APPENDIX D: TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDIX D: ACCIDENT ANALYSIS

This appendix of the *Site-wide Environmental Impact Statement for Continued Operation of Lawrence Livermore National Laboratory and Supplemental Stockpile Stewardship and Management Programmatic Environmental Impact Statement* (LLNL SW/SPEIS) presents the estimated consequences of accidents that could occur at the Lawrence Livermore National Laboratory (LLNL). The scenarios described here define the bounding envelope of accidents—that is, any other reasonably foreseeable accident at LLNL would be expected to have smaller consequences. These accident analyses are conservative, with little or no credit taken for existing preventative and mitigating features in each building or operation analyzed or the safety procedures that are mandatory at LLNL. Onsite transportation accidents are included in this appendix. The discussion of offsite transportation accidents is included in Appendix J.

Four types of accidents are discussed: (1) accidents with a potential for releases of radioactive material, (2) accidents with a potential for release of toxic chemicals, (3) accidents involving high explosives, and (4) accidents involving biological hazards. For accidents involving radioactive materials and toxic chemicals, this appendix describes how locations or operations were selected for analysis, the computer codes used to estimate consequences, the development of the scenario and assumptions about source terms, the selection of computer modeling and a description of the results, and predicted health effects. For accidents involving high explosives, this appendix discusses the uses of high explosives at the sites, the potential accidents associated with these uses, and the effects of potential accidents. For accidents involving biological hazards, this appendix summarizes and incorporates analyses previously performed for activities conducted by the U.S. Army (Army 1989).

D.1 APPROACH TO THE ANALYSIS OF POTENTIAL ACCIDENTS

D.1.1 Overview

Accident scenarios have been developed to reflect the broad range of accidents that might occur at LLNL. The scenarios are specific to particular buildings and operations. The following terms are used to define the scenarios:

- A reasonably foreseeable accident could include an accident with "impacts which have catastrophic consequences, even if their probability of occurrence is low, provided that the analysis of the impacts is supported by credible scientific evidence, is not based on pure conjecture, and is within the rule of reason" (40 *Code of Federal Regulations* [CFR] §1502.22). "Credible" means having reasonable grounds for believability, and the "rule of reason" means that the analysis is based on scientifically sound judgment.

- An accident is bounding if no reasonably foreseeable accident with greater consequences can be identified. A bounding envelope is a set of individual bounding accidents covering the range of probabilities and possible consequences. Presenting the impacts from bounding accidents provides a conservative representation of impacts from postulated accidents at LLNL.

A deterministic, nonprobabilistic approach was used to develop the accident scenarios, including those scenarios without a specific initiating cause. The wide range of postulated accidents characterizes the range of accident impacts associated with the operation of LLNL. Bounding scenarios were developed for specific hazards such as radioactive material, toxic chemicals, or high explosives for an operation in a building. The postulated accident scenario for radioactive material, toxic chemicals, or high explosives, can be reasonably evaluated in terms of the effective dose equivalent, specific toxic effects of individual chemicals, or the radius of impact; and from this, the bounding scenario can be determined. In all cases, bounding scenarios are based on the most limiting consideration: radiation exposure, chemical concentration, or peak overpressure.

The radiological exposures are discussed in the individual scenario descriptions reported in Section D.2.4. The health effects from these exposures are presented in Section D.2.5. The chemical exposures are discussed in the individual scenario descriptions reported in Section D.3.2. The health effects associated with chemical releases are analyzed separately and presented in Section D.3.3. The consequences of high explosive accidents are addressed in the individual scenario descriptions in Section D.4. The consequences of accidents involving biological hazards are described in Section D.5. Section D.6 presents the potential releases and consequences of a situation involving a multiple building event.

Scenarios involving malevolent, terrorist, or internationally destructive acts at LLNL are not included in this appendix. These scenarios have been evaluated using DOE criteria and the analyses and results are contained in classified and official use only documents approved by DOE.

D.1.2 Selection of Buildings and Operations for Accident Scenarios

Developing accident scenarios began with reviewing the initial database listing of all LLNL facilities, which comprised 738 individual facilities as of October 2002.

These facilities were reviewed with emphasis on building hazard classification and radionuclide and chemical inventories (including type, quantity, and physical form), high explosives usage, and storage and use conditions. Administrative buildings without hazardous materials were excluded. Buildings ranked as low hazard and those without radioactive materials were eliminated from consideration. The potential offsite consequences of facilities screened out would be well bounded by LLNL's bounding accident scenarios. The following 23 existing LLNL facilities and complexes remained after this initial screening process:

- Building 190, Multi-User Tandem Laboratory
- Building 191, High Explosives Application Facility (HEAF)
- Building 194, 100-MeV Electron-Positron Linear Accelerator (LINAC) Facility
- Building 233, Container Storage Unit (CSU)
- Building 235, 4-MeV Ion Accelerator
- Building 239, Radiography Facility

- Building 251, Heavy Element Facility
- Building 280, Dome
- Building 322, Plating Shop
- Building 331, Tritium Facility
- Building 332, Plutonium Facility
- Building 334, Hardened Engineering Test Building
- Building 368, BioSafety Level-3 Facility
- Buildings 514/612/625/693, Radioactive and Hazardous Waste Management Complex*
- Building 581, National Ignition Facility (NIF)
- Building 695, Decontamination and Waste Treatment Facility (DWTF)
- Building 696R, Radioactive Waste Storage Area
- Site 300 Materials Management Facilities*
- Site 300 Weaponization Program*
- Site 300 Process Area*
- Site 300 Chemistry Area*
- Site 300 Explosive Waste Treatment Facility (EWTF)*
- Site 300 B-Division Firing Areas*

*Includes several individual buildings.

In addition, the following proposed LLNL facilities or projects under the Proposed Action were analyzed:

- Building 581, NIF use of special nuclear material (SNM)
- Building 331, Tritium Facility material-at-risk (MAR) increase (30 grams)
- Building 332, Plutonium Facility MAR Increase (60 kilograms plutonium)
- Energetic Material Processing Center (EMPC)
- Building 239, Radiography Facility MAR Increase (50 kilograms highly enriched uranium)

The next step in the selection process was to identify the most current documentation describing/quantifying the hazards associated with each facility's operation. Current safety documentation was obtained for all of these facilities. Section D.2.4 uses data from these safety documents to describe accident scenarios for each facility. The potential offsite consequences associated with Building 695, Decontamination and Waste Treatment Facility, the Site 300 Process Area, and the Site 300 Chemistry Area were bounded by other similar facilities; thus, these facilities did not warrant further consideration in this analysis. The Building 233 Container Storage Unit no longer contains transuranic waste (LLNL 2001ax), therefore the Building 233 Container Storage Unit was removed from further consideration. Similarly, Building 280 Dome was removed from further consideration because using this facility for radioactive waste storage (LLNL 1999e) is no longer being contemplated. This left 18 existing and 5 proposed LLNL facilities/projects for detailed analysis.

D.2 ACCIDENTS WITH POTENTIAL RELEASE OF RADIOACTIVE MATERIAL

LLNL uses radioactive materials in a wide variety of operations including scientific and weapons research and development, diagnostic research, research on the properties of materials, isotope separation, surveillance and aging studies, machining and inspection, chemical processing, analytical chemistry, metallurgy, weapon component processing, and as calibration and irradiation sources. Radioactive materials are collected as waste products in forms varying from contaminated laboratory equipment and metal filings to contaminated trash and liquids. Radioactive materials are transported onsite. Therefore, there is a potential for releases of radioactive materials due to human error, failure or malfunctioning of equipment, accidents during the treatment, handling, or transportation of radioactive wastes, and severe natural events like earthquakes.

This section analyzes postulated accidents that could result in radioactive material releases. This section also describes how bounding scenarios were selected for analysis. Additionally, this section discusses the computer code that was used in the analysis as well as assumptions about weather conditions and atmospheric dispersion, presents the bounding scenarios, and estimates the potential health effects.

D.2.1 Scenarios, Consequence Analysis, and Risk

An accident is a sequence of one or more unplanned events with potential outcomes that endanger the health and safety of workers and the public. An accident can involve a combined release of energy and hazardous materials (radiological or chemical) that might cause prompt or latent health effects. The sequence usually begins with an initiating event, such as human error, equipment failure, or earthquake, followed by a succession of other events that could be dependent or independent of the initial event, which dictate the accident's progression and the extent of materials released. Initiating events fall into three categories:

- *Internal initiators* normally originate in and around the facility, but are always a result of facility operations. Examples include equipment or structural failures and human errors.

- *External initiators* are independent of facility operations and normally originate from outside the facility. Some external initiators affect the ability of the facility to maintain its confinement of hazardous materials because of potential structural damage. Examples include aircraft crashes, vehicle crashes, nearby explosions, and toxic chemical releases at nearby facilities that affect worker performance.

- *Natural phenomena initiators* are natural occurrences that are independent of facility operations and occurrences at nearby facilities or operations. Examples include earthquakes, high winds, floods, lightning, and snow. Although natural phenomena initiators are independent of external facilities, their occurrence can involve those facilities and compound the progression of the accident.

If an accident were to occur involving the release of radioactive or chemical materials, workers, members of the public, and the environment would be at risk. Workers in the facility where the accident occurs would be particularly vulnerable to the effects of the accident because of their location. The offsite public would also be at risk of exposure to the extent that meteorological conditions exist for the atmospheric dispersion of released hazardous materials.

Consequences of accidental radiological releases were determined using the MELCOR Accident Consequence Code System, Version 2 (MACCS2) computer code (Chanin and Young 1997). MACCS2 is a U.S. Department of Energy/Nuclear Regulatory Commission (DOE/NRC) sponsored computer code that has been widely used in support of probabilistic risk assessments for the nuclear power industry and in support of safety and NEPA documentation for facilities throughout the DOE complex.

The MACCS2 code uses three distinct modules for consequence calculations: ATMOS, EARLY, and CHRONC. The ATMOS module performs atmospheric transport calculations, including dispersion, deposition, and decay. The EARLY module performs exposure calculations corresponding to the period immediately following the release. This module also includes the capability to simulate evacuation from areas surrounding the release. The EARLY module exposure pathways include inhalation, cloudshine, and groundshine. The CHRONC module considers the time period following the early phase; i.e., after the plume has passed. The CHRONC module exposure pathways include groundshine, resuspension inhalation, and ingestion of contaminated food and water. Land use interdiction (e.g., decontamination) can be simulated in this module. Other supporting input files include a meteorological data file and a site data file containing distributions of the population and agriculture surrounding the release site.

Because of assumptions used in this document analysis, not all of the code's capabilities were used. It was conservatively assumed that there would be no evacuation or protection of the surrounding population following an accidental release of radionuclides.

The source term for each scenario was derived by multiplying the MAR times various release factors (damage ratio, airborne release fraction, respirable fraction, and leak path factor) that describe the material available to potentially impact a receptor. Facility inventory is the amount of a hazardous material present in a building or facility. MAR is a portion of the inventory and is defined as the maximum amount of the referenced material that is involved in the process and thus at risk in the event of a postulated accident.

The meteorological data consisted of sequential hourly wind speed, wind direction, stability class and precipitation measured for 1 year. Five years of data (1997 through 2001) were considered. The maximum impacts occurred in 1999, which was used in the analyses, although the impacts from all of the years are roughly equivalent (within 15 percent).

Ten radial rings and 16 uniform direction sectors were used to calculate the collective dose to the offsite population. The radial rings were every 1 mile to 5 miles, a ring at 10 miles, and every 10 miles, from 10 to 50 miles starting at the distribution center. Three centers of distribution were used to represent the Livermore Site: one in the south (Building 331), the center of the site, and the north (Building 381). The location of the offsite maximally exposed individual (MEI) was assumed to be along the site boundary or, for elevated or buoyant releases, at the highest point of offsite consequence. The shortest distance to the boundary from each release location, in all 16 directions sectors, was identified for the MEI analysis. Similarly, the noninvolved onsite worker location was taken as 100 meters from the release in any direction. The spatial distribution of onsite workers, on a quadrant-by-quadrant basis, was conservatively estimated and used in the calculation of noninvolved worker population dose.

Population doses were statistically sampled by assuming an equally likely accident start time during any 4-hour period of the year. All 4-hour periods were sampled. The results from each of these samples were then sorted to obtain a distribution of results (radiation dose), from which the median (50^{th} percentile) and unfavorable (95^{th} percentile) results were extracted and presented in this LLNL SW/SPEIS. Median results are presented in this LLNL SW/SPEIS to give an indication of the most likely consequences, while unfavorable results are presented to give an indication of what the consequences would be under unfavorable conditions. The unfavorable meteorological results can also be used for comparison with LLNL Documented Safety Analysis.

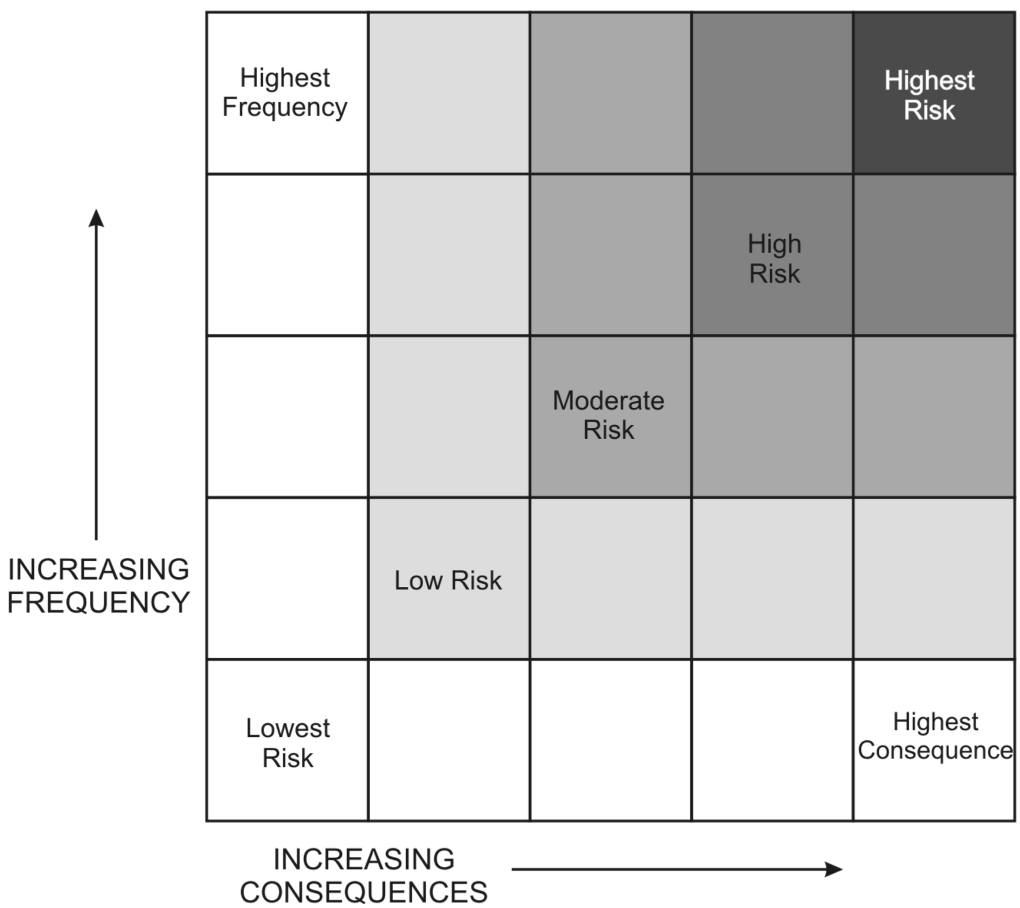
Similarly, two sets of MEI and noninvolved worker doses were calculated. Both sets included conservative assumptions, such as the wind blowing toward the site boundary location closest to the release and locating the receptor along the plume centerline. The first set assumed 95^{th} percentile meteorology (stability class F and a 0.5-meter-per-second wind speed for most Livermore cases and 1.3 meters per second for Site 300). The second set assumed median meteorology based on site measurements for 1999 (stability class D and 2.80 meters per second for Livermore Site or 5.80 meters per second for Site 300).

The doses (70-year committed effective dose equivalent for members of the public and 50-year committed effective dose equivalent for workers) were converted into latent cancer fatalities (LCFs) using the factor of 6×10^{-4} LCFs per person-rem for both members of the public and workers (Lawrence 2002). Seventy-year doses were used because they represent the expected average lifetime of a resident. Fifty-year doses represent the average lifespan of a worker after receiving a dose, assuming the worker was at least 20 years old when the dose was received.

To characterize the accident risk, this analysis chooses a range of types of accidents and consequences. This analysis does not attempt to identify every possible accident scenario, but instead selects accidents that characterize or dominate the risk to the public and workers from site operations. Such accidents do not imply a threshold or particular magnitude of risk. If the risk posed by a facility is small, then such an accident has a correspondingly small risk.

By grouping accidents according to their likelihood or frequency and the magnitude of their consequences, it is possible to select accidents for further characterization and qualitatively portray their relative risk. The accidents selected for this detailed analysis are those with bounding consequences and those that characterize the risk of operating LLNL.

Such grouping or "binning" of accidents is illustrated in Figure D.2.1–1. Accidents assigned to bins within a column vary in terms of their frequency but not their consequences. Accidents have an increasing level of risk going from left to right within a row or from bottom to top within a column. By selecting the accidents with the highest consequences for a particular frequency row, the accidents that contribute the most to overall risk from site operations can be considered.



Source: Original.

FIGURE D.2.1–1.—*Facility Accident Risk Matrix*

Any particular facility can be affected by a wide variety of accidents that may have about the same consequences. Such accidents might have similar frequencies and consequences, and so can be represented by a "representative accident." In the analysis, the frequency of that representative accident might be increased to account for other initiators that lead to the same release. Conversely, there may be an accident whose probability of release is low but that would have larger consequences than other releases. This postulated accident would be a "bounding accident" with consequences that not be exceeded with any reasonable probability.

D.2.2 Mitigation Measures

Mitigations to exposure and dose that would affect the postulated results of the accident scenarios are discussed below. In general, no mitigation was assumed for emergency response in the consequence analysis.

D.2.2.1 *Emergency Response and Protective Actions*

LLNL has detailed plans for responding to accidents of the type described here, and the response activities would be closely coordinated with those of local communities such as Alameda County. LLNL personnel are trained and drilled in the protective actions to be taken if a release of radioactive or otherwise toxic material occurs. Refer to Appendix I for further details on LLNL emergency planning and response information.

The underlying principle for the protective action guides is that under emergency conditions all reasonable measures should be taken to minimize the radiation exposure of the general public and emergency workers. In the absence of significant constraints, protective actions could be implemented when projected doses are lower than the ranges given in the protective action guides. No credit was taken for emergency response and protective actions in the consequence analysis.

D.2.2.2 *High-Efficiency Particulate Air Filtration*

In all areas where unconfined plutonium or other radioactive materials can be handled and can exist in a dispersible form, high-efficiency particulate air (HEPA) filters provide a final barrier against the inadvertent release of radioactive aerosols into the outside environment. However, these filters would not trap volatile fission products such as the noble gases and iodine; such gases would be released into the outside environment.

HEPA filter efficiencies are 99.99 percent or greater with the minimum efficiency of 99.97 percent for 0.3-micron particles, the size most easily passed by the filter. To maximize containment of particles and provide redundancy, two HEPA filters in a series are used. Actual data from HEPA filter replacement records in Building 332 show that none of the filters used to prevent a potential for release of plutonium to the atmosphere have degraded to the overall efficiencies assumed for the accident scenarios (LLNL 2003f). These HEPA filters are protected by building design features against the consequences of an earthquake or fire. Credit was taken for filtration in the consequence analysis when ventilation and building containment were shown by analysis to survive during the accident.

D.2.3 Derivation of Aircraft Crash Frequencies

In this appendix, the National Nuclear Security Administration (NNSA) considers the impacts of a postulated aircraft crash on Buildings 331, 332, 625, and 696R. A postulated aircraft crash into Buildings 239, 334, and 693 was also initially considered. However, NNSA determined that buckling failure or perforation of the concrete structures in Buildings 239 and 334 was not predicted. Building 693 has a lower radionuclide inventory and is physically smaller than Building 696R, and would be bounded by the analysis for Building 696R. Therefore, these three facilities were not evaluated further. The purpose of this section is to describe the process and data that NNSA used to derive the estimated frequencies for the aircraft crash for each of these four facilities.

The frequency evaluation for an aircraft crash uses a "four-factor formula" which considers the following factors:

1. The number of operations (N)
2. The probability that the plane will crash (P)
3. Given a crash, the probability that it will occur in a 1-square-mile area where the facility is located (f)
4. The effective area of the facility (A)

The annual aircraft crash frequency is calculated as follows:

$$F=\sum N_{i,j,k}\times P_{i,j,k}\times f_{i,j,k}(x,y)\times A_{i,j}$$

Where:

F = Estimated annual aircraft crash impact frequency for the facility (crashes per year)

N = Number of operations (operations per year)

P = Probability of a place crashing (crashes per operation)

f(x,y) = Aircraft crash location probability ($1/\text{mile}^2$)

A = Effective area of the facility (mile^2)

i = Phase of flight operation, i = 1, 2, 3 (takeoff, inflight, landing)

j = Aircraft type (commercial, military, general aviation, etc.)

k = Aircraft source (airports, inflight, etc.)

The values for each of these parameters are described in the following subsections.

D.2.3.1 *Number of Operations (N)*

In accordance with DOE standard "Accident Analysis for Aircraft Crash into Hazardous Facilities" (DOE-STD-3014-96), any airport further than 22 miles from LLNL would not increase the probability of an aircraft crash into the facility due to airport operations (takeoffs and landings). The airports in the vicinity of LLNL are Oakland International (28 miles), Hayward Municipal (23 miles), Livermore Municipal (6.5 miles), Moffett Field (26.5 miles), Tracy Municipal (14.5 miles), Meadowlark Field (1.5 miles), Byron (11.25 miles), and San Jose International (25.5 miles). The only airports within 22 miles are the Livermore Municipal, Tracy Municipal, Meadowlark Field, and Byron. These airports operate principally for general aviation.

Livermore Municipal Airport reported 252,470 operations during fiscal year (FY) 1999 (LLNL 2002bl). Of these, 158,592 were local, which only go as far as Livermore Avenue, and are not considered a direct threat to LLNL facilities. Of the remaining 93,878 operations, 1,711 were air taxi operations, 189 were military, and 91,978 operations were general aviation. The airport control tower is open from 7:00 a.m. to 9:00 p.m., but planes can land outside these hours. Therefore, an additional 10 percent of operations was assumed for general aviation. This results in 101,176 general aviation operations. Half of these operations were assumed to be takeoffs and half were assumed to be landings. At the Livermore Municipal Airport, 82 percent of takeoffs and landings are from the east to west; the remaining 18 percent are from the west to east.

Tracy Municipal Airport reported an average rate of 164 operations per day, which equals 59,860 operations per year (LLNL 2002bd). Approximately 1 percent of these operations (599 operations) are air taxi, and the remaining 59,261 operations are general aviation. Half of these operations were assumed to be takeoffs and half were assumed to be landings.

The Meadowlark Field Airport is a privately owned airfield, which reported about 3 flights per week, or 156 flights per year (LLNL 2002bl). The field is gravel and can only take general aviation planes. Half of these operations were assumed to be takeoffs and half were assumed to be landings.

The Byron Airport reported an average rate of 71 general aviation operations per day, or 25,915 per year (LLNL 2002bl). Half of these operations were assumed to be takeoffs and half were assumed to be landings.

D.2.3.2 *Crash Probability (P)*

Aircraft crash frequencies can be divided into two categories: accidents in the vicinity of an airport, and accidents while a plane is in flight. Aircraft crash frequencies are also a function of the type of aircraft. Generally, commercial air carriers have the lowest accident frequency for both takeoff and landing operations and per mile in flight. Military aviation and general aviation have higher accident frequencies. Analysis of aircraft frequencies have shown increased accident rates within 22 miles of an airport. Increased accident frequencies near airports are attributed to aircraft takeoff and landing traffic. DOE standard "Accident Analysis for Aircraft Crash into Hazardous Facilities" (DOE-STD-3014-96) contains crash rates and location probabilities for aircraft near airports associated with takeoffs and landings.

Aircraft crash probabilities while a plane is in flight are independent of the vicinity of airports. DOE standard gives this information as a combination of NPf(x,y).

D.2.3.3 *Aircraft Crash Location Probability (f)*

The f(x,y) values for the aircraft crash frequency equation are based on the location of the facility with respect to the airport (x and y). The x value is measured in the direction of aircraft travel and y value is measured perpendicular to aircraft travel. The values of f(x,y) were obtained from DOE standard for both takeoffs and landings. Values for air taxis were assumed to be the same as for commercial carriers.

Table D.2.3–1 presents that calculation of the aircraft crash probability at the Livermore Site using the values for N, P, and f discussed above.

D.2.3.4 *Effective Area of the Facility (A)*

The effective area of the facility needs to be determined to complete the frequency calculations. DOE standard defines the effective area as "… the ground surface area surrounding a facility such that if an unobstructed aircraft were to crash within the area, it would impact the facility, either by direct fly-in or skid into the facility. The effective area depends on the length, width, and height of the facility, as well as on the aircraft's wingspan, flight path angle, heading angle relative to the heading of the facility, and the length of its skid." The equation for effective area is as follows:

$$A = A_{sk}+A_{fp}+A_{sh}$$

$$A_{sk} = (WS+R) \times S$$

$$A_{fp} = L \times W+\frac{(2 \times L \times W \times WS)}{R}$$

$$A_{sh} = (WS + R) \times H \times \cot(\Phi)$$

Where:

A = total effective area

A_{sk} = effective area associated with the skid

A_{fp} = effective area associated with the footprint

A_{sh} = effective area associated with the shadow

WS = aircraft wingspan

S = aircraft skid distance

L = length of facility

W = width of facility

H = height of facility

cot(Φ) = mean of the cotangent of the building shadow angle

R = length of the diagonal of the facility = $(L^2 + W^2)^{0.5}$

Table D.2.3–2 presents the values for each of these parameters, as well as the calculated total area for each of the five LLNL facilities for each aircraft type. The total area is the sum of the A_{sk}, A_{fp} and A_{sh} values.

Table D.2.3–3 presents the product of the crash probabilities from Table D.2.3–1 and the total effective areas from Table D.2.3–2. As a result of the probabilities reflected in Table D.2.3–3, aircraft accidents involving the categories of general aviation and air taxi were considered.

The aircraft crash probability is dominated by general aviation, which represents approximately 99 percent of the total probability reflected in Table D.2.3–1. Operations at the Livermore Municipal Airport dominate the data for air taxi operations, which represent less than 1 percent of the probability reflected in Table D.2.3–1. The 1999 Livermore Municipal Airport data used for analysis had the highest number of total annual flight operations for 1993 through 2003. The annual number of air taxi operations has varied widely and were as low as 324 in the year 2000 versus the 1,711 analyzed in the data for the year 1999. Therefore, an aircraft accident at LLNL involving an air taxi was not considered reasonably foreseeable.

General aviation operations at the Livermore Municipal Airport represent approximately 93 percent of the total probability reflected in Table D.2.3–1. Over 95 percent of the Livermore Municipal Airport operations are represented by the general aviation subcategories of single-engine piston, multiengine aircraft, and helicopter aircraft. A similar distribution of airframes was assumed for the general aviation data for Tracy Municipal, Byron, and in-flight operations. Helicopter velocities are generally lower than that of fixed-wing aircraft and single-engine aircraft engines are generally heavier than multiengine aircraft for equivalent performance. Therefore, the consequences of a large single-engine piston aircraft impacting facilities at the Livermore Site bound the reasonably foreseeable accidents into LLNL facilities.

The conditional probability of occurrence of a fire from a general aviation aircraft crash is approximately 0.3 (LLNL 2003bg). This value is applied to those facilities where the MAR includes drums of transuranic waste (i.e., Buildings 625, 695, and 696R) and to Building 331. Also, approximately 20 percent of the total area of Building 696R is shielded by nearby facilities (LLNL 2003y). Thus, the frequencies must be multiplied by the fire factor and the unshielded fraction to give the values for "adjusted annual crash probability leading to an uncontrolled release," which are listed in the final column of Table D.2.3–4 and presented in the rest of the appendix.

TABLE D.2.3–1.—*Calculation of Aircraft Crash Probability*

Airport	Aircraft Type	Flight Phase	Number of Operations (N)	Aircraft Crash Rate (P)	X Distance (mi)	Y Distance (mi)	Crash Location Probability f(x,y) ($1/mi^2$)	Crash Probability ($crashes/mi^2$)
Livermore	Single-Engine Piston	Takeoff (E-W)	28,291	1.10×10^{-5}	-6.5	0	0	0.00
Livermore	Single-Engine Piston	Takeoff (W-E)	6,210	1.10×10^{-5}	6.5	0	1.50×10^{-3}	1.02×10^{-4}
Livermore	Single-Engine Piston	Landing (E-W)	28,291	2.00×10^{-5}	-6.5	0	2.90×10^{-3}	1.64×10^{-3}
Livermore	Single-Engine Piston	Landing (W-E)	6,210	2.00×10^{-5}	6.5	0	6.50×10^{-4}	8.07×10^{-5}
		Sub-Total	69,002					1.82×10^{-3}
Livermore	Multi-Engine Piston	Takeoff (E-W)	2,821	9.30×10^{-6}	-6.5	0	0	0.00
Livermore	Multi-Engine Piston	Takeoff (W-E)	619	9.30×10^{-6}	6.5	0	1.50×10^{-3}	8.64×10^{-6}
Livermore	Multi-Engine Piston	Landing (E-W)	2,821	2.30×10^{-5}	-6.5	0	2.90×10^{-3}	1.88×10^{-4}
Livermore	Multi-Engine Piston	Landing (W-E)	619	2.30×10^{-5}	6.5	0	6.50×10^{-4}	9.26×10^{-6}
		Sub-Total	6,880					2.06×10^{-4}
Livermore	Turboprop	Takeoff (E-W)	996	3.50×10^{-6}	-6.5	0	0	0.00
Livermore	Turboprop	Takeoff (W-E)	219	3.50×10^{-6}	6.5	0	1.50×10^{-3}	1.15×10^{-6}
Livermore	Turboprop	Landing (E-W)	996	8.30×10^{-6}	-6.5	0	2.90×10^{-3}	2.40×10^{-5}
Livermore	Turboprop	Landing (W-E)	219	8.30×10^{-6}	6.5	0	6.50×10^{-4}	1.18×10^{-6}
		Sub-Total	2,428					2.63×10^{-5}
Livermore	Turbojet	Takeoff (E-W)	581	1.40×10^{-6}	-6.5	0	0	0.00
Livermore	Turbojet	Takeoff (W-E)	127	1.40×10^{-6}	6.5	0	1.50×10^{-3}	2.68×10^{-7}
Livermore	Turbojet	Landing (E-W)	581	4.70×10^{-6}	-6.5	0	2.90×10^{-3}	7.92×10^{-6}
Livermore	Turbojet	Landing (W-E)	127	4.70×10^{-6}	6.5	0	6.50×10^{-4}	3.89×10^{-7}
		Sub-Total	1,416					8.57×10^{-6}
Livermore	Helicopter	Takeoff (E-W)	8,794	1.25×10^{-5}	-6.5	0	0	0.00
Livermore	Helicopter	Takeoff (W-E)	1,930	1.25×10^{-5}	6.5	0	1.50×10^{-3}	3.62×10^{-5}
Livermore	Helicopter	Landing (E-W)	8,794	1.25×10^{-5}	-6.5	0	2.90×10^{-3}	3.19×10^{-4}
Livermore	Helicopter	Landing (W-E)	1,930	1.25×10^{-5}	6.5	0	6.50×10^{-4}	1.57×10^{-5}
		Sub-Total	21,449					3.71×10^{-4}
		Livermore Total	**101,176**					$\mathbf{2.44 \times 10^{-3}}$

TABLE D.2.3–1.—*Calculation of Aircraft Crash Probability (continued)*

Airport	Aircraft Type	Flight Phase	Number of Operations (N)	Aircraft Crash Rate (P)	X Distance (mi)	Y Distance (mi)	Crash Location Probability f(x,y) (1/mi^2)	Crash Probability (crashes/mi^2)
Tracy	Single-Engine Piston	Takeoff	15,564	1.10×10^{-5}	14.5	0.5	0	0.00
Tracy	Single-Engine Piston	Landing	15,564	2.00×10^{-5}	-14.5	0.5	1.00×10^{-4}	3.11×10^{-5}
		Sub-Total	31,128					3.11×10^{-5}
Tracy	Multi-Engine Piston	Takeoff	3,891	9.30×10^{-6}	14.5	0.5	0	0.00
Tracy	Multi-Engine Piston	Landing	3,891	2.30×10^{-5}	-14.5	0.5	1.00×10^{-4}	8.95×10^{-6}
		Sub-Total	7,782					8.95×10^{-6}
		Tracy Total	**38,910**					**4.01×10^{-5}**
Byron	General Aviation	Takeoff	12,958	1.10×10^{-5}	9.62	5.83	0	0.00
Byron	General Aviation	Landing	12,958	2.00×10^{-5}	-9.62	5.83	0	0.00
Meadowlark	Single-Engine Piston	Takeoff	78	1.10×10^{-5}	0	1.5	1.50×10^{-2}	1.29×10^{-5}
Meadowlark	Single-Engine Piston	Landing	78	2.00×10^{-5}	0	1.5	1.20×10^{-2}	1.87×10^{-5}
In Flight	General Aviation	In Flight						1.00×10^{-4}
	General Aviation	**Total**						**2.61×10^{-3}**
In Flight	**Air Carrier**	**In Flight**						**5.00×10^{-7}**
Livermore	Air Taxi	Takeoff (E-W)	702	1.00×10^{-6}	-6.5	0	0	0.00
Livermore	Air Taxi	Takeoff (W-E)	154	1.00×10^{-6}	6.5	0	1.50×10^{-3}	2.31×10^{-7}
Livermore	Air Taxi	Landing (E-W)	702	2.30×10^{-6}	-6.5	0	8.60×10^{-3}	1.39×10^{-5}
Livermore	Air Taxi	Landing (W-E)	154	2.30×10^{-6}	6.5	0	0	0.00
Tracy	Air Taxi	Takeoff	300	1.00×10^{-6}	14.5	0.5	0	0.00
Tracy	Air Taxi	Landing	300	2.30×10^{-6}	-14.5	0.5	2.90×10^{-5}	2.00×10^{-8}
In Flight	Air Taxi	In Flight						2.00×10^{-6}
	Air Taxi	**Total**						**1.61×10^{-5}**
In Flight	Large Military	In Flight						2.00×10^{-7}
Livermore	Small Military	Takeoff (E-W)	78	1.80×10^{-6}	-6.5	0	0	0.00

TABLE D.2.3–1.—*Calculation of Aircraft Crash Probability (continued)*

Airport	Aircraft Type	Flight Phase	Number of Operations (N)	Aircraft Crash Rate (P)	X Distance (mi)	Y Distance (mi)	Crash Location Probability f(x,y) (1/mi^2)	Crash Probability (crashes/mi^2)
Livermore	Small Military	Takeoff (W-E)	17	1.80×10^{-6}	6.5	0	1.20×10^{-2}	3.67×10^{-7}
Livermore	Small Military	Landing (E-W)	78	3.30×10^{-6}	-6.5	0	1.40×10^{-2}	3.60×10^{-6}
Livermore	Small Military	Landing (W-E)	17	3.30×10^{-6}	6.5	0	1.10×10^{-4}	6.17×10^{-9}
In Flight	Small Military	In Flight						3.00×10^{-6}
	Military	**Total**						$\mathbf{7.18 \times 10^{-6}}$
		Grand Total						$\mathbf{2.63 \times 10^{-3}}$

Source: Original.
E = east; W = west.

TABLE D.2.3–2.—*Calculation of Effective Area by Aircraft Type*

Facility	Aircraft Type	Length of facility, L (ft)	Width of facility, W (ft)	Height of facility, H (ft)	Aircraft wingspan, WS (ft)	Cotangent of aircraft impact angle cot(Φ)	Aircraft skid distance, S (ft)	Length of Diagonal, R (ft)	Skid Area, A_{sk}, (mi^2)	Footprint Area, A_{fp} (mi^2)	Shadow Area, A_{sh} (mi^2)	Total Effective Area, A (mi^2)
B331	General Aviation (fixed wing)	240	68.5	14	50	8.2	60	249.6	6.45×10^{-4}	8.26×10^{-4}	1.23×10^{-3}	2.70×10^{-3}
B331	General Aviation (helicopter)	240	68.5	14	50	0.58	0	249.6	0.00	8.26×10^{-4}	8.73×10^{-5}	9.13×10^{-4}
B331	Air Carrier	240	68.5	14	98	10.2	1,440	249.6	1.80×10^{-2}	1.05×10^{-3}	1.78×10^{-3}	2.08×10^{-2}
B331	Air Taxi	240	68.5	14	59	10.2	1,440	249.6	1.59×10^{-2}	8.68×10^{-4}	1.58×10^{-3}	1.84×10^{-2}
B331	Large Military											
B331	Takeoff	240	68.5	14	223	7.4	780	249.6	1.32×10^{-2}	1.64×10^{-3}	1.76×10^{-3}	1.66×10^{-2}
B331	Landing	240	68.5	14	223	9.7	368	249.6	6.24×10^{-3}	1.64×10^{-3}	2.30×10^{-3}	1.02×10^{-2}
B331	In-Flight	240	68.5	14	223	7.4	780	249.6	1.32×10^{-2}	1.64×10^{-3}	1.76×10^{-3}	1.66×10^{-2}
B331	Small Military											
B331	Takeoff	240	68.5	14	94	8.4	246	249.6	3.03×10^{-3}	1.03×10^{-3}	1.45×10^{-3}	5.52×10^{-3}
B331	Landing	240	68.5	14	94	10.4	447	249.6	5.51×10^{-3}	1.03×10^{-3}	1.79×10^{-3}	8.34×10^{-3}
B331	In-Flight	240	68.5	14	94	8.4	246	249.6	3.03×10^{-3}	1.03×10^{-3}	1.45×10^{-3}	5.52×10^{-3}
B332	General Aviation (fixed wing)	240	87	16	6	8.2	60	255.3	5.62×10^{-4}	7.84×10^{-4}	1.23×10^{-3}	2.58×10^{-3}
B332	General Aviation (helicopter)	240	87	16	6	0.58	0	255.3	0.00	7.84×10^{-4}	8.70×10^{-5}	8.71×10^{-4}
B332	Air Carrier	240	87	16	98	10.2	1,440	255.3	1.82×10^{-2}	1.32×10^{-3}	2.07×10^{-3}	2.16×10^{-2}
B332	Air Taxi	240	87	16	59	10.2	1,440	255.3	1.62×10^{-2}	1.10×10^{-3}	1.84×10^{-3}	1.92×10^{-2}
B332	Large Military											
B332	Takeoff	240	87	16	223	7.4	780	255.3	1.34×10^{-2}	2.06×10^{-3}	2.03×10^{-3}	1.75×10^{-2}
B332	Landing	240	87	16	223	9.7	368	255.3	6.31×10^{-3}	2.06×10^{-3}	2.66×10^{-3}	1.10×10^{-2}
B332	In-Flight	240	87	16	223	7.4	780	255.3	1.34×10^{-2}	2.06×10^{-3}	2.03×10^{-3}	1.75×10^{-2}
B332	Small Military											
B332	Takeoff	240	87	16	94	8.4	246	255.3	3.08×10^{-3}	1.30×10^{-3}	1.68×10^{-3}	6.07×10^{-3}
B332	Landing	240	87	16	94	10.4	447	255.3	5.60×10^{-3}	1.30×10^{-3}	2.08×10^{-3}	8.99×10^{-3}
B332	In-Flight	240	87	16	94	8.4	246	255.3	3.08×10^{-3}	1.30×10^{-3}	1.68×10^{-3}	6.07×10^{-3}

TABLE D.2.3–2.—*Calculation of Effective Area by Aircraft Type (continued)*

Facility	Aircraft Type	Length of facility, L (ft)	Width of facility, W (ft)	Height of facility, H (ft)	Aircraft wingspan, WS (ft)	Cotangent of aircraft impact angle cot(Φ)	Aircraft skid distance, S (ft)	Length of Diagonal, R (ft)	Skid Area, A_{sk}, (mi^2)	Footprint Area, A_{fp} (mi^2)	Shadow Area, A_{sh} (mi^2)	Total Effective Area, A (mi^2)
B625	General Aviation (fixed wing)	120	37	8	50	8.2	60	125.6	3.78×10^{-4}	2.86×10^{-4}	4.13×10^{-4}	1.08×10^{-3}
B625	General Aviation (helicopter)	120	37	8	50	0.58	0	125.6	0.00	2.86×10^{-4}	2.92×10^{-5}	3.15×10^{-4}
B625	Air Carrier	120	37	8	98	10.2	1,440	125.6	1.15×10^{-2}	4.08×10^{-4}	6.54×10^{-4}	1.26×10^{-2}
B625	Air Taxi	120	37	8	59	10.2	1,440	125.6	9.54×10^{-3}	3.09×10^{-4}	5.40×10^{-4}	1.04×10^{-2}
B625	Large Military											
B625	Takeoff	120	37	8	223	7.4	780	125.6	9.75×10^{-3}	7.25×10^{-4}	7.40×10^{-4}	1.12×10^{-2}
B625	Landing	120	37	8	223	9.7	368	125.6	4.60×10^{-3}	7.25×10^{-4}	9.70×10^{-4}	6.30×10^{-3}
B625	In-Flight	120	37	8	223	7.4	780	125.6	9.75×10^{-3}	7.25×10^{-4}	7.40×10^{-4}	1.12×10^{-2}
B625	Small Military											
B625	Takeoff	120	37	8	94	8.4	246	125.6	1.94×10^{-3}	3.98×10^{-4}	5.29×10^{-4}	2.86×10^{-3}
B625	Landing	120	37	8	94	10.4	447	125.6	3.52×10^{-3}	3.98×10^{-4}	6.55×10^{-4}	4.57×10^{-3}
B625	In-Flight	120	37	8	94	8.4	246	125.6	1.94×10^{-3}	3.98×10^{-4}	5.29×10^{-4}	2.86×10^{-3}
B696R	General Aviation (fixed wing)	114	77	8	50	8.2	60	137.6	4.04×10^{-4}	5.44×10^{-4}	4.41×10^{-4}	1.39×10^{-3}
B696R	General Aviation (helicopter)	114	77	8	50	0.58	0	137.6	0.00	5.44×10^{-4}	3.12×10^{-5}	5.75×10^{-4}
B696R	Air Carrier	114	77	8	98	10.2	1,440	137.6	1.22×10^{-2}	7.63×10^{-4}	6.90×10^{-4}	1.36×10^{-2}
B696R	Air Taxi	114	77	8	59	10.2	1,440	137.6	1.02×10^{-2}	5.85×10^{-4}	5.75×10^{-4}	1.13×10^{-2}
B696R	Large Military											
B696R	Takeoff	114	77	8	223	7.4	780	137.6	1.01×10^{-2}	1.34×10^{-3}	7.66×10^{-4}	1.22×10^{-2}
B696R	Landing	114	77	8	223	9.7	368	137.6	4.76×10^{-3}	1.34×10^{-3}	1.00×10^{-3}	7.10×10^{-3}
B696R	In-Flight	114	77	8	223	7.4	780	137.6	1.01×10^{-2}	1.34×10^{-3}	7.66×10^{-4}	1.22×10^{-2}
B696R	Small Military											
B696R	Takeoff	114	77	8	94	8.4	246	137.6	2.04×10^{-3}	7.45×10^{-4}	5.58×10^{-4}	3.35×10^{-3}
B696R	Landing	114	77	8	94	10.4	447	137.6	3.71×10^{-3}	7.45×10^{-4}	6.91×10^{-4}	5.15×10^{-3}
B696R	In-Flight	114	77	8	94	8.4	246	137.6	2.04×10^{-3}	7.45×10^{-4}	5.58×10^{-4}	3.35×10^{-3}

Source: Original.
ft = feet; mi^2 = square mile.

TABLE D.2.3–3.—*Detailed Evaluation of Impact Frequency without Building Shielding*

Facility	Aircraft Subtype	Crash Probability (crashes/mi²)	Total Effective Area, A (mi²)	Impact Frequency, F, (crashes/yr)
B331	General Aviation			
B331	Single-Engine Piston	1.89×10^{-3}	2.70×10^{-3}	5.10×10^{-6}
B331	Multi-Engine Piston	2.15×10^{-4}	2.70×10^{-3}	5.81×10^{-7}
B331	Turboprop	2.63×10^{-5}	2.70×10^{-3}	7.11×10^{-8}
B331	Turbojet	8.57×10^{-6}	2.70×10^{-3}	2.32×10^{-8}
B331	Helicopter	3.71×10^{-4}	9.13×10^{-4}	3.39×10^{-7}
B331	In-Flight	1.00×10^{-4}	2.70×10^{-3}	2.70×10^{-7}
B331	Total General Aviation			6.39×10^{-6}
B331	Air Carrier	5.00×10^{-7}	2.08×10^{-2}	1.04×10^{-8}
B331	Air Taxi	1.61×10^{-5}	1.84×10^{-2}	2.97×10^{-7}
B331	Large Military	2.00×10^{-7}	1.66×10^{-2}	3.32×10^{-9}
B331	Small Military			
B331	Takeoff	3.67×10^{-7}	5.52×10^{-3}	2.03×10^{-9}
B331	Landing	3.61×10^{-6}	8.34×10^{-3}	3.01×10^{-8}
B331	In-Flight	3.00×10^{-6}	5.52×10^{-3}	1.65×10^{-8}
B331	Total Small Military			4.87×10^{-8}
B331	**Grand Total**	$\mathbf{2.63 \times 10^{-3}}$		$\mathbf{6.75 \times 10^{-6}}$
B332	General Aviation			
B332	Single-Engine Piston	1.89×10^{-3}	2.58×10^{-3}	4.86×10^{-6}
B332	Multi-Engine Piston	2.15×10^{-4}	2.58×10^{-3}	5.54×10^{-7}
B332	Turboprop	2.63×10^{-5}	2.58×10^{-3}	6.77×10^{-8}
B332	Turbojet	8.57×10^{-6}	2.58×10^{-3}	2.21×10^{-8}
B332	Helicopter	3.71×10^{-4}	8.71×10^{-4}	3.23×10^{-7}
B332	In-Flight	1.00×10^{-4}	2.58×10^{-3}	2.58×10^{-7}
B332	Total General Aviation			6.08×10^{-6}
B332	Air Carrier	5.00×10^{-7}	2.16×10^{-2}	1.08×10^{-8}
B332	Air Taxi	1.61×10^{-5}	1.92×10^{-2}	3.09×10^{-7}
B332	Large Military	2.00×10^{-7}	1.75×10^{-2}	3.49×10^{-9}
B332	Small Military			
B332	Takeoff	3.67×10^{-7}	6.07×10^{-3}	2.23×10^{-9}
B332	Landing	3.61×10^{-6}	8.99×10^{-3}	3.24×10^{-8}
B332	In-Flight	3.00×10^{-6}	6.07×10^{-3}	1.82×10^{-8}
B332	Total Small Military			5.29×10^{-8}
B332	**Grand Total**	$\mathbf{2.63 \times 10^{-3}}$		$\mathbf{6.46 \times 10^{-6}}$

TABLE D.2.3–3.—*Detailed Evaluation of Impact Frequency without Building Shielding (continued)*

Facility	Aircraft Subtype	Crash Probability (crashes/mi²)	Total Effective Area, A (mi²)	Impact Frequency, F, (crashes/yr)
B625	General Aviation			
B625	Single-Engine Piston	1.89×10^{-3}	1.08×10^{-3}	2.03×10^{-6}
B625	Multi-Engine Piston	2.15×10^{-4}	1.08×10^{-3}	2.32×10^{-7}
B625	Turboprop	2.63×10^{-5}	1.08×10^{-3}	2.83×10^{-8}
B625	Turbojet	8.57×10^{-6}	1.08×10^{-3}	9.23×10^{-9}
B625	Helicopter	3.71×10^{-4}	3.15×10^{-4}	1.17×10^{-7}
B625	In-Flight	1.00×10^{-4}	1.08×10^{-3}	1.08×10^{-7}
B625	Total General Aviation			2.53×10^{-6}
B625	Air Carrier	5.00×10^{-7}	1.26×10^{-2}	6.31×10^{-9}
B625	Air Taxi	1.61×10^{-5}	1.04×10^{-2}	1.68×10^{-7}
B625	Large Military	2.00×10^{-7}	1.12×10^{-2}	2.24×10^{-9}
B625	Small Military			
B625	Takeoff	3.67×10^{-7}	2.86×10^{-3}	1.05×10^{-9}
B625	Landing	3.61×10^{-6}	4.57×10^{-3}	1.65×10^{-8}
B625	In-Flight	3.00×10^{-6}	2.86×10^{-3}	8.59×10^{-9}
B625	Total Small Military			2.62×10^{-8}
B625	**Grand Total**	**2.63×10^{-3}**		**2.73×10^{-6}**
B696R	General Aviation			
B696R	Single-Engine Piston	1.89×10^{-3}	1.39×10^{-3}	2.62×10^{-6}
B696R	Multi-Engine Piston	2.15×10^{-4}	1.39×10^{-3}	2.99×10^{-7}
B696R	Turboprop	2.63×10^{-5}	1.39×10^{-3}	3.65×10^{-8}
B696R	Turbojet	8.57×10^{-6}	1.39×10^{-3}	1.19×10^{-8}
B696R	Helicopter	3.71×10^{-4}	5.75×10^{-4}	2.13×10^{-7}
B696R	In-Flight	1.00×10^{-4}	1.39×10^{-3}	1.39×10^{-7}
B696R	Total General Aviation			3.32×10^{-6}
B696R	Air Carrier	5.00×10^{-7}	1.36×10^{-2}	6.81×10^{-9}
B696R	Air Taxi	1.61×10^{-5}	1.13×10^{-2}	1.83×10^{-7}
B696R	Large Military	2.00×10^{-7}	1.22×10^{-2}	2.44×10^{-9}
B696R	Small Military			
B696R	Takeoff	3.67×10^{-7}	3.67×10^{-7}	1.35×10^{-13}
B696R	Landing	3.61×10^{-6}	3.61×10^{-6}	1.30×10^{-11}
B696R	In-Flight	3.00×10^{-6}	3.00×10^{-6}	9.00×10^{-12}
B696R	Total Small Military			2.22×10^{-11}
B696R	**Grand Total**	**2.63×10^{-3}**		**3.51×10^{-6}**

Source: Original.
mi² = square mile.

TABLE D.2.3–4.—*Calculation of Overall Aircraft Crash Frequency for a Single-Engine Piston General Aviation Aircraft*

Facility	Crash Probability (crashes/mi^2)	Total Effective Area, A (mi^2)	Product	Post-crash Fire Probability	Shielding	Adjusted Annual Crash Probability Leading to an Uncontrolled Release
B331	1.89×10^{-3}	2.70×10^{-3}	5.10×10^{-6}	0.3	0	1.53×10^{-6}
B332	1.89×10^{-3}	2.58×10^{-3}	4.86×10^{-6}	1	0	4.86×10^{-6}
B625	1.89×10^{-3}	1.08×10^{-3}	2.03×10^{-6}	0.3	0	6.10×10^{-7}
B696R	1.89×10^{-3}	1.39×10^{-3}	2.62×10^{-6}	0.3	0.2	6.29×10^{-7}

Source: Original.

D.2.4 Description of Accident Scenarios

From the safety documents obtained through the process described in Section D.1.2, the next step was to identify potential accident scenarios and source terms (release rates and frequencies) associated with those facilities. Some safety documents present accident frequencies as a range reflecting uncertainties in the analysis. Table D.2.4–1 lists the results of this process, and contains the accident name, its frequency, and its source term, for both the No Action Alternative and Proposed Action. Potential radiological accident scenarios for the Reduced Operation Alternative would be the same as for the No Action Alternative. The values shown are those contained in existing safety documents as noted in the references cited in Table D.2.4–1. In Table D.2.4–1, the bounding accident scenario for each facility is highlighted. These bounding scenarios are described in Sections D.2.4.1 through D.2.4.16.

Facilities that manage transuranic waste at LLNL employ the concept of plutonium-equivalent curies to normalize the quantity of transuranic radioactivity within waste containers to plutonium-239. Normalizing all radionuclides to a common radiotoxic hazard index allows for facility accident consequence analysis to be performed without the requirement to characterize the radionuclide composition of each waste stream or package. Plutonium-239, as a common component of most transuranic wastes generated by LLNL, was selected as the radionuclide to which the radiotoxic hazard of other transuranic radionuclides could be indexed.

From the listing of accidents in Table D.2.4–1, the next step was to perform MACCS2 calculations (as described in Section D.2.1) to identify the accidents that present the highest public or worker consequences for each facility (i.e., the “bounding” accidents). These accident scenarios were highlighted in Table D.2.4–1 and are discussed further below.

TABLE D.2.4–1.—*Potential Radiological Accident Scenarios*

Accident	Frequency (per year)	Source Term or Hazard (No Action Alternative)	Source Term or Hazard (Proposed Action)
190, Multi-User Tandem Laboratory[a]			
Exposure to incidental x-ray radiation	10^{-4} to 10^{-2}	Minimal radiation exposure to workers. No impacts to other onsite personnel or the offsite population.	Same
Exposure to prompt radiation	10^{-4} to 10^{-2}	Exposure to worker of "several rem." No impacts to other onsite personnel or the offsite population.	Same
Exposure to residual radiation	10^{-4} to 10^{-2}	Minor radiation exposure to workers. No impacts to other onsite personnel or the offsite population.	Same
191, High Explosives Application Facility[b]			
Personnel exposure to x-ray radiation	10^{-6} to 10^{-4}	Inadvertent exposure inside a firing tank or workroom area could possibly exceed exposure limits but acute effects probably would not occur.	Same
Radioactive material dispersion from a spill and fire	$<10^{-6}$	5.0×10^{-5} g Pu	Same
194, 100-MeV Electron-Positron LINAC Facility[c]			
Exposure to primary LINAC beam	$<10^{-6}$	Death to a person who might be present (e.g., in the 0° Cave or high-energy end of the Accelerator Cave) during beam operation. There would be no consequences to facility personnel, onsite personnel, the public, or the environment, other than Emergency Rescue workers who could receive moderate exposure from the high levels of residual radioactivity present immediately after beaming.	Same

TABLE D.2.4–1.—*Potential Radiological Accident Scenarios (continued)*

Accident	Frequency (per year)	Source Term or Hazard (No Action Alternative)	Source Term or Hazard (Proposed Action)
194, 100-MeV Electron-Positron LINAC Facility[c]			
Exposure to high levels of ionizing radiation	10^{-2} to 10^{-1}	Doses of up to a few rem to personnel who might be exposed to high levels of induced radioactivity present in the target areas after beam operation. Significant exposure could also occur from improper handling of calibration sources or other radioactive materials used in a particular experimental process. The activity induced in shielding materials, targets, or beam transport components, however, is nondispersible. Therefore, there is no risk to personnel outside of the facility, to the public, or to the environment.	Same
Exposure to airborne radionuclides	10^{-2} to 10^{-1}	Facility personnel could be accidentally exposed to airborne radioactivity because of a ventilation system failure for a target cave or from a major leak of a closed loop cooling water system. Exposed personnel could receive integrated radiation doses of up to 1 mrem (ventilation failure) or 4 mrem (cooling water leak). None of these events would result in an increased risk to the public or the environment.	Same
Design basis earthquake and fire	10^{-6} to 10^{-4}	0.0012 Ci C-11 0.047 Ci N-13 0.903 Ci O-15 3.4×10^{-4} Ci weapons-grade Pu	Same
235, 4-MeV Ion Accelerator[d]			
Exposure to ionizing radiation	10^{-4} to 10^{-2}	Small radiation doses to facility personnel, within all regulatory standards. No risk to the public or the environment.	Same

TABLE D.2.4–1.—*Potential Radiological Accident Scenarios (continued)*

Accident	Frequency (per year)	Source Term or Hazard (No Action Alternative)	Source Term or Hazard (Proposed Action)
239, Radiography Facility[e]			
Personnel exposure to x-ray radiation	10^{-4} to 10^{-2}	Minimal radiation exposure to workers. No impacts to other site personnel or the offsite population.	Same
Waste drum fire	$<10^{-7}$	8.0×10^{-3} g Pu-239 equivalent	Same
Fire involving SNM	$<\sim10^{-5}$	25 g HEU	50 g HEU
Uncontrolled oxidation of plutonium (fuel-grade plutonium)	$<\sim10^{-4}$	8.7×10^{-4} g fuel-grade Pu	Same
Uncontrolled oxidation of plutonium at elevated temperatures (weapons-grade plutonium)	$<4.5 \times 10^{-7}$	4.5×10^{-2} g weapons-grade Pu	Same
Release of tritium	$\sim7 \times 10^{-5}$	0.2 g tritium as HTO	Same
251, Heavy Element Facility[f]			
Spill release accident	10^{-4} to 10^{-2}	Unmitigated spill = 0.12 Ci (Am-241 equivalent) Mitigated spill = 1.2×10^{-3} Ci (Am-241 equivalent)	Same
Seismic (evaluation basis earthquake)	10^{-6} to 10^{-4}	0.051 Ci (Am-241 equivalent)	Same
Evaluation Basis Fire	10^{-6} to 10^{-4}	0.081 Ci (Am-241 equivalent)	Same
331, Tritium Facility[g]			
Tritium release during earthquake	10^{-6} to 10^{-4}	3.5 g tritium (0.035 g as HTO)	30 g tritium (0.3 g as HTO)
Aircraft crash with subsequent fire	1.53×10^{-6}	3.5 g tritium (as HTO)	30 g tritium (as HTO)

TABLE D.2.4–1.—*Potential Radiological Accident Scenarios (continued)*

Accident	Frequency (per year)	Source Term or Hazard (No Action Alternative)	Source Term or Hazard (Proposed Action)
Plutonium metal fire	10^{-4} to 10^{-2}	0.065 g fuel-grade Pu	Same
Waste drum event, fire	10^{-4} to 10^{-2}	0.0065 g fuel-grade Pu	Same
Waste drum event	10^{-4} to 10^{-6}	0.026 g fuel-grade Pu	Same
332, Plutonium Facility[h, i]			
Evaluation-basis room fire			
Room fire filtered	3×10^{-3}	1.0×10^{-5} g fuel-grade Pu	3.0×10^{-5} g fuel-grade Pu
Room fire unfiltered	3.9×10^{-7}	0.25 g fuel-grade Pu	0.75 g fuel-grade Pu
Fire in loft	3×10^{-2}	6.2×10^{-3} g fuel-grade Pu	Same
Radioactive Material Spill			
Spill filtered	4.8×10^{-3}	5.4×10^{-6} g fuel-grade Pu	Same
Spill unfiltered	$<10^{-6}$	0.11 g fuel-grade Pu	Same
Pyrophoric material event			
Filtered	9.8×10^{-2}	9.0×10^{-6} g fuel-grade Pu	Same
Unfiltered	2.3×10^{-6}	2.3×10^{-2} g fuel-grade Pu	Same
Aircraft crash			
Aircraft crash	4.86×10^{-6}	0.25 g fuel-grade Pu	Same
Materials Management Transport and Waste Drum Events			
Materials management transportation spill	4.5×10^{-4}	7.5×10^{-3} g fuel-grade Pu	Same
Waste drum puncture/rupture with fire	2.7×10^{-4}	0.19 g fuel-grade Pu	Same
Inadvertent Criticality			
Uranium criticality in a powder, slurry, or solution system in a workstation	3.2×10^{-5}	1×10^{18} fissions (see below for inventories released criticality events)	Same
Plutonium criticality for a powder, slurry, or solution system in a workstation	3.2×10^{-5}	1×10^{18} fissions (see below for inventories released criticality events)	Same
Evaluation-basis earthquake			
Evaluation-basis earthquake (filtered)	1.0×10^{-3}	1.4×10^{-5} g fuel-grade Pu	Same

TABLE D.2.4–1.—*Potential Radiological Accident Scenarios (continued)*

Accident	Frequency (per year)	Source Term or Hazard (No Action Alternative)	Source Term or Hazard (Proposed Action)
Hydrogen deflagration			
Hydrogen event filtered	8.1×10^{-5}	9.0×10^{-3} g fuel-grade Pu	0.027 g fuel-grade Pu
Hydrogen event unfiltered	$<1 \times 10^{-6}$	1.21 g fuel-grade Pu	3.63 g fuel-grade Pu
334, Hardened Engineering Test Building[j]			
Personnel exposure to x-ray radiation	10^{-4} to 10^{-2}	Minimal radiation exposure to workers. No impacts to other site personnel or the offsite population.	Same
Fire involving HEU (unmitigated)	$<\sim 10^{-5}$	100 g HEU	Same
Fire involving HEU (mitigated)	$<\sim 10^{-5}$	0.1 g HEU	Same
Uncontrolled oxidation of plutonium (unmitigated)	$<\sim 10^{-4}$	9.4×10^{-4} g fuel-grade Pu	Same
Uncontrolled oxidation of plutonium (mitigated)	$<\sim 10^{-4}$	9.4×10^{-7} g fuel-grade Pu	Same
Uncontrolled oxidation of plutonium at elevated temperatures	$<1 \times 10^{-6}$	0.185 g fuel-grade plutonium	Same
514/612/625/693, Radioactive and Hazardous Waste Management Complex[k]			
Earthquake	10^{-4} to 10^{-2}	1.6×10^{-4} Ci Transuranic Waste (use Am-241 as a surrogate), 5,000 Ci Tritium, 6.0×10^{-4} Ci Aqueous low-level waste (Pu-equivalent Ci)	Same

TABLE D.2.4–1.—*Potential Radiological Accident Scenarios (continued)*

Accident	Frequency (per year)	Source Term or Hazard (No Action Alternative)	Source Term or Hazard (Proposed Action)
Fire	10^{-4} to 10^{-2}	3.18×10^{-3} Ci Transuranic Waste (use Am-241 as a surrogate), 5,000 Ci Tritium, 3.48×10^{-4} Ci DU	Same
Leaks and Spills	10^{-4} to 10^{-2}	1.9×10^{-4} Ci Transuranic Waste (use Am-241 as a surrogate), 5,000 Ci Tritium, 6.0×10^{-4} Ci Aqueous low-level waste (Pu-equivalent Ci) 3.48×10^{-8} Ci DU	Same
Pressurized Releases	10^{-4} to 10^{-2}	1.0×10^{-4} Ci Aqueous low-level waste (Pu-equivalent Ci)	Same
Crane fall in Building 625 during severe earthquake	NA	0.0072 Pu-equivalent Ci	0.022 Pu-equivalent Ci
Aircraft Crash into Building 625	6.1×10^{-7}	0.46 Pu-equivalent Ci	1.40 Pu-equivalent Ci
581, National Ignition Facility			
Earthquake during No Action Alternative operations	2.0×10^{-8}	500 Ci tritium plus activated gases and particulates	Same
Earthquake during depleted uranium experiment	2.0×10^{-8}	0.005g depleted uranium plus 500 Ci tritium plus activated gases and particulates	0.1 g depleted uranium plus 500 Ci tritium plus fission products plus activated gases and particulates
Earthquake during HEU experiment	2.0×10^{-9}	NA	0.1 g HEU plus 500 Ci tritium plus fission products plus activated gases and particulates

TABLE D.2.4–1.—*Potential Radiological Accident Scenarios (continued)*

Accident	Frequency (per year)	Source Term or Hazard (No Action Alternative)	Source Term or Hazard (Proposed Action)
Earthquake during thorium experiment	2.0×10^{-9}	NA	0.45 g Th-232 plus 500 Ci tritium plus fission products plus activated gases and particulates
Earthquake during tracer experiment	2.0×10^{-9}	NA	0.031 Ci I-124 0.032 Ci I-125 0.075 Ci I-126 Plus 500 Ci tritium plus fission products plus activated gases and particulates
Earthquake during plutonium without yield experiment	2.0×10^{-9}	NA	0.003 g weapons-grade Pu plus 500 Ci tritium plus fission products plus activated gases and particulates
Earthquake during plutonium experiment in the in the presence of yield	2.0×10^{-9}	NA	0.001 g weapons-grade Pu plus 500 Ci tritium plus gaseous and particulate fission and activation products plus activated gases and particulates
696R, Radioactive Waste Storage Area[l]			
Large fire involving staged transuranic waste containers	$<\sim 10^{-6}$	0.092 Pu-equivalent Ci	Same
Deflagration in transuranic waste drum	10^{-4} to 10^{-2}	0.0016 Pu-equivalent Ci	Same
Spill of transuranic waste container in yard	10^{-4} to 10^{-2}	0.0013 Pu-equivalent Ci	Same

TABLE D.2.4–1.—*Potential Radiological Accident Scenarios (continued)*

Accident	Frequency (per year)	Source Term or Hazard (No Action Alternative)	Source Term or Hazard (Proposed Action)
Aircraft Crash	6.29×10^{-7}	0.925 Pu-equivalent Ci	Same
Site 300 Materials Management Facilities[m]			
Inadvertent exposure to hazardous materials	10^{-4} to 10^{-2}	Exposure to tritium gas (inside a room) at concentrations of up to 0.74 Ci/m^3, which would lead to 5-minute dose of 4.7 rem, and a 1-hour dose of 35 rem.	Same
Depleted uranium release by fire	10^{-4} to 10^{-2}	0.95 g/sec DU for two hours for a total of 6,840 g DU	Same
Onsite Transportation			
Radioactive and Hazardous Waste Management explosion	$<10^{-6}$	0.0059 Pu-equivalent Ci	Same
Materials Management Section package explosion	$<10^{-6}$	0.1 g fuel-grade plutonium	Same

Source: [a] LLNL 2002bw.
[b] LLNL 2002cp.
[c] LLNL 2002cq.
[d] LLNL 2000d.
[e] LLNL 2002ac
[f] LLNL 2001aj.
[g] LLNL 2002ad.
[h] LLNL 2002bo, LLNL 2002af.
[i] LLNL 2003t.
[j] LLNL 2001at.
[k] LLNL 2002bm.
[l] LLNL 2002da.
[m] LLNL 2002l.

DU = depleted uranium.
HTO = tritiated water.
SNM = special nuclear material.
G = gallon
Pu = plutonium
Ci = curies
HEU = highly enriched uranium
Am = americium

D.2.4.1 Building 332 Criticality Accident

Table D.2.4–2 lists the calculated source term that would be released to the environment following the postulated criticality event in Building 332. For criticality events that result in less than 10^{18} fissions, the source terms listed in Table D.2.4–2 were assumed to be linearly proportional to the number of fissions. The frequency of occurrence of this event is conservatively estimated to be 3.2×10^{-5} per year.

TABLE D.2.4–2.—*Inventories Released from 10^{18} Fission Criticality Events*

Nuclide	Uranium Criticality Released Inventories (Ci)	Plutonium Criticality Released Inventories (Ci)
^{83m}Kr	1.6×10^{1}	1.1×10^{1}
^{85m}Kr	1.5×10^{1}	7.1
^{85}Kr	1.6×10^{-4}	8.1×10^{-5}
^{87}Kr	9.9×10^{1}	4.3×10^{1}
^{88}Kr	6.5×10^{1}	2.3×10^{1}
^{89}Kr	4.2×10^{3}	1.3×10^{3}
^{131m}Xe	8.2×10^{-3}	1.0×10^{-2}
^{133m}Xe	0.18	0.22
^{133}Xe	2.7	2.7
^{135m}Xe	2.2×10^{2}	3.3×10^{2}
^{135}Xe	3.6×10^{1}	4.1×10^{1}
^{137}Xe	4.9×10^{3}	4.9×10^{3}
^{138}Xe	1.3×10^{3}	1.1×10^{3}
^{131}I	0.22	0.28
^{132}I	2.8×10^{1}	3.0×10^{1}
^{133}I	4.0	4.0
^{134}I	1.1×10^{2}	1.1×10^{2}
^{135}I	1.2×10^{1}	1.2×10^{1}

Source: LLNL 2002bo.
Ci = curie; I = iodine; Kr = krypton; m = isotope; Xe = xenon.

For plutonium releases, the isotopic composition of the source term depends on the type of material used. For accidents involving a plutonium release, in most cases the isotopic mixture of 30-year-old fuel-grade plutonium was used as the source term. In a few cases, 30-year-old weapons-grade plutonium was used as the source term. Table D.2.4–3 lists the isotopic mixtures for both fuel-grade and weapons-grade plutonium.

Table D.2.4–3.—*Isotopic Mixtures of 30-Year-Old Fuel-Grade and Weapons-Grade Plutonium*

Isotope	30-Year-Old Fuel-Grade Plutonium (Mass %)	30-Year-Old Weapons-Grade Plutonium (Mass %)
Plutonium-238	0.0789	0.03
Plutonium-239	77.9	93.26
Plutonium-240	17.9	5.98
Plutonium-241	0.376	0.14
Plutonium-242	0.490	0.04
Americium-241	3.00	0.45

Source: LLNL 2002bo.
Am = americium; Pu = plutonium.

D.2.4.2 *Building 190, Multi-User Tandem Laboratory—Exposure to Prompt Radiation*

Prompt radiation can be produced by the interaction of accelerated ion beams and targets. The prompt radiation in Building 190 can take the form of x-rays, gamma rays, and neutrons. In general, the amount of radiation produced is greater for light ions (such as protons or deuterons) and increases with increasing beam energy. Prompt radiation levels can be several tens of millirem per hour, 1 meter from the production point. As the prompt radiation levels depend upon the beam being accelerated, the energy of acceleration, losses along specific beam transport paths, and target and shielding materials of each beam line, specific analyses and controls are required for each experimental configuration. Shielding and access controls are implemented to keep radiation levels as low as reasonably achievable (ALARA). Although not achieved in any allowed operation, worst-case prompt radiation fields of a few rem per hour to workers are theoretically possible while operating any of the Building 190 accelerators. The frequency of occurrence of this event is conservatively estimated to be 10^{-4} to 10^{-2} per year. This bounding accident scenario applies to the No Action Alternative, the Proposed Action, and the Reduced Operation Alternative of this LLNL SW/SPEIS.

D.2.4.3 *Building 191, High Explosives Application Facility—Radioactive Material Dispersion from a Spill and Fire*

Although plutonium is not normally used in Building 191, a release of 200 milligrams of plutonium-239 was used to bound the radionuclide release scenarios. This bounding accident scenario applies to the No Action Alternative, the Proposed Action, and the Reduced Operation Alternative of this LLNL SW/SPEIS. A fire involving ordinary combustibles in the HEAF was considered to postulate a bounding release. It was assumed that a small quantity of plutonium metal present in the room would be involved in the fire. The plutonium would be partially burned, and oxide particles would be released to the environment through unfiltered room ventilation system.

The source term is computed using the bounding airborne release fraction and respirable fraction involving self-sustained oxidation of plutonium metal. Particle deposition mechanisms such as thermophoresis, gravitational settling, and agglomeration, which would substantially reduce the amount released to the atmosphere, are ignored in this analysis. Hence, the resultant conservative source term for this scenario is 5×10^{-5} grams of weapons-grade plutonium. The frequency of occurrence of this event is conservatively estimated to be less than 10^{-6} per year.

D.2.4.4 *Building 194, 100-MeV Electron-Positron LINAC Facility—Design Basis Earthquake and Fire*

This scenario assumes an earthquake with sufficiently violent ground motion as to cause structural damage to the facility. This bounding accident scenario applies to the No Action Alternative, the Proposed Action, and the Reduced Operation Alternative of this LLNL SW/SPEIS. Specifically, it assumes the collapse of the 30-meter exhaust stack, movement of the below ground cave doors (i.e., failure of the radiation confinement barriers), rupture of the sulfure hexafluoride and cryogenic liquid containment systems below ground, a belowground fire melting lead, uranium-235 foils, and sodium sources, and a complete rupture of the aboveground closed-loop cooling water system. Furthermore, this scenario assumes that this earthquake occurs during secondary beam generation, with saturation levels of radioactive and toxic gases in the 0° Cave, while experimenters are working belowground in the South Cave. The frequency of occurrence of this event is 10^{-6} to 10^{-4} per year.

An earthquake of sufficient magnitude to cause facility damage would certainly cause the failure of any of a number of key linear accelerator (LINAC) systems resulting in the immediate cessation of beam operation. The prompt radiation associated with beam operation would therefore cease, and there would be no risk of exposure of personnel inside or outside of the facility to lethal radiation levels.

The presence of special nuclear material (SNM) samples modestly increases the potential radiological impact of a design-basis earthquake and fire. The worst-case impact to the facility workers would involve a fire that released 3.4×10^{-4} curies of the sample (assumed to be weapons-grade plutonium) with the simultaneous failure of the ventilation system. All intense, prompt, and residual radiation would be completely contained within the belowground facility and no pathway would exist for exposure of or dispersal to aboveground personnel or to the environment. Noninvolved workers, the public, and the environment could be impacted by the release of radioactive materials. The release rate would be greatest if the ventilation system continued to function normally under emergency power. With the collapse of the 30-meter exhaust stack, the release would occur from a release height of 3 meters. The released quantities are summarized below in Table D.2.4.4–1.

TABLE D.2.4.4–1.—*Summary of Released Radiation Quantities, Building 194*

Radionuclide	Released Activity (Ci)
^{11}C	0.0012
^{13}N	0.047
^{15}O	0.903
Weapons-grade Plutonium	3.4×10^{-4}
Total	**0.952**

C = carbon; Ci = curies; O = oxygen; N = nitrogen.

D.2.4.5 *Building 235, 4-MeV Ion Accelerator—Exposure to Ionizing Radiation*

X-ray radiation due to the deceleration of secondary electrons and neutrons and gamma-ray radiation from bombardment of some materials by certain ions could pose a hazard to the personnel in the accelerator laboratory. The radiation level on the outside of the wall would be below LLNL design criterion of 0.25 millirem per hour during operation of the accelerator. The entrances to the accelerator enclosure are interlocked to ensure that any breaching of the interlocks turns off the equipment that produces the high acceleration voltages. The frequency of occurrence of this event is 10^{-4} to 10^{-2} per year.

Because of the accelerator enclosure and the alarmed and interlocked x-ray/gamma-ray and neutron detectors, exposures to ionizing radiation would be limited. The health and safety consequences would be negligible. This bounding accident scenario applies to the No Action Alternative, the Proposed Action, and the Reduced Operation Alternative of this LLNL SW/SPEIS.

D.2.4.6 *Building 239, Radiography Facility—Uncontrolled Oxidation of Plutonium at Elevated Temperatures (Weapons-Grade Plutonium)*

This bounding accident scenario applies to the No Action Alternative, the Proposed Action, and the Reduced Operation Alternative of this LLNL SW/SPEIS. In this scenario, the item is removed from its container and placed onto the table for radiography. While being removed, the item is rammed by a forklift, dropped while being carried by hand, or impacted by a failure of the overhead crane. The outer metal barrier becomes punctured, cracked, or fails completely. Air and moisture enter and react with the plutonium inside. Plutonium begins to oxidize and releases into the room. The released material mixes with the room air and 0.045 grams of weapons-grade plutonium is exhausted unfiltered from the ventilation system. The frequency of occurrence for this event is conservatively estimated to be less than 4.5×10^{-7} per year.

D.2.4.7 *Building 251, Heavy Element Facility—Evaluation Basis Fire*

In this scenario, falling debris in the aftermath of a major earthquake (> 0.57 *g* [where 1.0 *g* equals acceleration due to gravity]) is assumed to impact a rack that had previously fallen, crushing all underground storage vault containers and inner secondary containers, if any, to approximately half of their original volumes. A fire is assumed to be ignited in one of the waste drums that had been breached by the falling debris. The fire is assumed to spread to other drums and involve surface contaminated equipment. This bounding accident scenario applies to all the No Action Alternative, the Proposed Action, and the Reduced Operation Alternative of this LLNL SW/SPEIS.

The MAR for this scenario is 510 curies (americium-241 equivalent), which is assumed to be a powder. The airborne release fraction is assumed to be 5.3×10^{-4}, and the respirable fraction is 0.3. Therefore, the amount of material released to the environment is 0.081 curies (americium-241 equivalent). The frequency of occurrence of this event is 10^{-6} to 10^{-4} per year.

Airborne Release Fraction—The coefficient used to estimate the amount of a radioactive material that can be suspended in air and made available for airborne transport under a specific set of induced physical stresses. Applicable to events and situations that are completed during the course of the event.

Damage Ratio—The fraction of the MAR impacted by the accident-generated conditions.

Leak Path Factor—The fraction of airborne materials transported from containment or confinement deposition or filtration mechanism (e.g., fraction of airborne material in a glovebox leaving the glovebox under static conditions, fraction of material passing through a HEPA filter.)

Respirable Fraction—The fraction of airborne radionuclides as particles that can be transported through air and inhaled into the human respiratory system. This term is commonly assumed to include particles 10-µm Aerodynamic Equivalent Diameter and less.

D.2.4.8 *Building 331, Tritium Facility*

D.2.4.8.1 *Plutonium Metal Fire*

Actinide chemistry activities, including surface characterization, glow discharge mass spectrometry (GDMS), and elemental and isotopic analyses would be performed in three rooms of Building 331. Building 331 would receive metal samples contained in a GDMS cell or powdered samples pressed into indium and contained in a GDMS cell.

The powdered samples are pressed into indium and metal samples are contained in GDMS cells. No radioactive material spill or drop of metal or powder is considered, as there is no mechanism to cause the material to form an aerosol for distribution through the room and then to be transported to the environment. It is unlikely that a fire would be initiated within the building because flammable materials are kept to a minimum and within flameproof storage cabinets. In this scenario, it is assumed that 260 grams of fuel-grade equivalent plutonium are in the room. Using an airborne release fraction of 5×10^{-4} and a respirable fraction of 0.5 results in a release to the environment of 0.065 gram of fuel-grade plutonium. The frequency of occurrence for this event is 10^{-6} to 10^{-4} per year. This scenario represents the bounding accident for Building 331 under the No Action Alternative and Reduced Operation Alternative.

D.2.4.8.2 *Aircraft Crash with Subsequent Fire*

The total proposed tritium MAR for Building 331 under the Proposed Action is 30 grams of elemental tritium. At any given time, a portion of this inventory would be stored in uranium hydride beds and traps, while the tritium gas would be stored in containers with strict limits on quantity. For this scenario, the release of the total MAR of 30 grams of tritium gas (0.3 grams as HTO, tritiated water) was assumed.

It was assumed that an aircraft crash (single-engine piston aircraft) and subsequent gasoline pool fire occurred while a laboratory technician was opening or transferring the contents of a primary container holding 30 grams of tritium gas. All electrical power including emergency power was lost, shutting down the ventilation system. The glovebox was breached, allowing all of the tritium gas to enter the room. Because the roof in the room was damaged by the crash, tritium was released into the environment. All of the tritium is oxidized by fire into tritiated water. The ventilation system became inoperable, causing the tritium to be released at ground level instead of through the stack. The major impact to involved workers would have been injury or death from the crash or subsequent fire. These workers could have also been briefly exposed to tritiated water. The frequency of occurrence of this event was conservatively estimated to be 1.53×10^{-6} per year. This scenario represents the bounding accident for Building 331 under the Proposed Action.

D.2.4.9 *Building 332, Plutonium Facility*

D.2.4.9.1 *Aircraft Crash*

The principal threat to the gloveboxes and equipment in the room is expected to be from high velocity impacts of concrete shrapnel from a 30-inch radius, 10-inch-thick wall section created by impact of an aircraft. The flying concrete pieces may cause major damage in the room. There would be a range of types of concrete shrapnel, from low-velocity chunks falling off the walls or ceiling to small pieces of higher velocity. Gloveboxes in the impact path may sustain damage and possibly lose their confinement capacity but would not likely overturn, as they are robust and seismically restrained.

Because the general aviation aircraft engine is not expected to enter the room, the impacts of the concrete shrapnel are not expected to be of sufficient magnitude to credibly threaten the interior walls of the room. Thus, the maximum credible extent of the damage for this scenario is limited to a single room. All materials in the room would be threatened by the shrapnel and are assumed at risk. MAR estimates and release fractions were calculated using the factors of damage ratio, airborne release fraction, respirable fraction, and leak path factor. This analysis concluded that the largest source term for the No Action Alternative would be 0.25 grams of 30-year-old fuel-grade plutonium. The frequency of occurrence for this event is conservatively estimated to be 4.86×10^{-6} per year. This scenario represents the bounding accident for Building 332 under the No Action Alternative and Reduced Operation Alternatives.

D.2.4.9.2 *Evaluation-Basis Room Fire (Unfiltered)*

A an evaluation-basis room fire is postulated to be of sufficient magnitude that the entire room is threatened, that all of the radioactive MAR within the room is engulfed in the fire, and the fire burns long enough to release the material from storage containers to the glovebox, room, and the environment.

A fire in a room would most likely be initiated by human error. Potential ignition sources such as oxygen and fuel in the form of plastics, paper products, and wood are presumed to be present in the room. Fires caused by human error are minimized by control of both ignition sources and combustibles. Nevertheless, fewer failures are needed for fires caused by human error than for any other postulated initiator. A room fire caused by human error can be the result of procedural violation, carelessness, or misuse of power tools, to name a few.

Mechanical failure as the cause of the evaluation-basis room fire is less likely than human error because installation and inherent construction requirements minimize the potential for fire initiation and propagation. Experience at LLNL and other facilities indicates that equipment fires initiated by electrical faults generate smoke from smoldering or burning cable insulation and other plastics. This type of fire is quickly detected by facility workers or smoke detectors, and is readily extinguished by facility workers or responding emergency personnel.

The building structure is capable of containing a room fire of at least 1-hour severity for the radioactive material area (RMA) walls. The combustible loading within the RMA is maintained at a low level. Because of the robust nature of the construction of the building structure and the typical fire loads characteristic of building operations, no credible mechanisms were identified that would lead to a fire spreading beyond the specific room where the fire started.

The MAR in any room, excluding the vaults, was assumed to be the entire MAR limit of 20 kilograms of 30-year-old fuel-grade plutonium for the No Action Alternative and 60 kilograms of 30-year-old fuel-grade plutonium for the Proposed Action. This includes material in waste containers in RMA rooms and in the basement. Because most processes in any of the laboratories in Building 332 involve solid forms of plutonium, the airborne release fraction in a fire is assumed to be 5×10^{-4}. An appropriate respirable fraction is 0.5. A damage ratio of 1.0 is assumed.

If the room ventilation system exhaust and supply fans are inoperable, the air in the building will become stagnant with only very small pressure differences between the corridor and the environment, the rooms and the corridor, and the rooms and the gloveboxes. The primary unfiltered pathways for material to escape to the environment will be through the cracks around the RMA exit doors and possible by reverse flow through the room ventilation system supply ducting. The leak path factor for this case is bounded by a value of 0.05. Therefore the total release to the environment is 0.25 grams of 30-year-old fuel-grade plutonium for the No Action Alternative and 0.75 grams of 30-year-old fuel-grade plutonium for the Proposed Action. The frequency of this event is 3.9×10^{-7} per year. This scenario represents the bounding accident for Building 332 for the Proposed Action.

D.2.4.10 *Building 334, Hardened Engineering Test Building—Uncontrolled Oxidation of Plutonium at Elevated Temperatures*

Components containing SNM may be brought into the facility for nondestructive testing and measurements. SNM components are not stored in the facility, but are shipped back out of the facility once the testing and measurements are completed.

The potential exists for a fire to occur while a gasoline-powered vehicle is in the building. However, because test items are required to be in shipping containers when there is a fossil fuel-powered vehicle in the building and because the shipping containers are built to survive transport accidents including fire, the test items would be unaffected.

For items containing plutonium, there is no credible accident in which a fire could occur to engulf plutonium because the material is not packaged with any other significant amount of combustible material.

The concern with plutonium is an accident wherein the components' metal casing could be breached. If a component is dropped, rammed with a forklift, or crushed in an accident, the material inside could be exposed to the atmosphere. Subsequent room temperature oxidation would then release plutonium oxide into the area. In this uncontrolled oxidation scenario, the item is removed from its shipping container. While being removed, the item is rammed by a forklift, dropped while being hand-carried, or impacted by a failure of the overhead crane. The outer metal barrier is damaged. Air and moisture enter and react with the plutonium inside. Plutonium begins to oxidize and plutonium oxide is released into the room. The released material mixes with the room air and is exhausted by the ventilation system. The source term is calculated as 0.185 grams. The frequency of this event is conservatively estimated to be less than 1×10^{-6} per year. This bounding accident scenario applies to the No Action Alternative, the Proposed Action, and the Reduced Operation Alternative of this LLNL SW/SPEIS.

D.2.4.11 *Buildings 514/612/625/693, Radioactive and Hazardous Waste Management Complex—Aircraft Crash into Building 625*

The potential for a general aviation aircraft crash into Building 625 was considered. For an aircraft crash impacting Building 625, the most likely scenario would be an aircraft crashing into the building structure with subsequent gasoline pool fire. To determine the MAR for this scenario, the analysis considered the geometry of stored waste drums at Building 625 Radiological and Hazardous Waste Storage Facility, the effective area of an aircraft engine, and the potential size of the gasoline pool fire.

The calculated annual frequency of an aircraft crashing into the building structure with subsequent gasoline pool fire is 6.1×10^{-7}, which is less frequent than once in a million years. The aircraft accident scenario evaluated at Building 625 is very conservative in that it assumes the facility is loaded to its physical limit with containers of transuranic waste loaded to their maximum curie limit. The maximum curie limit under the Proposed Action is equivalent to an array of drums where one drum contains 60 plutonium-equivalent curies and the other surrounding drums contain 12 plutonium-equivalent curies. It is planned that by the end of 2005, all legacy transuranic waste drums in Building 625 would be shipped to the Waste Isolation Pilot Plant (WIPP). It is projected that waste shipments to WIPP would be completed before Building 625 and other LLNL transuranic waste storage facilities are fully loaded. Therefore, the consequences discussed above are associated with what would be considered a maximum peak inventory in Building 625 that would be allowed under the facilities operational procedures but may never occur.

It is anticipated that drums containing up to 60 plutonium-equivalent curies would be stored in Building 625. For the purpose of this analysis, the assumed inventory in the remaining involved drums is 12 plutonium-equivalent curies each. The number of failed drums from the aircraft crash and subsequent gasoline pool fire would correspond to the area of the gasoline pool. Drums are stored on pallets that measure 4 feet by 4 feet. Pallets, each with four drums, can be stacked two high. In addition, there is a 30-inch separation between rows of stacked drums. Dimensions of a general aviation aircraft engine are assumed to be approximately 36 inches by 20 inches.

For conservatism, it is assumed that the initial direct impact leads to penetration through the structure of Building 625 and catastrophic failure of a total of four drums on two stacked pallets (i.e., two drums per pallet) (LLNL 2003y). One of the four impacted drums is postulated to be a 60 plutonium-equivalent-curies drum. For those drums directly impacted by the engine, the product of the airborne release fraction and respirable fraction (ARF × RF) is assumed to be 1 percent (0.01). This value represents a standard value for drums subjected to impact followed by fire. The damage ratio (DR) and leak path factor (LPF) are both conservatively assumed to be 1. Therefore, for those drums directly impacted by the general aviation aircraft engine, the source term is as follows:

(1 drum)(60 plutonium-equivalent curies)(0.01)(1)(1) = 0.6 plutonium-equivalent curies

(3 drums)(12 plutonium-equivalent curies)(0.01)(1)(1) = 0.36 plutonium-equivalent curies

The equivalent diameter of the gasoline pool fire is 10 feet. Based on the pallet dimensions and the required 30-inch spacing between pallets, a total of 25 drums can be engulfed in the gasoline pool fire with an ARF × RF of 0.01. The catastrophic drum failure rate of 20 percent is assumed, from which 50 percent of the content is assumed to be expelled. Additionally, five other drums would fail from the engulfing fire with an ARF × RF of 5×10^{-4}. Of these five additional drums, 50 percent of the content is assumed to be expelled. A total of 36 additional drums within the dimensions of the gasoline pool fire are assumed to not have failed catastrophically, but to fail by lid seal failure leading to a release with an ARF × RF of 5×10^{-4}. The assumed DR for these 36 drums is 0.6 (LLNL 2003y). Therefore, the source term for the drums indirectly impacted is as follows:

(25 drum)(0.2)(12 plutonium-equivalent curies)(0.01)(0.5)(1) = 0.3 plutonium-equivalent curies

(5 drums)(12 plutonium-equivalent curies)(5×10^{-4})(0.5)(1) = 0.015 plutonium-equivalent curies

(36 drums)(12 plutonium-equivalent curies)(5×10^{-4})(0.6)(1) = 0.13 plutonium-equivalent curies

Thus, the total source term for the Proposed Action is:

0.6 curies + 0.36 curies + 0.3 curies + 0.015 curies + 0.13 curies = 1.40 plutonium-equivalent curies

The source term for the No Action Alternative and Reduced Operation Alternative is 0.46 plutonium-equivalent curies.

The peak heat release rate from a fire involving a full tank of gasoline (90 gallons) is 18.4 megawatts (LLNL 2003y). Because fire occurs inside the structure, the ambient heat loss to the surrounding walls must be accounted for in computing the plume sensible heat. For conservatism, the total heat loss to the environment, including the conduction loss to the structure is assumed to be 75 percent. Therefore, the plume sensible heat (a MACCS2 input) is 4.6 megawatts (18.4 megawatts × 0.25).

D.2.4.12 *Building 581, National Ignition Facility—Earthquake During Plutonium Experiment Without Yield*

The initiating event for this scenario is a severe earthquake. The event considers an earthquake of frequency 10^{-4} per year (~ 1 *g* horizontal ground acceleration) occurring at the time of a maximum credible yield experiment. Assuming 10 nonyield experiments per year, the estimated frequency of the accident is 2×10^{-8} per year, assuming a 1 minute window for the earthquake. Tritium sources located outside the target bay in the Laser and Target Area Building (LTAB) would also be vulnerable to release. These primarily include tritium in elemental form as stored targets or on the cryopumps, or tritium as oxide on the molecular sieve of the tritium processing system.

The target building has been shown by analysis to withstand a severe earthquake, but other areas and components have not been analyzed beyond their design basis. The beam tubes leading from the switchyard into the target chamber are assumed to fail in the proposed earthquake. The switchyards may sustain the earthquake, but are conservatively assumed to collapse. Components of the tritium processing system may be compromised and the area could be flooded by water released from failed water supply piping. Further, natural gas piping in areas of the LTAB outside the target bay could cause localized fires if damaged under these extreme conditions.

For inventories in the target bay, a pathway out to the environment is created through the beam tube penetrations in the target bay walls. Airborne activity in the target bay would be swept out to the environment by wind blowing through this volume. The wind is assumed to blow in through the penetrations on one side of the target bay, and out through the penetrations on the opposite side.

Radioactive inventories vulnerable to release under the Proposed Action include activated gases; activated particulate in the target chamber; tritium; and for fissile/fissionable materials, the source material (and for yield experiments, associated fission products). For the Proposed Action, there would be no change in the activated gas or tritium source terms. The activated particulate inventory in the target chamber would change based on the new materials proposed. In addition to the target chamber particulate, gaseous and semivolatile fission products would be present immediately after the experiments and would be vulnerable to release. Alternately, inventories from tracers that are part of the Proposed Action could also be present. Plutonium shots would add additional radioisotopes including weapons-grade plutonium and, for experiments with yield, associated fission products and activated particulates. These source terms would not all be simultaneously present.

The type of experiment that produces the largest offsite consequences under the Proposed Action is the plutonium experiment without yield. In this experiment, the quantity of target material present in the container is 3 grams of weapons-grade plutonium. It is assumed that this material would be subject to a release fraction of 1×10^{-3}, resulting in a release to the environment of 0.003 grams of weapons-grade plutonium (LLNL 2003d).

D.2.4.13 *Building 696R, Radioactive Waste Storage Area—Aircraft Crash*

For an aircraft crash impacting Building 696R, the most likely scenario would result in an aircraft crashing into the building structure with a subsequent gasoline pool fire. To determine the MAR for this scenario, the analysis considered the geometry of stored waste drums at Building 696R, the effective area of an aircraft engine, and the potential size of the gasoline pool fire.

The aircraft accident scenario evaluated at Building 696R is conservative in that it assumes the facility is loaded to its physical limit with containers of transuranic waste and that each container is loaded to the maximum curie limit. Given the plans to ship current and newly generated transuranic waste to the WIPP for disposal, the consequences would be associated with what would be considered an interim peak inventory for Building 696R.

For the purpose of this analysis, the inventory in the Building 696R drums is conservatively assumed to be 12 plutonium-equivalent curies each and the drums are assumed to be stacked two high. The number of failed 55-gallon drums from the aircraft crash and subsequent gasoline pool fire would correspond to the area of the gasoline pool. Drums are stored on pallets that measure 4 feet by 4 feet. Pallets, each with four drums, can be stacked two high. In addition, there is a 30-inch separation between rows of stacked drums. Dimensions of a general aviation aircraft engine are approximately 36 inches by 20 inches.

For conservatism, it is assumed that the initial direct impact leads to penetration through the structure of Building 696R and catastrophic failure of a total of four drums on two stacked pallets (i.e., two drums per pallet) (LLNL 2003y). For those drums directly impacted by the engine, the product of the ARF × RF is assumed to be 1 percent (0.01). This value represents a standard value for drums subjected to impact followed by fire. The damage ration and leak path factor are both conservatively assumed to be 1. Therefore, for those drums directly impacted by the engine, the source term is as follows:

> (4 drums)(12 plutonium-equivalent curies)(0.01)(1)(1) = 0.48 plutonium-equivalent curies

The equivalent diameter of the gasoline pool is 10 feet. Based on the pallet dimensions and the required 30-inch spacing between pallets, a total of 25 drums can be engulfed in the gasoline pool fire (with an ARF × RF of 0.01). The catastrophic drum failure rate of 20 percent is assumed, from which 50 percent of the content is assumed to expelled. Additionally, five other drums would fail from the engulfing fire (with an ARF × RF of 5×10^{-4}). Of these five additional drums, 50 percent of the content is assumed to be expelled. A total of 36 additional drums within the dimensions of the pool fire are assumed to not have failed catastrophically, but to fail by lid seal failure leading to a release with an ARF × RF of 5×10^{-4}. The assumed damage ratio for these 36 drums is 0.6 (LLNL 2003y). Therefore, the source term for indirectly impacted drums is as follows:

> (25 drum)(0.2)(12 plutonium-equivalent curies Ci)(0.01)(0.5)(1) = 0.3 plutonium-equivalent curies

(5 drums)(12 plutonium-equivalent curies)(5×10^{-4})(0.5)(1) = 0.015 plutonium-equivalent curies

(36 drums)(12 plutonium-equivalent curies)(5×10^{-4})(0.6)(1) = 0.13 plutonium-equivalent curies

Thus, the total source term is:

0.48 curies + 0.3 curies + 0.015 curies + 0.13 curies = 0.925 plutonium-equivalent curies

The peak heat release rate from a fire involving a full tank of gasoline (90 gallons) is 18.4 megawatts (LLNL 2003y). Because fire occurs inside the structure, the ambient heat loss to the surrounding walls must be accounted for in computing the plume sensible heat. For conservatism, the total heat loss to the environment, including the conduction loss to the structure is assumed to be 75 percent. Therefore, the plume sensible heat (a MACCS2 input) is 4.6 megawatts (18.4 megawatts × 0.25). The frequency of occurrence of this event is 6.29×10^{-7} per year. This bounding accident scenario applies to the No Action Alternative, the Proposed Action, and the Reduced Operation Alternative of this LLNL SW/SPEIS.

D.2.4.14 *Site 300 Materials Management Facilities—Depleted Uranium Release by Fire*

Depleted uranium is stored in Site 300 Controlled Materials Group facilities. The causes of a fire that releases depleted uranium could include human error in using materials handling equipment, fire in the storage magazine, natural phenomenon such as a lightning strike, or accidental detonation of explosives in a neighboring magazine. The most probable initiating cause of a depleted uranium release is the penetration of a storage bay and a container by a fragment from an explosion at a remote high explosives machining operation.

A magazine fire involving test assemblies could result in the exposure of worksite and other Site 300 personnel to fumes from the smoke. However, because personnel are not allowed in the area during a remote operation and do not approach a structure that is in flames, the actual probability of onsite exposure is low. The frequency of this event is mitigated by the strict control of ignition sources and fuel loadings in the facilities. These controls are extremely effective because depleted uranium does not burn well when in solid form. In addition, this material is packaged in its shipping container, which protects the material from ignition from the outside and limits the access to oxygen if a fire is ignited, which tends to snuff out the fire or at least slow its rate of burn. Approximately 0.95 grams per second is released for 2 hours, for a total of 6,840 grams of depleted uranium assumed to be released in this scenario. The frequency of this event is 10^{-4} to 10^{-2} per year. This bounding accident scenario applies to the No Action Alternative, the Proposed Action, and the Reduced Operation Alternative of this LLNL SW/SPEIS.

D.2.4.15 *Onsite Transportation—Materials Management Section Package Explosion*

The Materials Management Section (MMS) explosion scenario is characterized by an internal hydrogen deflagration occurring inside the MMS transfer package exposing the material inside the package to the blast effects of the deflagration. It is assumed that the explosion results in breach of the confining and containing barriers of the MMS transfer package on the transfer vehicle. This allows the potential release of the radioactive materials in the package. This bounding accident applies to the No Action Alternative, the Proposed Action, and the Reduced Operation Alternative of this LLNL SW/SPEIS.

The MMS explosion scenario is a representative event included to determine the impact of an internal explosion on the MMS transfer package. The event involves an internal explosion in the MMS transfer package originating from the deflagration of hydrogen. The hydrogen in the package is generated by radiolytic decomposition of any moisture in the material inside the package. Once flammable levels of hydrogen are reached, an ignition source such as a spark generated by metal-to-metal contact is assumed to occur. This results in a deflagration of the hydrogen. The deflagration causes an increase in the internal pressure of the package, resulting in package failure. The radioactive material inside the package is then exposed to the forces generated by pressurized venting of the package. In addition, it is assumed that after the deflagration and package failure, the contents of the package are exposed to aerodynamic entrainment for 2 hours. The frequency of occurrence of this event is conservatively estimated to be less than 1×10^{-6} per year.

The MAR for the MMS explosion is 50 grams of 30-year-old fuel-grade equivalent plutonium in the form of plutonium oxide powder. There are two components to the release of plutonium from this event: pressurized venting stress and aerodynamic entrainment stress. The source term for the pressurized venting stress component is 0.1 grams fuel-grade equivalent plutonium, with a release duration of 3 minutes. For the aerodynamic entrainment stress component, the source term is 0.004 grams fuel-grade equivalent plutonium with a release duration of 2 hours. This release is assumed to occur 800 meters from the closest site boundary.

D.2.5 Estimated Health Effects

Tables D.2.5–1 and D.2.5–2 show the frequencies and consequences of the postulated set of accidents for the Proposed Action and the No Action Alternative for a noninvolved worker, the population of noninvolved workers, and the public (offsite maximally exposed individual [MEI] and the general population living within 50 miles of LLNL) for both median and unfavorable meteorological conditions. These tables show both the radiation dose (collective dose) and the number of LCFs for the offsite population and the population of noninvolved workers. For the MEI and the individual noninvolved worker, these tables show radiation dose and the probability of an LCF, which is calculated using the same dose-to-risk conversion factor of 6×10^{-4} per person-rem as for the population doses. The results for the Reduced Operation Alternative are the same as for the No Action Alternative. The median meteorological conditions are presented to provide an indication of the average consequences, while the unfavorable are presented to give an indication of the unfavorable consequences. The results for the unfavorable meteorological conditions can also be used for comparison with LLNL safety documents.

For median meteorological conditions, the accident with the highest consequence to the offsite population (see Table D.2.5–1) is an aircraft crash into Building 625. The collective radiation dose to the approximately 6,900,000 people living within 50 miles of LLNL under median meteorological conditions was calculated to be approximately 2,020 person-rem. Using the dose-to-risk conversion factor of 6×10^{-4} per person-rem, the collective population dose is estimated to result in an additional 1.2 LCFs to this population.

For the noninvolved worker, the accident with the largest dose is an evaluation-basis fire in Building 251. The radiation dose under median meteorological conditions would be 5.7 rem at a distance of 100 meters. Using the dose-to-risk conversion factor of 6×10^{-4} LCFs per person-rem, the 100-meter dose has a probability of 3.42×10^{-3} (or one chance in 292) of the development of a fatal cancer.

For the population of noninvolved workers, the accident with the highest collective radiation dose is a room fire (unfiltered) in Building 332. The collective radiation dose to this noninvolved worker population under median meteorological conditions is 930 person-rem. Using the dose-to-risk conversion factor of 6×10^{-4} per person-rem, the collective noninvolved worker dose is estimated to result in an additional 0.56 LCFs in this population.

For the MEI, the accident with the highest dose is an aircraft crash into the Building 696R. The radiation dose at the site boundary nearest to the release (140 meters from the release point) under median meteorological conditions is 0.86 rem. Using the dose-to-risk conversion factor of 6×10^{-4} per person-rem, the MEI dose has a probability of 5.17×10^{-4} (or one chance in 1,934) of the development of a fatal cancer.

For the unfavorable meteorological conditions, the accident with the highest consequences to all receptors other than the noninvolved worker population is the aircraft crash into Building 625. The offsite collective dose to the approximately 6,900,000 people within 50 miles of LLNL for this accident was calculated to be 17,640 person-rem. Using the dose-to-risk conversion factor of 6×10^{-4} per person-rem, the collective population dose is estimated to result in an additional 10.6 LCFs to this population.

For the noninvolved worker, the radiation dose for the aircraft into Building 625 under unfavorable meteorological conditions would be 82.3 rem at a distance of 100 meters. Using the dose-to-risk conversion factor of 6×10^{-4} per person-rem, the 100-meter dose has a probability of 0.049 (or one chance in 20) of the development of a fatal cancer.

The radiation dose at the site boundary nearest to the release (250 meters east of the release point) for the aircraft into Building 625 under unfavorable meteorological conditions is 23.1 rem. Using the dose-to-risk conversion factor of 6×10^{-4} per person-rem, the MEI dose has a probability of 0.014 (or one chance in 72) of the development of a fatal cancer.

For the population of noninvolved workers, the accident with the highest collective dose is a room fire (unfiltered) in Building 332. The collective radiation dose to this noninvolved worker population under unfavorable meteorological conditions is 7,800 person-rem. Using the dose-to-risk conversion factors of 6×10^{-4} per person-rem, the collective noninvolved worker dose is estimated to result in an additional 4.7 LCFs in this population.

TABLE D.2.5–1.—*Potential Accident Frequency and Consequences (Median Meteorology)*[a]

			MEI		Offsite Population[b]		Individual Noninvolved Worker		Noninvolved Worker Population	
Building	**Accident**	**Frequency (per year)**	**Dose (rem)**	**LCFs[c]**	**Dose (person-rem)**	**LCFs[d]**	**Dose (rem)**	**LCFs[c]**	**Dose (person-rem)**	**LCFs[d]**
Building 191	Radioactive material dispersion from a spill and fire - No Action	$<10^{-6}$	3.32×10^{-5}	1.99×10^{-8}	4.70×10^{-3}	2.82×10^{-6}	7.23×10^{-5}	4.34×10^{-8}	9.72×10^{-3}	5.83×10^{-6}
	Radioactive material dispersion from a spill and fire - Proposed Action	$<10^{-6}$	Same	Same	Same	Same	Same	Same	Same	Same
Building 194	Design-basis earthquake and fire - No Action	10^{-6} to 10^{-4}	8.66×10^{-4}	5.20×10^{-7}	2.23×10^{-1}	1.34×10^{-4}	3.43×10^{-3}	2.06×10^{-6}	5.83×10^{-1}	3.50×10^{-4}
	Design-basis earthquake and fire-Proposed Action	10^{-6} to 10^{-4}	Same	Same	Same	Same	Same	Same	Same	Same
Building 239	Uncontrolled oxidation of plutonium at elevated temperature - No Action	$<4.5 \times 10^{-7}$	1.73×10^{-2}	1.04×10^{-5}	6.49	3.89×10^{-3}	2.47×10^{-1}	1.48×10^{-4}	2.59×10^{1}	1.55×10^{-2}
	Uncontrolled oxidation of plutonium at elevated temperature - Proposed Action	$<4.5 \times 10^{-7}$	Same	Same	Same	Same	Same	Same	Same	Same
Building 251	Evaluation basis fire - No Action	10^{-6} to 10^{-4}	6.01×10^{-1}	3.61×10^{-4}	1.88×10^{2}	1.13×10^{-1}	5.70	3.42×10^{-3}	8.26×10^{2}	4.96×10^{-1}
	Evaluation basis fire - Proposed Action	10^{-6} to 10^{-4}	Same	Same	Same	Same	Same	Same	Same	Same
Building 331	Plutonium Metal Fire - No Action	10^{-6} to 10^{-4}	5.02×10^{-2}	3.01×10^{-5}	2.39×10^{1}	1.43×10^{-2}	6.40×10^{-1}	3.84×10^{-4}	8.95×10^{1}	5.37×10^{-2}
	Aircraft crash with subsequent fire - Proposed Action	1.53×10^{-6}	1.63×10^{-1}	9.78×10^{-5}	1.13×10^{2}	6.78×10^{-2}	2.11	1.27×10^{-3}	2.73×10^{2}	1.64×10^{-1}
Building 332	Aircraft Crash - No Action	4.86×10^{-6}	1.48×10^{-1}	8.85×10^{-5}	9.70×10^{1}	5.82×10^{-2}	1.84	1.10×10^{-3}	3.18×10^{2}	1.91×10^{-1}
	Room Fire Unfiltered - Proposed Action	3.90×10^{-7}	4.40×10^{-1}	2.64×10^{-4}	2.80×10^{2}	1.68×10^{-1}	4.94	2.96×10^{-3}	9.30×10^{2}	5.58×10^{-1}

TABLE D.2.5–1.—*Potential Accident Frequency and Consequences (Median Meteorology) (continued)*[a]

			MEI		Offsite Population[b]		Individual Noninvolved Worker		Noninvolved Worker Population	
Building	**Accident**	**Frequency (per year)**	**Dose (rem)**	**LCFs[c]**	**Dose (person-rem)**	**LCFs[d]**	**Dose (rem)**	**LCFs[c]**	**Dose (person-rem)**	**LCFs[d]**
Building 334	Uncontrolled oxidation of plutonium at elevated temperatures - No Action	$< 1.00 \times 10^{-6}$	1.64×10^{-1}	9.84×10^{-5}	6.80×10^{1}	4.08×10^{-2}	3.25	1.95×10^{-3}	2.31×10^{2}	1.39×10^{-1}
	Uncontrolled oxidation of plutonium at elevated temperatures - Proposed Action	$< 1.00 \times 10^{-6}$	Same	Same	Same	Same	Same	Same	Same	Same
Building 581	Earthquake - No Action	2.00×10^{-8}	4.78×10^{-4}	2.87×10^{-7}	1.96×10^{-1}	1.18×10^{-4}	1.43×10^{-3}	8.60×10^{-7}	2.08×10^{-1}	1.25×10^{-4}
	Earthquake during plutonium experiment without yield - Proposed Action	2.00×10^{-9}	1.65×10^{-3}	9.89×10^{-7}	5.46×10^{-1}	3.28×10^{-4}	4.99×10^{-3}	3.00×10^{-6}	7.41×10^{-1}	4.45×10^{-4}
Building 625	Aircraft Crash - No Action	6.10×10^{-7}	2.39×10^{-1}	1.43×10^{-4}	6.62×10^{2}	3.97×10^{-1}	6.49×10^{-1}	3.89×10^{-4}	3.04×10^{1}	1.82×10^{-2}
	Aircraft Crash - Proposed Action	6.10×10^{-7}	7.27×10^{-1}	4.36×10^{-4}	2.02×10^{3}	1.21	1.97	1.18×10^{-3}	9.24×10^{1}	5.54×10^{-2}
Building 696R	Aircraft Crash - No Action	6.29×10^{-7}	8.61×10^{-1}	5.17×10^{-4}	1.29×10^{3}	7.71×10^{-1}	1.39	8.33×10^{-4}	8.33×10^{1}	5.00×10^{-2}
	Aircraft Crash - Proposed Action	6.29×10^{-7}	Same	Same	Same	Same	Same	Same	Same	Same
Site 300 Materials Management Facilities	Depleted uranium release by fire - No Action	10^{-4} to 10^{-2}	3.93×10^{-4}	2.36×10^{-7}	3.81×10^{-1}	2.29×10^{-4}	3.94×10^{-2}	2.36×10^{-5}	9.42×10^{-2}	5.65×10^{-5}
	Depleted uranium release by fire - Proposed Action	10^{-4} to 10^{-2}	Same	Same	Same	Same	Same	Same	Same	Same
Onsite Transportation	Materials Management Section package explosion - No Action	$< 1.00 \times 10^{-6}$	1.16×10^{-1}	6.96×10^{-5}	4.01×10^{1}	2.41×10^{-2}	2.79	1.67×10^{-3}	1.71×10^{2}	1.03×10^{-1}
	Materials Management Section package explosion - Proposed Action	$< 1.00 \times 10^{-6}$	Same	Same	Same	Same	Same	Same	Same	Same

Source: Original.
[a] The consequences for the Reduced Operation Alternative would be the same as for the No Action Alternative.
[b] Based on the population of approximately 6,900,000 persons residing within 50 miles of LLNL.
[c] Increased likelihood of a latent cancer fatality.
[d] Increased number of latent cancer fatalities (LCFs).

TABLE D.2.5–2.—*Potential Accident Frequency and Consequence (Unfavorable Meteorology)*[a]

			MEI		Offsite Population[b]		Individual Noninvolved Worker		Noninvolved Worker Population	
Building	**Accident**	**Frequency (per year)**	**Dose (rem)**	**LCFs[c]**	**Dose (person-rem)**	**LCFs[d]**	**Dose (rem)**	**LCFs[c]**	**Dose (person-rem)**	**LCFs[d]**
Building 191	Radioactive material dispersion from a spill and fire - No Action	$<10^{-6}$	4.25×10^{-4}	2.55×10^{-7}	4.20×10^{-2}	2.52×10^{-5}	7.14×10^{-4}	4.28×10^{-7}	6.96×10^{-2}	4.18×10^{-5}
	Radioactive material dispersion from a spill and fire - Proposed Action	$<10^{-6}$	Same	Same	Same	Same	Same	Same	Same	Same
Building 194	Design-basis earthquake and fire - No Action	10^{-6} to 10^{-4}	1.30×10^{-2}	7.80×10^{-6}	1.81	1.09×10^{-3}	3.30×10^{-2}	1.98×10^{-5}	3.47	2.08×10^{-3}
	Design-basis earthquake and fire- Proposed Action	10^{-6} to 10^{-4}	Same	Same	Same	Same	Same	Same	Same	Same
Building 239	Uncontrolled oxidation of plutonium at elevated temperature - No Action	$<4.5 \times 10^{-7}$	3.68×10^{-1}	2.21×10^{-4}	1.02×10^{2}	6.12×10^{-2}	2.97	1.78×10^{-3}	2.02×10^{2}	1.21×10^{-1}
	Uncontrolled oxidation of plutonium at elevated temperature - Proposed Action	$<4.5 \times 10^{-7}$	Same	Same	Same	Same	Same	Same	Same	Same
Building 251	Evaluation basis fire - No Action	10^{-6} to 10^{-4}	1.18×10^{1}	7.10×10^{-3}	1.22×10^{3}	7.34×10^{-1}	6.46×10^{1}	3.88×10^{-2}	4.52×10^{3}	2.71
	Evaluation basis fire - Proposed Action	10^{-6} to 10^{-4}	Same	Same	Same	Same	Same	Same	Same	Same
Building 331	Plutonium Metal Fire - No Action	10^{-6} to 10^{-4}	9.98×10^{-1}	5.99×10^{-4}	3.85×10^{2}	2.31×10^{-1}	7.52	4.51×10^{-3}	6.70×10^{2}	4.02×10^{-1}
	Aircraft crash with subsequent fire - Proposed Action	1.53×10^{-6}	3.26	2.28×10^{-4}	1.56×10^{3}	1.10×10^{-1}	2.55×10^{1}	1.79×10^{-3}	2.05×10^{3}	1.44×10^{-1}
Building 332	Aircraft Crash - No Action	4.86×10^{-6}	2.89	1.73×10^{-3}	1.19×10^{3}	7.14×10^{-1}	2.36×10^{1}	1.42×10^{-2}	2.53×10^{3}	1.52
	Room Fire Unfiltered - Proposed Action	3.90×10^{-7}	8.40	5.04×10^{-3}	3.26×10^{3}	1.95	4.46×10^{1}	2.68×10^{-2}	7.80×10^{3}	4.68

TABLE D.2.5–2.—*Potential Accident Frequency and Consequences (Unfavorable Meteorology) (continued)*[a]

			MEI		Offsite Population[b]		Individual Noninvolved Worker		Noninvolved Worker Population	
Building	**Accident**	**Frequency (per year)**	**Dose (rem)**	**LCFs[c]**	**Dose (person-rem)**	**LCFs[d]**	**Dose (rem)**	**LCFs[c]**	**Dose (person-rem)**	**LCFs[d]**
Building 334	Uncontrolled oxidation of plutonium at elevated temperatures - No Action	$<1.00 \times 10^{-6}$	3.68	2.21×10^{-3}	1.03×10^{3}	6.18×10^{-1}	4.39×10^{1}	2.63×10^{-2}	2.08×10^{3}	1.25
	Uncontrolled oxidation of plutonium at elevated temperatures - Proposed Action	$<1.00 \times 10^{-6}$	Same	Same	Same	Same	Same	Same	Same	Same
Building 581	Earthquake - No Action	2.00×10^{-8}	6.15×10^{-3}	3.69×10^{-6}	3.05	1.83×10^{-3}	1.33×10^{-2}	8.01×10^{-6}	2.22	1.33×10^{-3}
	Earthquake during plutonium experiment without yield - Proposed Action	2.00×10^{-9}	2.16×10^{-2}	1.30×10^{-5}	8.33	5.00×10^{-3}	4.69×10^{-2}	2.82×10^{-5}	8.23	4.94×10^{-3}
Building 625	Aircraft Crash - No Action	6.10×10^{-7}	7.59	4.55×10^{-3}	5.80×10^{3}	3.48	2.70×10^{1}	1.62×10^{-2}	6.44×10^{2}	3.86×10^{-1}
	Aircraft Crash - Proposed Action	6.10×10^{-7}	2.31×10^{1}	1.39×10^{-2}	1.76×10^{4}	1.06×10^{1}	8.23×10^{1}	4.94×10^{-2}	1.96×10^{3}	1.18
Building 696R	Aircraft Crash - No Action	6.29×10^{-7}	1.66×10^{1}	9.93×10^{-3}	1.06×10^{4}	6.38	2.16×10^{1}	1.30×10^{-2}	1.73×10^{3}	1.04
	Aircraft Crash - Proposed Action	6.29×10^{-7}	Same	Same	Same	Same	Same	Same	Same	Same
Site 300 Materials Management Facilities	Depleted uranium release by fire - No Action	10^{-4} to 10^{-2}	7.89×10^{-3}	4.73×10^{-6}	2.60	1.56×10^{-3}	6.27×10^{-1}	3.76×10^{-4}	5.50×10^{-1}	3.30×10^{-4}
	Depleted uranium release by fire - Proposed Action	10^{-4} to 10^{-2}	Same	Same	Same	Same	Same	Same	Same	Same
Onsite Transportation	Materials Management Section package explosion - No Action	$<1.00 \times 10^{-6}$	2.76	1.66×10^{-3}	6.50×10^{2}	3.90×10^{-1}	5.32×10^{1}	3.19×10^{-2}	1.02×10^{3}	6.12×10^{-1}
	Materials Management Section package explosion - Proposed Action	$<1.00 \times 10^{-6}$	Same	Same	Same	Same	Same	Same	Same	Same

Source: Original.
[a] The consequences for the Reduced Operation Alternative would be the same as for the No Action Alternative.
[b] Based on the population of approximately 6,900,000 persons residing within 50 miles of LLNL.
[c] Increased likelihood of a latent cancer fatality.
[d] Increased number of latent cancer fatalities (LCFs).

Involved Worker Impacts

Workers in the facility where the accident occurs would be particularly vulnerable to the effects of the accident because of their location. For all of the accidents, there is a potential for injury or death to involved workers in the vicinity of the accident. However, prediction of latent potential health effects becomes increasingly difficult to quantify for facility workers as the distance between the accident location and the worker decreases. This is because the individual worker exposure cannot be precisely defined with respect to the presence of shielding and other protective features. The worker also may be injured or killed by physical effects of the accident itself.

The facility ventilation system would control dispersal of the airborne radiological debris from the accident. Following initiation of accident/site emergency alarms, workers would evacuate the area in accordance with site emergency operating procedures and would not be vulnerable to additional radiological injury.

The bounding case radiological accident for involved workers is a plutonium criticality for a powder, slurry, or solution system in a workstation in Building 332. Severe worker exposures could occur inside the facility as a result of a criticality, due primarily to the effects of prompt neutrons and gammas. A criticality would be detected by the criticality alarm system, and an evacuation alarm would sound. All personnel would immediately evacuate the building.

Personnel close to the criticality event within the building may incur prompt external exposures. Depending on distance and the amount of intervening shielding material, lethal doses composed of neutron and gamma radiation could be delivered. The dose due to prompt gamma and neutron radiation at a distance can be evaluated by the following formulas:

Prompt gamma dose: Dg = 2.1 × 10–20 N d–2 exp–3.4d

Prompt neutron dose: Dn = 7.0 × 10–20 N d–2 exp–5.2d

Where:

D_g = gamma dose (rem)

D_n = neutron dose (rem) (neutron quality factor = 20)

N = number of fissions

d = distance from source (km)

At a distance of 10 meters, the combined prompt gamma and neutron radiation dose to personnel from a criticality in a powder, solution, or slurry of uranium or plutonium (1×10^{18} fissions) would be 867 rem (D_g = 203 rem plus D_n = 664 rem), which is greater than the average lethal radiation dose to humans of approximately 450 rem. Thus, the potential for lethal exposure exists. On average, there could be two workers in a room who could be exposed to this radiation.

In Building 332, the laboratory interior walls are a minimum of 8 inches of concrete. These walls provide substantial shielding, except through the doors. In the event of a criticality, this shielding and rapid evacuation from the laboratories would reduce doses to personnel not in the immediate vicinity of the criticality excursion.

Direct exposure to airborne fission products produced during the criticality event would contribute only a small fraction to the total worker dose to a worker. Because of ventilation system operation, other personnel inside the building would not likely incur radiation dose resulting from the inhalation of airborne radioactive materials or immersion in the plume. If the ventilation system were unavailable, this dose would be small in comparison to the direct dose received at the time of the burst. The worker immediately involved would act appropriately according to training and emergency procedures.

D.2.6 Assessment of Accident Risks for Lawrence Livermore National Laboratory Facilities

In this section, NNSA considers the consequence of an event with the probability that it will occur. This combination is referred to as the "risk." The risk is expressed mathematically as the product of the consequence and its probability. In illustration, if the expected public consequence of an accident at a particular facility is one LCF per accident, and if the accident has a probability of occurring once during a period of 1,000 years, then the continuing risk presented by that accident is (1 × 1/1,000) or 0.001 excess LCFs per year.

Tables D.2.6–1 and D.2.6–2 show the frequency and risk of the postulated set of LLNL facility accidents (shown in Tables D.2.5–1 and D.2.5–2) for a noninvolved worker (assumed to be a worker located 100 meters from the release point), the population of noninvolved workers, and the public (offsite MEI and the general population living within 50 miles of LLNL) for both median and unfavorable meteorological conditions.

TABLE D.2.6–1.—*Annual Cancer Risks from Accidents (Median Meteorology)*[a]

		MEI	Offsite Population[b]	Individual Noninvolved Worker	Noninvolved Worker Population
Building	**Accident**	**LCFs (per year)[c]**	**LCFs (per year)[d]**	**LCFs (per year)[c]**	**LCFs (per year)[d]**
Building 191	Radioactive material dispersion from a spill and fire - No Action	1.99×10^{-14}	2.82×10^{-12}	4.34×10^{-14}	5.83×10^{-12}
	Radioactive material dispersion from a spill and fire - Proposed Action	Same	Same	Same	Same
Building 194	Design-basis earthquake and fire - No Action	5.20×10^{-12}	1.34×10^{-9}	2.06×10^{-11}	3.50×10^{-9}
	Design-basis earthquake and fire- Proposed Action	Same	Same	Same	Same
Building 239	Uncontrolled oxidation of plutonium at elevated temperature - No Action	4.67×10^{-12}	1.75×10^{-9}	6.67×10^{-11}	6.99×10^{-9}
	Uncontrolled oxidation of plutonium at elevated temperature - Proposed Action	Same	Same	Same	Same
Building 251	Evaluation basis fire - No Action	3.61×10^{-9}	1.13×10^{-6}	3.42×10^{-8}	4.96×10^{-6}
	Evaluation basis fire - Proposed Action	Same	Same	Same	Same
Building 331	Plutonium Metal Fire - No Action	3.01×10^{-10}	1.43×10^{-7}	3.84×10^{-9}	5.37×10^{-7}
	Aircraft crash with subsequent fire - Proposed Action	1.50×10^{-10}	1.04×10^{-7}	1.94×10^{-9}	2.51×10^{-7}
Building 332	Aircraft Crash - No Action	4.30×10^{-10}	2.83×10^{-7}	5.37×10^{-9}	9.27×10^{-7}
	Room Fire Unfiltered - Proposed Action	1.03×10^{-10}	6.55×10^{-8}	1.15×10^{-9}	2.18×10^{-7}

TABLE D.2.6–1.—*Annual Cancer Risks from Accidents (Median Meteorology)[a] (continued)*

Building	Accident	MEI LCFs (per year) [c]	Offsite Population[b] LCFs (per year) [d]	Individual Noninvolved Worker LCFs (per year) [c]	Noninvolved Worker Population LCFs (per year) [d]
Building 334	Uncontrolled oxidation of plutonium at elevated temperatures - No Action	9.84×10^{-11}	4.08×10^{-8}	1.95×10^{-9}	1.39×10^{-7}
	Uncontrolled oxidation of plutonium at elevated temperatures - Proposed Action	Same	Same	Same	Same
Building 625	Aircraft Crash - No Action	8.74×10^{-11}	2.42×10^{-7}	2.37×10^{-10}	1.11×10^{-8}
	Aircraft Crash - Proposed Action	2.66×10^{-10}	7.38×10^{-7}	7.22×10^{-10}	3.38×10^{-8}
Building 581	Earthquake - No Action	5.74×10^{-15}	2.35×10^{-12}	1.72×10^{-14}	2.50×10^{-12}
	Earthquake during plutonium experiment without yield - Proposed Action	1.98×10^{-15}	6.55×10^{-13}	5.99×10^{-15}	8.90×10^{-13}
Building 696R	Aircraft Crash - No Action	3.25×10^{-10}	4.85×10^{-7}	5.24×10^{-10}	3.15×10^{-8}
	Aircraft Crash - Proposed Action	Same	Same	Same	Same
Site 300 Materials Management Facilities	Depleted uranium release by fire - No Action	2.36×10^{-10}	2.29×10^{-7}	2.36×10^{-8}	5.65×10^{-8}
	Depleted uranium release by fire - Proposed Action	Same	Same	Same	Same
Onsite Transportation	Materials Management Section package explosion - No Action	6.96×10^{-11}	2.41×10^{-8}	1.67×10^{-9}	1.03×10^{-7}
	Materials Management Section package explosion - Proposed Action	Same	Same	Same	Same

Source: Original.
[a] The risk for the Reduced Operation Alternative would be the same as for the No Action Alternative.
[b] Based on the population of approximately 6,900,000 persons residing within 50 miles of LLNL.
[c] Increased likelihood of a latent cancer fatality.
[d] Increased number of latent cancer fatalities (LCFs).
MEI = maximally exposed individual.

TABLE D.2.6–2.—*Annual Cancer Risks from Accidents (Unfavorable Meteorology)*[a]

		MEI	Offsite Population[b]	Individual Noninvolved Worker	Noninvolved Worker Population
Building	**Accident**	**LCFs (per year)[c]**	**LCFs (per year)[d]**	**LCFs (per year)[c]**	**LCFs (per year)[d]**
Building 191	Radioactive material dispersion from a spill and fire - No Action	2.55×10^{-13}	2.52×10^{-11}	4.28×10^{-13}	4.18×10^{-11}
	Radioactive material dispersion from a spill and fire - Proposed Action	Same	Same	Same	Same
Building 194	Design-basis earthquake and fire - No Action	7.80×10^{-11}	1.09×10^{-8}	1.98×10^{-10}	2.08×10^{-8}
	Design-basis earthquake and fire- Proposed Action	Same	Same	Same	Same
Building 239	Uncontrolled oxidation of plutonium at elevated temperature - No Action	9.94×10^{-11}	2.75×10^{-8}	8.02×10^{-10}	5.45×10^{-8}
	Uncontrolled oxidation of plutonium at elevated temperature - Proposed Action	Same	Same	Same	Same
Building 251	Evaluation basis fire - No Action	7.10×10^{-8}	7.34×10^{-6}	3.88×10^{-7}	2.71×10^{-5}
	Evaluation basis fire - Proposed Action	Same	Same	Same	Same
Building 331	Plutonium Metal Fire - No Action	5.99×10^{-9}	2.31×10^{-6}	4.51×10^{-8}	4.02×10^{-6}
	Aircraft crash with subsequent fire - Proposed Action	3.49×10^{-10}	1.68×10^{-7}	2.73×10^{-9}	2.20×10^{-7}
Building 332	Aircraft Crash - No Action	8.43×10^{-9}	3.47×10^{-6}	6.88×10^{-8}	7.38×10^{-6}
	Room Fire Unfiltered - Proposed Action	1.97×10^{-9}	7.62×10^{-7}	1.04×10^{-8}	1.83×10^{-6}

TABLE D.2.6–2.—*Annual Cancer Risks from Accidents (Unfavorable Meteorology)[a] (continued)*

Building	Accident	MEI LCFs (per year) [c]	Offsite Population[b] LCFs (per year) [d]	Individual Noninvolved Worker LCFs (per year) [c]	Noninvolved Worker Population LCFs (per year) [d]
Building 334	Uncontrolled oxidation of plutonium at elevated temperatures - No Action	2.21×10^{-9}	6.18×10^{-7}	2.63×10^{-8}	1.25×10^{-6}
	Uncontrolled oxidation of plutonium at elevated temperatures - Proposed Action	Same	Same	Same	Same
Building 581	Earthquake - No Action	7.38×10^{-14}	3.66×10^{-11}	1.60×10^{-13}	2.66×10^{-11}
	Earthquake during plutonium experiment without yield - Proposed Action	2.60×10^{-14}	1.00×10^{-11}	5.63×10^{-14}	9.88×10^{-12}
Building 625	Aircraft Crash - No Action	2.78×10^{-9}	2.12×10^{-6}	9.90×10^{-9}	2.36×10^{-7}
	Aircraft Crash - Proposed Action	8.45×10^{-9}	6.46×10^{-6}	3.01×10^{-8}	7.17×10^{-7}
Building 696R	Aircraft Crash - No Action	6.25×10^{-9}	4.01×10^{-6}	8.17×10^{-9}	6.53×10^{-7}
	Aircraft Crash - Proposed Action	Same	Same	Same	Same
Site 300 Materials Management Facilities	Depleted uranium release by fire - No Action	4.73×10^{-9}	1.56×10^{-6}	3.76×10^{-7}	3.30×10^{-7}
	Depleted uranium release by fire - Proposed Action	Same	Same	Same	Same
Onsite Transportation	Materials Management Section package explosion - No Action	1.66×10^{-9}	3.90×10^{-7}	3.19×10^{-8}	6.12×10^{-7}
	Materials Management Section package explosion - Proposed Action	Same	Same	Same	Same

Source: Original.
[a] The risk for the Reduced Operation Alternative would be the same as for the No Action Alternative.
[b] Based on the population of approximately 6,900,000 persons residing within 50 miles of LLNL.
[c] Increased likelihood of a latent cancer fatality.
[d] Increased number of latent cancer fatalities (LCFs).
MEI = maximally exposed individual.

D.3 ACCIDENT SCENARIOS INVOLVING TOXIC CHEMICALS

This section analyzes postulated accidents that could result in chemical releases. This section presents accident scenarios and source terms, selects bounding scenarios for each facility, and presents consequences.

D.3.1 Consequence Analysis

Consequences of accidental chemical releases were determined using the ALOHA computer code (EPA 1999). ALOHA is a U.S. EPA/National Oceanic and Atmospheric Administration (NOAA)-sponsored computer code that has been widely used in support of chemical accident responses and also in support of safety and NEPA documentation for DOE facilities.

The ALOHA code is a deterministic representation of atmospheric releases of toxic and hazardous chemicals. The code can predict the rate at which chemical vapors escape (e.g., from puddles or leaking tanks) into the atmosphere; a specified release rate is also an option. In the case of this LLNL SW/SPEIS, the chemical release rates were determined as part of the scenario development.

Either of two dispersion algorithms are applied by the code, depending on whether the release is neutrally buoyant or heavier than air. The former is modeled similarly to radioactive releases in that the plume is assumed to move with the wind velocity. The latter considers the initial slumping and spreading of the release because of its density. As a heavier than air release becomes more dilute, its behavior tends towards that of a neutrally buoyant release.

The ALOHA code uses a constant set of meteorological conditions (e.g., wind speed, stability class) to determine the downwind atmospheric concentrations. The same meteorological conditions used for the MACCS2 modeling of radiological releases were also used for the ALOHA modeling.

ALOHA contains physical and toxicological properties for approximately 1,000 chemicals. The physical properties were used to determine which of the dispersion models and accompanying parameters were applied. The toxicological properties were used to determine the levels of concern. Atmospheric concentrations at which health effects are of concern were used to define the footprint of concern. Because the meteorological conditions specified do not account for wind direction (i.e., it is not known *a priori* in which direction the wind would be blowing in the event of an accident), the areas of concern are defined by a circle of radius equivalent to the downwind distance at which the concentration decreases to levels less than the level of concern. The fraction of the area of concern actually exposed to the concentration of concern (footprint area/circle area) was noted.

The calculated concentrations were then compared to emergency response planning guidelines (ERPGs). These ERPGs are intended to provide estimates of concentration ranges at which adverse effects can be expected if exposure to a specified chemical lasts more than 1 hour. The ERPG levels are defined as follows:

- ERPG-1—The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing other than mild transient adverse health effects or perceiving a clearly defined, objectionable odor.

- ERPG-2—The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action.

- ERPG-3—The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects.

If a chemical did not have published ERPG values, the Temporary Emergency Exposure Limits (TEEL) were used. The TEELs were developed by the DOE Subcommittee on Consequences Assessment and Protective Actions (SCAPA) for chemicals where ERPG values are not available and serve as temporary guidance until ERPGs can be developed.

D.3.2 Description of Accident Scenarios

The next step was to identify potential accident scenarios and source terms (release rates and frequencies) associated with the facilities identified in Section D.2.1. Table D.3.2–1 lists the results of this process and contains the accident name, its frequency, the source term, the source document from which this information was obtained, and any other notes or assumptions related to the accident scenario. The source terms presented in Table D.3.2–1 apply to the No Action Alternative, the Proposed Action, and the Reduced Operation Alternative of this LLNL SW/SPEIS.

From the listing of accidents in Table D.3.2–1, the next step was to perform ALOHA calculations (as described in Section D.3.1) to identify the accidents that present the highest public or worker consequence for each facility (i.e., the "bounding" accidents). These accident scenarios are discussed further following Table D.3.2–1.

TABLE D.3.2–1.—*Potential Chemical Accidents*

Accident	Frequency (per year)	Source Term or Hazard
190, Multi-User Tandem Laboratory [a]		
Oxygen deficiency and exposure to SF_6	10^{-6} to 10^{-4}	Severe injury or death to worker or workers who enter into oxygen-deficient environment (pressure vessel or trench) caused by SF_6 release. No impacts on other site personnel or the offsite population.
191, High Explosives Application Facility[b]		
Chemical dispersion	10^{-4} to 10^{-2}	0.002 lb 1,2-dibromoethane 0.1 lb 1,2-dichloroethane 0.015 lb captan 0.125 lb xylene 0.065 lb carbon tetrachloride 0.075 lb chloroform 0.025 lb benzene

TABLE D.3.2–1.—*Potential Chemical Accidents (continued)*

Accident	Frequency (per year)	Source Term or Hazard
194, 100-MeV Electron-Positron LINAC Facility[c]		
Exposure to toxic gases	10^{-2} to 10^{-1}	Accidental exposure of facility workers to high concentrations of ozone or NO_x. Concentrations could cause respiratory damage or other injury. There would be no risk to the public or the environment.
Dispersal of toxic materials by fire	10^{-4} to 10^{-2}	0.1 g of lead is oxidized and dispersed
235, 4-MeV Ion Accelerator[d]		
Slow release of SF_6 gas	10^{-6} to 10^{-4}	Severe injury or death to facility workers who may be exposed to SF_6 gas. Minor risk to the public or the environment.
Sudden release of SF_6 gas	10^{-6} to 10^{-4}	Severe injury or death to facility workers who may be exposed to SF_6 gas. Peak SF_6 concentrations outside the facility of less than 1,000 ppm approximately 15 minutes after release; mean exposure level for 10 minutes is about 500 ppm.
SF_6 leak into acceleration tube	10^{-6} to 10^{-4}	Severe injury or death to facility workers who may be exposed to SF_6 gas. Minor risk to the public or the environment.
239, Radiography Facility[e]		
Fire involving lithium hydride	$<\sim10^{-5}$	48 g LiOH
Fire involving beryllium component	$<\sim10^{-5}$	5 g B_e
Impact involving BeO component	$<\sim10^{-5}$	2.5 g B_eO
Toxic gas release (NO_2)	$<\sim10^{-5}$	10,000 g NO_2
322, Plating Shop		
Single-container powder free-fall spill	NR	6.12×10^{-2} lb chromic trioxide
Single-container liquid spill	NR	100 lb nitric acid
Multiple-container liquid spill	NR	100 lb hydrofluoric acid
Mixing of incompatible liquids	NR	675 g hydrogen cyanide gas
Earthquake	NR	5,800 g hydrogen cyanide gas
331, Tritium Facility Actinide Activities		
Nitric acid spill	NR	38 L nitric acid solution
332, Plutonium Facility[f]		
Unmitigated chlorine rupture	5.7×10^{-7}	100 lb chlorine gas
Unmitigated chlorine rupture	5.7×10^{-7}	40 lb chlorine gas
Unmitigated hydrogen chlorine rupture	5.7×10^{-7}	55 lb hydrogen chloride gas
334, Hardened Engineering Test Building[g]		
Fire involving LiH component (unmitigated)	$<\sim10^{-5}$	192 g LiOH
Fire involving LiH component (mitigated)	$<\sim10^{-5}$	0.192 g LiOH
Fire involving Be component (unmitigated)	$<\sim10^{-5}$	40 g BeO
Fire involving Be component (mitigated)	$<\sim10^{-5}$	0.04 g BeO
Impact involving BeO component (unmitigated)	$<\sim10^{-5}$	20 g BeO
Impact involving BeO component	$<\sim10^{-5}$	0.20 g BeO

TABLE D.3.2–1.—*Potential Chemical Accidents (continued)*

Accident	Frequency (per year)	Source Term or Hazard
(mitigated)		
Toxic gas release	<~10^{-5}	40,000 g NO_2
514/612/625/693, Radioactive and Hazardous Waste Management Complex[h]		
Earthquake	10^{-4} to 10^{-2}	422 lb freon-22 (chlorodifluoromethane)
Leaks and spills	10^{-4} to 10^{-2}	550.8 lb hydrogen peroxide (at 0.28 g/sec) 826.2 lb sulfuric acid (at 0.01 g/sec) 688.5 lb sodium hydroxide (at 0.0087 g/sec) 741 lb ferric sulfate (at 0.0093 g/sec) 422 lb Freon-22 (chlorodifluoromethane)
Pressurized releases	10^{-4} to 10^{-2}	550.8 lb hydrogen peroxide (at 0.0069 g/sec) 826.2 lb sulfuric acid (at 0.01 g/sec) 688.5 lb sodium hydroxide (at 0.0087 g/sec) 741 lb ferric sulfate (at 0.0093 g/sec) 422 lb Freon-22 (chlorodifluoromethane)
581, National Ignition Facility		
Materials spill	NA	210 L acetone 400 L nitric acid solution (70%)
Mercury release from ignitrons	NA	9.8 g mercury
Earthquake	2×10^{-8}	0.13 g lithium hydride 0.2 g beryllium 0.45 g thorium 0.1 g uranium
Site 300 Materials Management Facilities[i]		
Inadvertent exposure to hazardous materials	10^{-4} to 10^{-2}	Exposure to isopropanol (inside a room) at concentrations of up to 860 ppm
Hazardous materials release by fire	10^{-4} to 10^{-2}	1,100 g LiOH
Site 300 Explosive Waste Treatment Facility[j]		
Fire	<10^{-1}	16.5 kg hydrogen fluoride
Explosion	<10^{-1}	0.66 kg hydrogen fluoride (released at ground level) 2.64 kg hydrogen fluoride (released at 69 meters)
Site 300 B-Division Firing Areas[i]		
Toxic gas/hazardous material exposure outside firing chamber in contained firing facility	10^{-6} to 10^{-4}	Serious injury or death to personnel who might be sufficiently exposed to these hazardous gases or materials.
Exposure of personnel upon re-entry into firing chamber to oxygen deficient and toxic atmospheres (contained firing facility only)	10^{-6} to 10^{-4}	Personnel might be exposed to HF and HCl levels that are high enough to create irreversible health effects and possibly death.

Source:
[a] LLNL 2002bw.
[b] LLNL n.d.
[c] LLNL 2002cq.
[d] LLNL 2000d.
[e] LLNL 2002ac.
[f] LLNL 2002bo, LLNL 2002af.
[g] LLNL 2001at.
[h] LLNL 2002bm.
[i] LLNL 2002l.
[j] LLNL 2001ax.
Be = Beryllium; LiH = Lithium hydride; LiOH = Lithium hydroxide; LINAC = Linear accelerator; NA = Not available; NO2 = Nitrogen dioxide; NR = Not reported; SF_6 = sulfur hexafluoride; NO_x = oxides of nitrogen.

D.3.2.1 *Building 190, Multi-User Tandem Laboratory—Oxygen Deficiency and Exposure to Sulfur Hexafluoride*

Approximately 30,000 cubic feet of sulfur hexafluoride gas is used in the operation of the various accelerators in Building 190. The accelerator pressure vessels and their associated gas handling systems are essentially leak-tight. However, there is the potential, under extreme fire scenarios or seismic conditions, for the pressure vessels to rupture or leak.

Although sulfur hexafluoride gas is considered to be nontoxic, it is an odorless, colorless asphyxiant, which is heavier than air and will completely exclude oxygen from whatever volume it occupies. In the event of a catastrophic breach of the accelerator vessels, there is sufficient gas to fill the Building 190 trench (16,000 cubic feet) and floor of the facility to a depth of 14 inches and create a potential asphyxiation hazard. Besides displacing oxygen and creating an oxygen deficient space, several decomposition products can be formed if arcing of corona discharge occurs in sulfur hexafluoride in the presence of air and water vapor. Decomposition products may include SOF_2, SO_2, F_2, SOF_4, HF, SO_2F_2, SF_4, and S_2F_{10}. The latter in particular is highly toxic. Many of the decomposition products are highly reactive and react with metal parts to form metal fluorides that are irritating to both the respiratory system and exposed skin.

The consequence to workers of an accident resulting from entering an oxygen deficient space is high (may cause death); however, through extensive administrative controls and the installed gas monitoring system, the probability of this accident occurring is extremely low (10^{-6} to 10^{-4} per year).

D.3.2.2 *Building 191, High Explosives Application Facility—Chemical Dispersion (1,2-Dichloroethane)*

The HEAF, Building 191, uses numerous chemicals in energetic materials research and development work. For a chemical dispersion outside the facility to occur, certain toxic gases, such as dichloroethane or chloroform, would have to be used in conjunction with energetic materials near a ventilation system that exhausts to the outside. The worst-case scenario is using a chemical in a fume hood and having an energetic reaction occur in the hood, which then drives the material out of the ventilation system. The selection of an energetic reaction rather than specifying a detonation is deliberate, as a detonation is likely to result in greater dispersion, thermal flux, and buoyancy, and thus lesser consequences.

Chemistry operations that may result in an undesired or unexpected energetic reaction are peer-reviewed to ensure that the desired results will be obtained. At least three people are involved in these reviews. The use of materials that could cause an exposure hazard outside the facility in proximity to one of these experiments would involve some type of human error. Therefore, this scenario is considered unlikely. This bounding scenario involves an inventory of 1,2-Dichloroethane in Building 191, which is 100 pounds. The airborne release fraction for this material is 0.001. Therefore, there would be a total of 0.1 pound of this material released to the environment in this event. The frequency of this event is 10^{-4} to 10^{-2} per year.

D.3.2.3 *Building 194, 100-MeV Electron-Positron LINAC Facility—Exposure to Toxic Gases*

A ventilation failure could result in accidental exposure to high concentrations of ozone and oxides of nitrogen. The worst-case situation would involve either a failure of the 0° Cave exhaust fan, or an improperly closed damper to restrict the ventilation rate. Ozone and oxides of nitrogen could build up to approximately 18 parts per million ozone and 80 parts per million oxides of nitrogen. These levels significantly exceed the National Institute of Occupational Safety and Health (NIOSH)-recommended immediately dangerous to life or health values of 10 parts per million ozone and 20 parts per million nitrogen dioxide, though not the immediately dangerous to life or health of 100 parts per million for nitrous oxide. No significant decrease in the concentrations would occur during the 10 minutes vent time allowed for exhausting the gases after the assumed continuous ventilation mode operation. If a worker entered the 0° Cave, the worker could potentially be overcome by the fumes. The air concentrations of ozone and oxides of nitrogen would decrease over several minutes to below immediately dangerous to life or health levels by diffusion into the rest of the belowground complex. Exposure to high levels of ozone could cause respiratory damage or other injury if the worker fails to retreat when the ozone odor is detected.

If the 0° Cave exhaust failed, but the supply fan continued to operate, the 0° Cave would have positive pressure with respect to the surrounding caves. In that situation, the ozone concentration in the 0° Cave was estimated to be approximately 60 parts per million. This could result in an increase in the ozone level in the corridor up to approximately 0.06 parts per million. Under nominal target configurations, a somewhat smaller rise in the corridor ozone concentration would be expected; however, the concentration in normally occupied areas could readily exceed the recommended 8-hour threshold limit values (TLV®) time-weighted average (TWA) of 0.05 parts per million. Although the resulting odor should be detectable by most people, it is plausible that workers that remain underground could be exposed to levels between 0.05 and 0.1 parts per million for long periods. The potential for respiratory irritation exists, but it would not cause irreversible damage.

Ventilation failures leading to toxic gas exposure can affect facility workers only. The release rate of ozone and oxides of nitrogen is not increased, and the concentrations aboveground remain 10 to 100 times below ambient levels. There is no impact on receptors outside the facility or on the environment. The frequency of this event is 10^{-2} to 10^{-1} per year.

D.3.2.4 *Building 235, 4-MeV Ion Accelerator—Sudden Release of Sulfur Hexafluoride Gas*

About 2,500 pounds of sulfur hexafluoride gas is put into the accelerator tank to pressurize it to about 85 pounds per square inch gauge. Sulfur hexafluoride itself is an inert, nontoxic gas that, in large quantities, can displace oxygen and create an asphyxiation hazard. A sudden release of sulfur hexafluoride gas could occur as a result of rupture of one of the two tanks or the gas-handling system or associated piping. This release would allow the entire mass of heavy gas to flow along the ground with little mixing into the air. The release of the total amount of sulfur hexafluoride gas from the accelerator tank or other parts of the gas-handling system inside the enclosure could fill the entire enclosure (up to near the top of the 9-foot-high wall) with pure sulfur hexafluoride gas at atmospheric pressure, assuming all doors to the enclosure are closed and neglecting losses. The frequency of this event is 10^{-6} to 10^{-4} per year.

An alarmed oxygen sensor is installed about 1 foot above the floor to continuously monitor the oxygen level near the floor of the enclosure. There are two levels of alarm: "Caution" at a reading of 19.5 percent O_2 and "Danger" at 18 percent O_2. If the alarm ever indicates to either level, all personnel would immediately leave the enclosure (closing the east door on their way out) and the main laboratory part of the room. The tripping of the alarm at the danger level would automatically summon help from the LLNL Fire Department.

D.3.2.5 *Building 239, Radiography Facility——Toxic Gas Release, Nitrogen Dioxide*

Containers or items containing other hazardous material may be brought into this facility about twice a month for radiography or computed tomography and may be an integral part of an assembly. Hazardous components brought into the facility for radiography or computed tomography are shipped out upon completion of the work. This accident scenario would result in a release of toxic gas. The item is removed from the shipping container and placed on a table for radiography. While being removed, the item is rammed with a forklift, dropped while being carried by hand or overhead crane, or crushed due to failure of the overhead crane. The protective barrier is damaged. A fire could be initiated as a result of combustion of other materials (or of the material itself), burning the entire contents, or the impact could cause a release of the material into the air. The release material mixes with room air and is exhausted unfiltered from the ventilation system.

The bounding scenario involves the maximum amount of hazardous material that may be brought into the building for radiography, which is limited to no more than what could otherwise result in a release of 10 kilograms of airborne material. Therefore, this scenario conservatively assumes the release of the maximum allowable amount of 10,000 grams of nitrogen dioxide. The frequency of this event is less than 10^{-5} per year.

D.3.2.6 *Building 322, Metal Finishing Facility – Multiple Container Liquid Spill*

Multiple containers of liquid chemical material being delivered by forklift or by hand are postulated to be spilled during handling. It is assumed that the entire contents of the containers would spill instantaneously and spread to a depth of 1 millimeter on smooth surfaces. No credit was taken for building holdup or plateout. The respirable fraction, damage ratio, and leak path factor were all conservatively assumed to be unity.

The bounding scenario for aqueous liquids was determined to be hydrofluoric acid. The facility inventory of hydrofluoric acid is 100 pounds. It was assumed that two containers, each containing 50 gallons of hydrofluoric acid, are involved in this scenario.

Transfers within the facility, from a storage container to a process tank, involve lesser amounts. In addition, spills within the facility would have a small leak path factor, increasing the conservatism. The primary consequences of a smaller liquid spill in the facility would be an increase in exposure of facility workers.

This chemical release scenario also bounds potential accidents from Chemistry and Materials Science Facilities.

D.3.2.7 *Building 331, Tritium Facility Actinide Activities—Nitric Acid Spill*

Chemicals would be used for miscellaneous cleaning and decontamination activities throughout Building 331. An anticipated scenario that might occur is a spill of decontamination solution onto the ground outside the facility, possibly caused by a forklift during handling or movement.

Projected inventories of chemicals at Building 331 were evaluated on the basis of the amount of MAR, exposure criteria, and volatility. Nitric acid was selected as the bounding scenario for consequence analysis. A maximum quantity of 10 gallons (38 liters) of nitric acid would be used in the facility at any one time. This maximum quantity was used as the source term for this event.

D.3.2.8 *Building 332, Plutonium Facility—Chlorine Release*

A chlorination operation is performed in furnaces housed in a glovebox. This operation uses either a 100-pound or 40-pound chlorine gas cylinder or a 55-pound hydrogen chloride cylinder. During the operation, a chlorine gas cylinder or a hydrogen chloride cylinder is installed in a ventilated toxic-gas cabinet located outside the building. The gas cabinet is monitored for both chlorine and hydrogen chloride. The delivery line inside the gas cabinet has an excess flow shutoff valve and an emergency shutoff valve located near the cylinder head.

A release of chlorine or hydrogen chloride has been evaluated. A potential cause of such an event could be the failure of various system components. The potential release paths include pipe ruptures in four different piping sections or leaks from the chlorine cylinder and the two valves in the system. These contributors to the release potential were considered. It was assumed that any leak inside the gas cabinet would be detected and mitigated in time. Unless the gas cylinder valve fails catastrophically, the safety features associated with the toxic-gas installation would allow only a very small release of toxic gas under any abnormal conditions. A more severe release could result if these features, or combinations of these features, failed to function.

A source term was developed for the unmitigated release from the apparatus. An unmitigated release of chlorine or hydrogen chloride through a small orifice, 0.18 inch in diameter (corresponding to the internal diameter of the piping used [0.25-inch outer-diameter]) or a small hole in the cylinder, was examined. The source terms for the bounding scenario were developed by assuming that the chlorine gas was released through 0.25-inch outer-diameter tubing directly into the atmosphere. No credit was taken for the flow-restricting device, whose size is much smaller than 0.25 inch. The frequency of this event is 5.7×10^{-7} per year.

D.3.2.9 *Building 334, Hardened Engineering Test Building—Toxic Gas Release, Nitrogen Dioxide*

Containers or items containing other hazardous material may be brought into the facility about twice a month for testing or measurement. These components are shipped out of the facility upon completion of the work. This accident scenario would result in a release of toxic gas. The item is removed from the shipping container and placed on a table for test or measurement. While being removed, the item is rammed with a forklift, dropped while being carried by hand or overhead crane, or crushed due to failure of the overhead crane. The protective barrier is damaged. A fire could be initiated as a result of combustion of other materials (or of the material itself), burning the entire contents, or the impact could cause a release of the material into the air. The release material mixes with room air and is exhausted from the ventilation system.

The bounding scenario involves the maximum amount of hazardous material that may be brought into the building for test or measurement is limited to no more than what could otherwise result in a release of 40 kilograms of airborne material. Therefore, this scenario conservatively assumes the release of the maximum allowable amount of 40,000 grams of nitrogen dioxide. The frequency of this event is less than 10^{-5} per year.

D.3.2.10 *Buildings 514/612/625/693, Radioactive and Hazardous Waste Management Complex—Earthquake Release of Freon-22*

Process reagents in this facility include sulfuric acid, hydrogen peroxide, ferric sulfate, and sodium hydroxide. These chemicals are presently stored in 55-gallon drums. It is assumed that these drums are not stacked two high and are stored in buildings that can withstand the design-basis earthquake. Therefore, no releases of reagents are assumed for this scenario.

The cold vapor evaporator contains 900 pounds of chlorodifluoromethane (Freon-22) as the refrigerant. It is assumed that during a design-basis earthquake, the pipes would break resulting in a release of approximately 422 pounds of Freon-22. This value was calculated assuming that one of the 2-inch copper pipes leading to the external condenser would be completely severed. Under this circumstance, the cold vapor evaporation unit would immediately lose vacuum and the compressor would automatically enter failure mode and cease functions due to the sudden loss of oil pressure resulting form the rapid release of Freon-22. This bounding scenario assumes that all of the Freon-22 in the system from the discharge side of the compressor up to and including any Freon-22 collected in the external condenser would be discharged to the atmosphere as an instantaneous release. No further Freon-22 releases would occur once the compressor stops since the compressor is a sealed unit that will not allow the passage or release of any additional Freon-22 once it has stopped.

D.3.2.11 *Building 581, National Ignition Facility—Materials Spill, Nitric Acid Solution*

Solvents would be used for cleaning activities throughout the NIF. Acidic and caustic solutions would also be used for various decontamination operations in the decontamination area of the Diagnostics Building. An anticipated scenario that might occur would be a spill of solvent or decontamination solution onto the ground outside the facility, possibly caused by a forklift during handling or movement.

Projected inventories of solvents at the NIF were evaluated on the basis of amount of MAR, exposure criteria, and volatility. That is, chemicals without inventory thresholds that are expected to be present in relatively small quantities, with low volatility, and those with relatively high exposure criteria were not considered further. A solvent (acetone) and a decontamination material (nitric acid) were selected for consequence analysis. The bounding scenario involves the chemical that presented the highest potential consequence, which was nitric acid.

D.3.2.12 *Site 300 Materials Management Facilities—Hazardous Materials Release by Fire (LiOH)*

The bounding scenario involves a fire involving lithium hydride (LiH), which is stored in Site 300 facilities. Lithium hydride burns and releases lithium oxide and lithium hydroxide (LiOH), with LiOH being the primary end product. The causes of a fire that releases LiOH could include human error in using materials handling equipment, fire in the storage magazine, natural phenomenon such as a lightning strike, or accidental detonation of explosives in a neighboring magazine. The most probable initiating cause of a LiOH release is the penetration of a storage bay and a container by a fragment from an explosion at a remote high explosives machining operation. The frequency of this event is 10^{-4} to 10^{-2} per year.

A magazine fire involving test assemblies could result in the exposure of worksite and other Site 300 personnel to fumes from the smoke. However, because personnel are not allowed in the area during a remote operation and do not approach a structure that is in flames, the actual probability of onsite exposure is low. The frequency of this event is mitigated by the strict control of ignition sources and fuel loadings in the facilities. These controls are extremely effective because LiH does not burn well when in solid form. In addition, this material is packaged in its shipping container, which protects the material from ignition from the outside and limits the access to oxygen if a fire is ignited, which tends to snuff out the fire or at least slow its rate of burn.

D.3.2.13 *Site 300 Explosive Waste Treatment Facility—Fire Release of Hydrogen Fluoride*

During an accidental explosives fire, toxic byproducts of combustion are given off and dispersed. In this analysis, several worst-case assumptions have been made, including:

- The fire's smallest radius is 1 meter.
- The thermal plume rise is taken to be 11 meters.
- The largest possible burnable explosive inventory of 350 pounds was used.

The bounding scenario source term is derived from the quantity of explosive involved (159 kilograms [350 pounds]) multiplied by the maximum value for hydrogen fluoride. This results in a total release of 16.5 kilograms of hydrogen fluoride. The frequency of this event is less than 10^{-1} per year.

D.3.2.14 *Site 300 B-Division Firing Areas—Toxic Gas/Hazardous Material Exposure Outside Contained Firing Facility Firing Chamber*

Explosive detonations within the Contained Firing Facility (CFF) can produce hazardous gases such as NH_3, HCN, carbon monoxide, oxides of nitrogen, HCl, and HF, and hazardous materials such as vaporized or particulate solids, including those from depleted uranium or beryllium. After a shot in the firing chamber, the CFF ventilation system removes particulates and soluble gases. Gases and particulates are further removed before the exhaust is discharged to the atmosphere by routing the ventilation exhaust through HEPA filters and an efficient gas absorption wet scrubber located in the ventilation exhaust piping. The CFF water washdown system can remove beryllium, uranium alloys, and miscellaneous metal particles resulting from the detonation. If personnel were sufficiently exposed to these hazardous gases or materials, serious injury or death could occur.

Isolation valves in the ventilation system might not be closed during a shot because of valve failure, human error, or control system error. As a result, gases would exhaust into the ventilation ducting system. The ducting in the supply side of the ventilation system cannot withstand shot pressure. As a result, it would fail, releasing toxic gases either to the outside or into the service area of the CFF. The same failure and toxic release would occur if the isolation valves were opened too soon after the shot. Although the areas where the releases would occur are outside of the approved shelter areas, personnel could be exposed to toxic gases if the affected areas were entered after the shot.

Personnel could also be exposed to hazardous gases or materials outside the CFF firing chamber if there was leakage through the firing door seals into the support area or leakage past camera or cable penetrations. The frequency of this event is 10^{-6} to 10^{-4} per year.

D.3.3 Estimated Health Effects

Table D.3.3–1 shows the consequences of the postulated set of accidents for a noninvolved worker and the public under median meteorological conditions. These consequences apply to the No Action Alternative, the Proposed Action, and the Reduced Operation Alternative of this LLNL SW/SPEIS. The accident with the highest consequence to the offsite population is the chlorine release from Building 332. For this accident, concentrations above the ERPG-2 level would exist as far out at 1.7 kilometers from Building 332, which would extend about 600 meters beyond the site boundary. At the site boundary, the concentration would be below ERPG-3 values, but above ERPG-2 values, indicating that persons exposed to this concentration could experience irreversible or other serious health effects or symptoms that could impair their ability to take protective action. At the noninvolved worker location, the concentration would be above ERPG-3 values, indicating that individuals exposed to this concentration could experience or develop life-threatening health effects.

Table D.3.3–2 shows the consequences of these accidents under unfavorable meteorological conditions. These consequences apply to the No Action Alternative, the Proposed Action, and the Reduced Operation Alternative of this LLNL SW/SPEIS. The accident with the highest consequence to the offsite population is the toxic gas release (nitrogen dioxide) from Building 334. For this accident, concentrations above the ERPG-2 level would exist as far out at 2.9 kilometers from Building 334, which would extend about 2,000 meters beyond the site boundary. At the site boundary and at the noninvolved worker location, the concentration would be above ERPG-3 values, indicating that individuals exposed to this concentration could experience or develop life-threatening health effects.

TABLE D.3.3–1.—*Lawrence Livermore National Laboratory Chemical Accident Consequences (Median Meteorology)*[a]

ERPG-2 Concentration (ppm)	ERPG-3 Concentration (ppm)	Noninvolved Worker Average Predicted Concentration (ppm)	Noninvolved Worker Fraction of ERPG-2	MEI Average Predicted Concentration (ppm)	MEI Fraction of ERPG-2	ERPG-2 Distance (meters)
Building 191, High Explosives Application Facility – Chemical Dispersion (1,2-Dichloroethane)						
200	300	0.108	5.4×10^{-4}	0.0175	8.8×10^{-5}	11
Building 239, Radiography Facility – Toxic gas release (NO_2)						
5	20	27.5	5.5	0.81	016	246
Building 322, Plating Shop – Multiple Container Liquid Spill (Hydrofluoric Acid)						
20	50	371	18.6	4.86	0.24	475
Building 331, Tritium Facility actinide activities – Nitric acid spill						
6	78	24	4	0.24	0.04	205
Building 332, Plutonium Facility – Chlorine release						
3	20	593	198	11.6	3.9	1,700
Building 334, Hardened Engineering Test Building – Toxic gas release (NO_2)						
5	20	110	22	2.02	0.40	529
Building 514/612/625/693, Radioactive and Hazardous Waste Management Complex – Earthquake release of Freon-22						
7,500	7,500	415	0.06	169	0.023	19
Building 581, National Ignition Facility – Material Spill, Release of Nitric acid solution						
6	78	130	21.7	12.3	2.1	536
Site 300 Materials Management Facility – Hazardous materials release by fire (LiOH)						
1	102	1.42	1.42	0	0	119
Site 300 Explosive Waste Treatment Facility – Fire release of hydrogen fluoride						
20	50	28.1	1.41	0.097	0.049	119

Source: Original.
[a] These consequences apply to alternatives.
ERPG = Emergency Response Planning Guideline; MEI = Maximally Exposed Individual; ppm = parts per million.

TABLE D.3.3–2.—*Potential Chemical Accident Consequences (Unfavorable Meteorology)* [a]

		Noninvolved Worker		MEI		
ERPG-2 Concentration (ppm)	**ERPG-3 Concentration (ppm)**	**Average Predicted Concentration (ppm)**	**Fraction of ERPG-2**	**Average Predicted Concentration (ppm)**	**Fraction of ERPG-2**	**ERPG-2 Distance (meters)**
Building 191, High Explosives Application Facility – Chemical Dispersion (1,2-Dichloroethane)						
200	300	1.41	7.1×10^{-3}	0.272	1.4×10^{-3}	11
Building 239, Radiography Facility – Toxic gas release (NO_2)						
5	20	1,430	286	35.2	7.04	1,600
Building 322, Plating Shop – Multiple Container Liquid Spill (Hydrofluoric Acid)						
20	50	4,680	234	46.4	2.32	1,400
Building 331, Tritium Facility actinide activities – Nitric acid spill						
6	78	68	11.3	1.1	0.18	358
Building 332, Plutonium Facility – Chlorine release						
3	20	5,220	1,740	16.9	5.64	1,900
Building 334, Hardened Engineering Test Building – Toxic gas release (NO_2)						
5	20	5,720	1,140	77.8	15.6	2,900
Building 514/612/625/693, Radioactive and Hazardous Waste Management Complex – Earthquake release of Freon-22						
7,500	7,500	4,080	0.54	1,312	0.17	75
Building 581, National Ignition Facility – Material Spill, Release of Nitric Acid Solution						
6	78	438	73	51.4	8.57	1,400
Site 300 Materials Management Facility – Hazardous materials release by fire (LiOH)						
1	102	59	59	0.151	0.15	865
Site 300 Explosive Waste Treatment Facility – Fire release of hydrogen fluoride						
20	50	1,168	58.4	2.98	0.15	860

Source: Original.
[a] These consequences apply to all alternatives.
ERPG = Emergency Response Planning Guideline; MEI = Maximally Exposed Individual; ppm = parts per million.

D.4 ACCIDENT SCENARIOS INVOLVING HIGH EXPLOSIVES

D.4.1 Site 300 Materials Management Facilities

D.4.1.1 *Accidental Detonation in an Explosives Assembly Storage Magazine*

The consequences of this accident would include severe injury or death to the facility workers (normally two) and the destruction of the magazine, with possible injuries to nearby personnel within intraline and fragment distance, and damage to nearby facilities. Additionally, low-level environmental releases and low-level exposures of personnel to airborne hazardous materials would be of lesser consequence. Onsite exposure to the resulting plumes would be below ERPG-3 levels. Offsite consequences would be limited to overpressures and the potential for hazardous material exposures below ERPG-2 levels. The frequency of this accident is estimated to be 10^{-6} to 10^{-4} per year.

D.4.2 Site 300 Weaponization Program

D.4.2.1 *Accidental Bare Explosives Detonation in a Test Building with Personnel Present*

Severe or fatal injuries to the immediate workers (normally two to five) and damage to the test equipment and building would occur. Injuries to nearby personnel subjected to blast effects also would be possible. Offsite consequences would be limited to overpressures in populated areas. The frequency of this accident is estimated to be 10^{-6} to 10^{-4} per year.

D.4.2.2 *Accidental Detonation in a Test Building During a Test With No Personnel Present*

The consequences of this accident would include damage to the test equipment and building, with possible injuries to nearby personnel. Offsite consequences would be limited to overpressures in populated areas. The frequency of this accident is estimated to be 10^{-4} to 10^{-2} per year.

D.4.2.3 *Accidental Detonation in a Storage Magazine*

The consequences of this accident would include severe or fatal injury to the immediate workers (normally two to three) and the destruction of the magazine, with possible injuries to nearby personnel subjected to blast effects. Offsite consequences would be limited to overpressures in populated areas. The frequency of this accident is estimated to be 10^{-6} to 10^{-4} per year.

D.4.3 Site 300 B-Division Firing Areas

D.4.3.1 *Accidental Detonation at a Bunker Firing Table*

The consequences of this accident would include severe or fatal injury to the personnel present. Blast pressures and fragments could also cause injury to other personnel in the open area outside the controlled access-firing table. Activities other than handling or work on the explosives also could lead to accidental detonations resulting in severe or fatal injury of many personnel (normally 2 to 10, with a maximum of 20). Offsite consequences would be limited to overpressures in populated areas. The frequency of this accident is estimated to be 10^{-6} to 10^{-4} per year.

D.4.3.2 *Accidental Detonation at the Contained Firing Facility Firing Chamber*

The consequences of this accident would include severe or fatal injury to personnel. The blast and the fragments might also injure personnel in the open area outside the facility. If an activity of higher level than the handling or work on the explosives led to an accidental detonation, the result could be severe or fatal injury to more personnel (normally 2 to 20). The exposure to blast and fragments from the detonation would be more severe than any exposure to airborne hazardous material, because the explosion would be more immediate and severe. An accidental detonation could result in significant damage to the service building and equipment. Offsite consequences would be limited to overpressures in populated areas. The frequency of this accident is estimated to be 10^{-6} to 10^{-4} per year.

D.4.3.3 *Accidental Detonation During Transport Through the Contained Firing Facility Service Building*

The consequences of this accident would include localized severe or fatal injury to the immediate workers (normally two or fewer) and the destruction of the building, with possible injuries to nearby personnel subject to the blast effects. Additionally, low-level environmental releases and low-level exposures of personnel to airborne hazardous materials would result in lesser consequences. Offsite consequences would be limited to overpressures in populated areas. The frequency of this accident is estimated to be 10^{-6} to 10^{-4} per year.

D.4.3.4 *Accidental Detonation in a Storage Magazine*

The consequences of this accident would include localized severe or fatal injury to the immediate workers (normally two or fewer) and the destruction of the magazine, with possible injuries to nearby personnel subject to the blast effects. Additionally, low-level environmental releases and low-level exposures of personnel to airborne hazardous materials would result in lesser consequences. Offsite consequences would be limited to overpressures in populated areas. The frequency of this accident is estimated to be 10^{-6} to 10^{-4} per year.

D.4.3.5 *Accidental Firing/Improper Trajectory from Propellant-Driven Gun*

The consequences of this accident would include property damage and severe or fatal injury to personnel on the bunker-firing table. Offsite consequences would be limited to overpressures in populated areas. The frequency of this accident is estimated to be 10^{-6} to 10^{-4} per year.

D.4.4 Energetic Materials Processing Center

Accidental Detonation

The consequences of this accident would include severe or fatal injury to personnel (normally two to six) involved in assembling high explosives and other components. An accidental detonation in an assembly bay would be the most severe, because the amount of explosives authorized in an assembly bay (100 kilograms) is more than for any other operation in EMPC. Other personnel within the EMPC would not be injured. The exposure to blast and fragments from the detonation would be more severe than any exposure to airborne hazardous material, because the explosion would be more immediate and severe. Offsite consequences would be limited to overpressures in populated areas. The frequency of this accident is estimated to be 10^{-6} to 10^{-4} per year.

D.4.5 Building 191, High Explosives Application Facility

D.4.5.1 *Accidental Detonation or Deflagration of Explosives in Storage*

Personnel who are present in a magazine room or workroom where an accidental detonation occurs could be fatally injured, depending on the amount of explosives in the room. Others in proximity to the room of occurrence could suffer severe or fatal injuries, depending on their location. Personnel outside the room of occurrence could experience eardrum rupture, but they should not suffer any major lung damage. Offsite consequences would be limited to overpressures in populated areas. The frequency of this accident is estimated to be 10^{-6} to 10^{-4} per year.

D.4.5.2 *Personnel Injury Due to Failure of Controls for Remote Explosives Operations*

The consequences of this accident would include property damage and severe or fatal injury to the worker. Offsite consequences would be limited to overpressures in populated areas. The frequency of this accident is estimated to be 10^{-6} to 10^{-4} per year.

D.4.5.3 *Accidental Detonation of Explosives During Contact Operations*

All personnel inside the room of occurrence (up to six people) could receive fatal injuries. Although the consequences in a workroom with a 10-kilogram limit would likely be more severe than those in workrooms with lower explosives limits, it still would be possible that the consequences in these rooms could equal the consequences in a workroom with a 10 kilogram limit. Personnel outside the room of occurrence could also receive injury from overpressure effects (walls, mazes, and doors would preclude fragment hazards). Overpressure predictions outside the room of occurrence (but inside the facility) would be expected to result in some eardrum rupture. Lung damage would also be possible. There would be no blast effects (overpressure or fragments) outside the facility. The frequency of this accident is estimated to be 10^{-6} to 10^{-4} per year.

D.5 SCENARIOS INVOLVING BIOLOGICAL HAZARDS

Microbiology laboratories are unique work environments that could pose special risks to personnel working within that environment. For purposes of this appendix, NNSA has selected a representative facility accident that has been previously analyzed by the U.S. Army in the *Final Programmatic Environmental Impact Statement Biological Defense Research Program* (Army 1989). NNSA believes that this accident scenario is comparable to and bounds any potential scenarios associated with the BioSafety Level-3 Facility (BSL-3), Building 368, at LLNL.

This accident scenario is being presented in order to provide a clear understanding of the BSL-3 activities and the extent of the potential impacts that could arise from these activities under unusual circumstances. The best available credible information has been applied to calculation of the results of this accident scenario using assumptions that yield the potential for more severe consequences. The U.S. Army has previously determined that releases of aerosols of biological materials from facilities such as the BSL-3 facility under appropriate containment conditions are not reasonably foreseeable (Army 1989). For the purpose of perspective and information, this appendix presents estimates of the extent of potential impacts resulting from accidental releases of biological aerosols from the BSL-3 facility. These findings are presented even though the event or series of events are not considered to be reasonably foreseeable and have never occurred within the U.S. Army Biological Defense Research Program (Army 1989). In summary, aerosolization and release of this agent would be very difficult, even under the assumed sequence of events described below.

D.5.1 Description of the Organisms

The organism selected for this scenario is *Coxiella burnetii*, the rickettsial causing Q fever, a disease of varying degrees of incapacitation. *Coxiella burnetii* grows to high concentrations in chicken embryos. It is a hardy organism that withstands laboratory manipulation with little or no loss in viability. It is highly stable in aerosol and undergoes a biological decay rate of about 1 percent per minute over a wide range of humidities. *Coxiella burnetii* is extremely infectious in a small particle aerosol. These properties (high concentration of rickettsial agent, low rate of biological decay, low infective dose for man) make *Coxiella burnetii* an ideal organism to use in a hypothetical, maximum credible laboratory accident.

D.5.2 Description of the Hypothetical Accident

An immunized laboratory worker would be processing 1 liter of *Coxiella burnetii* slurry that would be used to prepare an experimental vaccine. In this scenario, the laboratory worker would fail to use rubber O-rings to seal the centrifuge tubes, and all six bottles would leak, allowing some of the slurry into the rotor. Because the worker would also fail to properly tighten the safety centrifuge caps designed to prevent such a leak, some of the slurry would also escape into the centrifuge compartment that houses the rotor. This compartment is not sealed against the release of organisms in a small particle aerosol. The leakage of six bottles is highly improbable, but could potentially occur as a result of operator error as described above. This scenario assumes that most of the solution would remain in the centrifuge tubes. Of the solution that leaks, most would be contained within the covered rotor and not aerosolized (99 percent). Of the solution that escapes into the centrifuge cabinet, only a fraction would be aerosolized, and of that which is aerosolized, approximately 90 percent would settle as liquid droplets on the inside of the chamber.

A few minutes after the rotor stops, the worker would open the centrifuge door and reach in to remove the rotor. The worker would notice that there has been a leak of the slurry within the centrifuge. Two coworkers would provide assistance in managing the spill. Four other coworkers would enter the lab shortly after the incident, and thus are also accidentally exposed to the uncontained infectious organisms.

This scenario is based on an unlikely cascade of sequential events: the failure to seal properly both the centrifuge tubes and the safety centrifuge cups, the leakage of not one but six centrifuge bottles containing *Coxiella burnetii,* and the inappropriate behavior of the laboratory worker. The possibility of an accident of this degree, which is based on the sequential or simultaneous failure of multiple operational and procedural controls, is remote.

D.5.3 Impact of the Accident on the Noninvolved Worker and the Offsite Population

Potentially, the most serious consequence of the laboratory accident would be the release of enough infectious doses to override the building filter system and allow the subsequent release of a concentrated aerosol into the surrounding community. It is therefore necessary to calculate the maximum number of aerosol infectious doses presented to the filter. It is assumed that 10 percent leaked from the tubes, of which 99 percent remained in the rotor cup. Of that which escaped from the cup, 0.1 percent was aerosolized by the rotor and of that aerosolized, 90 percent settled as liquid droplets on the inside of the chamber. Thus, the total is 0.00001 percent aerosol escape into the room, which equals 9.9×10^6 HID_{50}[1] aerosolized. The building exhaust filter is 95 percent efficient, thus approximately 5×10^5 HID_{50} would have escaped from the building exhaust stack (Army 1989). Because laboratory work is normally performed during the day, ultraviolet rays from the sun would also destroy a large number of these rickettsiae.

The quantity of human infectious doses, by simple Gaussian plume dispersion models, is expected to be dissipated to less than 1 HID_{50} per liter of air in less than 2 meters from the stack, less than 0.1 HID_{50} per liter of air at 16 meters, and less than 0.01 HID_{50} per liter of air at 38 meters (Army 1989). Thus, this level of escape of *Coxiella burnetii* from the containment laboratory, even under the worst-case meteorological conditions, does not represent a credible hazard to the noninvolved worker or offsite population.

D.5.4 Impact of the Accident on Laboratory Workers

The centrifuge operator would be at the greatest risk of becoming ill with Q fever. In opening the centrifuge, the infectious aerosol would be released initially and momentarily into a very confined area. The concentration of airborne infectious doses, seconds after the lid was opened, was calculated as 1.3×10^3 HID_{50} per liter of air. Assuming that the centrifuge operator was in the area for no more than 5 minutes, the operator could have inhaled approximately 100,000 infectious doses. The two coworkers who came to the operator's assistance would be exposed to only slightly fewer doses.

Studies (Army 1989) reported that previously vaccinated men, when exposed to defined aerosols of 150 or 150,000 infectious doses of virulent *Coxiella burnetii,* did not consistently become ill. Because the centrifuge operator would receive about the same dose reported in these studies, it is problematical whether the operator would become sick, since he would be, by required procedures, immunized. These studies further indicate that if a non-immunized person were exposed to 150 or 150,000 infectious doses, the disease could be avoided by giving one milliliter of vaccine within 24 hours after exposure and by instituting antibiotic therapy.

[1] The term "HID_{50}" refers to the dose causing infection 50 percent of the time for man.

The other four laboratory workers also would be exposed for less than 1 minute to the aerosol after it was dispersed in the room and would be unlikely to have been exposed to more than 100 to 300 infectious doses. These four laboratory workers, since they also would have been vaccinated, should not develop Q fever. The two coworkers who came to the operator's assistance would also have been vaccinated and should not develop Q fever.

D.6 MULTIPLE-BUILDING EVENT

This section addresses the potential releases and consequences of a situation involving multiple source terms (both radiological and chemical) stemming from a single event affecting LLNL. An earthquake with a return period of 5,000 years (i.e., 2×10^{-4} per year) was postulated as the initiator for this accident scenario. This earthquake is assumed to have a horizontal ground acceleration of 0.8 *g*. As a rough comparison, the January 24 and January 27, 1980, Livermore earthquakes, recorded as 5.4 and 5.6 on the Richter Scale, generated maximum measured peak ground accelerations of 0.26 *g* at a distance of 18 kilometers from the epicenter.

D.6.1 Building Selection and Assumptions

The selection process described in Section D.1.1 is also the basis for buildings selected for seismic analysis. In all cases, buildings were evaluated based on a 0.8-*g* horizontal acceleration. In addition to those buildings identified as having a potential release initiated by an earthquake, all buildings identified for accident analysis were also subjected to seismic analysis. In some instances, the postulated scenario could not be initiated by a seismic event, and the locations and associated releases were not considered as part of the multiple-building event scenario.

For the cases analyzed, a secondary fire was eliminated from consideration because of the installation of seismic shutoff valves throughout the natural gas pipeline system and the limited amounts of combustible and flammable materials in the evaluated areas. This does not mean that an earthquake of this severity will not cause major fires at the various facilities. After the 1989 Loma Prieta earthquake, many fires burned uncontrolled in the city of San Francisco due to the failure of natural gas pipelines. The major cause for failure of the pipelines was the nature of the ground (landfill) in the affected areas. Specific information concerning the seismic stability of the area surrounding LLNL is contained in Appendix H. While fires may result from an earthquake such as that postulated for the initiating event in this section, the number and magnitude of the fires would not be expected to be as severe as those experienced in 1989. The fires would generally be expected to involve offices and administrative areas where fire loadings are higher than in rated buildings and where fire suppression capabilities are generally not as extensive.

D.6.2 Description of Potential Releases Following an Earthquake

This section provides a general description of the radiological and chemical releases that may occur as a direct result of an earthquake. Scenarios and consequences are discussed in general terms only. For specific information concerning individual scenarios, refer to the referenced sections.

D.6.2.1 *Radiological Releases*

Tables D.6.2–1 and D.6.2–2 present those facilities for which a radiological release has been postulated to be initiated by the earthquake for the Proposed Action and the No Action Alternative, respectively. Each of these individual facility releases was analyzed in Section D.2. Tables D.6.2–3 and D.6.2–4 present the results of the analysis for each of these facility releases for the Proposed Action for median and unfavorable meteorological conditions, respectively. Tables D.6.2–5 and D.6.2–6 present this same information for the No Action Alternative. As can be seen in these tables, under the multiple-building release scenario, the consequences to the offsite MEI and to the population within 50 miles of LLNL are primarily attributable to releases from Buildings 251, 331, and 334.

The offsite MEI for releases from the facilities listed in Table D.6.2–1 would not be at the same location. Therefore, summing the doses for each of the individual facilities as in Table D.6.2–2 is conservative. Taking this conservative approach results in a total radiation dose at the site boundary under median meteorological conditions of 1.03 rem. Using the dose-to-risk conversion factor of 6×10^{-4} per person-rem, the MEI dose has a probability of 6.02×10^{-4} (or one chance in 1,620) of the development of a fatal cancer.

The collective radiation dose to the approximately 6,900,000 people living within 50 miles of LLNL under the multiple-building release scenario for median meteorology was calculated to be 417 person-rem. Using the dose-to-risk conversion factor of 6×10^{-4} per person-rem, the collective population dose is estimated to result in an additional 0.24 LCF to this population.

Under unfavorable meteorological conditions, the radiation dose to the MEI for the multiple-building release scenario of 20.4 rem. Using the dose-to-risk conversion factor of 6×10^{-4} per person-rem, the MEI dose has a probability of 0.011 (or 1 chance in 95) of the development of a fatal cancer.

The collective radiation dose to the approximately 6,900,000 people living within 50 miles of LLNL under the multiple-building release scenario for unfavorable meteorological conditions was calculated to be 4,320 person-rem. Using the dose-to-risk conversion factor of 6×10^{-4} per person-rem, the collective population dose is estimated to result in 1.76 LCFs to this population.

For the No Action Alternative, as shown in Table D.6.2–5, the multiple-building release results in a total radiation dose at the site boundary under median meteorological conditions of 0.88 rem. Using the dose-to-risk conversion factor of 6×10^{-4} per person-rem, the MEI dose has a probability of 5.28×10^{-4} (or one chance in 1,894) of the development of a fatal cancer.

The collective radiation dose to the approximately 6,900,000 people living within 50 miles of LLNL under the multiple-building release scenario for median meteorology was calculated to be 296 person-rem. Using the dose-to-risk conversion factor of 6×10^{-4} per person-rem, the collective population dose is estimated to result in an additional 0.18 LCF to this population.

Under unfavorable meteorological conditions, the radiation dose to the MEI for the multiple-building release scenario for the No Action Alternative is 17.5 rem. Using the dose-to-risk conversion factor of 6×10^{-4} per person-rem, the MEI dose has a probability of 0.01 (or 1 chance in 95) of the development of a fatal cancer.

TABLE D.6.2–1.—*Facilities and Radiological Releases Under the Proposed Action Multiple-Building Accident Scenario*

Building	Accident	Source Term
Building 194, 100-MeV Electron-Positron LINAC Facility	Design basis earthquake and fire	3.4×10^{-4} g weapons-grade Pu
Building 239, Radiography Facility	Uncontrolled oxidation of plutonium at elevated temperatures (weapons-grade plutonium)	4.5×10^{-2} g weapons-grade Pu
	Fire involving SNM	50 g HEU
	Release of tritium	0.2 g tritium
Building 251, Heavy Element Facility	Evaluation basis fire	0.081 Ci (Am-241 equivalent)
Building 331, Tritium Facility	Tritium release during earthquake	30 g tritium gas (0.3 g as HTO)
Building 332, Plutonium Facility	Plutonium release during earthquake (filtered)	1.4×10^{-5} g fuel-grade Pu
Building 334, Hardened Engineering Test Building	Fire involving HEU (unmitigated)	100 g HEU
	Uncontrolled oxidation of plutonium at elevated temperatures	0.185 g fuel-grade Pu
	Release of tritium	0.2 g HTO
Building 514/612/625/693, Hazardous Waste Management Complex	Earthquake	1.6×10^{-4} Ci transuranic waste (use Am-241 as a surrogate) 5,000 Ci tritium 6.0×10^{-4} Ci aqueous low-level waste (Pu-equivalent Ci)
Building 581, National Ignition Facility	Earthquake during plutonium without yield experiment	0.003 g weapons-grade Pu
Building 625, Container Storage Unit	Crane fall during severe earthquake	0.022 Pu-equivalent Ci

Source: Original.
Am = americium; Ci = curie; g = gram; HEU = highly enriched uranium; HTO = tritiated water; LINAC = Lawrence Livermore National Laboratory Electron-Positron; Pu = plutonium; SNM = special nuclear materials.

TABLE D.6.2–2.—*Facilities and Radiological Releases Under the No Action Alternative Multiple-Building Accident Scenario*

Building	Accident	Source Term
Building 194, 100-MeV Electron-Positron LINAC Facility	Design basis earthquake and fire	3.4×10^{-4} g weapons-grade Pu
Building 239, Radiography Facility	Uncontrolled oxidation of plutonium at elevated temperatures (weapons-grade plutonium)	4.5×10^{-2} weapons-grade Pu
	Fire involving SNM	25 g HEU
	Release of tritium	0.2 g tritium
Building 251, Heavy Element Facility	Evaluation basis fire	0.081 Ci (Am-241 equivalent)
Building 331, Tritium Facility	Tritium release during earthquake	3.5 g tritium gas (0.035 g as HTO)
Building 332, Plutonium Facility	Plutonium release during earthquake (filtered)	1.4×10^{-5} g fuel-grade Pu
Building 334, Hardened Engineering Test Building	Fire involving HEU (unmitigated)	100 g HEU
	Uncontrolled oxidation of plutonium at elevated temperatures	0.185 g fuel-grade Pu
	Release of tritium	0.2 g HTO
Building 514/612/625/693, Hazardous Waste Management Complex	Earthquake	1.6×10^{-4} Ci transuranic waste (use Am-241 as a surrogate) 5,000 Ci tritium 6.0×10^{-4} Ci aqueous low-level waste (Pu-equivalent Ci)
Building 581, National Ignition Facility	Earthquake during plutonium without yield experiment	500 Ci tritium plus activated gases and particulates
Building 625, Container Storage Unit	Crane fall during severe earthquake	0.0072 Pu-equivalent Ci

Source: Original.
Am = americium; Ci = curie; g = gram; HEU = highly enriched uranium; HTO = tritiated water; LINAC = Linear Accelerator; Pu = plutonium; SNM = special nuclear materials.

TABLE D.6.2–3.—*Potential Lawrence Livermore National Laboratory Multi-Building Accident Scenario Radiological Consequences for the Proposed Action (Median Meteorology)*

	MEI		Offsite Population[a]		Individual Noninvolved Worker		Noninvolved Worker Population	
Source Term	**Dose (rem)**	**LCFs[b]**	**Dose (person-rem)**	**LCFs[c]**	**Dose (rem)**	**LCFs[b]**	**Dose (person-rem)**	**LCFs[c]**
Building 194, 100 MeV Electron-Positron LINAC Facility								
3.4×10^{-4} g weapons-grade Pu	8.66×10^{-4}	5.20×10^{-7}	2.23×10^{-1}	1.34×10^{-4}	3.43×10^{-3}	2.06×10^{-6}	5.83×10^{-1}	3.50×10^{-4}
Building 239, Radiography Facility								
4.5×10^{-2} g weapons-grade Pu plus 5.0×10^{1} g HEU plus 2.0×10^{-1} g tritium	2.34×10^{-2}	1.40×10^{-5}	8.97	5.38×10^{-3}	3.34×10^{-1}	2.00×10^{-4}	3.51×10^{1}	2.11×10^{-2}
Building 251, Heavy Element Facility								
8.1×10^{-2} Ci Am-241 equivalent	6.01×10^{-1}	3.61×10^{-4}	1.88×10^{2}	1.13×10^{-1}	5.70	3.42×10^{-3}	8.26×10^{2}	4.96×10^{-1}
Building 331, Tritium Facility								
3.0×10^{1} g tritium gas (0.3 g as HTO)	1.63×10^{-1}	9.78×10^{-5}	1.13×10^{2}	6.78×10^{-2}	2.11	1.27×10^{-3}	2.73×10^{2}	1.64×10^{-1}
Building 332, Plutonium Facility								
1.4×10^{-5} g fuel-grade Pu	8.22×10^{-6}	4.93×10^{-9}	5.22×10^{-3}	3.13×10^{-6}	9.21×10^{-5}	5.53×10^{-8}	1.74×10^{-2}	1.04×10^{-5}
Building 334, Hardened Engineering Test Building								
1.0×10^{2} g HEU plus 1.85×10^{-1} g fuel-grade Pu plus 2.0×10^{-1} g HTO	1.73×10^{-1}	8.63×10^{-5}	7.20×10^{1}	3.60×10^{-2}	3.42	1.37×10^{-3}	2.43×10^{2}	1.46×10^{-1}
Building 514/612/625/693, Hazardous Waste Management Complex								
1.6×10^{-4} Ci Am-241 plus 5.0×10^{3} Ci tritium plus 6.0×10^{-4} Pu-equivalent Ci	5.84×10^{-2}	3.50×10^{-5}	3.17	1.90×10^{-3}	1.10×10^{-1}	6.61×10^{-5}	2.03	1.22×10^{-3}
Building 581, National Ignition Facility								
3.0×10^{-3} g weapons-grade Pu	1.65×10^{-3}	9.89×10^{-7}	3.34	3.28×10^{-4}	4.99×10^{-3}	3.00×10^{-6}	7.41×10^{-1}	4.45×10^{-4}
Building 625, Container Storage Unit								
2.2×10^{-2} Pu-equivalent Ci	1.14×10^{-2}	6.84×10^{-6}	3.17×10^{1}	1.90×10^{-2}	3.10×10^{-2}	1.86×10^{-5}	1.45	8.71×10^{-4}
Total								
	1.03	6.02×10^{-4}	4.20×10^{2}	2.43×10^{-1}	1.17×10^{1}	6.35×10^{-3}	1.38×10^{3}	8.29×10^{-1}

Source: Original.
Am = americium; Ci = curie; g = gram; HEU = highly enriched uranium; HTO = tritiated water; LCF = latent cancer fatalities; LINAC = Linear Accelerator; MEI = maximally exposed individual; Pu = plutonium; SNM = special nuclear materials.
[a] Based on the population of approximately 6,900,000 person residing within 50 miles of LLNL.
[b] Increased likelihood of a latent cancer fatality.
[c] Increased number of latent cancer fatalities.

TABLE D.6.2–4.—*Potential Lawrence Livermore National Laboratory Multi-Building Accident Scenario Radiological Consequences for the Proposed Action (Unfavorable Meteorology)*

	MEI		Offsite Population[a]		Individual Noninvolved Worker		Noninvolved Worker Population	
Source Term	**Dose (rem)**	**LCFs[b]**	**Dose (person-rem)**	**LCFs[c]**	**Dose (rem)**	**LCFs[b]**	**Dose (person-rem)**	**LCFs[c]**
Building 194, 100 MeV Electron-Positron LINAC Facility								
3.4×10^{-4} g weapons-grade Pu	1.30×10^{-2}	7.80×10^{-6}	1.81	1.09×10^{-3}	3.30×10^{-2}	1.98×10^{-5}	3.47	2.08×10^{-3}
Building 239, Radiography Facility								
4.5×10^{-2} g weapons-grade Pu plus 5.0×10^{1} g HEU plus 2.0×10^{-1} g tritium	4.97×10^{-1}	2.98×10^{-4}	1.42×10^{2}	8.54×10^{-2}	4.02	2.41×10^{-3}	2.67×10^{2}	1.60×10^{-1}
Building 251, Heavy Element Facility								
8.1×10^{-2} Ci Am-241 equivalent	1.18×10^{1}	7.10×10^{-3}	1.22×10^{3}	7.34×10^{-1}	6.46×10^{1}	3.88×10^{-2}	4.52×10^{3}	2.71
Building 331, Tritium Facility								
3.0×10^{1} g tritium gas (0.3 g as HTO)	3.26	2.28×10^{-4}	1.56×10^{3}	1.10×10^{-1}	2.55×10^{1}	1.79×10^{-3}	2.05×10^{3}	1.44×10^{-1}
Building 332, Plutonium Facility								
1.4×10^{-5} g fuel-grade Pu	1.57×10^{-4}	9.41×10^{-8}	6.08×10^{-2}	3.65×10^{-5}	8.33×10^{-4}	5.00×10^{-7}	1.46×10^{-1}	8.74×10^{-5}
Building 334, Hardened Engineering Test Building								
1.0×10^{2} g HEU plus 1.85×10^{-1} g fuel-grade Pu plus 2.0×10^{-1} g HTO	3.88	2.33×10^{-3}	1.08×10^{3}	6.51×10^{-1}	4.62×10^{1}	2.77×10^{-2}	2.19×10^{3}	1.31
Building 514/612/625/693, Hazardous Waste Management Complex								
1.6×10^{-4} Ci Am-241 plus 5.0×10^{3} Ci tritium plus 6.0×10^{-4} Pu-equivalent Ci	8.95×10^{-1}	5.37×10^{-4}	2.60×10^{1}	1.56×10^{-2}	1.40	8.41×10^{-4}	3.66×10^{1}	2.20×10^{-2}
Building 581, National Ignition Facility								
3.0×10^{-3} g weapons-grade Pu	2.16×10^{-2}	3.69×10^{-6}	8.33	1.83×10^{-3}	4.69×10^{-2}	8.01×10^{-6}	8.23	1.33×10^{-3}
Building 625, Container Storage Unit								
2.2×10^{-2} Pu-equivalent Ci	3.08×10^{-2}	1.85×10^{-5}	2.77×10^{2}	1.66×10^{-1}	1.29	7.76×10^{-4}	3.08×10^{1}	1.85×10^{-2}
Total								
	2.04×10^{1}	1.05×10^{-2}	4.33×10^{3}	1.76	1.43×10^{2}	7.24×10^{-2}	9.10×10^{3}	4.37

Source: Original.
Am = americium; Ci = curie; g = gram; HEU = highly enriched uranium; HTO = tritiated water; LCF = latent cancer fatalities; LINAC = Linear Accelerator; MEI = maximally exposed individual; Pu = plutonium; SNM = special nuclear materials.
[a] Based on the population of approximately 6,900,000 person residing within 50 miles of LLNL.
[b] Increased likelihood of a latent cancer fatality.
[c] Increased number of latent cancer fatalities.

TABLE D.6.2–5.—*Potential Lawrence Livermore National Laboratory Multi-Building Accident Scenario Radiological Consequences for the No Action Alternative (Median Meteorology)*

	MEI		Offsite Population[a]		Individual Noninvolved Worker		Noninvolved Worker Population	
Source Term	Dose (rem)	LCFs[b]	Dose (person-rem)	LCFs[c]	Dose (rem)	LCFs[b]	Dose (person-rem)	LCFs[c]
Building 194, 100 MeV Electron-Positron LINAC Facility								
3.4×10^{-4} g weapons-grade Pu	8.66×10^{-4}	5.20×10^{-7}	2.23×10^{-1}	1.34×10^{-4}	3.43×10^{-3}	2.06×10^{-6}	5.83×10^{-1}	3.50×10^{-4}
Building 239, Radiography Facility								
4.5×10^{-2} g weapons-grade Pu plus 2.5×10^{1} g HEU plus 2.0×10^{-1} g tritium	2.34×10^{-2}	1.40×10^{-5}	8.97	5.38×10^{-3}	3.34×10^{-1}	2.00×10^{-4}	3.51×10^{1}	2.11×10^{-2}
Building 251, Heavy Element Facility								
8.1×10^{-2} Ci Am-241 equivalent	6.01×10^{-1}	3.61×10^{-4}	1.88×10^{2}	1.13×10^{-1}	5.70	3.42×10^{-3}	8.26×10^{2}	4.96×10^{-1}
Building 331, Tritium Facility								
3.5 g tritium gas (0.035 g as HTO)	1.90×10^{-2}	1.14×10^{-5}	1.32×10^{1}	7.91×10^{-3}	2.46×10^{-1}	1.48×10^{-4}	3.19×10^{1}	1.91×10^{-2}
Building 332, Plutonium Facility								
1.4×10^{-5} g fuel-grade Pu	8.22×10^{-6}	4.93×10^{-9}	5.22×10^{-3}	3.13×10^{-6}	9.21×10^{-5}	5.53×10^{-8}	1.74×10^{-2}	1.04×10^{-5}
Building 334, Hardened Engineering Test Building								
1.0×10^{2} g HEU plus 1.85×10^{-1} g fuel-grade Pu plus 2.0×10^{-1} g HTO	1.73×10^{-1}	1.04×10^{-4}	7.20×10^{1}	4.32×10^{-2}	3.42	2.05×10^{-3}	2.43×10^{2}	1.46×10^{-1}
Building 514/612/625/693, "Hazardous Waste Management Complex"								
1.6×10^{-4} Ci Am-241 plus 5.0×10^{3} Ci tritium plus 6.0×10^{-4} Pu-equivalent Ci	5.84×10^{-2}	3.50×10^{-5}	3.17	1.90×10^{-3}	1.10×10^{-1}	6.61×10^{-5}	2.03	1.22×10^{-3}
Building 581, National Ignition Facility								
5.0×10^{2} Ci tritium plus activated gases and particulates	4.78×10^{-4}	2.87×10^{-7}	1.96×10^{-1}	1.18×10^{-4}	1.43×10^{-3}	8.60×10^{-7}	2.08×10^{-1}	1.25×10^{-4}
Building 625, Container Storage Unit								
7.2×10^{-3} Pu-equivalent Ci	3.73×10^{-3}	2.24×10^{-6}	1.04×10^{1}	6.22×10^{-3}	1.01×10^{-2}	6.09×10^{-6}	4.75×10^{-1}	2.85×10^{-4}
Total								
	8.80×10^{-1}	5.28×10^{-4}	2.96×10^{2}	1.78×10^{-1}	9.83	5.90×10^{-3}	1.14×10^{3}	6.84×10^{-1}

Source: Original.
Am = americium; Ci = curie; g = gram; HEU = highly enriched uranium; HTO = tritiated water; LCF = latent cancer fatalities; LINAC = Linear Accelerator; MEI = maximally exposed individual; Pu = plutonium; SNM = special nuclear materials.
[a] Based on the population of approximately 6,900,000 person residing within 50 miles of LLNL.
[b] Increased likelihood of a latent cancer fatality.
[c] Increased number of latent cancer fatalities.

TABLE D.6.2–6.—*Potential Lawrence Livermore National Laboratory Multi-Building Accident Scenario Radiological Consequences for the No Action Alternative (Unfavorable Meteorology)*

	MEI		Offsite Population[a]		Individual Noninvolved Worker		Noninvolved Worker Population	
Source Term	**Dose (rem)**	**LCFs[b]**	**Dose (person-rem)**	**LCFs[c]**	**Dose (rem)**	**LCFs[b]**	**Dose (person-rem)**	**LCFs[c]**
Building 194, 100 MeV Electron-Positron LINAC Facility								
3.4×10^{-4} g weapons-grade Pu	1.30×10^{-2}	7.80×10^{-6}	1.81	1.09×10^{-3}	3.30×10^{-2}	1.98×10^{-5}	3.47	2.08×10^{-3}
Building 239, Radiography Facility								
4.5×10^{-2} g weapons-grade Pu plus 2.5×10^{1} g HEU plus 2.0×10^{-1} g tritium	4.97×10^{-1}	2.98×10^{-4}	1.42×10^{2}	8.54×10^{-2}	4.02	2.41×10^{-3}	2.67×10^{2}	1.60×10^{-1}
Building 251, Heavy Element Facility								
8.1×10^{-2} Ci Am-241 equivalent	1.18×10^{1}	7.10×10^{-3}	1.22×10^{3}	7.34×10^{-1}	6.46×10^{1}	3.88×10^{-2}	4.52×10^{3}	2.71
Building 331, Tritium Facility								
3.5 g tritium gas (0.035 g as HTO)	3.80×10^{-1}	2.28×10^{-4}	1.83×10^{2}	1.10×10^{-1}	2.98	1.79×10^{-3}	2.39×10^{2}	1.44×10^{-1}
Building 332, Plutonium Facility								
1.4×10^{-5} g fuel-grade Pu	1.57×10^{-4}	9.41×10^{-8}	6.08×10^{-2}	3.65×10^{-5}	8.33×10^{-4}	5.00×10^{-7}	1.46×10^{-1}	8.74×10^{-5}
Building 334, Hardened Engineering Test Building								
1.0×10^{2} g HEU plus 1.85×10^{-1} g fuel-grade Pu plus 2.0×10^{-1} g HTO	3.88	2.33×10^{-3}	1.08×10^{3}	6.51×10^{-1}	4.62×10^{1}	2.77×10^{-2}	2.19×10^{3}	1.31
Building 514/612/625/693, Hazardous Waste Management Complex								
1.6×10^{-4} Ci Am-241 plus 5.0×10^{3} Ci tritium plus 6.0×10^{-4} Pu-equivalent Ci	8.95×10^{-1}	5.37×10^{-4}	2.60×10^{1}	1.56×10^{-2}	1.40	8.41×10^{-4}	3.66×10^{1}	2.20×10^{-2}
Building 581, National Ignition Facility								
5.0×10^{2} Ci tritium plus activated gases and particulates	6.15×10^{-3}	3.69×10^{-6}	3.05	1.83×10^{-3}	1.33×10^{-2}	8.01×10^{-6}	2.22	1.33×10^{-3}
Building 625, Container Storage Unit								
7.2×10^{-3} Pu-equivalent Ci	1.01×10^{-2}	6.05×10^{-6}	9.07×10^{1}	5.44×10^{-2}	4.23×10^{-1}	2.54×10^{-4}	1.01×10^{1}	6.05×10^{-3}
Total								
	1.75×10^{1}	1.05×10^{-2}	2.75×10^{3}	1.65	1.20×10^{2}	7.18×10^{-2}	7.27×10^{3}	4.36

Source: Original.
Am = americium; Ci = curie; g = gram; HEU = highly enriched uranium; HTO = tritiated water; LCF = latent cancer fatalities; LINAC = Linear Accelerator; MEI = maximally exposed individual; Pu = plutonium; SNM = special nuclear materials.
[a] Based on the population of approximately 6,900,000 person residing within 50 miles of LLNL.
[b] Increased likelihood of a latent cancer fatality.
[c] Increased number of latent cancer fatalities.

The collective radiation dose to the approximately 6,900,000 people living within 50 miles of LLNL under the multiple-building release scenario for unfavorable meteorological conditions was calculated to be 2,750 person-rem. Using the dose-to-risk conversion factor of 6×10^{-4} per person-rem, the collective population dose is estimated to result in 1.65 LCFs to this population.

D.6.2.2 *Chemical Releases*

Table D.6.2–7 presents those facilities for which a chemical release has been postulated to be initiated by the 0.8-*g* earthquake. Each of these individual facility releases was analyzed in Section D.3. Tables D.6.2–8 and D.6.2–9 present the results of the analysis for each of these facility releases for median and unfavorable meteorological conditions, respectively. As can be seen in Table D.6.2–8, under the multiple-building release scenario, the consequences at the site boundary would be dominated by the chlorine rupture and release from Building 332 (median meteorology), and the toxic gas release (nitrogen dioxide) from Building 334 (unfavorable meteorological conditions).

TABLE D.6.2–7.—*Facilities and Chemical Releases Under the Multiple-Building Accident Scenario*

Building	Accident	Source Term
Building 191, High Explosives Application Facility	Chemical dispersion	0.1 lb 1,2-Dichloroethane
Building 231, Vault Materials Management Complex	Spill release of toxic materials	2,256 g LiOH
Building 239, Radiography Facility	Toxic gas release	10,000 g NO_2
Building 322, Plating Shop	Multiple Container Liquid Spill	100 lb hydrofluoric acid
Building 331, Tritium Facility actinide activities	Nitric acid spill	38 L nitric acid
Building 332, Plutonium Facility	Unmitigated chlorine rupture	100 lb chlorine
Building 334, Hardened Engineering Test Building	Toxic gas release	40,000 g NO_2
Building 514/612/693, Radioactive and Hazardous Waste Management Complex	Earthquake	422 lb Freon-22 (chlorodifluoromethane)
Building 581, National Ignition Facility	Materials spill	400 L nitric acid solution (70%)

Source: Original.
g = gram; L = liter; lb = pound; LiOH = lithium hydroxide; NO_2 = nitrogen dioxide.

For this accident, under median meteorological conditions, concentrations above the ERPG-2 level would exist as far out at 1.7 kilometers from Building 332, which would extend about 600 meters beyond the site boundary. At the site boundary, the concentration would be below ERPG-3 values, but above ERPG-2 values, indicating that persons exposed to this concentration could experience irreversible or other serious health effects or symptoms that could impair their ability to take protective action. At the noninvolved worker location, the concentration would be above ERPG-3 values, indicating that individuals exposed to this concentration could experience or develop life-threatening health effects.

For this accident, under unfavorable meteorological conditions, concentrations above the ERPG-2 level would exist as far as 2.9 kilometers from Building 334. At the site boundary and at the noninvolved worker location, the concentration would be above ERPG-3 values, indicating that individuals exposed to this concentration could experience or develop life-threatening health effects.

TABLE D.6.2–8.—*Potential Multi-Building Accident Scenario Chemical Consequences (Median Meteorology)*

		Noninvolved Worker		Site Boundary		
ERPG-2 Concentration (ppm)	**ERPG-3 Concentration (ppm)**	**Average Predicted Concentration (ppm)**	**Fraction of ERPG-2**	**Average Predicted Concentration (ppm)**	**Fraction of ERPG-2**	**ERPG-2 Distance (meters)**
Building 191, High Explosives Application Facility – Chemical dispersion (1,2-Dichloroethane)						
200	300	0.108	5.4×10^{-4}	0.0175	8.8×10^{-5}	11
Building 239, Radiography Facility – Toxic gas release (NO_2)						
5	20	27.5	5.5	0.81	016	246
Building 322, Plating Shop – Multiple Container Liquid Spill (Hydrofluoric Acid)						
20	50	371	18.6	4.86	0.24	475
Building 331, Tritium Facility actinide activities – Nitric acid spill						
6	78	24	4	0.24	0.04	205
Building 332, Plutonium Facility – Chlorine release						
3	20	593	198	11.6	3.9	1,700
Building 334, Hardened Engineering Test Building – Toxic gas release (NO_2)						
5	20	110	22	2.02	0.40	529
Building 514/612/693, Radioactive and Hazardous Waste Management Complex – Earthquake release of Freon-22						
7,500	7,500	415	0.06	169	0.023	19
Building 581, National Ignition Facility – Release of nitric acid solution						
6	78	130	21.7	12.3	2.1	536

Source: Original.
ERPG = Emergency Response Planning Guideline; NO_2 = nitrogen dioxide; ppm = parts per million.

TABLE D.6.2–9.—*Lawrence Livermore National Laboratory Multi-Building Accident Scenario Chemical Consequences (Unfavorable Meteorology)*

		Noninvolved Worker		Site Boundary		
ERPG-2 Concentration (ppm)	**ERPG-3 Concentration (ppm)**	**Average Predicted Concentration (ppm)**	**Fraction of ERPG-2**	**Average Predicted Concentration (ppm)**	**Fraction of ERPG-2**	**ERPG-2 Distance (meters)**
Building 191, High Explosives Application Facility – Chemical dispersion (1,2-Dichloroethane)						
200	300	1.41	7.1×10^{-3}	0.272	1.4×10^{-3}	11
Building 239, Radiography Facility – Toxic gas release (NO_2)						
5	20	1,430	286	35.2	7.04	1,600
Building 322, Plating Shop – Multiple Container Liquid Spill (Hydrofluoric Acid)						
20	50	4,680	234	46.4	2.32	1,400
Building 331, Tritium Facility – Nitric Acid Spill						
65	78	68	11.3	1.1	0.18	358
Building 332, Plutonium Facility – Chlorine release						
3	20	5,220	1,740	16.9	5.64	1,900
Building 334, Hardened Engineering Test Building – Toxic gas release (NO_2)						
5	20	5,720	1,140	77.8	15.6	2,900
Building 514/612/693, Radioactive and Hazardous Waste Management Complex – Earthquake release of Freon-22						
7,500	7,500	4,080	0.54	1,312	0.17	75
Building 581, National Ignition Facility – Release of Nitric Acid Solution						
6	78	438	73	51.4	8.57	1,400

Source: Original.
ERPG = Emergency Response Planning Guideline; NO_2 = nitrogen dioxide; ppm = parts per million.

D.7 REFERENCES

40 CFR §1502.22	Council on Environmental Quality (CEQ), "Protection of the Environment, Environmental Impact Statement, Incomplete or Unavailable Information," *Code of Federal Regulations*, Office of the Federal Register National Archives and Records Administration, U.S. Government Printing Office, Washington, DC, Revised July 1, 2003.
Army 1989	Army, *Final Programmatic Environmental Impact Statement Biological Defense Research Program,* United States Army, Medical Research and Development Command, Washington, DC, April 1989.
Chanin and Young 1997	Chanin, David and Mary L. Young, *Code Manual for MACCS2: Volume 1, User's Guide*, SAND97-0594.UC-610, Sandia National Laboratories, Accident Analysis/Consequence Assessment Department, Albuquerque, NM, March 1997.
EPA 1999	U.S. Environmental Protection Agency (EPA), *ALOHA (Areal Locations of Hazardous Atmospheres) User's Manual*, U.S. Environmental Protection Agency, Chemical Emergency Preparedness Office and NOAA Hazardous Materials Response Division, Washington, DC and Seattle, WA, August 1999.
Lawrence 2002	Lawrence, Andy, Memorandum from Andy Lawrence, U.S. Department of Energy, Office of Environmental Policy and Guidance, dated August 9, 2002, regarding the *Radiation Risk Estimation from Total Effective Dose Equivalents (TEDE's)*, Washington, DC, 2002.
LLNL 1999e	Lawrence Livermore National Laboratory (LLNL), *Preliminary Safety Analysis Report for Building 280*, UCRL-AR-125031, Lawrence Livermore National Laboratory, Livermore, CA, November 1999.
LLNL 2000d	LLNL, *Hazards Analysis Report, Building 327,* UCRL-AR-145432, Lawrence Livermore National Laboratory, Hazards Control Department, Livermore, CA, October 3, 2000.
LLNL 2001aj	LLNL, *Safety Analysis Report, Heavy Element Facility, Building 251*, UCRL-AR-113377, Rev. 1, Lawrence Livermore National Laboratory, Livermore, CA, April 1, 2001.

LLNL 2001at	LLNL, *Building 334 Safety Analysis Report*, SAR-B334, Rev.1, Lawrence Livermore National Laboratory, Defense and Nuclear Technologies Directorate, Livermore, CA, March 2001.
LLNL 2001ax	LLNL, *Building 233 Container Storage Unit Final Safety Analysis Report, Hazardous Waste Management Division*, UCRL-AR-123632, Rev. 1, Lawrence Livermore National Laboratory, Livermore, CA, April 26, 2001.
LLNL 2002l	LLNL, *Site 300 Materials Management Facilities Safety Analysis Report*, UCRL-AR-122035, Rev. 2, Lawrence Livermore National Laboratory, Engineering Directorate, Livermore, CA, February 2002.
LLNL 2002s	LLNL, *Hardened Engineering Test Building- Building 334 Safety Analysis Report*, UCRL-AR-123109-02-DR, Lawrence Livermore National Laboratory, Defense and Nuclear Technologies Directorate, Livermore, CA, September 2002.
LLNL 2002ac	LLNL, *UCNI-Safety Analysis Report, Building 239, Radiography Facility*, SAR-B239, Lawrence Livermore National Laboratory, Livermore, CA, March 2002.
LLNL 2002ad	LLNL, *Building 331 Safety Analysis Report*, TSR B331, Lawrence Livermore National Laboratory, Livermore, CA, June 2002.
LLNL 2002af	LLNL, *Building 332 (UNCI), Plutonium Facility Safety Analysis Report*, SAR-332, NMTP-02-067, Lawrence Livermore National Laboratory, *Nuclear Materials Technology Directorate,* Livermore, CA, June 26, 2002.
LLNL 2002bd	LLNL, *Figure showing California Red-legged Frog Critical Habitat at LLNL, Livermore Site*, Lawrence Livermore National Laboratory, Livermore, CA, 2002.
LLNL 2002bl	LLNL, *A Detailed Aircraft Crash Probability Analysis into LLNL Building 332 in Accordance with DOE-STD-3014096 using 1996 Data*, PuFO 02-176, Lawrence Livermore National Laboratory, Livermore, CA, May 2002.
LLNL 2002bm	LLNL, *Hazardous Waste Management Facilities Final Safety Analysis Report*, UCRL-CR-113523, Rev. 2, Lawrence Livermore National Laboratory, Environmental Protection Department, Livermore, CA, May 2002.

LLNL 2002bo LLNL, *Building 332 (UNCI), Plutonium Facility, Safety Analysis Report*, Vol. 2, Chapt. 6-17, UCRL-AR-119434-00, Lawrence Livermore National Laboratory, Defense and Nuclear Technologies Directorate, Livermore, CA, February 2002.

LLNL 2002bw LLNL, *Safety Assessment Document, Multi-User Tandem Laboratory, Building 190, Implementation of DOE O 420.2,* Lawrence Livermore National Laboratory, Livermore, CA, August 2002.

LLNL 2002cp LLNL, *Safety Analysis Report, High Explosives Applications Facility*, SAR-HEAP, UCRL-AR-144992, Rev.0, Lawrence Livermore National Laboratory, Livermore, CA, July 2002.

LLNL 2002cq LLNL, *Safety Assessment Document for the 100 MEV-Positron LINAC Facility,* Rev 7, Lawrence Livermore National Laboratory, Livermore, *CA,* July 22, 2002.

LLNL 2002da LLNL, *Safety Analysis Report for the B696R Radioactive Waste Storage Area*, HWMD-01-065, Rev. 2, Lawrence Livermore National Laboratory, Livermore, CA, June 2002.

LLNL 2003d LLNL, *NIF Project Input for Assessment of Environmental Impacts of NIF for the Site-wide Environmental Impact Statement*, UCRL-TR-155675, Lawrence Livermore National Laboratory, Livermore, CA, October 2003.

LLNL 2003f LLNL, *Environmental Microbial Biotechnology Research*, Operational Safety Plan No. 446.01, Lawrence Livermore National Laboratory, Livermore, CA, February 2003.

LLNL 2003t LLNL, *Safety Analysis Report and Technical Safety Requirements Regarding B332 DSA*, Lawrence Livermore National Laboratory, Livermore, CA, October 10, 2003.

LLNL 2003y LLNL, Letter from Ellen Raber, LLNL to D. Nakahara, DOE, dated May 29, 2003, regarding a*ircraft crash impact information for the Site-wide Environmental Impact Statement*, Lawrence Livermore National Laboratory, Livermore, CA, 2003.

LLNL 2003bg LLNL, Email from J. Yang, LLNL, to Tom Grim, NNSA, dated July 10, 2003, regarding *Composite Aircraft Crash Probability*, Lawrence Livermore National Laboratory, Livermore, CA, 2003.

LLNL n.d. LLNL, *Final Safety Analysis Report for the Explosives Waste Treatment Facility, Building 845 at Site 300*, UCRL-AR-127869DR, Lawrence Livermore National Laboratory, Livermore, CA, n.d.

NNSA 2001a National Nuclear Security Administration (NNSA)*, Safety Analysis Report, Building 231 Vault (UNCI)*, UCRL-AR-118884, Rev. 1, U.S. Department of Energy, National Nuclear Security Administration, Oakland Operations Office, Oakland, CA, December 14, 2001.