APPENDIX G
ACCIDENT ANALYSIS

G.1 INTRODUCTION

The NEPA decision maker and the stakeholders need to know the consequences of the different SWEIS alternatives. Some but not all of the consequences are those of the possible accidents. Accidents are defined as unexpected or undesirable events that lead to the release of hazardous material within a facility or into the environment (DOE 1996a), exposing workers and/or the public to hazardous materials or radiation.

There are two benefits from this SWEIS accident analysis. First, the analysis conservatively characterizes the overall risk posed by the operation, creating a context for the decision maker and putting the site in perspective for the public. Second, it quantifies the increment in risk among the several alternatives, as an input into the decision.

G.1.1 Characterization of the Risk from Accidents

Characterization includes a consideration of the type of the accident (e.g., fire, explosion, spill, leak, depressurization, criticality, etc.), the initiator (e.g., human error, chemical reaction, earthquake, strong wind, flood, vehicle accident, mechanical failure, etc.) the material at risk (e.g., plutonium, tritium, toxic chemical, explosives, inflammable gas, etc.). Characterization also considers the type of consequences of the accident (e.g., immediate fatalities, prompt reversible and irreversible health effects, latent cancers—some of which lead to eventual death), and the magnitude of the consequences (e.g., to workers only, to hypothetical members of the public, to a few, some or many real individuals off site, etc.). Finally, characterization considers the likelihood that an accident will occur.

Because LANL is a complex and diverse site, there are (as at any site) a wide range of accident scenarios that can be hypothesized, with a corresponding range of likelihoods and consequences, both realistic and imagined. For this SWEIS we analyze accidents that could result in the release of hazardous materials from particular facilities and operations. While such releases are not routinely expected, because controls are in place to prevent such releases or limit their consequences, there are many scenarios that could potentially end in such a release. The analyses in this SWEIS select the more probable scenarios.

To characterize the accident risk at LANL, this analysis has deliberately chosen a range of types of accidents and a range of consequences, including among these accidents for which the public has shown concern. This analysis does not attempt to identify every possible accident scenario, but instead selects accidents that characterize or dominate the risk to the public from site operations (referred to as risk-significant accidents). It thereby provides an objective context for the public to evaluate the risk posed by site operations and a context for the decision among alternatives.

Accident scenarios may be considered "risk-significant" when they pose risks that are significant in the context of the total risk posed by the site and when compared to other site accidents. The term "risk-significant" does not imply a threshold or particular magnitude of risk. If the risk posed by the site is small or very small, then a risk-significant accident at that site has a correspondingly small or very small risk.

By identifying the locations of appreciable quantities of hazardous material, the accidents associated with these materials can be assessed. By grouping these 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 as well as those that characterize the risk of operating LANL.

Such grouping or "binning" of accidents is illustrated in Figure G.1.1–1. Accidents assigned to bins within a row vary in terms of their consequences but not their frequencies. 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. Accidents that are in the same bin have about the same risk. Thus, when accidents are considered within the context of this matrix, they can be compared qualitatively, and their relative risk ranking can be used for decision making.

There can be, however, a large number of different potential accidents or scenarios at a site such as LANL, especially of those in the high probability-low consequence bins (for example, minor industrial accidents). However, the risk changes exponentially as one goes from one column or row to another. Therefore, by selecting accidents with the highest consequences for a particular frequency row, the accidents that contribute the most to the overall risk to the public from site operations can be considered. Also, these accidents can be characterized by the type of material-at-risk, accident initiators, their scenario progression, and the type and magnitude of their consequences. In particular, the question can now be considered as to the degree by which the risk-significant accidents change across the alternatives. In other words, is there a decision within this SWEIS that could and should be influenced by a change in risk? Not until the potential accidents change, from at least one frequency range or consequence range to another, or accidents are added or deleted as a result of changes in mission and operations, does the risk profile for the site change significantly.

Any particular facility or inventory can be affected by a wide variety of accidents that may have about the same frequency and about the same consequences. For instance, some of the gases in cylinders at a gas cylinder storage facility can be released by fire or by impact from a variety of initial causes. All of these 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 at that storage facility, at times, a larger inventory of a particularly toxic gas whose probability of release is low but that would have larger consequences than releases of the other gases. This postulated accident would be a "bounding accident" whose consequences would not be exceeded with any reasonable possibility or probability. For purposes of a SWEIS, the bounding accidents are intended to provide an envelope that captures variations in routine operations and inventories whose details cannot be predicted.

These representative and bounding accidents characterize the many accidents that could be postulated for that material or facility. There would be no benefit gained in a SWEIS from analyzing each of the many accidents so characterized.

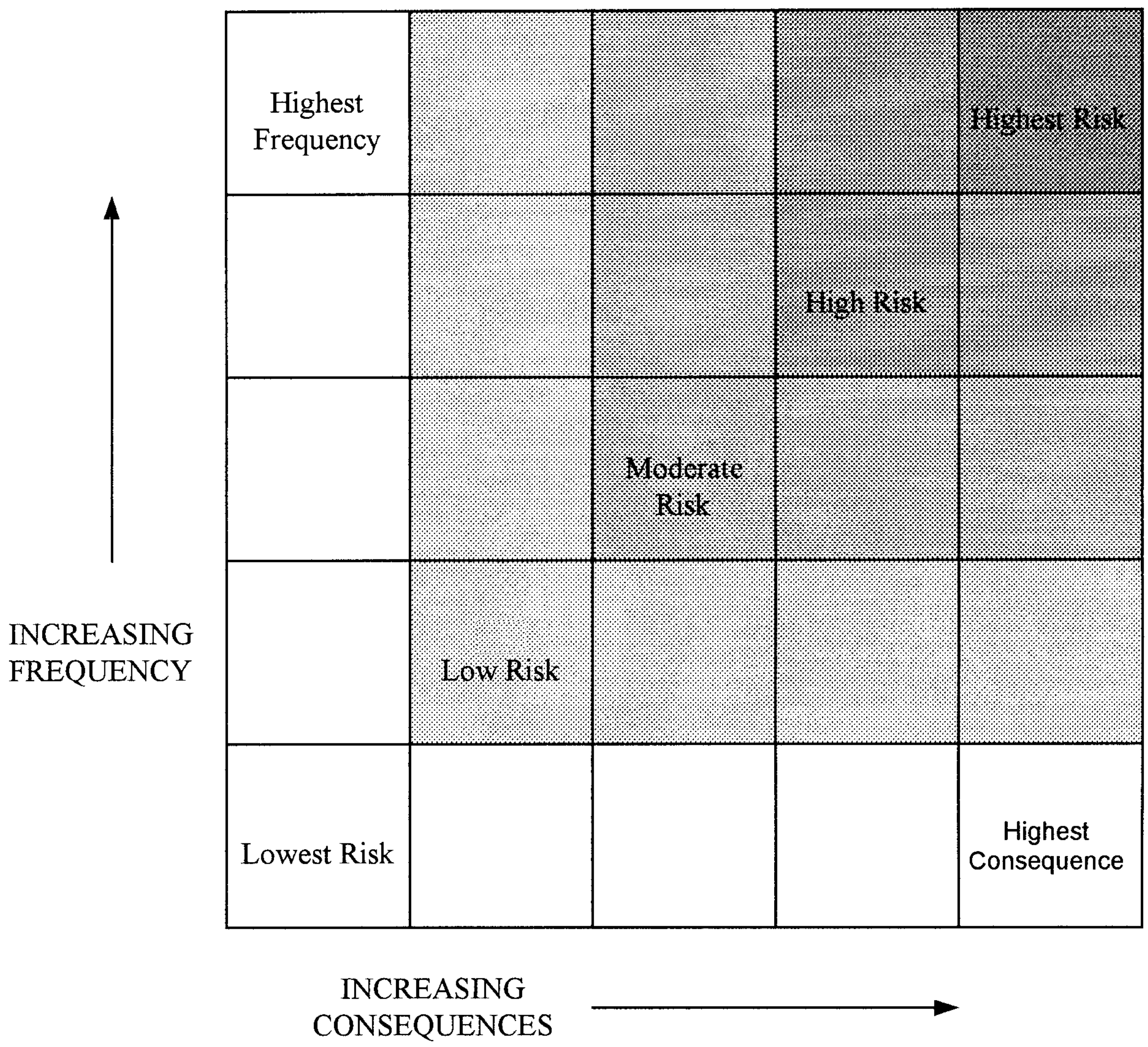

FIGURE G.1.1–1.—*Facility Accident Risk Matrix.*

G.1.2 The Meaning of Risk and Frequency as Used in this SWEIS

The word "risk" is defined in the dictionary as the probability that a specific loss or injury will occur. However, if the injury would be small, then most people would agree that the risk posed by the venture is small also. Therefore, DOE couples the consequence of an event with the probability that it will occur, and calls this combination the "risk." Note that a high-consequence event would not necessarily have significant risk (in the context of NEPA analysis) if its probability is very low.

For many events, the risk can be 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 cancer 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 x 1/1000 or 0.001 excess latent cancer per year. This product of consequence and probability is called "societal risk" in this SWEIS. It permits the ready comparison of accidents and alternatives without the burden of the details. The details are presented in this appendix.

The probability of the accident is typically expressed as its estimated frequency; that is, an accident with a frequency of 1×10^{-3} per year has a probability of occurring once in 1,000 years and twice in 2,000 years. This is another way of saying that the probability of the accident occurring in any particular year is 1 in 1,000. In the case of natural phenomena, this is also expressed as a "return period" of 1,000 years. This does NOT mean that once the phenomenon occurs, it will be another 999 years before it occurs (returns) again, because the probability is with regard to its occurring in any selected 12-month period[1].

G.1.3 Determining the Increment in Risk Among Alternatives

Although it is possible to characterize or represent the risk posed by the operation, there are too many possibilities and uncertainties to quantify the total absolute risk. Any attempt to adjust the expected frequency and calculated consequences of risk-dominant accidents so that their sum would equal the total risk of all accidents would be self-deceptive, as all these innumerable possibilities are not independent of one another nor accurately quantifiable.

In this SWEIS analysis, it was found that the nature of the accidents did not change among the alternatives; but the frequency and consequence of some of the accidents did change somewhat. Recalling that risk is the product of the consequence and its probability, it is therefore possible to provide the decision maker with estimates of the difference in risk among the alternatives. These differences are discussed later (in summary) in Table G.5–1.

To communicate the types of risk present at LANL, the detailed methodology and results are described below. The methodology considers accidents that are reasonably foreseeable. Although "reasonably foreseeable" does not have a precise definition, the accident analysis is guided by the primary purpose of making reasonable choices among alternatives. "Reasonably foreseeable" includes impacts that may have very large or catastrophic

1. This statement is correct from a statistical standpoint but must be qualified for certain events. In the case of natural phenomena, every occurrence and every nonoccurrence adds to the database from which the probabilities are estimated, so the probabilities do change. In the case of earthquakes, an occurrence may relieve stresses and reduce the probability of another quake for some time; whereas, in the case of heavy flooding, several occurrences in a few years suggest that floods may be more likely than the original data indicated. The important point is that the frequency and/or return period are estimated measures of the probability of an occurrence, not predictions of when it will occur.

consequences, even if their frequency of occurrence is low, provided that the impact analysis is supported by credible scientific evidence, is not based on pure conjecture, and is within the rule of reason.

If an accident is not reasonably foreseeable (incredible), DOE does not consider that it contributes substantially to the risk of operating LANL (DOE 1993a). If, on the other hand, a hazardous material has a reasonable chance of being involved in an accident, then the consequences and the likelihood of the accident are considered.

Specific accidents that contribute substantially to, or envelop the risk, are considered risk-dominant accidents or bounding accidents. They are not exceeded by other accidents analyzed or believed to be possible that involve that inventory. For instance, there may be a number of accidents that could disperse plutonium, with different initiators or different mitigation; but they are represented by the risk-dominant accident involving plutonium dispersal. This accident also may bound the consequences for other facilities that may have more sensitive site characteristics, such as larger populations, but have lesser inventories than those addressed by the analyses.

There is no intent or expectation that the sum of the consequences of these accident scenarios will add quantitatively to the total risk of the LANL site. However, from the results of this methodology, the decision maker is informed of the nature and magnitude of the risk posed by operating LANL facilities.

G.1.4 The Methodology for Selection of Accidents for Analysis

The analysis began with the establishment of the baseline risk from current operations, plus planned activities, that together constitute the No Action Alternative. The baseline was established by a process of safety documentation review, interviews with facility management, physical inspections (walkdowns) of facilities, and discussions with facility management. Changes in the baseline risk were estimated for the Expanded Operations Alternative, the Reduced Operations Alternative, and the Greener Alternative to ascertain the human health impacts of the alternatives[2].

Assessing the human health consequences of accidents for the alternatives is a four-step process. The first step was to identify a broad spectrum of potential accident scenarios. These scenarios were obtained from available site-specific safety and environmental documents, programmatic documents, discussions with facility management, and physical inspections (walkdowns) of the facilities.

The second step in the process used screening techniques to identify the specific scenarios that contribute significantly to risk (i.e., the scenarios that contribute an appreciable fraction of the total risk). Due to the large number of potential accident scenarios that could impact human health, it is impractical to evaluate them all in detail. This is a common problem encountered in risk assessments, and the standard approach (which was adopted here) is to apply rough bounding calculations during the screening steps.

2. Recall, from chapter 3, that the No Action Alternative is the continuation of current operations without change in mission or the nature of operations. The Reduced Operations Alternative would be a reduction in activities to those necessary to maintain the capability in the near term. Under the Expanded Operations Alternative, operations could increase to the highest reasonably foreseeable levels over the next 10 years that can be supported by the existing infrastructure (including upgrades and construction). The Greener Alternative uses existing capabilities, but also places an emphasis on basic science, waste minimization, dismantlement of weapons, nonproliferation, and other nonweapons areas of importance, resulting in increased activities and operations in those areas of interest.

The calculations are performed to progressively greater degrees of detail until it becomes clear that the accident is either, not risk-significant, or requires a detailed analysis in order to determine the frequency and consequences of the accident (i.e., its risk).

Rigorous evaluations (the third step in the process) were only performed for the potentially risk-dominant scenarios identified in step two, that is, those which had a frequency of 10^{-6} or more and led to off-site consequences beyond insignificant.

During the third step in the process, it was determined that a number of scenarios that had appeared to be risk-significant during the earlier screening steps were in fact insignificant contributors to risk. This situation arises due to the conservative approaches to frequency binning used in safety analysis reports (SARs), as described in DOE Standard 3009-94 (DOE 1994a). DOE facilities for which SARs are prepared are subjected to the most detailed assessments; less hazardous facilities are the subject of less detailed evaluations, in accordance with the graded approach to safety analysis. For facilities with SARs, potential accidents are assigned to one of the frequency bins identified in Table G.1.4–1 (DOE 1994a). In the DOE Standard 3009-94 approach, accident frequency binning is essentially a qualitative process rather than the product of a rigorous quantitative analysis. Accordingly, frequency bin assignments are made conservatively such that if a detailed quantification were performed, the calculated frequency would not place the accident in a higher bin and would in fact be more likely to result in placement in a lower frequency bin. Sometimes, simple methods are used for frequency binning, such as assigning a conditional probability of 1 for dependent events, a conditional probability of 0.1 to human errors, and a conditional probability of 0.01 to genuinely independent events.

At the end of the detailed accident analyses, it was found that a number of accidents had been assigned to higher frequency bins than warranted. Specifically, this was the case for RAD–02, RAD–04, RAD–06, RAD–10, RAD–11, and RAD–14, all of which were found to have mean frequencies of less than 10^{-6} per year. (The sequence of events described for RAD–10 was found to be credible for worker consequences because release out of the building is not necessary to result in worker exposures.)

The fourth step in assessing the human health impact of accidents for the alternatives was to carefully evaluate the effect of the alternatives on the accident scenarios. The important considerations involved in this evaluation were whether the alternative would result in the elimination of some accidents and the addition of others, whether the alternative would result in an increase or decrease in the frequency of some accidents, and whether the alternative would result in an increase or decrease in the amount of hazardous materials released. The results of the analysis indicate that, while a number of accidents are potentially affected by the alternatives, few of them pose significant risk to the public.

In the context of LANL, it is important to recognize that, as a result of several factors (the nature of the activities performed, the design features of the facilities at which the activities are performed, the conditions under which the activities are performed, and the location of the facility vis-a-vis the public), accidents are more likely to impact facility workers than they are to impact the public. This is true even though at LANL the public has access to many areas of laboratory via roadway (public access to roads through LANL can be controlled by DOE in the event of an accident). Even for facility workers, the consequences in many cases would be dependent on the use by facility workers of personal protective equipment (PPE) and on the effectiveness of emergency response and mitigation actions taken to limit consequences (e.g., the timeliness of evacuation from the facility).

G.1.5 Comparison of Other Accident Analysis to the SWEIS

The DOE, through its safety and environmental programs, conducts a variety of hazard and safety analyses for various purposes. Because all of the safety and hazard analyses are performed for different purposes, varying levels of conservatism, and therefore, different assumptions are made about physical phenomena and preventive and mitigative controls. In the analysis, if the applicable safety objectives or standard criteria can be met with a very conservative set of assumptions, then detailed analysis is not considered necessary. Further analysis is generally done to more accurately predict an outcome when greater realism is sought, or when very conservative assumptions lead to results that exceed safety objectives or criteria. Detailed analysis requires sophisticated calculations, and therefore, greater expenditure of resources. If a very conservative estimate of consequences demonstrates that the impacts to the public, environment, and worker are acceptable within regulation or guidelines, then it is unnecessary to incur higher costs to more accurately predict the outcome. This fact may be acknowledged in the safety or hazard analysis, but no further quantification of actual doses is made. This graded approach to accident analysis is an explicit part of the DOE safety policy.

In order to understand the results of the accident analysis as presented in this SWEIS compared to other safety analyses and environmental assessments, a brief discussion of hazard assessments is given in the following sections. This discussion assumes a release of radiological material.

G.1.5.1 *DOE Hazard Assessments*

The hazard assessment is a comprehensive evaluation of hazards associated with a particular activity or operation. The hazard analysis provides a clear definition of the activity and the facilities in which the activities will be conducted. The hazard analysis identifies potential accident scenarios. From this preliminary analysis, preventative and mitigative equipment (i.e., systems, structures and components) are identified, and controls on features are established. Not every scenario is analyzed but several (often hundreds) are postulated, and those with the greatest potential for off-site consequences are usually selected as "bounding."

The hazard assessment starts with a very conservative analysis of an accident. Although activities are not conducted without the use of controls, a hypothetical baseline is established that considers only the physics of the accident, such as atmospheric dispersion, not the controls that would either prevent or mitigate the consequences. This accident may be referred to as a "parking lot scenario" or a "what-if" scenario. It is a hypothetical scenario used to gage the reduction in consequences or frequency provided by control mechanisms.

Given this estimate of a material release and considerations of atmospheric transport, the consequences are evaluated for a member of the public standing at the site boundary. This hypothetical individual receives a dose from their exposure to a passing cloud of hazardous material. The individual is assumed to remain at this location for the entire passage of the cloud or plume. These assumptions are designed to give a maximum exposure from the hazardous material release. If the dose to this individual is less than the DOE safety evaluation guideline, then the equipment associated with this activity does not need to be designated as safety class equipment. This implies that quantifying the reduction in consequences due to additional safety controls is not necessary. However, hazard assessments will often give an expected dose based on taking credit for barriers such as building high efficiency particulate air (HEPA) filters, building confinement, etc. This equipment will then have necessary controls placed on it in order to assure its operability in the event of the analyzed bounding accident.

G.1.5.2 *Accident Analysis for this SWEIS*

As described above, the hazard assessment may provide a more conservative value for the frequency of an event. This result usually reflects an estimate of the frequency of initiating events and not the overall frequency of public impacts. The final results for the SWEIS, however, included the consideration of multiple barriers; generally it considered administrative barriers, process design barriers, and facility design barriers, as appropriate. Although, the consequences of a what-if scenario were considered, they were placed in the context of their frequency of occurrence.

As a rule of thumb, most process events become "incredible." If an initiating event is considered anticipated, or has a frequency on the order of 10^{-1}, and there are three independent controls (each with an estimated probability of failure of 10^{-3}), then the overall frequency of the event becomes incredible at 10^{-10}. Therefore, once the SWEIS took credit for these barriers, the frequency of many of the accidents became less than 10^{-6}.

Several scenarios, even though they are incredible, are provided in this appendix to illustrate the defense-in-depth policy of the DOE. These accidents are retained in this appendix to preserve the information they contain, in illustration of the range of the analyses, and in demonstration of the conservative nature of the screening. Incredible accidents are not relevant to the decision and so are segregated from credible accidents in volume I of the SWEIS.

The lower frequencies are difficult to comprehend. To provide a perspective for these frequencies, some examples of natural phenomena events at LANL are provided in Table G.1.5.2–1. Estimates of large meteor impact frequencies are included in order to be able to attain the lowest frequency range.

Although specific scenarios were analyzed, the results of the detailed evaluation represent a risk profile for LANL, given the types of operations described under each alternative. As long as specific process configurations support the same type of operations as considered in these alternatives and are implemented consistent with the DOE safety program, then the risks would be represented by the same set of accidents as presented for each alternative in this SWEIS.

G.1.6 Conservatism in the Analyses

At all steps, when faced with uncertainties, the analysts selected the most probable or conservative value for accident likelihoods and the quantity of hazardous materials released. Accepted models and conservative atmospheric dispersion parameters were used in the modeling. Exposure conditions (e.g., location, material released, time in the plume) were used that would maximize exposure of the total population and of individuals. The maximum risk factor for excess latent cancer fatalities (LCFs) was used to calculate health effects; whereas, the true risk factor may be considerably less, as described in appendix D, section D.1. The resulting estimates of risks are considered to be quite conservative. Incredible accidents are not relevant to the decision and so are segregated from credible accidents in volume I of the SWEIS.

TABLE G.1.5.2–1.—*Frequency of Some Natural Phenomena Events at LANL*

DESCRIPTIVE WORDS	RANGE OF ANNUAL FREQUENCY OF OCCURRENCE	PHENOMENON AND ITS FREQUENCY
Anticipated	10^{-2} to 10^{-1}	[a]Wind of 80 mph, 10^{-2}. 11.2 inches precipitation in one month and 64.8 inches snowfall in one month[b], 1.2 x 10^{-2}.
Unlikely	10^{-4} to 10^{-2}	[a]Wind of 95 mph, 10^{-3}. [c]Snowfall adding 35.0 inches in depth in 24 hours, 5 x 10^{-3}, rainfall of 2.7 inches in 24 hours, 5 x 10^{-3}. [d]Meteor causing destructive tidal wave somewhere on earth, 2 x 10^{-4}. [e]Magnitude 6.5 earthquake causing walls to fall, houses to shift from unsecured foundation, and cracks to open in wet ground, 10^{-4}.
Extremely Unlikely	10^{-6} to 10^{-4}	[a]Straight line wind of 120 mph, 10^{-5}. Tornado with wind of 70 mph, 10^{-5}.
Incredible	< 10^{-6}	[a]Tornado with wind 150 mph or greater, 2.5 x 10^{-7}. [d]Meteor at least three miles in diameter striking somewhere on the earth, 10^{-7}.

[a] Reference for LANL wind and tornado frequency (LLNL 1985). mph = miles per hour
[b] Estimated from the record annual precipitation at LANL during November 1910 to December 1997 (*Source*: http://weather.lanl.gov)
[c] Reference for 24-hour precipitations: LANL 1990a
[d] Estimates of worldwide meteor probability: PC 1998
[e] LANL earthquake data from Tables 4.2.2.2–2 and 4.2.2.2–3 in chapter 4.

G.2 HAZARDOUS MATERIALS IMPACTS ON HUMAN HEALTH

This section addresses the human health impacts resulting from exposure to hazardous materials. The sources of radiation pertinent to this SWEIS are examined in the first subsection. This discussion is followed by a discussion of health impacts resulting from exposure to hazardous chemicals. Finally, the computer models used to evaluate the consequences from both chemical and radiological accidents are discussed to provide an understanding of the applications and limitations of the models.

G.2.1 Sources of Radiation

The sources of radiation pertinent to the accident analysis in this SWEIS are facility specific. These sources include industrial sources used to generate x-rays and other types of electromagnetic radiation for nondestructive examination of components and assemblies. Exposure to these sources of radiation only poses a potential risk to workers and to others with authorized access to the facilities where these sources are in use. Facility-specific sources of radiation also include materials released into the environment as a result of an accident. In most cases, these materials are tritium and various mixtures of uranium and plutonium isotopes. In some cases where experiments involve pulse reactors or critical assemblies, or where criticality occurs inadvertently, fission products also can be released. Each accident scenario that involves radioactive materials includes a discussion of the isotopes and quantities considered. (The nature of radiation, and its effects on human health are discussed in section D.1 of appendix D, Human Health.)

G.2.2 Human Health Effects of Exposure to Hazardous Chemicals

Human health effects resulting from exposure to hazardous chemicals vary according to the specific chemical of interest and the exposure route and concentration. The most immediate risks to human health from exposure to chemicals in the environment arise from airborne releases of toxic gases, and it is this route of exposure upon which the accident analysis for the SWEIS is focused. (The effects of toxic chemicals are discussed in section D.1 of appendix D, Human Health.) In this analysis, exposures to toxic chemicals are compared to Emergency Response Planning Guidelines (ERPGs). ERPGs are community exposure guidelines derived by groups of experts in industrial hygiene, toxicology, and medicine. ERPGs are then published by the American Industrial Hygiene Association (AIHA) after review and approval by their ERPG Committee. ERPGs are defined as follows (AIHA 1991):

- ERPG–1 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing other than mild, transient adverse health effects or perceiving a clearly defined objectionable odor.
- ERPG–2 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair their abilities to take protective action.
- ERPG–3 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing life-threatening health effects.

Human responses to chemical exposure do not occur at precise exposure levels, but rather, extend over a wide range of concentrations. The values derived for ERPGs do not protect everyone, but are applicable to most individuals in the general population. Furthermore, the ERPG values are planning guidelines, not exposure guidelines. They do not contain the safety factors normally associated with exposure guidelines (AIHA 1991).

In developing an ERPG, emphasis is given to the use of acute or short-term exposure data. Human experience data are emphasized; but usually only animal exposure data are available. When it is believed that adverse reproductive, developmental, or carcinogenic effects might be caused by a single acute exposure, the data are considered in the ERPG derivation.

Unless one is provided information to the contrary by toxicologists, it is necessary to regard ERPGs as ceiling concentrations (i.e., the highest concentration acceptable for the time period). As such, the ERPG would be treated as an exposure that should not be exceeded within 1 hour. Any extrapolation from the ERPG is not to be made without significant considerations; specifically, to make such an adjustment, the ERPG documentation for each chemical must be reviewed fully by toxicologists. The effects of exposure times longer than 1 hour may not be limited to those associated with the ERPG.

In addition to ERPGs, this analysis incorporated the temporary emergency exposure limits (TEELs) developed by the DOE Emergency Management Advisory Committee, Subcommittee of Consequence Analysis and Protective Actions (SCAPA). Published ERPG values were available for only 69 chemicals. TEEL values are interim, temporary, or ERPG-equivalent exposure limits provided for an additional 297 chemicals. In the absence of ERPG or TEEL values, the hierarchy developed by SCAPA and published in the AIHA Journal was utilized (Craig et al. 1995).

ERPG–1 defines a level that does not pose a health risk to the community but that may be noticeable due to slight odor or mild irritation. Above ERPG–2, for some members of the community there may be significant adverse health effects or symptoms that could impair an individual's ability to take protective actions. These symptoms might include severe eye or respiratory irritation or muscular weakness. Above ERPG–3 there may be life-threatening effects and, at sufficiently high concentrations and exposure times that vary with the chemical, there could be death. The length of an individual's exposure to high concentrations will depend upon that individual's situation and response (that is, by his/her recognition of the threat and its location, attaining shelter, and escaping). Later in this analysis, consequences are presented as the number of people exposed to concentration greater than the ERPG–2 and ERPG–3 guidelines; but there are too many uncertainties to speculate as to the specific effects that would occur to those people.

G.2.3 Chemical Accidents—ALOHA™ Code

The Areal Locations of Hazardous Atmospheres (ALOHA™) code developed by EPA, the National Oceanographic and Atmospheric Administration (NOAA), and the National Safety Council (NSC), was used for the analysis of chemical releases. It is listed by DOE (DOE 1994c) and EPA (EPA 1996) as an acceptable code for air dispersion modeling.

The ALOHA™ code is designed to be used for emergency responders in the case of chemical accidents. The code predicts the rate at which chemical vapors may escape to the atmosphere from broken gas pipes, leaking tanks, and evaporating puddles and predicts how the resulting hazardous gas cloud disperses horizontally and vertically into the atmosphere following release (NSC 1995).

Especially near the source of a release, short-term gas concentrations depart markedly from average values in response to random turbulent eddies and are unpredictable. As the cloud moves downwind, concentrations within the cloud become more similar to ALOHA™ calculations. ALOHA™ shows concentrations that represent averages for time periods of several minutes and predicts that average concentrations will be highest near the release point and along the center line of the release cloud (this is typical Gaussian plume modeling). The concentration is modeled as dropping off smoothly and gradually in the downwind and crosswind directions.

ALOHA™ models neutrally buoyant gases with a Gaussian plume model. Airborne particulates are assumed to be passive; that is, they behave as nonbuoyant gases. Heavy gases are modeled using a variation of the DEGADIS heavy gas model. Some simplifications were implemented into ALOHA-DEGADIS to speed computational procedures and reduce the requirement for input data that would be difficult to obtain during an accidental release. These simplifications include the assumptions that: (1) all heavy gas releases originate close to ground level; (2) mathematical approximations are faster but less accurate than those in DEGADIS; and (3) modeling sources for which the release rate changes over time as a series of short, steady releases rather than a number of individual point source puffs. The authors worked closely to ensure a faithful representation of DEGADIS model dynamics, and the resulting ALOHA-DEGADIS model was checked to ensure that only minor differences existed in results.

Although ALOHA™ models the dispersion of heavy gases, the model assumes that the terrain is flat. Thus, if canyons are located between the release point and a potential receptor, ALOHA™ models the scenario as though the canyon were not present. This is a conservative approach because receptors are offered no protection from heavy gases by intervening canyons. Under the most stable atmospheric conditions (most commonly found late at night or very early in the morning), there is little wind, reduced turbulence, and less mixing of the release with the surrounding air. High gas concentrations can build up in small valleys or depressions and remain for long periods of time. ALOHA™ does not account for buildup of gas concentrations in low-lying areas. The properties of a heavy gas are discussed in section G.5.5.

ALOHA™ allows the user to enter only a single wind speed and wind direction, and assumes that these remain constant throughout the release and travel. In reality, air flow changes speed and direction when confronted with changes in terrain such as slopes, valleys, and hills. ALOHA™ ignores these effects. Because wind is likely to shift direction and change speed over both distance and time, ALOHA™ will not make predictions for more than 1 hour after a release begins, or for distances more than 6.2 miles (10 kilometers) from the release point. In general, wind direction is least predictable when the wind speed is low and at the lowest wind speed modeled in the code (1 meter per second), ALOHA™ presents the footprint as a circle. ALOHA™ does not calculate particulate settling and deposition. The ALOHA™ code presumes the ground beneath a leak or spill to be flat, so that the liquid expands evenly in all directions.

Combustion products rise rapidly while moving downwind, until they cool to the temperature of the surrounding air. ALOHA™ does not account for this rise. ALOHA™ models the release and dispersion of pure chemicals only, and the properties of chemicals in its chemical library are valid only for pure chemicals. ALOHA™ also does not account for chemical reactions of any kind. (This limitation can be avoided by modeling the resulting chemicals, if known. In the case of the seismic collapse of TA–3–66, the SWEIS has modeled the hydrogen cyanide that evolved from mixing metal cyanide solution and nitric acid.)

The limitations of ALOHA™ do not detract from its use in this SWEIS for screening chemical accidents and bounding their daytime consequences. During the preparation of this SWEIS, as upgrades to ALOHA™ code became available they were used. Trial calculations showed that the upgrades provided the same results as previous versions for the same inputs.

G.2.4 Radiological Accidents—MACCS 2 Code

The MACCS 2 computer code models the consequences of an accident that releases a plume of radioactive materials to the atmosphere. Should such an accident occur, the radioactive aerosols and/or gases in the plume would be transported by the prevailing wind while dispersing horizontally and vertically in the atmosphere. MACCS 2 uses a straight-line Gaussian plume model and the source term data input by the user to model the atmospheric dispersion and deposition of radionuclides released from facilities. Plume rise, dry deposition, and precipitation scavenging (below cloud washout) of aerosols, and resuspension of particulate matter that has deposited from the plume is explicitly modeled. The chronic exposure model calculates the resulting doses for all inhabitants living in the area. In the intermediate and long-term phases, the inhalation shielding factor for normal activity is used in the dose calculations. Decay of radionuclides to daughter products is accounted for.

The MACCS 2 calculations also estimate the range and probability of health effects caused by radiation exposures that are not avoided by protective actions. In these EIS calculations, no credit was taken for protective measures that might and would be used to decrease exposures. (MACCS 2 permits the modeling of various protective measures, such evacuation, sheltering, and relocation. A variety of protective measures can be taken in the long-term phase in order to reduce doses to acceptable levels: decontamination, interdiction, and condemnation of property.)

MACCS 2 divides the accident into three time phases: the emergency phase, the intermediate phase, and the long-term phase. The emergency phase begins immediately after the accident and could last up to 7 days following the accident. In this period, the exposure of the population to both radioactive clouds and contaminated ground is modeled. In the intermediate phase, the radioactive clouds are gone, and decisions are made regarding the type of protective actions that need to be taken; the only exposure pathways are those resulting from ground contamination. The long-term phase represents all time subsequent to the intermediate phase, and again, the only exposure pathways considered are those resulting from the contaminated ground.

In accidents there is an initial release, and there may be a continuing release thereafter. A single MACCS 2 calculation can handle four separate releases. To account for reduction of the source as it was depleted by the continuing suspension, the continuing release was treated as three consecutive continuing releases of 8 hours each. For those accidents that have both an initial and a continuing release, the releases were stopped no later than 24 hours after the initial release.

The region surrounding the site is divided into a polar coordinate grid centered on the facility from which the release originates. The angular divisions used to define the spatial grid correspond to the 16 directions of the compass. The user specifies the number of radial divisions as well as their endpoint distances. Up to 35 of these divisions may be defined, extending out to a maximum distance of 6,213 miles (10,000 kilometers).

The emergency phase calculations use dose-response models for early fatality and early injury, and are performed on a finer grid than the calculations of the intermediate and long-term phases. For this phase, the 16 compass sectors are divided into 3, 5, or 7 user-specified subdivisions in the calculations.

Each radiological release site was assigned to the closest one of the four weather stations (located in TA–6, TA–49, TA–53, and TA–54). The 1995 meteorological data were used for these calculations. Sensitivity calculations using data from 1991 to 1995 have been performed for one accident scenario to investigate the possible impact on consequences of using weather data from a particular year. In the near field (out to 1,312 feet [400 meters]), an approximate maximum 30 percent variation occurred in the calculated doses, depending upon which year is used. The results indicated that 1995 yields the largest consequence results of this 5-year period for the scenario modeled (Steele et al. 1997).

Consequence results were calculated for both ground level and elevated releases, according to the facility and the scenario. Downwind concentrations of radionuclides up to a distance of 50 miles (80 kilometers) were calculated for each of the 16 compass directions around the facility. Radiation doses to the on-site and off-site population were calculated by the dosimetry models within MACCS 2[3], using the concentrations. Exposure pathways were: direct radiation from the passing plume, direct radiation from radioactive material deposited on the ground and skin, inhalation while within the plume, and inhalation of resuspended ground contamination. Subsequent ingestion, which normally represents only a small fraction of total exposure and can be controlled, was not considered.

3. MACCS dosimetry models use risk factors that vary by nuclide, and result in approximately, but not exactly, an effective risk factor of 5×10^{-4} excess LCFs per person-rem of exposure. This is discussed in the primer on the effects of radiation in section D.1 of appendix D, Human Health.

Because population is not evenly distributed around the source, the consequences of an accident vary with wind direction. The probability of the consequence thus depends on the probability of that wind direction. Therefore, the results of the calculations are presented as the average of the consequences for all 16 directions weighted by the probability of the wind being toward that direction. Note that the calculations used both daytime and nighttime winds; whereas, the population distribution used was the daytime population described in section G.3.2. Because the daytime population is larger than the nighttime population, this overestimates the mean consequences.

Having the results from the multiple model runs, it was possible to calculate the mean dose to hypothetical individuals at points of closest public access; at points on the site boundary (referred to as doses to maximally exposed individuals [MEIs]); and mean doses at public population centers, such as towns, pueblos, and schools.

Note that these calculations capture all meteorological conditions, including the most adverse conditions, each weighted by its frequency of occurrence in the entire year. An alternative approach, use of the dispersion condition for which dispersion is greater than 95 percent the time (referred to as 95^{th} percentile meteorology) is often used for screening. It maximizes the concentrations downwind, but does not consider the population distribution. Therefore, it does not provide as much useful information.

Note that uncertainties as to the models' abilities to predict concentrations and exposures, and uncertainties in the range of meteorological conditions, apply equally to all the alternatives.

G.3 ACCIDENT SCENARIO SCREENING

LANL is one of the largest multiprogram research laboratories in the world, and a number of factors combined to make the selection of accident scenarios for the SWEIS a challenging task. These factors included:

- DOE NEPA guidance that mandates consideration of accidents within the design basis, as well as those beyond the design basis, to identify a spectrum of potential accident scenarios that could occur during the activities encompassed by the proposed action and analyzed alternatives.
- The diversity of activities performed at LANL, including: pit production; high explosives research, development, production, and testing; special nuclear material (SNM) processing, research and development, and storage; hydrodynamic testing and dynamic experimentation; accelerator operations, research, and development; fusion power research and development; operation critical assemblies and fast burst reactors; and radioactive, chemical, and mixed waste processing, characterization, disposal, and storage.
- A wide range of accident initiators (including process hazards, man-made hazards, and natural phenomena hazards) and the resulting human, system, and structural responses to those initiators.
- A large number of accident scenarios identified in underlying programmatic and LANL-specific NEPA documents (e.g., the Stockpile Stewardship and Management PEIS, and the Dual Axis Radiographic Hydrodynamic Test [DARHT] Facility EIS).
- The availability and vintage of a variety of hazard assessment and safety analysis documentation, performed to evolving DOE guidance.

- The diversity of material that could potentially be released in an accident (referred to as "material-at-risk" or MAR), including: tritium, plutonium, various enrichments of uranium, toxic chemicals such as chlorine, bulk acid storage, high explosives, and a wide variety of other chemicals and radioactive materials.
- The presence of some relatively complex facilities such as the Plutonium Facility (TA–55–4), the Chemistry and Metallurgy Research (CMR) Building (TA–3–29), the Tritium System Test Assembly (TSTA) Facility (TA–21–155), the Tritium Science and Fabrication Facility (TSFF, TA–21–209), the Weapons Engineering Tritium Facility (WETF, TA–16–205), and the critical assembly and fast burst reactor facilities at the Pajarito site (TA–18), for which hazard and safety analyses have identified dozens to hundreds of credible accident scenarios for each of these facilities.

The large number of facilities and processes at LANL, combined with the diversity of MAR and the variety of accident initiators, produce credible accident scenarios numbering at least in the many thousands. Analyzing each of these scenarios in detail is neither required under NEPA nor practical. Ideally, a comprehensive risk assessment would express the total human health risk as the sum of all potential accident scenarios. It is neither practical (due to cost) or necessary (from a NEPA compliance standpoint) to rigorously quantify all of these to produce a summation of the total risk. The purpose of screening is to identify for detailed analysis a suite of accidents that constitute a large fraction of the total risk.

Accident analyses, for a NEPA document, involve considerably less detail than a formal probabilistic risk assessment (PRA), but make use of PRA techniques and insights (such as event trees, failure rate data, and initiating event occurrence data) to identify risk-significant accident scenarios.

G.3.1 Accident Initiator Screening

It was recognized, based on review of available safety documentation for several important facilities, that there would be a very large number of credible accident scenarios for LANL facilities. The SWEIS accident analysis began with a detailed examination and screening of accident initiators and accident types in order to focus the attention of the remainder of the analysis on those accident initiators most important to risk. Accident initiators and accident types were identified and categorized into three broad classes: (1) process hazards, (2) man-made hazards, and (3) natural phenomena hazards (NPHs). Military action, sabotage, terrorism, or other forms of deliberately malevolent actions were not included. The magnitudes of the likelihood and consequences of such acts are independent of the site operations, under the purview of security and protection forces, and are considered to be outside the purview of accident analysis.

The list of accident types and initiators, arrayed into these three categories, is provided as Table G.3.1–1. These accident types and initiators were evaluated in the context of their likelihood and their potential for resulting in a release of hazardous materials or for causing an event that could result in such a release (e.g., a fire or explosion). Hazardous materials at LANL include radioactive materials, chemicals, biohazards, and high explosives.

The intent is to capture all accidents that have a frequency in excess of 1×10^{-6} per year. It is not possible to estimate accurately the likelihood (frequency) of accidents with very low probability. Therefore, accident types and accident initiators that could produce an accident with a frequency in excess of 1×10^{-7} per year when realistically estimated, or a frequency in excess of 1 x 10^{-6} per year when conservatively estimated, were treated as "credible" and "reasonably foreseeable."

Accidents with frequencies less than 1 x 10^{-6} were not dismissed without considering whether they were capable of producing worse consequences than credible accidents. Large earthquakes would affect the entire LANL site simultaneously. As a result, it is not considered plausible that many individual but unlikely accidents could rival earthquakes in overall risk, and thus, were not retained for detailed analysis.

A suite of accident type and accident initiator screening criteria was developed for the purpose of evaluating the master event list in Table G.3.1–1. It is important to recognize that, while some of the accident types or initiating events listed in Table G.3.1–1 may appear to some readers to stray into the realm of the absurd, the goal of the master listing and the screening process was to demonstrate that the consideration of accident types and accident initiators was as comprehensive as possible.

The accident types and initiators in the master list were screened, using the screening criteria in Table G.3.1–2. Results of the screening for process hazards, man-made hazards, and natural phenomena hazards are reported separately in Tables G.3.1–3, G.3.1–4, and G.3.1–5, respectively.

Table G.3.1–6 summarizes the three preceding tables as events the survived that screening. These were subsequently evaluated on a facility-specific basis, using detailed safety documentation review and facility walkdowns, as described in the following section G.3.2.

G.3.2 Facility Hazard Screening

DOE assigns different hazard categories to its facilities on the basis of the magnitude of maximum potential injuries and fatalities on site and off site. Although the system has a different purpose than identification of facilities to be considered in EIS analyses, the past categorization constituted an effective screening of facilities for this SWEIS.

In hazard classification, no credit is given designed active safety features[4], administrative controls (other than those limiting the total quantity of hazardous materials in the facility), or prompt emergency response. Credit for mitigation is assumed only for substantial passive primary barriers or natural removal or dispersal mechanisms associated with the distance between the facility and the receptor location (LANL 1995a). Hazard classification is therefore considered to represent an appropriate basis for an initial screening of LANL facilities to focus the attention of the SWEIS accident analysis on those facilities that have the most significant potential for causing impacts to workers, the public, and the environment.

This screening step is based on the hazard posed by the facility. There may be other reasons for including facilities in the accident analysis (e.g., stakeholder interest). Such additional facilities were selected by expert judgment. The facilities that were identified in the initial hazard categorization process are listed in Table G.3.2–1. Following detailed discussions with LANL, walkdowns of more than 40 facilities, and review of updated safety documentation, many of the facilities in Table G.3.2–1 were screened from further analysis. Table G.3.2–2 provides a listing of the facilities that were screened and a summary of the reasons for their exclusion from detailed analysis. Table G.3.2–3 provides the final list of facilities that were subjected to screening consequence analysis in

4. An "active safety feature" is one that is fallible, through its dependence upon maintenance, electrical power, human operation, etc. Examples would be a smoke alarm, filtering system or automatic electrical switch. A "passive" feature or barrier is one that does not require dependable human attention for its operation. Examples are a berm, catch basin, or firewall.

TABLE G.3.1–1.—*Accident Type and Initiating Event Master Classification List*

PROCESS HAZARDS	MAN-MADE HAZARDS	NATURAL PHENOMENA HAZARDS	NATURAL PHENOMENA HAZARDS (CONT.)
Biohazard Spill	Aircraft Crash[h]	Avalanche	Lightning Strike[bb]
Chemical Spill[a]	Arson	Barometric Pressure[s]	Liquefaction[cc]
Container Failure	Co-Located Facilities[i]	Biological Hazards[t]	Low Water Level
Criticality Event[b]	Dam Failure[j]	Blizzards[u]	Nontectonic Deformation
Explosion[c]	Dike Failure[j]	Climatic Change[v]	Precipitation Extremes
Fire[d]	Explosion[k]	Coastal Erosion	River Diversion
Flooding[e]	Fire[l]	Drought	Sand Storms
Hardware Failure[f]	Flooding[j]	Dust Storms	Seiche
Human Error[g]	Levee Failure[j]	Earthquakes[w]	Sink Holes and Collapse
Radioactive Spill	Military Action[m]	Extraterrestrial Objects[x]	Slope Stability
	Nuclear Detonation[n]	Fog	Snow
	Pipeline Failure[o]	Frost	Soil Consolidation
	Sabotage and Terrorism[p]	Glacial Activity[y]	Soil Shrink/Swell
	Satellite Orbital Decay	Hail	Storm Surge
	Shipwrecks	High Water[j]	Temperature Extremes[dd]
	Vandalism[q]	High Wind[z]	Tornadoes[ee]
	Transportation[r]	Hurricanes	Tsunami
		Ice and Ice Jams	Volcanism[ff]
		Landslides and Mudflows[aa]	Waves

Notes:

[a] Includes release of chemicals, including toxic gases, liquids, solids, high explosives, etc. that disperse into the facility or environment. Also includes uncontrolled chemical reactions due to inadvertent mixing of chemicals (e.g., mixing of metal cyanide solution and acid, which liberates hydrogen cyanide).

[b] Represents all accidental or unplanned nuclear criticality events, including criticality in solid systems, aqueous solutions, and waste forms. Does not include planned criticality during critical assembly experiments or fast burst reactor operations.

[c] Represents explosions due to sources of explosive materials (gases, etc.) originating within the facility. Does not include ingestion of explosive gases into the heating, ventilation, and air conditioning (HVAC) system from outside the facility. Explosions may be accompanied by a fire.

[d] Represents fires originating within a facility.

[e] Represents flooding originating within a facility (due, for example, to a pipe break or an inadvertent actuation of a fire sprinkler system).

[f] Includes hardware failures due to any cause (such as aging, overheating, overcooling, lubrication system failure, etc.) except military action, sabotage, terrorism, or other forms of deliberately malevolent actions.

[g] Includes human errors in any phase of design, construction, fabrication, operation, maintenance, modification, design control, management, emergency response, etc.

[h] Includes direct impact on the facility as well as a crash near the facility followed by the skidding of the aircraft or aircraft components into the facility. Also includes fires or explosions resulting from aircraft crash (due to combustion of aviation fuel and/or the contents of the aircraft), as well as impacts of missiles on the facility resulting from the aircraft crash or resulting fire/ explosion.

[i] Represents accidents at nearby facilities (off-site industrial facilities, other on-site facilities, military facilities, etc.) that cause an impact at the facility under evaluation. Such accidents would include explosions, fires, chemical accidents, toxic gas releases, etc.).

TABLE G.3.1–1.—*Accident Type and Initiating Event Master Classification List*-Continued

[j] Includes failures due to human errors (such as design errors, failure to anticipate sufficiently severe flood and debris conditions, construction errors, etc.).
[k] Includes explosions from sources outside the facility, but does not include explosions due to pipeline accidents, sabotage, or military action.
[l] Includes fires from sources outside the facility, such as wildfires.
[m] Includes acts of war, as distinguished from sabotage, terrorism, arson, etc. Also includes war-like actions during internecine conflicts.
[n] Includes only the inadvertent detonation of a nuclear explosive device. No nuclear weapons or nuclear explosive devices will be assembled, disassembled, or otherwise handled at LANL under any of the alternatives.
[o] Includes accidents involving natural gas pipelines that can result in fires and/or explosions.
[p] Includes acts committed by authorized insiders (persons with authorized access to the facility) or outsiders (including visitors) that are committed with the intent of causing a release of radioactive materials, hazardous chemicals, high explosives, or biohazards or that are committed with the intent of causing a nuclear criticality event. The acts could take place at the facility or outside the facility (e.g., destruction of a dam, deliberate crash of an aircraft, etc.).
[q] Includes acts committed by authorized insiders or outsiders (including visitors) that are not intended to cause a release of radioactive materials, hazardous chemicals, high explosives, or biohazards or that are not intended to cause a criticality, but that nonetheless result in such occurrences contrary to the intent of the perpetrators.
[r] Includes accidents resulting in release of radioactive materials, hazardous chemicals, high explosives, or biohazards, or that result in a nuclear criticality event, occurring in all modes of transportation (truck, car, rail, aircraft, or ship) that involve material being shipped to or from the facility. Also includes impact of a vehicle from all modes of transportation (except aircraft, which is analyzed separately in this appendix) on the facility that causes damage to the facility (but that may or may not be transporting hazardous cargo).
[s] Includes normal changes in barometric pressure. Does not include changes in air pressure due to the passage of a tornado, which is analyzed separately.
[t] Includes accidents caused by biological factors such as ingestion of plant debris by cooling systems, blockage of cooling systems by mussel and clam infestations, excessive biological growth on the exterior of facility structures, etc. Does not include fire involving plants (wildfire), which is analyzed separately.
[u] Includes effects from excessive loads due to snow accumulation on or against facility structures.
[v] Includes such effects as global warming (and its impacts), glaciation (and its impacts), and other impacts of changes in weather that are not within the range of normally expected conditions. Does not include impacts due to existing glaciers.
[w] Includes effects such as seismically initiated liquefaction, dam failures, fires, and flooding, as well as surface deformation, tectonic subsidence, tectonic uplift, and damage due to ground accelerations (vertical and horizontal).
[x] Includes direct impact on the facility of meteorites, comets, asteroids, and other extraterrestrial bodies, as well as collateral damage resulting from impacts elsewhere (surface deformation, missile impacts, flooding, etc.).
[y] Includes impacts due to glaciers existing at the time of the analysis. Such impacts include the effects of both the advance and retreat of glaciers.
[z] Includes straight winds, as distinguished from hurricanes and tornadoes, and also includes wind-borne missiles.
[aa] Does not include landslides and mud flows due to volcanic activity.
[bb] Includes the impacts of fires caused by lightning strikes. For structures with lightning protection, this requires consideration of possible failures of lightning protection systems.
[cc] Does not include seismically initiated liquefaction, which is included under earthquakes.
[dd] Includes effects of freezing of equipment due to low external temperatures.
[ee] Includes impacts due to tornado-borne missiles, differential pressure due to nearby tornado passage, and lightning strikes, hail, rain, and other phenomena due to storms associated with the tornado weather system.
[ff] Includes such effects as ash falls, rock falls, nueé ardente, rapid snow-pack-melt-induced flooding, mud flows, siltation, sedimentation, phreatomagmatism, pyroclastic activity, etc. and fire/explosion.

TABLE G.3.1–2.—*Accident Type and Accident Initiator Screening Criteria*

SCREENING CRITERION	SCREENING CRITERION DESCRIPTION
1	The accident type or initiating event is within the facility design basis, and the frequency in combination with the conditional probability of a sufficiently severe design error affecting parameters that would cause failure of the facility is considered to be incredible (i.e., frequency less than 1 x 10^{-6} per year (conservatively evaluated); or
2	The initiating event does not occur close enough to the facility to affect it (this is a function of the magnitude of the event and the proximity of the facility to the event); or
3	The accident type or initiating event is included in the definition of another event due to the similarity of impacts on the facility, and the frequency contribution of the other event includes the contribution from this event; or
4	The event has a sufficiently cataclysmic impact on the facility as well as on the surrounding region such that the consequences of the event on the surrounding region would not be significantly affected by the destruction of the facility; or
5	The accident type or initiating event has a conservatively estimated mean frequency of less than 1 x 10^{-6} or a realistically estimated mean frequency of less than 1 x 10^{-7} per year; or
6	The accident type or initiating event is under the purview of the security and protection forces and the security and safeguards related administrative and physical controls, and is the result of deliberate act; these events are considered to be outside the purview of an “accident” analysis, which is concerned with unanticipated events that occur at random.

TABLE G.3.1–3.—*Process Hazards Screening Results*

ACCIDENT TYPE OR INITIATING EVENT	SCREENING CRITERIA						SCREENS OUT (Y/N)	NOTES
	1	2	3	4	5	6		
Biohazard Spill							No	Applicable to workers only; no credible scenario for spread of biohazard beyond the LANL workforce
Chemical Spill							No	Chemical spill hazards bounded by toxic gases and liquids that are easily dispersed
Container Failure			X				Yes	Contributing event to chemical spill and radioactive spill
Criticality Event							No	Applicable to workers only; public dose consequences of criticality event are less than 100 millirem
Explosion							No	
Fire							No	
Flooding	X		X				Yes	Possible contributing cause for criticality events; criticality retained
Hardware Failure			X				Yes	Embedded in other events as contributory causes; also represented as causes of system failures after an initiating event
Human Error			X				Yes	Embedded in other events as contributory causes; also represented as causes of system failures after an initiating event
Radioactive Spill							No	

TABLE G.3.1–4.—*Man-Made Hazards Screening Results*

ACCIDENT TYPE OR INITIATING EVENT	SCREENING CRITERIA						SCREENS OUT (Y/N)	NOTES
	1	2	3	4	5	6		
Aircraft Crash							No	Analysis to be performed per DOE Standard 3014-96 (DOE 1996c)
Arson						X	Yes	Malevolent act
Co-Located Facilities							No	
Dam Failure		X			X		Yes	
Dike Failure		X			X		Yes	
Explosion							No	
Fire							No	
Flooding							No	TA–18 only; other hazardous facilities located on mesa tops
Levee Failure		X			X		Yes	
Military Action						X	Yes	Malevolent act
Nuclear Detonation					X	X	Yes	No nuclear weapons or nuclear explosive devices are assembled, disassembled, handled, or otherwise processed at LANL
Pipeline Failure							No	TA–3–29 only
Sabotage and Terrorism						X	Yes	Malevolent acts
Satellite Orbital Decay					X		Yes	
Shipwrecks		X			X		Yes	
Transportation							No	Transportation analysis performed separately from accident analysis
Vandalism						X	Yes	Malevolent acts

TABLE G.3.1–5.—*Natural Phenomena Hazards Screening Results*

ACCIDENT TYPE OR INITIATING EVENT	SCREENING CRITERIA						SCREENS OUT (Y/N)	NOTES
	1	2	3	4	5	6		
Avalanche		X					Yes	
Barometric Pressure	X						Yes	
Biological Hazards		X					Yes	
Blizzards	X						Yes	
Climatic Change				X			Yes	
Coastal Erosion		X					Yes	
Drought	X						Yes	
Dust Storms	X						Yes	
Earthquakes							No	
Extraterrestrial Objects					X		Yes	
Fog	X						Yes	
Frost	X						Yes	
Glacial Activity				X			Yes	
Hail	X						Yes	
High Water		X					Yes	
High Wind							No	
Hurricanes		X					Yes	
Ice and Ice Jams		X					Yes	
Landslides and Mud Flows		X					Yes	
Lightning Strike							No	
Liquefaction	X						Yes	
Low Water Level		X					Yes	
Nontectonic Deformation	X						Yes	
Precipitation Extremes	X						Yes	
River Diversion		X					Yes	
Sand Storm	X						Yes	
Seiche		X					Yes	
Sink Holes and Collapse		X					Yes	
Slope Stability							No	
Snow	X						Yes	
Soil Consolidation	X						Yes	
Soil Shrink/Swell	X						Yes	
Storm Surge		X					Yes	
Temperature Extremes	X						Yes	
Tornado					X		Yes	
Tsunami		X					Yes	
Volcanism							No	

TABLE G.3.1–6.—*Credible Accident Types and Accident Initiators that Survived Early Screening*

PROCESS HAZARDS
Biohazard Spill Chemical Spill Criticality Event[a] Explosion (Internal to Facility) Fire (Internal to Facility) Radioactive Spill
MAN-MADE HAZARDS
Aircraft Crash—analyzed based on DOE Standard 3014–96 (DOE 1996c) Co-Located Facilities[b] Explosion (External to Facility)[b] Fire (External to Facility) Flood (External to Facility)—TA–18 only[b] Pipeline Failure—TA–3–29 only; other facilities screened Transportation Accidents—analyzed separately from facility accidents
NATURAL PHENOMENA HAZARDS
Earthquakes High Wind[b] Lightning Strike[b] Slope Stability—TA–18 only[b] Volcanism[c]

[a] Screened out for public risk based on low dose; retained as a worker accident.
[b] Later screened out, based on subsequent facility- and site-specific review.
[c] Credible, but not used, based on higher level of risk posed by earthquakes.

order to select the final suite of facilities for detailed analysis.

G.3.2.1 *Description of the DOE Hazard Category System*

As background information only, this subsection describes the hazard categorization system used by DOE.

Facilities performing radiological operations are subdivided into hazard categories pursuant to DOE Order 5480.23 and DOE Standard 1027-92 (DOE 1992). There are three hazard categories based on the type of facility (Hazard Category 1) or the radiological inventory (Hazard Categories 2 and 3). These facilities are defined as nuclear facilities. Facilities that do not meet the threshold requirements for Hazard Category 3 but that still contain radioactive materials are categorized as radiological facilities.

The three hazard categories for these facilities are defined as follows (DOE 1992):

- *Hazard Category 1.* Hazard analysis shows the potential for significant off-site consequences (limited to Category A reactors and other facilities designated by the Program Secretarial Officer). (Note: There are no facilities at LANL designated by LANL or DOE as Hazard Category 1).
- *Hazard Category 2.* Hazard analysis shows the potential for significant on-site consequences (includes facilities with the potential for nuclear criticality events or with sufficient quantities of hazardous materials and energy that would require on-site emergency planning activities). Threshold quantities of radionuclides for Hazard Category 2 facilities are shown in Appendix A of DOE Standard 1027-92 (DOE 1992), with LANL-specific elaboration provided in a separate document (LANL 1995b).
- *Hazard Category 3.* Hazard analysis shows the potential for only significant localized consequences. Threshold quantities of radionuclides for Hazard Category 3 facilities are shown in Appendix A of DOE Standard 1027-92, with LANL-specific elaboration provided in a separate document (LANL 1994a).
- *Radiological Facilities.* Facilities not meeting at least Hazard Category 3 threshold criteria but that still possess some amount of radioactive materials. No other hazard identified than normal office or laboratory environment (electrical equipment, glassware, tools, etc.).

TABLE G.3.2–1.—*LANL Facilities Identified in Initial Hazard Categorization*

HAZARD CATEGORY 2 NUCLEAR FACILITIES	HAZARD CATEGORY 3 NUCLEAR FACILITIES	MODERATE HAZARD CHEMICAL FACILITIES	LOW HAZARD CHEMICAL FACILITIES	FACILITIES SELECTED BASED ON JUDGMENT
TA–2–1, Omega West Reactor	TA–3–66, Sigma Facility	TA–00–1109, Chlorinator	TA–3–39, Shops Building	TA–3–30, General Warehouse
TA–3–29, Chemistry & Metallurgy Research Building	TA–3–159, Sigma Thorium Storage Facility	TA–00–1110, Chlorinator	TA–3–141, Beryllium Technology Building	TA–3–35, Press Building
Dynamic experiment activities involving Special Nuclear Materials[a]	TA–18–23, Pajarito Site Kiva #1	TA–00–1113, Chlorinator	TA–3–1698, Materials Science Laboratory	TA–3–102, Shops Building
TA–16–205 Weapons Engineering Tritium Facility	TA–18–26, Pajarito Site Hillside Vault	TA–00–1114, Chlorinator	TA–21–5, Chemistry Building	TA–3–164, Uranium Storage Building
TA–18–32, Pajarito Site Kiva #2	TA–18–116, Pajarito Site Kiva #3	TA–3–31, Chemical Warehouse	TA–21–150, Molecular Chemistry Building	TA–3–166, Wastewater Treatment Plant
TA–21–155, Tritium Systems Test Assembly	TA–18–168, Pajarito Site Solution High-Energy Burst Assembly (SHEBA)	TA–3–170, Gas Plant	TA–43–1, Health Research Laboratory	TA–9–21, Analytical Chemistry Building
TA–21–209, Tritium Science and Fabrication Facility	TA–21–146, Filter Building	TA–3–476, Toxic Gas Storage Shed	TA–59–1, Occupational Health	TA–9–23, Shops Building
TA–50–37, Radioactive Materials Research, Operations, and Demonstration Facility	TA–35–2, Laboratory	TA–14–5, Toxic Gas Storage	TA–54–39, polychlorinated biphenyl (PCB) Waste Storage	TA–11–30, Vibration Test
TA–54–229, TA–54–230, TA–54–231, and TA–54–232, Transuranic Waste Inspectable Storage Project	TA–35–27, Nuclear Safeguards Laboratory	TA–16–560, Chlorinator	TA–60–29, Pesticide Storage	TA–15–184, Pulsed High-Energy Radiation Machine Emitting X-Ray (PHERMEX)
TA–54–48, TA–54–153, TA–54–224, TA–54–226, and TA–54–286, Transuranic Waste Storage Domes	TA–48–1, Radiochemistry Facility	TA–21–3, Chemistry Building		TA–16–260, High Explosives Processing (Example)
TA–55–4, Plutonium Facility	TA–50–1, Radioactive Liquid Waste Treatment Facility	TA–21–4, Chemistry Building		TA–16–305, High Explosives Chemical Storage (Example)

TABLE G.3.2–1.—*LANL Facilities Identified in Initial Hazard Categorization*-Continued

HAZARD CATEGORY 2 NUCLEAR FACILITIES	HAZARD CATEGORY 3 NUCLEAR FACILITIES	MODERATE HAZARD CHEMICAL FACILITIES	LOW HAZARD CHEMICAL FACILITIES	FACILITIES SELECTED BASED ON JUDGMENT
TA–55–41, Nuclear Materials Storage	TA–50–69, Waste Characterization, Reduction, and Repackaging Facility	TA–35–213, Target Fabrication Facility		TA–16–340, High Explosives Pressing (Example)
	Isotope production activities and radiation effects experiments at the Los Alamos Neutron Science Center (LANSCE)[b]	TA–46–340, Wastewater Treatment Facility Chlorination Building		TA–41–1, Ice House
	TA–54–38, Radioassay and Nondestructive Testing Facility	TA–54–216, Legacy Toxic Gas Storage		TA–46–154, Applied Photochemistry
	TA–55–185, Transuranic (TRU) Drum Staging Facility	TA–54–1008, Chlorinator		
		TA–72–3, Chlorinator		
		TA–73–9, Chlorinator		

[a] Activities utilize or occur at several host facilities at which special nuclear material associated with Hazard Category 2 may reside for short durations. These host facilities include TA–8–23 (Radiography), TA–16–411 (Assembly Building), and TA–15 (PHERMEX), and the DARHT facility when it is completed.

[b] LANSCE, TA–53, is a nonnuclear facility that hosts several activities typically of limited duration that are considered to be Hazard Category 3, including isotope production and experiments using small quantities of actinides. The risks associated with these occasional, short duration activities involving these materials at these facilities have been evaluated in DOE safety analyses and controls are in place while the material is in the facilities.

TABLE G.3.2–2.—*LANL Facilities Screened from Analysis, with Screening Rationale*

FACILITY	FACILITY NAME AND SCREENING RATIONALE
TA–0–1113	Potable Water Chlorinator—Located in canyon; chlorine is a heavy gas that in high concentrations will proceed down the canyon, away from populated areas; no unique worker accidents; no biohazards; no radioactive materials.
TA–0–1114	See TA–0–1113.
TA–2–1	Omega West Reactor—Not scheduled for operation in a SWEIS alternative. All nuclear material has been moved from this facility, and the facility has been removed from the site's nuclear facility list.
TA–3–30	General Warehouse—No radioactivity or biohazards; chemical inventory screened; no unique worker hazards.
TA–3–31	Chemical Warehouse—No radioactivity or biohazards; chemical inventory screened; no unique worker hazards.
TA–3–35	Press Building—Radiological facility only; radiological hazards bounded by other nearby facilities. No chemicals or biohazards. No unique worker hazards.
TA–3–39	Shops Building—No unique worker hazards; no biohazards. Impacts from depleted uranium or beryllium bounded by other facilities (TA–3–66, TA–3–141).
TA–3–102	See TA–3–39.
TA–3–141	Beryllium Technology Building—No credible public accidents. No biohazards; no radioactivity.
TA–3–142	Shipping and Receiving Warehouse—Transient radioactivity only (less than Hazard Category 3 quantities). Chemical inventory screened (ERPG–3 < 100 meters). No biohazards. No unique worker hazards.
TA–3–159	Sigma Thorium Storage Facility—Facility contains only thorium; consequences bounded by other facilities; passive storage only, nonpyrophoric forms, low combustible loading.
TA–3–164	Uranium Storage Facility—Inventory removed. No use projected for any SWEIS alternative.
TA–3–166	Wastewater Treatment Plant—Chlorine inventory removed; facility no longer treats wastewater. No biohazards or radioactivity. No unique worker hazards.
TA–3–170	Compressed Gas Processing Facility—No radioactivity or biohazards. No unique worker hazards. Chemical inventory screened (ERPG–3 <100 meters).
TA–3–1698	Materials Science Laboratory (MSL)—No credible accidents; radioactivity and chemical inventories screen. No unique worker hazards; no biohazards.
TA–8–22	Radiography—Facility performs radiography of (among other things) pits and DARHT assemblies. Low combustible loading and similar seismic resistance to other facilities at which these materials will be present for a much greater percentage of the time. The risks of accidents at TA–8–22 are bounded by the risks of accidents at the other facilities. No unique worker accidents (radiography performed at other facilities as well).
TA–8–23	See TA–8–22.
TA–9–23	Shops Building—Radiological inventory below Hazard Category 3; chemical inventory screens (ERPG–3 <100 meters). No biohazards. No unique worker hazards. Remote location.

TABLE G.3.2–2.—*LANL Facilities Screened from Analysis, with Screening Rationale*-Continued

FACILITY	FACILITY NAME AND SCREENING RATIONALE
TA–9–30	Nuclear Material Storage—Maximum radiological inventory is 100 kilograms of depleted uranium and less than 0.1 grams of tritium (less than Hazard Category 3). Chemical inventory screens (ERPG–3 < 100 meters). No biohazards. No unique worker hazards. Remote location; depleted uranium accident consequences bounded by other facilities with greater inventory and in more densely populated area.
TA–11–30	Vibration Test Building—Transient radiological inventory only (same materials present at other facilities in greater quantity and/or more frequently). No chemicals or biohazards. No unique worker hazards.
TA–14–5	Toxic Gas Storage Building—Inventory removed. No use projected for any SWEIS alternative.
TA–15–184	PHERMEX—Firing site with no unique hazards (any hazards at PHERMEX bounded by those at DARHT and other facilities). No unique worker hazards. No biohazards. More remote than other facilities with similar MAR.
TA–16–260	High Explosives Processing—No radioactivity or biohazards. No unique worker hazards. Detonation hazards limited to workers due to exclusion area and blowout panels.
TA–16–305	High Explosives Chemical Storage—No radioactivity or biohazards. No unique worker hazards. Chemical inventory screens (ERPG–3 < 100 meters). Contained in former high explosives magazine.
TA–16–340	High Explosives Pressing Facility—No radioactivity or biohazards. No unique worker hazards. Detonation hazards limited to workers due to exclusion area and blowout panels.
TA–16–410	Assembly Facility—Activities at TA–16–410 are comparable to those at TA–16–411, and the MAR at TA–16–410 is bounded in hazard and quantity by MAR at TA–16–411.
TA–16–560	Potable Water Chlorinator—Consequences limited to area containing few buildings. No public consequences (except possibly a limited number of commuters on West Jemez Road). No unique worker hazards; no biohazards; no radioactivity. Impacts bounded by other potable water chlorinators.
TA–18–26	Pajarito Site Hillside Vault—Passive vault storage of plutonium and highly enriched uranium (HEU) in a vault built into the side of a mesa. Very low combustible loading, no active HVAC systems. Infrequent access. Seismic collapse would bury MAR with no significant release to the environment. No credible accidents; very low frequency accidents bounded by those at other storage facilities (TA–3–29, TA–55–4).
TA–21–3	Chemistry Building—Facility undergoing decontamination and decommissioning; completion scheduled prior to final SWEIS issuance.
TA–21–4	See TA–21–3.
TA–21–5	See TA–21–3.
TA–21–146	Filter Building—Filter building for former plutonium activities at TA–21. Decontamination and decommissioning will be completed prior to final SWEIS issuance.
TA–21–150	See TA–21–3.
TA–35–2	Laboratory—The only MAR is radioactive sources, which screen under DOE Standard 1027-92 (DOE 1992).
TA–35–27	Nuclear Safeguards Laboratory—The only MAR is radioactive sources, which screen under DOE Standard 1027-92.

TABLE G.3.2–2.—*LANL Facilities Screened from Analysis, with Screening Rationale*-Continued

FACILITY	FACILITY NAME AND SCREENING RATIONALE
TA–35–213	Target Fabrication Facility—No radioactive materials (except less than Hazard Category 3 quantities of depleted uranium and tritium). No biohazards. Some toxic chemicals present, but located in fume hoods with active ventilation. Under seismic collapse conditions, toxic effects remain within TA (facility adjacent to canyon, which will preclude transport of high concentrations of heavy gases); workers would be impacted by the seismic collapse in any event.
TA–41–1	Ice House—Former radiological inventory removed (residual contamination only). No storage or processing in any SWEIS alternative. No chemicals or biohazards. No unique worker hazards.
TA–46–154	Applied Photochemistry—No radioactivity or biohazards. No unique worker hazards. Chemical inventory screens (ERPG–3 < 100 meters).
TA–48–1	Radiochemistry Facility—All MAR (radioactive and chemical) screen (i.e., radioactivity less than Hazard Category 3, except for hot cells; chemicals screen at ERPG–3 at less than 100 meters). Any impacts would be limited to the TA–48 site area.
TA–53	LANSCE and Manuel Lujan Neutron Scattering Center (MLNSC)—No credible accidents. No unique worker accidents. No biohazards.
TA–54–33	Drum Preparation Facility—No chemicals or biohazards. No unique worker hazards. MAR limited and bounded by other nearby facilities (TA–54–38, TA–54–G Transuranic Waste Inspectable Storage Project [TWISP]).
TA–54–49	Low-level Mixed Waste Storage Dome—No biohazards. No unique worker hazards. Radiological hazards bounded by other nearby facilities with much larger inventories (TA–54–G, TWISP).
TA–54–1008	Potable Water Chlorinator—No receptors within ERPG–2 distance. No unique worker hazards; no biohazards or radioactivity.
TA–55–5	Plutonium Facility Warehouse—Chemical inventory removed; staging area only with transitory chemical inventory. No changes expected for any SWEIS alternative. Bounded by TA–55–4 chemical accidents (e.g., chlorine, hydrogen fluoride gas, nitric acid, hydrochloric acid).
TA–55–41	Nuclear Materials Storage Facility (NMSF)—Storage activities at TA–55–41 mirror those at TA–55–4. No unique hazards at TA–55–41. TA–55–41 connected to TA–55–4 via an underground tunnel. Risks at TA–55–41 bounded by those at TA–55–4.
TA–60–29	Pesticide Storage Building—Passive storage facility; chemicals screen or are bounded by the effects of chemical releases at other nearby facilities. No biohazards or radioactivity.
TA–72–3	Potable Water Chlorinator—No receptors within ERPG–2 distance. No unique worker hazards; no biohazards or radioactivity.
TA–73–1	Los Alamos Airport—Covered under transportation accident analysis. Aircraft crash associated with missed landings, etc., covered in facility aircraft crash accident analysis (DOE Standard 3014-96, DOE 1996b).
TA–73–9	Potable Water Chlorinator—Located on steep hill. Chlorine is a heavy gas that in high concentrations will proceed downhill into a canyon. Any impacts to commuters on State Road 502 will be bounded by chlorine release from other potable water chlorinators (TA–0–1109, TA–0–1110).

TABLE G.3.2–3.—*Final List of LANL Facilities to be Subjected to Screening Consequence Analysis*

TECHNICAL AREA AND BUILDING NUMBER	FACILITY NAME
TA–0–1109	Potable Water Chlorinator
TA–0–1110	Potable Water Chlorinator
TA–3–29	CMR Building
TA–3–66	Sigma Facility
TA–3–476	Toxic Gas Storage Shed
TA–9–21	Analytical Chemistry Building (worker hazard only)
TA–15–312	DARHT Facility
TA–16–205	WETF
TA–16–411	Assembly Building
TA–18–23	Pajarito Site Kiva #1 (seismic and aircraft crash only)
TA–18–32	Pajarito Site Kiva #2 (seismic and aircraft crash only)
TA–18–116	Pajarito Site Kiva #3
TA–18–168	Pajarito Site SHEBA Building (seismic and aircraft crash only)
TA–21–155	TSTA
TA–21–209	TSFF
TA–43–1	Health Research Laboratory (HRL) (seismic only)
TA–46–340	Waste Water Treatment Facility (WWTF)
TA–50–1	Radioactive Liquid Waste Treatment Facility (seismic only)
TA–50–37	Radioactive Materials Research, Operations, and Demonstration Facility (RAMROD)
TA–50–69	Waste Characterization, Reduction, and Repackaging (WCRR) Facility
TA–54–G	TWISP (TA–54–229, TA–54–230, TA–54–231, and TA–54–232); Transuranic Waste Storage Domes (TA–54–48, TA–54–153, TA–54–224, TA–54–226, and TA–54–283); Tritium Waste Sheds (TA–54–1027, TA–54–1028, TA–54–1029, and TA–54–1041)
TA–54–38	Radioactive Assay and Nondestructive Test (RANT) Facility
TA–54–39	PCB Waste Storage Facility
TA–54–216	Legacy Toxic Gas Storage Facility
TA–55–4	Plutonium Facility
TA–55–185	Transuranic Waste Drum Staging Building
TA–59–1	Occupational Health Laboratory (worker hazard only)

Facilities that do not perform radiological operations are subdivided into three hazard classes based on the hazard potential of the chemical inventory according to guidance in DOE Order 5481.1B and DOE EM Standard 5502-94 (DOE 1994b). Facilities that do not fall into one of the three hazard classes are considered as nonhazardous facilities (i.e., no hazards identified other than a normal office environment) (LANL 1995a).

The four nonnuclear facility hazard classes are defined as follows (DOE 1994b):

- *High Hazard.* Hazards with a potential for on-site and off-site impacts to large numbers of people or for major impacts to the environment. (Note: There are no facilities at LANL designated by LANL or DOE as High Hazard).
- *Moderate Hazard.* Hazards that present considerable potential on-site impacts to people or the environment but at most only minor off-site impacts.
- *Low Hazard.* Hazards that present minor on-site and negligible off-site impacts to people and the environment.
- *Nonhazardous.* No hazards beyond those routinely encountered in an office environment (electrical equipment, glassware, tools, etc.).

G.3.2.2 *Use of Facility Safety Documentation and Walkdowns*

Based on the results of the accident initiator screening and facility screening, available facility safety documentation was reviewed. All other things being the same, potential accident scenarios with the largest release potential within each frequency row were selected for more detailed review and assessment. Prior to the conduct of facility interviews and walkdowns (in most cases), a preliminary list of accident scenarios was prepared based on facility safety documentation review in order to facilitate the walkdown and discussions with facility operations personnel.

A pre-visit facility walkdown/interview data collection form was prepared for each facility and transmitted to facility representatives (through the LANL SWEIS Project Office). Facility representatives, in coordination with the LANL SWEIS Project Office points-of-contact, then arranged for a facility discussion and walkdown. The walkdown/interview data collection forms were created to facilitate the collection of a consistent set of facility data. In preparing the forms, the previous experience of SWEIS accident analysis team in conducting previous accident evaluations (including safety analyses, probabilistic risk assessments, and process hazard analyses) was considered. In addition, the following specific source documents were considered:

- DOE Handbook 1100-96, *Chemical Process Hazard Analysis*, February 1996 (DOE 1996b).
- DOE EM Standard 5502-94, *Hazard Baseline Documentation*, August 1994 (DOE 1994b).
- DOE Standard 1027-92, *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports*, December 1992 (DOE 1992).
- DOE Standard 3009-94, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports*, July 1994 (DOE 1994a).

During and subsequent to the walkdowns, revised safety documentation was provided by the facility representatives. This documentation was subsequently reviewed, and a draft data collection document was prepared for each facility. These draft data collection documents were reviewed by the LANL SWEIS Project Office and facility representatives to ensure that the information about the facilities and their operation was correctly noted by the data collection team.

Where a facility had current safety documentation, that documentation was used in the first instance to define accident scenarios. Owing to differences in scope between safety documentation and NEPA accident analyses, some supplementation of the safety documentation was necessary in a few instances in order to provide the required NEPA coverage (this was especially true in the area of seismically initiated sequences). The facility walkdowns were used to further evaluate the accident scenarios identified in the safety documentation, to evaluate whether additional accident scenarios were possible that were not included in the safety documentation, to evaluate whether there were accident frequency or accident consequence mitigation capabilities present that were not credited in the safety documentation, and to assess the impacts of the SWEIS alternatives on the accident scenarios. This latter consideration included the following aspects:

- Evaluation of whether accident frequencies could increase or decrease across the alternatives
- Evaluation of whether the MAR could increase or decrease across the alternatives
- Evaluation of whether accident scenarios identified for the No Action Alternative would be eliminated across the remaining alternatives
- Evaluation of whether any accident scenario not identified for the No Action Alternative would be possible in any of the other alternatives

As a result of the facility walkdowns and interviews and the review of revised safety documentation for many facilities, a large number of credible radiological accident scenarios were identified and grouped by MAR (e.g., weapons grade plutonium, source material plutonium, tritium, highly enriched uranium, depleted uranium, etc.) for further consideration.

G.3.2.3 *Population Distributions*

Population distributions were created (using the SECPOP90 program) based on 1990 Census data for residential population and based on 1996 LANL workforce populations by TA.

LANL workforce populations were included in the analysis by centering the total TA population in the direction from the accident origination facility that represents the largest concentration of TA population for each TA. Although this is an approximation method and results in some double counting because facility workers also may have residences within the 50-mile (80-kilometer) radius of LANL for which consequence calculations were performed, this is believed to be an appropriate means for including LANL workforce consequences.

The aggregation of workforce population data by TA is the only available aggregation for which substantial questions do not exist. Although data are available on a building-by-building basis, those data represent where the LANL employees collect their mail and do not necessarily represent where they spend most of their work day. Neither is the LANL workforce varied across the alternatives for accident analysis purposes, although it is recognized that the LANL workforce varies in size by alternative. There is much greater variation in LANL workforce from shift to shift during any given day than there is across the alternatives. It is not practical nor feasible to refine the population within a TA quite close to a release point because such data are not available and would not be stable. The consequences are given in terms of collective exposure and the exposure at the MEI locations, which are adequate for differentiating among the alternatives for decision making.

In all cases in this accident analysis, the accidents are assumed to take place during the day shift with the maximum workforce population present. (Indeed, the entire workforce is represented in the aggregated workforce population data by TA, not just the daytime workforce.) The assumption of daytime conditions is conservative for those accidents that occur at random and are unrelated to processes in operation at any given time.

G.3.2.4 *Dispersion Parameters Used in Screening and Consequence Calculations*

Daytime populations, which are larger than nighttime populations near the source, were used for screening and calculating the consequences of chemical and radiological accidents. Accordingly, the meteorological conditions used were: (1) wind speed of 9.2 feet per second (2.8 meters per second); (2) Pasquill-Gifford stability Class C; (3) ambient temperature of 48°F (8.9°C); (4) mostly sunny, cloud cover conditions; and (5) 51 percent relative humidity. These are representative of daytime conditions in this area (LANL 1990a). They provide conservative dispersion under daytime conditions and will be referred to as such in this SWEIS. (Class A and B stabilities also occur during the daytime, but their greater vertical air motions will produce lower ground level concentrations. Stable atmospheres, which will produce higher concentrations, can occur but are atypical and therefore not used for screening.)

For the consequence assessment of chemical accidents, both conservative daytime dispersion and adverse dispersion conditions (stable atmosphere) were used. For radiological accidents, all meteorological conditions, in the relative frequency as they occurred in 1995, were used.

G.3.3 Chemical Accident Screening

G.3.3.1 *Summary of Chemical Accident Screening*

Thirty-seven chemicals were identified in the 1992 LANL database that met all of the following criteria:

- Has a time-weighted-average (TWA) less than 2 parts per million
- Is found in readily dispersible form (i.e., a gas or liquid)
- Has a boiling point less than 212°F (100°C) and vapor pressure greater than 0.5 millimeter mercury

These 37 chemicals were modeled for release of their largest 1992 inventory, using adverse dispersion conditions. The ten releases that exceeded the ERPG–3 guideline at 328 feet (100 meters) distance were retained for further analysis. To these were added another eight chemicals of interest.

Releases of the actual inventories of these 18 chemicals at 78 locations were then modeled to see which would exceed the ERPG–3 concentration under conservative daytime dispersion conditions. In this modeling:

- Release was at surface level
- Gases were released over 10 minutes
- Liquids were spilled instantaneously and then evaporated from a puddle 0.4 inch (1 centimeter) deep

The releases that exceeded the ERPG–3 concentration were examined with consideration of:

- Whether there is a large workforce nearby or if there is public exposure
- If a heavy gas, whether the public is protected by intervening canyons

- Whether the consequences are less than a release of the chemical from a different facility
- Whether the consequences are less than those of another chemical released from the same facility

With these considerations, a number of releases were selected and retained for detailed analysis. Formaldehyde also was retained because it represents the largest LANL inventory of a readily dispersible chemical carcinogen. These final selections are shown in Table G.3.3.1–3. The above process is described in detail in the following.

Details of Chemical Screening

There is a wide variety of chemicals in storage and in use at LANL facilities. This analysis assumes that all chemicals that are regulated or have established exposure guidelines are listed in the MULTUS database (Dukes 1995). This commercially available database contains information on over 2,800 controlled chemicals and over 23,000 associated synonyms. Because there are far more TWAs than other guidelines for chemicals, TWAs were chosen to represent toxicity for screening purposes. An upper threshold value of 2 parts per million was selected because it is the TWA for nitric acid. (There is a 6,100-gallon [23,100-liter] nitric acid tank at TA–55 that, because of its volume, was likely to represent the bounding consequence chemical accident.) The MULTUS database was searched for chemicals with TWAs less than 2 parts per million, resulting in a list of 330 chemicals.

The 1992 LANL Automated Chemical Inventory System (ACIS) chemical database (which represented LANL baseline data) was searched for these same 330 chemicals. Only 190 were found. Of these, if the chemical is ordinarily in solid form (nondispersible), it was screened from further analysis. (Although particles smaller than about 10 micrometers diameter are respirable, a liquid or gas is expected to have greater consequences in terms of area of impact and time urgency; thus, the analysis was focused on liquids and gases.) Application of this criterion reduced the list to 74 chemicals.

If the chemical has a boiling point of greater than 212°F (100°C) and has a vapor pressure of less than 0.5 millimeters of mercury under ambient conditions, the material was screened from further analysis. This criterion was developed based on an American Conference of Governmental Industrial Hygienists (ACGIH 1992) hazard index (HI) (which assigns a low vaporization/dispersion hazard to materials with boiling points greater than 212°F [100°C]) and the EPA List of Regulated Substances and Thresholds for Accidental Release Prevention. (The latter establishes a criterion of a vapor pressure of less than 0.02 inch [0.5 millimeter] of mercury under ambient conditions for toxic liquids to capture most substances that have a relatively low volatility but may still pose an airborne hazard in accidental release [40 CFR 68].) Application of this criterion further reduced the list to 37 chemicals.

For each of the 37 chemicals, ALOHA™ dispersion modeling was performed using its largest inventory in the 1992 ACIS database. Adverse dispersion conditions were used to determine whether concentrations as great as ERPG–3 would occur at a distance of 328 feet (100 meters) (the approximate distance to noninvolved workers and general public access). Ten chemicals were found to produce ERPG–3 concentrations at distances beyond 328 feet (100 meters): boron trifluoride, bromine, chlorine, formaldehyde, methyl hydrazine, nitric acid, phosgene, phosphorous oxychloride, selenium hexafluoride, and thionyl chloride.

In addition to the ten chemicals to survive the above screening process, the following seven chemicals were identified in the "significant chemicals in hazard analysis" table of the

LANL hazard assessment document (LANL 1995a), and were included for analysis: diborane, fluorine, hydrogen cyanide, hydrogen fluoride, nickel carbonyl, perfluoroisobutylene, hydrochloric acid, and sulfur dioxide. In addition, a review of the TA–3–170 Compressed Gas Processing Facility inventory resulted in the addition of nitric oxide to the list of chemicals of concern.

An information request was submitted to LANL for storage locations, quantities, physical form, units of measurement, and other associated information for these 18 chemicals. Upon receipt of the information from LANL, the materials were aggregated into storage locations, converted into common units of measurement, and adjusted for concentration. This process resulted in 183 chemical sources at 78 storage locations. The resulting chemical inventories were then modeled to determine which facilities contained total quantities that, if released, would exceed ERPG–3 concentrations at 328 feet (100 meters) under conservative daytime atmospheric dispersion conditions. This modeling identified chemical sources at the storage locations shown in Table G.3.3.1–1.

TABLE G.3.3.1–1.—*Preliminary ALOHA™ Chemical Screening Results*

CHEMICAL	LOCATION
Sulfur Dioxide	TA–54–216
Hydrochloric Acid	TA–55–249
Hydrogen Cyanide	TA–3–66
Nitric Acid	TA–50–1
	TA–50–5
	TA–55–4
	TA–59–1
Selenium Hexafluoride	TA–54–216
Chlorine	TA–00–1109
	TA–00–1110
	TA–00–1113
	TA–00–1114
	TA–3–476
	TA–16–560
	TA–33–200
	TA–46–340
	TA–54–1108
	TA–55–4
	TA–72–3
	TA–73–9
Fluorine	TA–54–216
Hydrogen Fluoride	TA–54–216
	TA–55–4

The initial data source, as indicated above, was the 1992 ACIS baseline data. The following information sources were utilized to find additional storage locations and potential release sites for these chemicals:

- The 1995 ACIS Database, which contains a listing of the chemicals ordered on an annual basis
- TA–54 Area L (hazardous waste management facility) gas cylinder inventory
- STORES Database
- Cheaper Database (recycled chemicals) and Gas Plant Database
- Facility-Specific SARs, Safety Assessments (SAs), and other safety documentation
- LANL Spill Prevention, Control and Countermeasure (SPCC) Plan
- Facility interview and walkdown data collection forms

The results in Table G.3.3.1–1 were examined with a further consideration of population distributions surrounding the release sites and, for heavy gases, consideration of whether the potential atmospheric transport to populated areas would be interrupted by canyons. Based on these considerations, a number of release sites were screened from further consideration. The results of this initial binning effort are shown in Table G.3.3.1–2.

The release sites and chemicals surviving this initial binning effort were then plotted on a map

TABLE G.3.3.1–2.—*Preliminary Binning of Chemical Accident Release Sites*

CHEMICAL	RELEASE SITE	PRELIMINARY BINNING COMMENTS
Chlorine	TA–00–1109	Retained for detailed analysis; located on the edge of a neighborhood
	TA–00–1110	Retained for detailed analysis; located on the edge of a neighborhood
	TA–00–1113	Screened; located in a canyon; any impacts bounded by TA–0–1109/1110
	TA–00–1114	Screened; located in a canyon; any impacts bounded by TA–0–1109/1110
	TA–03–476	Retained for detailed analysis; large LANL workforce nearby; intervening canyon prevents heavy gas transport to Los Alamos townsite
	TA–16–560	Screened; located at a site with no public receptors; impacts bounded by TA–03–476
	TA–33–200	Screened; located at a remote site with no public receptors and a very small LANL workforce population (less than 10); impacts bounded by TA–03–476
	TA–46–340	Screened; no credible accidents; release site is in a canyon; heavy gas plume will dissipate prior to reaching distant public receptors
	TA–54–1008	Screened; located at a remote site with no public receptors; impacts bounded by other chemicals released from TA–54–216 (closer to LANL workforce)
	TA–55–4	Retained for detailed analysis; intervening canyon prevents transport to public receptors; large LANL workforce population (TA–35, TA–48, TA–50, & TA–55)
	TA–72–3	Screened; located at a remote site with no public receptors; canyon prevents transport of a heavy gas to populated areas
	TA–73–9	Screened; located on a hill; heavy gas transport will be predominantly downslope into a canyon, away from public receptors and LANL workforce at TA–00 locations
Fluorine	TA–54–216	Screened; impacts bounded by sulfur dioxide and selenium hexafluoride
Hydrochloric Acid	TA–55–249	Retained for detailed analysis
Hydrogen Cyanide	TA–03–66	Retained for detailed analysis
Hydrogen Fluoride	TA–54–216	Screened; impacts bounded by sulfur dioxide and selenium hexafluoride
	TA–55–4	Screened; bounded by release of chlorine at the same site
Nitric Acid (80%)	TA–50–1	Screened; impacts bounded by chlorine and nitric acid release at TA–55–4
	TA–50–5	Screened; impacts bounded by chlorine and nitric acid release at TA–55–4
	TA–55–4	Retained for detailed analysis (large LANL workforce population at TA–55)
	TA–59–1	Screened; largest container is 2.6 gallons, bounded by much larger potential releases at other facilities
Selenium Hexafluoride	TA–54–216	Retained for detailed analysis
Sulfur Dioxide	TA–54–216	Retained for detailed analysis; other sites screened, bounded by release at TA–59–216

of Los Alamos County and evaluated based on the population grids (on-site and off-site) surrounding the respective chemical storage location. The population distributions for chemical release sites were generated from 1990 Census data and current LANL TA populations as described above. The evaluation considered the probability that the wind would blow in the direction of the population at the time of release.

In addition, the chemical storage locations were separated into the following bins relating to the potential accident scenario: natural phenomena hazards (e.g., seismic events), process hazards, and man-made hazards. This final binning effort is portrayed in Table G.3.3.1–3.

Formaldehyde at TA–43–1, which was originally screened as resulting in concentrations less than ERPG–3 at 328 feet (100 meters) under conservative daytime dispersion conditions, was added back to the list on the basis that it represents the largest LANL inventory of a readily dispersible carcinogen from the 51 confirmed, suspected and animal carcinogens in the site inventory.

G.3.3.2 *Assumptions Inherent in the Screening*

The following assumptions are inherent in the process:

- All hazardous LANL chemicals are in the MULTUS database.
- All hazardous LANL chemicals of significant inventory are in the LANL ACIS database or otherwise captured in the safety documentation and walkdowns.
- There are no readily dispersible particles that pose significant accident release consequence and that are not otherwise captured in the human health analyses and/ or in the site-wide and other accident scenarios.

TABLE G.3.3.1–3.—*Final Chemical Accident Binning*

CHEMICAL	RELEASE SITE	PROCESS HAZARD	MAN-MADE HAZARD	NATURAL PHENOMENA HAZARD	CARCINOGEN
Chlorine	TA–00–1109	X		X	
	TA–00–1110	X		X	
	TA–03–476		X		
	TA–55–4	X		X	
Formaldehyde	TA–43–1			X	X
Hydrochloric Acid	TA–55–249			X	
Hydrogen Cyanide	TA–03–66			X	
Nitric Acid	TA–55–4			X	
Selenium Hexafluoride	TA–54–216	X	X		
Sulfur Dioxide	TA–54–216	X	X		

Note: These releases are heavy gas releases except for selenium hexafluoride and hydrogen chloride. Heavy gases in high concentrations would not be capable of crossing canyons from mesa to mesa, but would instead flow down into the canyons and proceed downslope. Such diversion into canyons is not modeled by ALOHA™, which is a flat terrain model. Heavy gas behavior has been taken into account manually in the affected population results shown above. The formaldehyde release from TA–43–1 was screened on chemical consequence results. However, it was retained because it represents the largest inventory of a readily dispersible carcinogenic chemical.

- There are no solid (nondispersible) pyrophoric materials posing a release hazard of significant consequence that were not captured or bounded in one of the accidents considered.
- Gases were modeled as a 10-minute release (rather than an instantaneous release) in accordance with the EPA *Risk Management Plan Off-site Consequence Analysis Guidance* (EPA 1996) and the EPA/FEMA/ DOT *Technical Guidance For Hazards Analysis* (EPA 1987). However, instantaneous release may be possible for some gases, producing much higher concentrations (though for a shorter time).
- The terrain around LANL facilities is relatively flat in the first several hundred meters, and when not, this does not dramatically change the concentrations from those produced by ALOHA™.
- The surface around LANL facilities is represented by the surface roughness in the ALOHA™ model, which in turn affects the dispersion rate.
- The averaging time inherent in ALOHA™ does not smooth, to an average less than 2 parts per million, dangerously high momentary concentrations that would exist beyond 328 feet (100 meters).

These assumptions are reasonable for screening because the resultant screening is sufficiently conservative to have a reasonable assurance of capturing all chemicals and chemical locations that pose a risk to the public and workers outside the facility.

G.3.4 Facility Radiological Accident Screening

G.3.4.1 *Methodology for Consequence Screening*

To facilitate radiological facility accident screening, integrated population exposure was established as an evaluation criterion. Consequences were calculated for the release of a unit of material and multiplied by the source term magnitude to obtain approximate consequences for screening. The calculations were performed with the MACCS 2 code (as described in section G.2.4) for both ground level releases and elevated releases (which varied from 18.3 to 100 meters, depending on the facility and the scenario of interest). The following distance intervals were used in each of the 16 compass directions: 0 to 1 kilometer, 1 to 2 kilometers, 2 to 3 kilometers, 3 to 4 kilometers, 4 to 8 kilometers, 8 to 12 kilometers, 12 to 20 kilometers, 20 to 30 kilometers, 30 to 40 kilometers, 40 to 60 kilometers, and 60 to 80 kilometers.

G.3.4.2 *Source Terms*

For radiological accidents, there are two source terms of interest: the initial source term and the suspension source term. The initial source term is the radioactive material driven airborne at the time of the accident. The suspension source term is the radioactive material that becomes airborne subsequent to the accident as a result of evaporation, winds, or other processes. For most DOE nonreactor facilities, the dose from inhalation exposure dominates the overall dose from accidents.

Source terms were estimated based on the accident progression for the scenario being considered. DOE Handbook 3010-94, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities* (DOE 1994d), was used as the primary reference for calculation of source terms. DOE Standard 3014-96 (DOE 1996c), which covers aircraft crash accidents, has a separate source term methodology identified in Table II of the standard. Although it is stated to be based on DOE Handbook 3010-94, it is more conservative than the handbook. In order to maintain consistency across the accident analyses, and in accordance with the provision in Section 7.2.5 of the DOE standard, which provides that other methods can be used if justified, the DOE Handbook 3010-94 source term methodology has been applied to the aircraft crash accidents in this SWEIS.

MAR estimates were obtained from safety documentation and verified during the course of facility walkdowns. Two source term equations are used: one for the initial source term and one for the subsequent continuing suspension source term. The initial equation has the following general form:

Initial Source Term = (MAR) x (DR) x (ARF) x (RF) x (LPF)

where:

MAR = Material-at-risk (quantity of material available to be acted on by a given physical stress)

DR = Damage ratio (the fraction of the MAR actually impacted by the accident-generated conditions)

ARF = Airborne release fraction (the fraction of the material suspended in the air as an aerosol and, thus, available for transport due to the physical stresses from a specific accident or due to operation of HVAC systems)

RF = Respirable fraction (the fraction of the aerosols that can be transported through the air and inhaled into the human respiratory system, commonly assumed to include particles of 10 micrometers aerodynamic equivalent diameter or less)

LPF = Leak path factor (the fraction of the respirable aerosols transported through some confinement or filtration mechanism)

The suspension source term equation has the following general form:

Suspension Source Term = (MAR) x (DR) x (ARR/hr) x (24 hrs) x (RF) x (LPF)

where:

MAR = Material-at-risk

DR = Damage ratio

ARR/hr = Airborne release rate per hour

RF = Respirable fraction

24 hrs = Suspension calculational time period

LPF = Leak path factor

Note that the suspension source term includes all processes whereby material continues to become airborne. This includes evaporation of liquids, continuing leaks, and resuspension by air motions of material initially deposited. It is referred to as “suspension” to delineate it from resuspension, a term reserved for resuspension of deposited materials previously airborne.

G.3.4.3 *Identification of Accident Scenarios*

Two primary types of data sources were used for radiological accident analysis: (1) safety documentation, including SAs, hazard analyses (HAs), process hazard analyses (PrHAs), PRAs, and SARs; and (2) facility walkdown/interview data collection forms. Documentation relied upon for the radiological facility accident analysis included the following:

- The draft facility descriptions and hazard classification document for LANL, prepared by the LANL SWEIS Project Office (LANL 1995a)
- Descriptions of alternatives for key facilities prepared by the LANL SWEIS Project Office (LANL 1997c and LANL 1998a)
- The LANL seismic hazard evaluation (Wong et al. 1995)
- The LANL aircraft crash hazard evaluation (LANL 1996c)

- Various LANL memoranda and miscellaneous documentation
- Basis for Interim Operation, Operational Safety Requirements, and Technical Safety Requirements for various LANL facilities
- Environmental Assessments (EAs) and EISs
- Various DOE guidance documents
- DOE orders and standards
- Other nuclear industry data sources (e.g., Swain and Guttmann 1983 and Mahn et al. 1995)

Based on the results of the review of facility safety documentation and the facility walkdown/interview data collection process, a large suite of accident scenarios were identified and their consequences quantified by conservative screening methods. Table G.3.4.3–1 provides a consolidated listing of all of the various scenarios that were subjected to the conservative consequence screening analysis. Only those scenarios that were shown on a conservative screening basis to be potentially risk-dominant were then subjected to a more detailed analysis. (These are listed in Table G.4–1).

G.3.4.4 Addition of Site-Wide Wildfire to Screening Results

In the screening methodology, wildfire was not put into the list of natural phenomena hazards that might initiate accidents. Instead, the DOE initially treated wildfire as a subset of manmade fires (Table G.3.1–1). Manmade fires were considered at individual facilities, but were eliminated as the most frequent accident initiator, or the bounding or representative accident for the facility. Because of this, and because wildfires are not common in facility-specific hazard analysis documents, site-wide wildfires escaped consideration in the Draft SWEIS. At the same time, there was a general recognition of the threat to LANL, as evidenced by the multiple agency cooperation in an ongoing fuel reduction effort. This oversight was brought to the DOE's attention during the public hearings on the Draft SWEIS, and an analysis was immediately begun with input from the Española District of the Santa Fe National Forest, the Bandelier National Monument of the National Park Service, the Los Alamos Fire Department, and LANL departments and personnel. The final analysis appears as SITE–04.

G.3.5 Worker Accident Screening

Analysis of worker accidents was performed to provide estimates of potential health effects from chemical and radiological exposure for involved workers. (For purposes of this SWEIS, workers within the TA where the accident occurs are defined as "involved workers," and other on-site LANL employees are defined as "noninvolved workers.") Because worker health risk from industrial accidents (falls, electrical shock, crushing, etc.) dominates over worker health risk from exposure from radiological and chemical accidents, worker accident analysis is not as extensive or detailed as that for public impacts Also, there are far more low energy events whose impacts are highly dependent upon worker location and the details of the accident.

Worker accidents were reviewed qualitatively in order to arrive at a list of accidents that is representative of the accident potential at LANL under the four alternatives. The process used was similar to the analysis of accidents with public impact. The purpose of the separate worker accident screening was to identify whether there are accident scenarios that could have greater consequence to workers than the worker consequence associated with the public accident scenarios.

Data to support the accident analysis were obtained from a variety of sources, both facility- and site-specific as well as from industrial and

TABLE G.3.4.3–1.—*Consolidated List of Accidents Subjected to Radiological Consequence*

MATERIAL TYPE	HAZARD TYPE (PROCESS, MAN-MADE, NATURAL PHENOMENA)	FACILITY AND SCENARIO DESCRIPTION	ANNUAL FREQUENCY BIN
Highly Enriched Uranium, Depleted Uranium, Plutonium, Tritium, TRU	Natural Phenomena	Multiple facilities, site-wide earthquake resulting in structural damage or collapse	10^{-6} to 10^{-4}
Highly Enriched Uranium	Process	TA–3–29, fire/explosion in ULISSES solvent extraction line or HEU foundry	10^{-4} to 10^{-2}
	Process	TA–3–29, inadvertent criticality event due to multiple procedural violations and/or equipment failures	
	Man-Made	TA–3–29, aircraft crash and fire	10^{-6} to 10^{-4}
	Process	TA–18–116, power excursion leading to fuel melting	10^{-6} to 10^{-4}
	Process	TA–3–66, foundry fire	10^{-4} to 10^{-2}
Plutonium	Man-Made	TA–3–29, natural gas pipeline failure, ingestion of gas into building, explosion and fire	10^{-6} to 10^{-4}
	Process	TA–18–116, reactivity excursion, melting of Pu sample	10^{-6} to 10^{-4}
	Man-Made	TA–50–1, nonprocess-related boiler explosion, damage to clariflocculator	10^{-2} to 10^{-1}
	Process	TA–55–4, inadvertent criticality event due to multiple procedural violations and/or equipment failures	10^{-6} to 10^{-4}
	Process	TA–55–4, ion exchange column exothermic reaction and explosion, failure of HEPA filters	10^{-6} to 10^{-4}
	Process	TA–55–4, explosion and fire in hydride-dehydride glovebox, failure of HEPA filters	10^{-6} to 10^{-4}
	Process	TA–55–4, human error resulting in dropped plutonium oxide powder container, failure of HEPA filters	10^{-4} to 10^{-2}
	Process	TA–55–4, fire in heat source plutonium glovebox, fire suppression inoperable, HEPA filtration ineffective	10^{-6} to 10^{-4}
	Process	DARHT, inadvertent detonation	$< 10^{-6}$
	Process	DARHT, loss of containment	10^{-7} to 10^{-6}

TABLE G.3.4.3–1.—*Consolidated List of Accidents Subjected to Radiological Consequence*-Continued

MATERIAL TYPE	HAZARD TYPE (PROCESS, MAN-MADE, NATURAL PHENOMENA)	FACILITY AND SCENARIO DESCRIPTION	ANNUAL FREQUENCY BIN
Depleted Uranium	Process	TA–3–66, foundry fire	10^{-4} to 10^{-2}
Tritium	Process	TA–16–205, inadvertent opening of LP–50 container	10^{-2} to 10^{-1}
	Process	TA–16–205, high pressure gas handling system failure, ventilation isolation failure	10^{-4} to 10^{-2}
	Process	TA–16–205, tritium waste treatment system failure, ventilation isolation failure	10^{-4} to 10^{-2}
	Process	TA–21–155, release of tritium from nonsecondary contained system during maintenance, or release of tritium from glovebox due to leaking component	10^{-2} to 10^{-1}
	Process	TA–21–155, distillation column failure, vacuum jacket failure, fire	10^{-6} to 10^{-4}
	Process	TA–21–155, tritium leak, tritium waste treatment system failure	10^{-4} to 10^{-2}
	Man-Made	TA–21–155, aircraft crash and fire	10^{-6} to 10^{-4}
	Process	TA–21–209, molecular sieve regeneration error	10^{-4} to 10^{-2}
	Man-Made	TA–21–209, aircraft crash and fire	10^{-4} to 10^{-2}
	Man-Made	TA–54–1027, TA–54–1028, TA–54–1029, and TA–54–1041, unsuppressed wild fire, aircraft crash and fire, or truck fuel system leak and fire at tritium waste storage sheds	10^{-6} to 10^{-4}
	Process	TA–55–4, special recovery line de-inerting and fire	10^{-6} to 10^{-4}
TRU Waste	Man-Made	TA–50–37, aircraft crash and fire	10^{-4} to 10^{-2}
	Process	TA–50–69, TRU waste drum puncture by forklift outdoors	10^{-4} to 10^{-2}
	Man-Made	TA–50–69, truck fuel system leak and fire at outdoor container storage area	10^{-4} to 10^{-2}
	Man-Made	TA–54–38, truck fuel system leak and fire at outdoor container storage area	10^{-4} to 10^{-2}
	Man-Made	TA–54–229, TA–54–230, TA–54–231, and TA–54–232, aircraft crash and fire or unsuppressed wild fire at TWISP storage domes	10^{-6} to 10^{-4}

nuclear generic databases and compilations. Data sources included the following:

- Safety and hazard analysis documentation
- Data forms generated during the facility walkdowns
- LANL SWEIS alternatives documentation: generic data from industry and nuclear facilities including the following:
  - *Component Failure Rate Data with Potential Applicability to a Nuclear Fuel Plant* (Dexter and Perkins 1982)
  - *General Component Failure Data Base for Light Water and Liquid Sodium Reactor PRAs* (Eide et al. 1990)
  - *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Application* (Swain and Guttman 1983)
  - *Natural Phenomena Hazards Modeling Project: Seismic Hazard Models for Department of Energy Sites* (Coats and Murray 1984)
  - Office of Nuclear and Facility Safety, Office of Environment, Safety and Health, U.S. Department of Energy, Washington, DC. Maintains and compiles a series of databases and reports on worker accidents in DOE facilities, including: (1) Occurrence Reporting and Processing System (ORPS) reports for LANL and other DOE facilities; (2) Office of Operating Experience Analysis and Feedback, Safety Notices; and (3) Office of Operating Experience Analysis and Feedback, Operating Experience Weekly Summary
  - Occupational Safety and Health Administration Form 200 Injury/Illness Reports for LANL and other DOE facilities

The summary listing identified more than 600 potential worker accident scenarios. Potential worker accident scenarios were then sorted by material hazard and initiators and ranked according to relative risk. Risk was qualitatively assigned on the basis of the frequency and consequence ranking matrix for hazard evaluation described in DOE Standard 3009-94 (DOE 1994a) and shown in Figure G.1.1–1. The array of worker accidents was not dissimilar from the array of accidents with public impact, so that the worker accident component of the selected public accidents also provides a representative picture of the worker accident potential.

There are, however, some accidents that pose risk to workers but not to the public. An example is the medical research at TA–43–1, field work on small mammal capture and blood sampling, where the exposures to workers are localized and the exposure to the population from a release would be mitigated by environmental attenuation. Another exception is energetic hazards, where potential hazardous sources do not involve the public. Examples of energetic hazards are:

- High explosives
- Laser
- Pressurized gas
- Radiofrequency
- Liquid nitrogen/cryogen
- Neutron generator
- High pressure
- Hydrogen

Representative energetic hazard accidents include:

- Low pressure steam line failures (TA–16–205)
- Failure of cryogenic systems (TA–3–170, liquid nitrogen and liquid argon; TA–3–1698, liquid nitrogen; TA–16–205, liquid nitrogen; and TA–21–155, liquid nitrogen)
- Rupture of nontoxic gas bottles (TA–15–184, TA–50–1, TA–50–69, TA–54–39, and TA–59–1)

- Failure of noncombustible gas tube trailer (TA–3–29 and TA–50–69)
- Failure of pressurized gas lines (TA–16–205, TA–16–411)
- Electrical shock (all facilities)
- Laser accidents (TA–3–1698)
- Electromagnetic fields (TA–15–312 and TA–53)
- High explosive detonation (TA–15–184, TA–15–312, TA–16–260, TA–16–340, and TA–16–411)

The ranked worker accident scenarios were then compared to the public impact accidents with comparable risk rankings. From the review of the chemical and radiological accidents selected for detailed quantification of public risk, as well as a screen of these accidents against the worker accidents, the following worker accidents were selected for more detailed evaluation:

- Inadvertent high explosives detonation
- Biohazard contamination of a single worker
- Inadvertent criticality event
- Inadvertent exposure to electromagnetic radiation (x-rays, accelerator beam, laser, or RF source)

G.4 EVALUATION OF RISK-DOMINANT ACCIDENTS

The risk-dominant accidents that were selected for detailed evaluation and impact quantification are shown in Table G.4–1. These are five site-wide accidents (earthquakes of varying severity and a wildfire), six chemical accidents, sixteen radiological accidents, and four worker hazard accidents.

G.4.1 Accident Frequency Assessment

This section contains the methodology used to determine the frequency of the different accident scenarios. The resulting frequencies, summarized in Table G.4.1–1, cover a wide frequency range. To place these frequencies in perspective, Table G.1.5–1 (section G.1 of this chapter) gives the probability of some natural phenomena at LANL and the probability of large meteors impacting somewhere in the world.

G.4.1.1 *Earthquake Frequencies*

The frequency of accidents arising from earthquakes is predicated upon a methodology set forth in DOE Standard 1020-94, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities* (DOE 1994e). Conceptually, the earthquake accident frequency assessment considers two parameters: (1) the frequency per year that earthquakes of different ground acceleration levels occur and (2) the conditional probability of component or structural failure, given those ground accelerations.

In practice, facilities are designed for earthquakes according to their hazard potential. The design for general industry is based on the Uniform Building Code (UBC), which has evolved considerably over the period of time during which currently active facilities at LANL have been constructed (early 1950's through the 1990's). DOE nuclear facilities have design basis earthquake standards (depending upon the hazard potential of the facility) and performance requirements for avoiding hazardous material releases.

The treatment of earthquakes in facility safety documentation varies from the simple (screening earthquakes based on meeting the design basis earthquake guidance) to the bounding (assuming complete structural collapse) to the detailed (seismic margin analysis). In order to try to place the assessment of system and structural response for all LANL facilities on a consistent basis, estimates were made of a parameter known as the high confidence in low probability of failure (HCLPF). This is the ground acceleration level at which the analyst is very confident that the probability of failure is very low. The HCLPF value can be mathematically related to the seismic hazard (annual frequency of ground acceleration) to produce a point estimate of frequency at which system or structural failure will occur.

The seismic hazard at LANL was the subject of a state-of-the-art probabilistic seismic hazard analysis (PSHA) prepared for the laboratory and DOE by Woodward-Clyde Federal Services. The methodology used in the study is similar to (but more advanced in some areas) that approved by the U.S. Nuclear Regulatory Commission (NRC) for commercial nuclear power plant sites located east of the Rocky Mountains. The PSHA produces a variety of results expressing the annual frequency of ground motion at the LANL site. Among the more important results and implications of the LANL PSHA are the following:

- Many important facilities at LANL were designed and constructed in the 1950's through the late 1970's and do not compare favorably with current DOE seismic design requirements.

TABLE G.4–1.—*Risk-Dominant Accidents at LANL*

PROCESS HAZARD ACCIDENTS	
CHEM–01	Single cylinder release of chlorine (150 pounds) from a potable water chlorinator (TA–00–1109, bounding) due to equipment failure or human error during chlorine cylinder replacement or maintenance activities
CHEM–03	Single cylinder release of chlorine (150 pounds) from toxic gas cylinder storage facility (TA–3–476) due to human error during cylinder handling or cylinder deterioration due to unintended long-term exposure to weather
CHEM–06	Chlorine gas release (150 pounds) from a process line at the Plutonium Facility (TA–55–4) due to mechanical damage to a supply manifold
RAD–03	Reactivity excursion accident at Pajarito Site Kiva #3 (TA–18–116) with Godiva-IV outside the kiva, vaporizing part of the highly enriched uranium fuel and melting the remainder
RAD–04	Inadvertent detonation of a plutonium-containing assembly at or near the DARHT Facility firing point, resulting in an elevated, explosive-driven release of plutonium (TA–15)
RAD–09	Transuranic waste drum failure or puncture at TA–54, Area G (bounding)
RAD–10	Plutonium release from a degraded storage container in the Plutonium Facility (TA–55–4) vault during container retrieval (Note: Determined by detailed analysis to be a worker accident only.)
RAD–11	Container breach after detonation of a plutonium-containing assembly at the DARHT firing point (TA–15), resulting in a ground-level release of plutonium
RAD–13	Plutonium melting and release accident at Pajarito Site Kiva #3 (TA–18–116)
RAD–14	Plutonium release from ion exchange column thermal excursion at TA–55–4 (Note: Determined by detailed analysis to be a worker accident only.)
RAD–15	Plutonium release from hydride-dehydride glovebox fire at TA–55–4 (Note: Determined by detailed analysis to be a worker accident only.)
WORK–01	Worker fatality due to inadvertent high explosive detonation
WORK–02	Worker illness or fatality due to inadvertent biohazard contamination
WORK–03	Multiple worker fatality due to inadvertent nuclear criticality event
WORK–04	Worker injury or fatality due to inadvertent electromagnetic radiation exposure (x-ray, accelerator beam, laser, or RF source exposure)
MAN-MADE HAZARD ACCIDENTS	
CHEM–02	Multiple-cylinder chlorine release (1,500 pounds) due to explosion or unsuppressed fire affecting a toxic gas storage facility (TA–3–476)
CHEM–04	Single cylinder release of toxic gas (selenium hexaflouride, historical bounding chemical) from the legacy toxic gas storage facility (TA–54–216) due to random cylinder failure or a forklift accident
CHEM–05	Cylinder release of toxic gas (sulfur dioxide, historical bounding chemical) from the legacy toxic gas storage facility (TA–54–216) due to a fire, a propane tank boiling-liquid expanding vapor explosion (BLEVE), or a propagating random failure
RAD–01	Plutonium release due to container storage area fire involving transuranic waste drums (TA–54–38)
RAD–02	Plutonium release due to natural gas pipeline failure near TA–3–29, with no immediate ignition, ingestion of gas into facility, followed by explosion and fire
RAD–05	Aircraft crash with explosion and/or fire at TA–21 resulting in a tritium oxide release

TABLE G.4–1.—*Risk-Dominant Accidents at LANL*-Continued

RAD–06	Aircraft crash with explosion and/or fire at TA–50–37, resulting in a plutonium release from transuranic waste drums (Note: Retained based on preliminary calculations; final calculations determined that this accident screened on frequency less than 1 x 10^{-7} per year.)
RAD–07	Plutonium release due to container storage area fire involving transuranic waste drums (TA–50–9)
RAD–08	Aircraft crash with explosion and/or fire at the transuranic waste dome area at TA–54 (TA–54–229, TA–54–230, TA–54–231, and TA–54–232)
RAD–16	Aircraft crash with explosion and/or fire at TA–3–29 resulting in a plutonium release
NATURAL PHENOMENA HAZARD ACCIDENTS	
SITE–01	Site-wide earthquake, resulting in damage to low capacity structure or internal components at multiple facilities
SITE–02	Site-wide earthquake, resulting in damage to moderate capacity structures or internal components at multiple facilities
SITE–03	Site-wide earthquake, resulting in structural damage or collapse to all facilities
SITE–03, Surface Rupture	Site-wide earthquake with accompanying surface rupture on subsidiary faults, resulting in structural damage or collapse to all facilities
SITE–04	Site-wide wildfire, consuming combustible structures and vegetation.
RAD–12	Plutonium release from a seismically initiated event

TABLE G.4.1–1.—*Accident Annual Frequency Results, by Alternative*

ACCIDENT SCENARIO	NO ACTION	EXPANDED OPERATIONS	REDUCED OPERATIONS	GREENER
SITE–01	2.9×10^{-3}	same	same	same
SITE–02	4.4×10^{-4}	same	same	same
SITE–03	7.1×10^{-5}	same	same	same
SITE–03, Surface Rupture	1 to 3×10^{-5}	same	same	same
SITE–04	0.1	same	same	same
CHEM–01	1.2×10^{-3}	1.3×10^{-3}	1.1×10^{-3}	1.2×10^{-3}
CHEM–02	1.3×10^{-4}	1.5×10^{-4}	1.2×10^{-4}	1.3×10^{-4}
CHEM–03	1.2×10^{-4}	same	same	same
CHEM–04	4.1×10^{-3}	same	same	same
CHEM–05	5.1×10^{-4}	same	same	same
CHEM–06	6.3×10^{-2}	same	same	same
RAD–01	1.6×10^{-3}	same	same	same
RAD–02	$< 10^{-6}$ (Incredible)	same	same	same
RAD–03	3.4×10^{-6}	4.3×10^{-6}	3.4×10^{-6}	3.4×10^{-6}
RAD–04	$< 10^{-6}$ (Incredible)	same	same	same
RAD–05	3.8×10^{-6} (TSTA) 5.3×10^{-6} (TSFF)	same	same	same
RAD–06	$< 10^{-6}$ (Incredible)	same	same	same
RAD–07	1.5×10^{-4}	3.0×10^{-4}	1.1×10^{-4}	1.5×10^{-4}
RAD–08	4.3×10^{-6}	same	same	same
RAD–09	4.1×10^{-3} 0.4	4.9×10^{-3} 0.49	3.9×10^{-3} 0.38	4.1×10^{-3} 0.4
RAD–10	$< 10^{-6}$ (Incredible)	same	same	same
RAD–11	$< 10^{-6}$ (Incredible)	same	same	same
RAD–12	1.5×10^{-6}	same	same	same
RAD–13	1.6×10^{-5}	same	same	same
RAD–14	$< 10^{-6}$ (Incredible)	same	same	same
RAD–15	3.2×10^{-5}	same	same	same
RAD–16	3.5×10^{-6}	same	same	same
WORK–01	0.001 to 0.01	same	same	same
WORK–02	0.01 to 0.1	same	same	same

TABLE G.4.1–1.—*Accident Annual Frequency Results, by Alternative*-Continued

ACCIDENT SCENARIO	NO ACTION	EXPANDED OPERATIONS	REDUCED OPERATIONS	GREENER
WORK–03	$< 1.0 \times 10^{-5}$	same	same	same
WORK–04	0.01 to 0.1	same	same	same
WORK–05	0.23	same	same	same

- Earthquakes simultaneously affect all LANL facilities.
- All risk-significant facilities at LANL are located within 3.5 miles (5.6 kilometers) of the Pajarito Fault, which runs parallel to the western boundary of LANL and slopes down-to-the-east under the laboratory. The Pajarito Fault, along with the Embudo Fault (which runs to the north of LANL), is the principal source of large ground motions at LANL.
- The PSHA indicates that, for all eight LANL locations for which detailed calculations were performed, the frequency of a 1.0 g (where "g" is the acceleration due the Earth's gravity) peak horizontal ground acceleration is approximately 1×10^{-5} years (about once in one hundred thousand years), which is both well within the bounds of what is considered to be "credible" under NEPA (DOE 1993a) and large enough to heavily damage essentially all LANL facilities.

In order to evaluate earthquake damage to LANL facilities, HCLPF values were estimated based on a variety of sources of information, including detailed seismic margin studies[1] (e.g., TA–3–29 and TA–55–4) and safety documentation. Where no detailed information was available, HCLPF values were based on expert judgment and facility walkdowns. The HCLPF values were mathematically related to the PSHA results such that the HCLPF value is directly related to an annual frequency of occurrence. When this was done, the frequencies of failure of the facilities fell into three groupings for which the frequencies of occurrence differ by only a factor of 3 to 4 within the group. Considering the approximate method used to generate the results, this is considered to represent appropriate groupings for accident analysis purposes. The three earthquake scenarios, and their corresponding frequencies, are as follows:

- SITE–01, HCLPFs ranging from 0.04 g to 0.10 g, with a frequency of 3×10^{-3} per year, corresponding to failures of components and structures with relatively low seismic capacities.
- SITE–02, HCLPFs ranging from 0.10 g to 0.25 g, with a frequency of 4×10^{-4} per year, corresponding to failures of components and structures with moderate seismic capacities.
- SITE–03, HCLPFs ranging from 0.25 g to 0.44 g, with a frequency of 7×10^{-5} per year, corresponding to failure of components and structures with comparatively high seismic capacities.

Seismic studies recently completed and currently in progress have further evaluated the potential for ground faulting. These studies indicate the possibility of such events is low, but credible, at some locations on the LANL site. In addition, the potential of ground faulting at one facility of concern, the CMR Building, will be discussed as a subsection of the SITE–03 event. Section 4.2.2.2 (in volume I, chapter 4) and appendix I discuss further the recently completed studies and their implication for LANL and DOE.

In practice, with significant analytical resources assigned, it would be possible to derive robust HCLPF values and then convolve that information with the seismic hazard curve to identify failure frequencies for all important LANL facilities. However, even were this done, the uncertainties in the results would be substantial due to the uncertainty in the seismic hazard. For example, the range in ground acceleration from the 5th to the 95th percentile, result at a frequency of 1×10^{-5} per year, is from 0.55 g to more than 1.0 g. The representation of the earthquake risks by using the three site accidents identified above provides a reasonable level of resolution for the purposes of NEPA accident analysis.

1. A Seismic Margin Study is a study undertaken to quantify the ability of a structure, system, or component to withstand an earthquake greater than it was designed for and still achieve its function.

G.4.1.2 *Fire and Other Accident Frequencies and 1969 Rocky Flats Fire*

Accident frequency assessments were performed for accidents other than those caused by earthquakes and aircraft crash using PRA-based methods and available LANL and industry data sources. The accidents were examined in a step-by-step method that carefully examined the sequential progression of the accidents, beginning with an initiating event and continuing through the chain of equipment failures, human actions, and phenomenological events that constitute the accident scenario. General guidance for such calculations is provided in a Sandia National Laboratories (SNL) publication (Mahn et al. 1995), and this general guidance has been supplemented by numerous LANL-specific and other studies in order to provide a defensible basis for the accident frequency analysis.

It should be recognized that the DOE safety analysis guidance does not require PRA calculations to be performed in order to categorize the likelihood of accident scenarios (DOE 1994a). Rather, coarse binning efforts are undertaken to qualitatively rank the accident scenarios into frequency bins for the purposes of hazards analysis.

Fire other than from earthquake and aircraft crash was postulated to release MAR in several of the analyses (e.g., RAD–01 and RAD–07). A truck fire was considered more likely than other fire initiators (such as wildfire, lightning, and forklift fires) in outdoor areas and was used. However, a leaking fuel system on a truck that goes unnoticed long enough to pool a large amount of fuel, then followed with an ignition capable of igniting the nonvolatile diesel fuel, has a low frequency that is difficult to quantify. The same is true for wildfire in paved areas and for fires initiated by lightning. However, these accidents were retained for analysis because the combined frequency of fires from all causes is thought to pose a credible accident. (The explosive potential of diesel fuel tanks on trucks and other vehicles is very small and was screened out by more likely accident initiators at facilities where trucks might visit.)

In the Final Programmatic Environmental Impact Statement for Stockpile Stewardship and Management (SSM PEIS) (DOE 1996f) the reassignment of pit manufacturing to LANL was analyzed. In the resulting Record of Decision (ROD) (61 CFR 68014), DOE discussed the decision made, that is, to move pit manufacturing to LANL. Historically, pit manufacturing was conducted at the Rocky Flats Plant (now known as the Rocky Flats Environmental Technology Site [RFETS]). At RFETS, a major fire occurred in 1969, and minor fires occurred on other occasions in similar accidents. Plutonium was released in the 1969 fire-related accident.

To provide a better idea of the differences between the operations at Rocky Flats in 1969 and the operations in TA–55 today, a description of the 1969 Rocky Flats fire, as provided by the Atomic Energy Commission (AEC) at the time of the fire, is provided below (AEC 1969). This description includes the findings presented by the AEC. These findings have since been used to improve design characteristics and operating procedures in all DOE nuclear facilities. Thus, a similar sequence of events would not be possible either because of built in barriers that would restrict the initiation of such an event or would prevent the propagation of such a fire.

The LANL Plutonium processing facility, TA–55–4, was designed to correct the deficiencies that led to the 1969 Rocky Flats fire. In the following discussion, the AEC findings are crosswalked to design features and operating procedures that exist in TA–55 today. As demonstrated in this crosswalk, if the preventative measures that exist in TA–55 today were present at Rocky Flats in 1969, the major fire that resulted in release of plutonium would not have happened.

Fire is always a concern when working with any pyrophoric material such as plutonium. However, TA–55 was designed with specific engineering features to prevent fire and is where plutonium has been worked with, handled, and stored for many years. Its past and current research and development missions have been specifically focused on understanding plutonium and its material properties. Introducing pit production at Los Alamos, therefore, does not dramatically increase the potential for fire because TA–55–4 is where plutonium has been stored, handled, and processed since the facility's original inception.

In fact, the fire at Rocky Flats began in a process development area not a production area. The major differences in TA–55–4 that prevent a building-wide fire are specific operating procedures and design features (barriers) that were established based on lessons learned from fires such as that which happened at Rocky Flats. These barriers prevent the fire from starting, as well as prevent its spread should a fire start. As presented in the following discussion, the inference that TA–55–4 will have a building wide fire now that the facility is producing pits is misleading.

Description of the 1969 Fire at the Rocky Flats Plant

The available evidence indicates that the fire originated on the lower shelf of the storage cabinet in Glovebox 134-24 (see Figure G.4.1.2–1) in the North Line. Plutonium briquettes (discs 3 inches [8 centimeters] in diameter and 1 inch [3 centimeters] thick of either pressed scrap metal or lathe turnings) and some loose scrap metal were stored in uncovered cans in the storage cabinet. The exact cause of ignition is unknown; however, plutonium in the form of chips or lathe turnings is pyrophoric and caught fire. The heat from the burning plutonium metal evidently caused the storage cabinet, which was constructed mostly of cellulosic laminate material and plastic, to char and generate flammable gases that may have been ignited by burning plutonium. The heat of the burning gases may have ignited other briquettes and initiated a slow burning of the storage cabinet materials, particularly in the cracks between the joined sections of the cellulosic materials. Regardless of the process, the fire spread to the outer surfaces of the cabinet.

The smoke in the exhaust system of the North Line gradually clogged the filters. The flames on the outer surfaces of the cabinet spread to the combustible gloves and plastic windows on Glovebox 134-24. Up to this time, the fire was still undetected by the few people who were in the building that day because the smoke, flames, and heat were contained within the glovebox system. Because the heat detectors were located outside and under Glovebox 134-24 and were insulated by the floor of the storage cabinet, they were incapable of sensing the fire. (Similar detectors elsewhere in the glovebox system subsequently did function, and the alarm was sounded.)

Once the plastic windows of Glovebox 134-24 were breached, the air rushing in fanned the fire and caused it to spread into the North Conveyor Line and into the gloveboxes east of Glovebox 134-24.

The airflow in the North Conveyor Line normally flowed from east to west. However, because of the clogged filters, the airflow in the line reversed and followed the second ventilation system, which was part of the North-South Line and the Center Line. When the fire reached the North-South Line, it turned south because of two factors: a closed metal door in the North Line and the direction of the airflow. On reaching the Center Line, the fire again went east because of the airflow.

The first indication of a fire was an alarm received in the plant's fire station at 2:27 p.m.

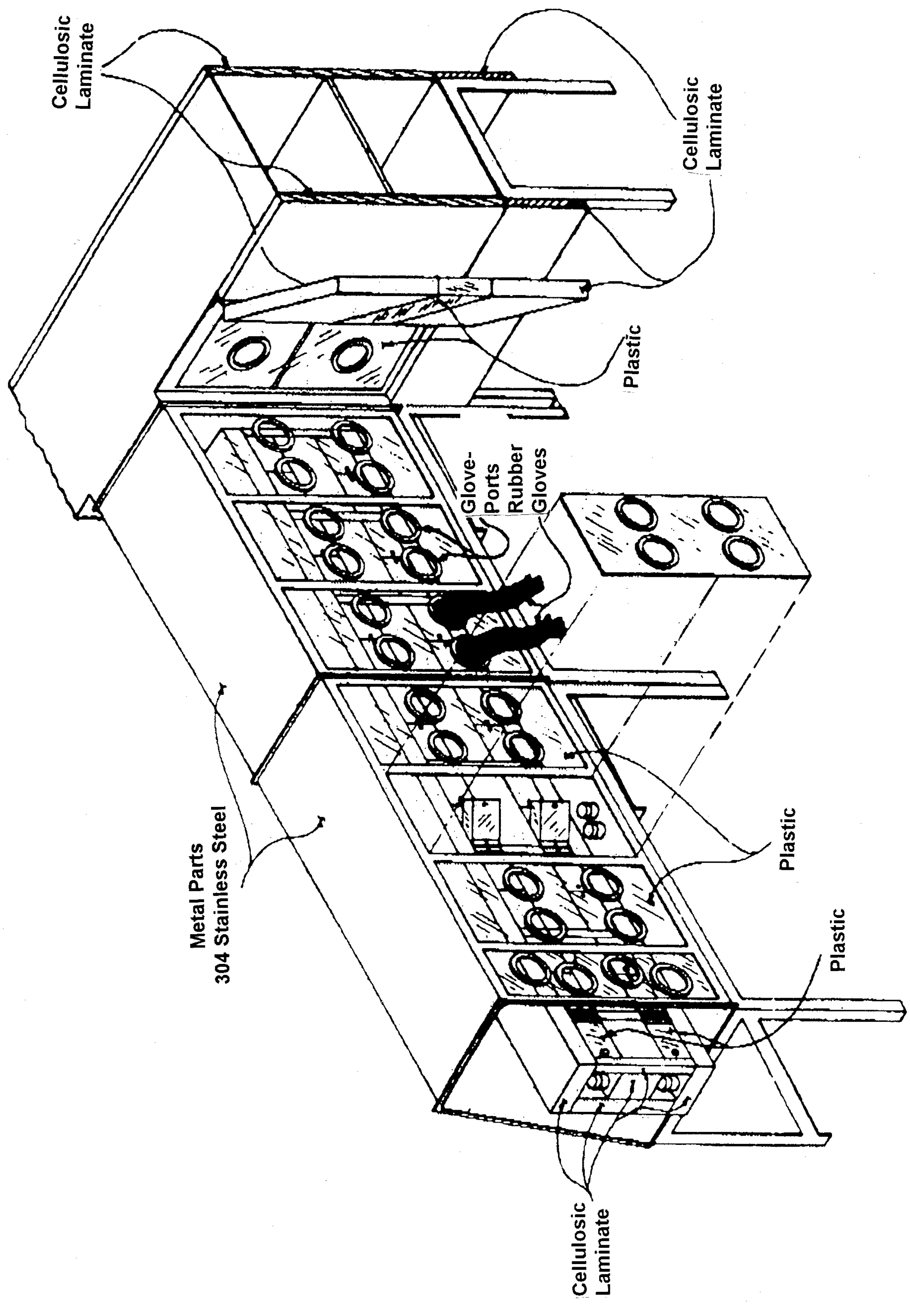

FIGURE G.4.1.2–1.—*Rocky Flats Site, Glovebox 123-24* on May 11, 1969, from the heat-sensing system that monitored temperatures at various locations in the glovebox systems in Building 776-777. Although the fire department responded promptly, the dense smoke, crowded conditions, and presence of large quantities of combustible shielding material made the fire very difficult to fight and extinguish. Because of the concern about the possibility of a nuclear criticality accident (a chain reaction), the standard firefighting procedures then in effect for Building 776-777 did not specify the use of water, except as a last resort. For this reason, there was no automatic sprinkler system in this area of the building. The first attack on the fire was made with carbon dioxide and was ineffective. Less than 10 minutes after the fire alarm was received, the fire captain initiated the use of water. Thereafter, water was used almost exclusively in the firefighting activities. No nuclear criticality occurred. The fire was brought under control about 6:40 p.m., but continued to burn or recur in isolated areas throughout the night.

The damage to Building 776-777 and its equipment was extensive. In addition to the actual fire and smoke damage, the building was heavily contaminated internally with plutonium. Substantial parts of the utility systems within the building were severely damaged. Some of the interconnected buildings sustained minor interior contamination. The fire did not breach the building roof, but slight exterior contamination was measured on the roof of Building 776 and an adjoining building, apparently due to a minor failure of a filter. Instrument readings indicated a level of 0.02 microcuries per 100 square centimeters with a few spots up to 0.2 microcuries per 100 square centimeters. Plutonium also was tracked out of Building 776 by the firefighters and was detectable on the ground around the building. Survey instrument readings in these areas indicated from 0.02 to 0.2 microcuries per 100 square centimeters.

AEC Findings on the May 1969 Rocky Flats Plant Fire

The AEC Report presented the following findings from the May 1969 fire at the Rocky Flats Plant (AEC 1969).

- With the available evidence, the AEC has no basis for concluding that the fire was set intentionally.
- The plastic windows contributed heavily to the spread of the fire and the extent of the loss. These windows, a major structural part of the containment system, provided a fuel surface on the inside of the glovebox-conveyor systems. Continued operation of the glovebox ventilation systems provided a supply of air to support the combustion. Under these conditions, burning of the windows and plutonium would have resulted essentially in the same loss as was experienced even if no other combustible materials had been present.
- Less than 1 percent of the total of almost 600 tons of combustible radiation shielding was consumed in the fire.
- The long interconnected conveyor system without physical barriers provided a path for the fire to spread. The closed metal door in the North Line demonstrated the effectiveness of even a simple firebreak in the line.
- The storage of plutonium briquettes in cans without lids provided potential ignition sources.
- Without the plastic and cellulosic laminate cabinet in Glovebox 134-24, it is unlikely that a plutonium briquette burning in an open metal container would have ignited the plastic windows.
- The addition of the storage cabinet, which nullified the heat-sensing system in Glovebox 134-24, prevented an earlier warning of fire.

Crosswalk of Design Barriers and Operating Procedures Between Rocky Flats in 1969 and TA–55–4 in 1998

The Rocky Flats fire started from the burning of plutonium metal scraps that were stored in metal containers without lids. In TA–55, plutonium is stabilized prior to storage. In this case, storage of scrap material is not permitted in open containers.

The storage containers at Rocky Flats were placed in storage cabinets that were made out of plastic and cellulosic laminate material, providing a fuel source for the burning plutonium. At TA–55, these types of storage cabinets are not used. Studies on combustible loadings are required for all operations that will be conducted within the gloveboxes, and restrictions are placed on the quantities of combustible materials to ensure that fires cannot be sustained and then propagated. Good housekeeping as well as other control measures such as conducting machining operations without oil has lead to a drastic reduction in incipient fires.

Once the fire at Rocky Flats was started, the fire detection systems did not sense the fire because the detectors were located on the outside of the gloveboxes, and the fire in its early stages was confined to the inside of the gloveboxes. Additionally, the glovebox acted to insulate the sensor from the heat of the fire—in effect preventing an early warning. In TA–55–4, the gloveboxes, have sensors both on the inside as well as on the outside of the gloveboxes, and additional sensors exist within the rooms. If the processes within the gloveboxes are modified, it is required to check the sensors to ensure that they have not been blocked.

Once the storage cabinets at Rocky Flats were set on fire, the fire propagated to the plastic gloves and plastic window on the glovebox, burned through, and created a breach in containment. Without the charring of the cabinets and the production of combustible gases, the fire would probably not have spread to the glovebox; however, in this case, the fire was sustained to the point that it could propagate to the glovebox. At TA–55–4 the gloveboxes themselves are required to provide a fire barrier between material in the glovebox and the room itself.

Once the fire at Rocky Flats breached the gloveboxes, there was radiation shielding that surrounded the gloveboxes and the conveyor lines. This material also was combustible, and a small percentage of it burned in the Rocky Flats fire. At TA–55–4 combustible loading within the separate laboratories is kept to a minimum. Also, due to the integration of safety management functions, the solution to one safety concern (such as the use of radiation shielding) is looked at for the potential to cause other safety concerns (such as the propagation of fires). Thus, radiation shielding used at TA–55–4 is not typically flammable.

At Rocky Flats there were no automatic sprinklers in this area of the building due to concerns about a criticality accident. At the time of the fire, the standard firefighting procedure was not to use water, except as a last resort. Within 10 minutes of the fire alarm, the firefighters used water and no criticality occurred. Automatic sprinkler systems are available in TA–55 to stop the spread of fires. In addition, fire water traps, that contain neutron absorbing material, are available to ensure that a criticality event does not occur.

The fire at Rocky Flats propagated east along the conveyor line, turning south following the airflow of the second ventilation system. Continuation of the fire through the North Line conveyor was stopped because of a closed metal door and the prevalent airflow conditions. The glovebox lines in TA–55–4 have automatic dampers that close in the event of a fire. These dampers are at the junction with each trunk line and between rooms. Also, the ventilation system is shutdown in the event of a fire to prevent airflow.

The degree of contamination in the buildings at Rocky Flats was due to regularly spaced plutonium material in the conveyor system and in the gloveboxes. Pit production at TA–55–4 will not come close to the capacity that was required at Rocky Flats. Thus, the amount of plutonium in the gloveboxes will be considerably less than was present at Rocky Flats. The processing lines will be configured in such a manner that a continuous source of exposed plutonium will not be present. Plutonium stored in the gloveboxes also must be in closed containers.

Additionally, Building 776-777 at Rocky Flats did not have an operations center that was staffed 24 hours a day providing full-time monitoring of systems. TA–55–4 has a fully staffed operations center to provide monitoring of systems and alarms on a 24-hours per day basis.

Summary of Differences Between Rocky Flats and TA–55–4

Substantial differences exist between the nuclear facility and operations being conducted in TA–55–4 today and those that were present at Rocky Flats in 1969. The above crosswalk illustrates the barriers that are in place at TA–55–4 that would have prevented the building wide fire at Rocky Flats. TA–55–4 was designed to correct the deficiencies detected in older facilities such as RFETS and is being upgraded to meet the even more stringent requirements of the 1990's, including enhanced seismic resistance and fire containment. Alarms are monitored, and the Operations Center is manned continually at TA–55. The amount of plutonium required for production at LANL is about half that required during RFETS operations. The manufacturing operations are substantively different than those at RFETS, significantly reducing risk. The concern that building wide fires will occur at TA–55–4 due to pit production operations being located at this facility is not plausible considering the controls that exist today.

Consideration of Fires at TA–55–4 in the SWEIS

The SWEIS, however, does consider the potential for fire in TA–55–4. A glovebox fire is analyzed in RAD–14, section G.5.6.14. A glovebox fire is considered credible; but the release of material to the public is not a credible event. A building-wide fire was screened based on the very low probability of propagating a glovebox fire to a laboratory, a laboratory fire to a wing, and a wing fire to the entire building. With the enhancement of pit production, the characterization of accidents at TA–55–4 and, therefore, the risk in operating the site does not change.

G.4.1.3 *Aircraft Crash Frequencies*

This section of the accident appendix presents an analysis of the frequency of an aircraft crash into structures located within the various TAs at LANL. In 1996, LANL issued a study performed by Selvage (LANL 1996c) that used the K. Solomon Model as a basis for aircraft crash frequency assessment. The LANL assessment has been overtaken by subsequent events.

In October 1996, DOE issued a final standard for *Accident Analysis for Aircraft Crash into Hazardous Facilities* that presents a standardized approach (DOE 1996c). The new standard was developed by an inter-agency working group with membership from DOE, the Defense Nuclear Agency, Westinghouse Savannah River Corporation, the Federal Aviation Administration (FAA), the EPA, and the NRC. The working group chairman and an expert panel (with technical experts from private industry, government, and the national laboratories) developed the standard. Technical support teams (data, modeling, structural, and exposure), which also included membership from private industry, government, and the national laboratories, provided technical input and data used in developing the standard. The standard was issued with a number of supporting technical documents for use in safety analysis.

In November 1996, the Final EIS on continued operation of the Pantex Plant and storage of nuclear weapon components was issued by DOE (DOE 1996a). Appendix E of the Pantex EIS included an aircraft crash frequency analysis prepared using the July 1996 draft of DOE Standard 3014. The final version of the DOE aircraft crash standard methodology was applied to LANL facilities to estimate the frequency of an aircraft crash into those facilities (DOE 1996c). Current and projected data describing air traffic are used in the analysis; aircraft traffic rates for Los Alamos Airport traffic reflect projected traffic for the year 2003, which is considered to be a reasonable approximation to the traffic in 2006 (the end of the SWEIS analytical period). The projected air traffic includes air taxi service to Los Alamos Municipal Airport (LAM), although no such service currently exists. This traffic component was retained because air taxi service has existed in the recent past and there is no way of knowing whether it will resume during the SWEIS analytical period extending to 2006.

An estimate of the frequency of an aircraft crash into any of the facilities of interest was generated and is shown in Table G.4.1.3–1. Table G.4.1.3–2 presents the projected number of aircraft operations at LAM.

Site Analysis of Crash Risk

Because there are no alternative sites included in the SWEIS, LANL is the only site that is analyzed with respect to the risk due to aircraft crash. LANL is located within 1 mile (1.6 kilometers) of LAM at its closest point. LAM consists of one runway, which runs from east to west. The primary purpose of LAM is to support the missions of the DOE and LANL (Greiner 1994) Due to local conditions, all takeoffs are to the east, and all landings are to the west. The west end of the runway is only used for runups and taxiing. There is prohibited airspace over LANL (Restricted Airspace R–5101) up to 14,000 feet (4,267 meters). The restricted airspace forces flights taking off from or landing at LAM to follow a path around LANL. During certain inclement weather flight conditions, LANL grants permission to overfly the Live Firing Range (TA–72). To perform this overflight, pilots must receive prior permission, and the firing range ceases operations during the overflight (LANL 1996c).

Note that the DOE standard (DOE 1996c) does not provide for a reduction in crash frequency to account for restricted airspace. Restricted airspace is an administrative control; no physical barriers exist. In the event of an aircraft accident, loss of control is presumed. Thus, the aircraft could, in principle, crash anywhere, including within a restricted airspace. Moreover, flights above 14,000 feet (4,267 meters) can overfly LANL in any event. Thus, while giving no credit to the restricted airspace in terms of reducing crash frequencies may be conservative, the degree of conservatism is not believed to be large enough to warrant a departure from the DOE Standard.

In addition to LAM, there are two airports in the vicinity of LANL. Santa Fe Municipal Airport is located approximately 18 miles (29 kilometers) southeast of LANL. Albuquerque International Airport is located approximately 56 miles (90 kilometers) southwest of LANL. These two airports are outside of the probability density function boundary for all categories of aircraft. Thus, only LAM airport activity and nonairport (in-flight) aircraft were included in the analysis as described in the DOE standard (DOE 1996c).

In this analysis, 1993 data obtained from the *Los Alamos Airport Master Plan* (Greiner 1994) indicate that there are approximately 12,431 operations per year at LAM. This number is split between Ross Aviation operations, permit

TABLE G.4.1.3–1.—*Aircraft Crash Rates*

AIRCRAFT CATEGORY	CRASH RATE	
	TAKEOFF (PER TAKEOFF)	LANDING (PER LANDING)
COMMERCIAL		
Air Carrier	1.9×10^{-7}	2.8×10^{-7}
Air Taxi	1.0×10^{-6}	2.3×10^{-6}
MILITARY		
Large[a]	5.7×10^{-7}	1.6×10^{-6}
Small[b]	1.8×10^{-6}	3.3×10^{-6}
GENERAL AVIATION		
Fixed-Wing, Single-Engine	1.1×10^{-5}	2.0×10^{-5}
Fixed-Wing, Multiple-Engine Piston	9.3×10^{-6}	2.3×10^{-5}
Fixed-Wing, Turboprop	3.5×10^{-6}	8.3×10^{-6}
Fixed-Wing, Turbojet	1.4×10^{-6}	4.7×10^{-6}

[a] Large military aircraft include bomber, cargo, and tanker aircraft.
[b] Small military aircraft include fighter, attack, and trainer aircraft.
Source: DOE 1996c

TABLE G.4.1.3–2.—*Projected LAM Yearly Flight Operations (Year 2003)*

AIRCRAFT CATEGORY	FLIGHT OPERATIONS	TAKEOFFS	LANDINGS
Air Carrier	0	0	0
Air Taxi	5,400	2,700	2,700
Large Military	0	0	0
Small Military	0	0	0
Single-Engine Piston	11,781	5,891	5,891
Multiple-Engine Piston	794	397	397
Turboprop	13	6	6
Turbojet	13	6	6
Total	18,000	9,000	9,000

Source: Greiner 1994

(based) aircraft operations, and transient aircraft operations.

The LAM Master Plan study forecasted future annual aircraft operations of 18,000 for the year 2003. This total includes 5,400 air taxi operations, 10,600 permit aircraft operations, and 2,000 transient aircraft operations. These projected numbers are used in the analysis, assuming half are takeoffs and half are landings.

According to the LAM Master Plan study, more than 99.9 percent of the aircraft forecasted to use LAM are Class A (12,500 pounds or less, single-engine) and B (12,500 pounds or less, multiple-engine) small aircraft. Less than 0.1 percent are Class C (12,500 to 300,000 pounds, multiple-engine), and no Class D (over 300,000 pounds, multiple-engine) aircraft can operate at LAM (Greiner 1994).

Based on the above percentages, the 13,800 general aviation operations were split between the four DOE standard (DOE 1996c) general aviation categories. The LAM Master Plan study indicates that the number of general aviation operations is dominated by "based" aircraft. Because based aircraft are predominately single-engine piston aircraft, the split between single-engine and multiple-engine aircraft was based on the percentage of based aircraft from these classes. Thus, 93.5 percent of the operations were assigned to single-engine aircraft, 6.3 percent to multiple-engine aircraft, and 0.1 percent each to turboprops and turbojets. One hundred percent of the air taxi operations were assumed to be accomplished using DHC–6 Twin Otter aircraft (Greiner 1994). This aircraft is considered an air taxi by the DOE standard technical support material (LLNL 1996). The actual wingspan of this aircraft is 65 feet (20 meters) (Jane's 1995). This wingspan was used in the calculation.

Because LANL TAs are within the aircraft category dependent exclusion distance from LAM, the aircraft operations of interest for this analysis are takeoff, landing, and in-flight modes. The length of the east-west runway at LAM is approximately 1.0 mile (1.61 kilometers). Due to the aircraft category dependent exclusion distance, all aircraft considered as in airport operation on the east-west runway were either in the takeoff or landing mode. For this runway, 50 percent of operations are takeoffs and 50 percent are landings. LANL resides within the aircraft category dependent exclusion distances, so a near-airport analysis was required, and probability density function values were used in this analysis.

The NPf (x,y) values provided in DOE Standard 3014-96 (DOE 1996c) for the various aircraft categories reflect the crashes per square mile, per year, centered at a given site for nonairport operations. In this analysis, the following NPf (x,y) values (in crashes per square mile per year, centered at the site) for LANL were used (DOE 1996c):

NPf (x,y) General Aviation = 2×10^{-4}

NPf (x,y) Air Carrier = 2×10^{-7}

NPf (x,y) Air Taxi = 3×10^{-6}

NPf (x,y) Large Military = 1×10^{-7}

NPf (x,y) Small Military = 5×10^{-6}

These values are specific to the LANL site, and are based on an analysis of the locations of past aircraft crashes within the continental U.S. The data are substantial for general aviation aircraft (over 1,000 crashes), while the available data for other aircraft categories (air carrier, large military, etc.) are very limited. Crash location frequencies for general aviation aircraft were based on the assumption that future levels of activity and flight patterns will be similar to the historical record.

Nonairport commercial and military crash frequencies are based on the assumption that the aircraft will fly point-to-point under the new

FAA regulations, rather than in specific airways. The model for these aircraft assumes that the traffic density within an Air Route Traffic Control Center (ARTCC) is uniform, and that given a crash within the ARTCC, the location of the crash is random. The crash rate is assumed to be uniform for the continental U.S. and proportional to the aircraft traffic volume handled at each ARTCC.

For small military aircraft, however, the number of crashes per year is estimated for each ARTCC based on the distribution of crash locations in the historical record. It is important to recognize that the in-flight analysis for military aviation applies only to normal in-flight operations outside military operations areas and low-level flight ranges.

Frequency of Releases as a Result of Aircraft Crash

It was recognized early in this SWEIS analysis that seismic events can cause simultaneous releases of hazardous materials from multiple facilities at frequencies in the range of 1 x 10^{-5} per year and higher. Accordingly, detailed aircraft crash consequence calculations were only performed if it appeared that the frequency and source term of the aircraft crash accident were risk-significant compared with the seismic event; that is, the products of the consequence and frequency were comparable. In this analysis, facilities that contain plutonium, tritium, and hazardous chemicals were considered.

The DOE Standard 3014-96 (DOE 1996c) provides methodologies for: (1) estimating the frequency of aircraft impact into a facility, based on a conservative, simplified equation; (2) determining the effect of the impact on the facility through structural response analysis; (3) determining the frequency of a release of hazardous materials from the facility, given an aircraft impact; and (4) evaluating the exposure resulting from such a release.

The DOE Standard 3014-96 approach to aircraft crash analysis is intended for use in safety analysis. The methodology provides an approximate level of risk, rather than a detailed risk assessment. As a result, the methodology adopts typical accident analysis practice by addressing uncertainty through the use of analytical margin instead of a formal uncertainty analysis. The focus is on analyzing the risk posed to the health and safety of the public and on-site workers. The standard does not consider the risk to the occupants of the aircraft, the risk to individuals inside a building affected by a crash, nor the risk to other individuals on the ground (either inside or outside a facility boundary) who might be directly impacted by the crash (DOE 1996c). The methodology also does not consider malicious acts (e.g., sabotage, terrorism, and war) (DOE 1996c).

Estimating the frequency of hazardous material releases as a result of aircraft involves a series of calculations of increasing analytical sophistication, to the level required to demonstrate that aircraft crash either does or does not cause a level of risk equivalent to that from other risk sources. The analysis considers the structural properties of the affected facility as well as its inventory of hazardous materials.

Local impacts to facilities include penetration, perforation, and scabbing. Penetration occurs when the missile (flying debris) striking a facility intrudes into the outer surface of the structure. Perforation occurs when the missile punctures a hole all the way through the concrete or steel surface. Scabbing occurs when the missile does not perforate, but does cause concrete to be ejected from inside face of the target into the facility.

Because heavy, high-speed aircraft have much greater potential to damage than do slow, light aircraft, the method requires that the population of aircraft in the skies around the site be resolved into subpopulations by weight and speed. A structural calculation is performed to determine if an aircraft that hits a facility will cause sufficient damage to warrant further analysis. Aircraft missiles (i.e., flying objects from the crash) for the structural calculations are selected by using representative engine weights and diameters. The structural analysis is performed by calculating the scabbing and perforation thickness for each aircraft category into the facility using an empirical model.

The first step in the process is to determine the representative type of aircraft for each category. Next, the effective area of a facility is determined based upon the length, width, and height of the facility and the aircraft's wingspan, flight path angle, heading relative to the heading of the facility, and the length of its skid. Using the calculated area of a facility, the number of operations near a facility, and crash rate density function, the frequency of hitting the facility for each aircraft category is calculated. The total frequency is the sum of all the aircraft category frequencies. If the total frequency of hitting a facility is greater than 1 x 10^{-6}, further analysis is conducted.

The calculations are refined to eliminate aircraft categories that cannot cause a release of hazardous materials, leaving only those that could, through impact and/or fire, release radionuclides or toxic chemicals. If the frequency of hitting a facility and causing either scabbing or perforation is greater than 1 x 10^{-6}, the DOE standard requires that a consequence analysis be performed (DOE 1996c).

Calculation of Facility Effective Area. The total effective area of a facility is the sum of the true area (the facility base area adjusted for aircraft dimension), the shadow area (defined by the facility height and the angle of postulated impact), and the skid area (the area covered by a skidding aircraft after impact with the ground).

The analysis was done on a building-by-building basis, treating each facility individually. The topographic features of the LANL site are such that the actual skid distances can be less than the skid distances given in the DOE standard. Subsequently, the skid distances were reduced based on actual site conditions. The majority of reduced skid distances affect only commercial and military aircraft. The angle of impact chosen was based on the values presented in the DOE standard (DOE 1996c). A total effective area for each facility was calculated using the reduced skid distance.

Table G.4.1.3–3 presents the various building dimensions. Table G.4.1.3–4 presents the aircraft operational data used, including the skid distances. Both the DOE standard and maximum wingspans for aircraft in the vicinity of LAM are given. Maximum wingspans were determined by selecting representative aircraft from *Jane's All the World's Aircraft* (Jane's 1995). The skid distances in the table correspond to the skid distances presented in DOE Standard 3014-96 (DOE 1996c).

Hit Frequency Calculation. Based on the center-line and perpendicular distances to the TA facilities of interest, all aircraft using LAM were analyzed using the near-airport model. The impact frequency was obtained for each facility by multiplying the number of flights, the impact area, the crash rate, and the crash density function for each category. Table G.4.1.3–5 contains the crash frequencies for landings, takeoffs, and the nonairport aircraft for each facility.

Structural Calculation. For this analysis, 70th percentile velocities of aircraft were used (LLNL 1996). The velocities chosen were in either takeoff or landing operations, whichever was the largest. For facilities with overburden, these velocities were reduced according to the earth overburden velocity reduction equation.

The local response equations for rigid missiles impacting reinforced concrete structures were applied to applicable facilities, and the local response steel equations for rigid missiles were applied to applicable facilities. A reduction in penetration depth was taken because the

TABLE G.4.1.3–3.—*LANL Building Dimensions*

BUILDING	BUILDING LENGTH (ft)	BUILDING WIDTH (ft)	BUILDING HEIGHT (ft)	WALL THICKNESS (in.)	ROOF THICKNESS (in.)
TA–3–29 CMR	550	254	50	8	6
TA–3–476	18	12	9	0	0
TA–16–205 WETF	131	112	14	8	4
TA–16–411	87	24	20	8	6
TA–21–155 TSTA	70	15	26	1	3
TA–21–209 TSFF	40	35	20	1	2
TA–50–37 RAMROD	142	110	46	8	24
TA–50–69 Container Storage Area	90	24	6	0	0
TA–54 TWISP	414	286	38	0	0
TA–55–4	284	265	22	14	10
TA–18–26 Hs. Vault	18	12	10	18	12
TA–18–32 Kiva #2	59	58	25	15	4
TA–18–116 Kiva #3	81	64	36	18	8
TA–55–185	60	40	14	0	0
TA–8–22	42	39	21	8	8
TA–8–23	48	40	30	30	6
TA–15 DARHT	6	6	6	0	0
TA–18–23 Kiva #1	61	48	26	8	3
TA–18–168 SHEBA	20	20	18	0	0
TA–54–38 Container Storage Area	12	8	6	0	0

Source: Safety analysis documentation, site location maps, and miscellaneous sources
Note: TSTA and TSFF wall thicknesses are based on an approximate reinforced concrete equivalence for concrete block, based on the Pantex EIS analysis of similar construction (DOE 1996a).

TABLE G.4.1.3–4.—*Aircraft Operational Data: Takeoff, In Flight, and Landing*

	AIR CARRIER	AIR TAXI	LARGE MILITARY	SMALL MILITARY	GENERAL AVIATION			
					SINGLE ENGINE	MULTI-ENGINE	TURBOPROP	TURBOJET
DOE Standard Wingspan (ft)	98	59[b]	223	78	50	50	73	50
Maximum Wingspan (ft)	211	75	223	93	50	50	80	78
Takeoff Skid Length (ft)	1,440	1,440	780[a]	246	60	60	60	60
Landing Skid Length (ft)	1,440	1,440	368	447[a]	60	60	60	60

[a] Conservatively used for inflight.
[b] Actual wingspan is 65 feet. This wingspan is used in the calculation and does not change the overall hit frequency because hit frequency is dominated by general aviation.
Source: DOE 1996c, Jane's 1995, and calculated values

TABLE G.4.1.3–5.—*Aircraft Crash Frequencies*

CRASH FREQUENCIES (PER YEAR)				
BUILDING	**TAKEOFF**	**LANDING**	**NONAIRPORT**	**TOTAL**
TA–3–29 CMR	7.1×10^{-8}	5.0×10^{-6}	3.6×10^{-6}	8.6×10^{-6}
TA–3–476	1.6×10^{-9}	1.1×10^{-7}	8.5×10^{-8}	2.0×10^{-7}
TA–16–205 and TA–16–205A	0	1.7×10^{-7}	4.7×10^{-7}	6.4×10^{-7}
TA–16–411[a]	0	1.4×10^{-7}	2.8×10^{-7}	4.1×10^{-7}
TA–21–155 TSTA	1.3×10^{-5}	2.7×10^{-5}	2.7×10^{-7}	4.1×10^{-5}
TA–21–209 TSFF	1.0×10^{-5}	2.1×10^{-5}	2.1×10^{-7}	3.1×10^{-5}
TA–50–37 RAMROD	1.8×10^{-6}	2.8×10^{-6}	9.5×10^{-7}	5.5×10^{-6}
TA–50–69 Container Storage Area	2.9×10^{-7}	4.5×10^{-7}	1.6×10^{-7}	9.0×10^{-7}
TA–54 TWISP	8.9×10^{-7}	7.4×10^{-7}	2.6×10^{-6}	4.3×10^{-6}
TA–55–4	4.5×10^{-6}	4.5×10^{-6}	1.5×10^{-6}	1.1×10^{-5}
TA–18–26	3.2×10^{-9}	3.0×10^{-8}	5.5×10^{-8}	8.8×10^{-8}
TA–18–32	1.8×10^{-8}	1.8×10^{-7}	3.1×10^{-7}	5.1×10^{-7}
TA–18–116	3.2×10^{-8}	2.0×10^{-7}	4.8×10^{-7}	7.1×10^{-7}
TA–55–185	7.3×10^{-8}	6.0×10^{-7}	2.1×10^{-7}	8.9×10^{-7}
TA–8–22[b]	0	9.1×10^{-8}	2.3×10^{-7}	3.2×10^{-7}
TA–8–23[b]	0	1.2×10^{-7}	3.0×10^{-7}	4.3×10^{-7}
TA–15 DARHT[a]	0	1.0×10^{-8}	4.9×10^{-8}	5.9×10^{-8}
TA–18–23	1.8×10^{-8}	1.7×10^{-7}	3.1×10^{-7}	5.0×10^{-7}
TA–18–168	7.7×10^{-9}	7.4×10^{-8}	1.3×10^{-7}	2.2×10^{-7}
TA–54–38 Container Storage Area	3.2×10^{-9}	3.1×10^{-8}	5.5×10^{-8}	8.9×10^{-8}

Source: calculated values

[a] Note: This is the raw crash frequency for this facility. There is a conditional probability of MAR being present that must be multiplied times the crash frequency to obtain the frequency of a crash with MAR present. The conditional probability is classified for this facility.

[b] Note: This is the raw crash frequency for this facility. There is a conditional probability of MAR being present that must be multiplied times the crash frequency to obtain the frequency of a crash with MAR present. The conditional probability is less than 5 percent.

missiles were nonrigid. In cases where the structural equations presented in the DOE standard do not apply (e.g., due to the facility construction), it was assumed that significant building damage to these facilities was a certainty (i.e., probability of 1, given impact). In this analysis, the aircraft engine was investigated as the missile of concern. These engines were treated in the equations as nonrigid missiles. Table G.4.1.3–6 presents maximum engine weights and diameters for aircraft landing and taking off at LAM. Maximum engine weights and diameters were determined by selecting representative aircraft from *Jane's All the World's Aircraft* (Jane's 1995). Maximum engine weights and diameters were then used in the structural calculations.

Local response structural calculations were performed for the various overburden and building thicknesses. Table G.4.1.3–7 presents the results for perforation.

Perforation and Scabbing Frequency Calculation. For this analysis, it was assumed that for facilities such as the TRU waste domes in TA–54, which are constructed of a rigid arch frame covered by a tensioned membrane, the release frequency due to aircraft crash is the same as the hit frequency. For facilities with high explosives, the bounding accident is a perforation or scab leading to an explosion. For facilities without high explosives, the bounding accident is a perforation leading to a fire. Scabbing leading to an explosion in steel facilities is not possible because steel does not scab. The areas for the facilities were reduced using the structural analysis results. The reduced areas were then used to recalculate perforation and scabbing frequencies. Table G.4.1.3–8 presents the frequencies of perforation leading to an explosion, and Table G.4.1.3–9 presents the frequencies of perforation leading to a fire for landings, takeoffs, and the nonairport aircraft for each facility.

The true, shadow, and skid areas for the various facilities were reduced for perforation and scabbing (Table G.4.1.3–7). If the facility roof does not sustain damage, then the true area is reduced to zero. If the facility walls do not sustain damage, then the shadow and skid areas are reduced to the width of the building times the skid distance.

TABLE G.4.1.3–6.—*Aircraft Missile Characteristics*

AIRCRAFT CATEGORY	IMPACT VELOCITY (ft/sec)	ENGINE WEIGHT (lb)	ENGINE DIAMETER (in.)
Air Carrier	282	9,874	86
Air Taxi	282	861	31
Large Military	439	8,731	105
Small Military	513	4,201	51
Single-Engine Piston	152	500	30
Multiple-Engine Piston	152	596	25
Turboprop	152	465	19
Turbojet	152	2,574	37

Sources: LLNL 1996 and Jane's 1995. Impact velocities are based on 70^{th} percentile values, corresponding to the skid distance values used in DOE Standard 3014-96 (DOE 1996c) and this analysis.

TABLE G.4.1.3–7.—*Structural Perforation Calculation Summary*

BUILDING	AIR CARRIER		AIR TAXI		LARGE MILITARY		SMALL MILITARY		GENERAL AVIATION							
									SINGLE ENGINE		MULTIPLE ENGINE		TURBO PROP		TURBO JET	
	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W
TA–3–29	X	X	X	X	X	X	X	X	X		X		X		X	X
TA–3–476	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TA–16–205	X	X	X	X	X	X	X	X	X		X		X		X	X
TA–16–411	X	X	X	X	X	X	X	X	X		X		X		X	X
TA–21–155	X	X	X	X	X	X	X	X	X		X		X		X	X
TA–21–209	X	X	X	X	X	X	X	X	X		X		X		X	X
TA–50–37	X	X		X	X	X	X	X								X
TA–50–69	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TWISP	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TA–55–4	X	X	X	X	X	X	X	X								X
TA–18–26	X	X			X											
TA–18–32	X	X	X	X	X	X	X	X	X		X		X		X	
TA–18–116	X	X	X	X	X	X	X	X							X	
TA–55–185	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TA–8–22	X	X	X	X	X	X	X	X							X	X
TA–8–23	X	X	X		X	X	X		X		X		X		X	
DARHT	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TA–18–23	X	X	X	X	X	X	X	X	X		X		X		X	X
TA–18–168	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TA–54–38	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

R = Roof
W = Walls
X = Damage; perforation occurs.
Blank = No damage; perforation does not occur.
Source: Calculated values

TABLE G.4.1.3–8.—*Aircraft Crash Frequencies per Year for Perforation Leading to Explosion*

	FREQUENCY (PER YEAR)			
BUILDING	**TAKEOFF**	**LANDING**	**NONAIRPORT**	**TOTAL**
TA–3–29	0	0	0	0
TA–3–476	1.6×10^{-9}	1.1×10^{-7}	8.5×10^{-8}	2.0×10^{-7}
TA–16–205	0	0	0	0
TA–16–411	0	1.7×10^{-8}	5.0×10^{-8}	6.7×10^{-8}
TA–21–155	0	0	0	0
TA–21–209	0	0	0	0
TA–50–37	0	0	0	0
TA–50–69 Container Storage Area	0	0	0	0
TA–54 TWISP	0	0	0	0
TA–55–4	0	0	0	0
TA–18–26	0	0	0	0
TA–18–32	0	0	0	0
TA–18–116	0	0	0	0
TA–55–185	0	0	0	0
TA–8–22	0	$< 1.0 \times 10^{-9}$	1.6×10^{-8}	1.6×10^{-8}
TA–8–23	0	1.5×10^{-8}	4.7×10^{-8}	6.3×10^{-8}
DARHT	0	1.0×10^{-8}	4.9×10^{-8}	5.9×10^{-8}
TA–18–23	0	0	0	0
TA–18–168	0	0	0	0
TA–54–38 Container Storage Area	0	0	0	0

Source: Calculated values

TABLE G.4.1.3–9.—*Aircraft Crash Frequency per Year for Perforation Leading to Fire*

BUILDING	FREQUENCY (PER YEAR)			
	TAKEOFF	LANDING	NONAIRPORT	TOTAL
TA–3–29 CMR	2.7×10^{-8}	2.0×10^{-6}	1.5×10^{-6}	3.5×10^{-6}
TA–3–476	1.6×10^{-9}	1.1×10^{-7}	8.5×10^{-8}	2.0×10^{-7}
TA–16–205 and TA–1–205A WETF	$< 1.0 \times 10^{-9}$	6.3×10^{-8}	1.9×10^{-7}	2.6×10^{-7}
TA–16–411 Assembly Building	$< 1.0 \times 10^{-9}$	1.7×10^{-8}	5.0×10^{-8}	6.7×10^{-8}
TA–21–155 TSTA	1.0×10^{-6}	2.8×10^{-6}	3.5×10^{-8}	3.8×10^{-6}
TA–21–209 TSFF	1.6×10^{-6}	3.7×10^{-6}	4.2×10^{-8}	5.3×10^{-6}
TA–50–37 RAMROD	6.7×10^{-9}	1.4×10^{-8}	4.4×10^{-8}	6.5×10^{-8}
TA–50–69 Container Storage Area	2.9×10^{-7}	4.5×10^{-7}	1.7×10^{-7}	9.0×10^{-7}
TA–54 TWISP	8.9×10^{-7}	7.4×10^{-7}	2.6×10^{-6}	4.3×10^{-6}
TA–55–4 Plutonium Facility	$< 1.0 \times 10^{-9}$	3.3×10^{-9}	8.0×10^{-6}	8.4×10^{-8}
TA–18–26 Hillside Vault	$< 1.0 \times 10^{-9}$	$< 1.0 \times 10^{-9}$	$< 1.0 \times 10^{-9}$	$< 1.0 \times 10^{-9}$
TA–18–32 Kiva #2	4.3×10^{-9}	3.2×10^{-8}	7.3×10^{-8}	1.1×10^{-7}
TA–18–116 Kiva #3	$< 1.0 \times 10^{-9}$	$< 1.0 \times 10^{-9}$	1.6×10^{-8}	1.6×10^{-8}
TA–55–185 TRU Staging	7.3×10^{-8}	6.0×10^{-7}	2.1×10^{-7}	8.9×10^{-7}
TA–8–22 Radiography	$< 1.0 \times 10^{-9}$	$< 1.0 \times 10^{-9}$	1.6×10^{-8}	5.5×10^{-8}
TA–8–23 Radiography	$< 1.0 \times 10^{-9}$	1.5×10^{-8}	3.9×10^{-8}	5.9×10^{-8}
TA–15 DARHT	$< 1.0 \times 10^{-9}$	1.0×10^{-8}	4.9×10^{-8}	5.9×10^{-8}
TA–18–23 Kiva #1	3.9×10^{-9}	2.8×10^{-8}	6.7×10^{-8}	9.9×10^{-8}
TA–18–168 SHEBA	7.7×10^{-9}	7.4×10^{-8}	1.3×10^{-7}	2.2×10^{-7}
TA–54–38 Container Storage Area	3.2×10^{-9}	3.1×10^{-8}	5.5×10^{-8}	8.9×10^{-8}

Source: Calculated values

Note: In the cases of TA–8–22, TA–8–23, TA–15 DARHT, and TA–16–411, there is a conditional probability significantly less than one of MAR actually being present.

Discussion of Aircraft Crash and Release Frequencies

The aircraft crash frequencies in Table G.4.1.3–5 provide an indication of the frequency with which personnel injuries or fatalities could occur as a result of an aircraft crash at the facilities listed in the table. Note that a crash is not necessarily equivalent to a release of hazardous material; however, the conditional probability of a release given a crash is dependent on the design and construction of the facility and the nature of the aircraft impacting the facility.

Two types of release scenarios were considered: perforation leading to an explosion and perforation leading to a fire. The perforation-induced explosion results are presented in Table G.4.1.3–8. The results, particularly when the conditional probability of explosives being present is taken into account, indicate that perforation-induced explosion is a very minor contributor to risk. With the exception of the TA–3–476 facility, the other facilities potentially affected have perforation-induced explosion frequencies of less than 1×10^{-8} per year. This frequency is so low compared with the seismic structural damage/collapse scenarios (which can result in a large source term) that perforation-induced explosion is not considered further.

The perforation-induced fire results indicate that four facilities with hazardous materials have perforation-induced fire frequencies above 1×10^{-6} per year. The frequency of perforation-induced fire aircraft crash events at these facilities was examined in comparison with the seismic structural damage/collapse scenarios in order to evaluate whether aircraft crash accidents needed to be evaluated in detail.

It is important to recognize that the DOE aircraft crash standard (DOE 1996c) was intended for use as a safety analysis screening tool. For facilities that, after full analysis in accordance with the standard, still have aircraft crash frequencies in excess of the evaluation guidelines in the standard (crash frequency of greater than 1×10^{-6} per year), it was intended that a more detailed analysis be performed in order to determine whether aircraft crash should be considered to be an evaluation basis accident for safety analysis purposes. For NEPA purposes, the results indicate that the TA–3–29 (CMR), TA–21–155 (TSTA), TA–21–209 (TSFF), and TA–54 TWISP facilities dominate the aircraft crash-induced release frequency. The releases from TSTA and TSFF due to aircraft crash represent bounding tritium release scenarios for LANL because they occur at a relatively high frequency (compared with other large tritium release accidents) and, because of the accompanying fire, the tritium released would be in oxide form (which is more radiologically hazardous than elemental tritium gas).

Plutonium release from the CMR Building (RAD–16), plutonium release (from TRU waste) at TA–54 TWISP (RAD–08), and tritium oxide release from TSTA/TSFF (RAD–05) due to aircraft crash and fire were retained as risk-dominant accidents.

Having the crash frequency estimates, a consequence analysis was performed for each accident. (An analysis also was conducted for an “incredible” aircraft crash at RAMROD (RAD–06). The consequence analyses are similar to the consequence analyses for other accident scenarios, except that release fractions specified in the DOE aircraft crash standard (DOE 1996c) are used, rather than release fractions from DOE Standard 3010-94 (DOE 1994d).

The remaining perforation-induced fire scenarios identified in Table G.4.1.3–9 are considered to be bounded in risk by seismic release scenarios that occur at a much higher frequency. (Seismic releases occur in the frequency range of to 7.1×10^{-5} to 2.9×10^{-3} per year; whereas, the remaining aircraft crash with perforation-induced fire releases occur in the frequency range from to 1.3×10^{-10} to 8.9×10^{-7} per year.) For an aircraft crash accident to dominate over a seismic release for the remaining facilities, the source term for the aircraft crash accident would have to be orders of magnitude greater than for the seismic structural damage/collapse. No such release potential was identified.

G.4.2 Accident Source Term Assessment

The "source term" is a description of the physical and chemical characteristics of the materials released inside the facility or to the environment. The source term parameters include not only the MAR and the amount and rate of release, but also parameters that determine the subsequent transport, dispersion, and effects. These include whether the material is gas or particulate, in elemental or oxide form (e.g., for tritium and plutonium), and whether the release occurs at ground level or at some elevation above the ground. The plume source height is determined by the intensity of the fire or explosion, or, if the release is from a stack, the stack parameters (e.g., stack height diameter and velocity, heat content, etc.).

G.4.2.1 *Chemical Accident Source Terms*

Chemical accident source terms are estimated in a straightforward manner for the SWEIS. The screening analysis identified toxic gases and liquids that could easily disperse in the event of an accident. The source terms are based on the MAR quantities appropriate to the accident initiator. For example, in the case of a building structural collapse due to an earthquake, the entire gaseous/liquid chemical contents of the building are assumed to be released. For a process-related accident, such as the failure of a valve on a 150-pound capacity cylinder of chlorine, the source term is the maximum contents of the cylinder (even though it is recognized that the container may not be full when the valve failure occurs).

Where there are physical constraints on the release, these are recognized in the modeling. The 150-pound chlorine cylinder release is a good illustration of this sort of constraint. The chlorine inventory in the cylinder is partially gaseous and partially liquid. When the valve fails, the gaseous chlorine depressurizes very quickly, releasing a jet of liquid. However, this act results in a cooling of the cylinder below the boiling temperature of the liquid chlorine, halting the large release. As a result, not all 150 pounds of chlorine are released quickly. Simulation predicts the release of 68 pounds in the first 45 seconds at a flow rate of 91.5 pounds per minute. The flow rate then decreases sharply (Gephart and Moses 1989). The remaining chlorine would be released slowly as the container heats up to ambient temperature. Such a slow release rate would not pose significant hazards downwind of the release point. This type of release can be modeled with ALOHA™.

In some cases, conservative assumptions must be made in order to model the accident. A good example of this is the fire at TA–3–476, which results in chlorine release by melting fusible plugs in the chlorine cylinders (which melt at 165°F [74°C] and release the chlorine at a pre-defined rate in order to prevent sudden rupture of the cylinder). There are potentially ten affected cylinders in this accident. In reality, not all ten would release at exactly the same time. Due to modeling limitations, however, it was necessary to assume a simultaneous release. This is a conservative and bounding representation of the accident, but is not necessarily the most realistic portrayal of the accident. Table G.4.2.1–1 provides a summary of source terms for the chemical accidents.

TABLE G.4.2.1–1.—*Summary of Chemical Accident Source Term Calculations*

ACCIDENT SCENARIO DESIGNATOR	AFFECTED FACILITY	CHEMICAL RELEASED	SOURCE TERM INFORMATION
CHEM–01	TA–00–1109	chlorine	150 pounds
CHEM–02	TA–3–476	chlorine	1,500 pounds
CHEM–03	TA–3–476	chlorine	150 pounds
CHEM–04	TA–54–216	selenium hexafluoride	75 liters
CHEM–05	TA–54–216	sulfur dioxide	300 pounds
CHEM–06	TA–55–4	chlorine	150 pounds
SITE–01	TA–00–1109 TA–00–1110 TA–3–66 TA–3–476 TA–9–21 TA–43–1	chlorine chlorine hydrogen cyanide chlorine phosgene formaldehyde	300 pounds 300 pounds 7.6 liters 150 pounds 3 pounds 30 liters
SITE–02	TA–00–1109 TA–00–1110 TA–3–66 TA–3–476 TA–9–21 TA–43–1 TA–55–4 TA–55–4 TA–55–249	chlorine chlorine hydrogen cyanide chlorine phosgene formaldehyde chlorine nitric acid hydrochloric acid	300 pounds 300 pounds 7.6 liters 150 pounds 3 pounds 30 liters 150 pounds 6,100 gallons 5,200 gallons
SITE–03	TA–00–1109 TA–00–1110 TA–3–66 TA–3–476 TA–9–21 TA–43–1 TA–55–4 TA–55–4 TA–55–249	chlorine chlorine hydrogen cyanide chlorine phosgene formaldehyde chlorine nitric acid hydrochloric acid	300 pounds 300 pounds 7.6 liters 150 pounds 3 pounds 30 liters 150 pounds 6,100 gallons 5,200 gallons
SITE–04	TA–43–1	formaldehyde	30 liters

G.4.2.2 *Radiological Accident Source Terms*

DOE has issued standard guidance on estimating source terms for nonreactor nuclear facility accidents as DOE Handbook 3010-94 (DOE 1994d). (Note: aircraft crash source terms were not calculated using DOE Handbook 3010-94. Rather, DOE Standard 3014-96 specifies the source term methodology for aircraft crash accidents. Although DOE Standard 3014-96 cites DOE Handbook 3010-94 as a basis for its values, there are differences, and DOE Standard 3014-96 was used for aircraft crash accidents.)

DOE Handbook 3010-94 received extensive peer review within the DOE technical community and is the best available current information on the subject. Although the handbook presents both median and bounding values in many cases, this accident analysis employs the bounding values. (Accordingly, where SARs have used more realistic, less conservative source terms, the SARs have projected lesser consequences.) Although the availability of a median and bounding estimate might result in a temptation to generate a statistical distribution of values, the handbook specifically cautions against such an approach (DOE 1994d):

"The generation and suspension of particles is the result of the interaction of multiple physiochemical variables that have not been completely characterized as the majority of the experiments performed were designed in an attempt to reflect reasonably bounding conditions for specific industrial situations of concern. Accordingly, the data obtained are more accurately characterized as selected points from multiple distributions against multiple parameters than as different values from a common distribution. Even if this point is neglected, there are still practically intractable problems in attempting to generate statistical distributions. While the data are presumed to be bounding for the purpose intended, it is largely unknown whether the data values are truly 90th percentile, 99th percentile, 99.9th percentile, etc. Further, in many cases it is considered likely that accident specific ARFs are actually distributed in a highly irregular manner (i.e., multi-modal or truncated distributions). Assuming a typical distribution (i.e., log-normal, Poisson) using standard deviations will produce seriously distorted values that may have little or nothing to do with reality."

The handbook also cautions against over reliance on the values contained therein (DOE 1994d). Table G.4.2.2–1 provides the details of source terms for radiological accidents.

TABLE G.4.2.2–1.—*Source Terms of Radiological Accidents at LANL*

ACCIDENT SCENARIO DESIGNATOR	AFFECTED FACILITY	MATERIAL RELEASED	SOURCE TERM INFORMATION
SITE–01	TA–3–29	Pu-239	96.9 g of Pu-239 initial; 9.4 g suspension
	TA–18–23	HEU	22.9 g of HEU initial; 0.22 g suspension
	TA–21–155	tritium oxide	200 g of tritium oxide
	TA–21–209	tritium oxide	200 g of tritium oxide
	TA–50–1	Pu-238, Pu-239, Am-241	5.8 x 10^{-5} g of Pu-238, 0.27 g of Pu-239 & 0.005 g of Am-241 initial; 1.3 x 10^{-4} g Pu-238, 5.85 g Pu-239 & 0.11g of Am-241 suspension
	TA–50–37	Pu-239	1.0 Pu-239 PE-Ci initial; 0.96 Pu-239 PE-Ci suspension
	TA–54–38	Pu-239	0.339 Pu-239 PE-Ci initial; 0.033 Pu-239 PE-Ci suspension
	TWISP	Pu-239	0.19 Pu-239 PE-Ci initial; 1.2 Pu-239 PE-Ci suspension
SITE–02	TA–3–29	Pu-239	102.8 g of Pu-239 initial; 9.4 g suspension
	TA–16–205	tritium oxide	100 g of tritium oxide
	TA–18–23	HEU	22.9 g of HEU initial; 0.22 g suspension
	TA–18–32	Pu-239, HEU	0.22 g Pu-239
	TA–18–116	Pu-239, HEU	0.028 g Pu-239
	TA–18–168	HEU	0.85 g HEU initial; 18.4 g suspension
	TA–21–155	tritium oxide	200 g of tritium oxide
	TA–21–209	tritium oxide	200 g of tritium oxide
	TA–50–1	Pu-238, Pu-239, Am-241	5.8 x 10^{-5} g of Pu-238, 0.27 g of Pu-239 & 0.005 g of Am-241 initial; 1.3 x 10^{-4} g Pu-238, 5.85 g Pu-239 & 0.11 g of Am-241 suspension
	TA–50–37	Pu-239	1.0 Pu-239 PE-Ci initial; 0.96 Pu-239 PE-Ci suspension
	TA–50–69	Pu-239	0.39 Pu-239 PE-Ci initial; 0.037 Pu-239 PE-Ci suspension
	TA–54–38	Pu-239	0.339 Pu-239 PE-Ci initial; 0.033 Pu-239 PE-Ci suspension
	TWISP	Pu-239	0.12 Pu-239 PE-Ci initial; 1.2 Pu-239 PE-Ci suspension
	TA–55–4	Pu-239, Pu-238, Pu-242, HEU	0.0174 g Pu-238, 5.31 g Pu-239, 0.201 g Pu-242 & 0.242 g HEU initial; 0.056 g Pu-238, 56.7 g Pu-239, 1.68 g Pu-242 & 0.025 g HEU suspension

TABLE G.4.2.2–1.—*Source Terms of Radiological Accidents at LANL*-Continued

ACCIDENT SCENARIO DESIGNATOR	AFFECTED FACILITY	MATERIAL RELEASED	SOURCE TERM INFORMATION
SITE–03	TA–3–29	Pu-239	140.8 g Pu-239 initial; 13.1 g suspension
	TA–16–205	tritium oxide, tritium gas	172 g of tritium oxide, 1,188 g tritium gas
	TA–18–23	HEU	22.9 g of HEU initial; 0.22 g suspension
	TA–18–32	Pu-239, HEU	0.22 g of Pu-239
	TA–18–116	Pu-239, HEU	0.028 g of Pu-239
	TA–18–168	HEU	0.85 g HEU initial; 18.4 g suspension
	TA–21–155	tritium oxide	200 g of tritium oxide
	TA–21–209	tritium oxide	200 g of tritium oxide
	TA–50–1	Pu-238, Pu-239, Am-241	5.8×10^{-5} g of Pu-238, 0.27 g of Pu-239 & 0.005 g of Am-241 initial; 1.3×10^{-4} g Pu-238, 5.85 g Pu-239 & 0.11 g of Am-241 suspension
	TA–50–37	Pu-239	1.0 Pu-239 PE-Ci initial; 0.96 Pu-239 PE-Ci suspension
	TA–50–69	Pu-239	0.39 Pu-239 PE-Ci initial; 0.037 Pu-239 PE-Ci suspension
	TA–54–38	Pu-239	0.339 Pu-239 PE-Ci initial; 0.033 Pu-239 PE-Ci suspension
	TWISP	Pu-239	0.25 Pu-239 PE-Ci initial; 2.4 Pu-239 PE-Ci suspension
	TA–55–4	Pu-239, Pu-238, Pu-242, HEU	2.04 g Pu-238, 69.2 g Pu-239, 0.062 g Pu-240, 3.36 g Pu-242 & 3.74 g HEU initial; 1.95 g Pu-238, 71.2 g Pu-239, 0.3 g Pu-240, 3.22 g Pu-242 & 3.6 g HEU suspension
	TA–55–185	Pu-239	0.006 Pu-239 PE-Ci initial; 0.06 Pu-239 PE-Ci suspension
SITE–03, Surface Rupture	TA–3–29	Pu-239	788.5 g Pu-239 initial; 27.6 g suspension
	TA–16–205	tritium oxide, tritium gas	172 g of tritium oxide, 1,188 g tritium gas
	TA–18–23	HEU	22.9 g of HEU initial; 0.22 g suspension
	TA–18–32	Pu-239, HEU	0.22 g of Pu-239
	TA–18–116	Pu-239, HEU	0.028 g of Pu-239
	TA–18–168	HEU	0.85 g HEU initial; 18.4 g suspension
	TA–21–155	tritium oxide	200 g of tritium oxide
	TA–21–209	tritium oxide	200 g of tritium oxide
	TA–50–1	Pu-238, Pu-239, Am-241	5.8×10^{-5} g of Pu-238, 0.27 g of Pu-239 & 0.005 g of Am-241 initial; 1.3×10^{-4} g Pu-238, 5.85 g Pu-239 & 0.11 g of Am-241 suspension
	TA–50–37	Pu-239	1.0 Pu-239 PE-Ci initial; 0.96 Pu-239 PE-Ci suspension
	TA–50–69	Pu-239	0.39 Pu-239 PE-Ci initial; 0.037 Pu-239 PE-Ci suspension
	TA–54–38	Pu-239	0.339 Pu-239 PE-Ci initial; 0.033 Pu-239 PE-Ci suspension
	TWISP	Pu-239	0.25 Pu-239 PE-Ci initial; 2.4 Pu-239 PE-Ci suspension
	TA–55–4	Pu-239, Pu-238, Pu-242, HEU	2.04 g Pu-238, 69.2 g Pu-239, 0.062 g Pu-240, 3.36 g Pu-242 & 3.74 g HEU initial; 1.95 g Pu-238, 71.2 g Pu-239, 0.3 g Pu-240, 3.22 g Pu-242 & 3.6 g HEU suspension
	TA–55–185	Pu-239	0.006 Pu-239 PE-Ci initial; 0.06 Pu-239 PE-Ci suspension
SITE–04	TA–16–205	tritium gas	1,360 g tritium gas
	TA–21–155	tritium oxide	200 g tritium oxide
	TA–21–209	tritium oxide	100 g tritium oxide
	TA–54	Pu-239	0.16 Pu-239 PE-Ci initial release (elevated); 0.74 Pu-239 PE-Ci suspension release (ground level)
RAD–01	TA–54–38	Pu-239	0.13 Pu-239 PE-Ci initial release (elevated); 0.60 Pu-239 PE-Ci suspension release (ground level)
RAD–02	TA–3–29	Pu-239	504 g Pu-239 released in 60 seconds (explosion), 6 g Pu-239 released in 2 hours (fire), 0.48 g Pu-239 suspension release (ground level)

TABLE G.4.2.2–1.—*Source Terms of Radiological Accidents at LANL*-Continued

ACCIDENT SCENARIO DESIGNATOR	AFFECTED FACILITY	MATERIAL RELEASED	SOURCE TERM INFORMATION
RAD–03	TA–18–116	HEU, Fission Products	7,194 g HEU and fission products initial release (ground level); 56.1 g HEU suspension release (ground level)
RAD–04	DARHT	Pu	Elevated release of Pu
RAD–05	TA–21–155 and/ or TA–21–209	tritium oxide	200 g tritium oxide, elevated release (fire), no suspension release
RAD–06	TA–50–37	Pu-239	0.63 Pu-29 PE-Ci released in 30 minutes (elevated release); 2.8 Pu-239 PE-Ci suspension release (ground level)
RAD–07	TA–50–69 Container Storage Area	Pu-239	0.28 Pu-239 PE-Ci released in 2.4 minutes (elevated); 0.52 Pu-239 PE-Ci suspension release (ground level)
RAD–08	TWISP	Pu-239	0.16 Pu-239 PE-Ci initial release (elevated); 0.74 Pu-239 PE-Ci suspension release (ground level)
RAD–09	TWISP	Pu-239	High activity container, 0.066 Pu-239 PE-Ci initial release (ground level; 0.63 Pu-239 PE-Ci suspension release (ground level); Average activity container, 0.0012 Pu-239 PE-Ci initial release, 0.012 Pu-239 PE-Ci suspension release
RAD–10	TA–55–4	Weapons-Grade Pu	2.7 g weapons-grade Pu initial release (stack); 4.3 g weapons-grade Pu suspension release (ground level)
RAD–11	DARHT	Pu	Ground-level release of Pu
RAD–12	TA–16–411	Pu	Elevated release of plutonium
RAD–13	TA–18–116	Weapons-Grade Pu, Fission Products	6 g weapons-grade Pu initial release, plus fission products (ground level); 0.6 g weapons-grade Pu suspension release (ground level)
RAD–14	TA–55–4	Weapons-Grade Pu	2.5 g weapons-grade Pu initial release (stack); 0.0983 g weapons-grade Pu suspension release (ground level)
RAD–15	TA–3–29	Weapons-Grade Pu	6.6 g weapons-grade Pu initial release; 4.34 g weapons-grade Pu suspension release (Expanded Operations Alternative only)
RAD–16	TA–3–29	Pu-239	0.69 g Pu-239 initial release (elevated); 0.21 g Pu-239 suspension release (ground level)

Note: As plutonium-239 (Pu-239) ages, there is an ingrowth of the daughter americium-241 (Am-241) that affects the gamma radiation levels. However, an analysis shows that health effects from the combined uptake are quite independent of the aging. Therefore, the MAR does not distinguish as to age of the material released.