ALARA	As Low as Reasonably Achievable
AMA	Aquatic Management Area
amsl	above mean sea level
ANSI	American National Standards Institute
BCC	Birds of Conservation Concern
bgs	below ground surface
BMPs	Best Management Practices
CAA	Clean Air Act
CIP	Conservation Improvement Program
CFR	Code of Federal Regulations
CN	Certificate of Need
CO2	Carbon Dioxide
DOE	US Department of Energy
DR	Demand Response
DSC	Dry Shielded Canister
DSM	Demand Side Management
DWSMA	Drinking Water Supply Management Area
EE	Energy Efficiency
EERA	MN Dept of Commerce - Energy Environmental Review & Analysis
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
FAA	Federal Aviation Association
FWS	US Fish and Wildlife
GWh	Gigawatt-hours
HSM-H	Horizontal Storage Module – Model H
INPO	Institute of Nuclear Power Operations
IPaC	Information for Planning and Consultation
IRP	Integrated Resource Plan
ISFSI	Independent Spent Fuel Storage Installation
ISG	Interim Staff Guidance
kW/kWh	kilowatt/kilowatt-hours
MBTA	Migratory Bird Treaty Act
MCBS	Minnesota County Biological Survey
MDNR	Minnesota Department of Natural Resources
MNGP	Monticello Nuclear Generating Plant ("the Plant")

MPCA	Minnesota Pollution Control Agency
MSP	Minneapolis-St. Paul International Airport
MTU	Metric Tons Uranium
MW	Megawatt
NAAQS	National Ambient Air Quality Standards
NHIS	Natural Heritage Information System
NLCD	National Land Cover Data
NPC	Native Plant Community
NPDES	National Pollutant Discharge Elimination System
NRC	US Nuclear Regulatory Commission
NRCS	Natural Resources Conservation Service
NRHP	National Register of Historic Places
NSA	Noise Sensitive Area
NUHOMS	NUTECH Horizontal Modular Storage System
NWI	National Wetlands Inventory
OSA	Office of the State Archaeologist
PCBs	Polychlorinated Biphenyls
PRRV	Present-Value of Revenue Requirements
PVSC	Present-Value of Societal Costs
PW	Public Waters
PWR	Pressurized Water Reactor
SBS	Site of Biodiversity Significance
SDS	State Disposal System
SLR	Subsequent License Renewal
SNA	Scientific and Natural Area
SPCC	Spill Prevention Control and Countermeasure
TIGER	Topologically Integrated Geographic Encoding and Referencing System
TMDL	Total Maximum Daily Limit
USGS	U.S. Geological Survey
WIMN	MPCAs What's in My Neighborhood
WPA	Wellhead Protection Area
WPA	Waterfowl Protection Area
Xcel Energy or "the Company"	Northern States Power-Minnesota d/b/a Xcel Energy

COMPLETENESS CHECKLIST

MINNESOTA RULE	INFORMATION REQUIREMENT	APPLICATION SECTION(S)
7855.0230	General Information	Chapter 2
7855.0240	Schedule of Other Filings	Chapter 3
7855.0250	Need Summary	Chapter 4
	A. Adequacy, Reliability, safety and Efficiency of Energy Supply	4.1
	B. Alternatives	4.2
	C. Consequences to Society	4.3
	D. Consistency With Other Rules and Regulations	4.4
7855.0260	Additional Considerations	Chapter 5
	A. socially beneficial uses of the output of the facility, including its uses to protect or enhance environmental quality	4.1, 4.3, 5.1, 9.3
	B. promotional activities that may have given rise to the need for the facility	5.2, 4.1.3
	C. the effects of the facility in inducing further development	5.3 Chapter 14
7855.0270	Conservation Programs	4.2.3 Chapter 6
7855.0280	Other Data Filed With Application	Chapter 7
7855.0600	Nuclear Waste, Disposal Facility; Description	Chapter 8

MINNESOTA RULE	INFORMATION REQUIREMENT	APPLICATION SECTION(S)
7855.0610	Alternatives	Chapter 9 4.2
7855.0620	Historical and Forecast Data	Chapter 10
7855.0630	Environmental Information Required	Chapter 11
7855.0640	Alternative Sites	11.0
7855.0650	Wastes and Emissions	Chapter 12 Appendix B Appendix C Appendix D
7855.0660	Pollution Control and Safeguards Equipment	Chapter 13
7855.0670	Induced Development	Chapter 14

Appendix B

RADIATION PRIMER

ISFSI CONSULTING SERVICES
Project Instruction No.: MN04-P501833

Prepared by

Kenneth L. Mossman, Ph.D.
Radiation Services Associates
Scottsdale, Arizona

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1.0 INTRODUCTION

This is a brief primer on radiation for readers who do not have a technical background in radiation science but require some knowledge about radiation, its public health impacts, and how it is controlled.[1] This primer covers the following subject material: characteristics of ionizing radiation, quantities and units used to measure radiation, sources of radiation, public health effects, and principles of radiation safety.

Radiation is an integral part of life. We live in a world in which radiation is naturally present everywhere. Light and heat from nuclear reactions in the Sun are essential to our existence. Radioactive materials occur naturally throughout the environment, and our bodies contain radioactive materials such as carbon-14, potassium-40 and polonium-210 quite naturally. All life on Earth has evolved in the presence of radiation. Without radiation life on Earth as we know it would not exist.

Radiation also can be made by man. This includes hundreds of beneficial uses, including medical X-rays, nuclear medicine pharmaceuticals, television sets and electricity generation from nuclear power plants. Man-made radiation is basically no different from naturally occurring radiation. But, unlike natural background radiation, the use and handling of man-made radiation is strictly controlled and regulated. Most of the public's exposure to man-made radiation comes as a result of medical X-rays, as well as other medical diagnostic treatments using radioactive materials. Nuclear power operations including storage of spent nuclear fuel exposes the population to only a tiny amount of radiation.

2.0 WHAT IS IONIZING RADIATION?

Radiation may be defined as the transport of energy in the form of waves or particles through space. Radiation can be classified according to the effects that are produced when radiation interacts with matter. *Ionizing radiation* (e.g. cosmic rays, X rays and the radiation from radioactive materials) have sufficient energy to ionize the irradiated material. *Non-ionizing radiation* (e.g., ultraviolet light, radiant heat, radio waves and microwaves) have insufficient energy to cause ionization but, nonetheless may cause damage through other physico-chemical processes. In this primer only ionizing radiation is considered. Ionizing radiation is generated by radioactive materials that are key components in the nuclear fuel used in electricity generation in nuclear power plants.

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1. This paper is based on various publications from the Nuclear Energy Institute and by the International Atomic Energy Agency. The Nuclear Energy Institute has developed a series of primers and reports for non-technical audiences. These may be found at: http://www.nei.org/index.asp?catnum=1&catid=6
The International Atomic Energy Agency has published an excellent document titled *Radiation, People and the Environment.* It may be accessed at:
http://www.iaea.org/Publications/Booklets/RadPeopleEnv/pdf/radiation_low.pdf

2.1 Radionuclides and radioactivity

Radionuclides (nuclides that are radioactive and emit radiation) are an important source of ionizing radiation. Atoms can be characterized by the composition of the atomic nucleus. *Nuclides* are defined as a species of atom with a given number of protons and neutron in the nucleus. Chemical and physical properties of a nuclide are determined by the number of neutrons and protons in the nucleus. All nuclides with the same number of protons in the nucleus (but different numbers of neutrons) are called *isotopes* and share the same chemical properties.

Although many nuclides are stable, most are not. An unstable nuclide is called a *radionuclide*. Stability is determined mainly by the balance between the number of neutrons and protons a nuclide contains. Smaller stable nuclides have about equal numbers of protons and neutrons; larger stable nuclides have slightly more neutrons than protons. Radionuclides with too many neutrons are unstable and tend to transform themselves to a more stable structure by converting a neutron to a proton: this process, known as beta decay, results in the emission of a negatively charged electron called a *beta particle*. Radionuclides with too many protons are also unstable and convert the excess protons to neutrons in a different form of beta decay: they lose positive charge through the emission of a *positron,* which is a positively charged electron.

These transformations often leave the nucleus with excess energy that it loses as *gamma rays* — high energy *photons,* which are discrete parcels of energy without mass or charge. The spontaneous transformation of a radionuclide is called *radioactivity,* and the excess energy emitted is a form of ionizing radiation. The act of transformation is termed *radioactive decay*.

Some very heavy radionuclides decay by producing an *alpha particle* consisting of two protons and two neutrons. Identical with a nucleus of helium, the alpha particle is much heavier than the beta particle and carries two units of positive charge.

2.2 Alphas, betas, gammas and neutrons

Alpha particles, beta particles, gamma rays and neutrons are products of the decay of radionuclides important in nuclear power plant operations. Nuclear fuel contains radionuclides that produce these forms of ionizing radiation:

Alpha radiation is a positively charged helium nucleus emitted by a larger unstable nucleus. It is a relatively massive particle, but it only has a short range in air (1–2 cm) and can be absorbed completely by paper or skin. Alpha radiation can, however, be hazardous if it enters the body by inhalation or ingestion, because large exposures can result in nearby tissues, such as the lining of the lung or stomach.

Beta radiation is an electron emitted by an unstable nucleus. Beta particles are much smaller than alpha particles and can penetrate further into materials or tissue. Beta radiation can be absorbed completely by sheets of plastic, glass, or metal. It does not normally penetrate beyond the top layer of skin. However large exposures to high-energy beta emitters can cause skin burns. Such emitters can also be hazardous if inhaled or ingested.

Gamma radiation is a very high energy photon (a form of electromagnetic radiation like light) emitted from an unstable nucleus that is often emitting a beta particle at the same time. Gamma radiation causes ionization in atoms when it passes through matter, primarily due to interactions with electrons. It can be very penetrating and only a substantial thickness of dense materials such as concrete, steel or lead can provide good shielding. Gamma radiation can therefore deliver significant doses to internal organs without inhalation or ingestion.

Neutron radiation is a neutron emitted by an unstable nucleus, in particular during atomic fission and nuclear fusion. Apart from a component in cosmic rays, neutrons are usually produced artificially. Because they are electrically neutral particles, neutrons can be very penetrating and when they interact with matter or tissue, they cause the emission of beta and gamma radiation. Neutron radiation therefore requires heavy shielding to reduce exposures.

3.0 RADIATION QUANTITIES AND UNITS

Ionizing radiation cannot be detected by our senses. But indirect methods are available that take advantage of the fact that ions are produced when radiation interacts with matter. Common methods of detection include *photographic films*, *Geiger–Müller tubes*, and *scintillation counters*, as well as newer techniques using *thermoluminescent materials* and *silicon diodes*. Measurements can be interpreted in terms of the energy that the radiation deposited throughout the human body or in a particular part of the body. When direct measurements are not possible (e.g., a radionuclide is deposited in an internal organ like the liver) the dose absorbed by that organ can be calculated provided that the amount of activity retained in the organ is known. The amount of energy that ionizing radiation deposits in a unit mass of matter, such as human tissue, is called the *absorbed dose*. It is expressed in a unit called the rad, where 1 rad is equal to 100 erg[2] per gram. Submultiples of the rad are often used, such as the millirad (mrad), which is one-thousandth of a rad.

Types of ionizing radiation differ in the way in which they interact with biological materials, so that equal absorbed doses (meaning equal amounts of energy deposited) do not necessarily have equal biological effects. For instance, 1 rad to tissue from alpha radiation is more harmful than 1 rad from beta radiation because an alpha particle, being slower and more heavily charged, loses its energy much more densely along its path. In order to put all the different types of ionizing radiation on an equal basis with respect to their potential for causing harm, the quantity *equivalent dose* is used. It is expressed in a unit called the rem. Submultiples of the rem are commonly used, such as the millirem (mrem), which is one-thousandth of a rem. Equivalent dose is equal to the absorbed dose multiplied by a factor that takes into account the way in which a particular type of radiation distributes energy in tissue. For gamma rays, X rays, and beta particles, this

[2] An erg is the metric unit of energy.

radiation-weighting factor is set at 1, so the absorbed dose and equivalent dose are numerically equal. For alpha particles, the factor is set at 20, so that the equivalent dose is 20 times the absorbed dose. Values of the radiation weighting factor for neutrons of various energies range from 5 to 20. Equivalent dose accounts for differences in radiation effectiveness to cause biological harm. The equivalent dose provides an index of the likelihood of harm to a particular tissue or organ from exposure to various types of radiation regardless of their type or energy. Accordingly, 1 rem of alpha radiation to the lung, for example, would create the same risk of inducing fatal lung cancer as 1 rem of beta radiation (although the absorbed doses are very different).

Tissues and organs also vary in their sensitivity to radiation induced harm. For a given effective dose one tissue may be more sensitive than another. For example, the risk of fatal malignancy per unit equivalent dose is lower for the thyroid than for the lung. Moreover, there are other important types of harm such as non-fatal cancers or the risk of serious hereditary damage caused by irradiation of the testes or ovaries. These effects are different both in kind and in magnitude and we must take them into account when assessing the overall detriment to the health of human beings arising from exposure to radiation. Differences in tissue and organ radiosensitivity may be accounted for by taking the equivalent dose in each of the major tissues and organs of the body and multiplying it by a weighting factor related to the risk associated with that tissue or organ. The sum of these weighted equivalent doses is a quantity called the *effective dose*. This quantity permits the various dose equivalents in the body to be represented as a single number. The effective dose also takes account of the energy and type of radiation, and therefore gives a broad indication of the detriment to health. Moreover, it applies equally to external and internal exposure and to uniform or non-uniform irradiation. It is common to abbreviate effective dose to *dose*.

It is sometimes useful to have a measure of the total radiation dose to groups of people or a whole population. The quantity used to express this total is the *collective effective dose* or just *collective dose.* It is obtained by adding, for all exposed people, the effective dose that each person in that group or population has received from the radiation source of interest. For example, in the United States the effective dose from all sources of radiation is, on average, 360 mrem in a year. Since the U.S. population is about 300 million, the annual collective effective dose to the whole U.S. population is the product of these two numbers, about 110 million *man rem*. The collective effective dose concept is very useful in describing trends in population exposures over time (e.g., doses to a worker population at a nuclear power plant over a 10 year period), and in comparing (population) exposures from different radiation sources. The concept however has its limitations. It should not be used to calculate probabilities of health effects in large populations from very small individual doses.

4.0 SOURCES OF RADIATION

Humans are exposed to radiation from outer space and from radionuclides in the Earth's crust. Radiation also comes from man-made sources. Natural sources of radiation, account for 82 percent of the radiation to which the public is exposed every year. There is no evidence of any increase in cancer among people living in areas where natural, background radiation is several times higher than average such as Han (China), Kerala (India) or Araxa-Tapira (Brazil).

The average American receives 360 millirem of radiation each year. Three hundred mrem come from natural sources: the sun's rays, rocks, soil, building materials and other background sources. The other 60 mrem come from human activities and products, like medical/dental X-rays and consumer products. According to the National Council on Radiation Protection and Measurements,[3] an independent scientific body, the major sources of radiation exposure to the public are:

Natural Radiation: Radon in Indoor Air. Small amounts of radon-222, a radioactive gas, seep from uranium that is widely distributed in the Earth's crust. On average, radon trapped in homes accounts for 55 percent of the radiation to which Americans are exposed -- approximately 200 millirem every year.

Natural Radiation: The Human Body. About 11 percent of the average person's total exposure -- an average of 39 millirem per year -- comes from the human body itself. Potassium-40 and other radionuclides found in air, water and soil are incorporated into the food we eat, then into our bodies' own tissues.

Natural Radiation: Rocks and Soil. Rocks and soil account for about 8 percent of the public's exposure to radiation from all sources, or 28 millirem per year. The exposure comes from the Earth's crust and from building materials derived from soil and rocks. Brick and cinder-block homes expose the public to more radiation than do wooden homes. Granite used to build large structures, such as Grand Central Station in New York City, also exposes the public to small amounts of radiation.

Natural Radiation: Cosmic Rays. The average person receives about 8 percent of his total exposure -- 28 millirem per year -- from cosmic radiation from outer space. Actual exposures vary, since cosmic radiation increases with altitude, roughly doubling every 6,000 feet. A resident of Denver (one mile high) receives an average dose of about 50 millirem per year from cosmic radiation; those in Leadville, Colorado., at an altitude of two miles, get a cosmic ray dose of about 125 millirem per year; while a resident of Florida (at sea level) receives about 26 millirem per year from this source. Similarly, a passenger in a jet airliner at 37,000 feet (seven miles) may receive 60 times as much cosmic radiation in a given time as does someone at sea level.

Man-Made Radiation: Medical Procedures. The average American receives about 15 percent of his exposure to radiation from X-rays and nuclear medicine procedures -- an average of 45 millirem per year. A typical chest x-ray results in a 10 mrem dose.

Man-Made Radiation: Consumer Products. The average American receives about 3 percent of his total exposure to radiation from consumer products, or approximately 9

3. National Council on Radiation Protection and Measurements. *Ionizing Radiation Exposure of the Population of the United States*. NCRP Report No. 93. Bethesda, MD: NCRP; 1987.

millirem per year. Radon in natural gas used in cooking ranges contributes about five millirem per year. Smaller exposures can come from some smoke detectors, which use americium-241, and television sets. The use of lawn fertilizer can also expose an individual to radiation. Fertilizer contains potassium, of which a tiny amount is potassium-40, a naturally radioactive material.

Man-Made Radiation. Nuclear Power and Other Sources. Individuals are exposed to tiny amounts of radiation -- less than 1 percent of their total exposure -- from a variety of other activities. This includes radiation exposure from nuclear power plant operations, exposure due to fallout from past atmospheric testing of nuclear weapons, and from the generation of electricity from coal-fired and geothermal power plants.[4] The average Nuclear power plant operations do not expose people living near the plants to more than tiny amounts of radiation. American gets less than 0.1 mrem from nuclear power plants per year. This includes radiation from storage of spent nuclear fuel. Extensive epidemiological studies of cancer in populations living near nuclear power plants indicate no long term effects that could be attributed to radiation exposure from nuclear plant operations.[5]

5.0 RADIOLOGICAL HEALTH EFFECTS

Scientists have studied the effects of radiation for more than 100 years, and they know a great deal about how to detect, monitor and control even the smallest amounts. In fact, more is known about the health effects of radiation than about most other physical or chemical agents.

5.1 Interactions of radiation with matter

Health effects of radiation exposure start with the deposition of radiation energy in cells, tissues and organs. When radiation passes through matter, it deposits energy in the material concerned. Alpha and beta particles, being electrically charged, deposit energy through *electrical interactions* with electrons in the material. Gamma rays and X rays lose energy in a variety of ways, but each involves liberating atomic (orbiting) electrons, which then deposit energy in interactions with other electrons. Neutrons also lose energy in various ways, the most important being through collisions with hydrogen atoms (a single proton in the nucleus). The protons are then set in motion and, being charged, they again deposit energy through electrical interactions. So in all cases, the radiation ultimately produces electrical interactions in the material.

The process by which a neutral atom or molecule becomes charged is called *ionization* and the resulting entity an *ion*. Once removed from an atom, an electron may in turn ionize other atoms or molecules. Any radiation that causes *ionization* — either directly, as with alpha and beta particles or indirectly as with gamma rays, X rays, and neutrons — is known as ionizing radiation.

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[4] Coal-fired and geothermal power plants release radioactive material into the environment from naturally occurring radioactive materials.
[5] Jablon, S. et al. *Cancer in Populations Living Near Nuclear Facilities*. NIH Publication 90-874. Washington, DC: U.S Government Printing Office; 1990.

It is the initial ionization and the resulting chemical changes that cause harmful biological effects. Radiation causes damage at the cellular level. Cells are the basic building blocks of all tissues and organs. When ionizing radiation traverses the cell, damage to a variety of molecules and cell structures may occur depending on the dose. A particularly important molecular target is DNA or deoxyribonucleic acid. This is the master molecule that controls all critical functions of the cell. Damage to DNA can result in death of the cell or mutations that can perturb cell functions.

A most important property of the various types of ionizing radiation is their ability to penetrate matter. The depth of penetration for a particular type of radiation increases with its energy, but varies from one type of radiation to another for the same amount of energy. With charged particles such as alpha and beta particles, the depth of penetration also depends on the mass of the particle and its charge. For equal energies, a beta particle will penetrate to a much greater depth than an alpha particle. Alpha particles can scarcely penetrate the dead, outer layer of human skin; consequently, radionuclides that emit them are not hazardous unless they are taken into the body through breathing or eating or through a skin wound. Beta particles penetrate about a centimeter of tissue, so radionuclides that emit them are hazardous to superficial tissues, but not to internal organs unless they too are taken into the body. For gamma rays and neutrons, the degree of penetration depends on the nature of their interactions with tissue. Gamma rays can pass through the body, so radionuclides that emit them may be hazardous whether on the outside or the inside. X rays and neutrons can also pass through the body.

5.2 High dose effects

Biological effects of radiation at high dose are primarily the result of cell killing in the irradiated tissues or organs. Cells are killed because of extensive, irreparable damage to the DNA and other critical cell components. Extensive cell killing as a result of radiation exposure may result in observable changes in the irradiated tissue within days or weeks of exposure. Such damage is referred to as acute effects. Radiation doses of different sizes, delivered at different rates to different parts of the body, can cause different types of health effect at different times. Very high doses to the *whole body* can cause death within weeks. For example, an absorbed dose of 500 rad or more received instantaneously would probably be lethal, unless treatment was given, because of damage to the bone marrow and the gastrointestinal tract. Appropriate medical treatment may save the life of a person exposed to 500 rad, but a whole body dose of 5,000 rad or more would certainly be fatal even with medical attention. A very high dose to a *limited area* of the body might not prove fatal, but other early effects could occur. For example, an instantaneous absorbed dose of 500 rad to the skin would cause erythema (i.e. painful reddening of the skin) within a week or so, whereas a similar dose to the reproductive organs might cause sterility. These types of effect are called *deterministic effects* because they occur only if the dose or dose rate is greater than some threshold value (usually in excess of 50 rad delivered in a short period of time), and the effect occurs earlier and is more severe as the dose and dose rate increase.

5.3 Low dose effects-cancer and genetic effects

If the dose is lower, or is delivered over a longer period of time, there is a greater opportunity for the body cells to repair the damage, and there may be no early signs of injury. Even so, tissues may still have been damaged in such a way that effects appear much later in life (perhaps decades). These types of effect are called *stochastic effects*. They are not certain to occur, but the likelihood that they will occur increases as the dose increases. Because radiation is not the only known cause of most of these effects, it is normally impossible to determine clinically whether an individual case is the result of radiation exposure or not.

The most important stochastic effect is *cancer*, which is always serious and often fatal. Although the exact cause of most cancers remains unknown or poorly understood exposure to agents such as tobacco smoke, asbestos, ultraviolet radiation, and ionizing radiation are known to play a role in inducing certain types of cancer. The development of cancer is a complex, multistage process that usually takes many years. Radiation appears to act principally at the initiation stage, by introducing certain mutations in the DNA of normal cells. These mutations do not kill the cell but allow it to enter a pathway of abnormal growth that can sometimes lead to the development of a malignancy.

Ionizing radiation is known to cause many different types of cancer. Major cancers that have been observed include cancer of the breast, lung cancer, thyroid cancer and leukemia (cancer of the bone marrow). Not all cancers are fatal. Some cancers like thyroid cancer has a high survival probability (90% or more); other cancers like lung cancer are associated with poor survival (about 10%). In radiological protection the risk of fatal cancer is of primary concern because of its extreme significance. The use of fatal cancer risks also makes it easier to compare them with the other fatal risks encountered in life.

5.4 Risks of Cancer

Given that we cannot distinguish between those cancer cases resulting from radiation exposure and those with other causes, how can the risk of cancer be calculated? In practice health risks are determined by conducting epidemiological studies (an observational science concerned with the distribution of diseases in a population and their causes) of specific diseases in specific population groups. Suppose that the number of people in an irradiated group and the doses they have received are known. By observing the occurrence of cancer in the group and comparing with the doses and the number of cancers expected in an otherwise similar but unirradiated group, the increased risk of cancer per unit dose can be estimated. It is most important to include data for large groups of people in these calculations so as to minimize the statistical uncertainties in the estimates and take account of factors, such as age and gender, that affect the spontaneous development of cancer.

The main sources of information on the additional risk of cancer following exposure of the whole body to gamma radiation are studies of the survivors of the atomic bombs dropped on Hiroshima and Nagasaki in 1945. Because a substantial number of the people who survived the bombings are still alive today, it is necessary to predict how many extra cancers will eventually be found to have occurred in the exposed population. Various mathematical methods are used for this purpose, but this is inevitably another source of uncertainty in the risk estimates. Yet another source of uncertainty is that the doses received by the survivors can only be estimated from whatever information is available, and different assessments have reached somewhat different conclusions. Various occupational and medical exposure situations (including radiation treatments for non-cancerous diseases) have also provided important information in support of the atomic bomb-derived risk estimates.[6] Authoritative bodies such as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCREAR), the International Commission on Radiological Protection (ICRP), the National Council on Radiation Protection and Measurements (NCRP), and the National Research Council's Biological Effects of Ionizing Radiation (BEIR) Committees periodically review published epidemiological and scientific data for the purposes of refining cancer risk estimates.

Most of the Japanese atomic bomb survivors and other exposed groups studied received high doses over short periods of time. Observations of the cancer incidence in these groups, along with estimates of the doses they received, indicate that, for high doses and high dose rates, there is a linear relationship between dose and risk. Thus, for example, doubling the dose would double the risk. However, most radiation exposure involves low doses delivered over long periods.

At these low levels of exposure, studies of cancer incidence in the exposed population do not provide any direct evidence about the relationship between dose and risk, because the number of extra cancers that might be expected to result from the radiation exposure is too small (compared to the total number of cancer cases in the population) to detect. It is, therefore, necessary to consider other scientific information about the effects of radiation on cells and organisms and to form a judgment as to the most likely form of the dose–risk relationship. For many years, the internationally accepted solution has been to assume that the relationship is linear for low doses, all the way down to zero (known as the 'linear–no threshold' or LNT hypothesis), i.e. that any radiation dose has a detrimental effect, however small. However, some radiobiological experiments have been interpreted as suggesting that low doses of radiation have no detrimental effect, because the body can successfully repair all of the damage caused by the radiation, or even that low doses of radiation may stimulate the repair mechanisms in cells to such an extent that they actually help to prevent cancer. Other experiments have been used as the basis for theories that low doses of radiation are more harmful (per unit of dose) than high doses, or that the hereditary effects of radiation could get worse from generation to generation. After a major review of biological effects at low doses of ionizing radiation, UNSCEAR concluded in 2000 that "…an increase in the risk of cancer proportionate to radiation dose is consistent with developing knowledge and it remains, accordingly, the most scientifically defensible approximation of low dose response." However, UNSCEAR also

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6. For a summary of many epidemiological studies see United Nations Scientific Committee on the Effects of Atomic Radiation. *Sources and Effects of Ionizing Radiation*. Volume II: Effects. UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes. New York: United Nations; 2000

accepted that there are uncertainties and stated that "… a strictly linear dose response relationship should not be expected in all circumstances."[7]

In reality, the risk to an actual person from a given dose will depend on that person's age at the time of the exposure and on their gender. For example: if a person receives a dose late in life, a radiation-induced cancer may not have time to appear before the person dies of another cause; and the risk of breast cancer is virtually zero for men and twice the listed 'average' value, 0.4×10^{-4} or 1 in 25,000 per rem, for women. Furthermore, recent scientific advances indicate that a person's genetic constitution can influence their risk of cancer after irradiation. At present, we can identify only rare families who may carry increased risk, but experts may in future be able to take some account of such inherited traits.

Risk factors are also different for different populations. This is partly because different populations have different distributions of ages and different natural incidences of disease. For example, since the average age of a population of workers is generally higher (and therefore their life expectancy is shorter) than that of the population as a whole, the risk factor for the former is somewhat lower than that for the latter. The risk factor for workers is 4×10^{-4} or 1 in 2500 per rem. The risk factor for the general population is 5×10^{-4} or 1 in 2000 per rem.

<u>5.5 Hereditary disease</u>

Apart from cancer, the other main late effect of radiation is hereditary disease. As with cancer, the *probability* of hereditary disease depends on dose. Genetic damage arises from irradiation of the testes and ovaries, which produce sperm cells in males and the egg cells in females. Ionizing radiation can induce *mutations* in these cells or in the germ cells that form them, mutations which may give rise to harmful effects in future generations. Mutations occur as a result of structural changes to the DNA in single germ cells, which subsequently carry the hereditary information in the DNA through future generations. The hereditary diseases that may be caused vary in severity ranging from early death and serious mental defects to relatively trivial skeletal abnormalities and minor metabolic disorders. Although mutations appear to arise in human beings without any apparent cause, natural radiation and other agents in the environment may also cause them and contribute to the prevailing occurrence of hereditary disease. *There has, however, been no conclusive evidence in human offspring for hereditary defects attributable to exposure from natural or artificial radiation.* Extensive studies of the offspring of the survivors of the atomic bombs, in particular, have failed to show increases of statistical significance in hereditary defects. Instead, the negative findings help to provide an upper estimate of the risk factor for them.

Large experimental studies have been made of the hereditary damage that ionizing radiation induces in animals, mainly mice. These have covered a wide range of doses and dose rates and clearly demonstrate that ionizing radiation does cause mutations. The

7. United Nations Scientific Committee on the Effects of Atomic Radiation. *Sources and Effects of Ionizing Radiation*. Volume II: Effects. UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes. New York: United Nations; 2000

results also show how often hereditary defects are induced by known doses. When considered with the findings for the atomic bomb survivors, this information allows estimates to be made of hereditary risk for human beings.

Against this background, the risk of severe hereditary disease in a general population exposed to low doses and dose rates has been estimated to be 1.0×10^{-4} per rem or 1 in 10,000 per rem for such diseases appearing at any time in all future generations. Mutations leading to diseases that are strictly heritable, such as hemophilia and Down Syndrome, make up about half of the total. The remainder comes from a group of so-called multifactorial diseases, such as diabetes and asthma. This estimate of risk carries considerable uncertainty especially for the multifactorial diseases where the interplay of the genetic and environmental factors that influence the disorders is poorly understood.

Irradiation of the testes and ovaries only carries a risk of hereditary effects if it occurs before or during the reproductive period of life. Since the proportion of a working population that is likely to reproduce is lower than that in the general population, the risk factor for workers is smaller. Risk estimates for workers is estimated to be 0.6×10^{-4} per rem or 1 in 17,000 per rem for severe hereditary diseases in all future generations.

An important consequence of the assumption that risk is proportional to dose, without a low dose threshold, is that the collective effective dose becomes an indicator of communal harm. Under this concept it makes no difference mathematically whether, in a community of 50,000 people, each receives an effective dose of 200 mrem, or in a community of 20,000 people, each receives 500 mrem; the collective dose in each community is 10,000 man rem, and the communal cost in each community may be five cancer deaths and one severe hereditary defect in future generations. Members of the smaller community, however, run the greater individual risk of fatal cancer. As indicated in Section 3.0 “Radiation Quantities and Units,” calculations of collective dose should not be taken too far: the product of a very large number of people and a very small dose is likely to be meaningless.

6.0 RADIOLOGICAL PROTECTION

Radiation exposures particularly from man-made sources are strictly controlled so as to avoid deterministic effects and to keep the probability of stochastic effects as low as possible. The current system of radiation protection in place in the U.S. and many other countries is based on three fundamental principles. Each of these is based on an in depth scientific understanding of radiation and radiological health effects but there are also social issues involved that require a considerable need for the use of judgment.

6.1 Justification of a practice

No practice involving exposure to radiation should be adopted unless it produces at least sufficient benefit to the exposed individuals or to society to offset the radiation detriment it causes. In diagnostic medicine, patients are routinely given small doses of radiation in the process of diagnosing or ruling out certain diseases. The benefits for the patient almost always outweigh the usually small risks of exposure. However, when there is no benefit to be gained by the proposed activity, even a small radiological risk would negate justification of a practice. For example use of diagnostic ultrasound only to determine the sex of an unborn child carries no benefit for the patient. This practice is not justified even though ultrasound risks are small.

6.2 Optimization of protection (ALARA)

In relation to any particular source of radiation within a practice, the dose to any individual from that source should be below an appropriate dose constraint, and all reasonable steps should be taken to adjust the protection so that exposures are ALARA (as low as reasonably achievable), economic and social factors being taken into account. Since we assume that no radiation dose is entirely free from risk, it is important to pay attention to all doses and to reduce them whenever it is reasonably achievable. Eventually the point must come when further reductions in dose become unreasonable, because social and economic costs would outweigh the value of the reductions. Any residual risk as a consequence of an ALARA program would be considered acceptable (otherwise additional resources would be allocated to reduce dose further) and protection would then be considered optimized.

The key to an effective ALARA program is identifying what is "reasonable" in terms of costs and benefits Unfortunately there is no clear decision rule that can be applied across all radiological environments. What may be reasonable and acceptable in one setting may not be in another because of differences in cost constraints and site-specific requirements.

6.3 Application of individual dose limits

The third principle establishes dose limits for individuals and populations.[8] For a practice that is justified there is an obligation not to expose individuals to an unacceptable risk. This is accomplished by imposing strict dose limits and applying the principle of optimization of protection to keep doses ALARA. In the U.S. dose limits are set by several federal agencies. For nuclear power plant operations, the U.S. Nuclear Regulatory Commission sets standards and dose limits. In the U.S. nuclear workers are limited to 5000 mrem per year to the whole body. The public is limited to an annual exposure of 100 mrem from all sources[9] (25 mrem per year from any single source[10]). These prime limits, expressed in terms of effective dose, are intended to control the incidence of serious effects such as cancer and hereditary harm that involve an element of probability. The limits are far below doses that produce health effects. Another set of limits, expressed in terms of equivalent dose, is to protect the eyes, skin and extremities against other forms of damage.

The U.S. dose limits reflect the prevailing assumption among government (and industry and many academic) technical authorities that an individual must receive a whole-body

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[8] Radiation exposure for the purposes of medical diagnosis and therapy are excluded from dose constraints.
[9] See 10 CFR 20.1301, note this standard is identical to the recently adopted Minnesota Department of Health rule which governs public dose limits from medical and industrial uses of radiation, Minn. Rule 4731.2090
[10] See 10 CFR 72.104 and 40 CFR 191.03

dose of about 25,000 mrem (15,000 mrem for a pregnant woman) before there is a significant increase in the risk of serious human health effects, and a dose of about 500,000 mrem (500 rem) before probable death as a result of radiological health effects. The ALARA objective is to maintain worker and public doses as far below the applicable limits as reasonably achievable given social, technical, economic and policy considerations. The ALARA concept recognizes the uncertainties associated with the risk of low level exposure to ionizing radiation. Coupled with this uncertainty is considerable technical controversy about the individual health effects of any additional exposures beyond background levels.

There are two common misconceptions about dose limits. The first is that they mark an abrupt change in biological risk, a line of demarcation between safe and unsafe. It should be clear from the discussion on dose and risk that this is not so. It should also be apparent from the fact that there are different dose limits for workers and members of the public. These limits differ because higher risks are deemed more acceptable for workers, who receive a benefit from their employment, than for members of the public, whose risk is involuntary. The second misconception is that keeping doses below the limits is the only important requirement in radiological protection. On the contrary, the overriding requirement is to keep doses as low as reasonably achievable. This is reflected in the increasing emphasis on investigation levels, which are, of course, set below dose limits.

7.0 PUBLIC ANXIETY

The greatest concern about ionizing radiation stems from its potential to cause malignant diseases in people exposed to it and inherited defects in later generations. The likelihood of such effects depends on the amount of radiation that a person receives, whether from a natural or an artificial source. As the effects of ionizing radiation have become better understood during recent decades, a system for radiological protection has been developed to protect people from exposure to sources of radiation. But public anxiety remains.

Radiation is one cause, among many, of the ‘dread disease’ cancer. Our senses cannot detect radiation, making this invisible risk seem even more insidious. Our collective anxiety is strengthened by memories of accidents at nuclear power plants and other facilities, and by the common tendency to associate any form of radiation with all things ‘nuclear’, including nuclear weapons. Another contributory reason for general heightened sense of concern about radiation may be the lack of reliable and accessible information and the misunderstandings that arise. Efforts to inform the public through public information campaigns can go a long way to address many concepts and facts about radiation and radiation safety that have been chronically misunderstood.

Update to Risk Assessment Provided in 2005 Certificate of Need (Docket E002-CN=05-123)

A Radiation Primer and an ISFSI Risk Assessment were included as appendices in both the initial CON application for Monticello (E002/CN-05-123) and the CON application for an expansion of the ISFSI at Prairie Island (E002/CN-08-510). The Radiation Primer is a discussion on radiation for readers who do not have a technical background in radiation science but require some knowledge about radiation, its public health impacts, and how it is controlled. The primer covers subjects including: characteristics of ionizing radiation, quantities and units used to measure radiation, sources of radiation, public health effects, and principles of radiation safety.

The purpose of the Risk Assessment is to provide pertinent information on populations at risk, exposure patterns, radiation doses, types of health effects and probabilities of health effects to risk managers, policy makers and regulators so that the best possible decisions can be made regarding management of the risk associated with the ISFSI. Risk assessments are theoretical exercises designed to present different risk scenarios, and as a result, the Risk Assessment is not intended to predict the actual health effects on any particular individual resulting from the Project. Further, risk assessments, particularly those involving very small exposures to hazardous agents, have a high degree of uncertainty. For that reason, conservative safety margins are built into any risk assessment to ensure protection of the public.

As the proposed project is an incremental increase in the existing fuel storage, the Risk Assessment for the initial ISFSI provided in the 2005 Monticello CON application ("2005 CON Risk Assessment") continues to be informative. The only component appropriate for an update is the specific risk estimation based on calculated offsite dose rates provided in Section 4.0 of the 2005 CON Risk Assessment. This section estimates the radiogenic cancer risk to the public and is a straightforward product of the dose and risk coefficient (i.e. lifetime risk of cancer per unit of radiation dose). It is then a simple task to update these values based on calculated dose rates for the expanded ISFSI. For example, the difference in the risk estimation between the Monticello and Prairie Island ISFSIs is equal to the difference in estimated dose rates for the two ISFSI facilities.

The 2005 CON Risk Assessment is based on a calculated dose rate of 0.86 mrem/year at the site boundary (Owner Controlled Area) and of 0.16 mrem/yr at the nearest resident to the facility. These values have significant conservatism built into the calculation, as they both assume 24/7/365 occupancy at that location (8,760 hrs/yr), and no member of the public would ever be expected to spend any significant time at the site boundary under any circumstances. Table 4 of the 2005 CON Risk Assessment presents a calculated cancer mortality risk to member of the public as a result of construction of the ISFSI.

An updated Table and associated description to reflect the expanded ISFSI is provided below.

Table 4 Cancer mortality risks to members of the public located at OCA boundary and nearest residence. *Updated for expanded ISFSI*

Integrated Risk	Lifetime Cancer Mortality Risk at OCA Boundary	Excess Cancer Deaths per 100,000 at OCA Boundary	Lifetime Cancer Mortality Risk at Nearest Residence	Excess Cancer Deaths per 100,000 at Nearest Residence
1 yr	1/861,000	0.11 (0-0.02)	1/5,000,000	0.025 (0-.05)
10 yr	1/86,100	1.1 (0-2.0)	1/500,000	0.25 (0-.5)
20 yr	1/43,400	2.4 (0-5)	1/250,000	0.5 (0-.75)
50 yr	1/17,200	5.3 (0-10.7)	1/100,000	1 .0 (0-1.75)
70 yr	1/12,400	8 (0-13.3)	1/72,000	1.5 (0-2.5)
Cancer deaths / no radiation	1/5	20,000	1/5	20,000

A (theoretical) person who lived continuously at the nearest residence for 70 years would have about a 1 in 72,000 chance of dying of cancer because of radiation exposure from the spent nuclear fuel stored at the ISFSI site. However, this same person's chance of dying of cancer without MNGP radiation exposure is about 1 in 5. This additional risk from radiation exposure from MNGP pales in comparison to the natural risk. To see this difference more clearly Table 4 provides estimates of the number of cancer deaths in a theoretical population of 100,000, all living at the same distance from the ISFSI as the nearest residence. One-fifth of this population—or 20,000 persons—would be expected to die of cancer from all causes. Seventy years of exposure to radiation for this population from living as close to the ISFSI as the nearest residence due to the spent fuel storage at MNGP would add less than one additional person expected to die from cancer. As a result, the most probable real-world outcome for expanding the spent fuel storage is zero additional cancer deaths.

Appendix D

MONTICELLO ISFSI INITIAL RISK ASSESSMENT

ISFSI CONSULTING SERVICES
Project Instruction No.: MN04-P501833

Prepared by

Kenneth L. Mossman, Ph.D.
Radiation Services Associates
Scottsdale, Arizona

October 1, 2004

0.0 SUMMARY

The Monticello Nuclear Generating Plant proposes to establish a dry cask storage facility on the plant site. Dose estimates from the radioactive decay of spent nuclear fuel indicate that the general public at the OCA boundary and at the nearest residence will be subject to very tiny doses in addition to the natural background radiation that everyone receives. Doses are a tiny fraction of federal public dose limits as established by the U.S. Nuclear Regulatory Commission. The doses are so low in fact that they are well within the natural variation of background levels across the State of Minnesota.

Health risks (as measured by cancer mortality) based on public dose projections indicate less than one additional cancer to a theoretical population of 100,000 persons living for 70 years at the location of the nearest residence. For comparison about 20,000 individuals in this population will die of cancer from all causes.

Conclusions:

- Projected radiation doses to individuals at the OCA boundary and at the nearest residence are very small. The doses are a small fraction of the federal public dose limit. The doses are so small that they fall within the variation of natural background radiation levels in the State of Minnesota.

- Radiation risks are also very small and cannot be reliably measured. Although risks can be calculated on a theoretical basis they are so small that they are of little or no consequence as a practical matter.

1.0 INTRODUCTION

As part of re-licensing efforts for the Monticello Nuclear Generating Plant (MNGP), Xcel Energy proposes to establish a temporary dry cask storage facility for spent nuclear fuel. The Independent Spent Fuel Storage Installation (ISFSI) would be located at MNGP. An Environmental Impact Statement (EIS), including potential health impacts to workers and the general public in the vicinity of MNGP, must be developed as part of the state regulatory process.

This report is an initial health risk assessment for the planned ISFSI at MNGP. One public health issue associated with ISFSI operations is exposure to gamma and neutron radiation resulting from the radioactive decay of radionuclides in the stored spent nuclear fuel. MNGP workers and members of the public living in close proximity to MNGP may be exposed to ionizing radiation from ISFSI. For the purposes of radiological risk assessment and management it is assumed that any radiation dose, no matter how small may increase the risk of cancer and genetic effects.[1]

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[1] Only cancer mortality risks are considered in this study. Severe genetic effects are a minor contribution to the total health detriment, and in comparison to radiogenic cancer are not known very well. See National

This risk assessment is based on the Shaw Final ISFSI Study.[2] Doses from inhalation of radionuclides or immersion in a radioactive plume as a result of leakage of canisters are assumed to be zero. Canisters are designed and tested to be leak tight. Thus, leakage is not considered to be a credible accident scenario. As discussed in the body of this report projected individual doses to members of the public are very small and pose no measurable public health hazard.

1.1 Purpose of risk assessment

How do we determine how hazardous or risky a particular agent might be? The process or procedure used to estimate the chance that humans will be adversely affected by a chemical or physical agent is called risk assessment. The purpose of risk assessment is to provide pertinent information to risk managers, policy makers and regulators so that the best possible decisions can be made regarding management of the risk. Risk assessment does not measure the *real* health effects that exposure to a hazardous agent may have on a population. Risk assessments may be conducted without considering what the actual exposures may be to a population considered at risk. Risk assessment particularly involving very small exposures to hazardous agents have a high degree of uncertainty but conservative safety margins are built into an assessment analysis to ensure protection of the public.

Exposure to ionizing radiation has been well characterized. Ionizing radiation can be easily measured and sources of natural background radiation are well known. The major source of ionizing radiation to human populations is inhalation of radon gas accounting for about half of the total exposure (Table 1).[3] When the risk assessment exercise involves very small doses of ionizing radiation the contribution of the natural background becomes important in assessing overall risk and putting the additional radiation doses into appropriate perspective. Humans are exposed primarily from natural sources; anthropogenic exposures including exposure from the nuclear fuel cycle (of which storage of spent nuclear fuel is an end stage) provide very little additional exposure.[3]

Council on Radiation Protection and Measurements, *Risk Estimates for Radiation Protection*. NCRP Report No. 115. Bethesda, MD: NCRP; 1993.

2. Shaw, Stone & Webster, Inc. *Monticello Final ISFSI Study* Report No. 101893.0100-P(D)-1, Rev.1. Prepared for Nuclear Management Company, Monticello Nuclear Generating Plant, Monticello, MN, May 2004.

3. United Nations Scientific Committee on the Effects of Atomic Radiation. *Sources and Effects of Ionizing Radiation*. Volume I: Sources. UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes. New York: United Nations; 2000

Table 1. Sources of human exposure to ionizing radiation

Average worldwide exposure to radiation (excluding medical exposure)

Source	Annual effective dose (mSv)	
	Average	Typical range
Cosmic rays	0.39	0.3-1.0
External terrestrial	0.48	0.3-0.6
Inhalation (mainly radon)	1.15	0.2-10
Ingestion	0.29	0.2-0.8
Man-made	Very small	
Total	2.4	1-10

Regulations to limit environmental and occupational exposures to ionizing radiation and other carcinogens are based on the assumption that any dose of the carcinogen, no matter how small, might cause cancer and that the relation between dose and cancer induction is linear. The biological assumptions underlying the linear, no-threshold (LNT) theory are now seriously questioned. There is now clear evidence that other biologically plausible theories are more appropriate for some tumors and carcinogens.

Risks are determined in a relatively straightforward process by determining risk levels from the dose-response relationship based on given doses. As the final step in the risk assessment process, risk characterization must include careful consideration of uncertainties in risk and identification of key sources of uncertainty. To do otherwise would imply that risks are known with a degree of certainty that is not borne out by the uncertainty in the data.

2.0 DOSES TO THE PUBLIC FROM DRY CASK STORAGE

Dose assessment is important for several reasons. Dose measurements are necessary in order to make decisions on siting of the ISFSI arrays within MNGP. The arrays must be sited such that the annual dose equivalents to individuals located beyond the controlled area does not exceed 25 mrem. Dose estimation is also important in the risk assessment process. Health risks to members of the general public are assumed to be directly proportional to the dose of radiation. MNGP considered up to five potential ISFSI sites.[4] The best choice was classified as the primary site and extensive worker and public dose projections were made for this site. This initial risk assessment focuses on doses to the public from the primary ISFSI Site only.[5] The dose estimates are based on the assumption that there is no canister leakage that would contribute to dose and that reactor plant operations contribute an additional dose of 10 mrem per year. Doses from the ISFSI sites are due to radionuclide decay of stored spent nuclear fuel.

Doses and health risks to workers at MNGP are not considered here. Radiation safety (ALARA) practices at MNGP are in full compliance under 10 CFR 20 and are not at issue.

2.1 Radionuclides contributing to dose

Spent nuclear fuel contains a number of biologically important radionuclides (Table 2). Radionuclides emitting gamma rays are particularly important because the radiation is highly penetrating and depending on the amount of shielding some fraction can escape containment and expose workers and the general public. Gamma ray dose decreases exponentially with increased shielding thickness. Radionuclides that emit alpha (α) and beta (β) radiation do not pose an external hazard because the radiation cannot penetrate the canister or ISFSI shielding. However, these radionuclides are a potential health hazard if contacted directly through inhalation, ingestion or skin contact. Neutrons can also be generated due to the interaction of high energy alpha radiation with surrounding material. For instance a mixture of Am-241 alpha rays and beryllium emits neutrons. Like gamma rays, neutrons can be highly penetrating and may expose individuals at a distance from the spent nuclear fuel elements.

The highest energy gamma radiation is emitted by Cs-137. It has a short half-life relative to other biologically important radionuclides (Table 2). In consideration of permanent disposal the concern is with the radiation emissions from the very long-lived transuranics (Table 2). These radionuclides emit relatively low energy gamma radiation. Thus the radiological hazard associated with gamma radiation emission would decrease significantly over several decades due to the decay of Cs-137. Radionuclides that emit gamma radiation do not constitute that portion of spent fuel which is of greatest concern with respect to storage of spent fuel over a long duration of time.

4. *Supra* note 2.
5. Email memo from Scott Quiggle to Kenneth Mossman September 24, 2004.

Table 2. Biologically Significant Long-Lived Radioisotopes in Commercial Spent Fuel

RADIONUCLIDE	HALF –LIFE	PRINCIPAL RADIATION EMISSIONS
Strontium-90/Yttrium-90	28.5 y	β^-, γ
Technetium-99	213,000 y	β^-
Cesium-137	30.2 y	β^-, γ
Neptunium-237	2,140,000 y	α, γ
Plutonium-238	87.7 y	α, γ
Plutonium-239	24,131 y	α
Plutonium-241	14.4 y	β^-
Americium-241	432 y	α, γ

2.2 Dose estimates

The following dose estimates were derived from the Monticello Final IFSFI Study as amended by the Transnuclear Report E-21600 (October 4, 2004). Doses in mrem are due to gamma ray and neutron exposure from radionuclide decay of spent nuclear fuel, and refer to exposure of the whole body (and maximally exposed organ). Dose estimates are conservative and are based on using the Horizontal Storage Module (HSM)-H storage module that provides a very high shielding capability. Public doses were calculated assuming a 8760 hour year.[6]

Table 3. Estimated doses to the general public and workers from ISFSI arrays

LOCATION	ANNUAL DOSE TO THE PUBLIC	ANNUAL NATURAL BACKGROUND LEVEL
OCA Boundary	0.86 mrem	240 mrem (100-1000)
Nearest Residence	0.16 mrem	

Public dose estimates are well within federal regulatory limits. The nearest real resident cannot receive a dose in excess of 25 mrem per year.[7] Although dose estimates at the OCA boundary are also well within federal dose limits, it is unreasonable to assume that

6. Dose estimates in the Stone and Webster report (*supra* note 2) were revised by Transnuclear based on utilization of the HSM-H container that provides improved shielding compared to the HSM-102 storage module considered in the Stone and Webster estimates. See Transnuclear, *Radiological Evaluation for Monticello*, Report E-21600; October 4, 2004

7. Dose limits for members of the general public may be found at 10 CFR 72.104. Also of relevant interest is a recently adopted Minnesota Department of Health rule governing medical and industrial uses of radioactive substances--which establishes a 100 mrem standard for members of the general public. See Minn. Rule 4731.2090.

a member of the public would establish residency at the OCA boundary because of the proximity of transportation barriers including railroad tracks and roads.[8]

2.3 Dose comparison with natural background radiation levels

Dose estimates at the OCA boundary and nearest residence are well within world-wide annual natural background radiation levels of about 200-300 mrem (Table 2; 1 mSv = 100 mrem). Natural background levels around the world range from about 100 mrem per year to about 1000 mrem per year. In fact the estimated doses from the ISFSI array are so small that they are well within local variations in natural background levels. Differences in natural background radiation levels in Minnesota exceed the dose estimates in Table 3 for the ISFSI array.[9]

The average American receives 360 millirem annually. Three hundred mrem come from natural sources: the sun's rays, rocks, soil, building materials and other background sources. The other 60 mrem come from human activities and products, like medical/dental X-rays and consumer products. According to the National Council on Radiation Protection and Measurements,[10] an independent scientific body, the major sources of radiation exposure to the public are:

Natural Radiation: Radon in Indoor Air. Small amounts of radon-222, a radioactive gas, seep from uranium that is widely distributed in the Earth's crust. On average, radon trapped in homes accounts for 55 percent of the radiation to which Americans are exposed -- approximately 200 millirem every year.

Natural Radiation: The Human Body. About 11 percent of the average person's total exposure -- an average of 39 millirem per year -- comes from the human body itself. Potassium-40 and other radionuclides found in air, water and soil are incorporated into the food we eat, then into our bodies' own tissues.

Natural Radiation: Rocks and Soil. Rocks and soil account for about 8 percent of the public's exposure to radiation from all sources, or 28 millirem per year. The exposure comes from the Earth's crust and from building materials derived from soil and rocks. Brick and cinder-block homes expose the public to more radiation than do wooden homes. Granite used to build large structures, such as Grand Central Station in New York City, also exposes the public to small amounts of radiation.

Natural Radiation: Cosmic Rays. The average person receives about 8 percent of his total exposure -- 28 millirem per year -- from cosmic radiation from outer space. Actual exposures vary, since cosmic radiation increases with altitude, roughly doubling every 6,000 feet. A resident of Denver (one mile high) receives an average dose of about 50 millirem per year from cosmic radiation; those in Leadville, Colorado., at an altitude of

8. *Supra* note 2.

[9] Natural background radiation levels vary across the State of Minnesota. The major source of variability is radon concentration. See http://www.epa.gov/radon/zonemap/minnesota.htm

[10]. National Council on Radiation Protection and Measurements. *Ionizing Radiation Exposure of the Population of the United States*. NCRP Report No. 93. Bethesda, MD: NCRP; 1987.

two miles, get a cosmic ray dose of about 125 millirem per year; while a resident of Florida (at sea level) receives about 26 millirem per year from this source. Similarly, a passenger in a jet airliner at 37,000 feet (seven miles) may receive 60 times as much cosmic radiation in a given time as does someone at sea level.

The estimate doses from the ISFSI arrays are only a tiny fraction of the dose attributable to any single component of the natural background.

3.0 PUBLIC HEALTH EFFECTS (FROM SMALL DOSES OF IONIZING RADIATION)

The principal health effect of concern following exposure to small doses of ionizing radiation is cancer induction. There is also some evidence that small doses of radiation may increase genetic effects but the study of genetic effects has been difficult and, consequently, genetic risks are not known as well as cancer risks are.

Ionizing radiation at high dose is a known human carcinogen. Numerous population studies involving military, medical, and occupational uses of radiation clearly show that leukemia and a variety of solid tumors may be induced by radiation. However at low doses of radiation (e.g., the dose estimates under consideration in this risk assessment) the evidence for cancer causation is much less compelling. Most low dose epidemiological studies show no consistent health effects. Only a few studies suggest a significant association between radiation and cancer. However, even in these investigations, the causal nature of such associations and the levels of risk remain highly uncertain.[11]

Radiation risks for cancer have been based primarily on studies of Japanese survivors of the atomic bombings.[12] Excess cancers have been observed in the Japanese cohort that received doses above 20,000 mrem. Below this dose, radiogenic cancers are proportionally lower in number and have been very difficult to detect. Extrapolation of data derived from the “high” dose cohort, using the linear no threshold theory, has been the basis for predicting cancer risk at low doses.

The four major cancer types identified in the Japanese survivors are: leukemia, female breast cancer, and cancer of the thyroid. The first cancer reported was leukemia which

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11. United Nations Scientific Committee on the Effects of Atomic Radiation. *Sources and Effects of Ionizing Radiation*. Volume II: Effects. UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes. New York: United Nations; 2000
12. The largest single source of radiogenic cancer risk data is the survivors of the atomic bombings of Hiroshima and Nagasaki in August, 1945. In the Life Span Study (one of several cohort-based epidemiological studies), conducted by the Radiation Effects Research Foundation, approximately 86,000 atomic bomb survivors are being studied with mortality and causes of death continuously updated. Individuals received doses ranging from less than 10,000 mrem to more than 500,000 mrem. The average dose to survivors was approximately 20,000 mrem. Over 6,000 cancer deaths have been observed; only about 400 of these cancers might attributable to radiation exposure. See Preston, D.L. et al., Studies of mortality of atomic bomb survivors, Report 13: Solid cancer and non-cancer mortality 1950-1997. *Radiation Research* **160:** 381-407 (2003).

began to appear in the exposed Japanese population a few years after the bombing. However, not all leukemia types were equally affected. Acute leukemia and chronic granulocytic leukemia were substantially increased in the exposed populations but chronic lymphocytic leukemia incidence remained unchanged in survivors. Radiation-induced solid cancers became apparent 5 to 10 years (at a minimum) after leukemia induction. Only after 1974 did the cumulative excess of solid cancers since 1950 exceed the leukemia excess. Cancers of the esophagus, stomach, urinary tract and lymphomas have also been observed in excess in the Japanese survivor studies.[13]

The Hiroshima and Nagasaki experience has formed the basis for an extensive human data base which has been used in the development of radiation risk estimates and radiation protection standards. Supplementing the atomic bomb survivor data are a large number of smaller epidemiological studies involving medical uses of radiation.[14]

4.0 RISK ESTIMATION

Based on the dose estimates presented in Section 2.0, radiogenic cancer risks to workers and the public can be determined. The calculation is straight forward and is simply the product of the dose and risk coefficient (i.e., lifetime risk of cancer per unit radiation dose). Several authoritative bodies have developed cancer risks for use in radiation protection.[15] For the purposes of this risk assessment the following nominal lifetime excess cancer risk coefficients have been assumed:

5.0×10^{-7} fatal cancers per mrem for members of the public

The nominal risk to the general public is 25% higher than the worker risk because the general population includes males and females of all ages (children are more sensitive than adults). Worker populations are predominantly male between the ages of 20 and 70. Thus, worker populations exclude women and children that contribute to the collective sensitivity of the population.

As discussed more completely in section 5.0 (Risk Assumptions and Uncertainties), risk estimates should be viewed as subject to many uncertainties including epidemiological limitations, risk extrapolation from high dose to low dose, and extrapolating risks from high dose rate to low dose rate. Although risk coefficients appear to be highly quantitative and better defined than risks for most other carcinogens, there is a need to carefully interpret risk assessments based on these risk coefficients.

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13. National Research Council, *Health Effects of Exposure to Low Levels of Ionizing Radiation*. BEIR V Report. Washington, DC: National Academy Press; 1990.
14. *Supra* note 9.
15. The International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements have general agreement on the magnitude of radiogenic cancer risks (see National Council on Radiation Protection and Measurements. *Limitation of Exposure to Ionizing Radiation*. NCRP Report No. 115. Bethesda, MD: NCRP; 1993. The U.S. National Research Council BEIR Committee also analyses scientific data and publishes risk estimates that are in general agreement with the ICRP and NCRP estimates. The risk estimates used in this report are taken from NCRP Report No. 115.

This risk assessment examines cancer mortality risks in the following populations:

1. members of the public at the OCA boundary
2. members of the public residing at the nearest residence beyond the OCA boundary

4.1 OCA boundary and nearest residence

A member of the public located at the OCA boundary or residing in a house near the OCA boundary may be exposed to ionizing radiation from the ISFSI arrays. The data in Table 3 indicate that the dose to members of the public is exceedingly small. Table 4 provides estimates of risks for these exposure scenarios. Risks (in terms of probabilities) and mortality rates (in terms of cancer deaths per 100,000 population) are calculated for different exposure periods (1-70 years). The probability of cancer death and the mortality rates per 100,000 population were calculated assuming 0.86 mrem/year at the OCA boundary and 0.16 mrem/year at the nearest residence (see Table 3).

Table 4. Cancer mortality risks to members of the public located at the OCA boundary and nearest residence

INTEGRATED RISK	Lifetime Cancer Mortality Risk at OCA Boundary	Excess cancer deaths per 100,000 at OCA boundary	Lifetime Cancer Mortality Risk at nearest residence	Excess cancer deaths per 100,000 at nearest residence
1 year	1/2,300,000	0.04 (0-0.008)	1/12,500,000	0.01 (0-0.02)
10 years	1/230,000	0.4 (0-0.8)	1/1,250,000	0.1 (0-0.2)
20 years	1/116,000	0.9 (0-2)	1/625,000	0.2 (0-0.3)
50 years	1/46,000	2 (0-4)	1/250,000	0.4 (0-0.7)
70 years	1/33,000	3 (0-5)	1/180,000	0.6 (0-1)
cancer deaths/ no radiation	1/5	20,000	1/5	20,000

Numbers in Table 4 have been rounded to facilitate analysis and presentation. Rounding should not diminish the high degree of uncertainty in these estimates. Because the doses are so small, the associated risks for cancer are also small and very difficult to measure. The probability and the respective mortality rates shown in both tables are equivalent expressions of risk. But the mortality rate may be easier to comprehend. For comparative purposes and to put the radiological risks into perspective, the probability of death from cancer and the resulting number of cancer deaths in a population of 100,000 persons are shown. Radiological risks for even a 70-year exposure scenario are a minuscule fraction of the total cancer burden in the population.

Mortality rates also include 90% confidence limits (numbers shown in parentheses in Table 4) based on an uncertainty analysis of lifetime cancer mortality risk estimates.[16] Because of the uncertainties in risk at doses approximating natural background radiation

16. National Council on Radiation Protection and Measurements. *Uncertainties in Fatal Cancer Risk Estimates Used in Radiation Protection*. NCRP Report No. 126. Bethesda, MD: NCRP; 1997.

levels, the lower bound of the 90% confidence interval includes zero.[17] The most probable outcome is no increase in cancer deaths as a result of radiation exposure. It should be emphasized that the possibility of health effects at small doses cannot be totally discounted. However, if there is a risk it is so small that it cannot be measured reliably.

A (theoretical) person who lived continuously at the nearest residence for 70 years would have about a 1 in 180,000 chance of dying of cancer because of radiation exposure from the spent nuclear fuel stored at the ISFSI site. However, this same person's chance of dying of cancer without MNGP radiation exposure is about 1 in 5. The additional risk from radiation exposure from MNGP pales in comparison to the natural risk. To see this difference more clearly Table 4 provides estimates of the number of cancer deaths in a theoretical population of 100,000 living at the nearest residence. One-fifth of this population or 20,000 persons is expected to die of cancer from all causes. Exposure to radiation from living in the nearest residence for 70 years due to the spent fuel storage at MNGP would add less than one additional cancer. In fact the most probable outcome is zero additional cancers.

5.0 RISK ASSUMPTIONS AND UNCERTAINTIES

A number of key principles have emerged in the study of cancer in exposed human populations that bear on interpretation of risk assessment data:

- Cancer is a very common collection of diseases. Incidence and mortality rates very significantly among cancer types but when all cancer are considered collectively roughly one in three individuals will get cancer and about one in five will die of cancer (in the U.S.).

- Radiation induced cancers are indistinguishable from the spontaneous or naturally occurring cancers. Breast cancer induced by ionizing radiation is indistinguishable from breast cancer that appears spontaneously.

- The clinical appearance of cancer has a long latent period that extends from years to a few decades. Lung cancer is thought to appear about 20 years after the beginning of smoking.

- Various host factors influence cancer risk including gender and age. Children are considered at higher risk because they are young enough to live beyond the cancer latent period. Individuals exposed at age 70 have a minimal risk because they are not likely to live beyond the latency period to express disease.

These principles make detection of small cancer risks extremely difficult to measure and to interpret. The multi-year latency period requires long term study of populations for which follow-up may be difficult. The high spontaneous rates of cancer may make it

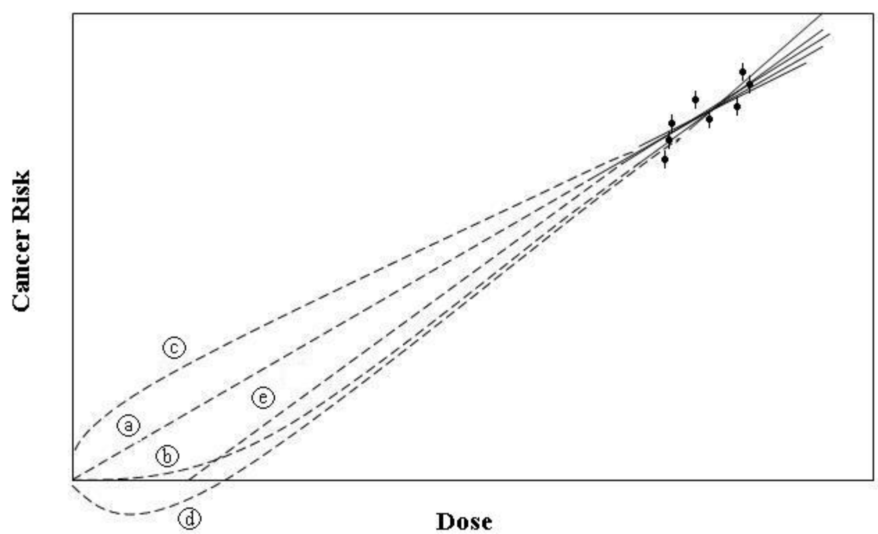
17. *Supra* note 11.

nearly impossible to detect radiation induced cancers (the signal) from the large number of spontaneous cancers that occur in the absence of radiation (the noise).

Risks at very small doses of ionizing radiation are theoretically determined and are highly uncertain. Risk estimates should be interpreted with great caution. Understanding and communicating very small risks must consider sources of uncertainty. Three major sources of uncertainty are considered below:

5.1 Estimating risks using the LNT predictive theory
Risks are uncertain in part because of lingering questions about the appropriateness of the LNT theory to predict risks at small doses.. This theory argues that any exposure to radiation is harmful, and one can calculate the probability of cancer from a linear extrapolation of observed cancer at high radiation exposures. This philosophy has led to the widespread belief that there is no safe dose of radiation and that regulations should establish exposure limits as low as possible if not zero.

Figure 1. Possible shapes of dose-response curves in risk assessment:



There are several biologically plausible theories that could be used in risk assessment Figure 1 compares (a) linear, no threshold, (b) sub-linear, (c) supra-linear, (d) hormesis or U-shape, and (e) threshold dose-response theories. As shown the different curves fit the data equally well at high doses but predict very different risks at low doses. The data points (with error bars) and the solid lines represent the region of direct observations; the dotted lines represent theoretical risk projections. Other theories predict risks that may be higher or lower than LNT derived risks. In fact the range of risk prediction at low doses is quite wide and includes the prediction of beneficial effects (hormesis prediction). Selecting a particular theory to the exclusion of alternatives is problematic because observations in the low dose range are inadequate to support a clear choice. There is now considerable evidence to suggest that the LNT theory overestimates risk in the low dose range. If the LNT theory overestimates risk then estimates of population health effects would be too high and actual detriment would be lower than predicted. In a 2001 report the National Council of Radiation Protection and Measurements admitted that there is substantial evidence against LNT but nevertheless continues to endorse the LNT by concluding that no other theory was more plausible than LNT.[18]

5.2 Dose extrapolation and detection limits in epidemiology

Dose extrapolation is also a serious source of uncertainty. For most carcinogens (including ionizing radiation) very large doses of the agent are needed in order to observe a statistically significant increase in cancer. This is because small doses typically encountered in environmental and occupational settings are associated with very low risks of cancer and, in the absence of any exposure, cancer occurs at a very high rate naturally (about 1 in 3 Americans will get cancer).

Predicting radiogenic health effects at environmental and occupational exposure levels requires that directly observable dose response data be extrapolated 2-3 orders of magnitude (i.e., 100-1000 times).[19] This degree of dose extrapolation strains the credibility of risk assessment at low dose and is comparable to the dose extrapolations used to "demonstrate" the human cancer-causing effects of commonly occurring chemicals including cyclamates, saccharin, Alar, and ethylene dibromide (EDB) based on laboratory animal data. Accordingly, numbers of cancer deaths due to low doses of carcinogens must be considered speculative; risk estimates at low dose have great uncertainties because they are theoretically derived. For ionizing radiation the possibility that there may be no health risks from doses comparable to natural background radiation levels cannot be ruled out; at low doses and dose rates, the lower limit of the range of statistical uncertainty includes zero.[20]

Dose estimates (Table 3) suggest that radiogenic risks are so small that they cannot be measured reliably. Figure 2 identifies the size of the population necessary to detect a significant risk at a given radiation dose (1 mSv = 100 mrem). The solid line is the boundary that defines the population size-dose space. Population sizes to the right of the boundary will be large enough to detect a significant risk for a given dose. Populations to the left of the boundary are too small to detect a radiogenic risk. To illustrate, examples of large populations exposed to small doses of radiation are plotted as points on the

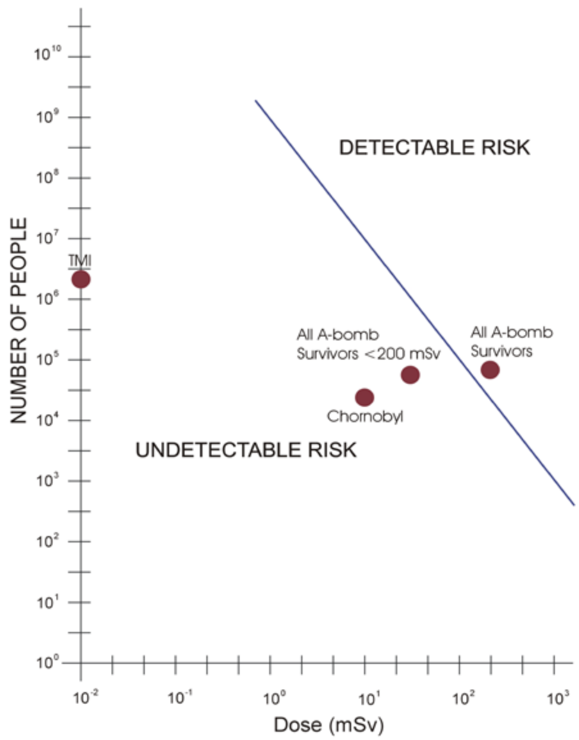
18. National Council on Radiation Protection and Measurements. *Evaluation of the Linear Nonthreshold Dose-Response Model for Ionizing Radiation*. NCRP Report No. 136. Bethesda, MD: NCRP; 2001.

19. Cancer risks are statistically significant at radiation of doses of 20,000 mrem and high based on analysis of Japanese atomic bomb survivors. The doses shown in Table 2 of this report range from about 20 to 200 mrem.

20. *Supra* note 11.

graph.[21] Except for the Japanese survivors that include those that received relatively high doses, no population group shown is large enough to detect significant risk.[22] An epidemiological study designed to detect an increased health risk in a population exposed to 0.86 mrem per year for 70 years (see Table 4) would require a population of 2 billion persons or roughly one-third of the world population (Figure 2). Obviously it is not possible to detect such small risks.

Figure 2. Large populations are needed to detect very small radiogenic risks.



5.3 Dose rate correction factor

21. The point identified as "all A-bomb survivors" represents about 86,000 Japanese survivors who received an average dose of 20,000 mrem in 1945. The point identified as "all A-bomb survivors <200 mSv" refers to the 65,000 A-bomb survivors who received doses less than 20,000 mrem. The point identified as "Chornobyl" refers to the 30,000 workers who received an average dose of about 1,000 mrem as a consequence of the Chornobyl nuclear plant accident in 1986. The point identified as "TMI" refers to the 2 million members of the general public who received about 1 mrem as a consequence of the nuclear power plant accident at TMI in 1979.

22. Significant increased cancer mortality in Japanese survivors receiving more than 20,000 mrem has been reported. The majority of reports of health studies of Pennsylvania residents near TMI report no elevated risks of cancer that could be attributed to radiation exposure. There have been reports of elevated thyroid cancer in children near Chornobyl. However thyroid doses were quite high due to the concentration of radioactive iodine by the thyroid glad. Otherwise there have been no consistent reporting of health detriment in the Chornobyl populations.

Radiogenic risks are primarily derived from studies of the Japanese survivors of the atomic bombings. The Japanese populations at Hiroshima and Nagasaki were exposed instantaneously and at a very high dose rates. It is a well known radiobiological principle that a dose of radiation administered at high dose rate is more biologically damaging than the same total dose delivered at low dose rate. The difference in the amount of damage is attributed to the capacity of cells and tissues to "repair" radiation injury. At low dose rates cells and tissues can repair injury more effectively than when exposed at high dose rate. Thus the atomic bomb-derived risk estimates must be modified when assessing health effects following exposure delivered at low dose rate.

The magnitude of the dose-rate correction factor is controversial. Numerous radiobiological and epidemiological studies suggest that the factor may be as low as 1.5 or as high as 10 or more. The National Council of Radiation Protection and Measurements estimates that uncertainties in the dose-rate correction factor (referred to as the dose and dose rate effectiveness factor or DDREF) accounts for about 40% of the total uncertainty in the lifetime radiogenic cancer mortality risk.[23]

The nominal risk coefficients used in this risk assessment include a conservative dose rate correction factor of 2 in order to account for the fact that workers and members of the public are exposed at very low dose rate comparable to natural background.[24]

6.0 RISKS IN PERSPECTIVE

An integral part of the risk assessment and risk management exercise is framing and communicating risks. In some ways this represents the most challenging part of risk analysis. If expressed improperly, risk information can result in misunderstandings and incorrect messages that may lead to inappropriate risk management decisions.

Risk assessment is primarily carried out by scientists who may be quite detached from the real world activities that involve the risks they are studying. They often express risks in ways that are not understandable by the public. In addition to assessing risk, scientists have a responsibility to distill scientific and technical information into a package that can be readily comprehended by risk managers and the public. Risk managers similarly must be able to effectively communicate highly technical information in easily understandable terms for policy makers and the public. Unless workers and the public have a clear understanding of the risks and how the risks are managed they may be reluctant to buy into the technology and any particular risk reduction strategy.

6.1 Speculation Versus Reality

Using LNT theory to calculate health effects of exposure to very small doses of carcinogens is now so ingrained that real risks are no longer distinguishable from

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23. *Supra* note 14.
24. National Council on Radiation Protection and Measurements. *Limitation of Exposure to Ionizing Radiation*. NCRP Report 116. Bethesda, MD: NCRP: 1993.

calculated, theoretical risks. Deaths are viewed the same whether they are real or calculated. Unwillingness to distinguish reality from speculation poses enormous problems in risk assessment and management. The idea that no dose is safe, and concerns for "trivial risks" has contributed to a system of increasingly restrictive regulations.

The idea that any dose is potentially harmful has led to unwarranted fears about radiation. In one survey of primary care physicians in Pennsylvania, 59% of the doctors identified fear of radiation as the primary reason for their patients' refusal of mammography examinations. Women who refuse mammography may be denying themselves an important medical benefit by compromising early detection and the subsequent management of disease. Following the Chornobyl accident in 1986, the International Atomic Energy Agency estimated 100,000-200,000 Chornobyl-related induced abortions in Western Europe. In Greece, as in other parts of Europe, many obstetricians initially thought it prudent to interrupt otherwise wanted pregnancies or were unable to resist requests from worried pregnant women in spite of the fact that doses were much lower than necessary to produce *in utero* effects.[25]

6.2 Communicating Risks

Risk communication is important because public perceptions of risk do not always match the actual risks. People fear the wrong things. We fret about activities that involve small risks and do not pay enough attention to risks that are significant and about which we can do something about. Consider automobile travel and airplane travel. Many people will not fly but have no hesitancy about getting into a car. In the 1990s Americans were, on a mile for mile basis, 37 times more likely to die in a car crash than on a commercial airliner. Commercial airline travel is so safe that the chances of dying in any flight are less than tossing heads twenty-two times in succession.[26] Although the risks are substantially higher for automobile travel, people do not seem to think the risks are anything to worry about. According to the National Highway Traffic Safety Administration, automobile traffic safety belts save about 9,500 lives per year. When used properly seat belts reduce fatal injury risk to front seat car passengers by 45%. More than 25% of Americans do not use seat belts.

Cigarette smokers who worry about radiation from mammograms or chest X- rays have perceptions of risk that are not congruent with what we actually know about these risks. There is no evidence that chest X-rays and mammograms kill anyone. However, cigarettes kill more than 400,000 people every year from cancer and heart disease. Certainly whether the risk is considered voluntary or controllable impacts how it is perceived. There is substantial literature on the subject of risk perception.[27]

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25. Fear of radiation-induced cancer or other health effects is one of many factors that might be considered by individuals who decline medical x-ray procedures and by pregnant women who elect to have abortions. For instance, women also decline to have mammography procedures because of the cost of the procedure or pain and discomfort. See Albanes, D. et al. A survey of physicians' breast cancer early detection practices. *Preventive Medicine* **17:** 643-652; 1988. Trichopoulos, D. et al. The victims of Chernobyl in Greece: Induced abortions after the accident. *British Medical Journal* **295:** 1100; 1987.
26. Myers, D.G. Do we fear the right things? *Skeptic* **10 (1):** 56-57; 2003.
27. Slovic, P. *The Perception of Risk*. London: Earthscan Publications, Ltd. 2000.

The Health Physics Society[28] has issued two relevant position statements. The first statement titled "Radiation Risk in Perspective" concludes that although there is substantial and convincing scientific evidence for health risks following high-dose exposures, below 5,000-10,000 mrem risks are either too small to be observed or are nonexistent. The Society recommends that below 5000 mrem in one year or a lifetime dose 10,000 mrem above natural background risk estimates should not be used. Expressions of risk should only be qualitative, that is, a range based on the uncertainties in estimating risk emphasizing the inability to detect any increased health detriment (that is, zero health effects is a probable outcome).[29] In the second statement titled "Ionizing Radiation –Safety Standards for the General Public" the Health Physics Society supports the establishment of an acceptable dose of radiation of 1 mSv/y (100 mrem/y) above the annual natural radiation background. At this dose, risks of radiation-induced health effects are either nonexistent or too small to be observed.[30]

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28. The Health Physics Society is a nonprofit scientific professional organization whose mission is excellence in the science and practice of radiation safety . The Society has approximately 6000 scientists, physicians, engineers, lawyers, and other professionals. Society activities include encouraging research in radiation science, developing standards, and disseminating radiation safety information. Society members are involved in understanding, evaluating and controlling the potential risks from radiation relative to the benefits.
29. Health Physics Society, Radiation Risk in Perspective, Position Statement of the Health Physics Society. *Health Physics News* **XXXII (10):** 15-16; October 2004.
30. Health Physics Society, *Ionizing Radiation –Safety Standards for the General Public*. Accessed at http://hps.org/documents/publicdose03.pdf