stewart and George Kneale published 1977, 1981 and 1993 studies on the effects of low radiation doses on workers at DOE's Hanford, Wash., nuclear complex. The 1981 analysis covered workers who died no later than 1977. The 1993 analysis included deaths from 1944 through 1986.

Among the questionable 1993 findings: 200 of the workers died or will die from radiation-induced cancer; older workers were at greater risk than younger workers; and doses as low as that from natural background radiation may be more harmful than implied in current radiation exposure standards for workers and the public.

Questions raised about the study's validity include:

- First, a 1992 study by the U.K. Radiological Protection Board of 95,000 nuclear power plant workers—who had received greater occupational doses than the Hanford employees—showed no excess cancers whatever.
- Second, Stewart and Kneale's results could have been marred by a flaw in their previous studies, in which they ignored exposures of workers to potential carcinogens besides radiation.
- Third, if doses as small as those in the Stewart study affected cancer rates, then 5 million residents of Colorado, where the natural radiation level is high because of the altitude, should show 50,000 excess cancer deaths over their lifetime. But between 1950 and 1988, Colorado residents experienced fewer—not more—leukemia deaths than people at sea level.

Gilbert Study. In a 1993 study published in Radiation Research, Hanford epidemiologist Ethel Gilbert found fewer cancer deaths in radiation workers than in nonradiation workers. More important, her analysis showed no increase in cancer mortality with higher worker doses.

International Agency for Research on Cancer. The International Agency for Research on Cancer studied the effects of low doses of radiation on more than 400,000 nuclear workers in 15 countries, including the United States.[4] The study sought to determine whether workers with higher radiation doses have a higher risk of cancer, including leukemia.

All individuals had worked for at least one year in environments that have the potential for radiation exposure—nuclear power plants, nuclear technology research, waste management, radioisotope production, fuel fabrication or weapons facilities. The statistical models used in the study accounted for such factors as age, gender (90 percent of those in the study group were men), the time between radiation exposure and death, how long individuals worked in that environment, and socioeconomic status. The study did not account for such variables as smoking, diet or other types of occupational exposures.

In some cases, the cumulative doses to individuals do not accurately reflect today's tough radiation protection standards, but instead reflect much earlier standards.

"Less than 5 percent of workers in this study received cumulative doses of the order of [10,000 millirems] over their entire career … and most of these doses were received in the early years of the industry, when protection standards were less stringent than today."

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[4] British Medical Journal, doi:10.1136/bmj.38499.599861. EO, published June 29, 2005.

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Based on its analysis, the panel estimated that radiation exposure could be responsible for 1 percent to 2 percent of cancer deaths among nuclear workers.

The study identified a difference in cancer mortality risk among the 15 countries—with one country, Canada, higher than the others—but it found nothing that might account for this difference. "Only when we excluded Canada was the excess relative risk [of cancer mortality] no longer significantly different from zero," the panel wrote.

The results confirm that current radiation protection standards keep workers safe. "We have provided radiation risk estimates from the largest study of nuclear workers conducted so far," the panel wrote. "These estimates are higher than, but statistically compatible with, the current bases for radiation protection standards."

This fact sheet also is available at www.nei.org.