
APPENDIX B

EVALUATION OF RADIOLOGICAL HUMAN HEALTH IMPACTS FROM ROUTINE NORMAL OPERATIONS

B.1 INTRODUCTION

This appendix provides a brief general discussion on radiation and its health effects. It also describes the methods and assumptions used for estimating the potential impacts and risks to individuals and the general public from exposure to releases of radioactivity during normal operations and postulated accidents at facilities used to perform Chemistry and Metallurgy Research (CMR) operations.

This appendix presents numerical information using engineering and/or scientific notation. For example, the number 100,000 also can be expressed as 1×10^5 . The fraction 0.001 also can be expressed as 1×10^{-3} . The following chart defines the equivalent numerical notations that may be used in this appendix.

FRACTIONS AND MULTIPLES OF UNITS			
<i>Multiple</i>	<i>Decimal Equivalent</i>	<i>Prefix</i>	<i>Symbol</i>
1×10^6	1,000,000	mega-	M
1×10^3	1,000	kilo-	k
1×10^2	100	hecto-	h
1×10	10	deka-	da
1×10^{-1}	0.1	deci-	d
1×10^{-2}	0.01	centi-	c
1×10^{-3}	0.001	milli-	m
1×10^{-6}	0.000001	micro-	μ

B.2 RADIOLOGICAL IMPACTS ON HUMAN HEALTH

Radiation exposure and its consequences are topics of interest to the general public. For this reason, this environmental impact statement (EIS) places emphasis on the consequences of exposure to radiation, provides the reader with information on the nature of radiation, and explains the basic concepts used in the evaluation of radiation health effects.

B.2.1 Nature of Radiation and Its Effects on Humans

What Is Radiation?

Radiation is energy transferred in the form of particles or waves. Globally, human beings are exposed constantly to radiation from the solar system and the Earth's rocks and soil. This radiation contributes to the natural background radiation that always surrounds us. Manmade sources of radiation also exist, including medical and dental x-rays, household smoke detectors, and materials released from nuclear and coal-fired power plants.

All matter in the universe is composed of atoms. Radiation comes from the activity of tiny particles within an atom. An atom consists of a positively charged nucleus (central part of an atom) with a number of negatively charged electron particles in various orbits around the nucleus. There are two types of particles in the nucleus: neutrons that are electrically neutral and protons that are positively charged. Atoms of different types are known as elements. There are more than 100 natural and manmade elements. An element has equal numbers of electrons and protons. When atoms of an element differ in their number of neutrons, they are called isotopes of that element. All elements have three or more isotopes, some or all of which could be unstable (i.e., decay with time).

Unstable isotopes undergo spontaneous change, known as radioactive disintegration or radioactive decay. The process of continuously undergoing spontaneous disintegration is called radioactivity. The radioactivity of a material decreases with time. The time it takes a material to lose half of its original radioactivity is its half-life. An isotope's half-life is a measure of its decay rate. For example, an isotope with a half-life of eight days will lose one-half of its radioactivity in that amount of time. In eight more days, one-half of the remaining radioactivity will be lost, and so on. Each radioactive element has a characteristic half-life. The half-lives of various radioactive elements may vary from millionths of a second to millions of years.

As unstable isotopes change into more stable forms, they emit electrically charged particles. These particles may be either an alpha particle (a helium nucleus) or a beta particle (an electron), with various levels of kinetic energy. Sometimes these particles are emitted in conjunction with gamma rays. The alpha and beta particles are frequently referred to as ionizing radiation. Ionizing radiation refers to the fact that the charged particle energy force can ionize, or electrically charge, an atom by stripping off one of its electrons. Gamma rays, even though they do not carry an electric charge as they pass through an element, can ionize atoms by ejecting electrons. Thus, they cause ionization indirectly. Ionizing radiation can cause a change in the chemical composition of many things, including living tissue (organs), which can affect the way they function.

When a radioactive isotope of an element emits a particle, it changes to an entirely different element, one that may or may not be radioactive. Eventually a stable element is formed. This transformation, which may take several steps, is known as a decay chain. For example, radium, which is a member of the radioactive decay chain of uranium, has a half-life of 1,622 years. It emits an alpha particle and becomes radon, a radioactive gas with a half-life of only 3.8 days. Radon decays first to polonium, then through a series of further decay steps to bismuth, and

ultimately to a stable isotope of lead. Meanwhile, the decay products will build up and eventually die away as time progresses.

The characteristics of various forms of ionizing radiation are briefly described below and in the box at right (see Chapter 7 for further definitions):

Alpha (α)—Alpha particles are the heaviest type of ionizing radiation. They can travel only a few centimeters in air. Alpha particles lose their energy almost as soon as they collide with anything. They can be stopped easily by a sheet of paper or by the skin’s surface.

Radiation Type	Typical Travel Distance in Air	Barrier
α	Few centimeters	Sheet of paper or skin’s surface
β	Few meters	Thin sheet of aluminum foil or glass
γ	Very large	Thick wall of concrete, lead, or steel
n	Very large	Water, paraffin, graphite

Beta (β)—Beta particles are much (7,330 times) lighter than alpha particles.

They can travel a longer distance than alpha particles in the air. A high-energy beta particle can travel a few meters in the air. Beta particles can pass through a sheet of paper, but may be stopped by a thin sheet of aluminum foil or glass.

Gamma (γ)—Gamma rays (and x-rays), unlike alpha or beta particles, are waves of pure energy. Gamma rays travel at the speed of light. Gamma radiation is very penetrating and requires a thick wall of concrete, lead, or steel to stop it.

Neutrons (n)—Neutrons are particles that contribute to radiation exposure both directly and indirectly. The most prolific source of neutrons is a nuclear reactor. Indirect radiation exposure occurs when gamma rays and alpha particles are emitted following neutron capture in matter. A neutron has about one-quarter the weight of an alpha particle. It will travel in the air until it is absorbed in another element.

Units of Radiation Measure

During the early days of radiological experience, there was no precise unit of radiation measure. Therefore, a variety of units were used to measure radiation. These units were used to determine the amount, type, and intensity of radiation. Just as heat can be measured in terms of its intensity or effects using units of calories or degrees, amounts of radiation or its effects can be measured in units of curies, radiation absorbed dose (rad), or dose equivalent (roentgen equivalent man, or rem). The following summarizes those units (see also the definitions in Chapter 7).

Curie—The curie, named after the French scientists Marie and Pierre Curie, describes the “intensity” of a sample of radioactive material. The rate of decay of 1 gram of radium was the basis of this unit of measure. Because the measured decay rate kept changing slightly as measurement techniques became more accurate, the curie was subsequently defined as exactly 3.7×10^{10} disintegrations (decays) per second.

Rad—The rad is the unit of measurement for the physical absorption of radiation. The total energy absorbed per unit quantity of tissue is referred to as absorbed dose (or simply dose). As sunlight heats pavement by giving up an amount of energy to it, radiation similarly gives up energy to objects in its path. One rad is equal to the amount of radiation that leads to the deposition of 0.01 joule of energy per kilogram of absorbing material.

**Radiation Units
and Conversions to
International System of Units**

1 curie = 3.7×10^{10} disintegrations per second
= 3.7×10^{10} becquerels
1 becquerel = 1 disintegration per second
1 rad = 0.01 gray
1 rem = 0.01 sievert
1 gray = 1 joule per kilogram

Rem—A rem is a measurement of the dose equivalent from radiation based on its biological effects. The rem is used in measuring the effects of radiation on the body as degrees centigrade are used in measuring the effects of sunlight heating pavement. Thus, 1 rem of one type of radiation is presumed to have the same biological effects as 1 rem of any other kind of radiation. This allows comparison of the biological effects of radionuclides that emit different types of radiation.

The units of radiation measure in the International System of Units are: becquerel (a measure of source intensity [activity]), gray (a measure of absorbed dose), and sievert (a measure of dose equivalent).

An individual may be exposed to ionizing radiation externally (from a radioactive source outside the body) or internally (from ingesting or inhaling radioactive material). The external dose is different from the internal dose because an external dose is delivered only during the actual time of exposure to the external radiation source, while an internal dose continues to be delivered as long as the radioactive source is in the body. The dose from internal exposure is calculated over 50 years following the initial exposure. Both radioactive decay and elimination of the radionuclide by ordinary metabolic processes decrease the dose rate with the passage of time.

Sources of Radiation

The average American receives a total of approximately 360 millirem per year from all sources of radiation, both natural and manmade, of which approximately 300 millirem per year are from natural sources. The sources of radiation can be divided into six different categories: (1) cosmic radiation, (2) terrestrial radiation, (3) internal radiation, (4) consumer products, (5) medical diagnosis and therapy, and (6) other sources (NCRP 1987). These categories are discussed in the following paragraphs.

Cosmic Radiation—Cosmic radiation is ionizing radiation resulting from energetic charged particles from space continuously hitting the Earth's atmosphere. These particles and the secondary particles and photons they create comprise cosmic radiation. Because the atmosphere provides some shielding against cosmic radiation, the intensity of this radiation increases with the altitude above sea level. The average dose to people in the United States from this source is approximately 27 millirem per year.

External Terrestrial Radiation—External terrestrial radiation is the radiation emitted from the radioactive materials in the Earth’s rocks and soils. The average dose from external terrestrial radiation is approximately 28 millirem per year.

Internal Radiation—Internal radiation results from the human body metabolizing natural radioactive material that has entered the body by inhalation or ingestion. Natural radionuclides in the body include isotopes of uranium, thorium, radium, radon, polonium, bismuth, potassium, rubidium, and carbon. The major contributor to the annual dose equivalent for internal radioactivity is the short-lived decay products of radon, which contribute approximately 200 millirem per year. The average dose from other internal radionuclides is approximately 39 millirem per year.

Consumer Products—Consumer products also contain sources of ionizing radiation. In some products, such as smoke detectors and airport x-ray machines, the radiation source is essential to the product’s operation. In other products, such as televisions and tobacco, the radiation occurs as the products function. The average dose from consumer products is approximately 10 millirem per year.

Medical Diagnosis and Therapy—Radiation is an important diagnostic medical tool and cancer treatment. Diagnostic x-rays result in an average exposure of 39 millirem per year. Nuclear medical procedures result in an average exposure of 14 millirem per year.

Other Sources—There are a few additional sources of radiation that contribute minor doses to individuals in the United States. The dose from nuclear fuel cycle facilities (e.g., uranium mines, mills, and fuel processing plants) and nuclear power plants has been estimated to be less than 1 millirem per year. Radioactive fallout from atmospheric atomic bomb tests, emissions from certain mineral extraction facilities, and transportation of radioactive materials contribute less than 1 millirem per year to the average dose to an individual. Air travel contributes approximately 1 millirem per year to the average dose.

Exposure Pathways

As stated earlier, an individual may be exposed to ionizing radiation both externally and internally. The different ways that could result in radiation exposure to an individual are called exposure pathways. Each type of exposure is discussed separately in the following paragraphs.

External Exposure—External exposure can result from several different pathways, all having in common the fact that the radiation causing the exposure is external to the body. These pathways include exposure to a cloud of radiation passing over the receptor (an exposed individual), standing on ground that is contaminated with radioactivity, and swimming or boating in contaminated water. If the receptor departs from the source of radiation exposure, the dose rate will be reduced. It is assumed that external exposure occurs uniformly during the year. The appropriate dose measure is called the effective dose equivalent.

Internal Exposure—Internal exposure results from a radiation source entering the human body through either inhalation of contaminated air or ingestion of contaminated food or water. In

contrast to external exposure, once a radiation source enters the body, it remains there for a period of time that varies depending on decay and biological half-life. The absorbed dose to each organ of the body is calculated for a period of 50 years following the intake. The calculated absorbed dose is called the committed dose equivalent. Various organs have different susceptibilities to harm from radiation. The quantity that takes these different susceptibilities into account is called the committed effective dose equivalent, and it provides a broad indicator of the risk to the health of an individual from radiation. The committed effective dose equivalent is a weighted sum of the committed dose equivalent in each major organ or tissue. The concept of committed effective dose equivalent applies only to internal pathways.

Radiation Protection Guides

Various organizations have issued radiation protection guides. The responsibilities of the main radiation safety organizations, particularly those that affect policies in the United States, are summarized below.

International Commission on Radiological Protection—This Commission has the responsibility for providing guidance in matters of radiation safety. The operating policy of this organization is to prepare recommendations to deal with basic principles of radiation protection and to leave to the various national protection committees the responsibility of introducing the detailed technical regulations, recommendations, or codes of practice best suited to the needs of their countries.

National Council on Radiation Protection and Measurements—In the United States, this Council is the national organization that has the responsibility for adapting and providing detailed technical guidelines for implementing the International Commission on Radiological Protection recommendations. The Council consists of technical experts who are specialists in radiation protection and scientists who are experts in disciplines that form the basis for radiation protection.

National Research Council/National Academy of Sciences—The National Research Council is an organization within the National Academy of Sciences that associates the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the Federal Government.

Environmental Protection Agency—The Environmental Protection Agency (EPA) has published a series of documents, *Radiation Protection Guidance to Federal Agencies*. This guidance is used as a regulatory benchmark by a number of Federal agencies, including the U.S. Department of Energy (DOE), in the realm of limiting public and occupational work force exposures to the greatest extent possible.

Limits of Radiation Exposure

Limits of exposure to members of the public and radiation workers are derived from International Commission on Radiological Protection recommendations. The EPA uses the National Council on Radiation Protection and Measurements and the International Commission on Radiological Protection recommendations and sets specific annual exposure limits (usually less than those

specified by the Commission) in *Radiation Protection Guidance to Federal Agencies* documents. Each regulatory organization then establishes its own set of radiation standards. The various exposure limits set by DOE and the EPA for radiation workers and members of the public are given in **Table B-1**.

Table B-1 Exposure Limits for Members of the Public and Radiation Workers

<i>Guidance Criteria (Organization)</i>	<i>Public Exposure Limits at the Site Boundary</i>	<i>Worker Exposure Limits</i>
10 CFR 835 (DOE)	—	5,000 millirem per year ^a
10 CFR 835.1002 (DOE)	—	1,000 millirem per year ^b
DOE Order 5400.5 (DOE) ^c	10 millirem per year (all air pathways) 4 millirem per year (drinking water pathway) 100 millirem per year (all pathways)	—
40 CFR 61 (EPA)	10 millirem per year (all air pathways)	—
40 CFR 141 (EPA)	4 millirem per year (drinking water pathways)	—

^a Although this is a limit (or level) that is enforced by DOE, worker doses must be managed in accordance with as low as is reasonably achievable principles. Refer to footnote b.

^b This is a control level. It was established by DOE to assist in achieving its goal to maintain radiological doses as low as is reasonably achievable. DOE recommends that facilities adopt a more limiting 500 millirem per year Administrative Control Level (DOE 1999b). Reasonable attempts have to be made by the site to maintain individual worker doses below these levels.

^c Derived from 40 CFR 61, 40 CFR 141, and 10 CFR 20.

B.2.2 Health Effects

Radiation exposure and its consequences are topics of interest to the general public. To provide the background for discussions of impacts, this section explains the basic concepts used in the evaluation of radiation effects.

Radiation can cause a variety of damaging health effects in people. The most significant effects are induced cancer fatalities. These effects are referred to as “latent” cancer fatalities because the cancer may take many years to develop. In the discussions that follow, all fatal cancers are considered latent; therefore, the term “latent” is not used.

The National Research Council’s Committee on the Biological Effects of Ionizing Radiation (BEIR) has prepared a series of reports to advise the U.S. Government on the health consequences of radiation exposures. *Health Effects of Exposure to Low Levels of Ionizing Radiation*, BEIR V (National Research Council 1990), provides the most current estimates for excess mortality from leukemia and other cancers that are expected to result from exposure to ionizing radiation. BEIR V provides estimates that are consistently higher than those in its predecessor, BEIR III. This increase is attributed to several factors, including the use of a linear dose response model for cancers other than leukemia, revised dosimetry for the Japanese atomic bomb survivors, and additional followup studies of the atomic bomb survivors and associated others. BEIR III employs constant, relative, and absolute risk models, with separate coefficients for each of several sex and age-at-exposure groups. BEIR V develops models in which the excess relative risk is expressed as a function of age at exposure, time after exposure, and sex for each of several cancer categories. The BEIR III models were based on the assumption that absolute risks are comparable between the atomic bomb survivors and the U.S. population. BEIR V models were based on the assumption that the relative risks are comparable. For a

disease such as lung cancer, where baseline risks in the United States are much larger than those in Japan, the BEIR V approach leads to larger risk estimates than the BEIR III approach.

The models and risk coefficients in BEIR V were derived through analyses of relevant epidemiologic data that included the Japanese atomic bomb survivors, ankylosis spondylitis patients, Canadian and Massachusetts fluoroscopy (breast cancer) patients, New York postpartum mastitis (breast cancer) patients, Israeli tinea capitis (thyroid cancer) patients, and Rochester thymus (thyroid cancer) patients. Models for leukemia, respiratory cancer, digestive cancer, and other cancers used only the atomic bomb survivor data, although results of analyses of the ankylosis spondylitis patients were considered. Atomic bomb survivor analyses were based on revised dosimetry, with an assumed relative biological effectiveness of 20 for neutrons, and were restricted to doses less than 400 rads. Estimates of risks of fatal cancers, other than leukemia, were obtained by totaling the estimates for breast cancer, respiratory cancer, digestive cancer, and other cancers.

The National Council on Radiation Protection and Measurements (NCRP 1993), based on the radiation risk estimates provided in BEIR V and the International Commission on Radiological Protection Publication 60 recommendations (ICRP 1991), has estimated the total detriment resulting from low dose¹ or low dose rate exposure to ionizing radiation to be 0.00056 per rem for the working population and 0.00073 per rem for the general population. The total detriment includes fatal and nonfatal cancers as well as severe hereditary (genetic) effects. The major contribution to the total detriment is from fatal cancer which is estimated to be 0.0004 and 0.0005 per rem for radiation workers and the general population, respectively. The breakdowns of the risk estimators for both workers and the general population are given in **Table B-2**. Nonfatal cancers and genetic effects are less probable consequences of radiation exposure. To simplify the presentation of the impacts, estimated effects of radiation are calculated only in terms of cancer fatalities. For higher doses to an individual (20 rem or more), as could be associated with postulated accidents, the risk estimators given in Table B-2 are doubled.

Table B-2 Nominal Health Risk Estimators Associated with Exposure to 1 Rem of Ionizing Radiation

<i>Exposed Individual</i>	<i>Fatal Cancer</i> ^{a,c}	<i>Nonfatal Cancer</i> ^b	<i>Genetic Disorders</i> ^b	<i>Total</i>
Worker	0.0004	0.00008	0.00008	0.00056
Public	0.0005	0.0001	0.00013	0.00073

^a For fatal cancer, the health effect coefficient is the same as the probability coefficient. When applied to an individual, the units are the lifetime probability of a cancer fatality per rem of radiation dose. When applied to a population of individuals, the units are the excess number of fatal cancers per person-rem of radiation dose.

^b In determining a means of assessing health effects from radiation exposure, the International Commission on Radiological Protection has developed a weighting method for nonfatal cancers and genetic effects.

^c For high individual exposures (greater than or equal to 20 rem), the health factors are multiplied by a factor of 2.
Source: NCRP 1993.

¹Low dose is defined as the dose level where DNA repair can occur in a few hours after irradiation-induced damage. Currently, a dose level of about 0.2 grays (20 rad), or a dose rate of 0.1 milligrays (0.01 rad) per minute is considered low enough to allow the DNA to repair itself in a short period (EPA 1999).

The numerical estimates of fatal cancers presented in this EIS were obtained using a linear extrapolation from the nominal risk estimated for lifetime total cancer mortality that results from a dose of 0.1 gray (10 rad). Other methods of extrapolation to the low-dose region could yield higher or lower numerical estimates of fatal cancers. Studies of human populations exposed to low doses are inadequate to demonstrate the actual level of risk. There is scientific uncertainty about cancer risk in the low-dose region below the range of epidemiologic observation, and the possibility of no risk cannot be excluded (CIRRPC 1992).

Health Effect Risk Estimators Used in This EIS

Health impacts from radiation exposure, whether from external or internal sources, generally are identified as “somatic” (i.e., affecting the exposed individual) or “genetic” (i.e., affecting descendants of the exposed individual). Radiation is more likely to produce somatic effects than genetic effects. The somatic risks of most importance are induced cancers. Except for leukemia, which can have an induction period (time between exposure to carcinogen and cancer diagnosis) of as little as two to seven years, most cancers have an induction period of more than 20 years.

For a uniform irradiation of the body, the incidence of cancer varies among organs and tissues; the thyroid and skin demonstrate a greater sensitivity than other organs. Such cancers, however, also produce relatively low mortality rates because they are relatively amenable to medical treatment. Because fatal cancer is the most probable serious effect of environmental and occupational radiation exposures, estimates of cancer fatalities rather than cancer incidence are presented in this EIS. The numbers of fatal cancers can be used to compare the risks among the various alternatives.

Based on the preceding discussion and the values presented in Table B-2, the number of fatal cancers in the general public during normal operations and for postulated accidents in which individual doses are less than 20 rem are calculated using a health risk estimator of 0.0005 per person-rem. For workers, a risk estimator of 0.0004 excess fatal cancers per person-rem is used. (The risk estimators are lifetime probabilities that an individual would develop a fatal cancer per rem of radiation received.) The lower value for workers reflects the absence of children (who are more radiosensitive than adults) in the workforce. The risk estimators associated with nonfatal cancer and genetic disorders among the public are 20 and 26 percent, respectively, of the fatal cancer risk estimator. For workers, these health risk estimators are both 20 percent of the fatal cancer risk estimator. The nonfatal cancer and genetic disorder risk estimators are not used in this EIS.

For individual doses of 20 rem or more, as could be associated with postulated accidents, the risk estimators used to calculate health effects to the general public and to workers are double those given in the previous paragraph, which are associated with doses of less than 20 rem.

The fatal cancer estimators are used to calculate the statistical expectation of the effects of exposing a population to radiation. For example, if 100,000 people were each exposed to a one-time radiation dose of 100 millirem (0.1 rem), the collective dose would be 10,000 person-rem. The exposed population would then be expected to experience five additional cancer fatalities

from the radiation (10,000 person-rem times 0.0005 lifetime probability of cancer fatalities per person-rem = five cancer fatalities).

Calculations of the number of excess fatal cancers associated with radiation exposure do not always yield whole numbers. These calculations may yield numbers less than one, especially in environmental impact applications. For example, if a population of 100,000 were exposed to a total dose of only 0.001 rem per person, the collective dose would be 100 person-rem (100,000 persons times 0.001 rem = 100 person-rem). The corresponding estimated number of cancer fatalities would be 0.05 (100 person-rem times 0.0005 cancer fatalities per person-rem = 0.05 cancer fatalities). The 0.05 means that there is 1 chance in 20 that the exposed population would experience one fatal cancer. In other words, the 0.05 cancer fatalities is the *expected* number of deaths that would result if the same exposure situation were applied to many different groups of 100,000 people. In most groups, no person would incur a fatal cancer from the 0.001 rem dose each member would have received. In a small fraction of the groups, one cancer fatality would result; in exceptionally few groups, two or more cancer fatalities would occur. The *average* expected number of deaths over all the groups would be 0.05 cancer fatalities (just as the average of 0, 0, and 0, added to 1 is 1/4, or 0.25). The most likely outcome is no cancer fatalities.

The same concept is applied to estimate the effects of radiation exposure on an individual member of the public. Consider the effects of an individual's exposure to a 360 millirem (0.36 rem) annual dose from all radiation sources. The probability that the individual will develop a fatal cancer from continuous exposure to this radiation over an average life of 72 years (presumed) is 0.013 (1 person times 0.36 rem per year times 72 years times 0.005 cancer fatalities per person-rem = 0.013). This corresponds to 1 chance in 77 that the individual would develop a fatal cancer in a lifetime.

B.3 METHODOLOGY FOR ESTIMATING RADIOLOGICAL IMPACTS

B.3.1 GENII Computer Code, a Generic Description

The radiological impacts from releases during normal operation of the facilities used to perform CMR operations were calculated using Version 1.485 of the GENII computer code (PNL 1988). Site-specific input data were used, including location, meteorology, population, and source terms. This section briefly describes GENII and outlines the approach used for normal operations.

B.3.1.1 Description of the Code

The GENII computer model, developed by Pacific Northwest National Laboratory, is an integrated system of various computer modules that analyze environmental contamination resulting from acute or chronic releases to, or initial contamination in, air, water, or soil. The model calculates radiation doses to individuals and populations. The GENII computer model is well documented for assumptions, technical approach, method, and quality assurance issues. The GENII computer model has gone through extensive quality assurance and quality control steps,

including comparing results from model computations with those from hand calculations and performing internal and external peer reviews (PNL 1988).

The GENII code consists of several modules for various applications as described in the code manual (PNL 1988). For this EIS, only the ENVIN, ENV, and DOSE computer modules were used. The output of one module is stored in a file that can be used by the next module in the system. The functions of the three GENII computer modules used in this EIS are discussed below.

ENVIN

The ENVIN module of the GENII code controls the reading of input files and organizes the input for optimal use in the environmental transport and exposure module, ENV. The ENVIN code interprets the basic input, reads the basic GENII data libraries and other optional input files, and organizes the input into sequential segments based on radionuclide decay chains.

A standardized file that contains scenario, control, and inventory parameters is used as input to ENVIN. Radionuclide inventories can be entered as functions of releases to air or water, concentrations in basic environmental media (air, soil, or water), or concentrations in foods. If certain atmospheric dispersion options have been selected, this module would generate tables of atmospheric dispersion parameters that are used in later calculations. If the finite plume air submersion option is selected in addition to the atmospheric dispersion calculations, preliminary energy-dependent finite plume dose factors can be prepared as well. The ENVIN module prepares the data transfer files that are used as input by the ENV module; ENVIN generates the first portion of the calculation documentation—the run input parameters report.

ENV

The ENV module calculates the environmental transfer, uptake, and human exposure to radionuclides that result from the chosen scenario for the user-specified source term. The code reads the input files from ENVIN and then, for each radionuclide chain, sequentially performs the precalculations to establish the conditions at the start of the exposure scenario. Environmental concentrations of radionuclides are established at the beginning of the scenario by assuming decay of pre-existing sources, considering biotic transport of existing subsurface contamination, and defining soil contamination from continuing atmospheric or irrigation depositions. For each year of postulated exposure, the code then estimates the air, surface soil, deep soil, groundwater, and surface water concentrations of each radionuclide in the chain. Human exposures and intakes of each radionuclide are calculated for: (1) pathways of external exposure from finite or infinite atmospheric plumes; (2) inhalation; (3) external exposure from contaminated soil, sediments, and water; (4) external exposure from special geometries; and (5) internal exposures from consumption of terrestrial foods, aquatic foods, drinking water, animal products, and inadvertent intake of soil. The intermediate information on annual media concentrations and intake rates is written to data transfer files. Although these may be accessed directly, they are usually used as input to the DOSE module of GENII.

DOSE

The DOSE module reads the intake and exposure rates defined by the ENV module and converts the data to radiation dose.

B.3.1.2 Data and General Assumptions

To perform the dose assessments for this EIS, different types of data were collected and generated. This section discusses the various data, along with the assumptions made for performing the dose assessments.

Dose assessments were performed for members of the general public at Los Alamos National Laboratory (LANL) to determine the incremental doses that would be associated with the alternatives addressed in this EIS. Incremental doses for members of the public were calculated (via GENII) for two different types of receptors:

- **Maximally Exposed Offsite Individual**—The maximally exposed offsite individual was assumed to be an individual member of the public located at a position on the site boundary that would yield the highest impacts during normal operations.
- **Population**—The general population living within 50 miles (80 kilometers) of the facility. An average dose to a member of this population is also calculated.

Meteorological Data

The meteorological data used for all normal operational scenarios discussed in this EIS were in the form of joint frequency data files. A joint frequency data file is a table listing the fractions of time the wind blows in a certain direction, at a certain speed, and within a certain atmospheric stability class. The joint frequency data files were based on measurements taken over a period of several years at LANL.

Population Data

Population distributions were based on U.S. Department of Commerce state population census numbers (DOC 2001). Estimates were determined for the year 2000 for areas within 50 miles (80 kilometers) of the release locations at LANL. The estimated site-specific population in 2000 was used in the impact assessments. The population was spatially distributed on a circular grid with 16 directions and 10 radial distances up to 50 miles (80 kilometers). The grid was centered at the location from which the radionuclides were assumed to be released.

Source Term Data

The source terms used to calculate the impacts of normal operations are provided in Section B.4.

Food Production and Consumption Data

Generic food consumption rates are available as default values in GENII. The default values are comparable to those established in the U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 1.109 (NRC 1977). This regulatory guide provides guidance for evaluating ingestion doses from consuming contaminated terrestrial and animal food products using a standard set of assumptions for crop and livestock growth and harvesting characteristics.

Basic Assumptions

To estimate annual radiological impacts to the public from normal operations, the following additional assumptions and factors were considered in using GENII:

- Radiological airborne emissions were assumed to be released to the atmosphere at a height of 52 feet (16 meters).
- Emission of the plume was assumed to continue throughout the year. Plume and ground deposition exposure parameters used in the GENII model for the exposed offsite individual and the general population are provided in **Table B-3**.
- The exposed individual or population was assumed to have the characteristics and habits of an adult human.
- A semi-infinite plume model was used for the air immersion doses.

Table B-3 GENII Parameters for Exposure to Plumes (Normal Operations)

<i>Maximally Exposed Offsite Individual</i>				<i>General Population</i>			
<i>External Exposure</i>		<i>Inhalation of Plume</i>		<i>External Exposure</i>		<i>Inhalation of Plume</i>	
<i>Plume (hours)</i>	<i>Ground Contamination (hours)</i>	<i>Exposure Time (hours)</i>	<i>Breathing Rate (cubic centimeters per second)</i>	<i>Plume (hours)</i>	<i>Ground Contamination (hours)</i>	<i>Exposure Time (hours)</i>	<i>Breathing Rate (cubic centimeters per second)</i>
6,136	6,136	8,766	270	4,383	4,383	8,766	270

Sources: PNL 1988, NRC 1977.

Worker doses associated with CMR operations were determined from historical data. Refer to Section B.4 for a further discussion of worker impacts.

B.3.1.3 Uncertainties

The sequence of analyses performed to generate the radiological impact estimates from normal operations include: (1) selection of normal operational modes, (2) estimation of source terms, (3) estimation of environmental transport and uptake of radionuclides, (4) calculation of radiation doses to exposed individuals, and (5) estimation of health effects. There are uncertainties associated with each of these steps. Uncertainties exist in the way the physical systems being analyzed are represented by the computational models and in the data required to exercise the models (due to measurement, sampling, or natural variability).

In principle, one can estimate the uncertainty associated with each source and predict the remaining uncertainty in the results of each set of calculations. Thus, one can propagate the uncertainties from one set of calculations to the next and estimate the uncertainty in the final results. However, conducting such a full-scale quantitative uncertainty analysis is neither practical nor a standard practice for a study of this type. Instead, the analysis is designed to ensure—through judicious selection of release scenarios, models, and parameters—that the results represent the potential risks. This is accomplished by making conservative assumptions in the calculations at each step. The models, parameters, and release scenarios used in the calculations are selected in such a way that most intermediate results and, consequently, the final estimates of impacts are greater than would be expected. As a result, even though the range of uncertainty in a quantity might be large, the value calculated for the quantity would be close to one of the extremes in the range of possible values, so the chance of the actual quantity being greater than the calculated value would be low. The goal of the radiological assessment for normal operation in this study is to produce results that are conservative in order to capture any uncertainties in operation at the new CMRR Facility.

The human health impacts from routine normal CMR activities may have different impacts on specific populations such as American Indians or Hispanics whose cultural heritage can result in special pathways of exposure that are different than those modeled to evaluate the doses to the general population and maximally exposed individual. Although the analyses performed to evaluate the public impacts of the CMR alternatives did include normally significant pathways and were designed to be conservative, no pathways were included to specifically address local population use of local resources. Therefore, there is potentially more uncertainty in the effects of CMR activities on these specific population groups. A qualitative evaluation of the potential impacts to these specific groups was performed based on the nuclides emitted and an understanding of the most significant pathways.

Parameter selection and practices of the population and maximally exposed individual were chosen to be conservative. For example, it was assumed that the population breathed contaminated air all the time (spent no time away from the local area) and that all food was produced in the potentially affected area (no food from outside the local area). The dose to a member of the public was dominated by internal exposures from inhalation and ingestion. Typically, about one third of the dose was from inhalation and two thirds was from ingestion. Inhalation of ambient air and the resulting dose would be about the same for all members of population surrounding LANL. Since the diet of the general population was modeled as coming completely from the local area, the most significant difference to the American Indian or Hispanic population would be the portions of the diet that come from different food groups than those modeled. The *LANL SWEIS* (DOE 1999a) evaluated potential impacts associated with special pathways associated with subsistence hunting, fishing, gathering, and consumption of tea (cota) made from local flora. **Table B-4** summarizes the results of the special pathways analysis.

As noted in the *LANL SWEIS*, the dose associated with these special pathways is primarily due to existing levels of radioactive materials in the environment. Although not quantitatively evaluated, the incremental impact of the alternatives evaluated in this EIS are judged to be minimal with respect to these special pathways. Additionally, the impacts would be roughly

proportional to the doses to the general public so they would not provide a discriminator among the alternatives.

Table B–4 Worst-Case Public Radiological Dose and Potential Consequences by Ingestion Pathways For Special Pathways Receptors, All Alternatives ^a

<i>Exposure Pathway</i>	<i>Special Pathways Receptors ^b</i>	
	<i>Dose (millirem per year)</i>	<i>Chance of an Excess Latent Cancer Fatality Per Year</i>
Fish	0.46	1 in 4,300,000
Elk Heart and Liver	0.034	1 in 59,000,000
Piñon Nuts	0.13	1 in 15,000,000
Indian Tea (Cota)	2.60	1 in 770,000
Total	3.22	1 in 620,000

^a Because almost all public ingestion is from naturally occurring radionuclides, weapons testing fallout, and contamination from past operations, the ingestion dose is not affected by the alternatives (DOE 1999b, Section 5.1.6).

^b Special pathways receptors are those with traditional Native American or Hispanic lifestyles.

B.4 RADIOLOGICAL RELEASES DURING ROUTINE NORMAL OPERATIONS

The estimated radiological releases to the environment associated with routine normal CMR operations are discussed below and are based on the methodology provided in Section B.3.1. The resulting impacts to the public and to workers associated with each alternative are presented and discussed in Chapter 4 of this EIS.

Routine radiological releases during normal CMR operations under the No Action Alternative and Alternatives 1 through 4 are presented in **Table B–5**. The actinide releases consist of plutonium, uranium, thorium, and americium isotopes. Of these isotopes, plutonium-239 has the highest equivalent dose in curies. Therefore, plutonium-239 was used for modeling purposes to conservatively represent all of the actinides released. By using plutonium-239, the estimated dose for members of the public presented in this EIS are higher than what would be experienced if the actual actinides were used in the model calculations.

Table B–5 Normal Operations Radiological Release

	<i>No Action Alternative (curies per year)</i>	<i>Alternatives 1-4 (curies per year)</i>
Actinides	0.00003	0.00076
Fission Products		
Kr-85	—	100
Xe-131m	—	45
Xe-133	—	1,500
Tritium	—	1,000

Source: DOE 1999a.

Under the No Action Alternative, air emissions of actinides (with no measurable releases of fission products or tritium) would continue from the existing CMR Building at current restricted operational levels. For Alternatives 1 through 4, the amount of anticipated radiological releases from CMR operations at the new CMRR Facility would be the same as that projected under the Expanded Operations Alternative in the LANL SWEIS Record of Decision.

B.5 REFERENCES

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