Steve Wing, Associate Professor, Department of Epidemiology, School of Public Health, University of North Carolina, steve_wing@unc.edu

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Mr. Chairman and Members of the Committee, thank you for inviting me to testify about health effects of low level radiation. I am an epidemiologist on the faculty at the University of North Carolina where I have studied radiation health effects among workers at Oak Ridge, Los Alamos, Hanford and Savannah River under funding from the Departments of Energy and Health and Human Services. Epidemiology, the study of disease in human populations, is especially important in risk estimation and standard setting because animal and laboratory studies necessitate extrapolation from high to low doses, from molecules and cells to organisms, and from other species to humans (1-3).

We know that ionizing radiation can cause cancer and inherited mutations by damaging DNA. Although epidemiologists have studied populations exposed to both high and low levels of radiation, extrapolation of risks from high to low doses has led to a debate over whether a straight line extrapolation, the linear no-threshold model, is appropriate. My testimony will make three points: current cancer risk estimates are too low by a factor of ten or more; current standards do not adequately protect workers and the public; and, a large and growing body of scientific evidence shows that there is no basis for further relaxation of radiation protection standards.

Extrapolation from high dose studies.

High dose studies examine special populations including patients receiving radiation treatments. By far the most influential are studies of survivors of the bombings of Hiroshima and Nagasaki that are currently the primary basis for cancer risk estimates. However, the A-bomb studies are flawed due to selective survival, poor dose measurement and confounding exposures (4-7).

The atomic bombings produced massive immediate casualties as well as delayed deaths due to lingering effects of radiation, infectious epidemics, and the destruction of food, housing, and medical services (8). Only the healthiest survived these conditions, especially among those who are most vulnerable, the young and the old. By 1950, when a list of survivors was assembled for long-term study, persons most susceptible to radiation had already died. The healthy survivor effect leads to

underestimation of risks, particularly for exposures in utero, during childhood, and at older adult ages (6).

Detection of radiation risks depends upon the ability of an epidemiological study to classify persons according to their exposure levels. A-bomb survivors were not wearing radiation badges, therefore their exposures had to be estimated by asking survivors about their locations and shielding at the time of detonation. In addition to the typical types of recall bias that occur in surveys, stigmatization of survivors made some reluctant to admit their proximity (9). Acute radiation injuries such as hair loss and burns among survivors who reported they were at great distances from the blasts (10, 11) suggests the magnitude of these errors, which would lead to under estimation of radiation risks.

Another bias occurs because of the higher exposures of distant survivors to residual radiation. Fallout affected distant survivors in both cities (8, 12). In addition, survivors who were shielded or exposed at greater distances were strong enough to enter the areas near the hypocenters of the blasts within hours of detonation, exposing themselves to residual radiation created by the atomic weapons (8, 12-14). Residual radiation exposures of lower dose survivors leads to an underestimate of radiation risks.

Direct observation from low dose studies.

In 1956 Dr. Alice Stewart and colleagues reported in The Lancet that fetal exposures during obstetric x-ray examinations are associated with elevated childhood cancer rates (15). The fetus is especially sensitive to radiation due to rapid cell division. Stewart's findings have been replicated in numerous other low dose studies (6, 16-18), and standards for medical practice now dictate that small doses of radiation associated with a single x-ray should be avoided during pregnancy.

Long-term studies of cancer among nuclear workers began to appear in the 1970s when Mancuso, Stewart and Kneale reported that small doses of radiation received at older ages raised cancer rates among workers at the plutonium production facility in Hanford, Washington (19). Manhattan Project scientists realized in the early 1940s that workers in the weapons plants faced special hazards, and they created a unique resource for health studies at some facilities by issuing each employee a radiation monitor that was incorporated into the security badge required at work. Although dose records are poor for many workers and veterans, long-term studies of well-monitored workers have now been reported from nuclear facilities in the U.S., the United Kingdom and Canada. Despite the fact that workers are generally healthy adults, many of these studies have demonstrated relationships between low level radiation and cancer death, particularly among older workers. The greater sensitivity of older adults to ionizing radiation was not recognized in A-bomb studies due to selective survival, however this observation is consistent with studies that show reductions in immune function and efficiency of DNA repair with aging (6, 20). Risk estimates from many occupational studies are approximately 10 times higher than estimates based on follow-up of A-bomb survivors (21-33), showing that current protection standards are too lax. In our recent study of multiple myeloma among

Oak Ridge, Hanford, Los Alamos and Savannah River workers, doses between 5 and 10 rems were associated with a threefold elevated risk, and doses over 10 rems were associated with a fivefold elevated risk (33). None of the multiple myeloma cases had recorded doses over the current U.S. occupational limit of five rems per year.

From the United Kingdom comes evidence that paternal preconception exposures are associated with risk of childhood cancer, stillbirth and an excess of male compared to female births (34-36). The ability of radiation to induce heritable genetic mutations in experimental animals has been recognized since the 1920s (37). This recent evidence suggests that small doses of radiation delivered in the period prior to conception can lead to genetic effects in human offspring. Evidence on genomic instability following exposure to alpha radiation raises concerns for both carcinogenic and inherited genetic effects (38-40).

The belief that radiation risks at low doses could be extrapolated from high dose studies led some to predict that cancer risks of radiation could not be detected among nuclear workers. Although this has turned out to be false, some researchers have pooled data from different worker populations in order to increase sample size, believing that this would increase power to detect radiation risks (41-43). Unfortunately, pooling populations with different types of radiation, exposure conditions, measurement qualities and worker selection factors, achieves statistical precision at the cost of accuracy, diluting radiation effects (43).

Diseases and genetic mutations caused by radiation do not carry a marker showing their origins, therefore epidemiologists look for excess rates of disease in populations with higher radiation exposures. However, it is easy to design an epidemiological study of environmental or occupational radiation exposure that is unable to detect low level effects. Only in special circumstances, such as the cases of well-monitored workers and certain medical exposures (44), is it possible to quantify low doses and subsequent risk. The sensitivity of epidemiological studies is compromised because people generally cannot be traced between the time they are exposed and the time disease develops, and because medical information (other than cause of death) is not routinely available for populations without universal medical care. It is incorrect to conclude that low level radiation is safe on the basis of studies that lack careful radiation measurements and follow-up of medical outcomes. Unfortunately such conclusions have been made based on studies of geographic variation in average background radiation (45).

Furthermore, some scientists have mistakenly claimed that there is no evidence of radiation health effects below some arbitrary level. Not only do such statements ignore an extensive medical literature on in utero and occupational radiation; they reflect a basic misunderstanding of how epidemiology works. In order to detect the risks from a hazardous agent, epidemiologists study a range of exposure levels. For example, we compare lung cancer rates of never-smokers to rates among people who smoke less than a pack a day, one pack a day, two packs a day, and three or more packs a day. It would be incorrect to separate the data for people who smoke one cigarette a day and declare that

low levels of smoking are safe. Conclusions about health effects of agents such as radiation and cigarettes should be derived from data on a range of exposures.

The current state of knowledge

As knowledge about ionizing radiation has grown, health effects have been recognized from activities that until recently were thought to be safe. Despite past assurances about the safety of nuclear weapons tests, the National Cancer Institute's recent study indicates that tens of thousands of Americans can expect to get thyroid cancer from just one of the radionuclides released by atmospheric testing (46). The fact that radiation protection standards have been reduced as scientific study of low doses increases is another measure of concern (7). Although the International Commission on Radiation Protection recommended in 1990 that the 5 rem per year limit for nuclear workers be reduced to 2, the U.S. continues to permit workers to be exposed to more than twice the radiation dose allowed by countries that adopted the international standard, including Canada and the European Union.

The nuclear age is little more than a half-century old. Although much has been learned about radiation during this time, there is much more that remains to be understood about human health effects. It is increasingly clear that there is great variability in the sensitivity of humans to low level radiation due to factors such as age, genetic susceptibility and exposures to chemical agents, infection or nutritional factors. Decisions about exposure standards should take account of the special risks faced by the young, the old and the genetically susceptible. Public health and moral principles demand that we protect the most vulnerable.

As amply documented by the Secretarial Panel for the Evaluation of Epidemiologic Research appointed by Admiral Watkins (47), President Clinton's Advisory Committee on Human Radiation Experiments (48), a taskforce of the Physicians for Social Responsibility (49), and numerous publications in the scientific literature (50-54), the body of scientific knowledge about the health effects of ionizing radiation has been compromised by concerns about secrecy and public relations. In its 1995 report, the President's Advisory Committee on Human Radiation noted that, "By the mid-1960s the possibility that data gathering could only get the AEC (Atomic Energy Commission) into more trouble became an incentive to 'not study at all'" (48). These attitudes have continued to affect research in recent decades (51, 52). In the case of regulatory standards that are intended to protect the health of workers and the public, policy makers should consider scientific evidence and testimony with the understanding that scientists have been restrained from fully investigating the effects of low level ionizing radiation.

Current radiation standards already fail to adequately protect workers and the public, even if flawed risk estimates from A-bomb studies are used. The 1994 GAO report on Nuclear Health and Safety notes that exposures permitted by current Nuclear Regulatory Commission and Department of Energy

guidelines, according to those agencies, would lead to 1 in 300 premature cancer deaths in the general public and 1 in 8 among workers (55). No other carcinogens are permitted such lax standards. I strongly urge members of Congress and the regulatory agencies to exercise precaution and prudence in order to protect the health and lives of the public and of future generations who will be affected by decisions on production and disposition of nuclear materials.

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