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This document is broadly broken into 2 sections, the Hazard Analysis Methodology and the Accident Analysis.

Hazard Analysis Methodology

The method that was used to prepare this analysis complies with the current SBP 114-2, Los Alamos National Laboratory (LANL) *Hazard Evaluation and Accident Analysis*, or successor documents. These techniques are consistent with DOE-STD-3009-94, Change 3, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports* and DOE O 420.1B, *Facility Safety*.

Hazard Identification

This subsection identifies the method used by analysts to identify and inventory hazardous materials and energy sources (in terms of quantity, form, and location) associated with the CMR Facility and its activities.

The first step in identifying hazards was to review existing information. These included sources of referenced information that are not an integral part of the hazard identification, such as the CMR-FHA-001, *Fire Hazard Analysis, CMR Facility*; work documents associated with the various activities performed in the facility; and occurrence reporting histories for the CMR Facility, as well as existing safety basis documents. Additionally, walkdowns of the entire facility, including outdoor areas, were performed to provide insight on the facility configuration, current operations, and existing safety documentation. These walkdowns also complemented the identification and inventory of hazardous materials and energy sources to identify potential interactions and synergistic effects.

Inventories of hazardous materials were primarily based on maximum historical inventories associated with a given process activity, which were obtained by reviews of process procedures and interviews with subject matter experts. For new or planned activities, interviews with subject matter experts were used to identify maximum expected inventories, with nominal additional material quantities added to account for process uncertainties to provide a bounding inventory value. In some cases, existing Technical Safety Requirement (TSR) or criticality safety inventory limits were used when clearly bounding.

Hazard screening criteria were applied to these inventories and energy sources to determine which hazards to carry forward to the Consolidated Hazards Analysis (CHA) as initiators or contributors to accidents. Two primary types of screening criteria were applied: chemical screening, and Standard Industrial Hazard (SIH) screening. The chemical screening used criteria set forth within DOE G 152.1-2 *Emergency Management Guide, Technical Planning Basis* and LANL SB-DO: CALC-07-024, R0 “Chemical Threshold Quantities for Safety Basis Categorization.” This criterion is described in more detail in the following text. The criteria in LANL SB-DO: CALC-07-024 specifically ensures that chemical consequences do not exceed threshold quantities at 100m, which is the distance to the collocated worker. As such, it also ensures these quantities are not exceeded for the public, which is located at approximately 667m. Other aspects of chemical storage and handling, such as cylinder missiles, etc. were also considered as energy source hazards, which could contribute to the initiation or development of an accident. Alternatively, energy source hazards were screened out if they were considered to be SIHs that did not act as accident initiators or contributors to accidents.

The research and development nature of the CMR operations requires the use, handling, and storage of a large variety of chemicals at the facility, but in relatively small quantities (e.g., gram and liter quantities). As such, there is an extensive list of chemicals that are present in the facility, or are required for programmatic activities. However, the hazards associated with these chemicals are typically well understood and can be managed using standard hazardous material and/or chemical handling programs. These chemicals were identified using site chemical and waste inventory databases and by reviewing existing safety documentation. The current Hazards Survey for CMR, EO-EPP-HS-007, RO, *Hazards Survey for Chemistry and Metallurgy Research Facility*, the output from the Chemlog database (a chemical inventory and tracking system utilized at LANL, *ChemLog*), (*CHEMLOG*, Licensed to Industrial Hygiene and Safety Division, Los Alamos National Laboratory, Los Alamos NM by EX3 Corporation, Accessed: May 4, 2009) and walkdowns of the facility were used for inputs to this process. The results of these inputs were documented in the tables provided in the Hazard Identification.

DOE-STD-3009-94 Chg 3 does not provide explicit criteria for chemical screening. The instruction in DOE-STD-1189, *Integration of Safety into the Design Process* (U.S. Department of Energy, Washington DC March 2008) was therefore taken into consideration, although this standard is written primarily for the use in the design of a new facility. DOE-STD-1189 refers to DOE G151.1-2 (*Emergency management Guide, Technical Planning Basis*, U.S. Department of Energy, Washington DC, July 11, 2007) for emergency preparedness, which includes the following chemical screening criteria:

(1) Common Public Use Exclusion – Materials that are commonly available to and used by the public are eliminated from further consideration, if the formulation and concentration is the same as for products that are distributed without significant restrictions to the public.

(2) Lab Scale Exclusion – Materials that are handled, stored and used in amounts that do not exceed laboratory-scale quantities are eliminated from further consideration. Laboratory-scale is defined in 29 CFR 1910.1450, *Occupational Exposure to Hazardous Chemicals in Laboratories*, as that for which containers used for reactions, transfer, and other handling of substances are designed to be easily and safely manipulated by one person. Individual containers that are being used, and small numbers of such containers kept in ready storage within or very near an end-user facility, may be screened out.

(3) Dispersability Exclusion – Chemicals that do not present an airborne exposure hazard due to their physical form or other factors are eliminated from further consideration.

(4) Low Toxicity Exclusion – Chemicals with an National Fire Protection Association (NFPA) 704, Standard System for the Identification of the Hazards of Materials for Emergency Response, Health Hazard rating (or equivalent NFPA Health Hazard rating) of 2 or lower do not need to be considered.

Chemicals not excluded by one of the above criteria must be quantitatively analyzed herein.

Chemicals were evaluated against the guidance outlined in DOE G151.1-2, to determine if further analysis would be required in the CHA for chemical consequences to the workers,

collocated workers, and/or public. Many chemicals that screened out for chemical consequences were not screened as accident initiators or contributors to accidents. These generally included chemicals that exhibited energetic characteristics (e.g., chemicals classified as flammable, combustible, or explosive). These chemical characteristics were considered as initiators or "causes" for scenarios within the CHA.

Only one chemical did not initially screen out against the chemical screening criteria in DOE G151.1-2, 55 gal of 3M ™ Novec ™ Engineered Fluid HFE-7100 located in Wing 5 of CMR because it is not a common public use chemical. This chemical is toxic - the NFPA Health Hazard Rating is 3. Additionally, it exceeds the Lab Scale threshold (of about 5 gal) with a vapor pressure (~ 200 mmHg) that exceeds the dispersability threshold of 1 mmHg. This chemical was screened against the criteria provided in LANL SB-DO: CALC-07-024, R0 "Chemical Threshold Quantities for Safety Basis Categorization." This document provides the chemical threshold quantities that correspond to the ERPG-3/TEEL-3 concentration at various distances from the dispersion of spilled material. According to these criteria, a spill of the entire inventory (55 gal) would not result in a significant consequence at 100 meters. Therefore, this chemical was not evaluated in the CHA as having significant chemical consequences.

As a result of the above evaluation, standard hazardous material and/or chemical handling programs are deemed sufficient to protect the public, collocated workers, and workers from all identified chemicals' hazards within the CMR facility. Hazards that were not screened out were carried forward to the hazard evaluation described below in the Hazard Evaluation subsection.

The documentation of the hazard identification process was prepared in accordance with SBP 114-2. Each type of hazardous material is described, including the amount/units, form, process/location, and comments concerning the hazard. Hazards considered include:

- Radioactive materials, including radioisotopes, activated materials, and fissile/fissionable materials
- Chemical and biological materials, including asphyxiants, biological agents, toxics (including Category I chemicals), irritants, allergens, and sensitizers,
- Fire and Explosive hazards, including explosive materials, flammable materials, pyrophoric materials, oxygen and oxidizers, combustible/combustion products, and time-sensitive chemicals.
- Reactive chemicals, including corrosive chemicals, and incompatible chemicals.

Energy sources considered include:

- Electrical hazards,
- Kinetic energy hazards, including linear, rotational, and vibrational energies.
- Potential energy hazards, including gravitational, magnetic, pressure, and vacuum.
- Thermal energy hazards and cryogenics,
- Prompt radiation hazards, including ionizing and non-ionizing radiation.

For each identified hazard or energy source, the worksheet indicated whether or not the hazard or energy source screened out. If the hazard screened out, then the reason for screening was also provided in the tables.

Hazard Evaluation

This subsection presents the basic approach and guidance used for generating the largely qualitative consequence and likelihood estimates in the hazard evaluation. The hazard evaluation evaluates the complete spectrum of accidents associated with the hazards and activities in the CMR Facility. The methodology for performing the hazard evaluation is described in summary fashion below.

A CHA process team was organized to ensure the mix of personnel required to successfully perform a CHA. The team included individuals knowledgeable with the laboratory operations, design authorities familiar with the CMR engineered systems, safety analysts experienced in hazard assessment and control selection, an individual fluent in executing the electronic CHA Process (eCHAP) code used to facilitate and document this CHA, and an experienced team leader.

The objective of the CHAP Team was to identify and evaluate hazards associated with the current or proposed operation of the CMR and to present possible control strategies that should be considered for the facility. Because of the many locations and types of activities that may be performed in the laboratory and the small quantities of radiological material generally used in individual process areas (i.e., tens of grams), the CHA was performed at a higher level or on a broader scope. In other words, each specific activity was not evaluated at the level of detail often desired, in which numerous event scenarios are developed assessing each type of process upset or initiator that could lead to a possible release of material. Instead, events were described more generically, with some grouping of initiators in a common event. Representative events were identified that allowed the CHAP Team to assign control sets that adequately protect the worker and public for all initiators listed. This kept the total number of events for the facility limited to a manageable level and still ensured that all conceivable smaller accidents were covered and all necessary Safety Significant (SS) controls identified. For Wings 2, 3, and 4, where the only potential operations are hazard reduction, specific events or activities could not be identified for which a detailed activity based hazard analysis could be completed. In Wings 5 and 7 and for the Hot Cells in Wing 9, some specific activities were identified. However, because of the nature of the research and development activities conducted at CMR, these limited specific activities are not expected to fully encompass all of the potential research activities conducted in the laboratories. Therefore, this HA was developed on the assumption that the accidents evaluated and the controls selected will bound the specific experiments and activities conducted in the laboratories. For some operations in Wing 9 (e.g., CVD Project) and the Waste Assay Facility (WAF), specific activities were evaluated and the controls were selected on the known or projected activities.

The HA structure is primarily location-based since events were defined for each wing or area in CMR. However, activity-based and hazards-based structures were also considered because of the similar hazards and activities occurring in multiple locations. For instance, the types of accidents

identified for Wings 2, 3, and 4 had much in common, as did the accidents identified for Wings 5 and 7. As part of the uncontrolled hazards analysis, which is primarily a qualitative process, events requiring mitigation and further quantitative accident analysis were identified. Potential preventive and mitigative features were identified and controls were selected for protection of the public, collocated workers, and workers.

Hazard scenarios were developed based on the types of activities and hazards identified for each of these areas using the "What-If" technique given in DOE Standard 3009-94. The CHAP Team considered hazards noted in the hazard identification process along with the activities described for the facility and posed questions concerning the potential for accidents. These "What-If" scenarios were recorded through the eCHAP process. Accidents for the following event categories were considered and evaluated:

- Fires (combustible material fires, pool fires, etc.)
- Explosions (flammable gas explosions, chemical explosions, etc.)
- Loss of Confinement (spills, drops, impacts, breach of confinements within the facility boundary)
- Direct Exposure (external doses, direct contact, ingestion or uptake from skin puncture)
- Criticality
- External Events (fires, explosions, impacts originating outside the facility such as vehicle impacts, aircraft crashes, nearby explosions, natural gas releases, toxic chemical release from nearby facility, etc.)
- Natural Phenomena (lightning strike, wildland fire, flood, high wind, and seismic event)
- Other (loss of power, water, ventilation, firearm discharge, etc.)

The key inputs and assumptions for each scenario are described in the scenario summary or listed in the HA table. The general methodology used in the development of the What-If scenarios is as follows:

Potential accidents caused by acts of sabotage or terrorism are not within the scope of this analysis because identifying and controlling the risk associated with potential acts of sabotage or terrorism are the responsibility of Security. The CMR Facility's primary mission does not involve retrieval, handling, storage, or processing of transuranic (TRU) waste containers, However, TRU waste is generated as a byproduct of CMR Facility operations and hazard reduction activities. As such, the guidance for TRU waste activities discussed in DOE-STD-5506-2007, *Preparation of Safety Basis Documentation for Transuranic (TRU) Waste Facilities*, was considered during the development of the HA. Because of the nature of the activities at the CMR Facility, the radiological material that is ultimately packaged as TRU waste previously existed in the facility in an unpackaged state and was evaluated as part of operations or hazard reduction activities.

Consequences were based on hazardous material releases (e.g., radioactive, toxic, etc.). They were not based on the direct impact of the initiating event on the worker, collocated worker, or the public, unless the initiator was considered to be outside the realm of SIHs. For instance, an explosion was screened as an SIH if it did not cause the subsequent release of a hazardous material. However, if this explosive event involved a release of radioactive material, then the public, collocated worker, and worker consequences were evaluated based on the exposure to the hazardous material, and not the effects of the explosive event. This is consistent with the methodology applied to other LANL

nuclear facilities.

Each hazard scenario is represented by a table, with each table containing the following information:

- Event Description and Location
- MAR (the bounding amount of material potentially at risk) and Release Mechanisms
- Assumptions and Causes
- Unmitigated System Effects and Unmitigated Frequency (A qualitative estimate of the initial event frequency based on operational experience or engineering judgment.)
- Mitigated Frequency (A qualitative estimate of the event frequency based on operational experience or engineering judgment after crediting the preventive controls.)
- Unmitigated Consequences (A qualitative or rough quantitative estimate of the unmitigated event consequences based on the available MAR impacted by the event.)
- Mitigated Consequences (A qualitative or rough quantitative estimate of the event consequences after crediting the mitigative controls.)
- Engineered and Administrative Preventive Features
- Engineered and Administrative Mitigative Features

All the controls classified within the tables as safety-significant (SS), Safety Management Program (SMP), and Specific Administrative Control (SAC) are covered within the CMR Facility TSRs. These controls may also be elevated to Safety Class (SC) or SC-equivalent controls, as determined by the accident analysis. Other controls that are applicable to the hazard, but not specifically credited, are listed within the tables as DID (Defense in Depth).

Once the hazard scenarios were developed, the unmitigated and mitigated frequency and consequences were qualitatively evaluated for each scenario using the criteria below.

Frequency Category

The likelihood (or frequency) of occurrence for postulated events is assessed qualitatively and divided into categories using the criteria in Table 1 below. Where an event frequency is judged to fall near the boundary between two frequency categories, the higher frequency category is conservatively assigned (e.g., Frequency Category I is assigned for events that occur approximately once per year). Further, it should be recognized that, due to the relatively large range of each frequency category, although two different scenarios may be assigned the same frequency category, they may differ in frequency by up to two orders of magnitude per year.

For controlled scenarios, the credited reduction in frequency for each preventive control was taken from the guidance in SBP 114-2, *Hazard Evaluation and Accident Analysis*:

• SMPs reduce the scenario frequency by a factor of 10.
• SACs, in general, reduce the event frequency by one frequency bin because these controls are considered equivalent to engineered controls.
• Engineering controls that have surveillance requirements are assumed to reduce the frequency by a factor of 100 (one frequency bin), unless there is specific data available for the control. Multiple, independent engineering controls can be credited to achieve greater than a factor-of-100 reduction.

Table 1 is taken from SBP 114-2.

Table 1 Frequency Categories

Frequency Category and Range	**Frequency Label**	**Frequency Description**
I ($\geq$1/yr)	**FREQUENT**	Events predicted to occur every, or almost every, year during the facility's lifetime (50 years). Only normal operations should be frequent events.
II (<1/yr to $\geq 10^{-2}$/yr)	**OCCASIONAL**	Events expected to occur once to several times during the facility's lifetime. Simple events, such as a single human error, could be categorized as occasional.
III ($<10^{-2}$/yr to $\geq 10^{-4}$/yr**)**	**PROBABLE**	Events not expected to occur during the facility's lifetime, but the possibility cannot be ruled out. If 100 to 200 identical facilities were operating, then the incident would be expected once in the entire population during the operating lifetime of the facilities.
IV ($<10^{-4}$/yr to $\geq 10^{-6}$/yr)	**IMPROBABLE**	Events that are unlikely to occur during the facility's lifetime. Even for 100 to 200 identical facilities operating, the incident is not expected to occur during the operating lifetime of the facilities.
V ($<10^{-6}$/yr)	**REMOTE**	Events that are inconceivable of occurring during the facility's lifetime.

Consequence Category

Accident consequence severity categories (Table 2) are estimated for three receptor locations: the public at 667 meters, the collocated worker at 100 meters, and the facility worker in the immediate area. The collocated worker was added as a receptor, consistent with the methodology used at most DOE nuclear sites. The consequence level criteria for the public and facility worker match those contained in SBP 114-2 and LA-UR-02-6229, *Quantitative Criteria for Categorization of Hazards at Nuclear Materials Technology Division Facility*, October 2002.

Table 2 Public, Collocated Worker and Worker Consequence Categories

Consequence Level	Offsite Public (rem)	Collocated Worker (rem)	Facility Worker*
A	TEDE ≥ 25	TEDE ≥ 400	Immediate health effects or loss of life.
B	5 ≤ TEDE < 25	25 ≤ TEDE < 400	Long-term health effects, disability, or severe injury (non-life-threatening).
C	0.1 ≤ TEDE < 5	5 ≤ TEDE < 25	Lost-time injury but no disability (work restriction).
D	0.01 ≤ TEDE < 0.1	0.1 ≤ TEDE < 5	Minor injury with no disability and no work restriction.
E	TEDE < 0.01	TEDE < 0.1	No measurable consequences.

* The quantitative values for the collocated worker in this table were used as the basis to qualitatively estimate the consequences to the facility worker. These numeric values generally are in alignment with the qualitative terms taken from SBP 114-2.

For controlled scenarios, there is no specific guidance in SBP 114-2 on the credited reduction in consequence for each mitigative control. The credited reduction is evaluated on a scenario-by-scenario basis, though a general approach can be applied for individual accident types (i.e., spills, fires, and explosions). The effectiveness of an individual control is judged relative to the characteristics of the control as compared to the characteristics of the event. That is, a particular control may be very effective in reducing consequences for a low-energy event with low material dispersal capability, but may have little effect for high-energy events that have high material dispersal capability. For example, enclosures (gloveboxes and ventilated hoods) and the exhaust ventilation system are very effective at reducing worker consequences to workers from spill events. However, enclosures and exhaust ventilation systems may provide minimal consequence reduction from explosions that overpressure the local area and disperse MAR outside of the enclosures. Relating the effectiveness of a control to the magnitude of the event is also performed within individual accident types. For example, small explosions impact the immediate local area, while large explosions may impact the entire wing.

• SMPs, in general, reduce the event consequence by a factor of 10. Multiple, independent SMPs can be credited to achieve greater than one consequence bin in reduction. Occasionally, an SMP may be credited for reducing the consequence by more than half a bin. For instance, more credit is taken for the Emergency Management Program in a relatively slow developing event such as a large fire that requires significant time to propagate, since plenty of time would be available for effective evacuation.

• SACs, in general, reduce the event consequence by one consequence bin because of their specific nature and attention devoted to their performance in the Technical Safety Requirements (TSR). Multiple, independent SACs can be credited to achieve greater than a one bin reduction.

• Engineering controls (SS SSCs) that have surveillance requirements are assumed to reduce the consequence by one consequence bin, unless there is specific data available for the control supporting a different reduction factor. The building ventilation system/ high-efficiency particulate air (HEPA) filters were credited 2 bins in events where they are not damaged or loaded with soot (e.g., small fires, small explosions, and spills).

• Multiple, independent engineering controls can be credited to achieve greater than one bin reduction.

Risk Classification

Once the likelihood and consequence bins have been determined, the Risk Class category can be assigned using the criteria in Tables 3 and 4 that follow. Risk categorization provides a useful tool for risk-based decisions, such as selection of preventative or mitigative controls. The risk categories are major risk (Risk Class 1), serious risk (Risk Class 2), marginal risk (Risk Class 3), and negligible risk (Risk Class 4). Table criteria are identified in DOE-STD-3009-94, Chg 3 and SBP 114-2.

Table 3 Public Risk Matrix

Consequence \ Frequency	I	II	III	IV	V
A	1	1	2	2	3
B	1	2	2	3	3
C	1	2	3	3	4
D	3	3	3	4	4
E	4	4	4	4	4

Table 4 Collocated Worker Risk Matrix

Consequence \ Frequency	I	II	III	IV	V
A	1	1	2	2	3
B	1	1	2	3	4
C	1	2	3	4	4
D	3	3	4	4	4
E	4	4	4	4	4

Selection of Controls

• Engineered controls (SSCs) are preferred over administrative controls (AC).
• Passive SSCs are preferred over active SSCs.
• Preventive controls are preferred over mitigative controls.
• Controls closest to the hazard, between the hazard and the nearest receptor if possible, are preferred.
• Facility SSCs are preferred over personal protective equipment (PPE).
• Controls that are effective for multiple hazards are preferred.

The above criteria are combined in the following preference order (listed from most preferred to least preferred):

1. SSCs which are preventive and passive
2. SSCs which are preventive and active
3. SSCs which are mitigative and passive
4. SSCs which are mitigative and active
5. Administrative Controls (ACs) which are preventive
6. ACs which are mitigative

Any control remaining would be ranked from closest to the hazard to farthest from the hazard to identify the controls that protect the most receptors.

Uncontrolled scenarios with marginal risk (Risk Class 3) or negligible risk (Risk Class 4) to the public, collocated workers, or workers require no further evaluation. SMPs are typically relied upon to prevent and mitigate harm from these scenarios. However, those uncontrolled Risk Class 3 events that challenge the offsite evaluation guideline (EG) (public consequence category B) were evaluated further for risk reduction.

For uncontrolled scenarios with major risk (Risk Class 1) or serious risk (Risk Class 2) to the public, collocated workers, or workers, the goal is to first identify preventive controls to achieve a Risk Class of 3 or 4. If the Risk Class is still a 1 or 2 after application of preventive controls, then mitigative controls are credited for the public, collocated worker, and/or worker until a risk class 3 or 4 is achieved, if possible. As a general rule of thumb, mitigative controls that protect the public were assumed to also protect the collocated worker to the same degree as the public. For instance, HEPA filtered exhaust provides the same filtered radioactive material release (source term) to personnel outside the facility, regardless of their distance from the facility.

Engineered controls are preferred over administrative controls and are selected first if they are available. Development of additional engineered controls was considered but deemed impractical for the CMR facility since it is approaching its end-of-life and is undergoing hazard reduction activities. Therefore, there is an increased reliance on administrative controls and SMPs in the CMR due to the age and condition of the facility and its engineered safety features.

The identified controls may include engineered SSCs or ACs. Select ACs that provide preventive and/or mitigative functions for specific potential accident scenarios, and which also have safety importance equivalent to engineered controls that would be classified as SC or SS if the engineered controls were available, were elevated to a SAC, as required per DOE-STD-1186-2004, *Specific Administrative Controls.* Additional DID controls considered during selection of the credited controls are also identified for each accident scenario. For some potential low-frequency initiators [such as natural phenomena hazards (NPH)], a sufficient number and type of controls may not be available to reduce the scenario risk to a Class 3 or 4. Due to their low frequency and the application of generally conservative analytical methods, the higher risk class of these events is considered to be acceptable.

SMPs are designed to prevent or mitigate the consequences of specific types of hazards and are frequently considered for control selection. If a single, clearly defined SMP attribute is relied upon to prevent or mitigate the consequences of an accident, that attribute must be considered for elevation to a SAC. If the cumulative effect of multiple attributes within an SMP, or processes within an SMP, is relied upon to prevent or mitigate the consequences of an accident scenario, the overall SMP may be relied upon for a required control. Reliance on an SMP to provide a required control must be based on a determination that the control is consistent with the general TSR commitment to the SMP, such that designation of a separate control is not necessary.

Accident Analysis at CMR

Accident analysis typically starts with formal descriptions of accident scenarios. All major assumptions in scenarios are identified. The next step is determination of accident source terms (STs). The STs for accidents are obtained through phenomenological and system response calculations. Once a ST has been determined, consequences due to atmospheric dispersion or other relevant pathways of concern are determined.

The consequence to the public of an accident involving a release of Pu is calculated as the dose to the maximally exposed offsite individual (MEOI) at the public or site boundary. As delineated by the methodology below, it is expressed as the product of two terms – the ST and a source-to-dose conversion factor (DCF). The ST, which is the amount of material released to the environment as a respirable aerosol, was calculated using the five-factor formula from DOE-HDBK-3010-94, Airborne Release Fractions/Rates and Respirable Fractions for Non-Reactor Nuclear Facilities. That formula of the handbook can be written

$$ST = MAR \times DR \times ARF \times RF \times LPF$$

Where,
ST = source term to the outdoor atmosphere;
MAR = material-at-risk;
ARF = airborne release fraction;
RF = respirable fraction;
DR = damage ratio;
LPF = leak path factor.

The resulting ST is used to determine consequences to the onsite receptor at 100 meters and the offsite receptor at the LANL site boundary using dose conversion and atmospheric dispersion factors.
The individual terms of the above equation are defined as follows:

Material-at-Risk
MAR is the nuclear material that may be involved in the postulated accident**.**

Damage Ratio (DR)
The DR is the fraction of the MAR that is affected by the stresses of a specific accident scenario. The product of these two quantities, MAR × DR, is thus the amount of material that is involved in that specific scenario.

Airborne Release Fraction & Respirable Fraction (ARF/RF)
The airborne release fraction (ARF) multiplied by the respirable fraction (RF) is the fraction of the *MAR* × DR that is aerosolized and made airborne as respirable aerosol particles by the accident. The values ARF and RF are specific to the characteristics of the accident and the material involved. Bounding values are estimated from those presented in DOE-HDBK-3010-94 for situations that most closely simulate those of the accident of interest.

Leak Path Factor (LPF)
The LPF is the fraction of the airborne release from the MAR that is transported to the outdoors. The LPF accounts for attenuation caused by aerosol particle deposition along the leak path from the local source to the outdoor environment. For conservatism, a LPF of 1.0 was assumed. That is, it is assumed that all of the material that becomes airborne eventually leaves the facility. The shortest distance from the CMR Facility to the MEOI is 667 m.

The actual dose to the MEOI is calculated by

Dose to MEOI = $= ST\ x\ {}^{X}/_{Q}\ x\ BR\ x\ SA\ x\ DC$

Where,
ST = source term to the outdoor atmosphere
${}^{X}/_{Q}$ = atmospheric dispersion factor
BR = Breathing rate
SA = Specific Activity
DC = Dose Conversion Factor

Chi-Over-Q (${}^{X}/_{Q}$)
The atmospheric dispersion factor is based on an elevated release, using 95th percentile meteorological conditions, and does not include any buoyancy effects. The dispersion factor does include particle depletion, which uses a deposition velocity of 1 cm/s.

Breathing Rate (BR)
Breathing rate (BR) is 3.3E-4 m3/s. The BR is a weighted average of two breathing rates in International Commission on Radiation Protection (ICRP) 66, *Human Respiratory Tract Model for Radiological Protection* that is widely used, as established in SBT: 14BE-32792, *Approval of Breathing Rates for Safety Basis Accident Analysis*.

Specific Activity (SA)
The specific activity of ^{239}Pu is 6.22E-2 Ci/g.

Dose Conversion Factor (DC)
The dose conversion factor is 5.92E7 rem/Ci and 1.85E8 rem/Ci for slow and moderate-class material, respectively ICRP Publication 72, *Age-dependent Doses to the Members of the Public from Intake of Radionuclides*, Part 5, Compilation of Ingestion and Inhalation Coefficients. In order to ensure conservative calculations, the moderate DCF is used to calculate the associated doses for postulated accidents.

The primary purpose of the DBA analysis is to identify SSCs that warrant Safety Class (SC) designation. Comparison of the unmitigated consequences for a limited subset of potential accidents to the EG is performed to determine if the need for designation of SC SSCs exists. If the EG value is judged to be challenged by the unmitigated consequences of a release scenario, a need for SC SSC designation is indicated.

Specific accidents considered in the following text include criticality accidents, aircraft impacts, fires in multiple wings, outside fires and seismic events coupled with fire.

Criticality

A criticality event at the CMR Facility is considered to exhibit a trivial risk with the proper application of the Nuclear Criticality Safety Program. The HA identified several locations that this could occur, including Wing 9, locked rooms in Wing 5 and 7, the WAF, and the Main Vault.

The general characteristics of a nuclear criticality accident can be inferred from the accidents that have occurred and from critical experiments. Of 22 known process criticality accidents, 21 were from a solution criticality, while the remaining accident was from a metal criticality. The majority of experiments provide evidence for either a lengthy power excursion or multiple excursions, which varied from fractions of a second to hours (hr) in duration. As the duration of the release increases, the radiation fields generated approach a quasi-steady-state plateau.

The radiological dose must consider three major contributors. First, prompt neutron and gamma radiation from the criticality may or may not be a factor for the MEOI, depending on the distance and the number of fissions. Second, a criticality will generate a large quantity of fission product gases. External cloud shine provides an external radiological dose to the MEOI from beta and gamma decay. Third, some of the solution will be aerosolized with the criticality to cause an internal radiological dose to the receptor.

Generally, the doses from the non-volatile fission products do not contribute significantly to the dose to the MEOI. Only the fission products krypton, xenon, and iodine, with half-lives greater than 2 hrs, are considered in the dose estimation. Noble gases are freely released from the solution, but 75% of the iodine is often considered to be retained.

Metal criticalities typically result in a single pulse, where the critical configuration is disassembled or the fuel is consumed resulting in a subcritical configuration. Solution criticalities are capable of pulsing until the fuel is consumed.

With metal criticalities, fission products tend to become trapped in the metal lattice. In solution, the fission products are readily released, providing additional cloud shine. Also, the boiling of liquid causes fissile material from the solution to become airborne leading to an internal exposure to the MEOI.

Scenario Development

The HA identified an uncontrolled frequency for a criticality occurring at CMR as Category II ($<10^0$/yr to $\geq 10^{-2}$/yr).

Concerning the type of criticality, the likelihood of a metal criticality accident is judged to be well below that for an aqueous or solution criticality accident. The main reasons for this adjudication are as follows:

• It is less likely to violate the mass limit on large, well-defined quantities of solid fissile materials because operations personnel are more likely to detect off-normal inventory conditions. For aqueous operations, it is more difficult to notice deviations in solution concentrations and volume changes. In addition, for solutions, reliance on sample results is required.

• Transfer and handling of solid fissile materials is typically a hands-on operation, while the transfer of a fissile solution material can result in misrouting, multiple transfers, etc.

• The minimum critical mass for U or Pu metal is at least 10 times greater than that for the same material in solution.

• Liquid has the ability to accumulate in a critical geometry.

• Fissile material in solution can be concentrated or diluted beyond operational norms, resulting in a reduced safety margins.

Therefore, in this instance, the solution criticality accident bounds the criticality induced by fissile metals.

In addition, while the solution criticality is addressed, and some discussion has been provided concerning trapping fission products in the metal lattice, it should be noted that there are no real differences in the dose consequences concerning metal, oxide or solution criticality. The standards utilized in the development of this scenario are fairly independent of the form of the material when considering dose consequences.

Operational wings, other than Wing 9, have small quantities of Pu solutions. Wing 9 stores U solutions that have been used collectively to induce criticalities.

This scenario does not credit the Nuclear Criticality Safety Program. Before a new operation with fissionable material is begun, or before an existing operation is changed, this program shall provide a determination to ensure the entire process will be subcritical under both normal and credible abnormal process conditions. In addition, this program is used to ensure process designs incorporate sufficient factors of safety to require at least two unlikely, independent, and concurrent changes in process conditions before a criticality accident is possible.

Source Term Analysis

MAR

Fissionable material exists at the CMR Facility as uranium and plutonium. The uranium can exist in various forms, and it currently consists of [material type (MT)-31 and MT-33], which are both slightly enriched. The plutonium can also exist in various forms, and it is typically MT-52.

A criticality accident is presented for consequence purposes only (without consideration for frequency or probability). The physical form of the MAR can be conservatively assumed to be solutions. The 1.0E+19 total fissions, as it appears to bound most historical and estimated yields, is assessed to be the bounding reference yield. An excursion in a solution is often described as being terminated by the evaporation of 100 liters of solution over an eight hour period [DOE-HDBK-3010-94].

For 100 L of 400 g/L MT-33 (i.e., 40 kg MT-33), and the ^{239}Pu equivalent conversion factors for moderate absorption (i.e., 3.02E-5) from SB-DO:CALC-09-025, *Material Type and Nuclide Conversion Factors*, the MAR associated with Case 1 is considered to be 1.2 g 239Pu equivalent material. This MAR is used for determining inhalation dose consequences for Case 1.
For the 100 L of fissile solution consisting of 500 g/L for Pu solutions would exceed the Wing 9 MAR limit (the largest limit for individual wings). For the purposes, criticality will assume enough solution for criticality, yet not exceeding the MAR Limit. The MAR used for determining inhalation dose consequences for Case 2 is assumed to be 5800 g 239Pu equivalent material. This quantity is an extremely conservative assumption, and normal processes within CMR would never see this much material in a solution because of the Nuclear Criticality Safety Program.

The amount of fission products produced by the excursion is a function of the total fissions from the criticality and the specific fissionable radionuclide involved. The fission yield is assumed to be 1E19 fissions total.

Standard quantities have been modeled as shown in Regulatory Guide 3.33 for spent fuel, and as shown in Regulatory Guide 3.35 for Pu solution criticalities. However, TA18-AB-SAD-0102, *Los Alamos National Laboratory Technical Area 18 (TA-18) Basis for Interim Operation*, Appendix D.6 (Fission Product Dose Assessment) describes a much more comprehensive analysis of the fission product ST for a range of fission yields. To determine the ST generated by the criticality excursion, an ORIGEN2 calculation was conducted. TA18-AB-SAD-0102 describes fission product generation and release from solution criticality events for yields as high as 1.0E+19 fissions.

ARF/RF

The physical form of the MAR can be conservatively assumed to be solutions. The bounding *ARF x RF* values for this physical form are caused by stresses induced by criticality.

DOE-HDBK-3010-94, Section 3.2.1.3, discusses boiling of aqueous solutions in flowing air, where bubbles continuously breaking the surface of the bulk liquid with < 30% of the volume of the liquid as bubbles. However, the boiling of the solutions is not considered to be a constant phenomenon. The criticality occurs in pulses. As such the value offered by the handbook for the release from a solution to a criticality is typically used. DOE-HDBK-3010-94, Section 6.1, discusses the release of salts, i.e., non-volatile fission products and base solution, in liquid evaporated during a large volume solution excursion. Salts, non-volatile fission products and base solution are released as the solution evaporates with an *ARF x RF* combination of 5E-4.

DR
The MAR is conservatively assumed to be non-containerized. As such, the ST analysis will consider the DR to be 1.

LPF
As an unmitigated analysis, no confinement by facility systems or structures is assumed. Therefore, a LPF of 1 is used.

Source Term
The total ST released will be used to determine the dose consequences. This methodology is provided in the following table (Table 5).

Table 5, Source Term for Solution Criticality

Description	MAR (g)	ARF x RF	DR	LPF	ST (g)
Case 1 – Criticality with U-Solution	1.2 (=40,000 g MT-33x3.01E-05 ^{239}Pu/MT-33)	5E-4	1	1	6E-4
Case 2 – Criticality with Pu-Solution	5800	5E-4	1	1	2.9

Using the methodology provided in DOE-HDBK-3010-94, the airborne ST to consider for internal exposure is 6.0E-4 g 239Pu equivalent material (Case 1) or 2.9 g ^{239}Pu equivalent material (Case 2).

Based on analyses of fission product generation for a range of fission yields, an incremental dose of 0.5 rem is added to the unmitigated dose estimates calculated from the STs. This estimate includes radiological dose from inhalation and immersion into a cloud of fission products. The doses were found to increase linearly with fission yield (0.14 rem for 3×10^{18} fissions, 0.44 rem for 1×10^{19} fissions and the X/Q of 1.5E-4 s/m^3).

Consequence Analysis
Internal Uptake
Using the methodology provided in DOE-HDBK-3010-94, the unmitigated radiological dose consequence to the MEOI associated with the release from the criticality is several orders of magnitude below the EG for Case 1, and over an order of magnitude below the EG for Case 2. In addition, to these consequences, the following doses are included in the Cumulative Effective Dose Equivalent (CEDE) for this scenario.
Prompt Radiation
The prompt dose can be calculated using methodology presented in US NUREG, Regulatory Guide 3.33, *Assumptions Used for Evaluating the Potential Radiological consequences of Accidental Nuclear Criticality in a Fuel Reprocessing Plant* and in US NUREG, Regulatory Guide 3.35, *Assumptions Used for Evaluating the Potential Radiological Consequences of Accidental Nuclear Criticality in a Plutonium Processing and Fuel Fabrication Plant* The prompt radiation is based on a total of 1E19 fissions. The dose for each pulse is in the mrem range. The cumulative dose is well below a rem.

Cloud Shine
The fission product generation with thermal fission of uranium solution is roughly the same as the thermal fission of plutonium solution. Dose consequences from cloud shine are estimated to be between one and two orders of magnitude below the EG.

Comparison to Guidelines
The bounding dose from the Criticality is from a plutonium solution criticality. The bounding dose does not challenge the 25 rem EG.

Summary of SC SSCs, SACs, and TSR Controls
No controls are required to be elevated to SC.

Aircraft Crash into Wing 9

The postulated accident is a small aircraft (general aviation, light aircraft) impact to the CMR Facility building during normal operations or hazard reduction activities. The impact collapses the lighter portions of the aircraft, but the larger components (such as the engine and shaft) that have greater weight are carried into the wing building and entrain fuel. Under these conditions, it is assumed that some of the fuel is aerosolized (fragmented into droplets) and generates an explosive-like fireball. It is postulated that the fireball causes a large fire. It is assumed that the aircraft has sufficient fuel to cause a large fire that progresses into a wing-wide fire.

Scenario Development
The postulated accident is assumed to result in an initial impact release of a single wing followed by a fire release event. The impact is assumed to occur in Wing 9, which may contain up to 5,800g ^{239}Pu equivalent material that is being processed, staged, or moved within the wing. An additional 200g ^{239}Pu equivalent material is assumed to be present in the wing as holdup. This material is bounding for Wings 2, 3, 4, 5, and 7. Since the impact occurs first, all MAR confinement systems (e.g., containers, enclosures, etc.) are assumed to be damaged by the event such that these features do not protect MAR during the subsequent fire.

A recent analysis, *Hazards Survey for Chemistry and Metallurgy Research Facility*, EO-EPP-HS-007, calculates the total annual impact frequency (summed over all aircraft categories) for an aircraft crash into a CMR Facility wing as 8.7E-06/yr. This is consistent with a frequency category IV event (i.e., $\geq 10^{-6}$/yr to $<10^{-4}$/yr). The calculated total annual impact frequency (summed over all aircraft categories) is compared to the impact frequency EG (10^{-6} per year) provided in DOE-STD-3014-2006, *Accident Analysis for Aircraft Crash into Hazardous Facilities*.

The referenced calculation provides all the major assumptions that went into the frequency model. Assumptions concerning Los Alamos Airport operations from the calculation are as follows:

• 1,500 Air Taxis per year,
• 15,000 Local General Aviations per year,
• 3,500 Itinerant General Aviations per year, and

• The number of military aircraft operations at the Los Alamos airport is conservatively used for each of the 3 military aircraft types (large, small high-performance, and small low-performance) that DOE-STD-3014-2006 evaluates. This value is estimated as 95 military aircraft operations per year.

The total MAR of 6,000g ^{239}Pu equivalent material in Wing 9 is bounding for all wings.

Source Term Analysis

MAR

The bounding MAR for Wing 9 is 5,000g ^{239}Pu equivalent material as non-reactive powder within an opened BG (Bolas Grande) Sphere or, packaged material within the Wing 9 general area. Additionally, 800g ^{239}Pu equivalent material is assumed to be present as unpackaged material in any form within the Wing 9 hoods. The MAR associated with this accident scenario also includes the holdup associated with the wing. The holdup is expected to be no more than 200 g ^{239}Pu equivalent in the form of non-reactive powders. As such, up to 6,000g ^{239}Pu equivalent material is involved in the event.

ARF/RF

Impact Release

DOE-HDBK-3010-94 discusses an airborne release from free-fall spill and impaction stress of powders. The ARF value is consistent with suspension of bulk powder by debris impact and air turbulence from falling objects. The ARF and RF values for this event are 1E-2 and 0.2, respectively. As such, an *ARF x RF* of 2E-3 would apply to any MAR impacted by the event.

Thermal Release

During the subsequent thermal release, it is assumed that the fire causes a pressurized powder release, even though the MAR containers and enclosures are assumed to be significantly damaged by the impact event. DOE-HDBK-3010-94 discusses an airborne release from the venting of pressurized powders at lower pressures, $\leq$ 25 psig. This value is commensurate with the value for accelerated air flow parallel to the surface, which is expected to be the dominant effect for low-pressure venting above powder. The ARF and RF values for powders under these conditions are 5E-3 and 0.4, respectively. Thus, the combined *ARF x RF* is 2E-3 for response of powders to this fire environment. This is also bounding for any other MAR form within Wing 9.

DR

No protection is afforded by the containers outside of that implicitly included in the established *ARF x RF* values. As such, the DR for this ST estimation is 1.

LPF

As the wing is initially damaged by the aircraft impact event, no confinement by facility systems or structures is assumed; therefore, a LPF of 1 is used.

Source Term

The STs for the proposed accident first consider the release of the initial MAR by a structural failure; second, the remaining MAR (initial MAR minus the ST from the previous mechanism and the hold-up) is considered in a release from a fire.

Table 6, ST Assumptions for Aircraft Crash into Wing 9

	MAR (g)	ARF x RF	DR	LPF	ST (g)
Impact	6,000	2E-3	1	1	12.0
Fire for Wing	6,000 -12.0 5988	2E-3	1	1	12.0
TOTAL					24.0

Using the methodology presented previously, the ST for this scenario is 24.0 g ^{239}Pu equivalent material.

Consequence Analysis
Using the methodology presented previously, the unmitigated consequence associated with the release from an aircraft crash is 14.4rem.

Comparison to Guidelines
The bounding dose from the Aircraft Crash involving 6,000g ^{239}Pu equivalent material MAR is 14.4 rem. This dose is below the 25 rem EG but is considered to challenge the EG.

Mitigated
No engineered controls are available to mitigate this accident. Since the event initiates external to the facility, no preventive controls are available for the event.

Summary of SC SSCs, SACs, and TSR Controls
No controls are required to be elevated to SC.

Note: *There are two 2-wing fires considered. One involves wings 7 and 9, the other wings 5 and 9. Both have the same MAR and dose consequences and are presented for consideration.*

Spreading Fire Engulfs Wings 7 and 9

This accident scenario is a spreading fire that initiates within a wing enclosure, laboratory, basement, first floor, or attic space. The initial fire spreads to engulf Wings 7 and 9, which are located directly across the Spinal Corridor from each other. This accident scenario bounds other HA scenarios such as a fire that spreads across the Spinal Corridor to involve both Wings 3 and 5, and a spreading fire that initiates in the Spinal Corridor.

Scenario Development

The fire is postulated to occur within Wing 7 and spreads to Wing 9. The Wing 7 processes typically conducted are analytical chemistry, which involve the use of assorted laboratory equipment, e.g., spectrometers, furnaces, ovens, hot plates, acid digestion vessels. Processes can also use reactive chemicals, and the potential exists for mixing of incompatible chemicals.

A number of reactive chemicals, flammable gases and liquids, and thermal and electrical energy sources are identified for potentially initiating a fire. Additionally, maintenance, modifications, or waste management work activities potentially could initiate a fire.

Localized fire initiation in a wing is considered to be a frequency category II ($< 10^{-0}$/yr to $\geq 10^{-2}$/yr) event based on historical data. A localized fire that spreads to engulf a wing is considered to be a frequency category III event ($< 10^{-2}$/yr to $\geq 10^{-4}$/yr). A fire of this magnitude could occur if fire protection features fail within the wing, such as the wing Fire Suppression System, combustible loading controls, and/or Fire Protection Program elements (e.g., control of ignition sources, etc.). These types of fires are a much lower frequency correlating with a progression from initiating a fire to growing to involve the initial wing, and to threaten the Spinal Corridor and the adjacent wing.

Source Term Analysis

MAR

The bounding MAR for this scenario is the total MAR associated with two operating wings. The bounding MAR for Wing 7 is 3,800g ^{239}Pu equivalent material in any form, which is assumed to reside in the wing enclosures. The bounding MAR for Wing 9 is 5,000g ^{239}Pu equivalent material as non-reactive powder within an opened BG Sphere or, packaged material within the Wing 9 general area. Additionally, 800g ^{239}Pu equivalent material is assumed to be present as unpackaged material in any form within the Wing 9 hoods. The MAR associated with this accident scenario also includes the holdup associated with these two operating wings. The holdup is expected to be no more than 200 g 239Pu equivalent in the form of non-reactive powders for each operational wing. Therefore, the total MAR associated with this scenario is 10 kg ^{239}Pu equivalent.

ARF/RF

In Wing 7, unpackaged MAR may be present within enclosures in any form, including powders, solutions, and metals. Both the low pressure venting of powder releases and the boiling solution release are deemed applicable to unpackaged MAR in the Wing 7 and Wing 9 fires (i.e., MAR located in the wing CVD workstation, gloveboxes and/or hoods). DOE-HDBK-3010-94 discusses an airborne release from the venting of pressurized powders at lower pressures, ≤ 25 psig. This value is commensurate with the value for accelerated air flow parallel to the surface, which is expected to be the dominant effect for low-pressure venting above powder. The ARF and RF values for powders under these conditions are 5E-3 and 0.4, respectively. DOE-HDBK-3010-94 also discusses boiling (bubbles continuously breaking the surface of the bulk liquid with < 30% of the volume of the liquid as bubbles) of aqueous solutions in flowing air. The ARF and RF values for solutions under these conditions are 2E-3 and 1.0, respectively. Thus, the combined *ARF x RF* is 2E-3 for response of solutions or powders to this fire environment.

In Wing 9, the MAR involved in the event is within an opened BG (Bolas Grande) Sphere containing up to 5,000g ^{239}Pu equivalent material, or in closed containers. The debris in the sphere is assumed to be consistent with nonreactive powders. DOE-HDBK-3010-94 discusses dispersability of powders that were measured by heating nonreactive plutonium oxide particles in the presence of airflow. The ARF and RF values for thermal stress of these powders are 6E-3 and 0.01, respectively. However, a more conservative RF of 0.1 is used per the handbook if the amount of respirable material originally present in the source MAR is not known. Thus, the combined *ARF x RF* value is 6E-4 for BG Sphere MAR. This is also bounding for packaged MAR in the Wing 9 general area that is not associated with a BG Sphere. The ARF/RF values for packaged MAR are consistent with thermal stress of contaminated combustible materials heated or burned in packages with largely non-contaminated exterior surfaces, which are 5E-4 and 1.0, respectively.

An additional 800g of ^{239}Pu equivalent material is assumed to be present as unpackaged MAR within a Wing 9 hood. This MAR may be in the form of powders or solutions, both of which have a combined *ARF x RF* value of 2E-3, as previously discussed.

The wing holdup involved in the fire event is considered to be in the form of non-reactive powders. These ARFs were measured by heating nonreactive plutonium oxide particles in the presence of airflow. The ARF and RF values for non-reactive powders under thermal conditions are 6E-3 and 0.01, respectively. However, a more conservative RF of 0.1 is used per the handbook if the amount of respirable material originally present in the source MAR is not known. Thus, the combined *ARF x RF* is 6E-4 for the response of the holdup in this fire environment.

DR

No protection is afforded by the containers outside of that implicitly included in the established ARF X RF values. The DR for this scenario is conservatively assumed to be 1.

LPF

No confinement by facility systems or structures is assumed; therefore, a LPF of 1 is used.

Source Term

The total ST released will be used to determine the dose consequences. This methodology is provided in the following tables.

Table 7, ST Assumptions for Wing 7 Fire

Description	MAR (g)	ARF x RF	DR	LPF	ST (g)
Unpackaged MAR, any form	3800	2E-3	1	1	7.6
Holdup	200	6E-4	1	1	0.1
TOTAL					7.7

Table 8, ST Assumptions for Wing 9 Fire

Description	MAR (g)	[ARF x RF]	DR	LPF	ST (g)
BG Sphere MAR and/or packaged MAR	5000	6E-4	1	1	3.0
Unpackaged MAR – any form	800	2E-3	1	1	1.6
Holdup	200	6E-4	1	1	0.1
TOTAL					4.7

Using the methodology provided in DOE-STD-3009, the combined unmitigated ST for the two wing fire is 12.4g ^{239}Pu equivalent material.

Consequence Analysis
Using the methodology provided in DOE-STD-3009, the unmitigated radiological dose consequence associated with the release from a Wing 7 fire is 4.6 rem. The unmitigated radiological dose consequences associated with the release from a Wing 9 fire is 2.8 rem. Therefore, the combined dose consequence for a two wing fire is 7.4 rem.

Comparison to Guidelines
The bounding unmitigated dose from the two wing fire involving 10 kg ^{239}Pu equivalent material MAR is 7.4 rem. This dose is considered sufficient to challenge the 25 rem EG. However, this dose consequence can be mitigated to 4.6 rem when credit is given to the controls listed in Table 9.

Mitigated
A single wing fire is assumed to occur after one or more fire protection features within the wing have failed, such as the Fire Suppression System and its associated combustible loading controls. Therefore, limited (if any) credit can be taken for these features to subsequently mitigate a wing to wing fire progression event. However, regardless of the operability of the Fire Suppression System and other wing controls, a wing to wing fire event can be mitigated by limiting the fire to the wing of origination. The Spinal Partitions, including the Vertical Rise of Building Walls through the roof, limits fire spread potential from the involved wing into the Spinal Corridor. The very low combustible-loading in the Spinal Corridor provides further assurance of minimal fire extension and ensures that fire spread from the Spinal Corridor to the wings is not a credible event.

When these features are credited, the fire is limited to Wing 7, and the dose consequence is reduced to 4.6 rem.

Summary of SC SSCs, SACs, and TSR Controls
Controls needing an elevation to a SC designation are shown in Table 9.

Table 9, SC SSCs and SC SACs for Two-Wing Fire

SSCs	Description of SSC Function
Spinal Partitions	Spinal Partitions ensures walls exist to prevent the spread of fire by convection or radiation.
Spinal Corridor Spacing	Spinal Corridor Spacing ensures a separation distance between opposing wings across the Spinal Corridor exists to prevent the spread of fire.
Vertical Rise of Building Walls	Vertical Rise of Building Walls provide a partial fire break to retard fire spread from the Spinal Corridor to the wings across the Facility roof.
SACs	**Description of SAC Function**
Combustible Loading Control	The Combustible Loading Control controls combustible material in the Spinal Corridor and adjacent rooms (S-Rooms). The control prevents the spread of fire.
MAR Inventory Control	The MAR Inventory Control ensures that the consequences of the event are not exceeded by limiting the amount of MAR present within a Hot Cell bank, wing, area, or the facility.

Spreading Fire Engulfs Wings 5 and 9

This accident scenario is a spreading fire that engulfs both Wings 5 and 9. This fire is different from a wing to wing fire that spreads through the Spinal Corridor, which is evaluated separately.

Scenario Development

The processes typically conducted in Wing 5 use assorted laboratory equipment, e.g., spectrometers, furnaces, ovens, hot plates, etc. To a lesser extent, similar laboratory equipment can also be used in Wing 9. Reactive chemicals, flammable gases and liquids, thermal and electrical energy sources may also be used for processing and present in the wing. These are identified as potential fire initiators. Additionally, maintenance, modification, or waste management activities could initiate a fire.

Localized fire initiation is considered to be a frequency category II ($< 10^{-0}$/yr to $\geq 10^{-2}$/yr) event based on historical data. A localized fire that spreads to engulf a wing is considered to be a frequency category III event ($< 10^{-2}$/yr to $\geq 10^{-4}$/yr). A fire of this magnitude could occur if fire

protection features fail, such as the Fire Suppression System, combustible loading controls, or Fire Protection Program elements. Once the fire engulfs an entire wing, it will spread to the yard where there is no automatic Fire Suppression System, and no credit is given for the building structure or combustible controls in the yard with preventing the spread to an adjacent wing. As such, the likelihood of a wing to wing fire through the CMR yard is a frequency category III event. These types of fires have a much lower frequency, of spreading the fire to the adjacent wing.

Source Term Analysis

MAR

The MAR for this scenario is the total MAR associated with two operating wings. The MAR for Wing 5 is 3,800g ^{239}Pu equivalent material in any form, assumed to reside in wing enclosures. The MAR for Wing 9 is 5,800g ^{239}Pu equivalent material. Up to 5,000g is considered to be unpackaged non-reactive powder as expected from an opened BG Sphere or packaged material. The remaining material is considered to be 800g ^{239}Pu in any form, assumed to reside within Wing 9 hoods. The MAR associated with this accident scenario also includes the holdup associated with these two operating wings. The holdup is expected to be no more than 200 g ^{239}Pu equivalent in the form of non-reactive powders for each operational wing. Therefore, the total MAR associated with this scenario is 10 kg ^{239}Pu equivalent.

ARF/RF

In Wing 5, unpackaged MAR may be present within enclosures in any form, including powders, solutions, and metals. Both the low pressure venting of powder releases and the boiling solution release are deemed applicable to unpackaged MAR in the Wing 5 and Wing 9 fires. DOE-HDBK-3010-94, Section 4.4.2.3.2, discusses an airborne release from the venting of pressurized powders at lower pressures, ≤ 25 psig. The ARF and RF values for powders are 5E-3 and 0.4, respectively. DOE-HDBK-3010-94, Section 3.2.1.3 also discusses boiling of aqueous solutions in flowing air with bubbles continuously breaking the surface of the bulk liquid. The ARF and RF values for solutions under these conditions are 2E-3 and 1.0, respectively. Thus, the combined *ARF x RF* is 2E-3 for response of solutions or powders to this fire environment.

In Wing 9, the MAR involved in the event is within an opened BG Sphere containing up to 5,000g ^{239}Pu equivalent material, or is packaged material. The debris in the sphere is assumed to be nonreactive powders. DOE-HDBK-3010-94 discusses dispersability of powders that were measured by heating nonreactive plutonium oxide particles in the presence of airflow. The ARF and RF values for thermal stress of these powders are 6E-3 and 0.01, respectively. However, a more conservative RF of 0.1 is used per the handbook if the amount of respirable material present in the source MAR is not known. Thus, the combined *ARF x RF* value is 6E-4. This value is considered bounding for MAR within a BG Sphere during the fire event. This is also bounding for packaged MAR in the Wing 9 general area that is not associated with a BG Sphere. The ARF/RF values for packaged MAR are consistent with thermal stress of contaminated combustible materials heated or burned in packages with largely non-contaminated exterior surfaces, which are 5E-4 and 1.0, respectively.

An additional 800g of ^{239}Pu equivalent material is assumed to be present as unpackaged MAR within a Wing 9 hood. This MAR may be in the form of powders or solutions, both of which have a combined ARF x RF value of 2E-3, as previously discussed.

The wing holdup involved in the fire event is considered to be in the form of non-reactive powders. These ARFs were measured by heating nonreactive plutonium oxide particles in the presence of airflow. The ARF and RF values for non-reactive powders under thermal conditions are 6E-3 and 0.01, respectively. However, a more conservative RF of 0.1 is used per the handbook if the amount of respirable material originally present in the source MAR is not known. Thus, the combined *ARF x RF* is 6E-4 for the response of the holdup in this fire environment.

DR

No protection is afforded by the containers outside of that implicitly included in the established ARF x RF values. The DR for this scenario is conservatively assumed to be 1.

LPF

No confinement by facility systems or structures is assumed; therefore, a LPF of 1 is used.

Source Term

A summary of the ST results for each wing is provided in the following tables.

Table 10, ST for Wing 5 Fire

Description	MAR (g)	ARF x RF	DR	LPF	ST (g)
Unpackaged MAR, any form	3800	2E-3	1	1	7.6
Holdup	200	6E-4	1	1	0.1
TOTAL					7.7

Table 11, ST for Wing 9 Fire

Description	MAR (g)	ARF x RF	DR	LPF	ST (g)
BG Sphere MAR and/or packaged MAR	5000	6E-4	1	1	3.0
Unpackaged MAR	800	2E-3	1	1	1.6
Holdup	200	6E-4	1	1	0.1
TOTAL					4.7

The combined unmitigated ST for the two wing fire is the sum from the above two tables, or 12.4g ^{239}Pu equivalent material.

Consequence Analysis

Using the methodology provided in DOE-STD-3009, the unmitigated radiological dose consequence associated with the release from a Wing 5 fire is 4.6 rem. The unmitigated

radiological dose consequences associated with the release from a Wing 9 fire is 2.8 rem. The combined dose consequence for a two wing fire is therefore 7.4 rem.

Comparison to Guidelines
The bounding unmitigated dose from the two wing fire involving 10 kg ^{239}Pu equivalent material MAR is 7.4 rem. This dose is considered sufficient to challenge the 25 rem EG. However, this dose consequence can be mitigated to 4.6 rem when credit is given to the controls listed in Table 3-34.

Mitigated
The mitigation of the fire accident scenario essentially is done by removing the MAR from one of the wings from the fire. To reduce the likelihood of a wing to wing fire through the CMR yard, combustible materials, including wood, roofing tar, combustible insulation (foam insulation, etc.) should be separated a minimum of 10 ft from concrete and glass block walls. Combustible materials should be kept a minimum of 25 ft from the ends of the wing filter towers. This does not include routine delivery vehicles at the loading docks. It is also recognized that routine maintenance, grounds keeping, and other ordinary activities around the building will necessitate temporarily introducing small amounts of combustible materials in these areas. These materials are to be limited to no more than 50 lb of combustible materials in any 100 ft^2 area.

The mitigated radiological dose consequence associated with limiting the fire spread to a single wing is 4.6 rem.

Summary of SC SSCs, SACs, and TSR Controls
Controls needing an elevation to a SC designation are shown in the following table.

Table 12, SC SSCs and SC SACs for Two-Wing Fire (Wing 5 and 9)

SSCs	Description of SSC Function
None	N/A
SACs	**Description of SAC Function**
Combustible Loading Control	The Combustible Loading Control SAC controls the level of combustible material in the CMR Yard. This control reduces the likelihood of MAR being impacted by the fire spread.
MAR Inventory Control	The MAR Inventory Control ensures that the consequences of the event are not exceeded by limiting the amount of MAR present within a Hot Cell bank, wing, area, or the facility.

Outside Fire

This accident scenario involves a fire initiating in the CMR Yard or Loading Dock, which spreads to involve all the MAR within the yard, including MAR in transit, and MAR that is staged in the yard. MAR in transit may include closed BG Spheres, TRU waste containers, and

packaged material shipments in support of programmatic activities. MAR staged in the yard includes low level radioactive waste (LLW) and DCON Spheres.

Scenario Development

It is postulated that this fire event has a variety of causes, including diesel fuel tank leak or rupture, equipment failure or malfunction, vehicle malfunction, and transportation accidents. The ignition of fuel or combustibles is assumed.

The HA identified an uncontrolled frequency for this scenario as a Frequency Category II event ($< 10^{-0}$/yr to $\geq 10^{-2}$/yr) based on historical data. A fire initiated in the yard is postulated to grow and involve combustible material that is present in the yard in the form of vegetation, maintenance, or staging of materials. The yard is not equipped with automatic fire protection features.

The MAR is assumed to be packaged while present in the yard. Although the MAR may be packaged in robust containers such as Type A containers and BG Spheres, no credit is given to the robustness of these features with preventing or mitigating the uncontrolled event.

Source Term Analysis

MAR

During transfer of a BG Sphere, up to 5,000g ^{239}Pu equivalent material may be present in the yard as non-reactive powder. Additionally, up to 1,150g ^{239}Pu equivalent material may also be present in the yard as packaged TRU waste, LLW, DCON Spheres and/or other MAR in transit.

ARF/RF

While all of the material is packaged, the dominant form of material is present in the BG Sphere as debris, which is considered as consistent with non-reactive powder. DOE-HDBK-3010-94 discusses dispersability of powders that were measured by heating nonreactive plutonium oxide particles in the presence of an airflow. The ARF and RF values for thermal stress of these powders are 6E-3 and 0.01, respectively. However, a more conservative RF of 0.1 is used per the handbook if the amount of respirable material originally present in the source MAR is not known. Thus, the combined *ARF x RF* value is 6E-4.

Other packaged MAR in the yard may be present as contaminated combustible materials. Per DOE-HDBK-3010-94 the bounding ARF and RF values for thermal stress of contaminated combustible materials heated or burned in packages with largely non-contaminated exterior surfaces is 5E-4 and 1.0, respectively.

Thus, the *ARF x RF* of 6E-4 is considered bounding for all the MAR within that may be present in CMR Yard during the fire event.

DR

No protection is afforded by the containers outside of that implicitly included in the established *ARF x RF* values. Otherwise, the ST analysis will consider the DR to be 1.

LPF
As an unmitigated analysis, no confinement by facility systems or structures is assumed. Therefore, a LPF of 1 is used.

Source Term
A summary of the ST input assumptions is provided in the following table.

Table 13, Source Term for Outside Fire Scenario

Description	MAR (g)	ARF x RF	DR	LPF	ST (g)
BG Sphere	5,000	6E-4	1	1	3.0
All other packaged MAR	1,150	5E-4	1	1	0.6
TOTAL	6,150				3.6

Using the above inputs and the methodology provided in DOE-HDBK-3010-94, the unmitigated ST for this accident scenario is 3.6 grams.

Consequence Analysis
Using the methodology provided in DOE-STD-3009, the unmitigated radiological dose consequence associated with the release from the 6,150 g with the accident scenario is 2.2 rem.

Comparison to Guidelines
The bounding unmitigated dose from the fire involving 6,150 g ^{239}Pu equivalent material MAR is 2.2 rem. This dose does not challenge the 25 rem EG.

Summary of SC SSCs, SACs, and TSR Controls
Controls needing an elevation to a SC designation are shown in the table below.

Table 14, Summary of SC SSCs, SACs, and TSR Controls for Outside Fire

SSCs	Description of SSC Function
None	N/A
SACs	**Description of SAC Function**
MAR Inventory Control	The MAR Inventory Control ensures that the consequences of the event are not exceeded by limiting the amount of MAR present within a Hot Cell bank, wing, area, or the facility.

Seismic Event with Fire

Earthquakes are natural phenomena that could challenge or involve the entire CMR Facility. A seismic event could also lead to electrical shorts, movement of materials and containers, and disruption of services. It is postulated that the initiation of a fire is an effect of the seismic event.

Scenario Development

A seismic event with a peak ground acceleration significant enough to cause failure of a wing or vault within the CMR Facility is not expected to occur during the lifetime of the CMR facility and is considered unlikely, according to Table 3-4 of DOE-STD-3009-94, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*. The occurrence of an earthquake strong enough to destroy the CMR Facility is considered a Frequency Category III event ($<10^{-2}$/yr to $\geq 10^{-4}$/yr). The occurrence of an ensuing fire that involves all the MAR in the facility is considered to be a Frequency Category IV ($<10^{-4}$/yr to $\geq 10^{-6}$/yr) event in the HA.

This scenario postulates that an earthquake occurs and affects the entire CMR Facility MAR. The design and construction of the wings, main vault, and other structures vary, so each wing or structure may sustain different degrees of damage in a seismic event. The extent of damage to a wing or structure depends on the magnitude of the earthquake and the construction of the wing or structure.

This unmitigated scenario assumes that all confinement systems (e.g., hoods, gloveboxes, exhaust ventilation, etc.) are breached due to failure of walls, supports, falling debris, and collapsing structures during the seismic event. As such, debris impacts from this event are conservatively assumed to result in a release of all the MAR within the facility. This scenario also assumes that utilities and support systems (e.g., electric power, sprinkler system, etc.) fail. A subsequent fire is assumed to occur and involve all uncontained MAR that was released as a result of the seismic impacts. Therefore, no credit is given for any MAR confinement systems during the fire event.

Source Term Analysis

MAR

The entire facility could be affected by a seismic event. The maximum facility inventory limit is 15,150g ^{239}Pu equivalent.

ARF/RF

Impact Release

DOE-HDBK-3010-94, *Airborne Release Fractions/ Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, discusses experiments that investigated the size and weight of the debris used and the fall heights for bounding a number of phenomena in nonreactor nuclear facilities, including seismic vibration and impacts on large confinement structures such as gloveboxes. The "median" values of ARF and RF for all experimental configurations tested were 4E-4 and 0.2 and the highest *ARF x RF* value was 4E-4. Due to the uncertainty in the test conditions, a conservative bounding value for the ARF is assessed to be 1E-2 with a RF of 0.2. This yields an *ARF x RF* value of 2E-3, which is a factor of 5 greater than the largest measured value, a factor of 25 greater than the median, and of the same order as values assessed for accelerated airflow parallel to powder surface and deflagration over relatively unconfined powder.

Thermal Release (Fire)
MAR that is released as a result of the seismic event may be in any form, including powders, solutions, and metals. This material is then subject to the resulting fire. Both the low pressure venting of powder releases and the boiling solution release are deemed applicable to unpackaged MAR in the facility. DOE-HDBK-3010-94 discusses an airborne release from the venting of pressurized powders at lower pressures, ≤ 25 psig. The ARF and RF value for powders is 5E-3 and 0.4, respectively. Although all the MAR in the facility is assumed to be released during the seismic impact, this ARF/RF is provided for comparison to other material forms. DOE-HDBK-3010-94 also discusses boiling of aqueous solutions in flowing air with bubbles continuously breaking the surface of the bulk liquid. The ARF and RF values for solutions under these conditions are 2E-3 and 1.0, respectively. Thus, the combined *ARF x RF* is 2E-3 for response of solutions or powders to this fire environment. This *ARF x RF* is conservatively applied to all the facility MAR for thermal release during the fire subsequent to the seismic event.

DR
No protection is afforded by the containers outside of that implicitly included in the established *ARF x RF* values. The DR for this scenario is conservatively assumed to be 1.

LPF
As an unmitigated analysis, no confinement by facility systems or structures is assumed. Therefore, a LPF of 1 is used.

Source Term
A summary of the ST input assumptions is provided in the following table.

Table 15, Source Term for Seismic Event Followed by Fire

Description	MAR (g)	ARF x RF	DR	LPF	ST (g)
Impact from Structural Collapse	15,150	2E-3	1	1	30.3
Thermal Release from Fire	15,150 -30.3 15,119.7	2E-3	1	1	30.2
TOTAL					60.5

Using the above inputs and the methodology provided in DOE-STD-3009, the unmitigated ST for this accident scenario is 60.5 g.

Consequence Analysis
With the above source term of 60.5 g from a seismic event with fire, and using the methodology defined in DOE-STD-3009, the unmitigated consequences to the MEOI associated with an unmitigated release from an earthquake and fire is 36.3 rem. Note that should a fire not occur, the source term from just the seismic event is approximately ½ that of the seismic event with fire. The consequences from just a seismic event would then be approximately 18.2 rem.

Comparison to Guidelines
The bounding dose from the Seismic Event with Fire involving 15,150g ^{239}Pu equivalent material MAR is 36.3 rem. This dose exceeds the 25 rem EG. For just the seismic event alone, with no fire, the consequences of 18.2 rem do not exceed the EG.

Mitigated Consequences
Due to the age of the facility there are no credible engineered controls available for mitigation after the event. Therefore, the mitigated consequences remain at the level slightly above the EG at 36.3 rem to the MEOI. The Emergency Management Program exists to reduce doses to workers and to the public through notification and appropriate response.

Summary of SC SSCs, SACs, and TSR Controls
Controls needing an elevation to a SC designation are shown in the table below.

Table 16, Summary of SC SSCs, SACs, and TSR Controls

SSCs	Description of SSC Function
None	N/A
SACs	**Description of SAC Function**
MAR Inventory Control	The MAR Inventory Control ensures that the consequences of the event are not exceeded by limiting the amount of MAR present within a Hot Cell bank, wing, area, or the facility.