APPENDIX C
EVALUATION OF HUMAN HEALTH IMPACTS FROM FACILITY ACCIDENTS

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C.1 Introduction

Accident analyses were performed to estimate the impacts on workers and the public from reasonably foreseeable accidents for the alternatives in this *Draft Supplemental Environmental Impact Statement for the Nuclear Facility Portion of the Chemistry and Metallurgy Research Building Replacement Project at Los Alamos National Laboratory, Los Alamos, New Mexico (CMRR-NF SEIS)*. The analyses were performed in accordance with U.S. Department of Energy (DOE) National Environmental Policy Act (NEPA) guidelines, including the process followed for the selection of accidents, definition of accident scenarios, and estimation of potential impacts. The sections that follow describe the methodology and assumptions, accident selection process, selected accident scenarios, and consequences and risks of the accidents evaluated.

C.2 Overview of Methodology and Basic Assumptions

The radiological impacts from accidental releases from the facilities used to perform chemistry and metallurgy research (CMR) operations were calculated using the MACCS [MELCOR Accident Consequences Code System] computer code, Version 1.13.1 (MACCS2). A detailed description of the MACCS model is provided in NUREG/CR-6613 (NRC 1990). The enhancements incorporated in MACCS2 are described in the *MACCS2 Users Guide* (Chanin and Young 1998). This section presents the MACCS2 data specific to the accident analyses. Additional information on the MACCS2 code is provided in Section C.7.

As implemented, the MACCS2 model evaluates doses due to inhalation of airborne material, as well as external exposure to the passing plume. This represents the major portion of the dose that an individual would receive because of a facility accident. The longer-term effects of radioactive material deposited on the ground after a postulated accident, including the resuspension and subsequent inhalation of radioactive material and the ingestion of contaminated crops, were not modeled for this *CMRR-NF SEIS*. These pathways have been studied and found to contribute less significantly to the radiation dose than the inhalation of radioactive material in the passing plume; they are also controllable through interdiction. Instead, the deposition velocity of the radioactive material was set to zero, so that material that might otherwise be deposited on surfaces remained airborne and available for inhalation. Thus, the method used in this *CMRR-NF SEIS* is conservative compared with dose results that would be obtained if deposition and resuspension were taken into account.

The impacts were assessed for the offsite populations surrounding the proposed site of the Chemistry and Metallurgy Research Building Replacement (CMRR) Nuclear Facility (CMRR-NF) and the existing CMR Building, as well as a maximally exposed individual (MEI), and noninvolved worker at each of these locations. The impacts on involved workers, those working in the facility where the accident occurs, were addressed qualitatively because no adequate method exists for calculating meaningful consequences at or near the location where the accident could occur. Involved workers are also fully trained in emergency procedures, including evacuation and personal protective actions in the event of an accident.

The offsite population is defined as the general public residing within 50 miles (80 kilometers) of each site. The population distribution for each proposed site is based on U.S. Department of Commerce (Census Bureau) population data at the block group level (DOC 2000, 2010). These data were fitted to a polar coordinate grid with 16 angular sectors aligned with the 16 compass directions, with radial intervals that

extend outward to 50 miles (80 kilometers). The population data were extrapolated based on the population growth over the 1990–2010 period to estimate the projected population for the year 2030. The offsite population within 50 miles (80 kilometers) was estimated to be about 545,000 persons for Technical Area 55 (TA-55) (for the No Action Alternative and Modified CMRR-NF Alternative) and about 536,000 persons for TA-3 (for the Continued Use of CMR Building Alternative). For this analysis, no credit was taken for emergency response evacuations and other mitigative actions, such as temporary relocation of the public.

The MEI is defined as a hypothetical individual member of the public who would receive the maximum dose from an accident. This individual is usually assumed to be located at a site boundary. The MEI location was determined for each alternative. The MEI location can vary at LANL based on accident conditions. For this analysis, the MEI was located 0.75 miles (1.2 kilometers) north-northeast of TA-55, and 0.42 miles (0.7 kilometers) north-northeast of TA-3.

A noninvolved worker is defined as an onsite worker who is not directly involved in facility activities where the accident occurs. The noninvolved worker was conservatively assumed to be exposed to the full release, without any protection, located at the technical area boundaries, a distance of about 300 yards (about 280 meters) for TA-3, and about 240 yards (about 220 meters) for TA-55. Workers would respond to a site emergency alarm and evacuate to a designated shelter area, reducing their exposure potential. For purposes of the analyses, however, no credit was taken for any reduced impacts afforded by evacuation.

Doses to the offsite population, the MEI, and a noninvolved worker were calculated based on site-specific meteorological conditions. Site-specific meteorology is described by 1 year of hourly windspeed, atmospheric stability, and rainfall recorded at the site. The MACCS2 calculations produce distributions based on the meteorological conditions. For these analyses, the results presented are based on mean meteorological conditions. The mean produces more-realistic consequences than a 95th percentile condition, which is sometimes used in safety analysis reports. The 95th percentile condition represents low-probability meteorological conditions that are not exceeded more than 5 percent of the time.

The probability coefficient for determining the likelihood of a latent cancer fatality (LCF) for low doses or dose rates is 0.0006 fatal cancers per person-rem or, when applied to individual workers and the MEI, 0.0006 fatal cancers per rem (DOE 2003a). For high doses or dose rates, the probability coefficient is 0.0012 fatal cancers per rem applied to any individual. The higher-probability coefficients apply where individual doses are above 20 rem (NCRP 1993).

The preceding discussion focuses on radiological accidents. Chemical accident scenarios were not evaluated, since inventories of hazardous chemicals to support CMR operations do not exceed the Threshold Planning Quantities as stipulated on the Extremely Hazardous Substances List provided in Section 3.02 of the Emergency Planning and Community Right-to-Know Act (EPA 1998).

C.3 Accident Scenario Selection Process

In accordance with DOE NEPA guidelines, this *CMRR-NF SEIS* considers a representative set of accidents that includes various types, such as fire, explosion, mechanical impact, criticality, spill, human error, natural phenomena, and external events. DOE's Office of NEPA Policy and Compliance, in the *Recommendations for Analyzing Accidents under the National Environmental Policy Act* (DOE 2002), provides guidance for preparing accident analyses in environmental impact statements. The guidance supplements *Recommendations for the Preparation of Environmental Assessments and Environmental Impact Statements, Second Edition* (DOE 2004).

The accident scenario selection was based on evaluation of accidents reported in the hazards analysis documentation provided for the CMR Building (LANS 2011a) and the CMRR-NF (LANS 2011b). The selection and evaluation of accidents was based on a process described in the *DOE Standard: Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses (Nonreactor SAR Preparation Guide)* (DOE 2006). The accident selection process for this *CMRR-NF SEIS* is described in Sections C.3.1 and C.3.2 for Steps 1 and 2, respectively. For additional details on this process, see the documents referenced above.

C.3.1 Hazard Identification – Step 1

Hazard identification, or hazards analysis, is the process of identifying the material, system, process, and plant characteristics that can potentially endanger the health and safety of workers and the public and analyzing the potential human health and safety consequences of accidents associated with the identified hazards. The hazards analysis examines the complete spectrum of accidents that could expose members of the public, onsite workers, facility workers, and the environment to hazardous materials. Hazards that could be present in the CMRR Facility were identified by reviewing data in source documents, assessing their applicability to the CMR Building and the proposed CMRR-NF, and identifying the potential hazards posed by the CMR activities that would be carried out in these facilities.

C.3.2 Accidents Selected for this Evaluation – Step 2

Major hazards were reviewed using a hazards analysis process based on guidance provided by the *Nonreactor SAR Preparation Guide* (DOE 2006). The process ranks the risk of each hazard based on estimated frequency of occurrence and potential consequences to screen out low-risk hazards. Based on this process, a spectrum of accidents was selected. The selection process included, but was not limited to: (1) consideration of the impacts on the public and workers of high-frequency/low-consequence accidents and low-frequency/high-consequence accidents; (2) selection of the highest-impact accident in each accident category to envelope the impacts of all potential accidents; and (3) consideration of only reasonably foreseeable accidents. In addition, hazards and accident analyses for the alternatives were reviewed to determine the potential for accidents initiated by external events (for example, aircraft crash, and explosions in collocated facilities) and natural phenomena (for example, external flooding, earthquake, extreme winds, and missiles). Accident scenarios initiated by human error were also evaluated.

The results of the Step 2 selection process are presented below.

Fire—Fires that occur in the facility could lead to the release of radioactive materials with potential impacts on workers and the public. Initiating events may include internal process and human error events; natural phenomena, such as an earthquake; or external events, such as an airplane crash into the facility. Combustibles near an ignition source could be ignited in a laboratory room containing the largest amounts of radioactive material. The fire may be confined to the laboratory room, propagate uncontrolled and without suppression to adjacent laboratory areas, or lead to a facility-wide fire. A fire or deflagration in a high-efficiency particulate air (HEPA) filter could also occur due to an exothermic reaction involving reactive salts and other materials.

Explosion—Explosions that could occur in the facility could lead to the release of radioactive materials with potential impacts on workers and the public. Initiating events may include internal process and human error events; natural phenomena, such as an earthquake; or external events, such as an explosive gas transportation accident. Explosions could disperse nuclear material as well as initiate fires that could propagate throughout the facility. An explosion of methane gas followed by a fire in a laboratory area could potentially propagate to other laboratory areas and affect the entire facility.

Spills—Spills of radioactive and/or chemical materials could be initiated by failure of process equipment and/or human error, natural phenomena, or external events. Radioactive and chemical material spills typically involve laboratory room quantities of materials that are relatively small compared to releases caused by fires and explosions. Laboratory room spills could affect members of the public, but may be a more serious risk to the laboratory room workers. Larger spills involving vault-size quantities are also possible.

Criticality—The potential for a criticality exists whenever there is a sufficient quantity of nuclear material in an unsafe configuration. Although a criticality could affect the public, its effects are primarily associated with workers near the accident.

Operations at the CMR Building and the proposed CMRR-NF would mostly involve fissile material handling below the minimum critical mass. Only a few operations would involve fissile materials in excess of critical masses. These operations have been reviewed by NNSA and the LANL contractor and it was concluded that existing procedures, limits, and controls would make a criticality accident an incredible event (an event with an annual likelihood of occurrence less than 1 in 1 million). Even for a beyond-design-basis accident, an extreme earthquake-driven accident with sufficient reflector material (water), whereby the entire vault inventory ends up on the floor, DOE's evaluations concluded that the size and volume of the vault would maintain subcriticality. If a criticality accident were assumed to occur, its consequences and risks to the public and workers would be small in comparison to the consequences and risks from the low-frequency accidents analyzed in this *CMRR-NF SEIS*. Since a criticality accident was found to be a low-consequence and low-frequency event, it was not included among the accidents analyzed in detail.

Natural Phenomena—The potential accidents associated with natural phenomena include earthquakes, high winds, flooding, and similar naturally occurring events. For *CMRR-NF SEIS* alternatives, a severe earthquake could lead to the release of radioactive materials and exposure of workers and the public. A severe earthquake could cause the collapse of facility structures, falling debris, and failure of gloveboxes and nuclear materials storage facilities. An earthquake could also initiate a fire that propagates throughout the facility and results in an unfiltered release of radioactive material to the environment. In addition to the potential exposure of workers and the public to radioactive and chemical materials, an accident could also cause human injuries and fatalities from the force of the event, such as falling debris during an earthquake or the thermal effects of a fire.

Chemical—The quantities of regulated chemicals used and stored in the facility are well below the threshold quantities set by the U.S. Environmental Protection Agency (40 CFR 68), and pose minimal potential hazards to public health and the environment in an accident condition. Accidents involving small laboratory quantities of chemicals would primarily present a risk to the involved worker in the immediate vicinity of the accident. There would be no bulk quantities of chemicals stored at the CMR Building or the proposed CMRR-NF.

Airplane Crash—The potential exists for an airplane crash into a building. The probability of an airplane crash during overflight is less than 10^{-6} and, under DOE NEPA guidelines, does not need to be considered in this *CMRR-NF SEIS*. During landing and takeoff operations at the local Los Alamos airport, there is a reasonable probability of a small commercial or military airplane crashing into the facility. However, the impacts of a small airplane crash into the facility are bounded by other accidents addressed in this *CMRR-NF SEIS*.

C.4 Accident Scenario Descriptions and Source Terms

This section describes the accident scenarios and corresponding source terms developed for the *CMRR-NF SEIS* alternatives. The spectrum of accidents described in this section was used to determine, for workers and the public, the consequences and associated risks of each alternative. Assumptions were made when further information was required to clarify the accident condition, update parameters, or facilitate the evaluation process; these are referenced in each accident description.

The source term is the amount of respirable radioactive material released to the air, in terms of curies or grams, assuming the occurrence of a postulated accident. The airborne source term is typically estimated by the following equation:

$$\text{Source term (ST)} = \text{MAR} \times \text{DR} \times \text{ARF} \times \text{RF} \times \text{LPF}$$

where:

MAR	=	material at risk
DR	=	damage ratio
ARF	=	airborne release fraction
RF	=	respirable fraction
LPF	=	leak path factor

The material at risk is the amount of radionuclides (in curies of activity or grams of each radionuclide) available for release when acted upon by a given physical stress or accident. The material at risk is specific to a given process in the facility of interest. It is not necessarily the total quantity of material present, but is that amount of material in the scenario of interest postulated to be available for release.

The damage ratio is the fraction of material exposed to the effects of the energy, force, or stress generated by the postulated event. For the accident scenarios discussed in this analysis, the value of the damage ratio varies from 0.1 to 1.0.

The airborne release fraction is the fraction of material that becomes airborne due to the accident. In this analysis, airborne release fractions were obtained from the hazard analysis information for the CMR Building and CMRR-NF (LANS 2011a, 2011b), or the *DOE Handbook* on airborne release fractions (DOE 1994).

The respirable fraction is the fraction of the particulate matter with an aerodynamic diameter of 10 microns (0.0004 inches) or less that could be retained in the respiratory system following inhalation. The respirable fraction values are also taken from the hazard analysis information for the CMR Building and CMRR-NF (LANS 2011a, 2011b), or the *DOE Handbook* on airborne release fractions (DOE 1994).

The leak path factor accounts for the action of removal mechanisms, for example, containment systems, filtration, and deposition, to reduce the amount of airborne radioactivity ultimately released to occupied spaces in the facility or the environment. A leak path factor of 1.0 (no reduction) is assigned in accident scenarios involving a major failure of confinement barriers. Leak path factors were obtained from the hazard analysis information for the CMR Building and CMRR-NF (LANS 2011a, 2011b) and site-specific evaluations.

Since the isotopic composition and shape of some of the nuclear materials are classified, the material inventory has been converted to equivalent amounts of plutonium-239. The conversion was on a constant-consequence basis, so that the consequences calculated in the accident analyses are equivalent to

what they would be if actual material inventories were used. The following sections describe the selected accident scenarios and corresponding source terms for the alternatives.

Four accidents are included in this *CMRR-NF SEIS* to represent a wide range of possible accidents and risks. The four accident scenarios are common to all three alternatives being analyzed in this *CMRR-NF SEIS*. They are a facility-wide fire, a loading dock spill/fire, a seismically induced spill, and a seismically induced fire.

C.4.1 New CMRR Facility Alternatives

C.4.1.1 No Action Alternative (2004 CMRR-NF)

The accident analysis performed for this *CMRR-NF SEIS* incorporates current knowledge of the threat associated with a design-basis earthquake at LANL and is new compared to the analysis presented in the *Final Environmental Impact Statement for the Chemistry and Metallurgy Research Building Replacement Project at Los Alamos National Laboratory, Los Alamos, New Mexico (CMRR EIS)* (DOE 2003b). The accidents described in this section pertain to the 2004 CMRR-NF at TA-55. For these accidents, two sets of source terms are presented. First, the conservative, bounding source term estimates developed in the safety-basis process at LANL for the purposes of identifying the controls necessary to protect the public are presented. In general, these source term estimates take little if any credit for the integrity of containers or building confinement under severe accidents and assume a damage ratio of 1, meaning that all similar containers or other material at risk would be subjected to the similar, near-worst-case conditions. Furthermore, these safety evaluations generally assume a leak path factor of 1, meaning that all of the material that is made airborne and respirable within the building or process enclosure is released to the environment.

For purposes of this *CMRR-NF SEIS*, a second set of source terms has been developed that attempts to present reasonable, but still conservative, estimates of source terms. These source terms take into account a range of responses of facility features and materials containers and typical operating practices at plutonium facilities at LANL and elsewhere. Therefore, for design-basis-type accidents, a damage ratio of 1 would not normally be realistic if the containers, process enclosures, limits on combustibles, and similar types of safety systems were expected to function during the accident. Similarly, the building confinement, including HEPA filters, is expected to continue functioning, although perhaps at a degraded level, during and after the accident.

Facility-Wide Fire—The accident scenario postulates that combustible materials near an ignition source are ignited in a laboratory area. This fire is a widespread fire involving the entire laboratory area. The fire could be initiated by natural phenomena, human error, or equipment failure.

Safety-Basis Scenario: The fire is assumed to propagate uncontrolled and without suppression to adjacent laboratory areas and the entire facility. The material at risk is estimated to be approximately 660 pounds (300 kilograms) of plutonium-239 equivalent in the form of metal (90 percent), oxide (8.3 percent), and liquid (1.7 percent). The scenario conservatively assumes the damage ratio and leak path factors are 1.0. No credit is taken for equipment and facility features and mitigating factors that could cause the damage ratio and leak path factors to be less than 1.0. The released respirable fraction (airborne release fraction times respirable fraction) is estimated to be 0.00025 for metal, 0.00006 for oxide, and 0.002 for liquid. The source term for radioactive material released to the environment is about 2.8 ounces (80 grams). The frequency of the accident is estimated to range from 0.000001 to 0.0001 or once every 10,000 to 1,000,000 years. The frequency is conservatively assumed to be 0.0001 per year for risk calculation purposes.

SEIS Scenario**:** Typical building construction for a reinforced concrete structure and normal limits on combustible materials would make a fire that propagates beyond the immediate vicinity of a glovebox or a room extremely unlikely without an additional source of fuel to support a propagating fire. Normal design standards for plutonium facilities would ensure that rooms were isolated with appropriate fire walls and barriers. Thus, a fire that propagates to the extent that it becomes a facility-wide fire would be considered a beyond-design-basis fire and the estimated frequency would be less than once every 1,000,000 years. The frequency is conservatively assumed to be 1×10^{-6} per year for risk calculation purposes.

The fire is assumed to propagate uncontrolled and without suppression to adjacent laboratory areas and the entire facility. The materials at risk and release mechanisms are conservatively assumed to be the same as those for the Safety-Basis Scenario. Thus, the material at risk is estimated to be approximately 660 pounds (300 kilograms) of plutonium-239 equivalent in the form of metal (90 percent), oxide (8.3 percent), and liquid (1.7 percent). The scenario conservatively assumes the damage ratio is 0.1, taking credit for equipment and facility features and mitigating factors that should prevent most of the material from being out and vulnerable even in a facility-wide fire. The released respirable fraction (airborne release fraction times respirable fraction) is estimated to be 0.00025 for metal, 0.00006 for oxide, and 0.002 for liquid. The building leak path factor is unknown, but it is expected that in an event this severe, the performance of the HEPA filters would be degraded. For a design-basis fire, the efficiency of a bank of HEPA filters in an air-handling system is expected to be 99 to 99.5 percent. For this beyond-design-basis, facility-wide fire, the filters are assumed to be partially bypassed and a leak path factor of 0.1 is assumed. The source term for radioactive material released to the environment is about 0.028 ounces (0.80 grams).

Loading Dock Spill/Fire—This accident scenario was selected to represent a wide range of spills and fires that might occur outside the CMRR-NF associated with the loading dock. This scenario is postulated to involve waste containers being shipped from the loading dock or a large vessel being delivered to the facility for processing or cleanup. Many engineered controls should prevent or mitigate both the likelihood of this type of accident or the damage that might occur, including design of the loading dock to prevent or minimize the risk of impacts to multiple containers and use of shipping packages designed to withstand shipping accidents. It is very conservatively assumed that a vehicle impacts waste drums containing the entire material at risk of 13.2 pounds (6.0 kilograms) of plutonium-239 equivalent with a subsequent spill or fire involving the containers. Since this accident would occur outside, any material would be released directly to the environment. For safety basis purposes, it is assumed that the damage ratio is 0.1 for mechanical insults associated with vehicles moving in and around a loading dock per DOE-STD-5506-2007 (DOE 2007).

Safety Basis Scenario: The leak path factor is assumed to be 1.0. The released respirable fraction (airborne release fraction times respirable fraction) is very conservatively estimated at 0.001 for the spill. The resulting source term of radioactive material released to the environment is estimated at 0.0212 ounces (0.60 grams). The frequency of the initiating accident is estimated to range from 0.0001 to 0.01 or once every 100 to 10,000 years. The frequency of a spill accident of this magnitude is conservatively assumed to be 0.01 per year for risk calculation purposes. A loading dock spill and subsequent fire was also considered but found, with reasonable assumptions regarding the airborne release fraction, respirable fraction, and the source term, that the consequences would not be higher than those predicted with the spill source term. (With a damage ratio of 0.1 and a leak path factor of 1.0, and assuming that some of the drum contents are ejected and subject to unconfined burning and some are subject to confined burning, a source term of 0.0198 ounces (0.56 grams) was estimated.)

SEIS Scenario: The descriptions of the scenario and releases fractions are the same as those described under the safety basis scenario. For this scenario, the initiating accident is estimated to range from

0.000001 to 0.0001 or once every 10,000 to 1,000,000 years. The frequency for this scenario is conservatively assumed to be 0.0001 per year for risk calculation purposes.

Seismically Induced Events—Subsequent to the issuance of the *CMRR EIS*, it was concluded that the proposed 2004 CMRR-NF structure would not perform as originally intended during a LANL design-basis earthquake. Based on an updated probabilistic seismic hazards analysis, it was concluded that a design-basis earthquake, with a return interval of about 2,500 years and an estimated horizontal peak ground acceleration of 0.52 *g* (URS 2007) could cause the structure to fail and confinement could not be ensured. The 2004 CMRR-NF confinement function was estimated to fail with a peak horizontal ground acceleration exceeding 0.30 *g*, which has a revised estimated return interval of about 1,000 years. For earthquakes less severe than that, the building structure and confinement systems would be expected to continue to provide their safety functions. Many other safety systems that are not directly dependent on the complete integrity of the building structure for their safety function, such as process containers, would also be expected to remain intact during this lower magnitude earthquake, as well as during more-severe earthquakes.

Seismically Induced Spill—This accident scenario postulates an earthquake that causes internal enclosures to topple and become damaged by falling debris.

Safety-Basis Scenario: The material at risk is estimated to be 6.6 tons (6.0 metric tons) of plutonium-239 equivalent (all of the material at risk in the facility) in powder form. The scenario conservatively assumes the damage ratio and leak path factors are 1.0 indicating that the building structure has failed and is providing an open pathway to the environment. No credit is taken for equipment and facility features and mitigating factors that could cause the damage ratio and leak path factors to be less than 1.0. The released respirable fraction (airborne release fraction times respirable fraction) is estimated at 0.002 for powder. The source term for radioactive material released to the environment is about 26 pounds (12 kilograms). The frequency of the accident is estimated to be in the range of 0.0001 to 0.01 per year or once every 100 to 10,000 years. The frequency is conservatively assumed to be 0.01 per year for risk calculation purposes.

SEIS Scenario: This accident scenario postulates an earthquake that causes many of the internal enclosures to topple and become damaged by falling debris. Much of the material in strong containers and in the vault is expected to survive the vibrations and impacts from falling equipment and falling debris. The materials at risk and release mechanisms are conservatively assumed to be similar to those for the Safety-Basis Scenario. Thus, the material at risk is estimated to be 6.6 tons (6.0 metric tons) of plutonium-239 equivalent in powder form. The scenario assumes the damage ratio is 0.01, taking credit for equipment and facility features and mitigating factors that should prevent most of the material from being out and vulnerable to release due to impacts, vibrations, or pressurized venting from cans. It is very conservatively assumed that all of this material is powder and subject to pressurized release. The released respirable fraction (airborne release fraction times respirable fraction) for the material at risk is estimated to be conservatively represented by an airborne release fraction of 0.005 and respirable fraction of 0.4, or 0.002 for the venting of powders or confinement failure to pressures of approximately 25 pounds per square inch or less (DOE 1994).

The building leak path factor is unknown, but it is expected that in an event this severe, building confinement would fail and pathways would exist for the material that becomes airborne to be released directly to the environment. Thus, a leak path factor of 1.0 is assumed. The source term for radioactive material released to the environment is about 0.26 pounds (120 grams). The frequency of the accident is estimated to be on the order of once in 1,000 years, based on the seismic studies that indicate that this 2004 CMRR-NF design would not perform its structural and safety confinement functions adequately in the event of an earthquake of the intensity currently estimated for a LANL design-basis earthquake. This

frequency is a factor of 10 higher than that expected for a similar but more seismically resistant facility, such as the Modified CMRR-NF, that would meet current design standards. The frequency is conservatively assumed to be 0.001 per year for risk calculation purposes.

Seismically Induced Fire—This accident scenario postulates an earthquake that causes internal enclosures to topple and become damaged by falling debris. Combustibles in the facility are ignited and the fire engulfs radioactive material.

Safety-Basis Scenario: The material at risk is estimated to be 6.6 tons (6.0 metric tons) of plutonium-239 equivalent (all of the material in the facility) in powder form. The scenario conservatively assumes the damage ratio and leak path factors are 1.0. No credit is taken for equipment and facility features and mitigating factors that could cause the damage ratio and leak path factors to be less than 1.0. The released respirable fraction (airborne release fraction times respirable fraction) is estimated at 0.07 for powder, which is a highly conservative estimate for a very high pressurized release from a storage can subjected to a long-burning fire. The source term for radioactive material released to the environment is about 926 pounds (420 kilograms). The frequency of the accident is estimated to be in the range of 0.000001 to 0.0001 per year or once every 10,000 to 1,000,000 years. The frequency is conservatively assumed to be 0.0001 per year for risk calculation purposes.

SEIS Scenario: This accident scenario postulates an earthquake that causes many of the internal enclosures to topple and become damaged by falling debris. Much of the material in strong containers and in the vault is expected to survive the vibrations and impacts from falling equipment and falling debris. Multiple local fires are assumed to occur within the debris. Material that is out and close to the fires is expected to be vulnerable to release. Material away from the fires and in strong containers is not expected to be released by the fires. Normal limits on combustible materials in a facility such as the CMRR-NF would make a fire that propagates beyond the immediate vicinity of the localized fires extremely unlikely without an additional source of fuel to support a propagating fire.

The material at risk and release mechanisms are conservatively assumed to be similar to those for the Safety-Basis Scenario. Thus, the material at risk is estimated to be 6.6 tons (6.0 metric tons) of plutonium-239 equivalent in powder form and to include that stored in the vaults. The scenario conservatively assumes the damage ratio is 0.01, taking credit for equipment and facility features and mitigating factors that should prevent most of the material from being out and vulnerable. It is likely that even with a collapse scenario, material in the vaults would not be subject to release either through impacts or the thermal stress of fires. The released respirable fraction (airborne release fraction times respirable fraction) for the material at risk is estimated to be conservatively represented by an airborne release fraction of 0.005 and respirable fraction of 0.4, or 0.002, for the venting of powders or confinement failure to pressures of approximately 25 pounds per square inch or less (DOE 1994).

In addition to the release due to spills, some of the material is also vulnerable to release due to fires as with the facility-wide fire scenario. As with that scenario, it is conservatively assumed that the material at risk in the fire is estimated to be approximately 660 pounds (300 kilograms) of plutonium-239 equivalent in the form of metal (90 percent), oxide (8.3 percent), and liquid (1.7 percent). The fire release portion of the scenario conservatively assumes the damage ratio is 1.0, taking no credit for equipment and facility features and mitigating factors that should prevent most of the material from being out and vulnerable even in a seismically initiated facility-wide fire. The released respirable fraction (airborne release fraction times respirable fraction) is estimated to be 0.00025 for metal, 0.00006 for oxide, and 0.002 for liquid. The overall effective released respirable fraction for the fire release is 0.000267.

The building leak path factor is unknown, but it is expected that in an event this severe, building confinement would fail and pathways would exist for the material that does become airborne to be released

directly to the environment. Thus, a leak path factor of 1.0 is assumed. The source term for radioactive material released to the environment is about 4.2 ounces (120 grams) from the spill release and 2.8 ounces (80 grams) from the fire, for a total of about 7.0 ounces (200 grams). The frequency of the earthquake that results in wide-scale damage and loss of confinement for the building (on the order of once in 10,000 years), coupled with a widespread seismically initiated fire, is estimated to be in the range of 0.000001 to 0.0001 per year or once every 10,000 to 1,000,000 years. The frequency is conservatively assumed to be 0.0001 per year for risk calculation purposes.

C.4.1.2 Modified CMRR-NF Alternative

The accidents described in this section pertain to the Modified CMRR-NF at TA-55. These accidents apply to the Modified CMRR-NF regardless of whether it was constructed under the Deep or Shallow Excavation Option. The two construction options would not affect the performance of the building once it was constructed. Under either construction option, the resulting building would meet the current standards required for a Performance Category 3 facility so it would perform the same in the event of a seismic accident.

The four accident scenarios analyzed for the 2004 CMRR-NF as described in Section C.4.1.1 would be applicable to the Modified CMRR-NF. Both the facility-wide fire and loading dock spill/fire accidents associated with the 2004 CMRR-NF would be directly applicable to the Modified CMRR-NF and accident scenarios and source terms should be similar. Because the Modified CMRR-NF would be stronger and could withstand higher peak ground accelerations than the 2004 CMRR-NF, the seismically induced spill and fire scenario would have a lower likelihood (would require higher seismic accelerations to fail, for example), and would likely release lower quantities of radioactive material to the environment. These safety-basis and NEPA accidents have been included for the Modified CMRR-NF because this facility is being designed to survive a design-basis earthquake accident (expected to occur once every 2,500 years), with an estimated horizontal peak ground acceleration of 0.52 *g*, and thus, the releases from such an earthquake would be mitigated, whereas the 2004 CMRR-NF is predicted to fail in an earthquake exceeding 0.3 *g* horizontal peak ground accelerations. The Modified CMRR-NF would be a stronger structure and would include safety-class and safety-significant structures, systems, and components, collectively known as safety structures, systems, and components. As a result, mitigated releases were evaluated for the seismically induced spill accident and seismically induced fire accident, as described below:

Seismically Induced Spill—This accident scenario postulates an earthquake, of the intensity of the LANL design-basis earthquake, causes internal enclosures to topple and become damaged by falling debris.

<u>Safety-Basis Scenario</u>: The material at risk is reduced from 6.6 tons (6.0 metric tons) to 660 pounds (300 kilograms) of plutonium-239 equivalent in powder form because it is assumed that the vaults would survive this earthquake in the Modified CMRR-NF. The scenario assumes that the damage ratio and leak path factors are 1.0. Credit is taken for equipment and facility features and mitigating factors that could cause the airborne release fraction and respirable fraction to be reduced from those assumed for the 2004 CMRR-NF (unmitigated) accident. The released respirable fraction (airborne release fraction times respirable fraction) is estimated at 0.0001, compared to 0.002 for the 2004 CMRR-NF accident. The source term for radioactive material released to the environment is about 1.1 ounces (30 grams) compared to 26 pounds (12 kilograms) for the 2004 CMRR-NF accident. The frequency of the accident is estimated to be in the range of 0.000001 to 0.0001 per year or once every 10,000 to 1,000,000 years. The frequency is conservatively assumed to be 0.0001 per year, or once in 10,000 years, for risk calculation purposes.

<u>SEIS Scenario</u>: This accident scenario postulates an earthquake that causes many of the internal enclosures to topple and become damaged by falling debris. Much of the material in strong containers and

in the vault is expected to survive the vibrations and impacts from falling equipment and falling debris. The materials at risk and release mechanisms are conservatively assumed to be similar to those for the Safety-Basis Scenario. The material at risk is reduced from 6.6 tons (6.0 metric tons) to 660 pounds (300 kilograms) of plutonium-239 equivalent in powder form because it is assumed that the vaults in the Modified CMRR-NF would survive this earthquake. The scenario assumes the damage ratio is 0.01, taking credit for equipment and facility features and mitigating factors that should prevent most of the material from being out and vulnerable to release due to impacts, vibrations, or pressurized venting from cans. It is very conservatively assumed that all of this material is powder and subject to pressurized release. The released respirable fraction (airborne release fraction times respirable fraction) for the material at risk is estimated to be conservatively represented by an airborne release fraction of 0.005 and respirable fraction of 0.4, or 0.002, for the venting of powders or confinement failure to pressures of approximately 25 psig or less (DOE 1994).

The building leak path factor is unknown, but it is expected that in an event this severe, building confinement would fail and pathways would exist for the material that becomes airborne to be released directly to the environment. Thus, a leak path factor of 1.0 is assumed. The source term for radioactive material released to the environment is about 0.21 ounces (6.0 grams). The frequency of the accident is estimated to be on the order of once in 10,000 years, based on the fact that this facility would be designed to meet current seismic standards and would perform its structural and safety confinement functions adequately in the LANL design-basis earthquake (an estimated horizontal peak ground acceleration of 0.52 *g* with a return interval of about 2,500 year). This frequency is a factor of 10 lower than is expected for a similar but less seismically robust-type facility, such as the original 2004 CMRR-NF design that would not meet current design standards. The frequency is conservatively assumed to be 0.0001 per year for risk calculation purposes.

Seismically Induced Fire—This accident scenario postulates that an earthquake, of the intensity of the LANL design-basis earthquake, causes internal enclosures to topple and become damaged by falling debris. Combustibles in the facility are ignited and the fire engulfs radioactive material.

Safety-Basis Scenario: The material at risk is 6.6 tons (6.0 metric tons) of plutonium-239 equivalent including metal, oxides, contained waste, and unconfined waste, in the form of contaminated combustible paper and trash located in the long-term vault, short-term vault, or in use in gloveboxes. Credit is taken for equipment and facility features and mitigating factors that could cause the damage ratio, airborne release fraction, and respirable fraction to be reduced from those assumed for an unmitigated accident. A range of released respirable fractions (airborne release fraction times respirable fraction) are estimated depending on the form of the material at risk. The source term for radioactive material released to the environment is about 1.9 ounces (53 grams) compared to 926 pounds (420 kilograms) for the unmitigated accident. The frequency of the accident is estimated to be in the range of 0.000001 to 0.0001 per year or once every 10,000 to 1,000,000 years. The frequency is conservatively assumed to be 0.0001 per year for risk calculation purposes.

SEIS Scenario: This accident scenario postulates an earthquake that causes many of the internal enclosures to topple and become damaged by falling debris. Much of the material in strong containers and in the vault is expected to survive the vibrations and impacts from falling equipment and falling debris. Multiple, local fires are assumed to occur within the debris. Material that is out and close to the fires is expected to be vulnerable to release. Material away from the fires and in strong containers is not expected to be released by the fires. Normal limits on combustible materials would make a fire that propagates beyond the immediate vicinity of the localized fires extremely unlikely without an additional source of fuel to support a propagating fire.

The release mechanisms are assumed to be similar to those for the Safety-Basis Scenario. The material at risk is reduced from 6.6 tons (6.0 metric tons) to 660 pounds (300 kilograms) of plutonium-239 equivalent in powder form because it is assumed that the vaults in the Modified CMRR-NF would survive this earthquake. The scenario conservatively assumes the damage ratio is 0.01, taking credit for equipment and facility features and mitigating factors that should prevent most of the material from being out and vulnerable. It is likely that even with a collapse scenario, material in the vaults would not be subject to release either through impacts or the thermal stress of fires. The released respirable fraction (airborne release fraction times respirable fraction) for the material at risk is estimated to be conservatively represented by an airborne release fraction of 0.005 and respirable fraction of 0.4, or 0.002, for the venting of powders or confinement failure to pressures of approximately 25 pounds per square inch or less (DOE 1994).

In addition to the release due to spills, some of the material is also vulnerable to release due to fires as with the facility-wide fire scenario. As with that scenario, it is conservatively assumed that the material at risk in the fire is estimated to be approximately 660 pounds (300 kilograms) of plutonium-239 equivalent in the form of metal (90 percent), oxide (8.3 percent), and liquid (1.7 percent). The fire release portion of the scenario conservatively assumes the damage ratio is 1.0, taking no credit for equipment and facility features and mitigating factors that should prevent most of the material from being out and vulnerable even in a seismically initiated facility-wide fire. The released respirable fraction (airborne release fraction times respirable fraction) is estimated to be 0.00025 for metal, 0.00006 for oxide, and 0.002 for liquid. The overall effective released respirable fraction for the fire release is 0.000267.

The building leak path factor is unknown, but it is expected that in an event this severe, building confinement would fail and pathways would exist for the material that does become airborne to be released directly to the environment. Thus, a leak path factor of 1.0 is assumed. The source term for radioactive material released to the environment is about 0.21 ounces (6.0 grams) from the spill release and 2.82 ounces (80 grams) from the fire, for a total of about 3.03 ounces (86 grams). The frequency of the earthquake that results in wide-scale damage and loss of confinement for the building (on the order of once in 100,000 years), coupled with a widespread seismically initiated fire, is estimated to be in the range of 0.000001 to 0.00001 per year or once every 100,000 to 1,000,000 years. The frequency is conservatively assumed to be 0.00001 per year for risk calculation purposes.

C.4.2 Continued Use of CMR Building Alternative

The accidents described in this section pertain to the CMR Building. For this existing building, the safety-basis scenarios and the NEPA scenarios are similar since they are based on the existing facility and the existing safety analyses. The principal differences in the safety-basis approach and the NEPA approach is the degree of conservatism in the estimation of the material at risk, release mechanisms, damage ratios, fractions made airborne and respirable, and leak path factors. The safety-basis scenarios assume damage ratios of 1.0. The fractions made airborne and respirable by the real-world stresses implied by these scenarios are also conservative. Because of the age and construction of the building, the NEPA scenarios would assume similar damage ratios and leak path factors as the safety-basis scenarios and no separate analyses are provided. It is estimated that real-world releases for any of these CMR Building accident scenarios would be somewhat lower than these conservative safety-basis estimates. Operational practices and limits at the CMR Building limit the potential consequences of these accidents by limiting the material at risk within the building.

Wing-Wide Fire—This accident scenario postulates that combustible materials near an ignition source are ignited in a laboratory area and the fire spreads to a second wing, engulfing both wings. The fire could be initiated by natural phenomena, human error, or equipment failure. The fire is assumed to propagate uncontrolled and without suppression to adjacent laboratory areas. The material at risk is estimated to be

approximately 22 pounds (10 kilograms) of plutonium-239 equivalent in any form (for example, metals, solutions, oxides, powders). The scenario conservatively assumes the damage ratio and leak path factors are 1.0. No credit is taken for equipment and facility features and mitigating factors that could cause the damage ratio and leak path factors to be less than 1.0. A range of released respirable fractions (airborne release fraction times respirable fraction) are estimated depending on the form of the material at risk. The source term for radioactive material released to the environment is about 0.4 ounces (12 grams). The frequency of the accident is estimated to range from 0.0001 to 0.01 or once every 100 to 10,000 years. The frequency is conservatively assumed to be 0.01 per year for risk calculation purposes.

Loading Dock Spill/Fire—This scenario was selected to represent a wide range of spills and fires that might occur outside the CMR Building associated with the loading dock. This scenario is postulated to involve waste containers being shipped from the loading dock or a large vessel being delivered to the facility for processing or cleanup. Many engineered controls should prevent or mitigate both the likelihood of this type of accident or the damage that might occur, including design of the loading dock to minimize the risk of impacts to multiple containers and use of shipping packages designed to withstand shipping accidents. It is very conservatively assumed that a vehicle impacts waste drums containing the entire material at risk of 13.2 pounds (6.0 kilograms) of plutonium-239 equivalent with a subsequent spill or fire involving the containers. Since this would occur outside, any release would be directly to the environment. For safety basis purposes, it is assumed that the damage ratio is 0.1 for mechanical insults associated with vehicles moving in and around a loading dock per DOE-STD-5506-2007 (DOE 2007).

The leak path factor is assumed to be 1.0. The released respirable fraction (airborne release fraction times respirable fraction) is very conservatively estimated at 0.001 for the spill. The resulting source term of radioactive material released to the environment is estimated at 0.0212 ounces (0.60 grams). The frequency of the initiating accident is estimated to range from 0.0001 to 0.01 or once every 100 to 10,000 years. The frequency of a spill accident of this magnitude is conservatively assumed to be 0.01 per year for risk calculation purposes. A loading dock spill and subsequent fire was also considered but found to be with reasonable assumptions, ARFs, and RF, the source term and consequences would not be higher than those predicted with the bounding spill source term. With a damage ratio of 0.1 and a leak path factor of 1.0, and assuming that some of the drum contents are ejected and subject to unconfined burning, and some subject to confined burning, a source term of 0.0198 ounces (0.56 grams) was estimated.

Seismically Induced Spill—This accident scenario postulates that an earthquake causes internal enclosures to topple and become damaged by falling debris. The material at risk is estimated to be about 33 pounds (15 kilograms) of plutonium-239 equivalent. The reduced material at risk in this scenario compared to the CMRR-NF accident scenarios is a result of changes made in CMR operations due to safety concerns associated with the performance of the CMR Building in an earthquake such as the one postulated in this accident scenario. Material at risk that is released as a result of the seismic event may be in any form, including powders, solutions, and metals. The scenario conservatively assumes the damage ratio and leak path factors are 1.0 indicating that the building structure has failed and is providing an open pathway to the environment. No credit is taken for equipment and facility features and mitigating factors that could cause the damage ratio and leak path factors to be less than 1.0. A range of released respirable fractions (airborne release fraction times respirable fraction) are estimated depending on the form of the material at risk. The source term for radioactive material released to the environment is about 1.1 ounces (30 grams). The frequency of the accident is estimated to be in the range of 0.0001 to 0.01 per year or once every 100 to 10,000 years. The frequency is conservatively assumed to be 0.01 per year for risk calculation purposes.

Seismically Induced Fire—This accident scenario postulates an earthquake causes internal enclosures to topple and become damaged by falling debris. Combustibles in the facility are ignited and the fire engulfs

radioactive material. The material at risk is estimated to be about 33 pounds (15 kilograms) of plutonium-239 equivalent. The reduced material at risk for this scenario compared to the CMRR-NF accident scenarios is a result of changes made in CMR operations due to safety concerns associated with the performance of the CMR Building in an earthquake such as the one postulated in this accident scenario. Material at risk that is released as a result of the seismic event may be in any form, including powders, solutions, and metals. The scenario conservatively assumes the damage ratio and leak path factors are 1.0. No credit is taken for equipment and facility features and mitigating factors that could cause the damage ratio and leak path factors to be less than 1.0. A range of released respirable fractions (airborne release fraction times respirable fraction) are estimated depending on the form of the material at risk. The source term for radioactive material released to the environment is about 2.1 ounces (61 grams). The frequency of the accident is estimated to be in the range of 0.000001 to 0.0001 per year or once every 10,000 to 1,000,000 years. The frequency is conservatively assumed to be 0.0001 per year for risk calculation purposes.

C.5 Accident Analyses Consequences and Risk Results

The potential impacts of a radiological accident on workers and the public can be measured in a number of ways depending on the application. Three measures are used in this *CMRR-NF SEIS*. The first measure of consequences is individual dose, expressed in terms of rem or millirem for a member of the public or worker, and collective dose, expressed in terms of person-rem for members of the public or a population of workers. The second measure is a post-exposure effect that reflects the likelihood of an LCF for an exposed individual or the expected number of LCFs in a population of exposed individuals. Individual or public exposure to radiation can only occur if there is an accident involving radioactive materials, which leads to the third measure. The third measure of potential accident impacts is referred to as risk that takes into account the probability (or frequency) of the accident's occurrence. Risk is the mathematical product of the probability or frequency of accident occurrence and the LCF consequences. Risk is calculated as follows:

For an individual

$R_i = D_i \times F \times P$ where:

R_i is the risk of an LCF for an individual receiving a dose D_i in LCFs per year
D_i is the dose in rem to an individual
F is the dose-to-LCF conversion factor, which is 0.0006 LCFs per rem for individuals.
P is the probability or frequency of the accident, usually expressed on a per-year basis.

For a population

$R_p = D_p \times F \times P$ where:

R_p is the risk for a population receiving a dose D_p in LCFs per year
D_p is the dose in person-rem to a population
F is the dose-to-LCF conversion factor, which is 0.0006 LCFs per person-rem for a population of workers for members of the public.
P is the probability or frequency of the accident, usually expressed on a per-year basis.

Once the source term, the amount of radioactive material released to the environment for each accident scenario, is determined, the radiological consequences are calculated. The calculations and resulting impacts vary depending on how the radioactive material release is dispersed, what materials are involved, and which receptors are being considered.

For example, if the dose to an individual (the MEI or a noninvolved worker) is 10 rem, the probability of an LCF for an individual is $10 \times 0.0006 = 0.006$, where 0.0006 is the dose-to-LCF conversion factor. If the individual receives a dose exceeding 20 rem, the dose-to-LCF conversion factor is doubled, to 0.0012. Thus, if the MEI receives a dose of 30 rem, the probability of an LCF is $30 \times 0.0012 = 0.036$. For an individual, the calculated probability of an LCF is in addition to the probability of cancer from all other causes.

For the population, the same dose-to-LCF conversion factors are used to determine the estimated number of LCFs. The calculated number of LCFs in the population is in addition to the number of cancer fatalities that would result from all other causes. The MACCS2 computer code calculates the dose to each individual in the exposed population and applies the appropriate dose-to-LCF conversion factor to estimate the LCF consequences, 0.0006 for doses less than 20 rem or 0.0012 for doses greater than or equal to 20 rem. Therefore, for some accidents, the estimated number of LCFs will involve both dose-to-LCF conversion factors. This indicates that some members of the population are estimated to receive doses in excess of 20 rem.

Tables C–1 through **C–6** present the facility accident impacts under the alternatives. For each alternative, there are two tables showing the impacts. The first table presents the consequences (doses and LCFs) assuming the accident occurs, that is, not reflecting the frequency of accident occurrence. The second table shows the accident risks that are obtained by multiplying the LCF values in the first table by the frequency of each accident listed in the first table.

Table C–1 Accident Frequency and Consequences under the No Action Alternative

		Maximally Exposed Individual		*Offsite Population* [a]		*Noninvolved Worker at Technical Area Boundary*	
Accident	*Frequency (per year)*	*Dose (rem)*	*Latent Cancer Fatality* [b]	*Dose (person-rem)*	*Latent Cancer Fatalities* [c]	*Dose (rem)*	*Latent Cancer Fatality* [b]
Safety-Basis Scenarios							
Facility-wide fire	0.0001	1.1	0.0007	710	0 (0.4)	5.9	0.004
Seismically induced spill	0.01	600	0.7	140,000	80	20,000	1
Seismically induced fire	0.0001	5,000	1	3,800,000	2,000	27,000	1
Loading dock spill/fire	0.01	0.028	0.00002	6.4	0 (0.004)	1.0	0.0006
SEIS Scenarios							
Facility-wide fire	0.000001	0.011	0.000007	7.2	0 (0.004)	0.059	0.00004
Seismically induced spill	0.001	6.0	0.004	1,400	1 (0.8)	200	0.2
Seismically induced fire	0.0001	2.4	0.001	1,800	1	13	0.008
Loading dock spill/fire	0.0001	0.028	0.00002	6.4	0 (0.004)	1.0	0.0006

SEIS = supplemental environmental impact statement.

[a] Based on a projected 2030 population estimate of 545,000 persons residing within 50 miles (80 kilometers) of TA-55.

[b] Increased likelihood of an LCF for an individual, assuming the accident occurs.

[c] Increased number of LCFs in the offsite population, assuming the accident occurs (results rounded to one significant figure). When the reported value is zero, the result calculated by multiplying the collective dose to the population by the risk factor (0.0006 LCFs per person-rem) is shown in parentheses.

Table C–2 Annual Accident Risks under the No Action Alternative

Accident	*Risk of Latent Cancer Fatality*		
	Maximally Exposed Individual [a]	*Offsite Population* [b, c]	*Noninvolved Worker at Technical Area Boundary* [a]
Safety-Basis Scenarios			
Facility-wide fire	7×10^{-8}	4×10^{-5}	4×10^{-7}
Seismically induced spill	7×10^{-3}	8×10^{-1}	1×10^{-2}
Seismically induced fire	1×10^{-4}	2×10^{-1}	1×10^{-4}
Loading dock spill/fire	2×10^{-7}	4×10^{-5}	6×10^{-6}
SEIS Scenarios			
Facility-wide fire	7×10^{-12}	4×10^{-9}	4×10^{-11}
Seismically induced spill	4×10^{-6}	8×10^{-4}	2×10^{-4}
Seismically induced fire	1×10^{-7}	1×10^{-4}	8×10^{-7}
Loading dock spill/fire	2×10^{-9}	4×10^{-7}	6×10^{-8}

SEIS = supplemental environmental impact statement.
[a] Risk of a LCF to the individual.
[b] Risk of an additional LCF in the offsite population.
[c] Based on a projected 2030 population estimate of 545,000 persons residing within 50 miles (80 kilometers) of TA-55.

Table C–3 Accident Frequency and Consequences under the Modified CMRR-NF Alternative

Accident	*Frequency (per year)*	*Maximally Exposed Individual*		*Offsite Population* [a]		*Noninvolved Worker at Technical Area Boundary*	
		Dose (rem)	*Latent Cancer Fatality* [b]	*Dose (person-rem)*	*Latent Cancer Fatalities* [c]	*Dose (rem)*	*Latent Cancer Fatality* [b]
Safety-Basis Scenarios							
Facility-wide fire	0.0001	1.1	0.0007	720	0 (0.4)	5.9	0.004
Seismically induced spill with mitigation	0.0001	1.5	0.0009	350	0 (0.2)	51	0.06
Seismically induced fire with mitigation	0.0001	0.6	0.0004	480	0 (0.3)	3.4	0.002
Loading dock spill/fire	0.01	0.028	0.00002	6.4	0 (0.004)	1.0	0.0006
SEIS Scenarios							
Facility-wide fire	0.000001	0.011	0.000007	7.2	0 (0.004)	0.059	0.00004
Seismically induced spill with mitigation	0.0001	0.3	0.0002	69	0 (0.04))	10	0.006
Seismically induced fire with mitigation	0.00001	1.0	0.0006	770	0 (0.5)	5.5	0.003
Loading dock spill/fire	0.0001	0.028	0.00002	6.4	0 (0.004)	1.0	0.0006

CMRR-NF = Chemistry and Metallurgy Research Building Replacement Nuclear Facility, SEIS = supplemental environmental impact statement.
[a] Based on a projected 2030 population estimate of 545,000 persons residing within 50 miles (80 kilometers) of TA-55.
[b] Increased likelihood of an LCF for an individual, assuming the accident occurs.
[c] Increased number of LCFs in the offsite population, assuming the accident occurs (results rounded to one significant figure). When the reported value is zero, the result calculated by multiplying the collective dose to the population by the risk factor (0.0006 LCFs per person-rem) is shown in parentheses.

Table C–4 Annual Accident Risks under the Modified CMRR-NF Alternative

Accident	Risk of Latent Cancer Fatality		
	Maximally Exposed Individual [a]	*Offsite Population* [b, c]	*Noninvolved Worker at Technical Area Boundary* [a]
Safety-Basis Scenarios			
Facility-wide fire	7×10^{-8}	4×10^{-5}	4×10^{-7}
Seismically induced spill with mitigation	9×10^{-8}	2×10^{-5}	6×10^{-6}
Seismically induced fire with mitigation	4×10^{-8}	3×10^{-5}	2×10^{-7}
Loading dock spill/fire	2×10^{-7}	4×10^{-5}	6×10^{-6}
SEIS Scenarios			
Facility-wide fire	7×10^{-12}	4×10^{-9}	4×10^{-11}
Seismically induced spill with mitigation	2×10^{-8}	4×10^{-6}	6×10^{-7}
Seismically induced fire with mitigation	6×10^{-9}	5×10^{-6}	3×10^{-8}
Loading dock spill/fire	2×10^{-9}	4×10^{-7}	6×10^{-8}

CMRR-NF = Chemistry and Metallurgy Research Building Replacement Nuclear Facility, SEIS = supplemental environmental impact statement.
[a] Risk of a LCF to the individual.
[b] Risk of an additional LCF in the offsite population.
[c] Based on a projected 2030 population estimate of 545,000 persons residing within 50 miles (80 kilometers) of TA-55.

Table C–5 Accident Frequency and Consequences under the Continued Use of CMR Building Alternative

Accident	Frequency (per year)	*Maximally Exposed Individual*		*Offsite Population* [a]		*Noninvolved Worker at Technical Area Boundary*	
		Dose (rem)	*Latent Cancer Fatality* [b]	*Dose (person-rem)*	*Latent Cancer Fatalities* [c]	*Dose (rem)*	*Latent Cancer Fatality* [b]
Wing-wide fire [d]	0.01	0.26	0.0002	130	0 (0.08)	0.65	0.0004
Seismically induced spill	0.01	2.2	0.001	450	0 (0.3)	21	0.03
Seismically induced fire	0.0001	4.3	0.003	900	1 (0.5)	42	0.05
Loading dock spill/fire	0.01	0.07	0.00004	8.5	0 (0.005)	0.7	0.0004

CMR = chemistry and metallurgy research.
[a] Based on a projected 2030 population estimate of 536,000 persons residing within 50 miles (80 kilometers) of TA-3.
[b] Increased likelihood of an LCF for an individual, assuming the accident occurs.
[c] Increased number of LCFs for the offsite population, assuming the accident occurs (results rounded to one significant figure). When the reported value is zero, the result calculated by multiplying the collective dose to the population by the risk factor (0.0006 LCFs per person-rem) is shown in parentheses.
[d] A major fire was assumed to involve two wings.

Table C–6 Annual Accident Risks under the Continued Use of CMR Building Alternative

Accident	Risk of Latent Cancer Fatality		
	Maximally Exposed Individual [a]	*Offsite Population* [b, c]	*Noninvolved Worker at Technical Area Boundary* [a]
Wing-wide fire	2×10^{-6}	8×10^{-4}	4×10^{-6}
Seismically induced spill	1×10^{-5}	3×10^{-3}	3×10^{-4}
Seismically induced fire	3×10^{-7}	5×10^{-5}	5×10^{-6}
Loading dock spill/fire	4×10^{-7}	5×10^{-5}	4×10^{-6}

CMR = chemistry and metallurgy research.
[a] Risk of a LCF to the individual.
[b] Risk of an additional LCF in the offsite population.
[c] Based on a projected 2030 population estimate of 536,000 persons residing within 50 miles (80 kilometers) of TA-3.

C.6 Analysis Conservatism and Uncertainty

The analysis of accidents is based on calculations relevant to postulated sequences of accident events and models used to calculate the accident's consequences. The models provide estimates of the frequencies, source terms, pathways for dispersion, exposures, and the effects on human health and the environment that are as realistic as possible within the scope of the analysis. In many cases, the rare occurrence of postulated accidents leads to uncertainty in the calculation of the consequences and frequencies. This fact has promoted the use of models or input values that yield conservative estimates of consequences and frequency.

Due to the layers of conservatism built into the accident analysis for the spectrum of postulated accidents, the estimated consequences and risks to the public represent the upper limit for the individual classes of accidents. The uncertainties associated with the accident frequency estimates are enveloped by the conservatism in the analysis.

The numerical estimates of LCFs presented in this *CMRR-NF SEIS* were obtained using a linear extrapolation from the nominal risk estimated for lifetime total cancer mortality that results from a dose of 10 rad. Other methods of extrapolation to the low-dose region could yield higher or lower numerical estimates of LCFs. 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. However, comprehensive review of available biological and biophysical data supports a "linear-no-threshold" risk model—in which the risk of cancer proceeds in a linear fashion at lower doses without a threshold—and that the smallest dose has the potential to cause a small increase in risk to humans (National Research Council 2006). Because the health risk estimators are multiplied by conservatively calculated radiological doses to predict fatal cancer risks, the fatal cancer values presented in this *CMRR-NF SEIS* are expected to be conservative estimates.

C.7 MACCS2 Code Description

The MACCS2 computer code is used to estimate the radiological doses and health effects that could result from postulated accidental releases of radioactive materials to the atmosphere. The specification of the release characteristics, designated a "source term," can consist of up to four Gaussian plumes that are often referred to simply as "plumes."

The radioactive materials released are modeled as being dispersed in the atmosphere while being transported by the prevailing wind. During transport, whether or not there is precipitation, particulate material can be modeled as being deposited on the ground. If contamination levels exceed a user-specified criterion, mitigating actions can be triggered to limit radiation exposures.

There are two aspects of the code's structure basic to understanding its calculations: (1) the calculations are divided into modules and phases, and (2) the region surrounding the facility is divided into a polar-coordinate grid. These concepts are described in the following sections.

MACCS is divided into three primary modules: ATMOS, EARLY, and CHRONC. The three modules correspond to three phases of exposure from an accident, defined as the emergency, intermediate, and long-term phases. The relationship among the code's three modules and the three phases of exposure are summarized below.

The ATMOS module performs all of the calculations pertaining to atmospheric transport, dispersion, and deposition, as well as the radioactive decay that occurs before release and while the material is in the atmosphere. It uses a Gaussian plume model with Pasquill-Gifford dispersion parameters. The

phenomena treated include building wake effects, buoyant plume rise, plume dispersion during transport, wet and dry deposition, and radioactive decay and in-growth. The results of the calculations are stored for use by EARLY and CHRONC. In addition to the air and ground concentrations, ATMOS stores information on wind direction, plume arrival and departure times, and plume dimensions.

The EARLY module models the period immediately following a radioactive release. This period is commonly referred to as the "emergency phase." The emergency phase begins at each successive downwind distance point when the first plume of the release arrives. The duration of the emergency phase is specified by the user and can range between 1 and 7 days. The exposure pathways considered during this period are direct external exposure to radioactive material in the plume (cloud shine); exposure from inhalation of radionuclides in the plume (cloud inhalation); exposure to radioactive material deposited on the ground (ground shine); inhalation of resuspended material (resuspension inhalation); and skin dose from material deposited on the skin. Mitigating actions that can be specified for the emergency phase include evacuation, sheltering, and dose-dependent relocation.

The CHRONC module performs all of the calculations pertaining to the intermediate and long-term phases (not used in the current analysis). CHRONC calculates the individual health effects that result from both direct exposure to contaminated ground and from inhalation of resuspended materials, as well as indirect health effects caused by the consumption of contaminated food and water by individuals who could reside both on and off the computational grid.

The intermediate phase begins at each successive downwind distance point upon the conclusion of the emergency phase. The user can configure the calculations with an intermediate phase that has a duration as short as zero or as long as 1 year. In the zero-duration case, there is essentially no intermediate phase and a long-term phase begins immediately upon conclusion of the emergency phase.

Intermediate models are implemented on the assumption that the radioactive plume has passed and the only exposure sources (ground shine and resuspension inhalation) are from ground-deposited material. It is for this reason that MACCS2 requires the total duration of a radioactive release be limited to no more than four days. Potential doses from food and water during this period are not considered.

The mitigating action model for the intermediate phase is very simple. If the intermediate phase dose criterion is satisfied, the resident population is assumed to be present and subject to radiation exposure from ground shine and resuspension for the entire intermediate phase. If the intermediate phase exposure exceeds the dose criterion, then the population is assumed to be relocated to uncontaminated areas for the entire intermediate phase.

The long-term phase begins at each successive downwind distance point upon the conclusion of the intermediate phase. The exposure pathways considered during this period are ground shine, resuspension inhalation, and food and water ingestion.

The exposure pathways considered are those resulting from ground-deposited material. A number of protective measures, such as decontamination, temporary interdiction, and condemnation, can be modeled in the long-term phase to reduce doses to user-specified levels. The decisions on mitigating action in the long-term phase are based on two sets of independent actions: (1) decisions relating to whether land at a specific location and time is suitable for human habitation (habitability), and (2) decisions relating to whether land at a specific location and time is suitable for agricultural production (ability to farm).

All of the calculations of MACCS2 are stored based on a polar-coordinate spatial grid with a treatment that differs somewhat between calculations of the emergency phase and calculations of the intermediate and long-term phases. The region potentially affected by a release is represented with a (r, θ) grid system

centered on the location of the release. The radius, r, represents downwind distance. The angle, θ, is the angular offset from north, going clockwise.

The user specifies the number of radial divisions as well as their endpoint distances. The angular divisions used to define the spatial grid are fixed in the code. They correspond to the 16 points of the compass, each being 22.5 degrees wide. The 16 points of the compass are used in the United States to express wind direction. The compass sectors are referred to as the "coarse grid."

Since emergency phase calculations use dose-response models for early fatalities and early injuries that can be highly nonlinear, these calculations are performed on a finer grid basis than the calculations of the intermediate and long-term phases. For this reason, the calculations of the emergency phase are performed with the 16 compass sectors divided into three, five, or seven equal, angular subdivisions. The subdivided compass sectors are referred to as the "fine grid."

Two types of doses may be calculated by the code, "acute" and "lifetime." Acute doses are calculated to estimate deterministic health effects that can result from high doses delivered at high dose rates. Such conditions may occur in the immediate vicinity of a nuclear facility following hypothetical severe accidents where confinement and/or containment failure has been assumed to occur. Examples of the health effects based on acute doses are early fatality, prodromal vomiting, and hypothyroidism.

Lifetime doses are the conventional measure of detriment used for radiological protection. These are 50-year dose commitments to either specific tissues (for example, red marrow and lungs) or a weighted sum of tissue doses defined by the International Commission on Radiological Protection and referred to as "effective dose." Lifetime doses may be used to calculate the stochastic health effect risk resulting from exposure to radiation. MACCS2 uses the calculated lifetime dose in cancer risk calculations.

C.8 References

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