DRAFT
SUPPLEMENT ANALYSIS:
PIT MANUFACTURING FACILITIES
AT LOS ALAMOS NATIONAL LABORATORY,
STOCKPILE STEWARDSHIP AND MANAGEMENT
PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT

June 1999

SUMMARY

The 1996 Department of Energy (DOE) Stockpile Stewardship and Management (SSM) Programmatic Environmental Impact Statement (PEIS) analyzed the environmental impacts of locating an enhanced pit manufacturing[1] capability at either its Los Alamos National Laboratory (LANL) or its Savannah River Site (SRS). In December 1996, DOE issued a Record of Decision (ROD) reestablishing the pit manufacturing mission at LANL. In August 1998, the U.S. District Court for the District of Columbia, while ruling in DOE's favor in litigation challenging the adequacy of the SSM PEIS, directed DOE to take another look at certain new studies regarding seismic hazards at LANL, and to provide a factual report and technical analysis of the plausibility of a building-wide fire at LANL's plutonium facility (PF-4 at TA-55). The Court directed that DOE prepare a Supplement Analysis to help determine whether a supplemental SSM PEIS should be issued to address these studies.

DOE has analyzed the seismic and fire issues in this Supplement Analysis and has concluded that there is no need to prepare a supplemental SSM PEIS to address reestablishing pit manufacturing capability. The seismic studies, although they contain new information, do not provide significant information beyond that considered in the SSM PEIS. The analyses of the plausibility and consequences of building-wide fires indicates that such fires are extremely unlikely to occur and that the consequences would not be greater than those identified through other analyses, including the SSM PEIS. The risk of building-wide fires at TA-55 does not change as a result of adding the pit manufacturing mission to TA-55. Moreover, these risks are very low and represent only a small fraction of the DOE Safety Goal. Through this Supplement Analysis DOE concludes that neither a Supplemental PEIS nor a new EIS is necessary.

INTRODUCTION

Purpose of this Document

This document is a Supplement Analysis prepared pursuant to 10 CFR 1021.314(c) to assist the Department of Energy (DOE) in determining whether to supplement its *Final Programmatic Environmental Impact Statement for Stockpile Stewardship and Management* (DOE/EIS-0236), September 1996 [A.R. No. I-1561][2] (SSM PEIS) by preparing a Supplemental SSM PEIS. This Supplement Analysis specifically addresses the issue of those aspects of DOE's nuclear weapons pit manufacturing capability and capacity that were assigned to Los Alamos National Laboratory (LANL) in the SSM Record of Decision (ROD) (a "pit" is a central component of a nuclear weapon). Site-specific implementation of the SSM pit decision was analyzed in the *Site-Wide*

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[1] For the purposes of this Supplement Analysis, the terms manufacturing and fabrication are synonymous, and defined in the Los Alamos National Laboratory (LANL) SWEIS, Page 2-29. Production is also defined in the LANL SWEIS as fabrication/manufacturing of a relatively large quantity of parts.

[2] All references to "A.R" are to the Administrative Record compiled for the preparation of the Stockpile Stewardship and Management Programmatic Environmental Impact Statement.

Environmental Impact Statement for Continued Operation of the Los Alamos National Laboratory (SWEIS, DOE/EIS-0238, January 1999).

Background - SSM PEIS

Before considering whether the SSM PEIS should be supplemented, this Supplement Analysis addresses background information regarding the PEIS, its purpose, the formulation of issues in the PEIS, and the decisions reached based on the PEIS. This information assists in arriving at conclusions regarding supplementing the SSM PEIS or preparing a new EIS to address pit manufacturing.

The SSM PEIS was prepared in accordance with the National Environmental Policy Act (NEPA) [42 USC 4321 et seq.], the Council on Environmental Quality (CEQ) NEPA implementing regulations [40 CFR Parts 1500 - 1508], and the DOE NEPA implementing regulations [10 CFR Part 1021]. In March 1996 DOE published a Draft PEIS on its nuclear weapons SSM Program [A.R. No. I-1385]; DOE published the Final SSM PEIS in September 1996 [DOE/EIS-0236, A.R. No. I-1561]. The SSM PEIS analyzed at a programmatic level how DOE might carry out its nuclear weapons mission assignments, including alternative locations where DOE might assign various SSM missions. A ROD, based in part on the environmental analyses in the SSM PEIS, was issued on December 19, 1996 [61 FR 68014, A.R. No. I-1606, A.R. No. VII.B-26]. The SSM PEIS and ROD addressed the programmatic decisions facing DOE regarding implementation of its SSM program. A two-tiered NEPA strategy was adopted wherein implementing the programmatic decisions at a site-specific level in many cases would be accomplished through subsequent tiered project-specific NEPA reviews [SSM PEIS Vol. I, Sec. 1.5, p. 1-8; see also SSM ROD, Sec. 3.A.4].

The SSM PEIS and the SSM ROD covered those proposed actions which were the salient decision factors for determining how DOE would implement the SSM program for the foreseeable future. One of the proposals involved “Reestablishing Manufacturing Capability and Capacity for Pit Components” [SSM PEIS, Vol. I, Sec. 2.5.3, p. 2-11]. Capability is the practical ability to perform a basic function, and SSM capabilities are needed independent of future nuclear weapons stockpile sizes. Capacity is the size of the capability; for example, the number of components that could be fabricated at a specific facility over a specific time. The SSM PEIS analyzed the potential capacity at different sites to support a potential nuclear weapons stockpile of various sizes (numbers of weapons) in order to examine the sensitivity of programmatic decisions to transfer weapons manufacturing activities to sites such as LANL [SSM PEIS Vol. I, Sec. 1.1, p. 1-2].

DOE needed to reestablish the capability to produce stockpile-ready pits that was lost in 1992, when DOE ceased plutonium pit manufacturing operations at its Rocky Flats Plant (RFP) (now known as the Rocky Flats Environmental Technology Site) in Colorado [SSM PEIS Vol. I, Sec. 2.5.3, p. 2-11]. The programmatic question addressed in the SSM PEIS and ROD related to pit manufacturing was which DOE site should receive this mission assignment. Programmatic alternatives for locating pit manufacturing alternatives were limited to sites which had some level of technical or facility infrastructure [SSM PEIS Vol. I, Sec. 2.5.3, p. 2-11; SSM PEIS Vol. I, Sec. 3.4.3, p. 3-57]. SSM PEIS alternatives included reestablishing pit capability and capacity at the DOE's LANL; reestablishing the capability and capacity at the DOE's Savannah River Site (SRS); or to continue to rely on the existing capability and capacity at LANL and the DOE's Lawrence Livermore National Laboratory (LLNL). LANL's facility infrastructure is located in several buildings at different Technical Areas (TAs). The three siting alternatives discussed and analyzed in the SSM PEIS were:

- No Action (continue to use existing limited capabilities at LANL and continue to use the limited capability at LLNL to support material and technology development);
- Reestablish pit fabrication at LANL (use existing facilities at TA-55, -3, -8, -50 and -54, and construct some upgrades);
- Reestablish pit fabrication at SRS (use space in existing "hardened" nuclear facilities with extensive equipment and construction upgrades).

The SSM PEIS provided a comparative analysis of the programmatic impacts that would be expected to occur if the pit fabrication capability were to be reestablished at either LANL or SRS, compared against the No Action baseline [SSM PEIS, Vol. I, Section 4.6.3, p. 4-276]. Because construction of new buildings was not anticipated to be needed in order to assign the pit fabrication mission to LANL, notable environmental impacts were primarily limited to those from operations, such as radiological impacts and socioeconomic impacts. If the pit manufacturing mission had been relocated to SRS, some new construction would have been needed [SSM PEIS, Vol. I, Section 4.3.3, p. 4-107]. Appendix A [SSM PEIS, Vol. II, Sec. A.1.5, p. A-28] provided greater detail of the Defense Programs facilities in use at LANL, including the plutonium (Pu) facilities at TA-55 and the Chemical and Metallurgical Research (CMR) Building and Sigma Complex at TA-3, [Table A.1.5-1]. Similar information was presented for SRS [SSM PEIS, Vol. II, Sec. A.1.2, p. A-10]. Appendix A also discussed the specific facilities anticipated to be used for pit manufacturing at LANL [SSM PEIS, Vol. II, Sec. A.3.3.1, p. A-117]; a list of specific facilities (including the Plutonium Facilities (PF) 4 at TA-55 and CMR at TA-3 and type of construction was provided [SSM PEIS, Vol. II, Table A.3.3.1-1]. Appendix A pointed out that if LANL were selected as the pit manufacturing site, the then-current stockpile pit rebuild program at LANL would be absorbed within the pit manufacturing effort since the activity would be the same --only the number of pits would be different (greater) [SSM PEIS Vol. II, p. A-120]. Similar information was provided for SRS [SSM PEIS Vol. II, Sec. A.3.3.2, p. A-124]

The SSM PEIS established that:

- DOE needed to reestablish pit manufacturing capability
- LANL and SRS were the two reasonable alternative sites for pit manufacturing
- There would be no significant difference in the human health and environmental impacts of locating this program at either LANL or SRS
- Site-specific implementation of the pit manufacturing mission would be further analyzed in subsequent, tiered, site-specific NEPA reviews [SSM PEIS Vol. I, Sec. 1.5, p. 1-8]

In December 1996, DOE issued its programmatic decisions regarding how it would implement the SSM Program. The SSM ROD was based on more than just the environmental analysis of the SSM PEIS. DOE considered "other factors such as DOE statutory mission requirements, national security policy, cost, schedule, and technical risks. Additional technical descriptions and assessments of cost, schedule and technical risk are found in the Analysis of Stockpile Management Alternatives (DOE/AL, July 1996), the Stockpile Management Preferred Alternatives Report (DOE/AL, July 1996)" [SSM ROD, Supplementary Information -- Background]. The technical and cost analyses for production capability and capacity alternatives analyzed in the SSM PEIS were covered in the draft "Stockpile Management Preferred Alternatives Report" [A.R. No. I-1381] and the "Analysis of Stockpile Management Alternatives" [A.R. No. I-1381], both dated February 1996, mentioned in the Final SSM PEIS [see, for example, SSM PEIS Vol. IV, comment response 40.18, p. 3-107]. The analyses in these reports showed that, compared to SRS, locating the pit manufacturing mission at LANL would be lower in cost and have less technical risk because LANL had recent experience in providing pits for nuclear explosive testing [SSM PEIS Vol. IV, comment response 32.03, p. 3-81; 32.06, p. 3-81]. These draft reports mentioned in the SSM PEIS were released in final form in July 1996 [A.R. No. I-1506], following the SSM PEIS and were used by the decisionmaker in determining SSM Program implementation decisions.

The DOE SSM decision regarding reestablishing pit fabrication was:

> ...to reestablish the pit fabrication capability, at a small capacity, at LANL. ... This decision limits the plutonium fabrication facility plans to a facility sized to meet expected programmatic requirements over the next ten or more years. It is not sized to have sufficient capacity to remanufacture new plutonium pits at the same production rate as that of their original manufacture. DOE will perform development and demonstration work at its operating plutonium facilities over the next several years to study alternative facility concepts for larger capacity. Environmental analysis of this larger capacity has not been performed at this time because of the uncertainty in the need for such capacity and the uncertainty in the facility technology that would be utilized. Should a larger pit

fabrication capacity be required in the future, appropriate environmental and siting analysis would be performed at that time.

<u>Mitigation.</u> Specific mitigation measures are not addressed for the stockpile management decisions of the ROD, although many potential mitigation measures are identified in the PEIS. In accordance with the Stockpile Stewardship and Management Program's two-tiered NEPA Strategy, these specific mitigation measures will be addressed, as necessary, on a site-by-site basis, in any site-specific NEPA analyses needed to implement the stockpile management decisions of this ROD. [ROD, A.R. No. I-1606, Sec. 3.A.4]

Judicial Review of SSM PEIS

In May 1997, a coalition of 39 organizations including the Natural Resources Defense Council (NRDC) brought an action in the U.S. District Court for the District of Columbia against DOE for failure to comply with NEPA. The plaintiffs alleged that DOE, among other things, failed "to adequately analyze the environmental effects of, and reasonable alternatives to" the SSM Program [*NRDC v. Peña*, Complaint for Declaratory and Injunctive Relief, May 2, 1997, p. 7]. Plaintiffs sought to enjoin construction of new SSM facilities, as well as major upgrades to mission capability. On August 8, 1997, the Court denied plaintiffs' motion. In January 1998, plaintiffs filed an amended complaint against DOE for alleged failure, among other things, "to prepare a Supplemental [PEIS] based upon significant new information regarding the potential environmental impacts arising from ... the fabrication of nuclear weapon cores, or pits, at [LANL], [*NRDC v. Peña*, Amended Complaint for Declaratory and Injunctive Relief, January 30, 1998, p. 6 - 7]. DOE and plaintiffs subsequently cross-filed for summary judgment on the issue of whether or not a Supplemental PEIS would be required to address four issues: recent studies of seismic risks at LANL; likelihood of plutonium fires such as occurred in the past at RFP; plans for a larger pit production facility; and plans for future use of the National Ignition Facility at LLNL. The parties engaged in extensive, but ultimately unsuccessful, discussions regarding the possibility of settlement. The Court then directed each of the parties to file a draft summary judgment order. DOE's draft order provided that DOE would prepare a Supplement Analysis on implementing pit production at LANL. On August 18, 1998, the Court issued a Memorandum Opinion and Order ("August 18 Order," or "Order"), which denied plaintiffs' motion for summary judgment and granted DOE's motion.

In its August 18 Order, the Court directed DOE to take six actions with regard to plutonium pit fabrication.

1. Prepare, peer-review, and publish by December 31, 1998, the following seismic studies:

   Strategic [Stratigraphic] Survey for Technical Area (TA)-55,
   FY97 Pajarito Trench Study,

Core Holes (Facility Specific) Study
Probabilistic Surface Rupture Assessment for Technical Area (TA) -3

2. Prepare, peer-review, and publish by March 31, 1999, the following seismic studies:

   Strategic [Stratigraphic] Survey for TA-3
   FY98 Pajarito Trench Study

3. Upon completion of the above seismic studies, issue a Supplement Analysis to the SSM PEIS, to contain a technical analysis of whether the information presented in the seismic studies is "significant" within the meaning of NEPA.

4. This Supplement Analysis is also to contain a technical analysis and full factual report on the projected extent to which a building-wide fire at the LANL plutonium facility PF-4 at TA-55 would result in the release of ^{238}Pu and ^{239}Pu. The technical analysis is also to include a re-examination of the plausibility of a building-wide fire under the following three hypothetical circumstances: the propagation of a "glove-box" fire to a building-wide fire; a building-wide fire resulting from a severe earthquake; and a building-wide fire resulting from sabotage.

5. The Supplement Analysis is to be issued in draft form for a 30-day public comment period. After considering the information in the Supplement Analysis and the public comments received, DOE is to determine whether there is a need to prepare a Supplemental SSM PEIS. If DOE determines a Supplemental SSM PEIS is required, it is to be prepared in accordance with 10 CFR 1021.314.

6. A Supplemental SSM PEIS will be prepared prior to taking any action committing to a pit production capability for a capacity in excess of the level analyzed in the SSM PEIS (in other words, fabrication of pits at a rate greater than 50 pits per year under routine conditions and 80 pits per year under multiple shift operations).

ISSUES RELATED TO PIT MANUFACTURING FACILITIES

Overview

This Supplement Analysis has been prepared to help DOE determine whether to supplement that portion of the SSM PEIS which deals with the proposed action to reestablish at LANL a manufacturing capability and capacity for pits. It specifically examines five issues raised through judicial review.

These issues are:

- Implications of recent seismic studies regarding pit manufacturing actions at LANL

- Plausibility of a building-wide fire at LANL propagated from a glovebox
- Plausibility of a building-wide fire at LANL resulting from a severe earthquake
- Plausibility of a building-wide fire at LANL resulting from sabotage
- Extent to which a building-wide fire at LANL would result in the release of plutonium

The Supplement Analysis also examines the following issue not identified through judicial review;

- Extent to which a building-wide fire could result in consequences to the General Public, and implications for siting the pit fabrication mission.

This section describes in more detail these six issues examined in this Supplement Analysis. First, it describes and defines certain facilities and certain terms to allow a better understanding of the discussion of issues.

Explanation of Terms

"Pit Manufacturing": The SSM PEIS analyzed, at a programmatic level, the impacts of locating the pit manufacturing (also known as fabrication) mission at LANL. The PEIS presumed that pit manufacturing activities at LANL would take place in PF-4 at TA-55, which is the main plutonium processing facility at LANL. The PEIS noted that other activities and facilities would be used to support pit manufacturing, such as the analytical chemistry services provided at the CMR Building, at TA-3.

"Plutonium" is an element used in nuclear weapons that has various isotopic forms. "^{238}Pu" is an isotopic form used for Radioisotopic Thermoelectric Generators (RTGs), which are used to power deep space craft and for other uses. "^{239} Pu" is an isotopic form used in the manufacture of nuclear weapons pits. "Weapons grade plutonium" is plutonium in which the abundance of fissionable isotopes of plutonium is high enough that the material is suitable for use in thermonuclear weapons. As used in this document, a "pit" is the central core of a nuclear weapon containing weapons grade plutonium and/or other materials [SSM PEIS, Vol. I, Figure 1.3.2-1.; Glossary].

"Material-at-risk" (MAR) is the amount of material, such as radionuclides, available to be acted on by a given physical stress. For facilities, processes, and activities, the MAR is a value representing some maximum quantity of material present or reasonably anticipated for the process or structure being analyzed.

"Source term" refers to that fraction of radioactive materials present in a building that would be released in the event of an accident.

“Gloveboxes” are specialized pieces of equipment used for working with hazardous or radioactive material such as plutonium, and are comprised of an airtight box with a closed filtration system. A glovebox has thick air-tight gloves to allow a worker to manipulate material without directly touching it [SSM PEIS, Vol. I, Glossary, p. 9-9].

“Seismic hazard” is a description of the potential for dangerous earthquake related natural phenomena such as ground motion (also known as ground shaking) or fault rupture. Ground motion is represented by horizontal as well as vertical accelerations. These accelerations are forces that shake buildings or other structures. Depending on the motions induced in the buildings, structural damage or failure may occur. A fault rupture is permanent ground displacement. If the displacement is sufficient, structural damage to a building may occur.

“Slip rate” is an indicator of the frequency of movement on individual earthquake faults or amount of movement per year. The higher the slip rate, the more movement there is that needs to be accommodated by the fault over a period of time. If the rate of movement is higher, the more likely that earthquakes with damaging ground motion could occur.

“Frequency” is the probability, or chance, that in any given year a particular event could occur. A frequency of “10^{-6} per year” states the chance in any particular year that a given event could occur. In this case, this can also be expressed as the probability that one such event could occur every 1 million years.

“Return period” is commonly used to express the mean time period between events such as between ground motions of a particular amplitude, or between earthquakes of a particular magnitude. “Recurrence interval” is another common term used to express the mean time period between earthquakes of a given magnitude.

“Sabotage,” as used in this document, means deliberate acts intended to damage or disable safety and security systems.

Issues Raised Through Judicial Review

This Supplement Analysis examines in detail the following five issues, as required by the August 18 Order.

1. **Implications of recent seismic studies regarding conducting pit manufacturing actions at PF-4, TA-55 and CMR, TA-3.** LANL has completed and DOE has reviewed seven separate studies on seismic conditions in the vicinity of TA-55 and TA-3. These studies are summarized in Appendix A of this Supplement Analysis and incorporated by reference. As described in Appendix A, one of the six studies listed in the August 18 Order was divided into two separate studies, yielding a total of seven completed studies. Five of the studies were completed prior

to issuance of the LANL SWEIS; a summary of these studies is included as Appendix I of the LANL SWEIS. At issue is whether these seven studies present significant new information bearing on the suitability of TA-55 to receive and CMR to support pit manufacturing mission assignments, hence whether the SSM PEIS should be supplemented.

2. **Plausibility of a building-wide fire at PF-4, TA-55, propagated from a glove-box.** LANL has completed and DOE has reviewed a technical analysis setting forth the projected extent to which a building-wide fire initiating in a glove-box in PF-4 at TA-55 could result in the release of ^{238}Pu and ^{239}Pu. The technical analysis is included in Appendix B of this Supplement Analysis. Based on this technical analysis DOE reexamined its previous determinations regarding the plausibility of this type of fire disrupting operations at TA-55.

3. **Plausibility of a building-wide fire at PF-4, TA-55, resulting from a severe earthquake.** LANL has completed and DOE has reviewed a technical analysis setting forth the projected extent to which a fire in PF-4 at TA-55, resulting from a severe earthquake, could lead to a building-wide fire and result in the release of ^{238}Pu and ^{239}Pu. The technical analysis is included in Appendix B of this Supplement Analysis. Based on this technical analysis DOE reexamined its previous determinations regarding the plausibility of this type of fire disrupting operations at TA-55.

4. **Plausibility of a building-wide fire at PF-4, TA-55, resulting from sabotage.** LANL has completed and DOE has reviewed a technical analysis, derived from the Design Basis Threat Policy, on the plausibility of a building-wide fire in PF-4 at TA-55 resulting from sabotage.

5. **Extent to which a building-wide fire at PF-4, TA-55, would result in the release of plutonium.** LANL has completed and DOE has reviewed a technical analysis on the projected extent to which a building-wide fire in PF-4 at TA-55 would result in the release of ^{238}Pu and ^{239}Pu. The technical analysis is included as Appendix C of this Supplement Analysis.

Other Issues

This Supplemental Analysis also examines a sixth issue, not required by the August 18 Order:

6. **Extent to which a building wide fire would result in consequences to the general public surrounding TA-55 and implications for siting the pit manufacturing mission**. DOE has reviewed site-specific information from the LANL SWEIS to estimate the consequences of a release of ^{239}Pu or ^{238}Pu, calculated under issue 5, and has analyzed whether this information should affect its decision to re-establish the pit manufacturing mission at LANL.

PRIOR ANALYSES OF PIT MANUFACTURING MISSION

Overview

Establishing a pit manufacturing capability at LANL has been analyzed in three recent NEPA reviews. The mission to manufacture pits at LANL was established through the 1996 SSM PEIS, as discussed above. In March 1998, DOE prepared a Supplement Analysis which addressed, in part, the SSM PEIS analysis of the pit manufacturing mission. In January 1999, DOE issued the final LANL SWEIS which addressed, among other things, implementing the pit manufacturing mission at LANL.

Pit Manufacturing in SSM PEIS

The 1996 SSM PEIS analyzed the programmatic question of where the DOE could reestablish the capability to produce pits for the nation's nuclear weapons stockpile. That mission assignment had been carried out at DOE's RFP since the early 1950's; as described above, in 1992, DOE lost the RFP capability to manufacture pits. Along with the No Action Alternative of continuing to utilize existing capabilities at both LANL and LLNL, the SSM PEIS analyzed two siting alternatives: LANL and SRS. LANL had maintained the ability to produce limited numbers of prototype pits for design, research and development, or surveillance purposes. Because of that on-going capability, because LANL already had the facility infrastructure needed to work with plutonium, and because of less technical risk overall, LANL was identified in the SSM PEIS as the preferred site for the pit mission and was eventually selected for that mission through the 1996 SSM ROD. The SSM PEIS analyzed a base capacity of up to 50 pits per year, with a surge capacity of up to 80 pits per year if multiple work shifts were used. The SSM ROD assigned the pit manufacturing mission to LANL based on that production rate and stated that if a larger capacity were ever needed, DOE would readdress the question through follow-on NEPA reviews (see ROD excerpt, above).

At issue here is whether the studies provide significant new circumstances or information relevant to environmental concerns and bearing on the proposed action or its impacts. Seismic hazards were considered in the SSM PEIS, which noted that "During implementation and operation of the new functions, seismic activity in the area could pose a potential hazard to the facilities and personnel at LANL. Modifications of site facilities to accommodate new pit fabrication functions would take into account the moderate seismic risk in the LANL area. All facilities would be designed for earthquake-generated ground accelerations in accordance with DOE O 420.1 and accompanying safety guides." [SSM PEIS, Volume I, Chapter 4, Section 4.6.3.5, p. 4-289]. Thus, the overall seismic hazard was considered in the context that it can be controlled within the design of the existing buildings and the implementation of the mission in accordance with DOE policy and safety guides. The manner in which any site implements the pit production mission may be different, particularly because of the details of its seismic hazards, but the overall risk of implementing the mission would remain consistent with the DOE's safety guide for protection of the public regardless of the site selected. In such a context, seismic risk posed by the alternatives was not a distinguishing feature for making the siting decision. The specifics of the seismic hazards that were considered for the SSM PEIS will be dealt with in the following discussion.

The SSM PEIS also considered representative accidents to develop the impact estimates for siting the pit program at LANL. Overall the accidents associated with the pit manufacturing program would be expected to have a statistical risk of one fatal cancer to a member of the public approximately every 160,000 years [SSM PEIS, Summary, p. S-38]. These representative accidents included release of radioactive material due to a seismic event at PF-4, TA-55. These accidents did not consider every possible accident, but did consider a spectrum of accidents that represent operations that could be associated with the pit production program. These accidents did not include a building-wide fire because such an event would either be represented or bounded by a different accident scenario. For example, the release of material during a seismic event could bound the possible risk of the release of material during a building-wide fire.
The representative accidents analyzed are associated with pit manufacturing operations. These accidents were analyzed for PF-4 at TA-55, because pit manufacturing activities would be located there. Impacts for accidents associated with other support operations were not analyzed separately, because impacts from these functions occur regardless of whether or not the pit manufacturing program was implemented at LANL. Impacts associated with reconfiguring any site infrastructure would be considered as part of tiered site-specific NEPA analyses.

Pit Manufacturing in SSM PEIS Supplement Analysis

In 1998, as part of the litigation described above, DOE prepared a SSM Supplement Analysis which addressed the SSM analysis and decision leading to establishing the pit manufacturing mission at LANL. The Supplement Analysis considered five issues raised by plaintiffs NRDC et al., and four issues raised by DOE.

- **Issues raised by plaintiffs:**
  Impacts at TA-55, PF-4.
  Connected actions: six projects at TA-55 and TA-3.
  Surge planning scenario: fabricating up to 500 pits per year.
  Safety considerations raised in a December 1997 letter from the Defense Nuclear Facilities Safety Board to DOE.
  Accidents involving ^{238}Pu at PF-4, TA-55.

- **Issues raised by DOE:**

Pit production strategy: formulating a new strategy for implementing pit production at LANL.
CMR construction project management considerations.
CMR safety reviews and organizational changes in 1997 and 1998.
Earthquake faulting studies at LANL: new studies started in 1997.

DOE considered each of these issues in some detail, and for each one, concluded that the information did not warrant preparing a Supplemental SSM PEIS or amending the SSM ROD. The Supplement Analysis was part of the record before the Court in 1998, when the Court granted DOE's motion for summary judgment.

Pit Manufacturing in LANL SWEIS

In January 1999, DOE issued the final LANL SWEIS. This document analyzed the site-specific impacts of implementing the pit manufacturing mission at LANL under the conditions set by the SSM ROD: capacity of up to 50 pits per year under normal mission requirements, with a capacity to surge to 80 pits per year if required. The LANL SWEIS analyzed four alternatives [SWEIS, Vol. I, Chapter 3]:

- No Action (maintain the *status quo*, defined as including the capability and capacity to manufacture up to 14 pits per year);
- Expanded Operations Alternative (identified as the preferred alternative);
- Reduced Operations Alternative;
- "Greener" Alternative, which looked at an emphasis other than the historic weapons-related mission.

Volume II of the Final LANL SWEIS includes project-level analyses for implementing pit production at a level up to 80 pits per year (multiple shifts).

In the final SWEIS, DOE modified the preferred alternative to reflect implementation of the pit production mission in the near term (next ten years) at a capacity of up to only 20 pits per year and a delay implementing the full mission assignment given in the SSM ROD. DOE reiterated that the long-term mission goal remains at 50 to 80 pits per year, and that DOE will continue to examine the means to achieve this goal [SWEIS, Summary, Sec. S.1.3.1; *see also* Vol. II Part B].

The accident analysis in the LANL SWEIS examined representative accidents that either characterize or dominate the risk to the public from site operations. Characterizing accidents includes looking at the type of the accident, the initiator, the materials at risk (MAR), the type of consequences, and the likelihood of the accidents. When evaluating the different alternatives, the accident analysis looked at the ways these representative accidents could change with the alternative or if other representative accident scenarios needed to be included because of the alternative under consideration. The LANL SWEIS concluded that there were negligible differences between the representative accidents for the No Action Alternative and the Expanded Alternative. Thus, the addition of pit manufacturing does not change the types, kinds, consequences, or frequencies of the accidents compared to impacts from ongoing activities that already exist at the site.

ANALYSIS OF ISSUES

Analysis Factors

For each of the six issues outlined above, this Supplement Analysis examines the factors given in the CEQ regulations at 40 CFR 1502.9(c)(l):

> (c) Agencies:
> (1) Shall prepare supplements to either draft or final environmental impact statements if:
> (i) The agency makes substantial changes in the proposed action that are relevant to environmental concerns; or
> (ii) There are significant new circumstances or information relevant to environmental concerns and bearing on the proposed action or its impacts.

Analysis of Issues Raised

1. **Implications of recent seismic studies regarding conducting pit manufacturing actions at PF-4, TA-55, and CMR, TA-3.**

Seven seismic studies have been completed over the past year regarding seismic hazards at certain locations at LANL. These studies provide data for determining site specific slip rates and uncertainty estimates. In the Woodward-Clyde Federal Services Report (Wong (1995)), which supported the SSM PEIS, these slip rates had been estimated based on then-available expert judgment and knowledge about the fault systems and seismic activity in the area. Slip rates are fundamental parameters that are used to determine seismic hazard curves. These seismic hazard curves give the ground accelerations, i.e. the ground motion that can be expected at a specific location, along with the probabilities that those accelerations would occur. These seismic hazard curves are then used as input to predict the response of a building or other structure to this ground motion. The amount of ground motion that would lead to structural damage or other types of building failure can be estimated from this information. The information in the seven recent studies does not indicate any need to revise the seismic hazard curves in the Wong (1995) study.

These recent studies also looked into a separate but related item -- surface rupture, which is another mechanism that can lead to structural damage or failure. Surface rupture generally *occurs on existing faults and is defined as permanent ground displacement. Building cracking and failure can occur if ground displacements are large enough. The studies examined several sites, including TA-55 and TA-3, to determine if faults existed there. At TA-55, there is no evidence of a fault, and therefore surface rupture is not an issue for PF-4. At TA-3, a fault exists under the CMR building. However, a surface rupture at CMR sufficient to cause structural damage (cracking) is at least 20 times less likely than ground motion that could also damage the building. Damaging ground motion, as assessed in the Wong (1995) study, therefore remains the most likely result of a seismic event. Thus, the new studies do not indicate a significant increase in the seismic hazard to buildings at LANL compared to the hazards that were considered in preparing the SSM PEIS.*

LANL recently completed seven studies related to the seismic hazard in the vicinity of TA-3 and TA-55. These studies are listed and summarized in Appendix A, and are incorporated by reference into this Supplement Analysis. The LANL SWEIS also includes a summary of those studies completed prior to its issuance in January 1999 and their relevance to the SWEIS analysis of LANL operations [SWEIS, Vol. I, Chapter 4, Sec. 4.2.2.2, and Vol. III, Part B, Appendix I].

These studies are of issue for this Supplement Analysis because they address the seismic hazard at PF-4, TA-55, and CMR, TA-3. In the SSM PEIS, PF-4 at TA-55 was the proposed site for carrying out the pit manufacturing mission. As the tiering document to the PEIS for this mission, the LANL SWEIS examined options for the site-specific implementation of pit manufacturing at LANL. One option analyzed in the SWEIS looked at using CMR to receive certain on-going activities now occurring in PF-4 in order to make additional space available in the facility for pit manufacturing activities (DOE did not propose to manufacture pits at CMR) [SWEIS, Vol. II, Part II]. However, under the LANL SWEIS Preferred Alternative, DOE would not need to move any existing operations from PF-4 to provide a 20 pit per year manufacturing capacity. Under both the No Action and the Preferred Alternatives, DOE would operate CMR over the next ten years to provide analytical chemistry support for all LANL mission assignments, including pit manufacturing. If the Preferred Alternative is selected, DOE would continue to study its long-term options of providing this type of mission support and implementing a 50 pit per year manufacturing capability (80 pit per year multiple-shift capacity). [SWEIS, Summary, p. S-12].

<u>Seismic Hazards at LANL</u>

The term “seismic hazard” refers to and describes the potential for earthquake-related natural phenomena such as ground motion, surface fault rupture, or ground failure. An earthquake originates as movement along a fault, and, as a result of that movement, seismic waves travel away from the fault. One expression of these traveling seismic waves is ground motion, which can shake buildings and result in damage, particularly if the shaking is strong. Ground motion is generally expressed as a fraction of the acceleration due to gravity, with values larger than 0.1 g (g being the acceleration due to gravity [9.8 meters/second^2] and 0.1 g being one tenth of the acceleration due to gravity) being the point that damage to a building starts. Building construction determines when a building will be affected by ground shaking, but most masonry block construction will experience damage at 0.1 g or greater. Buildings with robust seismic designs can withstand much higher ground shaking.

Seismic hazard studies at LANL have been underway since the early 1990's, and these studies continue today. LANL is located on the Pajarito Plateau within the Rio Grande Rift, a seismically active area in the Western United States. The Rio Grande Rift is considered a potential source of earthquakes. Contained within the Rio Grande Rift are a number of individual earthquake faults which are also potential sources of earthquakes.

The presence of these earthquake faults running under Los Alamos County is well known and well documented. Of interest are three faults in the vicinity of LANL: the Pajarito, Guaje Mountain, and Rendija Canyon Faults. The SSM PEIS acknowledged the presence of these faults, and discussed the known moderate seismic risk at LANL [SSM PEIS, Vol. I, Sec. 4.6.2.5, p. 4-256; Vol. I, Sec 4.6.3.5, p. 4-288; Vol. II, Appendix F, Sec. F.2.3.1, p. F-21, F-22; see also SSM PEIS Vol. I, Glossary, definition of "capable fault," p. 9-3]. Although the new studies take a much more detailed look at certain aspects of the seismic hazard than information available to the DOE at the time the SSM PEIS was prepared, the results of these studies do not indicate a significant increase in the seismic hazard.

At the time the SSM PEIS was prepared, the understanding of the seismic hazard at the LANL site was based on the "Seismic Hazards Evaluation of the Los Alamos National Laboratory" prepared by Woodward-Clyde Federal Services (Wong, (1995))[3] (A.R. No. I-1124/1125 Chapter 1, Reference 21; Declaration of Jeffrey K. Kimball, May 18, 1998, Exhibit 2). The Wong (1995) study included paleoseismic investigations, subsurface geologic investigations and evaluation of the seismicity recorded by LANL, as well as reviews of the historical record and previous seismic hazard investigations. This study continues to be the guiding document for establishing ground motion criteria for the design and evaluation of structures, systems and components at LANL [Wong (1995)].

The objective of Wong (1995) was to perform a state-of-the-art probabilistic seismic hazard assessment. The study recognized that very little data on the faults in the vicinity of LANL was available. Steep topography on the Pajarito fault made field measurements difficult and the Rendija Canyon and Guaje Mountain faults had not been fully characterized. To address uncertainties created by the lack of more complete data on the above faults, the study built conservative assumptions (described below) into the seismic hazard assessment.

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[3] In the document filed in *NRDC v Peña*, the Woodward-Clyde Federal Services study was referred to as Wong (1995).

The frequency of movement on individual earthquake faults can be expressed by a rate of slip, or amount of movement per year. The rate of slip on the Pajarito fault, the largest of the three local faults and thus the fault of most significance to LANL, received particular focus in Wong (1995). Wong (1995) also estimated how often earthquakes of various sizes (expressed as earthquake magnitude) occur on each of the faults in the vicinity of LANL.

Accounting for potential high rates of slip (which result in damaging earthquakes more often) for the Pajarito fault was intentionally considered in Wong (1995) to address uncertainties as a result of geologic field studies undertaken as of that date. While the average rate of slip for the Pajarito fault was estimated to be about 0.1millimeters/year (mm/yr), values as large as 0.95 mm/yr were considered and included in Wong (1995) as conservative assumptions. This was done even though there was no direct evidence that the Pajarito fault had experienced movement in historic times (SSM PEIS, Vol. I, Section 4.6.2.5).

At the time that the PEIS was published there was no evidence that any of the three local faults directly intersected a building site. An earthquake fault that directly intersects a building site and experiences a significant earthquake (above magnitude 6 to 6.5) may damage that building as a result of fault movement or displacement commonly referred to as surface rupture.

In 1997, LANL initiated new studies which focus on the seismic history of the Pajarito fault and the potential for surface rupture at TA-55. In 1998, these studies continued and the surface rupture investigation expanded to include TA-3. For surface rupture, studies have centered on mapping faults in specific technical areas. In addition, a probabilistic surface rupture assessment has been completed for TA-3, once it was judged that TA-3 may be intersected by at least one of the faults in the vicinity of LANL (Rendija Canyon).

As discussed in the following sections, the information from these studies indicate that ground motion is still considered to be the predominant seismic hazard. An event that causes surface rupture is much more unlikely than an event that causes damaging ground motion. There is no evidence of seismic ruptures at the TA-55 location. For TA-3, CMR, damaging ground motion remains the most likely result of a seismic event.

The following discussions summarize the results of the studies and their relevance to the understanding of ground motion and surface rupture at LANL.

Seismic Hazard, Ground Motion Results:

As discussed above, the Wong (1995) study was used to support the SSM PEIS. The results of Wong (1995) for the whole of LANL show that, at a return period of 1,000 years, the ground acceleration is 0.22 g amplitude, while at a return period of 10,000 years the ground acceleration is 0.56 g amplitude. These numbers are essentially a summary of the probabilistic hazard curves that have been developed for LANL. Each facility location has a unique hazard curve based on its distance from the main faults in the area. In general, if a building has a seismic capacity that is approximately equal to 0.22g then its frequency of structural damage (cracking) is $1x10^{-3}$. If a building has a seismic capacity that is on the order of 0.56g then its frequency for structural damage (cracking) is $1x10^{-4}$ (Appendix A, Tables 3 & 4). It is these hazard curves that have been used to establish seismic design and evaluation criteria (level of ground shaking) for LANL facilities [Wong (1995), Executive Summary, p. 5]. As discussed below, these curves continue to be valid given the results of the new studies.

As part of the recent seismic studies at LANL, fourteen trenches have been excavated to study the earthquake history on the Pajarito fault. The purpose of the studies has been to determine when the most recent ground rupturing event occurred on the Pajarito fault, to get a better understanding of recurrence intervals for earthquakes (slip rates), and to help determine if the three main faults (Pajarito, Rendija Canyon and Guaje Mountain) in the Los Alamos area are connected.

The results of these studies (Appendix A, Ref. 3 and 14) show that the Pajarito Fault has moved in historic times. The 1997 work found that the most recent event occurred about 1,500 years ago and the 1998 work found that the most recent event occurred between 2,000 and 12,000 to 20,000 yrs ago. Using this new information, slip rates contained in Wong (1995) have been reviewed. The slip rates based on the 1997 and 1998 trench work have been found to fall within the bounds contained in Wong (1995). In other words, the conservative assumptions made by Wong (1995) properly addressed the uncertainty of historic frequency of earthquakes on the Pajarito fault (see Appendix A). The seismic hazard ground motion results contained in Wong (1995), before the DOE at the time the SSM PEIS was prepared, have not changed as a result of the new geologic studies. The assumptions made and the logic used in the Wong (1995) study are still valid [Wong (1995), Table 7.1].

In order to put the results of the next section dealing with surface rupture into perspective, it is important to understand how the seismic hazard curves from Wong (1995) translate into recurrence intervals for damaging ground motion at specific LANL facilities. In recent studies, DOE used seismic hazard curves from Wong (1995) to assess the seismic structural integrity of both PF-4 at TA-55 and CMR at TA-3. Seismic loads that would collapse the PF-4 building structure at TA-55 were originally estimated for the TA-55 Final Safety Analysis Report, and have been updated for this Supplement Analysis. The median capacity for PF-4 at TA-55 is > 1.0g, and is associated with an annual probability of failure of $5x10^{-6}$ per year (200,000 year recurrence interval). Because PF-4 at TA-55 is a modern building built to withstand seismic events, it can resist earthquake ground motion well beyond its design basis (0.3g) prior to reaching structural collapse. Seismic loads which would collapse the CMR building structure were estimated by Goen (1996). The median capacity for CMR (i.e., the ground acceleration which results in a 50% probability of collapse) is 0.14g, and is associated with an annual failure probability of about $2x10^{-3}$ per year (500 year recurrence interval).

Seismic Hazard Surface Rupture Results:

At the time the SSM PEIS was prepared there was no known surface rupture seismic hazard for TA-55 or TA-3. The recent studies resulted in a better understanding of the seismic surface rupture through the preparation of fault maps for various areas of LANL, including those at TA-55 and TA-3.

Fault mapping in a very detailed manner is possible at LANL in part because of the unique topography: the surficial geologic strata are cut by sheer-sided, deep canyons at frequent intervals, which allows for direct observation of the underlying strata. Approximately 15 canyons dissect the land comprising LANL. These run in essentially parallel lines in a west-northwest to east-southeast direction towards the Rio Grande at the eastern boundary of LANL. Detailed mapping of faults has been completed from a high precision three dimensional survey of the cliff faces, core drilling at specific building or potential building sites, and from review of old aerial photographs which pre-dated current buildings, allowing potential geologic features (such as faults) to be identified.

The fault mapping studies indicate that there is no evidence of existing faults in or near TA-55 (Appendix A, Ref. 1), thus the area is not susceptible to surface rupture from earthquakes. For TA-3, it is evident that faults in the Bandelier tuff (which is about 1.22 million years old) with vertical displacements in the range of 1 to 10 feet are present in some areas (Appendix A, Ref. 13), including one under the CMR Building with a vertical offset of approximately 8 feet (Appendix A, Ref. 4). From the probabilistic assessment of surface rupture in the TA-3 area (Appendix A, Ref. 6), earthquakes that might result in permanent ground displacements which would cause significant cracking in buildings are estimated to have a frequency on the order of 10^{-4} (about once in 10,000 years) (Appendix A, Ref. 3). Earthquakes which would result in permanent ground displacements capable of causing structures to collapse are estimated to have a frequency on the order of $1x10^{-5}$ (about once in 100,000 years) (Appendix A). (The current design basis for DOE non-reactor nuclear facilities is to withstand, without collapse, an earthquake that would be expected to occur about once every 10,000 years.)

The relatively long return period for damaging surface rupture at the CMR site is instrumental in evaluating the significance of the new studies. As mentioned above, at the CMR site, the probability of damaging surface rupture is about $1x10^{-4}$ (10,000 year recurrence interval). In contrast, the probability of damaging ground motion to the CMR Building in its current condition is about $2x10^{-3}$ (500 year recurrence interval). This frequency was based on the probabilistic seismic hazard analysis presented in Wong (1995). Thus, the frequency of damaging ground motion is at least 20 times greater than the probability of damage caused by surface rupture, and dominates the risk of seismic damage. Therefore, the presence of the fault under the building, and the accompanying risk of surface rupture and damaging ground displacement, does not significantly increase the seismic risk at CMR, as that risk was understood during the preparation of the SSM PEIS.

DOE Plans for Pit Manufacturing

Although the new studies provide valuable information regarding the seismic hazard at LANL, this information would not significantly change the outcome of the impact analysis in the SSM PEIS. The current estimations of the collapse of PF-4 at TA-55 gives a frequency of $5x10^{-6}$ which is well beyond its design basis of providing confinement functions at the Design Basis Earthquake. Thus, at TA-55, damaging ground motion does not play a major factor for the structural integrity of the building until frequencies are at or beyond $5x10^{-6}$ (Appendix B, Section 4.4, Table 4.2 & 4.3, Sequence 11). Accidents with the release of radioactive material for TA-55 were considered at a wide range of accident frequencies in the SSM PEIS (10^{-4} to 10^{-7}). Differences of an order of magnitude are within the uncertainty band for these types of events. After reviewing the new seismic studies, DOE still considers that the accidental release of radioactive material due to a seismic event is very unlikely at LANL. DOE believes that PF-4, TA-55 is not at greater seismic risk than originally considered for the SSM PEIS.

The new surface rupture seismic hazard information is most pertinent in relation to the CMR Building. Even here, however, consideration of the new information has not significantly increased DOE's assessment of the resulting seismic risk of structural damage. DOE will continue to operate the CMR Building at LANL to provide analytical chemistry support to the ongoing research and science activities it now supports, including pit manufacturing. In this context, it should be understood that the impacts for operating CMR were considered in the SSM PEIS as part of the No Action Alternative, because CMR was not part of the proposal for the pit manufacturing mission (no pit manufacturing operations would be conducted in CMR). Instead, CMR is part of the LANL infrastructure that is maintained to support all of its missions. The SSM PEIS acknowledged that this infrastructure would be maintained and therefore DOE would not have to establish a new infrastructure at LANL to provide this support.

Support for analytical chemistry will continue at LANL, even though specific decisions on CMR operations may change and DOE may consider alternative means to provide analytical chemistry support in future reviews. DOE may decide, as indicated in the recent SWEIS, that it is not cost-effective to complete the planned seismic upgrades to CMR at this time [SWEIS, Summary, Sec. S.1.3.1, p. S-13; Vol. III, Part B, Appendix I]. If DOE selects the preferred alternative for pit manufacturing in the SWEIS, it will not be necessary to move specific operations from PF-4, TA-55, to CMR to make more dedicated space in PF-4 available for pit manufacturing operations [SWEIS, Summary, Sec. S.1.3.1, p. S-13;Vol. I, Sec. 4.2.2.2, p. 4-29; Vl. II, Part II]. In that case, further evaluation will be considered for implementing pit manufacturing above a capacity of

20 pits per year. However, in any event, support for analytical chemistry operations at LANL will be retained at CMR.

2. Plausibility of a building-wide fire at PF-4, TA-55, propagated from a glove-box.

Appendix B provides details of the probability assessment for a building-wide fire at PF-4, TA-55, propagated from a glove-box fire. The event has been evaluated as the probability that a fire could propagate from a glove-box and spread to engulf the entire facility. The combination of design features, limits on combustible loading, and mitigative features at PF-4, TA-55, make the probability of such an event on the order of $1x10^{-10}$ per year or lower (i.e., once in every 10 billion years). Because the probability of such an event is so remote, the accident is not considered plausible.

PF-4, at TA-55, is the building where DOE has manufactured prototype pits in the past and will manufacture pits pursuant to the SSM ROD. The potential for fire at PF-4 is of interest to DOE because of the need both to protect worker life, health and safety, and to guard against release of radioactive material to the environment. Through the SSM PEIS, DOE considered the incremental impacts of locating the pit manufacturing mission at LANL. The impacts were estimated based on examination of representative accidents for pit manufacturing. These accidents were considered to bound the additional risk of implementing a pit manufacturing mission at LANL. The specific risk of a building-wide fire resulting from a glove-box fire was not shown in detail because it falls within the range of risks presented in the SSM PEIS. The risks established for the pit fabrication mission was one (1) excess latent cancer fatality (LCF) in 160,000 years or $6.2x10^{-6}$ LCF per year [SSM PEIS, Summary, p. S-38].

The SSM PEIS analyzed the incremental environmental impacts and the incremental increase in source term that would occur if the pit manufacturing mission were to be reestablished at LANL. Pit manufacturing operations and the handling of pit materials were proposed to take place in PF-4 alongside other ongoing activities and missions involving special nuclear materials. The SSM PEIS analyzed impacts from accidents as well as impacts from normal operations. One accident scenario analyzed in the SSM PEIS was a fire starting outside of a glove-box that would damage the gloves and result in a release of plutonium [SSM PEIS, Vol. II, Appendix F, Sec. F.2.3.1, p. F-20]. The SSM PEIS concluded that the frequency and the amount of material that would be released would be the same regardless if the pit fabrication mission were reestablished at LANL or SRS [SSM PEIS, Vol. II, Appendix F, Sec. F.2.3.1, p. F-20].

The issue to be examined in this SA is the plausibility of a building-wide fire in PF-4[4]. This result is slightly different than what was considered for the SSM PEIS, since the objective there was to look at only the changed risks that could be incurred due to the implementation of a pit

[4] The consequences of a building-wide fire are examined below in a separate section.

manufacturing mission at LANL. In this analysis the objective is to look at the plausibility of building-wide fire regardless of whether the mechanisms can be associated with pit manufacturing type operations or separate on-going operations. However, since the same operations needed for pit manufacturing currently exist in PF-4, the frequency of a building-wide fire would not increase with the addition of this mission to PF-4.

One way the public could be exposed to the radioactive materials in PF-4 would be if there were a breach in the building structure or the containment for the radioactive materials; one cause of breaching could be a fire. One way that a fire could occur in PF-4 would be from spontaneous combustion of pyrophoric materials (such as plutonium) inside the glove-boxes used to handle the material.

RFP experienced fires in its plutonium handling lines in the 1950's and again in the 1960's; a major fire occurred in 1969. The 1969 RFP fire is discussed in the SWEIS [SWEIS, Vol. I, Sec. 5.2.11.2, p. 5-89; Appendix G, Sec. G.4.1.2, p. G-50]. DOE learned from the RFP experience and incorporated the lessons learned into subsequent design and operating standards for its nuclear facilities. PF-4, at TA-55, was constructed in the 1970's and the design of the facility and equipment such as the glove-boxes took into account the lessons learned from the cause and spread of the RFP fires.

Because plutonium metal is pyrophoric, and subject to spontaneous combustion in certain forms or circumstances, there is a risk of a plutonium fire starting within the glove-boxes used to handle the material. To counter that risk the glove-boxes contain an inert atmosphere, such as argon or nitrogen, which will mitigate the potential for ignition of the plutonium. Other means to counter the hazard of fire include controls on equipment and materials. The glove-boxes are made from metal, glass and plastics that do not easily burn, the plutonium material is kept in containers except when in use, and the amount of combustible material in the glove-box is carefully controlled. PF-4 is robustly designed with many engineered safety features including passive controls (such as firewalls), systems controls (such as alarms) and administrative controls (such as limits on the amount of nuclear material which may be held in any given location and transient combustibles allowed in a given room).

The report, *Probabilistic Analysis of the Potential for Building-Wide Fire in PF-4*, Appendix B, provides a technical analysis of the potential for a building-wide fire at PF-4. The analysis considers the probability of a fire that starts as a small fire inside a glove-box and spreads to a building-wide fire, eventually engulfing all of PF-4. Based on consideration of both the probabilistic analysis presented in Appendix B and of the engineering design and administrative controls in place, the scenario of a building-wide fire at PF-4 starting from a glove-box fire is not a plausible event.

Appendix B used a standard probabilistic accident risk analysis “event tree” model to portray various ways that a fire could progress through PF-4. The “event tree” allows a time-sequence from the initiating event (that is, a fire in a glove box) through intermediate steps (such as “spread to the room,” “spread to a larger area”) to the final event (such as “building-wide fire”). These pathways are called the “accident sequence.” For each “accident sequence,” a probability of occurrence was determined by multiplying the frequency of the initiating event (such as “average number of glove-box fires expected per year”) with the probability for failure or success of each of the intermediate steps (such as the likelihood that a firewall would be breached or otherwise fail). The conclusion of the analysis was that the probability of a building-wide fire starting from a fire inside a glove-box is extremely unlikely, about one chance in approximately 10 billion years ($1x10^{-10}$).

The extremely low probability is due to the fact that a number of barriers have to fail in order for a fire to spread. These include: first, there has to be a failure of administrative limits on the amount of combustible material held in one place to result in enough combustible material to sustain a fire; second, the fire rated walls would have to fail; third, the fire detection system would have to fail; fourth, the fire suppression system would have to fail; fifth, the ventilation system would have to fail; sixth, the corridor spacing is such that it would be extremely difficult for a fire to bridge this gap; and seventh, the barrier wall which separates the two halves of the building would have to fail. Under this scenario there would be no common occurrence or initiating event that would cause failure of all of these systems; therefore the probability of a building-wide fire spreading from a fire inside of a glove-box, regardless of the location of the glove-box within PF-4, becomes vanishingly small.

This analysis concludes (1) that the SSM PEIS analyzed an accident comparable to a building-wide fire at PF-4 resulting from the propagation of a glove-box fire, (2) the frequency of a building-wide fire caused in this manner would not increase with the addition of the pit manufacturing mission and (3) that the probability of such a fire occurring is extremely small. Therefore, the analysis does not provide significant new circumstances or information relevant to environmental concerns, and consequently no supplement to the SSM PEIS is required.

3. Plausibility of a building-wide fire at PF-4, TA-55, resulting from a severe earthquake.

Appendix B provides details of the probability assessment for a building-wide fire in PF-4, TA-55, resulting from a severe earthquake. The event has been evaluated as the probability that a building-wide fire could propagate from random fires or specific room fires resulting from a severe earthquake. The combination of design features, limits on combustible loading, and mitigative features in PF-4 at TA-55 make the probability of such an event on the order of $4x10^{-6}$ per year (i.e., once in every 250,000 years). Because the probability of such an event is extremely unlikely, the accident is not considered plausible.

The release of material in a building-wide fire due to a severe earthquake was not presented in the SSM PEIS, although the PEIS did discuss the known moderate seismic risk at LANL and did consider the potential for accidental release of radioactive materials due to a seismic event [SSM PEIS, Vol. II, Appendix F, Sec. F.2.3.1, p. F-21, F-22]. As noted above under Issue 1, the likelihood of an earthquake strong enough to cause structural collapse of PF-4 is considered to be very low, and recent seismic studies of this area do not indicate that there would be a significant increase in this low probability from that considered in the SSM PEIS.

One way that a fire could occur in PF-4 would be if there were a severe earthquake that resulted in failure of a glove-box, which could expose flammable materials to an ignition source such as a heat source operating at the time of the event. In addition, if an earthquake did result in structural damage to PF-4, there could be sufficient damage to the building or fire suppression systems that it would be difficult to extinguish a fire. Moreover, an earthquake strong enough to cause structural damage to PF-4 would also probably cause damage to roads and disrupt emergency response services.

Appendix B to this Supplement Analysis analyzes the probability of a fire that starts as a result of a seismic event and spreads to a building-wide fire, eventually engulfing all of PF-4. Based on consideration of both the probabilistic analysis presented in Appendix B and of the engineering design and administrative controls in place, the scenario of a building-wide fire at PF-4 arising after a severe earthquake is not plausible.

A standard probabilistic accident risk analysis “event tree” model was used to portray various ways that a fire could progress through PF-4. This model is described above under Issue 2. For a fire starting after a severe earthquake, the “accident sequences” assumed that one or more fire suppression systems fail, and that internal as well as external walls fail. The conclusion of the analysis was that the probability of a fire starting in the aftermath of a severe earthquake spreading to a building-wide fire at PF-4 would be very low, or about one chance in approximately 250,000 years ($4x10^{-6}$).

The low frequency reflects the fact that several failures would have to occur simultaneously to reach the final state of a building-wide fire. In addition to the failure of the integrity of the glove-box, the following would have to happen: there must be an ignition source close enough to flammable materials to start a fire; the fire sprinkler system must fail; and there would have to be a large-scale violation of administrative controls regarding placement of material. On the other hand, these failures were also modeled in a conservative manner. For example, possible ignition sources were considered to be capable of starting a fire 100% of the time even though they are turned off for a significant periods of time during each day. The fire spread was assumed to be independent of the operational status of the ventilation system. If this were analyzed further, the results could possibly increase the combustible loading necessary to sustain and propagate the fire.

Also the heat loading to the fire walls was assumed to be very high; this assumption made the combustible loading higher than would actually be the case if the fire was assumed to grow until it reached a maximum heat load to the fire walls. Because of the conservative assumptions and methods used in modeling this accident scenario along with its low frequency, this event is not considered plausible.

This scenario does not represent a release of materials due to the operation of pit manufacturing. Instead the possibility that the fire could spread is a function of the on-going work at TA-55 that is not associated with pit production work. As indicated in the LANL SWEIS, the addition of the pit production work would not change the frequency (or the consequences) of this event, since the amounts and distribution of material in PF-4 is also not expected to change.

This analysis concludes that the probability of a building-wide fire at PF-4 as the result of a severe earthquake is very small and well within the assumptions of the SSM PEIS regarding seismic events at LANL. Therefore, the analysis does not provide significant new circumstances or information relevant to environmental concerns, and consequently no supplement to the SSM PEIS is required.

4. Plausibility of a building-wide fire at PF-4, TA-55, resulting from sabotage.

A building-wide fire at PF-4, TA-55, resulting from an act of sabotage is not plausible, based on a number of multi-faceted and validated mechanisms that are in place to preclude such an occurrence. These measures include a Vulnerability Assessment (VA) for each nuclear weapons facility consistent with the Design Basis Threat (DBT) Policy for Department of Energy Programs and Facilities, an approved Human Reliability Program for employees, and physical security and access controls that are documented in a facility Site Safeguards and Security Plan (SSSP). In addition, there are periodic Security Surveys, Self Assessments, and Independent Oversight Evaluations to validate compliance with DOE safeguards and security protection requirements. Based on these in-depth preventative measures, no credible adversaries were determined to possess the capability, motive and opportunity to initiate a building wide fire at PF-4.

DOE did not explicitly consider, in the SSM PEIS, impacts resulting from possible acts of sabotage. In developing its overall NEPA policy and program, DOE has acknowledged that these impacts are often the same as, or similar to, the impacts associated with accident scenarios, and are therefore bounded by the analysis in the SSM PEIS. Accordingly, DOE does not attempt to consider them as a separate part of a NEPA impact analysis. In addition, consideration of sabotage would not, in general, help DOE distinguish among alternatives, because the means to protect material against theft, terrorists, and other threats would be similar regardless of the alternative selected. Therefore, there is no sabotage-related scenario analyzed in the SSM PEIS.

DOE facilities could be the focus of many specific threats; and analyses are performed to determine, for each identified threat, the potential adversaries and their likely objectives. DOE Order 470.1, "Safeguards and Security Program," directs all major nuclear facilities to have a current SSSP which includes a VA Report. As part of this process, a comprehensive analysis is conducted of various sets of credible threats to DOE facilities with various types of adversary (e.g., an employee seeking to cause a sabotage event). The result of this comprehensive analysis is the identification of both potential risks and the security measures necessary to ensure that adversaries cannot achieve their objectives. The SSSP contains, at a minimum, current protection strategies, programs, procedures and risk assessments validated through performance testing which is specific to major threats. A formal validation of the SSSP is conducted by the relevant DOE Operations Office in conjunction with the DOE Headquarters Office of Security Affairs and the Program Office to ensure that the Plan adequately addresses all threats, in-depth facility protection elements, corrective actions to mitigate identified vulnerabilities, and reduction of residual risks.

The first stage of the analysis is adversary identification, using the DBT Policy. The current document implementing the policy is the "Design Basis Threat for Department of Energy Programs and Facilities," February 1999. This classified document was coordinated with the Department of Defense (DoD), the Nuclear Regulatory Commission, the DoD U.S. Nuclear Command and Control System Support Staff, and the Federal Bureau of Investigation (FBI). The document was produced in accordance with existing Memoranda of Agreement on Design Basis Threats, and is based upon information provided by the intelligence community, including the Department of Justice, the FBI, the Central Intelligence Agency, the Defense Intelligence Agency, and the Bureau of Alcohol, Tobacco and Firearms. This document identifies, characterizes and estimates the capabilities of a wide range of adversaries including terrorists, white-collar criminals, organized criminals, psychotics, disgruntled employees, violent activists, and intelligence collectors.

Everyone working in PF-4, TA-55, is covered by an approved Human Reliability Program (HRP). Each HRP includes at a minimum, the following elements: an individual security clearance/access authorization, initial and random substance abuse testing, initial and annual medical assessments which may include a psychological evaluation, and an annual supervisory review. The LANL HRP was established in accordance with the requirements of 10 CFR Part 710, and is designed to identify any individuals whose judgment may be impaired by physical or emotional disorders, or substance abuse, including the excessive use of alcohol. The HRP, in concert with DBT provisions and combined other non-HRP elements of a multi-faceted insider threat mitigation program (e.g. personnel security, a materials control and accountability program, administrative procedures, a "two-person rule", an employee assistance program and/or mental health program), greatly reduces the risk of an employee committing a violent act such as sabotage.

Assessments and inspections at the PF-4, TA-55 facility have confirmed that an approved, validated HRP is in place, and is combined with the other defense in-depth elements described above. Personnel with direct access to special nuclear materials (SNM) and unescorted access into the PF-4 Material Access Area (MAA) are covered by the HRP. Other individuals who may require a single access into the MAA are escorted by at least one qualified PF-4 HRP-covered escort at all times. Escorts receive special training designed to ensure that SNM protection elements that are in place to ensure safety and security are not compromised.

Access into the TA-55 Protected Area is through an entry portal under the control and observation of Security Police Officers (SPO's). These portals are equipped with metal detectors, SNM detectors and an X-ray machine. Regular TA-55 employees require a DOE standard badge with a magnetic strip and a personal identification number (PIN) for entry at both vehicle and personnel portals. Employees swipe their badges through a badge reader and enter their PIN. A database verifies the compatibility of the PIN and checks the information on the badge. It also notifies the SPO who is controlling the portal access. The SPO physically compares the picture on the badge with the individual. Only after personnel successfully undergo the entry portal screening checks are they granted access into the Protected Area. Additional screening is required prior to entry into PF-4. Access to the PF-4 MAA is further limited by requirements for a specific access authorization after certification of proper security and safety training.

To achieve a sabotage-related building-wide fire at TA-55, PF-4, an adversary would have to possess characteristics and capabilities regarding personality, training, knowledge, skill levels, etc., that are incompatible with the characteristics and capabilities determined to be credible by the multi-agency intelligence community. For example, an adversary could be postulated to be an insider, but in order to cause a building-wide fire, that insider would have to possess an extensive knowledge of the defeat mechanisms for TA-55, PF-4 plutonium processing, have the ability to overcome the administrative limits for materials in process, have a knowledge of source term effects, and the ability to defeat fire suppressing systems, alarms, propagation barriers, and security procedures, and, notwithstanding the screening mechanisms of the HRP, be prone to violent acts. On this basis a building-wide fire resulting from an act of sabotage is not considered plausible. This analysis does not provide significant new circumstances or information relevant to environmental concerns, and consequently no supplement to the SSM PEIS is required.

5. Extent to which a building-wide fire in PF-4, TA-55, would result in the release of plutonium.

The source term for a building-wide fire in PF-4, TA-55, was assessed to determine the extent of potential plutonium release in a building-wide fire. Appendix C provides a detailed description of the source term analysis. A total source term of 123 g ^{239}Pu dose equivalent was calculated from all operations, with 56 g being associated with ^{238}Pu sources and 67 g being associated with weapons-grade plutonium sources.

The SSM PEIS did consider the extent of radioactive release of material due to various accident scenarios. The amount of material assumed to be released was the potential incremental increase as a result of adding pit manufacturing operations. Thus, in the SSM PEIS the accident analysis assumed the release of an additional 0.61 to 0.63 g of plutonium in an evaluation basis earthquake and a beyond-evaluation-basis earthquake [SSM PEIS, Appendix F, Sec. F.2.3]. In contrast, the analysis in the following discussion applies to material from all of PF-4, including operations not associated with pit manufacturing.

If an accident were to occur, particles that are respirable, 10 μm Aerodynamic Equivalent Diameter or less, could be transported through the air and inhaled into the human respiratory system. Moreover, because the majority of the nuclear materials in PF-4 are alpha emitters, the respirable particles would provide the greatest dose and are therefore of primary interest in determining the potential effects of an accidental release of material. The extent to which plutonium is released from a building wide-fire would best be quantified by the amount of respirable particles released to the environment. This quantity and form of released material is commonly referred to as the "source term."

A number of factors affect the amount of material that could be released during a fire. These factors include the material form, the nature of the accidents, quantities of material affected by the accident and other factors. For these calculations, a best estimate source term was evaluated for a postulated building-wide fire (App C, p. C-2). This means that the calculations were not based on the maximum allowable inventories in PF-4. Rather, they were based on the "expected" values for the materials at risk (MAR) and take into account the mechanisms by which this material could be exposed to the fire.

A technical report on the considerations that went into the source term analysis is presented in "Building-Wide Fire: TA-55/PF-4 Source Term," Appendix C of this Supplement Analysis. The total source term for this analysis is 123 g of ^{239}Pu dose equivalent. The source term comprises 56 g of ^{239}Pu dose equivalent from ^{238}Pu sources and 67 g of ^{239}Pu dose equivalent from weapons-grade plutonium sources.

This source term would include contributions from all available inventory used in or stored in glove-boxes in PF-4. The inventory supports all on-going operations conducted in the facility. The distribution of material in glove-boxes and the average available quantities are not expected to change substantially with pit production. Thus, this analysis represents an "expected" release amount for operating TA-55, including consideration of the modifications for pit production.

6. Extent to which a building-wide fire would result in consequences to the general public surrounding TA-55 and implications for siting the pit manufacturing mission.

The consequences of a building-wide fire at TA-55 have been estimated at 22 to 33 excess latent cancer fatalities (LCFs). No prompt fatalities would be expected from radiation exposure. If the fire were a result of a severe earthquake, fatalities would be expected in the general population as a result of the earthquake itself. Incremental changes in inventories and actual processes due to a pit manufacturing mission at PF-4, TA-55 would be minor. Therefore, the possible incremental increases in either the source term or the consequences would be negligible.

The consequence to the public surrounding TA-55 in the event of an earthquake are estimated to be approximately 22 to 33 excess LCFs. This estimate is based on consequences and source terms provided in the LANL SWEIS, accident scenario “Site-03, Site-Wide Earthquake Causing Damage to All Structures/Internals” [LANL SWEIS, Appendix G, p. G-73 and p. G-99]. By scaling these results, the consequences for a building-wide fire can be estimated. Specifically, the LANL SWEIS concluded that an earthquake of this magnitude would result in the following releases:

Initial Plume

Material	Amount (grams)
^{238}Pu	2.04
^{239}Pu	69.2
^{240}Pu	0.062
^{242}Pu	3.36
HEU	3.74

In Suspension from Material at the Accident Site

Material	Amount (grams)
^{238}Pu	1.95
^{239}Pu	71.2
^{240}Pu	0.3
^{242}Pu	3.22
HEU	3.6

(LANL SWEIS, p. G-72). These quantities are equivalent to a dose that would be received from 1218 g ^{239} Pu[5]. The release of 1218 g ^{239}Pu dose equivalent would result in 111 excess latent cancer fatalities which would be the contribution from TA-55 to the overall estimates of 134 excess LCFs in the Site-03 earthquake [LANL SWEIS, Appendix G, p. G-76]. Thus, the LCFs per gram (^{239} Pu equivalent) is on the order of 0.09 LCF per gram. Using this value, the 123 g (^{239}Pu dose equivalent, Expected MAR value) released during a postulated building wide fire would result in approximately 11 LCF. The transport of material within a buoyant release, such as for a fire, can be two to three times greater than the transport of a non-buoyant release, such as in the case of a seismic collapse. Therefore, for purposes of this analysis, it is assumed that a

[5] The SWEIS calculation of a release of 1218 g ^{239}Pu equivalent is based on a severe earthquake at TA-55. In order to give an upper bound for the possible impacts, the SWEIS analysis assumed that the maximum amount of material allowed by administrative limits would be at risk at the time of the earthquake. In contrast, as discussed in the previous section and also in Appendix C, this Supplement Analysis reflects a more likely "actual" or "expected" amount of material at risk in calculating a 123 g.^{239}Pu dose equivalent as the extent to which a building wide fire would result in the release of plutonium.

building wide fire at TA-55 could result in an additional dose that would lead to 22 to 33 excess LCF's.

No prompt fatalities would be expected from population exposures of this magnitude. An individual latent cancer fatality risk for this accident would be on the order of 7.3×10^{-9} LCF/ year [(33 excess LCF / 18,000 people) x 4×10^{-6} per year = 7.3×10^{-9} excess LCF per individual per year][6]. This value, when compared to the safety goal of 2×10^{-6} LCF/yr, as outlined in the DOE Nuclear Safety Policy (SEN 35-91), represents a very small fraction of the safety goal, about 0.37%.

It is important to note that these consequences are based on the MAR for PF-4, at TA-55, as a whole. This analysis demonstrates that the probability of those consequences occurring are extremely unlikely and therefore the risks are extremely small. However, the key question for a decision on whether to site the pit manufacturing mission is what are the incremental additional impacts of that mission. DOE has consistently maintained that adding the pit production mission will not significantly change the general distribution of material or the amount of MAR in TA-55. The PEIS assumed that adding the pit manufacturing mission would result in an additional release of 0.61g to 0.63 g of plutonium in the event of an earthquake-induced collapse of TA-55, with projected consequences of 0.014 excess LCFs. In preparing the more detailed analysis for the LANL SWEIS, DOE concluded that any difference between the MAR, with and without the pit manufacturing mission, would be nominal and would be well within the day-to-day variance of the amount of material on the floor of the facility and not in the storage vaults. Thus, the analysis for both the LANL SWEIS No Action Alternative (without the additional pit manufacturing mission) and the Expanded Operations Alternative (with the additional pit manufacturing mission) assumed that the same amount of material would be at risk, as controlled by administrative limits for the facility. Therefore, the analysis contained in the SSM PEIS adequately bounded the impacts of a catastrophic accident at TA-55, such as a building-wide fire, in the context of adding the pit manufacturing mission to the facility.

This analysis concludes (1) that the risk of an individual latent cancer fatality as a result of a building-wide fire at PF-4 is very small and (2) that the SSM PEIS adequately bounded the effect which adding the pit manufacturing mission to PF-4 would have on the impacts of such a fire. Therefore, the analysis does not provide significant new circumstances or information relevant to environmental concerns, and consequently no supplement to the SSM PEIS is required.

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[6] The number of excess LCF was estimated for a population within a 80 kilometer (50 mile) radius of TA-55. For purposes of a conservative comparison with the DOE safety goal, this dose has been assigned to the population within a 10 mile radius, approximately 18,000 people, instead of the population within a 50 mile radius, approximately 290,000 people. This conservative comparison is made to ensure that a comparison to the Safety Goal is not unduly biased by lower doses over a larger population at greater distances from the facility.

CONCLUSIONS

In this Supplement Analysis, DOE has considered the new information available from the seven recent seismic studies and has developed more detailed analysis on the potential for building-wide fires in PF-4 at TA-55. This information and analysis has been compared to the environmental impacts that were known at the time the SSM PEIS was prepared to determine if they are significant and would substantially influence the decision to site the pit manufacturing mission at LANL. DOE has reached the following conclusions.

- At the time the SSM PEIS was prepared, the understanding of seismic hazard at the LANL site was based on the conclusions of Wong (1995). The recent seismic studies reaffirmed those conclusions. That is, the slip rates calculated from the recent studies fall within the range of slip rates assumed in Wong (1995).
- Likewise, the Wong (1995) seismic hazard curves developed from the slip rates remain valid for estimating recurrence intervals for damaging ground motion at specific facilities. The ground acceleration with a 50% probability of collapse has a 200,000 year recurrence interval for PF-4 at TA-55, and a 500 year recurrence interval for CMR. (Appendices A and B).
- The recent seismic studies determined that there are no faults in the area of PF-4, and thus there is no risk of surface rupture in the area of PF-4 at TA-55.
- The recent seismic studies determined that there is a fault under CMR, and concluded that the recurrence interval for damaging surface rupture (building cracking) for the facility is at least 10,000 years. However, since this is 20 times less than the probability of damaging ground motion for the facility, the detection of the fault does not significantly alter the risk of damage to CMR from an earthquake.
- A probabilistic risk assessment, based on very conservative assumptions, concluded that the probability of a glove-box fire in PF-4 propagating into a building-wide fire is once in every 10 billion years.
- The same assessment concluded that the probability of a building-wide fire occurring in PF-4 as a result of a severe earthquake is once in every 250,000 years.
- There are sufficient preventative mechanisms in place to preclude an act of sabotage which would result in a building-wide fire in PF-4.
- A building-wide fire in PF-4 would result in the release of small amounts of various isotopes of plutonium, totaling the equivalent of 123 grams of plutonium 239.
- A release of this magnitude as a result of a building-wide fire could lead to 22 to 33 latent cancer fatalities. An individual latent cancer fatality risk for this accident would be approximately 7.3×10^{-9} LCF/year. This is less than one percent of DOE’s safety goal. No prompt fatalities would be expected from population exposures of this magnitude.

This Supplement Analysis also reaffirms the following conclusions germane to DOE’s decision to site the pit manufacturing mission at PF-4, TA-55:

- Manufacturing pits for the U.S. nuclear weapons stockpile will not significantly increase the amount of nuclear materials at risk at any one time in PF-4.
- DOE does not now propose, and has never proposed, to manufacture pits in CMR.
- If DOE implements the preferred alternative of the LANL SWEIS, no operations will be moved from PF-4 to CMR in order to site the pit manufacturing mission in PF-4.

As a result of the information and analysis contained in this Supplement Analysis, DOE has concluded that none of the six issues analyzed in this Supplement Analysis either represent substantial changes to the actions considered in the SSM PEIS, or provide significant new information relevant to the environmental concerns discussed in the SSM PEIS, and therefore that no supplement to the SSM PEIS is required.

APPENDIX A

Implications of Recent Seismic Hazard Studies at LANL

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FIGURES

IMPLICATIONS OF RECENT SEISMIC HAZARD STUDIES AT LANL

1.0 Summary

A number of studies (Table 1) have been completed in the last two years to address seismic issues at Los Alamos National Laboratory (LANL). These studies have focused on the potential for surface rupture at Technical Area (TA)-55 and TA-3 and the seismic hazard in general. For surface rupture, studies have centered around the mapping of faults in and around specific technical areas. In addition, a probabilistic surface rupture assessment has been completed for TA-3. For the seismic hazard, studies have focused on the earthquake history on the Pajarito fault.

Table 1 – Seismic Hazard Studies

Task	Ref.
1) Stratigraphic Survey for TA-55	1
2) FY97 Pajarito Trench Study	3
3) Probabilistic Surface Rupture Assessment for TA-3	6
4a) Core Hole Study at SCC/NISC Site	5
4b) Core Hole Study at CMR Site	4
5) Stratigraphic Survey for TA-3	13
6) FY98 Pajarito Trench Study	14

<u>Surface Rupture</u>

The stratigraphic survey (Ref. 1) for TA-55 found no evidence for existing faults. Thus the area is not susceptible to surface rupture from earthquakes.

The stratigraphic survey for TA-3 (Ref. 13) found faults with vertical displacements in the range of 1-10 feet in 1.22 million year old Bandelier tuff in the TA-3 area. The heaviest concentration of these faults is in the southeast corner of TA-3. This concentration is believed to be defining the southern end of the Rendija Canyon fault. The faults found include one under the Chemistry and Metallurgical Research (CMR) Building (Ref. 4) with a vertical offset of approximately 8 feet.

For non-nuclear facilities at TA-3, surface rupture is not a concern based on the probabilistic study (Ref. 6) and Department of Energy (DOE) guidance (Ref. 11). Designing structures systems and components in the TA-3 area to resist the ground motion caused by an earthquake remains the primary concern when considering the seismic hazard. While surface rupture is not a concern for these structures, siting new facilities over faults with significant vertical offsets should not be done.

For the CMR Building, which is a non-reactor nuclear facility as defined by DOE Order 5480.23, the probability of damaging ground displacement is at or beyond the performance goal for the facility. In its current condition, the probability of damaging ground motion is at least 20 times greater than the probability of damage caused by surface rupture. Therefore, the discovery of the fault under the building does not increase the seismic risk at CMR.

The discovery of a fault under the CMR Building has an impact on decisions concerning upgrades and future uses for the facility. From the seismic perspective, the question which needs to be assessed is whether or not it is prudent to upgrade the structure to resist ground motion loads when the probability of damaging surface rupture is near the performance goal level for the facility. While it is possible to upgrade to resist the displacements caused by permanent ground deformation, the upgrade costs would increase substantially. It should be noted that this site would not be considered adequate for a new nuclear facility.

Seismic Hazard

In the last two years, a number of trenches have been excavated to study the earthquake history on the Pajarito fault. Many aspects of the fault had to be assumed when the probabilistic seismic hazard assessment for Los Alamos (Ref. 2) was complete.

From the 1997 trenches (Ref. 3) it has been determined that the most recent event (MRE) on the Pajarito fault occurred about 1,300 to 2,300 years ago. For the trenches excavated in 1998, the results (Ref. 14) show that the MRE is bracketed by the age of the surface soil, 2,000 years, and the youngest buried soil, 12,000 to 20,000 years. While it is possible to infer that the event found in the 1998 trenches is the same as the most recent event the 1997 trenches at about 2,000 years ago, it can not be conclusively stated because of the large uncertainty indicated by the age span associated with the 1998 trenches.

The slip rate range estimated in the 1997 trench study was 0.06 to 0.21 millimeters/year (mm/yr). The slip rate range estimated in the 1998 trench study was 0.07 to 0.13 mm/yr. The slip rate range used in Reference 2 is 0.01 to 0.95 mm/yr. Thus the data collected in the 1997 and 1998 trench studies are within the parameters assumed in the 1995 probabilistic seismic hazard analysis (Ref. 2). Reference 2 is the basis for the LANL earthquake ground motion used in design of new facilities and in the design of upgrades for existing facilities.

The data gathered in these two studies is not sufficient to conclude whether the Pajarito, Rendija Canyon and Guaje Mountain faults operate in unison or independently during large seismic events. The significance of this information is that the multiple scenarios as to the dependency of the three faults used in the calculation of the seismic hazard in Reference 2 continues to be a valid approach.

2.0 Introduction

Currently, the guiding document for the seismic hazard at the LANL site is “Seismic Hazards Evaluation of the Los Alamos National Laboratory” prepared by Woodward Clyde Federal Services (Ref. 2). Reference 2, issued in 1995, included paleoseismic investigations, subsurface geologic investigations and evaluation of the seismicity recorded by LANL, as well as reviews of the historical record and previous seismic hazard investigations. Ground motion criteria for the design and evaluation of structures, systems and components at LANL are based on this study.

For LANL, the seismic hazard is dominated by the closest sources with the highest likelihood of producing large earthquakes. The Pajarito fault, whose slip rate was estimated to be about 0.1 mm/yr, is the most dominant contributor to the hazard at return periods beyond 1,000 years. Based on minimal information concerning the seismic history on the Pajarito fault, some of the parameters needed for the probabilistic seismic hazard had to be estimated and/or conservatively assumed. In addition, little was known for the potential for surface rupture at specific sites.

In Fiscal Year (FY) 1997, the first two tasks shown in Table 1 were undertaken to better understand the seismic hazard at the Los Alamos National Laboratory (LANL) site. One study was to investigate the possibility of the Rendija Canyon fault extending through TA-55. The other was to investigate seismic history on the Pajarito fault. From preliminary results of these two studies, questions were raised concerning the structural connection of the Pajarito, Rendija Canyon and Guaje Mountain faults, shown in Figure 1, and surface rupture at TA-3. The additional tasks shown in Table 1 were added to help answer these questions.

At TA-55, the study (Ref. 1) found that the Rendija Canyon fault does not run through TA-55 and that the site is free of any observable faulting. The study did find evidence for faulting further to the west, in the vicinity of TA-3. As indicated in Reference 13, a zone of faulting runs south southwest through the eastern part of TA-3 with some cross fault running to the northwest.

On the Pajarito fault, trench studies were conducted to try to estimate when the last event on the fault occurred, to try to estimate recurrence intervals on events for the estimation of slip rates, and to help determine whether or not the Pajarito, Guaje Mountain and Rendija Canyon faults are interdependent. As indicated above, all of these factors were assumed in Reference 2 and physical data is needed to confirm that the assumptions made were valid and conservative. The investigation initiated in FY97 (Ref. 3) has resulted in finding the most recent event on the Pajarito approximately 1,300 – 2,300 years ago and that slip rates were consistent with those assumed in Reference 2. A similar study (Ref. 14) was begun in FY98. The results of this study indicate that the most recent event occurred 2,000 – 20,000 years ago. Although data permit the most recent event to be the same event in both of the two studies, they also allow for different interpretations. The FY98 study agrees with the FY97 study that the slip rate is within the range assumed in Reference 2.

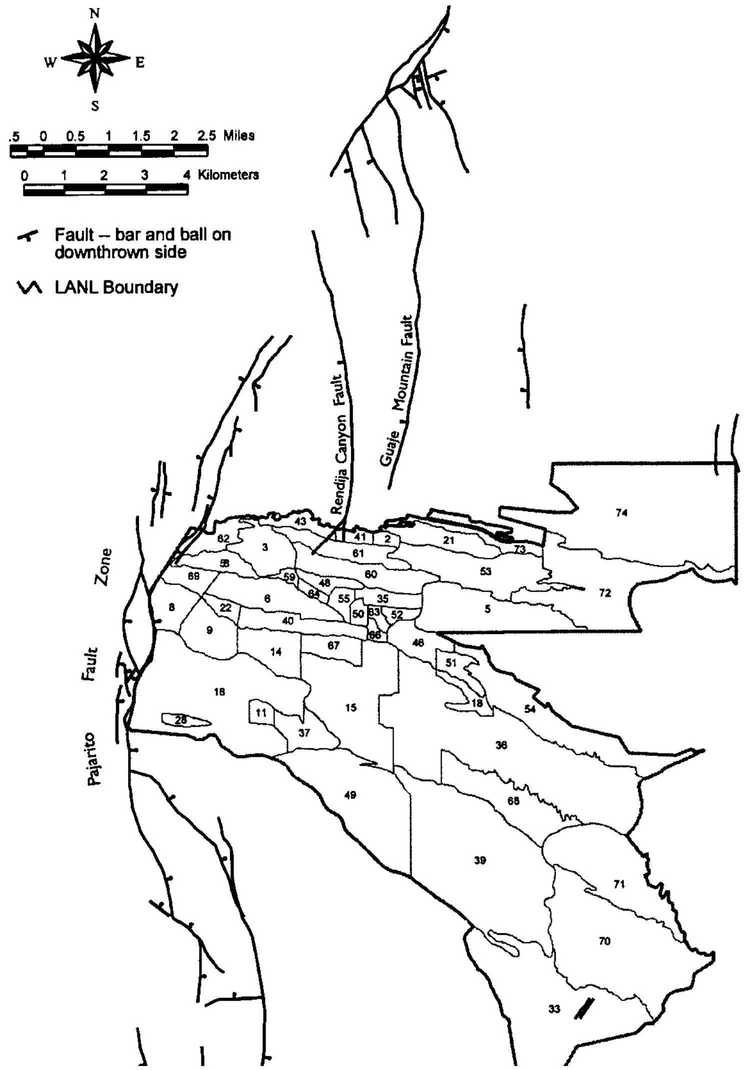

Figure 1 – Major Surface Faults at LANL

In this report, the results of these studies are discussed as well as what the implications are for new and existing construction in TA-3. Findings for individual studies are first presented followed by a summary of DOE seismic requirements. Finally, the impacts on the understanding of the seismic hazard on facilities at LANL, in particular those in TA-3 such as CMR, are presented.

3.0 Findings

The emphasis for work over the last two years falls in two categories: the potential for surface rupture at TA-55 and TA-3, and, investigation of the seismic history on the Pajarito fault.

3.1 Surface Rupture Investigations

Work in this area can be divided into three areas, fault mapping at TA-55 (1st task in Table 1), fault mapping at TA-3 (4th and 5th tasks in Table 1), and probabilistic surface rupture assessment of TA-3 (3rd task in Table 1).

3.1.1 Fault Mapping and Surface Rupture Investigation at TA-55

In Reference 1, results are presented of high-precision geologic mapping in the vicinity of TA-55 that has been done to identify parts of the southern portion of the Rendija Canyon fault, or any other faults, with the potential for seismic surface rupture. To assess the potential for surface rupture at TA-55, an area of approximately 3 square miles that includes the Los Alamos County Landfill and Twomile, Mortandad, and Sandia Canyons has been mapped in detail.

This mapping indicates that there is no faulting in the near surface directly below TA-55, and that the closest fault is about 1500 feet west of the Plutonium Facility. Faulting is more abundant on the western edge of the map area, west of TA-48, near TA-3, in uppermost Mortandad Canyon, upper Sandia Canyon, and at the County Landfill. With the exception of the County Landfill, measured vertical offsets ranged from 1 to 8 feet. At the County Landfill, a distributed zone of faulting over 1000 feet wide with a net down to the west vertical displacement of 30 feet was found. Individual faults within this zone have vertical offsets ranging from 1 to about 15 feet.

3.1.2 Fault Mapping and Surface Rupture Investigation at TA-3

The surface rupture investigation of Reference 1 was expanded to the west to include TA-3. The investigation at TA-3 includes locating and mapping of existing faults using two different methods. One of methods used is high precision mapping employed for the TA-55 study. This method locates the elevations of stratigraphic contacts using total station surveying techniques in exposures around the study area. The other method is the drilling of core holes to locate stratigraphic contacts at specific sites, namely the CMR site (Ref. 4) and the proposed site for the Strategic Computing Center (SCC) and Nonproliferation and International Security Center (NISC) projects (Ref. 5), within TA-3. The entire study of the TA-3 area is documented in Reference 13.

<u>High Precision Mapping at TA-3:</u>

Based on findings presented in Reference 1, the high precision mapping was expanded to include TA-3. The results of this expanded effort are presented in Reference 13. This reference combines the results provided in References 1, 4 and 5 to provide a detailed summary of the faults found from TA-55 to TA-3.

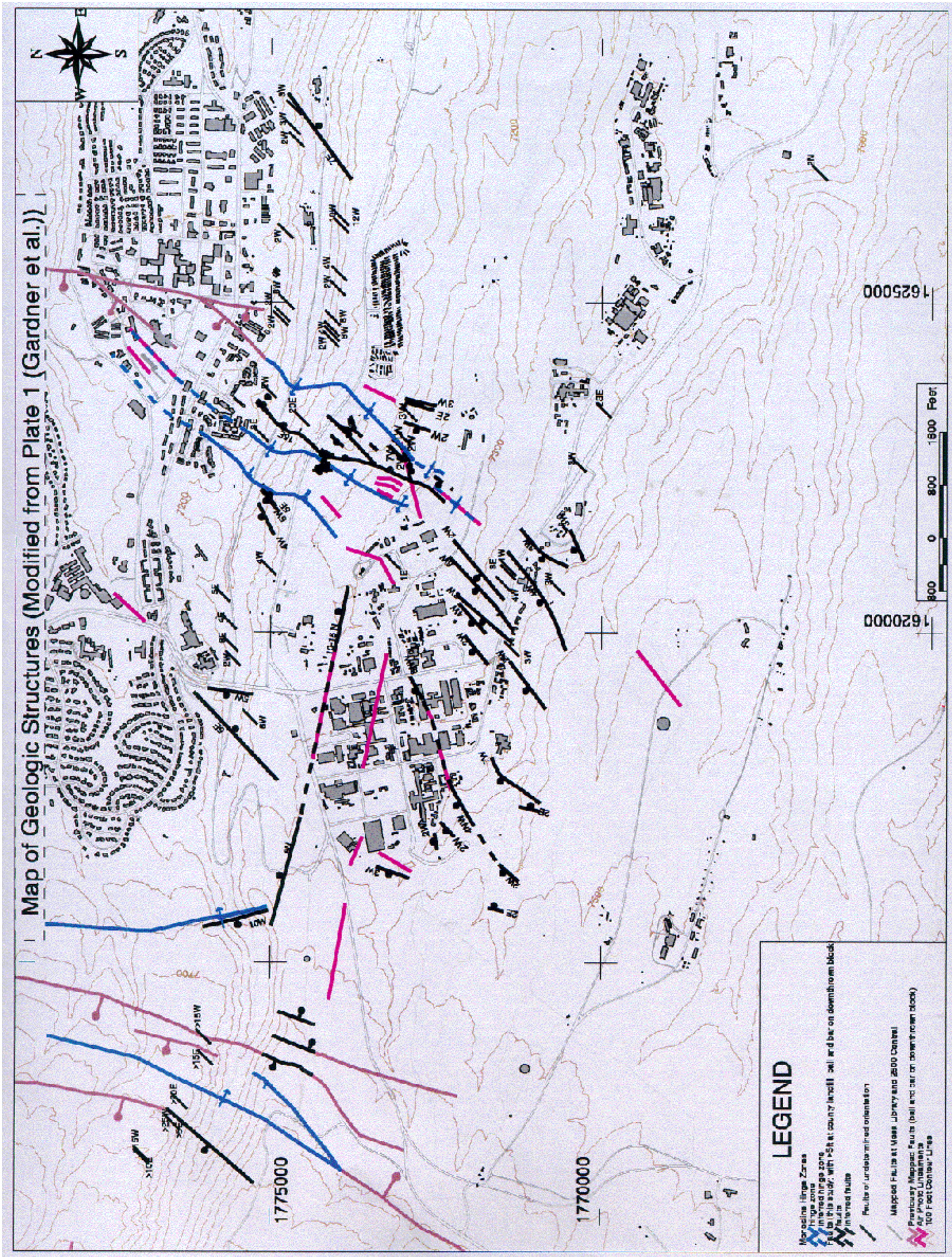

Figure 2 –Map of Fault Location in TA-3 (Reference 13)

Figure 2 depicts the location faults found from TA-55 to TA-3 along with linear features found in the examination of air photos dating to the 1940's. The majority of the faults found lie in the eastern portion of TA-3, trending toward the southwest. The faults form a zone of vertical deformation which appears to be defining the southern end of the Rendija Canyon fault.

The fault zone increases in width as it progresses southward from approximately 2,000 feet at Los Alamos Canyon at the northern edge of the study to approximately 5,000 feet at Twomile Canyon at the southern edge of the study. The net vertical displacement across the zone as well as the amount of vertical displacement across individual faults gets smaller as the faults extend to the southwest. The net displacements decrease from approximately 100 feet at Los Alamos Canyon to less than 30 feet at Twomile Canyon with individual faults being less than about 10 feet. All of the displacements on these faults occurred over the last 1.22 million years.

The linear features from air photos could indicate linear features such as fences trails and roads but could also indicate the location of faults. These linear features were initially used as guides in the data gathering and analysis portions of this study. As can be seen in the figure, some of the lineaments do coincide with faults found in conjunction with this study, while others are located where no evidence for faulting has been found. It should be noted that the one air photo lineament trending to the northwest through the middle of TA-3 has been identified as a fault on the construction drawings for Buildings TA-3-42 and TA-3-200 but could not be verified in this study.

<u>CMR Core Hole Investigation:</u>

At the site of the existing CMR Building, nine closely spaced, shallow holes were drilled. The purpose of the holes was to obtain the cores and to establish the elevation at which contacts between particular layers of the Bandelier Tuff are located. These elevations were then used to develop a contour map at a particular contact. Abrupt changes in the contours might indicate the presence of faulting. The goal of the investigation was to identify faults that may have the potential for earthquake-induced surface ruptures at the site.

Analysis (Ref. 4) of the data obtained indicates that a fault is present at the CMR Building. Its location and inferred orientation are shown in Figure 3. The fault is contained within the core obtained from the CMR-6 and can be inferred to occur between the CMR-2 and CMR-3 locations. This orientation is consistent with one of the air photo lineaments shown in Figure 2 and faults found in Twomile Canyon (Ref. 13). The total displacement of the faulted stratigraphy in the CMR-6 core is approximately 8 feet in the last 1.22 million years.

Based on this investigation, it can be concluded that the CMR Building site has, in the past, been impacted by fault rupture. However, as discussed later in this report, the probability of an earthquake causing significant surface displacement at this site in the future is small.

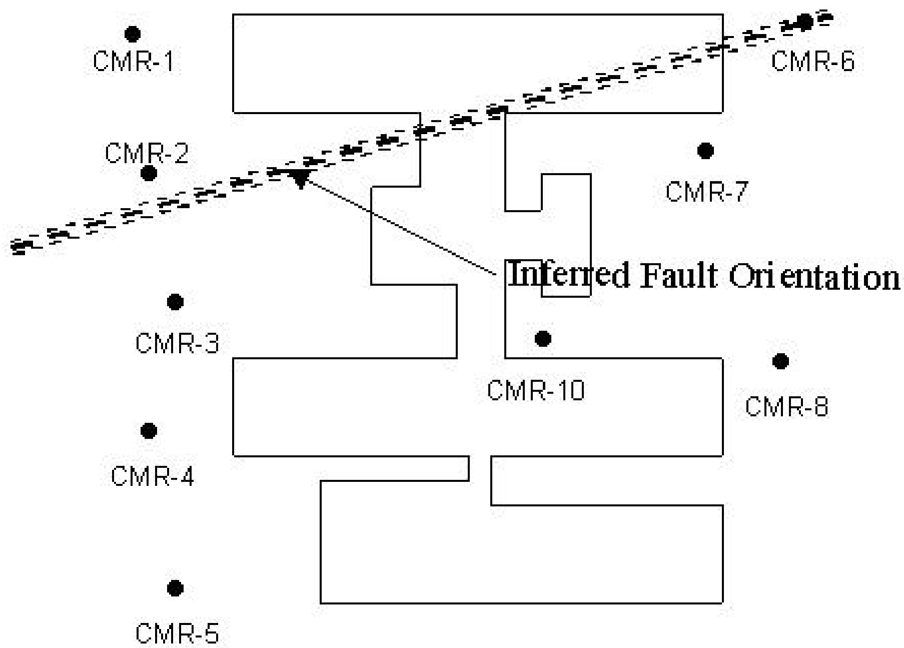

Figure 3 – Plan View of CMR Building With Inferred Location of Fault

<u>SCC/NISC Core Hole Investigation:</u>

At the site proposed for the new Strategic Computing Center (SCC) and the new Nonproliferation and International Security Center (NISC) projects, ten closely spaced, shallow holes were drilled. The purpose of the holes is the same as the holes drilled at the CMR Building.

From analysis (Ref. 5) of the data gathered, there is no evidence for faults under the building sites. Because no significant or cumulative faulting events have disturbed the site in the last 1.22 million years, the age of the Bandelier Tuff, it is unlikely that surface rupture will occur at the site in future large earthquakes.

3.1.3 Probabilistic Surface Rupture Analysis

A probabilistic seismic hazard analysis for potential surface fault displacement at TA-3 has been performed and is described and summarized in Reference 6. The objective of the analysis was to estimate the potential surface rupture hazard posed by the Pajarito fault system, in particular, a possible splay of the Rendija Canyon fault that may transect TA-3. The principal products of this study are probabilistic surface rupture hazard curves for the CMR and SCC/NISC sites. The study focused on these two sites at TA-3 and provides bounding case assessments of the surface rupture potential at each site.

Three different cases were considered in the hazard analysis: (1) distributed faulting only; (2) principal faulting at the CMR site; and, (3) principal faulting at the SCC/NISC site. Principal faulting is faulting occurring along the main plane(s) of crustal weakness responsible for the release of seismic energy during an earthquake. Distributed faulting is defined as rupture that occurs on other faults, shears, or fractures in the vicinity of the principal rupture in response to the principal displacement. The three cases correspond to three different possible scenarios for the southern end of the Rendija Canyon fault. For Case 1, three different hypothetical conditions were assumed: (a) a distributed fault with 9 meters (m) of cumulative displacement in the Bandelier Tuff, (b) a distributed fault with 1 m of cumulative displacement, and (c) a fracture with no observable displacement in the tuff. A total of 15 m of cumulative displacement is assumed in cases 2 and 3.

The results, summarized in Table 2, show that for annual frequencies of 10^{-4} or larger, surface rupture is minimal or nonexistent. The hazard curves developed for the two sites are shown in Figures 4 and 5. Hazard curves that investigate the sensitivity of the three main faults being connected or not are shown in Figure 6.

Table 2 – Probabilistic Surface Rupture Results

Annual Frequency	Case 1a	Case 1b	Case 1c	Case 2&3
10^{-4}	<1 mm	<1 mm	<1 mm	2 cm
10^{-5}	50 cm	20 cm	10 cm	70 cm

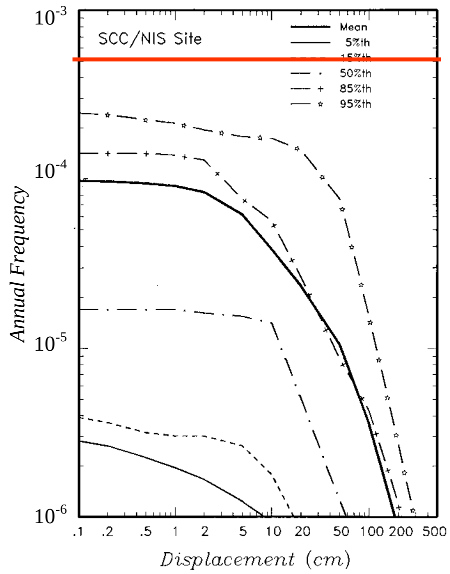

Figure 4a – Case 1a:
Distributed Faulting w/ 9 m
Cumulative Displacement

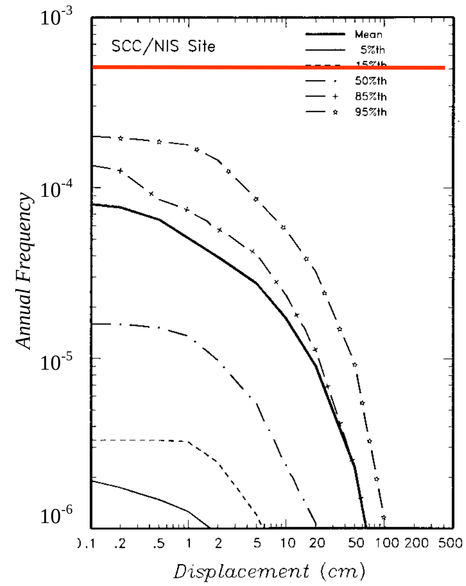

Figure 4b – Case 1b:
Distributed Faulting w/ 1 m
Cumulative Displacement

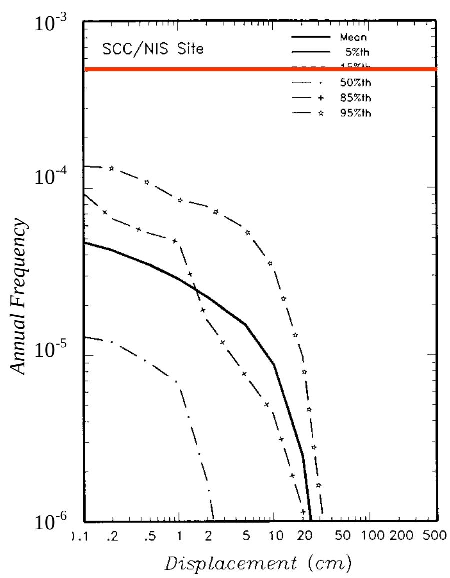

Figure 4c – Case 1c:
Distributed Faulting w/ no
Cumulative Displacement

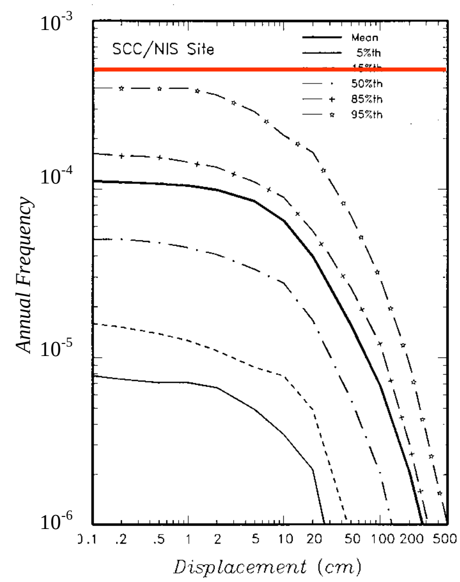

Figure 4d – Case 2:
Principal Faulting w/ 15 m
Cumulative Displacement

Figure 4 – Surface Rupture Hazard Curves for the SCC/NISC Site (Performance Goal for Performance Category (PC) 2 Facilities is $5x10^{-4}$)

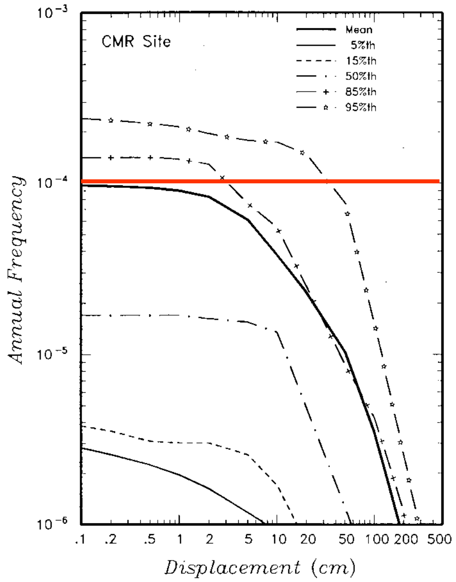

Figure 5a - Case 1a:
Distributed Faulting
9 m Cum. Displacement

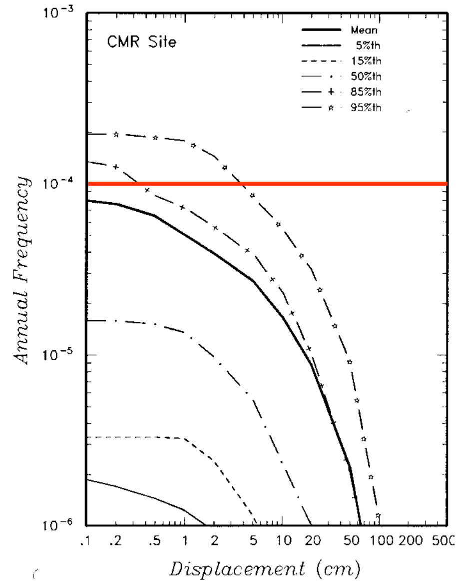

Figure 5b - Case 1b:
Distributed Faulting
1 m Cum. Displacement

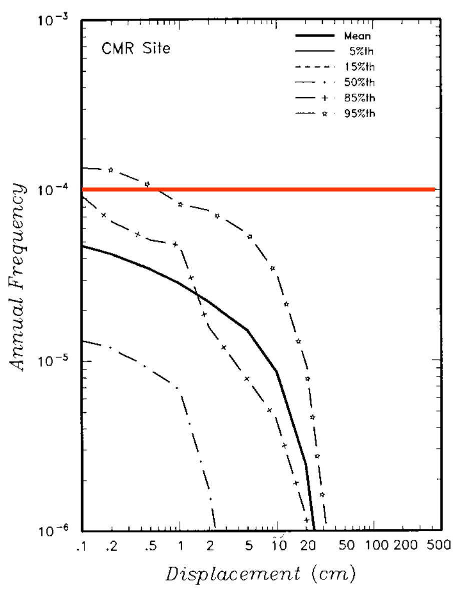

Figure 5c - Case 1c:
Distributed Faulting
No Observable Displacement

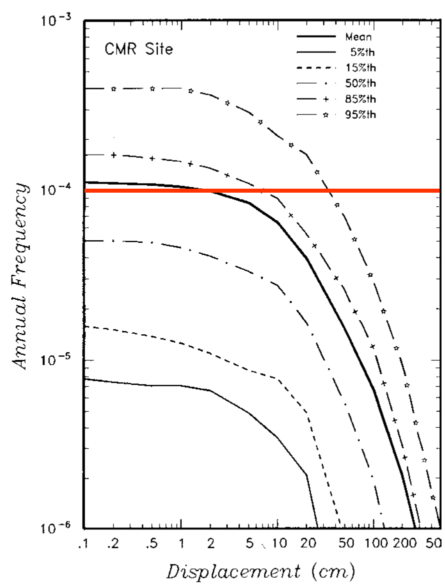

Figure 5d - Case 3:
Principal Faulting
15 m Cum. Displacement

Figure 5 – Surface Rupture Hazard Curves for the CMR Building Site (Performance Goal for Performance Category (PC) 3 Facilities is $1x10^{-4}$)

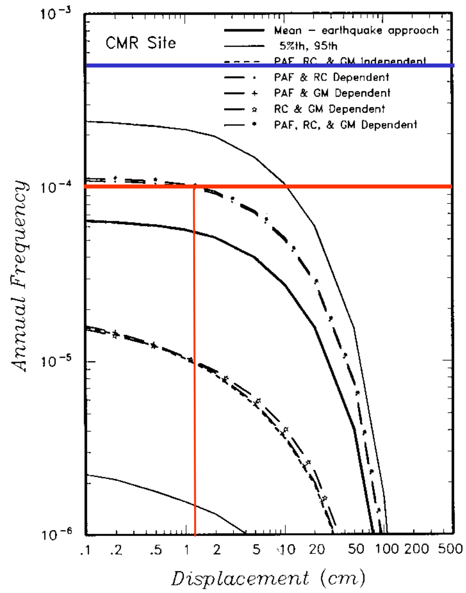

Figure 6a – Case 1b
Distributed Faulting w/ 1 m
Cumulative Displacement

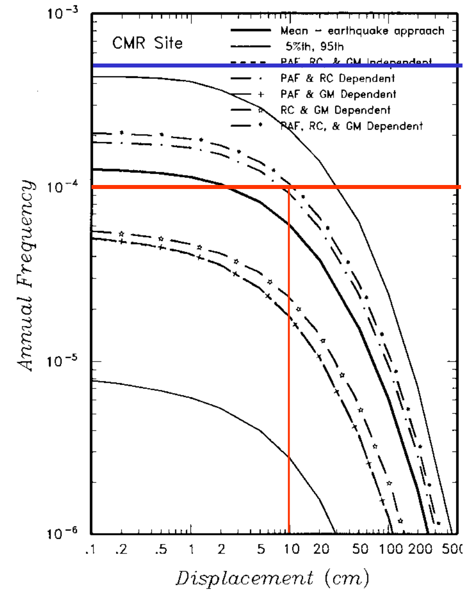

Figure 6b – Case 3:
Principal Faulting w/ 15 m
Cumulative Displacement

Figure 6 – Surface Rupture Hazard Curve Sensitivity Results (Illustrates the effects of assuming fault dependency on hazard curves.)

3.2 Paleoseismic Investigations

Recent paleoseismic investigations have focussed on the Pajarito Fault. Two separate but related studies were initiated in 1997 and 1998. Locations of the studies are shown in Figure 7. Fieldwork for the paleoseismic studies is completed in a fairly short time frame but the analysis of samples required to develop date constraints is a time consuming process.

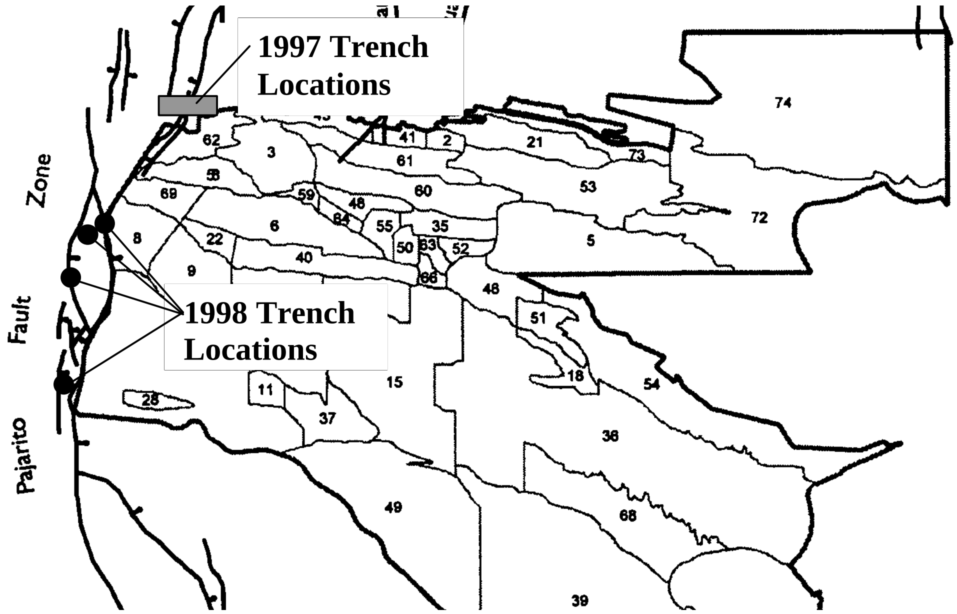

Figure 7 – Locations of Paleoseismic Studies

3.2.1 1997 Paleoseismic Investigation on the Pajarito Fault

In July 1997, seven trenches were excavated across strands of the Pajarito fault zone to characterize the most recent faulting event (MRE), and to refine characterization of previous faulting events. The strategy for capturing the MRE was to excavate a series of seven trenches along an east-west transect across the fault zone south of Los Alamos Canyon, where parallel faults span a zone nearly 2 km wide. Two of the seven trenches were located on the main 50 m high scarp of the Pajarito fault, with the remainder on smaller east- and west-facing scarps. This study is presented in Reference 3.

The best paleoseismic records were preserved on scarps that faced west, or upslope. Each of these trenches displayed evidence of a mid- to late-Holocene MRE. The MRE appears to fall in a relatively narrow age range between about 1300 to 2300 years ago with a likely age of about 1500 years. The net slip rate calculated for the information gathered from these trenches is 0.06 to 0.21 mm/yr.

The MRE, dated at about 1500 years, does not appear to be contemporaneous with the MRE on the Guaje Mountain fault, dated at 4000-6000 years or the MRE on the Rendija Canyon fault, dated at either 8 or 23 thousand years. The trenches on the Pajarito are ambiguous regarding events at either 4000-6000 years or 8000 years. However, it is clear that the 1,500 year event did not rupture the Guaje Mountain or Rendija Canyon faults.

3.2.2 1998 Paleoseismic Investigation on the Pajarito Fault

In June, 1998, seven additional trenches were excavated across the Pajarito fault zone further south than the FY97 study. Again, the purpose of the excavations was to characterize the most recent faulting event (MRE), and to refine characterization of previous faulting events

Four of the trenches did not expose any faults. In the remaining three faults, the MRE falls in a relatively large age range between about 2,000 years, based on the age of the surface soil and 12-20 thousand years based on the age of the uppermost buried soil. The net slip rate calculated for the information gathered from these trenches is 0.07 to 0.13 mm/yr. The MRE in the 1998 trenches could be the same event as the MRE in the 1997 trenches although the broad age range from the 1998 trenches prevents this from being solidly concluded. In addition, the broad age range overlaps with the MRE for the Guaje Mountain fault at 4,000 to 6,000 years and the MRE for the Rendija Canyon fault at 8,000 or 23,000 years.

For both the 1997 and 1998 trenches, there was evidence for only one Holocene (last 10,000 years) earthquake. However, as pointed out in the 1998 report (Ref. 14), the older half of the Holocene (5,000-10,000 years) record was not found in the deposits in the trenches.

4.0 DOE Requirements

The DOE, through orders and standards, provides guidance for facility siting and design with respect to earthquakes. The guidance is probabilistically based.

The Implementation Guide to DOE Order 420.1 “Natural Phenomena Hazards for DOE Nuclear Facilities and Non-Nuclear Facilities” (Ref. 7) requires that structures systems and components be designed and constructed to withstand the effects of natural phenomena hazards (NPH) using a graded approach. The target safety levels for structures systems and components (SSCs) subject to NPH are given in the guide in terms of performance goals. These performance goals are defined as the acceptable annual probability of failure. The performance goals are shown in Table 3 and are a function of performance categorization. Performance categorization is determined in accordance with DOE STD 1021 (Ref. 8). The guide also states that siting of structures over active geologic faults should be avoided.

Table 3 – Categories and Performance Goals for SSCs

Performance Category	Description of Performance Required	Seismic Performance Goal (1 yr)
PC0	No consideration.	N/A
PC1	Prevent major structural damage or collapse which would endanger personnel (life-safety).	$1x10^{-3}$
PC2	Maintain operation of essential facilities allowing relatively minor structural damage.	$5x10^{-4}$
PC3	Confinement of hazardous materials.	$1x10^{-4}$
PC4	Confinement of hazardous materials	$1x10^{-5}$

DOE STD 1020 (Ref. 9) specifies seismic loading in probabilistic terms. The annual exceedance probability for the ground motion associated with the various performance categories is shown in Table 4. The peak ground accelerations for LANL are based on the information in Reference 2.

Table 4
Peak Ground Accelerations at LANL

Performance Category	Annual Probability of Exceedance (Return Period)	Horizontal Peak Ground Acceleration (g)	Vertical Peak Ground Acceleration (g)
PC1	$2x10^{-3}$ (500 yr.)	0.15	0.11
PC2	$1x10^{-3}$ (1,000 yr.)	0.22	0.19
PC3	$5x10^{-4}$ (2,000 yr)	0.31	0.27
PC4	$1x10^{-4}$ (10,000 yr)	0.57	0.58

For seismic design, the standard recommends using deterministic design rules that are familiar to design engineers and which have a controlled level of conservatism. This level of conservatism combined with the specification of probabilistic seismic loading leads to performance goal achievement.

DOE STD 1022 (Ref. 10) provides guidance for NPH Characterization Criteria including the necessity for establishing the potential for surface rupture and points to Environmental Protection Agency (EPA) guidance for offsetting hazardous waste facilities from active faults. Active faults are characterized “by the presence of surface or near surface deformation of geologic deposits of a recurring nature within the last approximately 500,000 years or at least one in the last approximately 50,000 years.”

DOE STD 1023 (Ref. 11) provides criteria for NPH assessment. In this document, some guidance is provided for ground failure (surface rupture). If surface rupture may occur near a facility, a probabilistic evaluation may be necessary. If the annual probability of ground failure is greater than the necessary performance goal either the site should be avoided, mitigation measures taken, or an evaluation performed of the effects of fault offset.

5.0 Implications of Findings

This section discusses the implication of the findings on projects at TA-3 and for the Laboratory in general. These studies have implications for LANL in two areas: (1) surface rupture potential at TA-3 with respect to both non-nuclear facilities and the CMR Building, and (2) design ground motion for all facilities.

5.1 Surface Rupture at TA-3

The studies indicate that there are faults in some locations at TA-3 including under the CMR Building. Based on the seismic history on the primary faults surrounding Los Alamos, these faults are assumed to be "active". Therefore faults will be addressed in a manner consistent with DOE guidance. For new facilities, building sites should be selected such that significant faults are avoided. For existing facilities that are located over faults the probabilistic approach presented in DOE STD 1023 will be followed.

<u>Non-Nuclear Facilities (PC 1 and PC 2):</u>

For the SCC and NISC projects, a site specific study (Ref. 5) was performed to determine if significant faulting was present at the proposed site. The results of this study indicate the site is clear of faulting and is therefore acceptable for new construction.

For existing facilities, hazard curves developed in the probabilistic surface rupture study (Ref. 6) for TA-3 are used. At the performance goals for PC 1 and PC 2, $1x10^{-3}$ and $5x10^{-4}$, respectively, the estimated displacement for any of the cases as shown in Figures 4 and 5 and summarized in Table 2 is less than 1 millimeter. This is true even for the case where all faults are assumed to be connected. This small amount of displacement has a negligible effect on structures. Therefore, for existing PC 1 and PC 2 facilities, surface rupture is not a credible hazard and the only aspect of the seismic hazard at TA-3 that should be considered is ground motion.

<u>The CMR Building (PC 3)</u>

As previously indicated, it has been determined that there is an existing fault under the CMR. The vertical offset in this fault is approximately 8 feet in the last 1.22 million years. The identification, location and orientation of the fault under the CMR shown in Figure 4 is based on air photo interpretation, high precision mapping of faults in canyons to the south of TA-3, and examination of cores taken from the nine holes drilled around the CMR Building. The air photos indicate a linear feature running through the CMR site from the northeast corner of the facility and through the site to the west-southwest. The high precision mapping effort located a fault with about 5 feet of vertical offset in Twomile Canyon to the southwest which coincides with the southwest end of the air photo feature. The examination of the cores showed that the core taken at the northeast corner (CMR-6) of the facility cut through a fault with a total vertical offset of about 8 feet and that it is likely that the same fault lies between cores CMR-2 and CMR-3. This information also coincides with the air photo feature. The location and orientation of the fault shown in Figure 4 are consistent with the information presented in the referenced studies.

If this site were to be considered for a new nuclear facility, it would not be used and an alternate site, clear of faulting concerns, would be chosen. However, since this is an existing facility, the impact on the safe operation of the facility must be assessed. For this assessment a probabilistic approach is used.

The CMR Building is a PC 3 facility that contains special nuclear materials. The performance goal for design basis earthquakes is $1x10^{-4}$. The vertical offset of the fault under the facility lies between the existing conditions evaluated in cases 1a (9m offset) and 1b (1m offset) in Reference 6. As shown in Table 2, the probable offset for these cases at the performance goal is less than 1 mm. This small amount of displacement has a negligible effect on structures and it could be concluded that the discovery of this fault is not a credible hazard for the design basis event.

However, if the worse case assumption is made that this is a principal fault and that all three faults are connected, the estimated offset from Figure 6 for the PC 3 performance goal is approximately 10 centimeters (4 inches). A displacement of this magnitude can cause significant cracking in a concrete shear wall structure such as those used in the construction of the CMR Building. This cracking could result in a loss of confinement.

It can be shown (Ref. 12) that the annual probability of seismic induced failure, based on ground motion associated with an earthquake, is about $2x10^{-3}$ for most areas of the CMR Building. The exceptions to this is the vault that has an annual probability of seismic induced failure, again, based on ground motion, of about $7x10^{-5}$, and the floor wells which have yet a lower probability of failure. The significance of this information is that ground motion could cause a loss of confinement for most areas of the CMR Building at frequency that is at least 20 times greater than surface rupture.

In the safety analysis for the CMR Building, the consequences of the seismic accident are assessed assuming that the CMR building, with the exception of the vault and floor wells, collapses at the frequency indicated above. With the vault and floor wells located such that they would not be directly effected by surface displacement, the assumptions used in the safety analysis for the seismic accident are still valid even with new knowledge of a fault beneath the facility.

Based on the information from the referenced studies, the fault under the CMR site is a subsidiary fault. As a result, any movement on the fault is likely to be small and would be a result of a large (Magnitude 6 to 7) earthquake on the Rendija Canyon or the Pajarito fault. Such earthquakes are low probability events. In Figure 8 the estimated annual frequency of damage caused by ground motion is compared to the annual frequency of damage caused by surface rupture. This figure illustrates that damaging surface rupture is far less likely to occur than damaging ground motion.

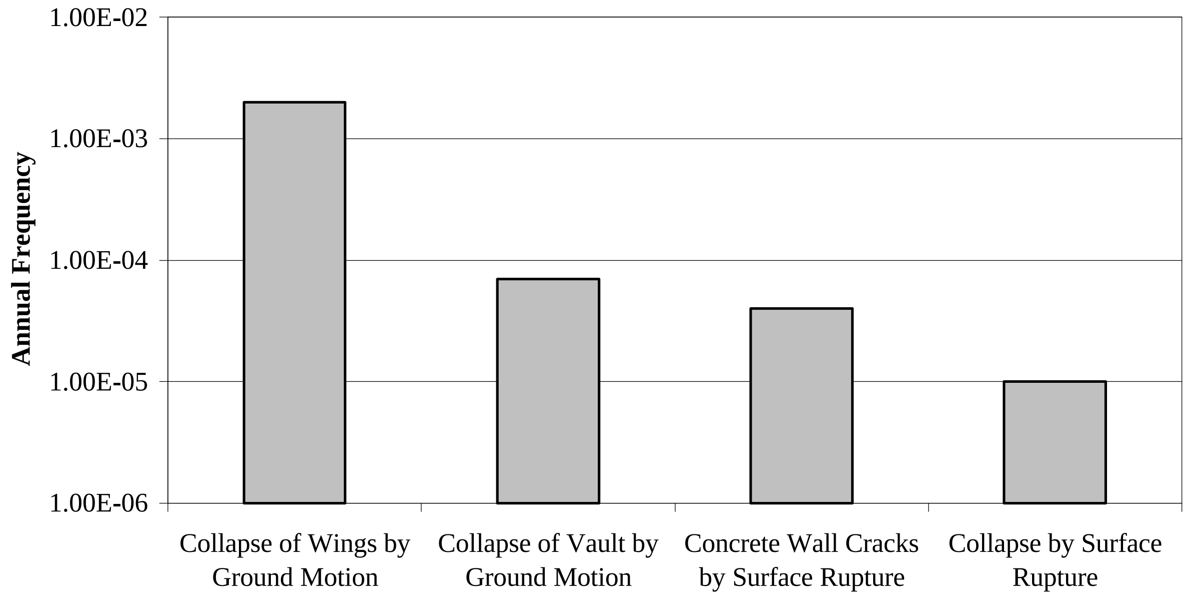

Figure 8 – Frequency of Seismic Induced Damage at CMR Building

5.2 Design Ground Motion

Of the current seismic hazard studies, only the paleoseismic investigations could influence the design ground motion at LANL.

The design ground motion at LANL is based on the results of the probabilistic seismic hazard analysis (PSHA) presented in Reference 2. According to this reference, the net slip rate of the Pajarito fault is the most important input parameter in the PSHA. For this fault the PSHA assumed the slip rates shown in Table 5. One of the objectives of the paleoseismic investigations is to get a more accurate assessment of the slip rate or recurrence intervals on the Pajarito fault.

Table 5 – Net Slip Rates for Pajarito Fault Used In PSHA

Net Slip Rate (mm/yr)	Probability[1]	Percentile[2]
0.01	0.1	5th
0.05	0.2	20th
0.09	0.4	50th
0.20	0.2	80th
0.95	0.1	95th

[1]Probability used in PSHA Logic Tree
[2]Cumulative percentile

Based on the results of the FY97 paleoseismic investigation (Ref. 3) on the Pajarito fault, the net slip rate is 0.06-0.21 mm/yr. From the results of the 1998 study, the net slip rate is 0.07 – 0.13 mm/year. The lower end of the two ranges is less than the median slip rate value of 0.09 mm/yr assumed in the PSHA. The higher end of the two ranges is equal to or less than the 80th

percentile motion assumed in PSHA. Therefore, the slip rates calculated in the 1997 and 1998 studies have been bounded by the assumptions made in the PSHA documented in Reference 2. Therefore, the results presented in Reference 2 are still valid for use at the LANL site.

Questions concerning the dependency of the three major faults are based on the physical location and style of deformation of the three faults. Their relative proximity to one another and style of deformation could lead to the conclusion that they must be connected at depth below the earth's surface. However, based on the paleoseismic studies to date, there is no evidence that earthquakes rupture all faults together. The MRE on the Pajarito fault, dated at 1300-2300 years, is not coincident with either the MRE on the Guaje Mountain fault, dated at 4000-6000 years or the MRE on the Rendija Canyon fault, dated at either 8 or 23 thousand years.

Because of the broad age range of the MRE on the 1998 trenches, the data gathered in these two studies are not sufficient to conclude whether or not the Pajarito, Rendija Canyon and Guaje Mountain faults are dependent. The data are sufficient to state that the Pajarito fault can rupture without rupturing the other two based on the MRE on the 1997 trenches and the MRE ages on the other two faults. However, the data are not sufficient to state that one of the other two can rupture without the Pajarito fault also rupturing. The significance of this information is that the logic used to calculate the seismic hazard in Reference 2 is still valid. That study included multiple scenarios as to the dependency of the three faults. Therefore, the results and the methodology of the PSHA are still valid.

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APPENDIX B

PROBABILISTIC ANALYSIS OF THE POTENTIAL FOR BUILDING-WIDE FIRE IN PF-4

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PROBABILISTIC ANALYSIS OF THE POTENTIAL FOR BUILDING-WIDE FIRE IN PF-4

EXECUTIVE SUMMARY

This technical analysis consists of a re-examination of the plausibility of a building-wide fire at the Los Alamos National Laboratory (LANL) Plutonium Facility (PF-4) at TA-55 under the following hypothetical circumstances: (1) the propagation of a glovebox fire; and (2) fire from a severe site-wide earthquake. PF-4 is a Category 2 nuclear facility that has been in operation since 1978. The chemical and metallurgical processes conducted at PF-4 routinely involve hazardous chemicals and special nuclear material (SNM). These processes are carried out in gloveboxes that are located within various laboratory rooms in PF-4. Fire barriers are used to separate adjacent laboratory rooms, as well as the two building wings. Other design features are in place to help prevent fire propagation, including a dedicated automatic fire suppression system. The building structure, fire walls, and many other PF-4 items have been designed specifically or hardened to withstand a seismic event.

For the purpose of this study, a building-wide fire is defined as a fire large enough to encompass all PF-4 laboratory and basement areas and subject the entire building inventory of the plutonium material at risk to high temperatures. The overall objective of the analysis was to generate point-value estimates for the frequency of building-wide fires using conservative, bounding assumptions where necessary. By comparison, a “best-estimate” analysis, if performed, would attempt to eliminate conservative assumptions through additional studies and deterministic analyses. It was deemed reasonable that frequency estimates from the conservative, bounding analysis, together with engineering judgment, would form the basis for drawing conclusions related to “plausibility.”

This study was carried out in two parts. First, the PF-4 design features were compared with the codes and standards for design and operation of facilities having similar hazards. This design verification activity included extensive walk-downs of the PF-4 building. Results from the design verification provided valuable insights about the robustness of the PF-4 building and provided a means for analysts to ensure that the analysis would represent the present state of PF-4 operations accurately. In the second part of the study, a probabilistic analysis was performed to evaluate the initiation, growth, and propagation of fires at PF-4. The probabilistic analysis included an examination of how each safety feature would inhibit or prohibit fire propagation. The probabilistic analysis was based on established risk assessment methods that included the use of event- and fault-tree logic models. Results from the probabilistic analysis provided a quantitative measure of the relative effectiveness of each safety feature, as well as an estimate of the overall frequency of a building-wide fire at PF-4.

Deterministic computer models were developed and analyzed to evaluate various physical phenomena related to fire propagation. In selected instances, the analysis used simplifying but conservative modeling assumptions to address issues related to fire spread instead of performing complex analyses using nonstandard tools. For the seismic portion of the analysis, the entire site-specific seismic hazard curve was sampled instead of truncating the analysis at an arbitrary pre-set maximum level for ground motion. The probabilistic analysis used actual plant operational data to support quantification of the results.

Propagation of a glovebox fire into a building-wide fire is estimated to occur with a point-value frequency of 4×10^{-10}/yr. Stated differently, this type of accident scenario would be expected to occur about 1 time in every 2.5 billion years. The frequency for this accident scenario is very low because of a combination of fire mitigation factors and design features, including an automatic fire suppression system, limited and monitored amounts of combustible materials in laboratory rooms, and robust fire barriers. Several very conservative assumptions were used in this portion of the analysis. For example, even though there have been no instances of laboratory room or basement fires at TA-55, the analysis assumed that a room fire would occur with the same frequency as a glovebox fire. Furthermore, the frequency of a glovebox fire was based conservatively on some events that were not actual glovebox fires, but were instead only precursor events having a low potential to ignite a fire. Also ignored was the fact that glovebox fires will often self-extinguish because of the relatively small amount of combustible materials typically present in gloveboxes. In addition, no credit was taken for the response and mitigating actions of dedicated, off-site fire department personnel.

The analysis of building-wide fire from a severe site-wide earthquake produced two scenarios of interest. The first scenario involves a seismic-induced fire that spreads throughout an entire wing as a result of failure of the fire suppression system or interior fire walls. Seismic-induced failure of the H-wall crossover dampers subsequently allows the fire to spread to the other wing, resulting in a building-wire fire. The frequency of this scenario is estimated to occur with a point-value frequency of $4x10^{-6}$/yr. The second scenario involves the collapse of the building as a result of the seismic event. The frequency of this scenario is estimated to be $5x10^{-6}$/yr. Stated differently, these accidents would be expected to occur once every 500,000 yr. It was assumed in these calculations that fire spread would be independent of the operational status of the ventilation system even though some calculations suggest that the ventilation system would have to remain operable for fire to spread.

In summary, a conservative bounding analysis has demonstrated that a building-wide fire is unlikely to occur during the life cycle of PF-4. A "best-estimate" analysis, if performed, would provide the basis for further judgment into the degree of conservatism inherent in many of the analysis assumptions. Elimination or relaxation of conservative assumptions, in turn, would reduce the point-value frequency estimates of a building-wide fire.

1.0. INTRODUCTION

1.1. Background

Construction and Operation of PF-4 Facility

The Plutonium Facility (PF-4) at LANL, TA-55 is a Category 2 nuclear facility that has been in operation since 1978. The chemical and metallurgical processes conducted at PF-4 routinely involve hazardous chemicals and special nuclear materials. The PF-4 building is broadly divided into two wings separated by a 3-hour (3-hr) fire-rated[1] concrete wall called the "H-Wall" (see Fig. 1-1). Each wing is formed of two areas that in turn are formed of a strip of laboratory rooms. Each of the 100, 200, 300 and 400 Areas has its own dedicated heating, ventilation, and air conditioning (HVAC) system equipped with intake and exhaust high-efficiency particulate air (HEPA) filters. Laboratory room walls, floors, and ceilings are constructed of 2-hr-rated fire barrier materials to provide qualified fire isolation from the adjoining rooms, the attic, and the basement. The laboratory room doors are constructed of 1.5-hr-rated fire barrier materials. In addition, each room is equipped with manual (e.g., A/B/C fire extinguishers) and automated (wet pipe 212^{o}F fire sprinklers and Halon) fire suppression systems. The fire sprinklers are supplied with water by a dedicated fire water supply system (FWSS) with on-site water tanks and redundant fire pumps. In addition, each laboratory room has central and local fire alarms to alert operators of possible fires. The PF-4 building perimeter walls serve as the ultimate confinement barrier against uncontrolled release of material at risk (MAR), whereas the laboratory room boundary forms a "qualified" fire barrier against propagation of fire within the building. By design, the PF-4 structure, HEPA filter plenums, and the associated HVAC ductwork will withstand the effects of an evaluation-basis event (EBE) earthquake with 0.3-g peak horizontal acceleration. Through various engineering analyses, it has been established that the interior walls, ceilings, and floors have a high confidence and low probability of failure (HCLPF)[2] at 0.5 g, whereas the perimeter walls and the H-wall have a HCLPF of almost 0.8 g.

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[1] The fire rating is based on the National Fire Protection Association (NFPA) design criteria for fire barriers. The construction details of these walls are provided in Sec. 2 and Appendix-B.

[2] An HCLPF of 0.5 g implies that at a mean ground acceleration of 0.5 g, that structure has a failure probability of 10^{-2} with 95% confidence. Structural experts made such a determination based on experimental simulations and modeling activities.

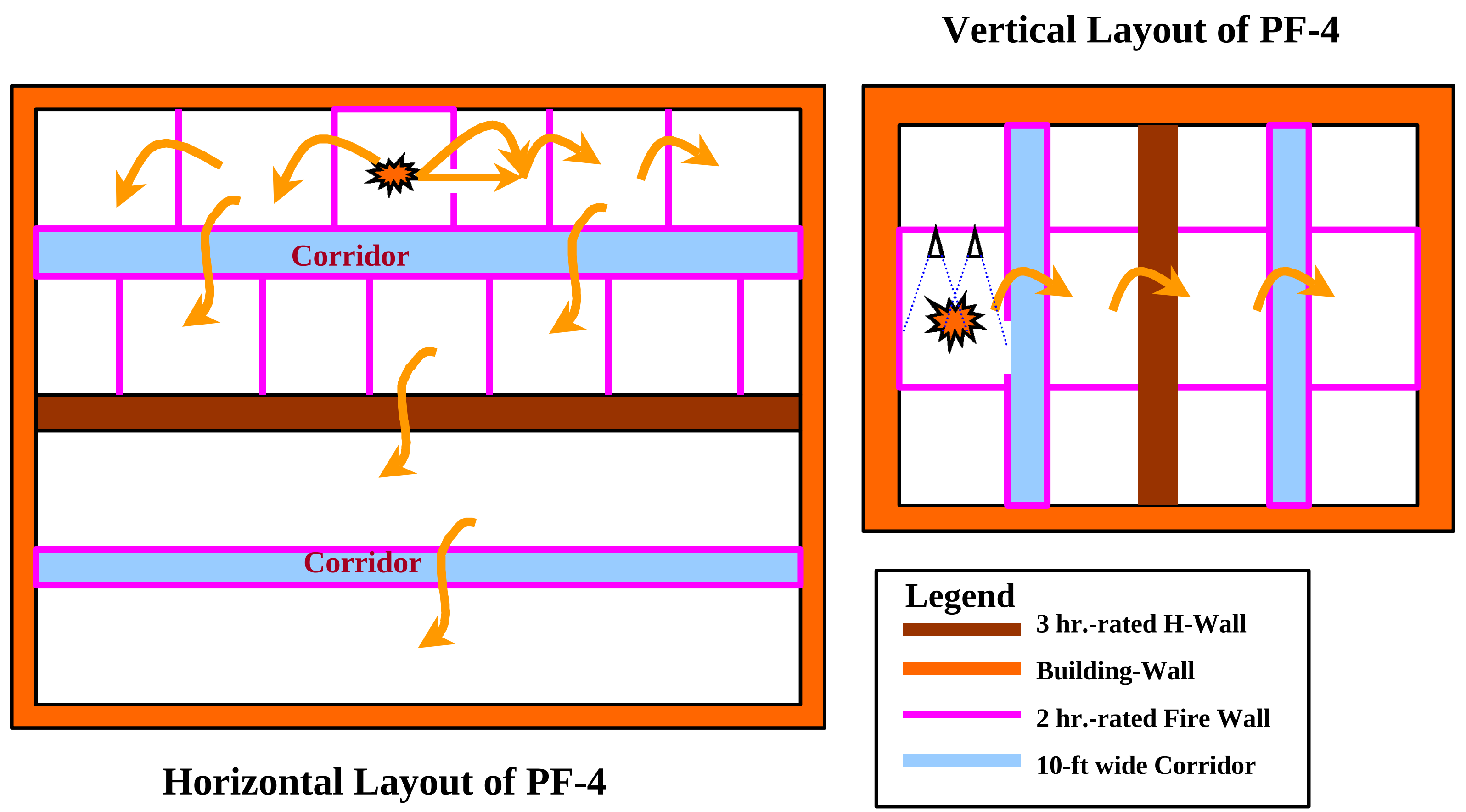

Fig. 1-1. Layout of PF-4 Building.

Each laboratory room contains numerous seismically qualified gloveboxes in which all operations involving hazardous materials (including their storage) are undertaken. A glovebox is typically a leak-proof, enclosed steel structure with noncombustible glass windows and ports cut out for housing rubber gloves. The glovebox forms the primary confinement. MAR is stored in special containers within the glovebox to minimize release in the event of fire or seismic event.[3] At any given time, a majority of the gloveboxes is very sparsely used, and they contain few (if any) combustible materials. The gloveboxes in which significant quantities of nuclear MAR, pyrophoric materials, or heat sources are processed (or stored) have the following additional safety features.

1. They are inerted.[4]
2. They are specially braced to withstand beyond-evaluation-basis earthquakes.[5]
3. They are equipped with heat detectors and alarms.
4. They have dedicated exhaust HEPA filters.
5. They have certain controls on the type, form, method of storage, and amount of combustible (or pyrophoric) materials that can be stored inside.

To minimize fire risk, administrative controls are placed on the quantity of transient combustible materials (in terms of equivalent cellulose pounds per square foot) permissible in a laboratory room and the storage of combustible gases. Biweekly surveys of the location and quantity of combustible materials in PF-4 (covering the entire year of 1998) clearly established that transient combustible loads in most of the PF-4 laboratory rooms are far below 1/2 lb/ft^2. The combustible gasses (e.g., hydrogen and methane) are permitted within the building in small quantities and are stored in high-pressure 1-L gas cylinders at 2250 psig. These limited volumes do not present a flammability hazard if they are released to the rooms accidentally.

Further details on the PF-4 construction and safety systems are provided in Sec. 2 and in the Updated Final Safety Analysis Report (FSAR).

FSAR Accident Analysis

The FSAR identified a set of credible accidents, referred to as the evaluation-basis accidents (EBAs) and analyzed them systematically to quantify their on-site and off-site consequences. These accidents were selected based on detailed hazard analyses performed for each process underway at TA-55. The following fire and seismic accidents are analyzed in the FSAR.

1. **Operational Accident: Laboratory Fire in the Heat Source Production Area.** This accident represents various scenarios of Laboratory Room or Glove Box fires that breach glovebox confinement followed by loss of active ventilation.
2. **Operational Accident: Ion Exchange Column Thermal Excursion.** This accident covers various scenarios that result in explosion induced release of MAR due to a glove box breach.
3. **Natural Phenomena: Earthquake.** This accident evaluated the potential effects of an earthquake with a mean peak horizontal acceleration of 0.3 g on PF-4. The earthquake is modeled to cause free fall spill of MAR into the laboratory rooms, followed by failure of the ventilation system. Although secondary fires are possible, they were screened out because they would be small and their effects would be bounded by other seismic event assumptions.
4. **Operational Beyond-Evaluation-Basis Accident (BEBA).** Fire in the Heat-Source Production Area. This is a more severe version of the fire scenario described above.

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[3] Powders and liquids are stored in screw-top, thick-steel-pipe containers. Metals and pellets are stored in press-on containers. These containers currently are being upgraded.

[4] "Inerted" is a word used to describe a glovebox in which air is purged from the interior volume and replaced with gases such as nitrogen and argon that do not support combustion. Such gloveboxes are isolated from the neighboring gloveboxes and equipped with oxygen monitors and alarms.

[5] Independent studies by Los Alamos scientists and outside experts have concluded with high confidence that a majority of the gloveboxes will withstand a design-basis earthquake (0.3 g). The high-risk gloveboxes are being braced to withstand beyond-design-basis earthquakes (between 0.4 and 0.5g).

5. **Natural Phenomena Beyond-Evaluation-Basis Accident (BEBA): 0.5-g Earthquake.** This accident examines increase in risk associated with a 0.5-g earthquake at TA-55.

The results of the analyses were instrumental in identifying the safety-class structures, systems, and components (SCSSCs) and safety-significant structures, systems, and components (SSSSCs) that would be required to mitigate accident progression and limit public and worker consequences. These results were used later in the LANL Site-Wide Environmental Impact Statement (SWEIS), and the Storage and Disposition of Weapons-Usable Fissile Materials Programmatic Environmental Impact Statement (PEIS) as needed.

1.2. Scope and Objectives of the Present Study

The overall objective of this study is to examine the "plausibility" of a building-wide fire at TA-55 under the following hypothetical circumstances: (1) the propagation of a glovebox fire and (2) fire resulting from a severe site-wide earthquake. For the sake of this study, a "building-wide" fire is defined as a fire large enough to encompass all four areas of the PF-4 building (i.e., 100, 200, 300, and 400 areas) and subject the entire building inventory of MAR to high temperatures. The primary focus of the study was to conservatively estimate the frequency of a building-wide fire at PF-4 with the understanding that the frequency estimates together with engineering judgement can be used to draw conclusions related to "plausibility." The study would quantify the frequency after taking into consideration the process modifications that are necessary for pit manufacturing.

This study was carried out in two parts. The first part involved comparing the PF-4 design features with the codes and standards for design and operations of facilities of similar hazards—both government and civilian facilities. This process of design verification also included extensive walk-downs of the PF-4 building by the analysts to ensure that PF-4, as analyzed, accurately reflects the present state in which it is being operated. The results of this part of the analysis provided valuable insights regarding the robustness of the PF-4 construction. The second part of the analysis involved a systematic evaluation of fire initiation, growth and propagation at PF-4. This evaluation examined how each mitigating system (or barrier) would inhibit fire propagation, and coupled that information with the probability for failure of each mitigating system to quantify the cumulative frequency (or likelihood) of a building-wide fire. Event trees and fault trees were used to integrate the probabilistic results with the accident progression. This approach provided a "quantitative" measure of the relative effectiveness of each safety feature, as well as the overall frequency of a building-wide fire at PF-4.

This study evaluated the frequency for a building-wide fire as an outgrowth of two initiators: (1) an operational accident, a small local fire[6] initiated in a laboratory room, and (2) natural phenomena, a fire resulting from an earthquake. The study modeled existing mitigating systems and gloveboxes in their present configuration.[7] Established computer models were used to establish the effect of a mitigating system's failure/deficiency on fire propagation, for example, failure of fire sprinklers. Where necessary, simplifying and conservative modeling assumptions were adopted in lieu of performing complex analyses using nonstandard tools. On the probability front, actual plant operational data were used to derive initiator frequency as well as mitigating systems component failure probabilities. For seismic events, this study sampled the entire seismic hazard curve instead of truncating the analysis at any preset maximum. The overall outcome of the study is a numerical point estimate of the frequency of a building-wide fire.

1.3. Applicability and Limitations

This study was oriented primarily toward quantification of frequency (or plausibility) of a building-wide fire at PF-4. In other words, the accident sequence of interest is propagation of a small fire throughout the building. Very little effort was devoted to best-estimate quantification of the likelihood or consequences of sequences resulting in limited damage to the facility. Such sequences are addressed in the PF-4 SAR. Therefore, the results of this analysis should not be used to draw conclusions regarding any issues other than the likelihood of a building-wide fire.

As with any engineering study of complex facilities, several simplifying assumptions were made to limit the complexity of analyses to be performed. Therefore, the results of this study should not be taken out of context. For

[6] An example of such a fire is spontaneous ignition of alcohol-soaked rags located in a glovebox.
[7] It is assumed that the present system configuration will not change substantially for pit fabrication.

example, this study did not undertake detailed analyses related to conditions required for a small glovebox fire to grow into a larger laboratory room fire. Instead, the study assumed that all glovebox ignitions, irrespective of their size and local combustible loads, would grow to be a laboratory room fire if not immediately attended to by laboratory workers. This assumption is very conservative because at the low glovebox combustible loads that are typical of PF-4, small glovebox fires would likely self-extinguish. Therefore, the frequency estimates for laboratory room fires are very conservative. This conservatism is ultimately reflected in the estimates for the frequency of a building-wide fire.

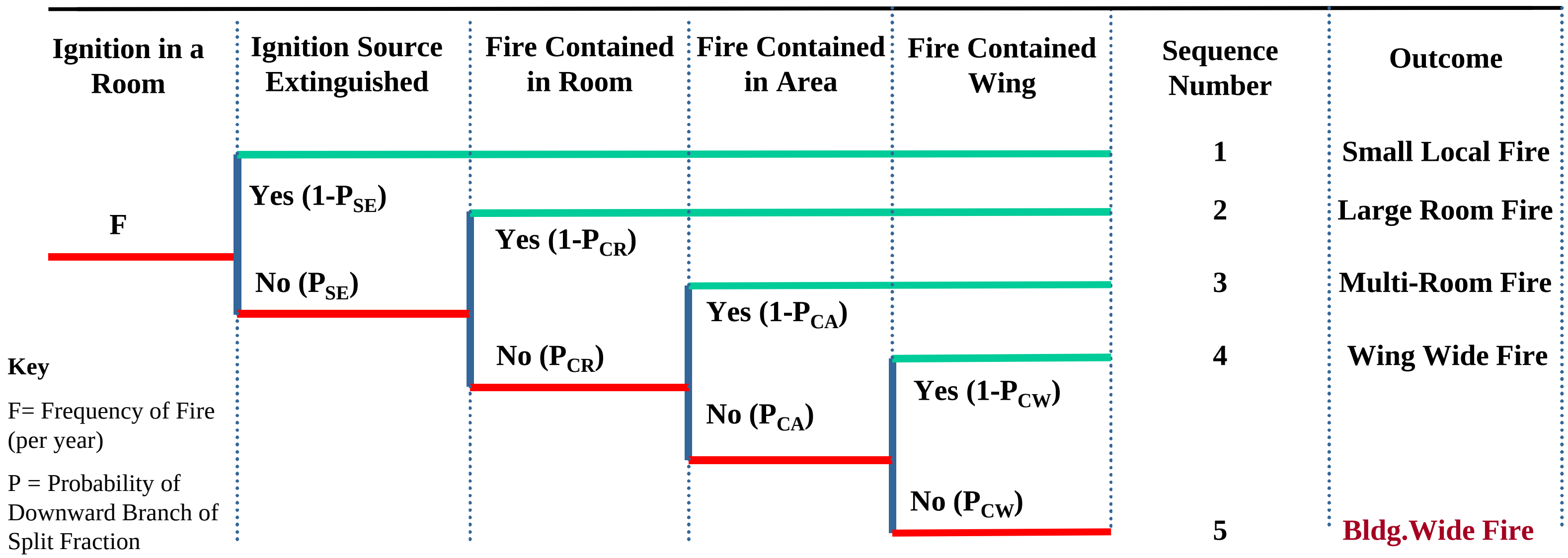
1.4. Report Outline

The technical analysis is presented in Secs. 25. Section 2 presents an overview of the probabilistic risk assessment methodology used to estimate the frequencies. Section 3 presents the results of a building-wide fire resulting from an operation fire. Section 4 presents the results of a building-wide fire resulting from a seismic event, and finally Sec. 5 presents the conclusions of this report.

2.0. OVERVIEW OF THE METHODOLOGY

Fire propagation within the PF-4 building was evaluated probabilistically by developing and analyzing an event/fault-tree logic model. An event tree is a graphical model that portrays various possibilities for the progression of an accident. Figure 2-1 is a generic event tree that describes the progression of an operational fire in PF-4. The event tree is structured so that the progression of the accident is represented in a time-ordered manner from left to right. The event tree contains a set of "event headings," the first of which represents the initiating event (e.g., glovebox fire), whereas the subsequent headings represent post-initiator events that may or may not occur in the accident progression (e.g., fire contained in the laboratory room). The last heading on the event tree (far right) represents the outcome of the accident (e.g., Small Local Fire). The post-initiator events represent the success or failure of various mitigating systems/features that are designed to contain fire during that phase of propagation. Separate pathways through the tree, which flow from the left to right, represent the various possibilities for accident progression. These pathways are referred to as "Accident Sequences" and are usually identified by a name or number. "Success" of a post-initiator event is delineated by the pathway branching upward, failure is shown by the pathway branching downwards, and no effect is shown by not branching. In Fig. 2-1, for example, Accident Sequence 2 represents a fire (initiating event) that was not extinguished promptly but was contained in the room of origin. The outcome was a small local fire.

The accident-sequence frequency is quantified by multiplying the frequency of the initiating event (for example, the number of fires per year) with the failure/success probabilities (split fractious) of each post-initiator event associated with that sequence. For example, in Fig. 2-1, the **failure** probability under each intermediate event is the estimated probability that mitigating systems associated with that event would **not** function properly and extinguish the fire. The success probability is a complement of the failure probability (≈ 1-Failure Probability). These failure probabilities are calculated using fault-tree models that model various faults in each item or component of the associated mitigating systems that would render them inoperable. Each fault is quantified with a numerical probability of occurrence derived from PF4-specific operational history as well as external data sources. These



Calculation of Sequence Frequencies

Sequence 1: Frequency = $F^*(1-P_{SE})$

Sequence 2: Frequency = $F^*P_{SE}{}^*(1-P_{CR})$

Sequence 3: Frequency = $F^*\ P_{SE}{}^*P_{CR}{}^*(1-P_{CA})$

Sequence 4: Frequency = $F^*\ P_{SE}{}^*P_{CR}{}^*P_{CA}{}^*(1-P_{CW})$

Sequence 5: Frequency = $F^*\ P_{SE}{}^*P_{CR}{}^*P_{CA}{}^*P_{CW}$

Fig. 2-1. Event tree representing progression of an operational fire in PF-4.

faults are combined in a logical manner so that when solved, the fault-tree model yields an estimate of the failure probability of each post-initiator event.

The event-tree quantification process used in this study consisted of four major steps, which are shown in Fig. 2-2. These steps and their outcomes are described briefly below with the results and discussions provided in Secs. 3 and 4.

2.1. Selection of Initiating Events

A major objective of this study is to estimate the frequency with which a fire initiated by either (a) a glovebox fire or (b) a severe site-wide earthquake spreads to engulf the entire PF-4 building. The first element of the study is to estimate the frequency with which glove box fires occur, and to estimate the frequency of an earthquake of sufficient magnitude to start a fire in the PF-4 building. The methods used to develop these initiating event frequencies are explained below. The methods used to characterize the companion probabilities that either of these categories of fires would spread to the entire building are described in subsequent sections of this report.

Operational Fire: A Small Local Fire Initiated in a Laboratory Room

A typical example of an operational fire at TA-55 would be spontaneous ignition of a pile of alcohol-wetted and ^{238}Pu-contaminated rags stored in a glovebox. Operational history suggests that such events are rare because contaminated rags are stored in gloveboxes only for a brief period of time at PF-4 (and never in gloveboxes that also have other flammable materials or MAR). Furthermore, every incident of glovebox fire in the past was either

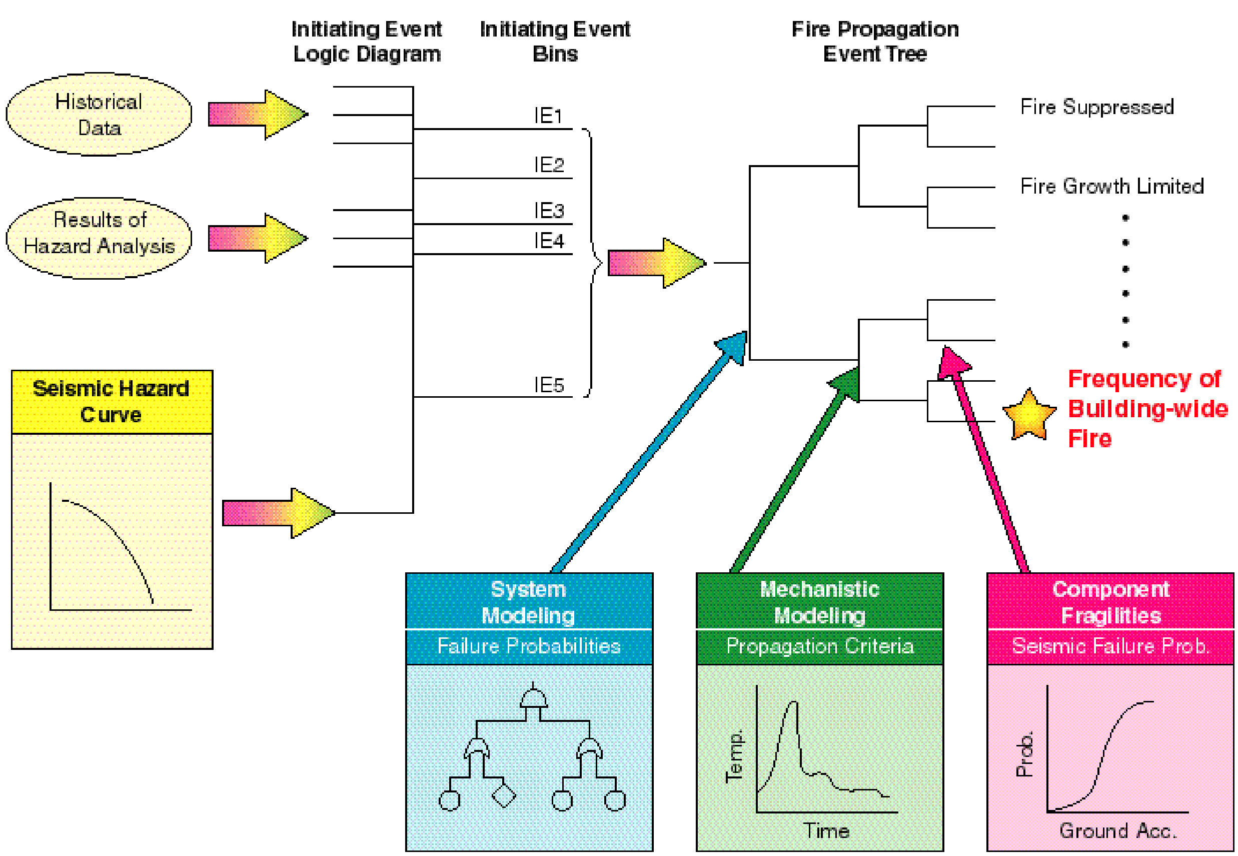


Fig. 2-2. Overview of analysis methodology.

extinguished immediately by a TA-55 worker or self-extinguished because of the small quantity of combustible material involved. Nevertheless, if one were to postulate that as a result of human error, rags were left in a glovebox that contains large inventories of fast-burning flammable liquids, then rapid fire growth could result. Leonard (1999) provides descriptions of analyses undertaken to model various steps involved in the progression of a glovebox fire. Most of the gloveboxes possess such small quantities of combustibles that the hot gases from the fire would be vented off easily by the HVAC system, resulting in an insignificant increase in glovebox temperatures. However, if the combustible loads are sufficiently large the combustion products together with radiant heat transfer can breach the gloves (either burn through them or overpressure them). In turn, escaping hot gases may ignite flammable materials located outside the glovebox. This would result in a small local fire in a region close to the glovebox. Alternately, the fire may start in the laboratory room as a result of human error and/or as a result of other precursors identified in the hazard analyses. The analyses conducted as part of this study demonstrated that irrespective of the location where the fire initially starts (i.e., inside or outside the glovebox), pathways for fire growth are essentially same. As a result, it was decided to merge these two initiating events into a single event, "operational fire" and analyze them together.

Operational fire is not expected to affect any of the mitigating systems such as the fire suppression system or HVAC. However, it is assumed that possible release of radioactivity into the laboratory room may limit TA-55 worker response except for an initial few minutes.

Natural Phenomena: A Fire Resulting from a Severe Earthquake

The TA-55 FSAR addressed the mechanical release of MAR as a result of evaluation-basis and beyond-evaluation-basis earthquakes. This study analyzed the potential for fire as a result of seismic activity and subsequent fire propagation.

A postulated severe site-wide earthquake could lead to failure of several gloveboxes depending on the magnitude of the earthquake and the relative strength of each glovebox. The glovebox seismic failure mechanisms can vary from interruption of inert gas flow to the gloveboxes, where pyrophoric materials are stored, to toppling of gloveboxes in which ignition sources (e.g., a furnace) are operated/stored. The extent to which a glovebox is damaged depends on its fragility and the magnitude of earthquake. In either extreme, postulated failure may lead to ignition located either within the glove box or in the close proximity of the glovebox. Mechanistic determination of the exact criterion for initiating a fire following a seismic event is very complex and would involve major assumptions regarding the PF-4 manufacturing processes. For the sake of simplification, it was assumed conservatively that a seismic event powerful enough to "fail" a glovebox would result in ignition provided that the glovebox contains sources of ignition[8] (e.g., furnaces) or is used to store pyrophoric materials.

The seismic events are assumed to cause a loss of off-site electrical power, which would affect the HVAC and FWSS performance negatively.[9] Additionally, it would limit the response of both the TA-55 workers and the fire department staff. Severe earthquakes also may introduce large-scale cracks in the room walls and roof that can act as penetrations.

2.2. Systems Analyses

The PF-4 facility Systems Description Document (SDD), FSAR, and hazard analysis (HA) were reviewed to gather information regarding active and passive systems available for mitigating various accident sequences. This information was supplemented by facility walkdowns and personnel interviews.[10] For each system listed below, the information compiled included the system design, its present configuration, procedures for testing and maintenance, deficiencies or vulnerabilities, failure rates, and anticipated human response. This information was used to develop the fault trees for each system [see Darby (1999)]. To validate these models, underlying assumptions and the results of the fault tree analyses were discussed with the facility operators.

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[8] No attempt was made to estimate the probability that the heat source would be operational when the earthquake occurs.

[9] TA-55 also has an on-site, backup power supply that, if available, could be used to power the FWSS. While a seismic event of sufficient strength could also fail this backup power supply, the FWSS piping is less resistant to seismic events. Thus, a seismic event sufficiently strong to fail the backup power supply would also fail the FWSS.

[10] One registered fire protection engineer and two PRA experts were involved in the walkdowns.

Passive Barriers

The following passive barriers were modeled in the study.

1. The walls, ceiling, and floor of every laboratory room are constructed of 4-in.-thick gypsum wallboard that meets the National Fire Protection Association (NFPA) criterion for 2-h fire barriers. These firewalls have a HCLPF of 0.5 g. Typically, every room has one or two doorways connecting it to the adjoining room and the corridor. These doors are normally closed and meet the NFPA criterion for a 1.5-h fire barrier. A walkdown of the PF-4 facility revealed that small penetrations exist in the room walls and that gaps in the doorway may leak at high pressures. A typical example of a penetration is sealed electrical conduit. As shown in Bartlein (1999), such penetrations were found to have an insignificant effect on fire propagation. The success criterion for containing fire within the laboratory room was derived conservatively assuming that room doors will remain open throughout the accident.
2. A 10-ft-wide corridor separates each Area from the adjoining Area (100 from 200 and 300 from 400). The corridor is kept free of combustible materials at all times. This separation ensures that no continuous fuel train connects the adjoining areas. Deterministic analyses have shown that corridors are not very effective at containing hot combustible gasses emanating from the area under fire to ignite flammable materials in the adjoining area. This pathway for fire propagation was modeled in the study.
3. A 2-ft-thick concrete wall (H-wall) separates the north and south wings, which meets the NFPA requirements for 3-h fire separation. It has a HCLPF of 0.6 g, at which point large cracks and penetrations could develop in the wall. However, the HCLPF for catastrophic failure is 0.7 g. There are five penetrations in the wall. There are two sets of access doors in the upper level and two sets of access doors in the basement. These doors are normally closed and are equipped with automatic closure mechanisms (fusible links) that would close them when the nearby temperature exceeds 212^{o}F. The other penetration is a 4-ft x 7-ft trolley crossover line that also is equipped with a fusible link fire closure mechanism. This study quantified the probability associated with failure to close these penetrations and analyzed their effect on fire propagation.

Active Systems

The following active systems were modeled in this study.

1. ***Fire Sprinkler System.*** The PF-4 facility is fully protected by wet-pipe fire sprinkler systems. The FWSS, which feeds the sprinklers, consists of two independent ground-level storage tanks located remotely from each other. Each tank supplies a pump house containing one electric-driven, and one diesel-driven fire pump. Each of the four pumps is capable of supplying the demand of the fire sprinkler systems. Both pump houses supply water to the sprinkler system via a dedicated fire loop around the PF-4 facility. The fire loop, tanks, and pump houses have a HCLPF of 0.5 g. However, some of the sprinkler pipe hangers inside the PF-4 building have a HCPLF of 0.3 g.

2. ***HVAC System.*** The PF-4, Zone II, HVAC design uses a cascading scheme maintaining airflow from areas of low probability of contamination to areas of higher probability of contamination. Air enters the basement, from the outside through HEPA-filtered inlets, is distributed to the upstairs corridors, flows into the laboratory spaces, and is pulled into the basement plenum where approximately 10% of the air is exhausted through HEPA filters to a monitored stack. The building is maintained at a negative pressure with respect to the environment. This system, if operational during a fire, would lower laboratory room temperature, thus minimizing potential for flashover. On the other hand, during the late stages of accident progression, the HVAC may aid flashover by aiding in the distribution of hot gases.

   The PF-4, Zone I, HVAC design draws air from the basement, through HEPA filters, through the gloveboxes, and exhausts 100% of the glovebox air through HEPA filters, to the monitored stack. The glovebox lines are always maintained at a negative pressure with respect to the laboratory rooms.

Administrative Controls

The only administrative control taken credit for in this model is the transient combustible loads program. The findings from this program (which includes monthly walkdowns) were used in this study to establish probable fuel loadings within each laboratory room in PF-4. The program is implemented as a Technical Safety Requirement (TSR) for the facility and is under the control of a fire protection engineer. The transient fuel loads were added to the fixed combustible fuel loads (e.g., PMMA shields) to obtain room total fuel loads. The rooms with the highest fuel loading are 207, 208, and 209, primarily because of the PMMA shielding on the gloveboxes. The remainder of the facility maintains exceptionally low combustible loads (most < 0.5 lb/ft^2), which would limit fire propagation.

Human Response

The only human response taken credit for in this study involved a TA-55 worker extinguishing an operational fire during an early stage. In the model, for the worker to extinguish the fire (a) the worker must be present when the ignition occurs and (b) the worker is trained and equipped to undertake fire fighting. Operational history has shown that TA-55 worker intervention is a very effective means for containing fire. However, this study assigned a low probability for workers being successful at containing (or extinguishing) fires (24% for operational fires and 0% for seismic fires). The study did not give any credit for Los Alamos Fire Department response or the late response of TA-55 workers. Thus, the study assumptions regarding human response are very conservative.

2.3. Deterministic Modeling

Deterministic models were used to evaluate the pathways by which a TA-55 fire could ultimately propagate throughout the remainder of the PF-4 building, thereby resulting in a building-wide fire. Two computer codes were used in this analysis, *CFAST* and *MELCOR*. *CFAST* was used to model fires in large PF-4 enclosures, specifically laboratory areas/rooms and the building basement. *CFAST* is a zone model capable of predicting the environment in a multicompartment structure subjected to a fire. It calculates the time-evolving distribution of smoke and fire gases and the temperature throughout a building as a result of a postulated fire. *CFAST* was developed and verified by the National Institute of Standards and Technology and is recognized in the fire protection community. A registered fire protection engineer performed the *CFAST* calculations for PF-4. The *CFAST* calculations postulated fires of different severities and analyzed their response to the operation of various mitigating systems. The mitigating systems modeled included fire barriers (with and without penetrations), the fire sprinkler system, and the HVAC. These analyses were conducted based on very conservative assumptions regarding flashover and fire propagation.

The *MELCOR* computer code was used to model fires in small, interconnected compartments in PF-4, such as glove box lines. *MELCOR* has the capability of modeling HVAC and gas flows to a high degree of fidelity. *MELCOR* is an engineering-level computer code developed and verified by the US Nuclear Regulatory Commission (NRC) that models the progression of accidents in light-water reactor nuclear power plants. The *CFAST* and *MELCOR* analyses and associated results are described in detail in References 1 and 3. Figure 2-3 shows all fire propagation pathways modeled in the study and the barriers in place to prohibit propagation. The major findings from these analyses are as follows.

> The physical construction of the glove box system in PF-4 (including the trunklines, drop boxes, etc.) is such that the events that occurred during two major glove box system fires at the Rocky Flats Plant could not occur at TA-55. The walls of the conveyor system (and all other boundaries of the glove box lines) in PF-4 are made of stainless steel, not the flammable Plexiglas/Benelex material used at Rocky Flats. Consequently, propagation of a fire that originates in a single glove box to other locations in PF-4 is conceivable under only two conditions:
>
> 1. Flame propagation along a continuous train of <u>transient</u> combustible material (e.g., temporary storage of trash or other combustible materials in glove box trunklines); or
> 2. Transport of hot combustion gases to other locations, causing ignition of combustible materials elsewhere in the system (i.e., flashover).
>
> While the first condition is not precluded by current facility operating procedures, normal facility housekeeping practices include packaging and removal of residual, combustible materials from glove box lines, particularly those with active processes.[11]
>
> Calculations performed to address the second condition [see Leonard (1999)] indicate propagation of a fire originating in a single glove box to other critical locations, such as neighboring glove boxes, drop boxes or

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[11] Implicitly, fire propagation by means other than flashover are ruled out because (a) PF-4 walk-downs and surveys did not reveal a single instance where there were continuous fuel trains in a room or between gloveboxes and (b) the radiant heat flux is not sufficient to ignite materials not physically connected.

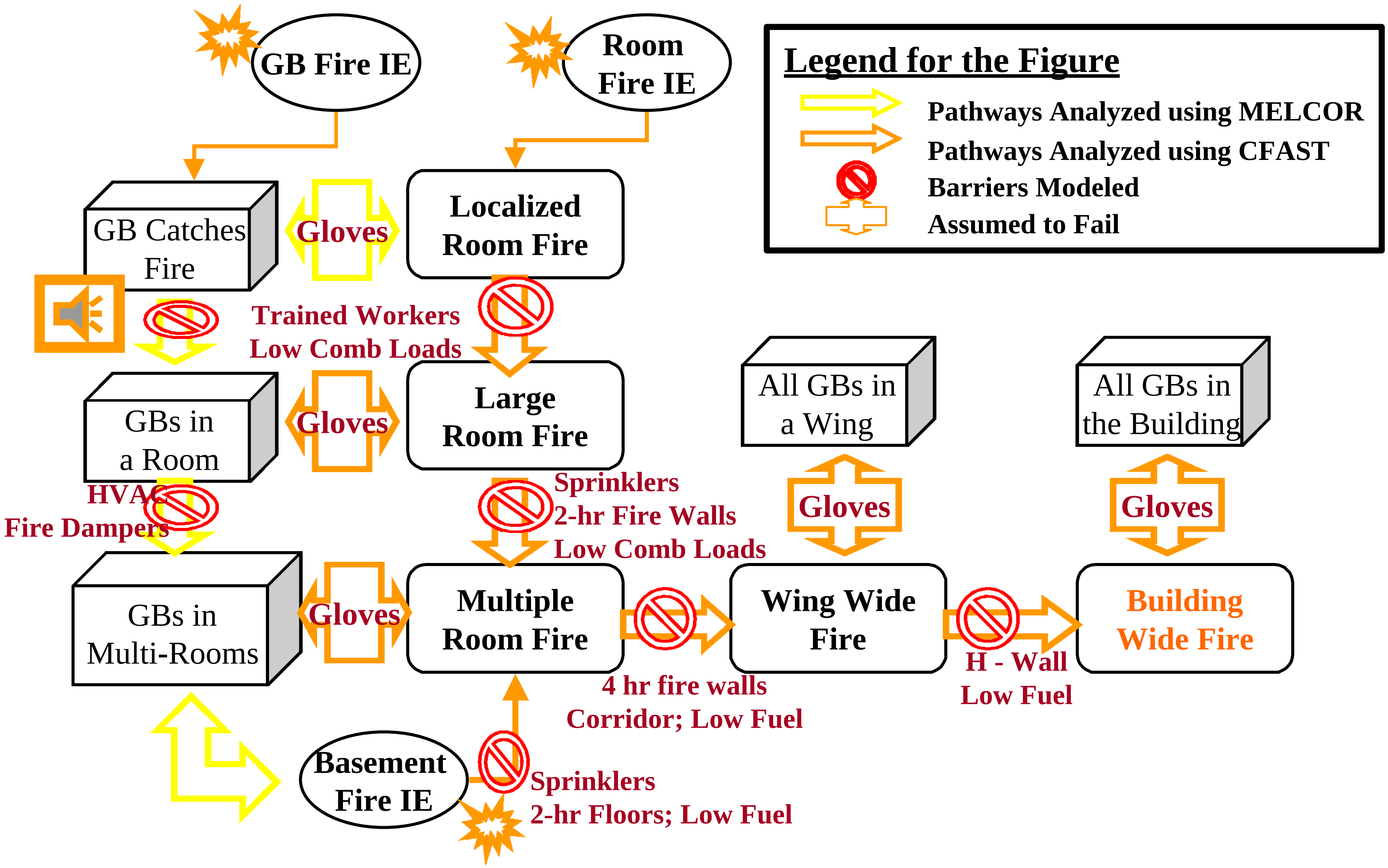


Fig. 2-3. Pathway and barriers to fire propagation.

ventilation system exhaust plena is extremely unlikely. Even under conditions in which engineered safety systems are postulated to fail (e.g., glovebox ventilation or drop box fire dampers), temperatures at any location other than (perhaps) highly localized regions of the room containing the glovebox were found to be well below values that would cause ignition of other combustible materials.

A small room fire[12] can propagate into local gloveboxes or grow to become a larger laboratory room fire if the TA-55 worker fails to extinguish/control the fire **and** the combustible loading is sufficient to cause flashover.[11]

A large laboratory room fire will actuate the 212^{o}F sprinklers and heat sensors and will be contained if the FWSS systems function properly. If the sprinkler system fails, such a fire can breach the room fire walls provided sufficient combustible loads exist in the laboratory room. One of the mechanisms available for propagation generally is referred to as "flashover" and relates to the process by which hot combustion gases produced in the room will escape through the open penetrations and doorways and build up high temperatures in the adjoining room. The other mechanism relates to thermal failure of fire barriers because of overheating, i.e., when they are heated for periods longer than 2 h or when flame temperatures exceed the design temperature. Both these mechanisms can ultimately lead to ignition of flammable materials located in the adjoining room. CFAST was used to define the conditions under which room-to-room fire propagation would occur.

The understanding gained regarding various pathways for available fire propagation was instrumental in developing the event trees (i.e., the event trees were structured to reflect the insights gained from the modeling effort). The results of the modeling effort also were used to determine minimum set of systems and human actions that are necessary to contain/extinguish a fire at each phase of the accident progression. These results also were used to devise the logic by which individual system models (i.e., fault trees) are linked together to estimate sequence frequencies.

2.4. Accident-Sequence Quantification

This study developed two event trees, one each for operational fire and seismic fire. System fault trees were used to estimate the failure/success probabilities of the branch points (split fractions) on the event tree. The built-in logic for event-tree/fault-tree linking ensured that common-cause failures and system dependencies were handled accurately (e.g., a seismic event will take out electrical fans in the HVAC). The event- and fault-tree models were developed, quantified, and analyzed using the *SAPHIRE* computer code developed by the Idaho National Engineering Laboratory (INEL) for the NRC.

Operational history specific to TA-55 was used to derive initiating event frequencies and fault tree event probabilities. These data were supplemented, where necessary, by other available data sources.

3.0. BUILDING-WIDE FIRE RESULTING FROM OPERATIONAL FIRE IN A LABORATORY ROOM

The initiator considered in this section is an operational fire, which is defined as ignition either in or outside the glovebox. The potential for its propagation ultimately resulting in a building-wide fire is analyzed in this section. Supporting analyses for the results summarized in this section are presented in References 1 through 3.

3.1. Quantification of Initiating-Event Frequency

Various sources of historical data were reviewed to estimate the frequency of occurrence of random (operational) fires in the TA-55 building. Historical data specific to TA-55 were used where possible and were supplemented as necessary with data from other nuclear facilities. These estimates were compared with data derived from the operational histories of other DOE laboratory facilities (including Rocky Flats).

Historical data specific to TA-55 were derived primarily from Unusual Occurrence Report (UOR) events. UORs are generated for a variety of off-normal conditions or situations, for example, loss of glovebox integrity, spills, leaks, equipment failures, human errors, explosions, and fires. UOR events were gathered from various

[12] It is assumed that a small laboratory room fire will not trigger the sprinkler system until it grows to become a larger fire. It may trigger heat sensors and alert operators.

sources, including DOE's Safety Performance Measurement Systems (SPMS) database, DOE's Occurrence Reporting and Processing System (ORPS), a set of pre-ORPS data, and various TA-55 internal memoranda from 1981 and 1983. The earliest events contained in this set of data occurred in 1981. It is noteworthy that the incident history before implementation of the Pre-ORPS database in September 1990 may be incomplete. Table 3-1 lists all the fire-related events extracted from these data sources that pertain to TA-55.

Ignition Outside the Glovebox

Given the information from the preceding set of UOR data, there have been no occurrences of an ignition in a PF-4 laboratory room outside the glovebox. The primary reasons for such a low frequency are (a) no process involving ignition sources (including temporary storage of heat sources) is allowed outside the glovebox and (b) no flammable materials are stored outside the gloveboxes except for flammable gases, which are stored in pressure vessels. It is interesting that PF-4 hazards analyses also did not identify any process that would start a fire outside the glove box, in a laboratory room. Given zero PF-4 laboratory room fires in the 18 yr from 1981 through 1998, the median frequency of laboratory room fires at PF-4 can be estimated to be 0.04/yr, with 5^{th} and 95^{th} confidence values of 0.003/yr and 0.15/yr, respectively.[13] The 95^{th} confidence value of 0.15/yr was used in this study to address the eventuality that a human error or other random events can cause ignition in the laboratory room, outside the glovebox. These values compare as follows with the data from other facilities.

Two documents published by the DOE's Office of the Deputy Assistant Secretary for Safety and Quality Assurance ("Summary of Fire Protection Programs of the US DOE Calendar Year 1991" and "Summary of Fire Protection Programs of the US DOE Calendar Year 1992") and an unpublished book by Walter Maybe ("AEC/ERDA/DOE Fire Protection History," August 1995) indicate that across the DOE Complex, there were 280 room fires between 1975 and 1990, 120 fires in 1991 and 131 fires in 1992. Based on the preceding data, there were at least 531(= 280 + 120 + 131) fires during the 18-yr inclusive period between 1975 and 1992. These data cover over 10,000-laboratory building-years of operation and result in a mean frequency of 0.05/yr. This value is lower than the frequency of 0.15/yr used in the present study.

Fire incident data pertinent to the DOE's Rocky Flats site was documented in the Stone and Webster Engineering Company Report title "SFAR Review Team Report on Rocky Flats Building 707" (Volume 1, Main Report, November 1991). This report summarizes Rocky Flats building fire events that occurred outside gloveboxes but inside modules at several plutonium-related buildings. There were 94 of these types of fires among several Rocky Flats plutonium buildings (559, 707, 771, 776/777, and 779) over an interval of 175 building-years. Per these data, the frequency of a room fire at Rocky Flats during the reporting period was about 0.5 per building per year. This value is higher than the value of 0.15/yr used in the present study to represent the frequency of a laboratory room fire in the PF-4 building.

Ignition Inside the Glovebox

Per the TA-55 UOR data previously described, a total of 10 occurrences of glovebox fires or glovebox fire precursor events was identified at TA-55 for the years 1981 through 1998 inclusive. These 10 glovebox incidents are summarized in Table 3-1. The sources for the events summarized in Table 3-1 are internal memos and the referenced database reports collected for the period 1981 through 1998. Again, the history before implementation of the Pre-ORPS database in September 1990 may be incomplete.

Table 3-2 summarizes the TA-55 glovebox fire and fire precursor statistics as derived from Table 3-1. There are 10 fires or fire precursor events for 1981 through 1998. As indicated in Table 3-2, six of these events occurred from 1991 onward, a time interval for which the recorded data are complete. Therefore, the point estimate rate of glovebox fires at TA-55 over the 8-yr period from 1991 through 1998 inclusive is 0.75 per year.

This value is conservative because some of the recorded events are precursors and did not include an actual ignition. The extent of conservatism can be demonstrated by considering an event-tree model (Fig. 3-1) that displays the pathways by which each event category can lead to a glovebox fire. For explosion/fire events, the

[13] Non-zero estimates for median, 5^{th} and 95^{th} confidence values were derived from a binomial probability distribution given zero observed fires in 18 yr.

Table 3-1
List of Fires and Fire Precursor Events for TA-55 Gloveboxes–1981 through 1998

Applicable UOR	Event Description	Type of Event	Remarks
SPMS-82701	Ignition of either smoke generated during incineration of mixture of plastics and damp and rinsed and dried (cheesecloth) rags or of the rags themselves resulted in glovebox over-pressurization; two windows blown off glovebox.	Explosion/fire	Accident may be applicable to other oxygen-sparged, high-temperature reduction of organic materials processes. Alternate process considered but no indication whether process changed.
SPMS-82703	Exothermic reaction during air purification of mixture of 13 sweepings over-pressurized glovebox and blew out top window. Furnace temperature lowered to 350ºF from normal 500ºF because rust-brown, sand-consistency sample (produced in 1965) was labeled “refrigerate”.	Explosion/fire	Accident occurred in spite of operator’s precautions. Procedures instituted to analyze and/or reduce questionable samples to metal and to prevent mixing of characterized and uncharacterized samples.
SPMS-85755	Mixture of polypropylene filters in nitric acid dried out and ignited during overnight hot-plate digestion process. Heat detector worked; glovebox train successfully isolated and fire starved.	Overheated equipment	Hot-plate temperature set too high.
SPMS-87755	Thermocouple wiring insulation contacted furnace element after normal working hours. Guard noticed resulting smoke and pulled manual fire alarm, which did not operate. Guard called control room operator, who confirmed no alarm was received; guard pulled another alarm that operated successfully.	Overheated equipment	No indication that control room operator independently contacted fire department.
ALO-LA-TA-55-1993-0036	Spark from plasma arc cutter ignited pile of cheesecloth rags; fire tamped out using a glove, and fire embers sprayed with liquid cleaning fluid (Fantastik).	Spontaneous ignition	
ALO-LA-TA-55-1994-0033	Alcohol-wetted, plutonium-contaminated rags in open steel storage can located in a drop box thermally decomposed to ash. Plastic bottle in contact with can melted	Spontaneous ignition	Drop box heat-sensing unit having a 140ºF set point temperature did not actuate.
ALO-LA-TA-55-1994-0037	Alcohol-wetted plutonium-contaminated rags that had been removed from an externally corroded storage can spontaneously combusted in glovebox. Manual alarm actuated, glovebox manually isolated, and fire department responded to alarm.	Spontaneous ignition	During post-fire inspection, two additional similar cans discovered to have corroded exteriors and placed in inerted gloveboxes. EPA incineration stoppage has forced situation where combustibles are stored with heat-producing radionuclide.
ALO-LA-TA-55-1995-0002	Oxidized metal being scraped form metalographic sample fell onto nearby terry cloth, which ignited. Employee placed towel in transfer box and inerted box.	Spontaneous ignition	Glovebox heat-sensing unit having a 190ºF set-point temperature did not actuate.
ALO-LA-TA-55-1997-0008	During crushing and pulverizing operation employee noticed excessive plutonium residue smoldering in a catch pan. Employee covered can with steel lid (provided for this purpose) and inerted glovebox.	Spontaneous ignition	Smoldering reaction is anticipated to occur during crushing and pulverizing operations.
ALO-LA-TA-55-1998-0038	Employee observed smoke coming from a trolley system electric motor. Employee de-energized motor and actuated manual fire alarm. Fire department successfully responded to alarm.	Overheated equipment	Not a combustion event.

Table 3-2
Summary of Fires and Fire Precursor Events for TA-55 Gloveboxes

Event Category	Number of Events
TA-55 UOR Data From 1981 Through 1998, Inclusive (18 yr period)	
Explosion/Fire	2
Spontaneous Ignition	5
Overheated Equipment	3
Total 1981–1998	10
Frequency (per year)	**$5.6x10^{-1}$ (mean, point estimate)**
TA-55 UOR Data From 1991 Through 1998, Inclusive (10 yr period)	
Explosion/Fire	0
Spontaneous Ignition	5
Overheated Equipment	1
Total 1991–1998	6
Frequency (per year)	**$7.5x10^{-1}$ (mean, point estimate)**

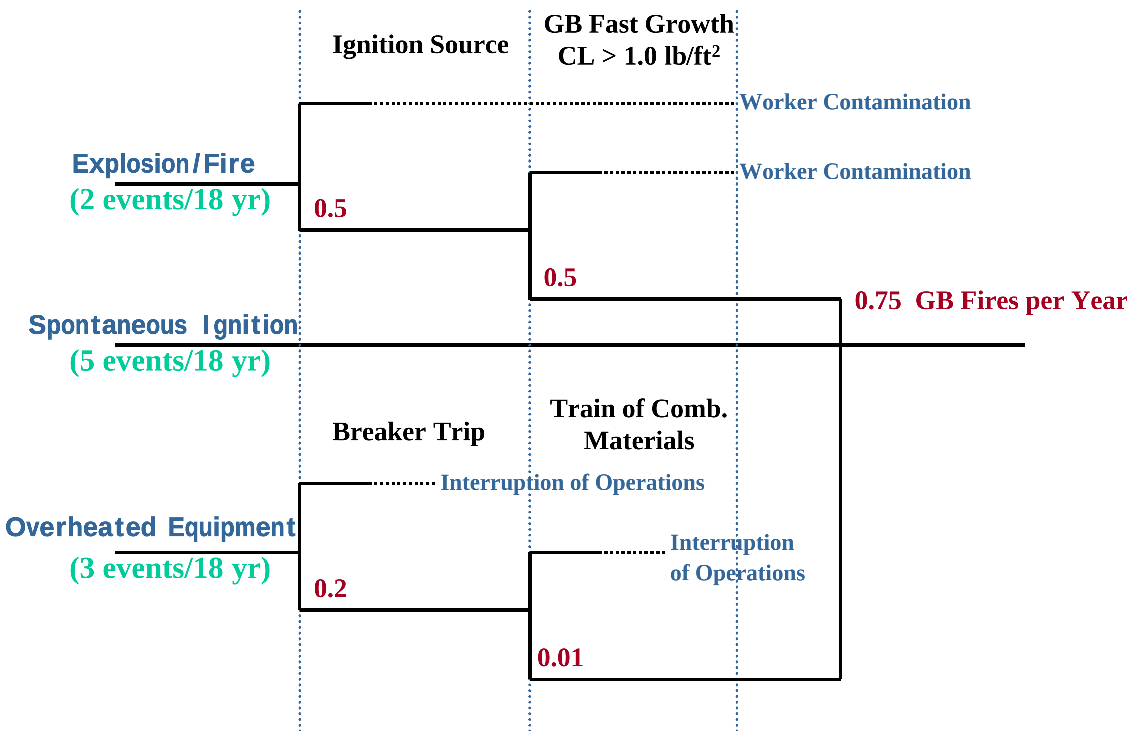


Fig. 3-1. Pathways that may lead to a glovebox fire.

occurrence of a fire requires that a post-explosion ignition source be present. Without an ignition source, the event will simply lead to worker contamination. Given an ignition source, the fire will be self-limiting unless the quantity of combustible materials inside the glovebox is greater than 3 lb. Given a post-explosion ignition source and sufficiently high combustible loading, the explosion event will lead to a glovebox fire as shown in Fig 3-1. Using the split fraction data, a glovebox fire resulting from an explosion would occur only 25% of the time. However, to be conservative, an explosion event was assumed to result in a glovebox fire 100% of the time. Similarly, events involving overheated equipment often do not lead to fires. As indicated in Fig. 3-1, there is a significant possibility that protective circuit breakers will interrupt electrical current to overheated equipment before a fire can occur. Even if flames erupt, there is only a small probability that there will be a sufficient quantity of combustible materials in the immediate vicinity of the overheated equipment to sustain the fire. Again, to be conservative, events involving overheated equipment were assumed to result in a glovebox fire 100% of the time.

Total Frequency of Ignition in a Laboratory Room

Based on the preceding considerations, the frequency of glovebox fires at TA-55 was assumed conservatively to be 0.75/yr. This frequency estimate was added to that obtained for ignition outside the glovebox (0.15/yr.) to arrive at the frequency of a randomly caused PF-4 laboratory room fire of 1/yr. Given that there are 115 rooms in PF-4, the frequency of a fire occurring in any particular room was estimated conservatively to be $9\text{x}10^{-3}$/yr.

In summary, various methods have been used to estimate the frequency of fires at PF-4. The frequency estimates are summarized in Table 3-3.

3.2. Formulation of Success Criteria for Fire Containment

Deterministic analyses (described in Appendices A and B) were used to derive a set of success criteria related to containment of fire during various stages of its progression. This section summarizes the success criteria.

Criteria for Fire Contained in the Local Area Where It Was Started: For a fire to be contained within the local area, **either** (a) the operator should contain and extinguish fire within the first few minutes **or** (b) local fuel loading should not exceed 1 lb/ft^2. No qualified fire barriers exist within a room to prevent fire spread beyond the local point of ignition. This criterion takes into consideration that (a) because of possible release of radioactivity into the laboratory room, TA-55 worker response will be limited to few minutes after ignition and (b) a fuel loading of 1 lb/ft^2 will not lead to flashover [see Item (A) in Fig. 3-2].

Criteria for Fire Contained in the Laboratory Room in Which It Started: Two-hour NFPA-qualified fire barriers separate each room from the adjoining rooms, basement, and attic. In addition, each laboratory room is equipped with 212^{o}F wet-pipe fire sprinklers. For fire to be contained in the laboratory room of origin, **either** (a) the fire sprinkler system must actuate and provide adequate water flow **or** (b) effective combustible loading in the room must not exceed 8 lb/ft^2. Fire containment by Los Alamos fire fighters is not credited in this study. This criterion takes into consideration propagation of fire to the adjoining rooms as a result of (a) flashover resulting from hot fire gases leaking through open wall penetrations and (b) thermal failure of the fire wall [see Item (B) in Fig. 3-2].

Criteria for Fire Contained in the Area: The only possible mechanism for fire spread throughout the area (or a major portion of the area) is flashover, a mechanism by which hot combustion gasses leaking from one room to the other ignite flammable materials. For this condition **not** to occur (a) the effective combustible loading in the room adjacent[14] to the room where the fire started must not exceed 8 lb/ft^2 or (b) the Zone 1 ventilation system fails (thus limiting the spread of hot gases). Fire containment by Los Alamos fire fighters or sprinkler system recovery from the failed state is not credited in this study. This criterion takes into account the enhanced propagation of fire from one area to the other by flashover when the HVAC system is operational [see Item (C) in Fig. 3-2].

[14] Any room next to the room with the initial fire and in the same area is an "adjacent" room. A room across the corridor or in another area across from the room with the fire is not considered an adjacent room.

Table 3-3
Summary of Frequency Estimates for Room and Glovebox Fires and Precursor Events

Frequency of Fire (per year)	Method Used to Estimate Frequency	Notes
Ignitions outside glovebox (per year)		
Used in this Study PF-4 Bldg.: 0.15 (95th percentile) Per Room: $9x10^{-3}$	TA-55 UOR data, binomial distribution for 0 fires out of 18 yr with 95% confidence.	Represents the frequency of a laboratory room fire out of the total population of laboratory rooms in TA-55 For PF-4, there are 115 rooms; thus, the frequency of a fire per room per year at PF-4 would be 0.15/115 = **$9x10^{-3}$.**
All DOE Laboratory Rooms Per Bldg.: $3x10^{-3}$ (mean)	Statistics of fires averaged over numerous DOE facilities	Represents frequency of a laboratory room fire out of the total population of laboratory rooms in a representative DOE building
Rocky Flats Experience Per Bldg.: 0.5 (mean)	Rocky Flats operational data	Represents frequency of a laboratory room fire estimated from Rocky Flats experience. Major differences exist between Rocky Flats and PF-4 regarding construction, operation and administrative controls.
Ignitions inside glovebox (per year)		
Used in this Study PF-4 Bldg.: 0.75 (Mean) Per GB $1.9x10^{-3}$ (mean)	TA-55 UOR data	Annual rate of fires or precursor events summed over all 400+ gloveboxes at PF-4 is **$7.5x10^{-1}$/yr** (mean)
Rock Flats Experience: PF-4 Bldg.: 10 (Mean) Per GB: $2.5x10^{-2}$	Rocky Flats operational data. This number represents a high-end estimate because (1) the majority of the glovebox fires occurred before installation of glovebox inerting systems at Rocky Flats and (2) Rocky Flats typically processed larger quantities of materials than TA-55, thereby increasing the chances that a glovebox fire would occur there	Per individual glovebox. Rocky Fats experience of $2.5x10^{-2}$ per glovebox per year was multiplied by 400 to obtain 10 glovebox ignitions per year. These data are not applicable to PF-4 because PF-4 gloveboxes are inerted and they do not process nearly as much material as the gloveboxes at Rocky Flats.

Criteria for Fire Contained in the Wing: For a fire in one wing not to propagate to the other wing as a result of flashover, the following must be satisfied [see Item (D) in Fig. 3-2].

- Both of the two sets of doors in the H-wall on the upper level must remain closed, **AND**
- Both of the two sets of doors in the H-wall in basement must remain closed, **AND**
- One of the two fire dampers in the trolley crossover line must remain closed.

In summary, a small fire in a PF-4 room is postulated to grow into a larger room fire if the manual fire suppression fails to act and the local combustible loads exceed 1 lb/ft^2. A large room fire was assumed to propagate into an adjacent room via flashover if the fire suppression fails and the combustible loading exceeds 8 lb/ft^2 in the burning room. If an adjacent room also has a combustible loading that exceeds 8 lb/ft^2, the fire then can spread to the associated PF-4 Area (i.e., 100, 200, 300, or 400). If the ventilation system remains on, an area fire can propagate to the associated wing (i.e., North or South). The combustible loading in various PF-4 regions is insufficient to allow fire propagation through the interior fire barrier (H-wall) separating the two wings. However, if a mechanical pathway through the H-wall exists, a wing fire can spread into the remaining wing, resulting in a building-wide fire. An H-wall mechanical pathway is created if a trolley line crossover is open, an upper or lower level door is open, or an H-wall penetration is open for test/maintenance activities. It again is emphasized that fire

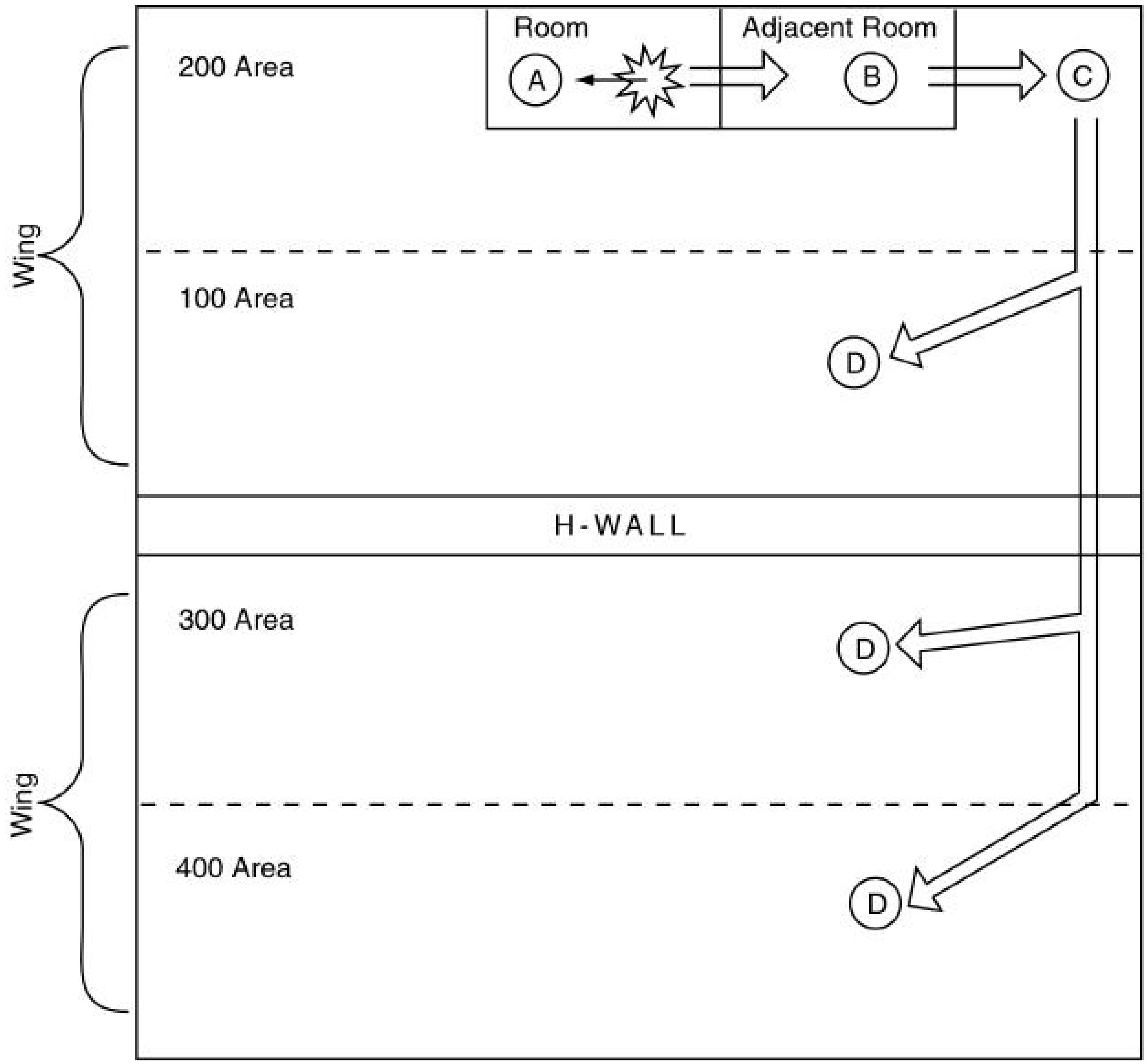


Fig. 3-2. Overview of fire progression.

propagation also requires failure of the automatic and manual fire suppression. Also, this study does not credit either the Los Alamos fire department response or the TA-55 staff response to recover a failed fire suppression system.

Alternatively, a building-wide fire can be avoided if <u>any</u> of the following conditions exist.

- Manual fire suppression actions in less than 2 min *or*
- Operation of the automatic fire suppression system *or*
- Quantity of combustible material in the local area where fire started does not exceed 1 lb/ft^2 *or*
- Quantity of combustible material in the room where fire started does not exceed 8 lb/ft^2 *or*
- Quantity of combustible material in any room adjacent to the ignition area does not exceed 8 lb/ft^2 *or*
- Ventilation system is off (either turned off or fails because of high gas temperature) *or*
- All interior fire pathways between wings (H-walls) are closed

3.3. Quantification of Fire Spread Sequences

As discussed above, a PF-4 room fire can propagate into a PF-4 area *if and only if* each of two adjacent rooms has a combustible loading in excess of 8 lb/ft^2. In addition, the fire would have had to originate in one of these rooms. Based on facility walkdowns and reviews of facility records and documentation, only one set of PF-4 rooms was identified where these criteria can be met, namely, Rooms 207 and 208. Room 207 usually has a combustible loading in excess of 8 lb/ft^2, and Room 208 normally contains about 6 lb/ft^2 of combustible material, although historical experience indicates that the amount of combustible material exceeds 8 lb/ ft^2 approximately 0.26% of the time. No other room at PF-4 has combustible loads (transient plus fixed) larger than 2.5 lb/ft^2. Therefore, for a fire to propagate beyond the room of its origin, (a) it has to originate in Room 207, spread to Room 208, and, given sufficient combustible loading in Room 208, subsequently spread to the PF-4 200 Area, **or** (b) the fire could originate in Room 208 during a period where combustible loading exceeds 8 lb/ft^2, spread to Room 207, and subsequently spread throughout the remainder of the PF-4 200 Area.

3.3.1. Event-Tree Model. Figure 3-3 shows the event tree used in the analysis. This event tree portrays the possibilities for the progression of a room fire. The event tree is structured so that the progression of the accident is represented in a time-ordered manner from left to right. In this model, successful mitigation of the room fire occurs whenever the fire is contained before it becomes the building-wide fire.

There are five headings on the event tree. Starting from the left, the first heading represents the room fire-initiating event: fire started in Room 207 or 208. The second heading is used to indicate whether the source of ignition is extinguished. The third heading represents the status of the fire with regard to containment in the room of origin. Likewise, the fourth and fifth headings represent the status of the fire with regard to area and wing containment, respectively.

The event tree has five sequences; four (OF-1 through OF-4) represent success (no building-wide fire), whereas Sequence OF-5 represents failure (a building-wide fire). Each of these sequences is described in more detail below.

Sequence OF-1 represents the situation where either (a) the ignition source in the room is extinguished by workers in the vicinity or (b) local combustibles loads are low (do not exceed 1lb/ft^2).

In Sequence OF-2, workers are unavailable to extinguish the fire. However, the fire is contained in the room of origin because either (a) the fire water suppression system successfully operates or (b) the combustible loading in the room does not exceed 8 lb/ft^2. (As previously discussed, the room combustible loading must exceed 8 lb/ft^2 before a room fire can fail the room firewalls.)

In Sequence OF-3, an initial room fire propagates into adjacent room(s). The fire is able to propagate beyond the room of fire origin because fire suppression is unavailable and the room has a combustible loading that exceeds 8 lb/ft^2. However, fire propagation beyond the room of origin and the adjacent room(s) into the entire wing is avoided because (a) the combustible loading in room(s) adjacent to the room of fire origin does not exceed 8 lb/ft^2 or (b) the ventilation system is turned off. The building confinement system is intact for this sequence; thus, item (b) has little contribution.

In Sequence OF-4, an initial room fire propagates into an entire wing. For this situation to occur, combustible loading in both the room of fire origin and an adjacent room must exceed 8 lb/ft^2 and the building ventilation system must be on. (As in Sequence OF-3, the fire suppression system in the room of fire origin has failed.) Fire propagation into the entire building is prevented because all interior fire pathways between wings (H-walls) are closed.

Sequence OF-5 is similar to Sequence OF-4, except that Sequence OF-5 includes an open H-wall pathway between wings. An H-wall pathway can occur from an open trolley line crossover, an open upper or lower door, or an H-wall penetration that happens to be open for test/maintenance activities. Given an open H-wall pathway, a building-wide fire is postulated to occur.

3.3.2. Sequence Quantification. Per the discussion in Sec. 4.1.2, the frequency of fires per room at PF-4 was assumed to be 9×10^{-3}/yr. This value was used to represent the frequency of fire in either Room 207 or 208 to be

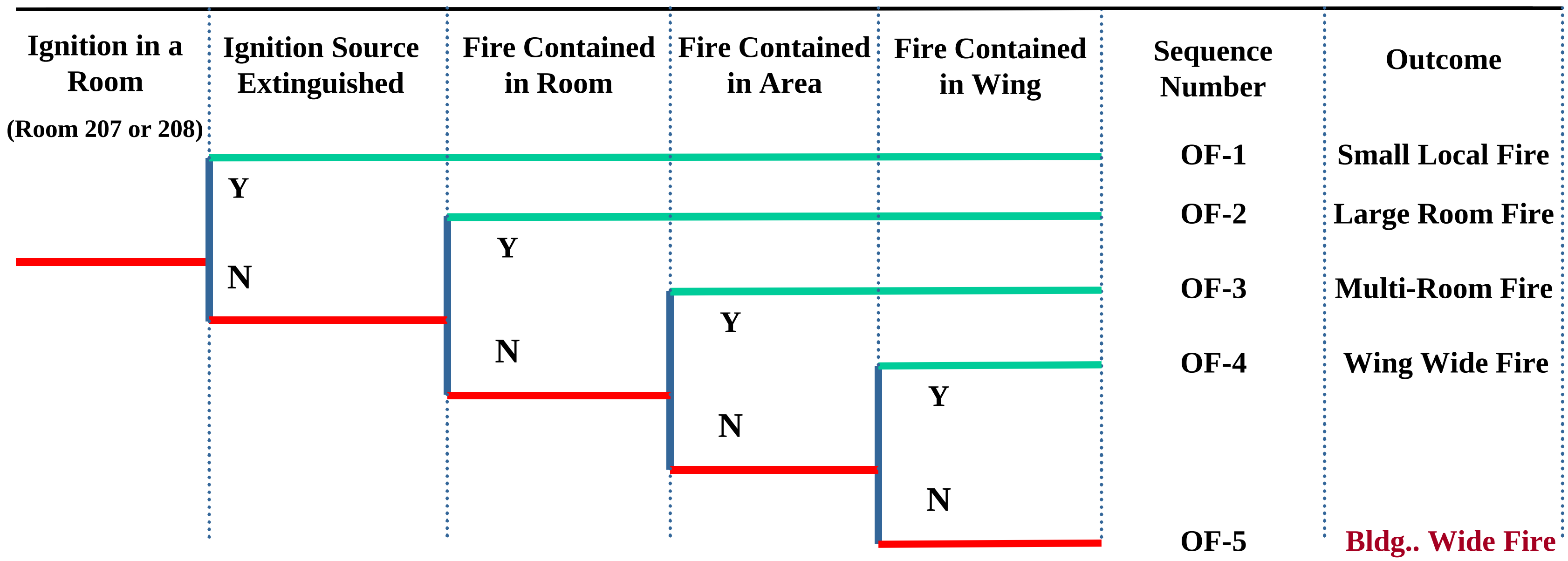


Fig. 3-3. Event tree used in operational fire analysis.

$2x10^{-2}$/yr. Use of this number for Room 208 is conservative because it is not very common that Room 208 has a fuel loading in excess of 8 lb/ft^2.

Fault-tree models were developed to evaluate split fraction probabilities for the other event tree headings.

- Ignition Source Extinguished (indicates whether a fire has been extinguished in source region)
- Fire Contained in Room (status of the fire with regard to room containment)
- Fire Contained in Area (status of the fire with regard to area containment)
- Fire Contained in Wing (status of the fire with regard to wing containment)

The fault-tree models for the above event-tree headings are summarized below. A complete set of fault trees and quantification data is provided in Darby (1999).

The fault tree for the event tree heading “Ignition Source Extinguished” models the possibility that a fire in Room 207 or 208 cannot be extinguished in the room of origin (downward portion of the split fraction). As explained previously, there must be in excess of 1 lb/ft^2 of combustibles in a room for an initiator not to self-extinguish. Given that the fire is assumed to originate in either Room 207 or Room 208, which have combustible loads in excess of 1 lb/ft^2, the postulated fire initiator will not self-extinguish. The probability that on-site workers manually extinguish the fire was determined by the fraction of time that workers would not be present, which is approximately 76% of the time. (Workers were assumed to be present 40 h per week.)

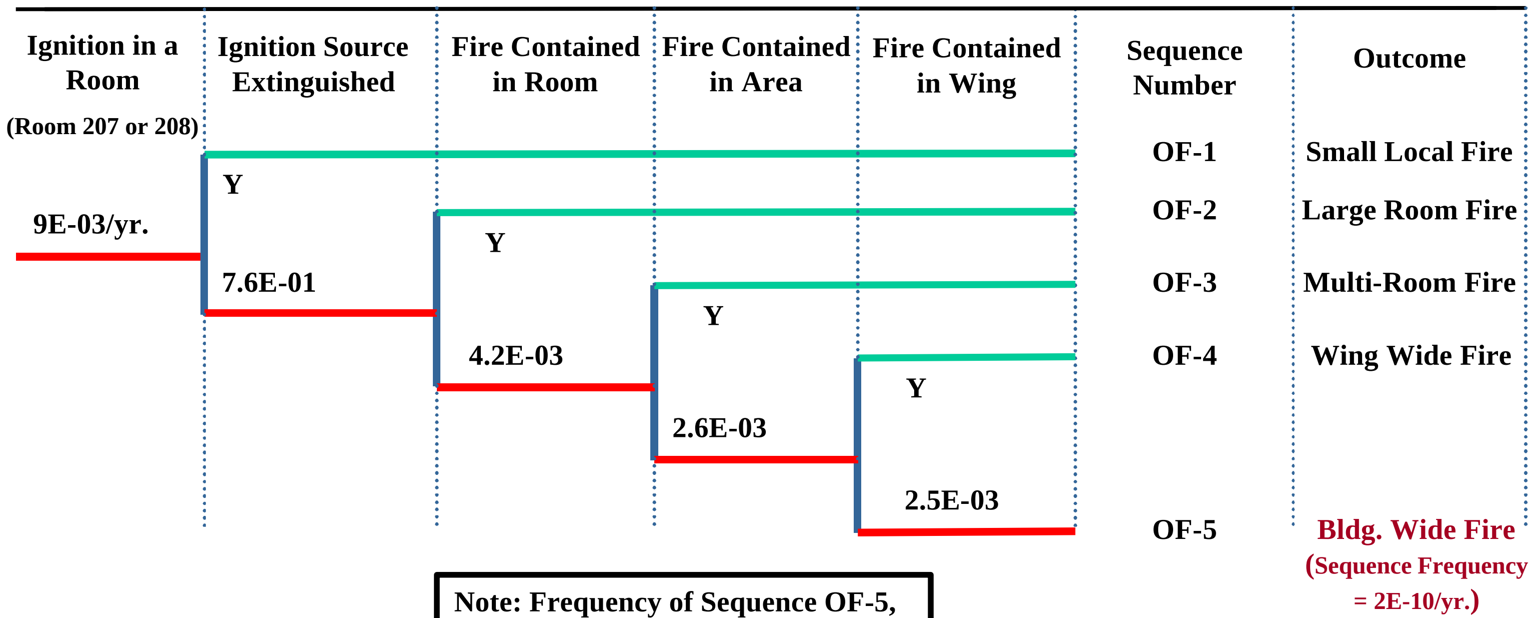
The fault tree for event-tree heading “Fire Contained in Room” represents the possibility that the fire is not contained in its room of origin but will instead propagate to an adjacent room (downward portion of the split fraction). This fault-tree logic requires that the combustible loading in the fire origination room exceed 8 lb/ft^2 along with failure of the FWSS. These two elements of the fault tree are combined together in **AND** logic. The fault-tree structure for the FWSS is developed further into the sprinkler and water supply subsystems. The required support systems, for example, electrical power, also are modeled. The sprinkler and water supply and their support systems are developed to the component level. It was modeled that one of four fire water supply pumps would provide sufficient flow to the sprinklers. Quantification of the fire water supply fault tree was based on TA-55 specific data and operating experience to the extent possible.

The event-tree heading “Fire Contained in Area” represents the possibility that a fire that has expanded into an adjacent room will propagate into an area-wide fire (downward portion of the split fraction). The corresponding fault-tree logic requires that the combustible loading in the room adjacent to the fire origination room exceeds 8 lb/ft^2 and that the ventilation system operates. These two elements of the fault tree are combined together in **AND** logic. As previously discussed, Room 207 usually has a combustible loading in excess of 8 lb/ft^2, whereas Room 208 has this level of combustible loading about 0.26% of the time. For this analysis, it was assumed conservatively that the ventilation system would be on during the fire. Therefore, the corresponding event representing ventilation system operation was assigned a probability of 1.

The fault tree for event-tree heading “Fire Contained in Wing” represents the possibility that the wing fire will propagate to the remaining wing, resulting in a building-wide fire (downward portion of the split fraction). Propagation of a wing fire into a building-wide fire will occur if an interior fire wall barrier (H-wall) is open. The fault tree models the four possible methods by which an H-wall pathway can occur: an open trolley line crossover, an open upper level door, an open lower level door, or an H-wall penetration that is open for test/maintenance activities. Quantification of the fault-tree bottom events was based on TA-55 specific data and operating experience where possible.

3.4. Results and Discussions

Figure 3-4 shows the split fractions and sequence frequencies for a fire initiated in either Room 207 or Room 208. Per the analysis, a building-wide fire has a point-value frequency estimate of $2x10^{-10}$/yr. Given that a fire could occur in either Room 207 or Room 208, the overall point-value estimate for the frequency of a building-wide fire is $4x10^{-10}$/yr.



Note: Frequency of Sequence OF-5, 2E-10/yr., is a result of a fire in either Room 207 or Room 208; the total frequency of a building-wide fire is therefore <u>4E-10/yr.</u>

Fig. 3-4. Event tree results for operational fire in PF-4.
Note for example: 9E-03 = $9x10^{-3}$

The very low frequency of a building-wide fire is a result of a combination of the following low-frequency/probability events.

1. The frequency for a random fire in one of only two rooms that has sufficient combustible loading to promote fire propagation (either Room 207 or 208): $9x10^{-3}$/yr.
2. The conditional probability for failure of the fire water suppression system: $4.2x10^{-3}$.
3. The conditional probability that combustible loading in a room adjacent to the room of fire origin is sufficient to allow fire propagation: $2.6x10^{-3}$.
4. The conditional probability that penetrations in the H-wall are open, thus allowing fire to spread to the other wing: $2.5x10^{-3}$.

There is one relatively high probability event, namely, ignition source not extinguished by local worker response, which has a conditional probability of 0.78. The product of these probabilistic data for these independent events is essentially the frequency of a building-wide fire because there is little sharing of structures, systems, and components (SSCs) among the constituent events in the sequence.

Two dominant cut sets[15] collectively represent about 46% of the total building-wide fire frequency. The most dominant sequence cut set, which represents about 29% of the building-wide fire frequency, includes two important failure events: (a) failure of the sprinkler alarm check valve to open on demand and (b) failure of the room heat detector to close cross-over trolley dampers. The second most dominant cut set, representing about 17% of the building-wide fire frequency, includes the following important failure events: (a) failure of the sprinkler alarm check valve to open on demand and (b) an H-wall penetration that is open for test/maintenance activities.

3.5. Limitations and Conservatism

A number of conservative assumptions were made in this analysis. Examples of some of these conservative assumptions are summarized below.

- Even though there have been no instances of laboratory room or basement fires at TA-55, the analysis assumed that a room fire would occur with the frequency of glovebox fires. Furthermore, the frequency of glovebox fires was estimated conservatively by including several events that were only potential fire precursor events and not actual fires.
- Deterministic calculations indicate that for a flashover fire to occur, combustible loadings in two adjacent rooms must each exceed 8 lb/ft^2 and the combined floor area of these rooms must exceed 4500 ft^2. There are no pairs of adjacent rooms in PF-4 where this situation occurs. The analysis conservatively assumed that flashover could occur simply if the 8-lb/ft^2 combustible room loading was met without consideration of the total floor area.
- It was assumed that laboratory room doors would remain open during a fire scenario. Closed room doors would represent a 1.5-h fire barrier.
- No credit was taken for the response and mitigating actions of dedicated, off-site fire department personnel.
- Propagation of an area-wide fire to an entire wing requires that the ventilation system remain on. The analysis conservatively assumed that the ventilation system would be on during the fire sequences.

4.0. BUILDING-WIDE FIRE RESULTING FROM SEISMIC EVENT

4.1. Overall Approach for Seismic Analysis

The analysis method used in the seismic analysis is largely based on an approach described by Kennedy et. al. (R. P. Kennedy et. al. *Probabilistic Seismic Safety Study of an Existing Nuclear Power Plant,* Nuclear Engineering and Design Vol. 59, pp. 315-338, March 1980). The three major Analysis Elements used in the TA-55 approach are:

[15] A "cut-set" is a combination of the initiating event (fire) and a specific set of subsequent failure events that result in a building-wide fire.

1. Estimate the ground motion (peak ground acceleration) as a function of the annual frequency of occurrence,
2. Estimate the conditional probability of failure for structures, equipment, etc. as a function of ground acceleration (fragility), and
3. Combine the estimates from elements (1) and (2) into system and event tree models to estimate the frequency of seismic-induced fires that release bulk Pu.

Section 4.1.1 summarizes Analysis Element (1), the quantification of seismic initiating event frequencies at TA-55. Section 4.1.2 describes Analysis Element (2), which involves the development of system and component fragility curves. Analysis Element (3), the quantification of fire-related Pu releases, is summarized in Sec. 4.1.3. Further details on the analysis approach are provided in Darby (1999).

4.1.1. Quantification of Initiating-Event Frequency. The frequency of a seismic event cannot be represented by a single value because the frequency of a seismic event is a strong function of the resulting ground motion. The seismic hazard at a given site is represented most easily by a plot of the annual frequency of exceedance vs peak ground acceleration (PGA). Figure 4-1 displays the annual frequency of exceedance vs PGA for the TA-55 site as developed by Woodward-Clyde Federal Services. This figure includes separate curves representing mean, median, 16^{th}-84^{th} percentiles, and 5^{th}-95^{th} percentiles. The mean value curve in Fig. 4-1 was used to generate frequency estimates for seismic activity at TA-55. The analysis sampled the entire seismic hazard curve.

The annual frequency of occurrence for a seismic event within a specific PGA interval can be obtained from the differential of the frequency of exceedance curve with respect to the PGA. Specifically, let $H(x)|_x = X$ be the function in Fig. 4-1 representing the frequency that a seismic event exceeds a specific PGA of value X. Then, – $(dH/dx)|_{x=X}$ * dx is the frequency for an initiating event with a PGA that is in the interval (X, X + dx); the minus sign is necessary because H is an exceedance function.

4.1.2. System/Component Fragility Curves. Fragility curves were developed to account for the ability of various TA-55 structures, systems, and components (SSCs) to withstand a seismic event. The fragility of an SSC is defined as the conditional probability of the SSC's failure given a specific value of the PGA.

An approach described by R. P. Kennedy and as implemented by L. Goen of Los Alamos was used to derive best-estimate fragility curves for the various SSCs modeled in the analysis. (References: R. P. Kennedy et.al. Probabilistic Seismic Safety Study of an Existing Nuclear Power Plant, Nuclear Engineering and Design 59 (1980), pp. 315-338, March 1980; LANL Memorandum to P. Pan from Larry Goen, March 3, 1995.) Using this approach, the best-estimate fragility curve for a component is represented in Eq. (1) as $P_{fail}(x)$, where x is a given value for the PGA.

$$P_{fail}(x) = \Phi\left[\frac{\ln\left(\dfrac{x_{cg}}{\dfrac{HCLPF_{84\%}}{1.2}\,e^{2.326\,b}}\right)}{b}\right] \qquad (1)$$

In the above equation, Φ(z) is the cumulative normal distribution function for the standard variable z (z has a mean of 0 and a standard deviation of 1). For this application, z is the argument of Φ as given in Eq. (1). The variable x_{cg} is the PGA at the center of gravity of the SSC. $HCLPF_{84\%}$ is the HCLPF value at a reference PGA where the response spectrum (actual frequency/acceleration spectrum seen by the SSC) is not exceeded with 84% confidence.[16] The quantity β is a composite logarithmic standard deviation representing both random (stochastic) and state-of-knowledge (epistemic) uncertainty. Here $\beta = (\beta_R^2 + \beta_U^2)^{0.5}$, where β_R and β_U represent random and state-of-knowledge uncertainty, respectively.

[16] The HCLPF capacity represents a 1% to 2% probability of failure for the component.

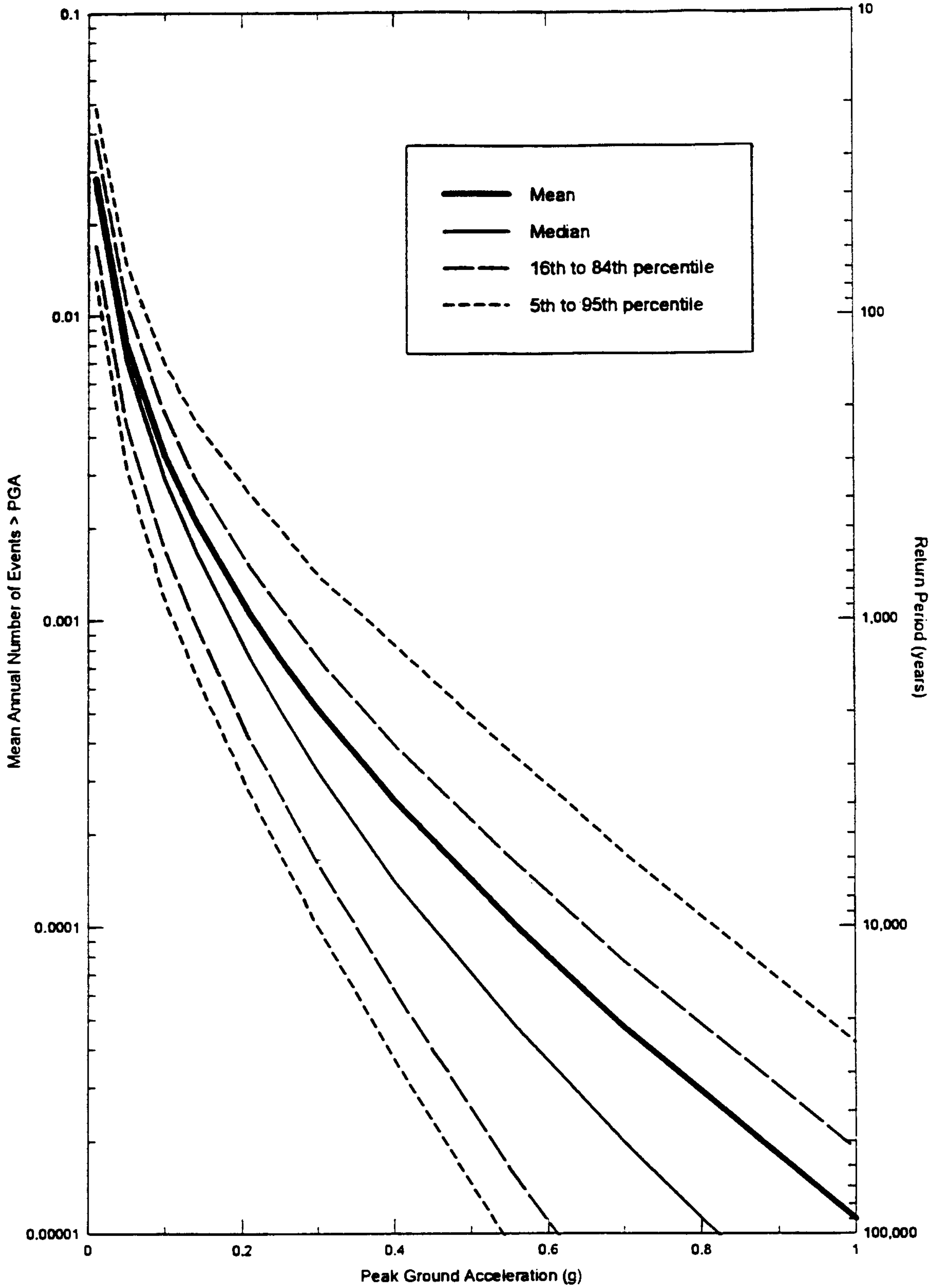


Fig. 4-1. Frequency of exceedance seismic data for TA-55.

The $HCLPF_{84\%}$ values for SSCs at PF-4 were estimated based on walkdowns of the facility and design information for the SSCs in the facility. The $HCLPF_{84\%}$ values used in the analysis for individual SSCs are summarized in Table 4-1. A value of 0.4 was used for the standard deviation parameter β.

Additional details regarding the fragility calculations are provided in Darby (1999), including the methods used to treat dependence among gloveboxes.

4.1.3. Quantification of Accident Frequencies. The seismic event is the initiating event for the accident and, as such, is quantified as a frequency. Per Sec. 4.1.1, the frequency for an initiating event with a magnitude in the interval (X, X + dx) is represented by $-(dH/dx)|_{x=X} * dx$, where $H(x)|_x = X$ is the function that represents the frequency that a seismic initiating event exceeds a specific PGA value of X. Let $P(A \mid x)|_{x=X}$ be defined as the probability that a particular component A fails given x is a specific value X; it is assumed that $P(A \mid x)|_{x=X}$ is uniquely defined given X. If f(x) is defined to be ≡ –(dH/dx), the overall frequency for the initiating event followed by failure of component A is given in Eq. (2):

$$\int f(x)\, P(A \mid x)\, dx \qquad (2)$$

This approach can be extended to consider a cut set of events with each event representing the failure of an SSC because of an external event. Let $P_{jm}(x)$ be the function that represents the probability that an SSC designated as m in cut set j fails at magnitude x. The frequency of the j^{th} cut set is given in Eq. (3).

$$\int -\left(\frac{dH}{dx}\right)\prod_{m} P_{jm}(x)\, dx \qquad (3)$$

Using the rare event approximation, the accident frequency is calculated from Eq. (4).

$$f \;=\; \sum_{j}\int -\left(\frac{dH}{dx}\right)\prod_{m} P_{jm}(x)\, dx \;=\; \int\sum_{j} -\left(\frac{dH}{dx}\right)\prod_{m} P_{jm}(x)\, dx \qquad (4)$$

The integrand weights each probability by the likelihood of the initiating event at a specific x, and the integration is over all x. In Eq. (4), j denotes a cut set, m denotes a basic event in a cut set, and n denotes a mesh point in the discrete set of bins for the magnitude x.

Table 4-1
Summary of $HCLPF_{84\%}$ Values Used in the Analysis

Structure, System, Component (SSC)	**$HCLPF_{84\%}$ (g)**
Fire water piping (in fire suppression system)	0.19
H-wall (crossover trolley dampers)	0.78
Interior fire walls	0.59
Gloveboxes that are ignition sources	
Room 207 (three ignition-source gloveboxes)	0.13 (one glovebox), 0.24 (one glovebox), 0.5 (one glovebox)
Room 208 (five ignition-source gloveboxes)	0.08 (all five gloveboxes)
Room 209 (four ignition-source gloveboxes)	0.08 (two gloveboxes), 0.09 (one glovebox), 0.11 (one glovebox)
Other Rooms (about 10% of the gloveboxes are ignition sources)	Wide range; many at about 0.1
Building	0.77

The minimal cut set upper bound is a better approximation than the rare-event approximation for independent events. Using the minimal cut set upper bound, the accident frequency is calculated as shown in Eq. (5):

$$f \;=\; \int -\left(\frac{dH}{dx}\right)\left[1 \;-\; \prod_{j}(1 \;-\; \prod_{m} P_{jm}(x))\right]dx \tag{5}$$

Equations (4) and (5) do not consider uncertainty in the H and P functions; that is, these equations account for randomness but not uncertainty. Best-estimate functions for H(x) and for P(x) should be used in Eqs. (4) and (5) to provide the best-estimate point value for the accident frequency. (To consider uncertainty, families of curves for H and P can be generated, each with a specific confidence.)

Equations (4) and (5) imply that every event is dependent on x; that is, every failure probability is a function of the magnitude of the external initiating event. Random failures not dependent on x can also occur; this is a degenerate case in which certain of the $P_{jm}(x)$ are constants independent of x.

An event tree was constructed to delineate the various fire-related scenarios at TA-55, while fault trees were used to model random failures. Darby (1999) provides further details regarding the quantification of frequencies for the fire-related scenarios.

4.2. Success Criteria for Fire Containment

As discussed in Sec. 3.2.1, deterministic models were used in the operational (random) fire analysis to develop success criteria for avoiding a building-wide fire. With a few exceptions and additions, the same set of success criteria was used in the seismic analysis. These exceptions and additions are summarized in Sec. 4.2.1.

4.2.1. Success Criteria Elements Specific to Seismic Analysis. Success criteria specific to the seismic analysis are described below.

Fire Suppression. For the seismic analysis, only the automatic fire suppression system was considered as a potential means of fire suppression. Unlike the case for operational (random) fires, no credit was taken for manual fire suppression. A major seismic event would lead to evacuation of personnel from the facility, and manual fire suppression would not be feasible. Like the case for operational (random) fires, no credit was taken for a dedicated, off-site fire response force. Given a major seismic event, an off-site fire response force might not be able to travel to TA-55 because of the potential for seismic-induced damage to roadways and structures housing fire equipment. Communication also might be disrupted.

Very Many Simultaneous Fires. Although a situation involving many simultaneous fires was shown to have a negligible frequency for operational (random) fires, this situation cannot be readily screened out for a seismic initiating event. If simultaneous fires occur in a very large number of rooms, the plutonium from each room can be released if the combustible loading in each room exceeds 1 lb/ft^2. A total of 66 out of 115 rooms (57%) have a loading greater than 1 lb/ft^2. Because so many rooms have loadings in excess of 1 lb/ft^2, simultaneous fires in all these rooms are equivalent in consequence to a building-wide fire. Because these many localized fires occur on both sides of the H-wall, there is no requirement for the H-wall to fail for this case.

Ignition-Source Gloveboxes. Certain gloveboxes were identified that contain an ignition source. Given failure of this type of glovebox, it was assumed that a fire would occur with a probability of 1. Each of the ignition-source gloveboxes in Rooms 207, 208, and 209 was identified specifically. There are three ignition-source gloveboxes in Room 207, five ignition-source gloveboxes in Room 208, and four ignition-source gloveboxes in Room 209. A sampling of other PF-4 rooms taken during a walkdown identified 4 out of 40 gloveboxes, or 10%, that had potential ignition sources. Based on this walkdown, it was assumed that, on average, 10% of all gloveboxes in PF-4 would contain an ignition source.

Catastrophic Building Collapse. Given a catastrophic building collapse, it was assumed that many fires would erupt with a widespread release of plutonium. The fire suppression system would have been disabled as a result of the building collapse.

Ventilation System Status. Unlike the operational (random) fire analysis, the seismic analysis assumed that the ventilation system would not have to be operating to promote the spread of fire.

4.2.2. Summary of Success Criteria for Seismic Analysis. A summary set of success criteria was developed based on the information presented in the preceding section. These success criteria are used to prevent either (a) a plutonium release resulting from a building-wide fire or (b) plutonium releases from many localized fires**.**

A plutonium release resulting from a building-wide fire will be prevented if any of the following conditions exist:

1. Operation of the automatic fire suppression system.
2. Favorable combustible loading in fire origin areas (all three of the loading criteria below must be satisfied):
   a) Given a single ignition source, combustible loading in the ignition source room does not exceed 8 lb/ft^2, or combustible loading in each room adjacent to the ignition source room does not exceed 8 lb/ft^2.
   b) Given a single ignition source in an adjoining set of rooms in the same wing where separation walls have failed, the combined combustible loading in these rooms does not exceed 36,000 lb.
   c) Given multiple ignition sources in an adjoining set of rooms in the same wing where separation walls are intact, the combined combustible loading in these rooms does not exceed 36,000 lbs.
3. All interior fire pathways between wings (H-walls) are closed.

A group of plutonium releases from many localized fires will be prevented if any of the following conditions exist:

1. Ignition-source gloveboxes are not present in the entire population of 41 rooms that contain low-fragility gloveboxes.
2. The seismic event has insufficient strength to fail the low-fragility gloveboxes in each of the above 41 rooms.
3. Favorable combustible loading exists in one or more of the above 41 rooms (i.e., the loading does not exceed 1 lb/ft^2).
4. The building structure and filtering system remain intact.

4.3. Quantification of Fire Spread Sequences

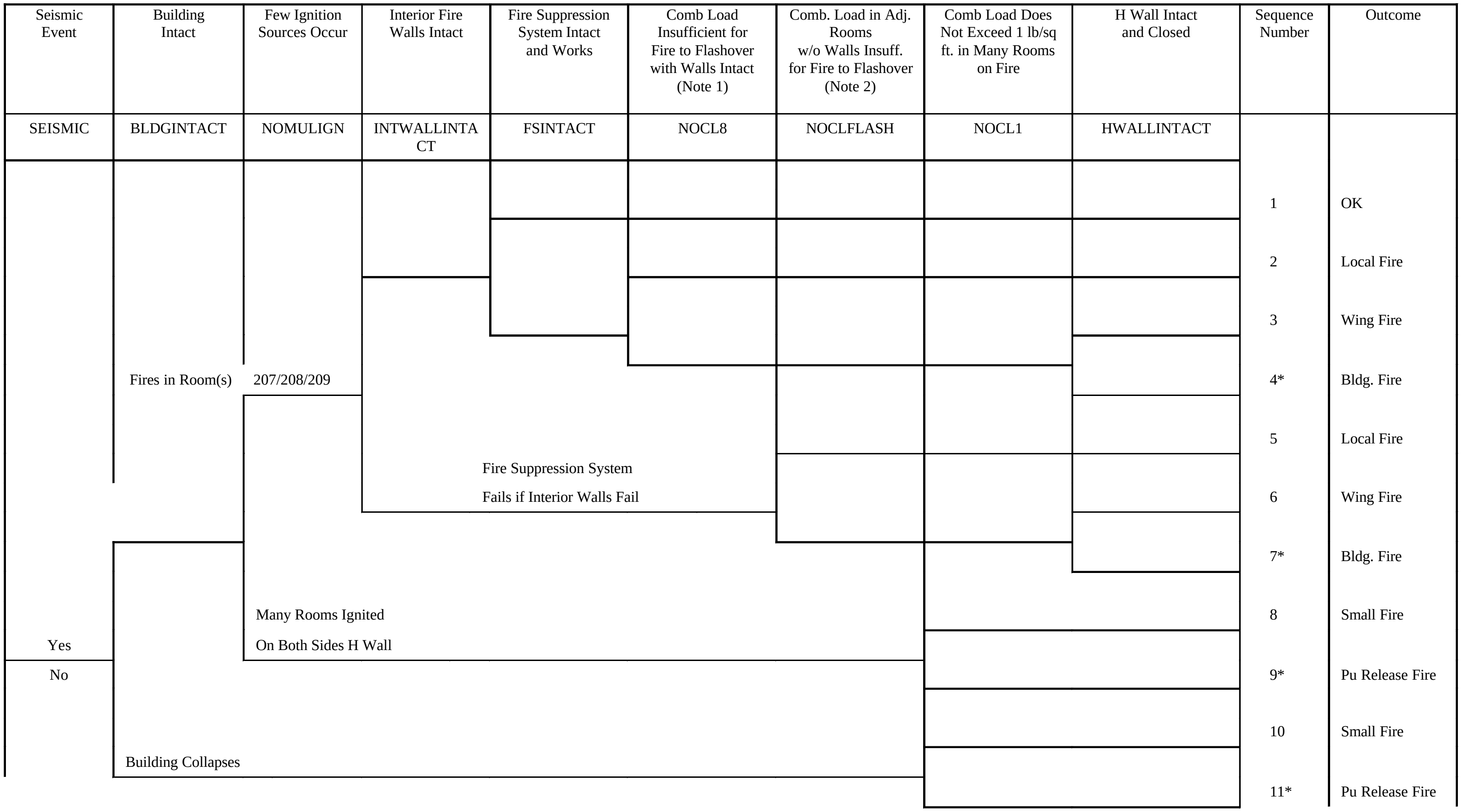
The potential for fire spread within the PF-4 building was evaluated probabilistically by developing and analyzing an event/fault-tree logic model. This model is based on the success criteria described in Sec. 4.2. Section 4.3.1 below describes the event tree used in this analysis, and Sec. 4.3.2 describes the associated fault trees.

4.3.1. Event Trees. Figure 4-2 displays the event tree used in this portion of the analysis. This event tree portrays the possibilities for the progression of a room fire due to a seismic initiating event. The event tree is structured so that the progression of the accident is represented in a time-ordered manner from left-to-right. In this model, successful mitigation of the room fire occurs whenever the building confinement remains intact.

The first event-tree heading (SEISMIC) represents the seismic initiating event. The next eight event-tree headings are used to denote the subsequent (post-initiator) status of PF-4 with regard to the building integrity, fire suppression availability, and type of fire.

The heading (BLDGINTACT), which occurs immediately after the initiating event, indicates whether the building remains intact or collapses. The next heading (NOMULIGN) is used to divide the ignition sources into one of two categories. A fire that is limited to one or more of the three Rooms 207, 208, or 209 represents one category of ignition source. The other category of ignition source involves many room fires on both sides of the H-wall because of failure of numerous low-fragility gloveboxes.

The next heading (INTWALLINTACT) represents the status of the interior fire walls. The subsequent heading (FSINTACT) is used to represent the availability of the fire suppression system. The following heading (NOCL8) indicates a decision as to whether the degree of combustible loading in the source room and any adjacent room exceeds 8 lb/ft^2.



Note 1: For a single fire: Comb Load < 8 lb/sq ft in both source and any adjacent room. For multiple fire: Comb Load < 36000 lb total in all rooms with fire.

Note 2: For a single fire in adjacent rooms with interior walls failed Comb Load <36,000 lb.

DEFINITION OF OUTCOME STATES:
OK: Fire Extinguished
For Fire Flashoever Scenariors:
Local Fire: Fire in a few rooms
Wing Fire: Fire throughout one wing
Bldg. Fire: Fire in entire Bldg., both sides H wall
For Scenarios involving many localized fires releasing Pu
Small Fire: Fires insufficient to release Pu

*Sequences that represent the release of bulk Pu

Fig. 4-2. Event tree used in seismic analysis.

Under the next heading (NOCLFLASH), a decision is made as to whether the total combustible loading in any set of adjoining rooms (assuming failure of interior fire walls) exceeds 36,000 lb. Yet another heading (NOCL1) is used to indicate a decision on whether the combustible loading exceeds 1 lb/ft^2 in each of many individual rooms that are on fire. Finally, the last split-fraction-related heading (HWALLINTACT) represents the status of the H-wall (intact or open).

The event tree has 11 sequences. Each of these sequences can be characterized by one of six possible end states or outcomes. The end state “OK” denotes that the fire is extinguished, confinement remains intact, and no plutonium is released. The end state “local fire” represents a fire that remains confined to a few rooms. In a “local fire” end state, the fire does not spread via flashover, confinement remains intact, and a release of plutonium is avoided. The end state “wing fire” represents a fire contained to one wing. In the “wing fire” end state, the fire does not spread via flashover to the entire building, confinement remains intact, and a release of plutonium is avoided.

A “building fire” end state represents a building-wide fire that has occurred from flashover and is assumed to result in confinement failure and release of plutonium. Finally, a “Pu release fire” end state denotes the release of plutonium from many simultaneous small fires. Here, the fire suppression system is not credited because it cannot extinguish numerous simultaneous fires. Confinement is assumed to have failed as a result of excessive ash loading on the ventilation filters.

Sequence 1 of the event tree represents an intact building structure with fires limited to at most Rooms 207, 208 and 209. Because the interior fire walls also remain intact and the fire suppression operates successfully, flashover is avoided, the building confinement remains intact, and no plutonium is released. This sequence has been assigned an end state status of “OK.”

Sequence 2 also represents an intact building structure with fires limited to at most Rooms 207, 208, and 209. Though the interior fire walls also remain intact, the fire suppression system fails. Because the combustible loading does not exceed 8 lb/ft^2 both in the source room(s) and in any adjacent room, flashover is avoided, the building confinement remains intact, and no plutonium is released. An end state status of “local fire” has been assigned to this sequence.

Sequences 3 and 4 are similar to Sequence 2, except that the combustible loading exceeds 8 lb/ft^2 in the source room(s) and an adjacent room. As a result, the fire is able to propagate into the remainder of the associated building wing. In Sequence 3, all interior fire pathways between wings (H-walls) are closed, and thus, fire propagation into the other wing via flashover is avoided. However, in Sequence 4, an open H-wall pathway is present, and the wing fire spreads into the remainder of the building. The building confinement remains intact in Sequence 3, whereas it fails in Sequence 4. Sequences 3 and 4 have been assigned end states of “wing fire” and “building fire,” respectively.

In Sequence 5, the building structure is intact with fires limited to at most rooms 207, 208 and 209. However, the PGA is sufficiently high to cause failure of the fire walls. Because the fire suppression system has a significantly lower fragility than the fire walls, it fails prior to failure of the fire walls.[17] The fire is contained within the room(s) of origin only because the total combined loading of combustibles in these rooms does not exceed 36,000 lbs. The building confinement remains intact, and no Pu is released. An end state status of “local fire” has been assigned to this sequence.

Sequences 6 and 7 are similar to Sequence 5, except that the total combined loading of combustibles in adjoining rooms (at least one of which is on fire) exceeds 36,000 lb. As a result, the fire is able to propagate into the remainder of the associated building wing. In Sequence 6, all interior fire pathways between wings (H-walls) are closed, thus preventing fire propagation into the other wing. The building confinement remains intact, and no plutonium is released. However, in Sequence 7, an open H-wall pathway is present, and the wing fire spreads into

[17] Even if the fire suppression system had a higher fragility than the fire walls, collapse of the fire walls would disable the fire suppression system

the remainder of the building. The building confinement is lost, and plutonium is released. Sequences 6 and 7 have been assigned end states of "wing fire" and "building fire," respectively.

In Sequences 8 and 9, the building remains intact but with numerous room fires on both sides of the H-wall. The fire suppression system was not credited as it cannot extinguish many individual fires simultaneously. For Sequence 8, the combustible loading in the burning rooms does not exceed 1 lb/ft^2. As a result, these fires are incapable of releasing bulk plutonium. However, for Sequence 9, the combustible loading in the burning rooms exceeds 1 lb/ft^2, with the result that plutonium is released locally from each fire. Sequences 8 and 9 have been assigned end states of "small fire" and "Pu release fire," respectively.

Finally, in Sequences 10 and 11, the building collapses as a result of the seismic event, and many fires erupt. Because the fire suppression system has a significantly lower fragility than the building structure, it fails prior to failure of the building.[18] In Sequence 10, the combustible loading in the burning rooms does not exceed 1 lb/ft^2. As a result, the fires are incapable of releasing bulk plutonium. However, for Sequence 11, the combustible loading in the burning rooms exceeds 1 lb/ft^2, with the result that plutonium is released locally from each fire. Sequences 10 and 11 have been assigned end states of "small fire" and "Pu release fire," respectively.

In summary, Sequences 4, 7, 9, and 11 are the sequences that represent the release of bulk plutonium. As such, they are the sequences of interest in this analysis.

4.3.2. Fault Trees. Fault-tree models were developed to evaluate the probabilities for random failure of the fire suppression system and H-wall. These are the same fault trees used to support the operational (random) fire analysis and were described in Sec. 3.3.2.

4.4. Results and Discussions

In general, each of the seismic sequences of interest has a number of individual cut sets. To facilitate presentation and discussion of the results, the individual sequence cut sets were mapped into a smaller set of scenarios. Each scenario defines a unique combination of ignition sources and other types of failures necessary to result in a building-wide fire and release of bulk plutonium.

Table 4-2 summarizes a set of scenarios generated from the analysis. For each scenario, the table identifies the applicable event-tree sequence number, the scenario number, a brief description of the scenario, and pertinent comments and/or assumptions.

The final step in the analysis was to estimate the overall frequency of plutonium release represented by these scenarios. To partially correct for over-conservatism in the rare event approximation as previously discussed in Sec. 4.1.3, the initial set of scenarios in Table 4-2 was remapped into an updated set of scenarios. These updated scenarios account for common failure elements to facilitate use of the minimal cut set upper bound approximation, which is better estimate than the rare event approximation. These updated scenarios and their frequencies are summarized in Table 4-3.

There are two dominant scenarios, namely Scenario D and Scenario A. Scenario D, with a frequency of $5x10^{-6}$/yr, involves a total collapse of the building because of the seismic event. Many small fires are ignited from numerous internal/external (to building) sources. Scenario A, with a frequency of $4x10^{-6}$/yr, involves a seismic-induced fire that spreads throughout an entire wing as a result of failure of the fire suppression system or failure of the interior fire walls. Seismic-induced failure of the H-wall crossover dampers subsequently allows the fire to spread to the other wing, thereby resulting in a building-wide fire.

4.5. Conservatisms

A number of conservative assumptions were made in this analysis. Examples of some of these conservative assumptions are summarized below.

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[18] Even if the fire suppression system had a higher fragility than the building structure, collapse of the building would disable the fire suppression system.

Table 4-2
Summary of Dominant Seismic Scenarios

Event-Tree Sequence Number	Scenario ID	Scenario Description (Important Elements in Each Scenario are Denoted by a Bullet)	Bounding Model Assumptions and Comments
4	4a	• Any one of eight ignition-source gloveboxes in Rooms 207/208 fails because of the seismic event and causes ignition (there are three ignition-source gloveboxes in Room 207 and 5 ignition-source gloveboxes in Room 208); HCLPF values for most of these gloveboxes range from 0.08 g to 0.13 g • The combustion load in Room 208 > 8 lb/ft^2 as a result of a random transient load; probability = $2.6x10^{-3}$ • Fire suppression fails because of seismic event; HCLPF 0.19 g • The H-wall opening fails as a result of seismic event; HCLPF 0.78 g	Many of the ignition-source gloveboxes will fail before the fire suppression system or H-wall because of their lower fragility (see data at left and in Table 4-1). Therefore, it is assumed that at least one ignition-source glovebox will fail, with ignition guaranteed in the associated room. In this scenario, the combustible loading in Room 208 happens to be > 8 lb/ft^2. Given that Room 207 already has a combustible loading > 8 lb/ft^2 and that the fire suppression system has failed, a fire in either room spreads to the other room and subsequently throughout the associated wing. Fire propagation to the other wing (a building-wide fire) occurs because the H-wall also has failed.
4	4b	• Any one of eight ignition-source gloveboxes in Rooms 207/208 fails because of the seismic event and causes ignition (there are three ignition-source gloveboxes in Room 207 and five ignition-source gloveboxes in Room 208); HCLPF values for most of these gloveboxes range from 0.08 g to 0.13 g • The combustion load in Room 208 > 8 lb/ft^2 because of a random transient load; probability = $2.6x10^{-3}$ • Fire suppression fails randomly; probability = $4.2x10^{-3}$ • The H-wall opening fails as a result of seismic event; HCLPF 0.78 g	*This scenario is the same as scenario 4a except that the fire suppression system fails randomly instead of from the seismic event.*
4	4c	• Any one of eight ignition-source gloveboxes in Rooms 207/208 fails because of the seismic event and causes ignition (there are three ignition-source gloveboxes in Room 207 and five ignition-source gloveboxes in Room 208); HCLPF values for most of these gloveboxes range from 0.08 g to 0.13 g • The combustion load in Room 208 > 8 lb/ft^2 because of random transient load; probability = $2.6x10^{-3}$ • Fire suppression fails because of seismic event; HCLPF 0.19 g • H-wall opening fails randomly; probability = $2.5x10^{-3}$	*This scenario is the same as scenario 4a except that the H-wall opening fails randomly instead of from the seismic event.*

Event-Tree Sequence Number	Scenario ID	Scenario Description (Important Elements in Each Scenario are Denoted by a Bullet)	Bounding Model Assumptions and Comments
4	4e	• One ignition-source glovebox in <u>each</u> of Rooms 207/208/209 fails because of the seismic event; (there are three ignition-source gloveboxes in Room 207, five ignition-source gloveboxes in Room 208, and four ignition-source gloveboxes in Room 209); HCLPF values for most of these gloveboxes range from 0.08 g to 0.13 g. • Fire suppression fails because of the seismic event; HCLPF 0.19 g. • The H-wall opening fails because of the seismic event; HCLPF 0.78 g.	Many of the ignition-source gloveboxes in Rooms 207/208/209 will fail before the fire suppression system or H-wall because of their lower fragility (see the data at left and in Table 4-1). Therefore, it is assumed that an ignition-source glovebox failure will occur in each room, with ignition guaranteed in each room. The collective combustible loading in Rooms 207/208/209 exceeds 36,000 lb. Therefore, given a fire in each of these three rooms and failure of the fire suppression system, the fire spreads throughout the associated wing. Fire propagation to the other wing (a building-wide fire) occurs because the H-wall has also failed.
4	4f	• One ignition-source glovebox in <u>each</u> of Rooms 207/208/209 fails because of the seismic event; (there are three ignition-source gloveboxes in Room 207, five ignition-source gloveboxes in Room 208, and four ignition-source gloveboxes in Room 209); HCLPF values for most of these gloveboxes range from 0.08 g to 0.13 g • Fire suppression fails randomly; probability = $4.2x10^{-3}$ • H-wall opening fails because of the seismic event; HCLPF 0.78 g	*This scenario is the same as scenario 4e except that the fire suppression system fails randomly instead of from the seismic event.*
4	4g	• One ignition-source glovebox in <u>each</u> of Rooms 207/208/209 fails as a result of the seismic event; (there are three ignition-source gloveboxes in Room 207, five ignition-source gloveboxes in Room 208, and four ignition-source gloveboxes in Room 209); HCLPF values for most of these gloveboxes range from 0.08 g to 0.13 g • Fire suppression fails because of the seismic event; HCLPF 0.19g • The H-wall opening fails randomly; probability = $2.5x10^{-3}$	*This scenario is the same as scenario 4e except that the H-wall opening fails randomly instead of from the seismic event.*

Event-Tree Sequence Number	Scenario ID	Scenario Description (Important Elements in Each Scenario are Denoted by a Bullet)	Bounding Model Assumptions and Comments
7	7a	• Any one of 12 ignition-source gloveboxes in Rooms 207/208/209 fails as a result of the seismic event; (there are three ignition-source gloveboxes in Room 207, five ignition-source gloveboxes in Room 208, and four ignition-source gloveboxes in Room 209); HCLPF values for most of these gloveboxes range from 0.08 g to 0.13 g • Interior fire walls fail as a result of the seismic event; HCLPF 0.59 g • The H-wall opening fails because of the seismic event; HCLPF 0.78 g	Many of the ignition-source gloveboxes in Rooms 207/208/209 will fail before the interior fire walls or H-wall because of their lower fragility (see data at left and in Table 4-1). Therefore, it is assumed that an ignition-source glovebox failure will occur in at least one room, with ignition guaranteed in that room. Given failure of the interior fire walls, the fire spreads so that it includes all three rooms (207, 208, and 209). Because the fire suppression system has failed and because the collective combustible loading in Rooms 207/208/209 exceeds 36,000 lb, the fire spreads throughout the associated wing. Fire propagation to the other wing (a building-wide fire) occurs because the H-wall also has failed.
7	7b	• Any one of 12 ignition-source gloveboxes in Rooms 207/208/209 fails due to the seismic event. (There are three ignition-source gloveboxes in Room 207, five ignition-source gloveboxes in Room 208, and four ignition-source gloveboxes in Room 209); HCLPF values for most of these gloveboxes range from 0.08 g to 0.13 g • The interior fire walls fail as a result of the seismic event; HCLPF 0.59 g • The H-wall opening fails randomly; probability = $2.5x10^{-3}$	*This scenario is the same as scenario 7a except that the H-wall opening fails randomly instead of from the seismic event.*
11	–	Total collapse of building; HCLPF = 0.77 g	Many small fires are ignited from numerous internal/external (to building) sources.

Table 4-3
Summary of Updated Scenarios and Frequency Estimates

Updated Scenarios ID	Set of Initial Scenarios Mapped Into Updated Scenario	Common Failure Elements in Initial Scenario	Frequency (per year)
A	4a, 4b, 4e, 4f, 7a	H-wall crossover dampers fail as a result of a seismic event (HCLPF = 0.78 g)	$4.1x10^{-6}$
B	4c, 4g	Fire suppression fails as a result of a seismic event (HCLPF = 0.19 g) and H-wall crossover dampers fail to close as a result of a random effects (probability = $2.5x10^{-3}$)	$8.2x10^{-7}$
C	7b	Interior fire walls fail as a result of a seismic event (HCLPF = 0.59) and H-wall crossover dampers fail to close as a result of a random effects (probability = $2.5x10^{-3}$)	$3.3x10^{-8}$
D	11	Building collapses as a result of a seismic event (HCLPF = 0.77)	$5.4x10^{-6}$

*The total frequency estimate of 9.5E-06 per year is slightly less that the sum of the frequency of the individual scenario because of the use of the minimal cut set upper bound refinement.

- It was assumed that all glovebox heat sources would be on immediately prior to a seismic event. No attempt was made to lower sequence frequencies by accounting for the fraction of time that glovebox heat sources are not in use.
- It was assumed that the fire spread would be independent of the operational status of the ventilation system.

5.0. CONCLUSIONS

Two categories of building-wide fires at FP-4 were evaluated. The first fire category, an operational fire, is initiated by a random fire that starts in or near a glovebox. The other fire category involves a secondary fire that is initiated by a severe seismic event. The analysis considered seismic initiating events over the entire hazard curve, including seismic events that exceed the beyond-evaluation-basis earthquake.

Propagation of a glovebox fire into a building-wide fire is estimated to occur with a point-value frequency of $4x10^{-10}$/yr. Stated differently, this type of accident scenario would be expected to occur about 1 time in every 2.5 billion years. The very low frequency of a building-wide fire is due to the availability of a number of barriers and mitigation features, including

- administrative controls on the amount of combustible material held in one location,
- an automatic fire water sprinkler system,
- fire walls that separate individual laboratory rooms and areas, and
- fire walls that separate the building wings.

There is one relatively high-probability event, namely, ignition source not extinguished by local worker response, which has a conditional probability 0.78. The product of the probabilistic data from of all these independent events (when also multiplied by a factor of 2 to account for fire initiation in either Room 207 or Room 208) is essentially the frequency of a building-wide fire because there is little sharing of SSCs among the constituent events in the sequence.

The analysis of a building-wide fire from a severe site-wide earthquake produced two dominant scenarios. The first involves a seismic-induced fire that spreads throughout an entire wing as a result of failure of the fire suppression system or interior fire walls. Seismic-induced failure of the H-wall crossover dampers subsequently allows the fire spread to the other wing. The frequency of this scenario is estimated to occur with a point value frequency of $4x10^{-6}$/yr. The second scenario involves the collapse of the building as a result of the seismic event. In this scenario, many small fires are ignited from numerous internal/external sources. The frequency of this scenario is estimated to occur with a point value frequency of $5x10^{-6}$/yr. Stated differently, these accidents would be expected to occur once every 500,000 yr.

These preceding frequency estimates for building-wide fires were based on conservative, bounding analyses. Even so, these results demonstrate that a building-wide fire is unlikely to occur during the life cycle of PF-4. A "best-estimate" analysis, if performed, would provide the basis for further judgment into the degree of conservatism inherent in the analysis assumptions. In turn, elimination or relaxation of conservative assumptions would reduce the point-value frequency estimates of a building-wide fire.

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APPENDIX C

BUILDING-WIDE FIRE: TA-55/PF-4 SOURCE TERM

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BUILDING-WIDE FIRE:
TA-55/PF-4 SOURCE TERM

SUMMARY

A "best-estimate" source term was estimated for a postulated building-wide fire at the Plutonium Facility (PF-4) at Technical Area (TA)-55 at the Los Alamos National Laboratory. The total source term for this postulated accident is 123 grams (g) of ^{239}Pu dose equivalent. The source term comprises 56 g of ^{239}Pu dose equivalent from ^{238}Pu sources and 67 g of ^{239}Pu dose equivalent from weapons-grade plutonium sources.

1. INTRODUCTION

This appendix summarizes the analysis that was performed to determine the amount of nuclear material that might be released to the atmosphere as a result of a building-wide fire at the Los Alamos National Laboratory's Plutonium Facility (PF-4) at TA-55. The release is termed the "airborne (radiological) building source term."

The phenomenology of the building-wide fire was examined using deterministic analyses of fire propagation (between laboratories, between gloveboxes, and between laboratories and gloveboxes) that were undertaken as part of a Probabilistic Risk Assessment (PRA) (see Appendix B). A fire that engulfs the whole building is expected to fail all gloveboxes (the gloves burn). Therefore, radiological material in gloveboxes, as well as such material in containers on floors or shelves of laboratories or storage areas, will be exposed to fire. The analysis assumed failure of the high-efficiency particulate air (HEPA) filters in the ventilation system. Therefore, material made airborne by the fire in either the gloveboxes or the laboratories will be released to the atmosphere unhindered. However, because even the radiological material in gloveboxes is usually in containers, the fire must breach the containers before the material can become airborne. If the fire is preceded by a seismic event of a sufficient magnitude to topple gloveboxes, a mechanical dispersal of container contents may take place before their exposure to the fire. Without that mechanical breach, the containers will mitigate releases. The effects of containers on mitigating release were examined as a part of this analysis.

The following sections discuss the approach taken and the assumptions made in deriving the airborne building source term and give its magnitude.

2. APPROACH

The basic approach for determining a source term follows the methodology outlined in *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities* (US Department of Energy handbook DOE-HDBK-3010-94, December 1994). The handbook provides a five factor formula for determining the source term for a postulated accident at a DOE nonreactor nuclear facility. The formula is as follows:

$$BST = MAR \times DR \times ARF \times RF \times LPF.$$

Where,

MAR	is the material at risk,
DR	is the damage ratio,
ARF	is the airborne release fraction,
RF	is the respirable fraction,
LPF	is the leakpath factor,
BST	is the respirable Building Source Term.

In this analysis the values for the five factor formula are discussed individually and the approach used to determine each value is discussed.

2.1. Material at Risk (MAR)

One issue in developing the source term is how to determine the inventory of nuclear material that might be affected by the fire that is, the Material at Risk (MAR). That inventory is constantly changing and cannot be predicted precisely. However, it was decided that the inventory could be represented approximately by an arithmetic mean over the last 12 months of the inventories reported by the Material Accountability and Safeguards System (MASS) for PF-4 on a monthly basis. The method used to calculate this average is presented in the following sections.

2.1.1 MASS Data Reduction

Inventory data were extracted from the MASS system 1998 monthly reports (one set of data for each month). The data sets consisted of spreadsheets with line entries under the following heading.

Date; Account No.; Mass Location No.; Summary Material Type; Item Description; Sum of NM.

Here the *Account No*. and *Mass Location No*. locate the nuclear material (NM) for safeguard and accountability purposes. That location may be as precise as a single glovebox or as broad as a glovebox line. For this analysis, the correspondence between accountability location and gloveboxes was not made because it was not needed (example, all gloveboxes were assumed to fail).

The *Summary Material Type* (SMT) designates the nuclear material by isotope or chemical element. If it is a chemical element, it constitutes a rollup of several subcategories containing various mixes of isotopes. For example, the category *Enriched Uranium* contains subcategories of various degrees of enrichment. The Safety Analysis Report (SAR) for TA-55 combines these into one generic category, enriched uranium (EU), and defines the isotopic mix of that category. A similar rollup category gives a generic isotopic mix for weapons-grade (WG) plutonium, also treated as such in the SAR. For other generic categories, those isotopes having the worst health effects (inhalation dose conversion factors or DCFs) were taken conservatively as representative.

The *Item Description* (IDES) gives a reasonably detailed description of the material form at the identified location. The major subdivisions are as follows.

A. Assembly
B. Non-Weapon Assembly
C. Compound
E. Reactor Element
G. Gas
K. Combustible
L. Liquid/Solution
M. Metal
N. Non-Combustible
R. Process Residue

Further subdivisions distinguish between chemical forms (such as carbide, dioxide, and so on) and physical forms, such as parts, subassemblies encapsulated, standard, source, and so on. These characterizations were used to assign airborne release fractions in a first cut. Additional information on ^{238}Pu was obtained from LANL subject matter experts to refine these assignments for this source-term-dominating isotope.

2.1.2 Plutonium-239 Dose Equivalence

PF-4 contains a large number of different radioisotopes, all of which may contribute to the radiological source term; that is, they yield their own source terms. It is useful to normalize these separate inventories to that of the isotope ^{239}Pu so that the total inventory can be expressed as a single number. This was done on a dose-equivalence basis so that when the normalized inventory of any isotope is multiplied by the appropriate conversion factor for ^{239}Pu, it gives the inhalation dose to a given receptor. This approach also allows ready comparison with other source terms that may have been developed at other DOE sites.

The MASS database provides the inventories of the various isotopes in PF-4 in convenient units. These were first converted to grams. Next, the dose [in rem cumulative effective dose equivalent (CEDE)] from an inhaled gram of each isotope was extracted from the literature. This is the dose conversion factor (DCF). The ratio of the

DCF of the isotope (or isotopic mix) of interest to that of ^{239}Pu was determined. Multiplying the gram inventory of the isotope of interest by this ratio gives the inventory of that isotope in dose-equivalent grams of ^{239}Pu.

2.2. Damage Ratio (DR)

It was assumed for this analysis that the building-wide fire is sufficiently severe to involve nuclear material in all rooms of PF-4. In addition, the fire is assumed to involve all gloveboxes by burning through the gloves and exposing the nuclear material contained in the gloveboxes to ignition temperatures. This provides for a damage ratio of one.

However, the vaults are sufficiently robust and their combustible loading is sufficiently low so that they will not be affected by either an earthquake or a building-wide fire. For material in the vaults, the damage ratio is zero.

2.3. Respirable Release Fractions (RRF = ARF x RF)

Developing the source term requires an estimate of the amount of each nuclear material in each of its physico-chemical forms that becomes airborne as a result of the fire (and earthquake). This release usually is expressed in terms of the airborne release fraction (ARF) for the material form and the stress type (fire). Moreover, because the major of nuclear materials in PF-4 are all alpha emitters, the source term of primary interest is that for respirable particles. In turn, this is taken into account with the respirable fraction (RF). A complete compendium of recommended ARFs and RFs is given in DOE-HDBK-3010-94. The ARFs and RFs used in this analysis were extracted from the DOE Handbook, which provides bounding and median (most likely) values. Median values were used for this analysis to be consistent with the stated objectives of providing a "best estimate" of the amount of material released. Other assumptions used in determining ARFs and RFs are presented below.

2.3.1 Container RRFs

The DOE handbook generally provides ARFs and RFs associated with unconfined, directly exposed material. On the other hand, almost all nuclear material in the gloveboxes of PF-4 is contained in metal screw-top or slip-top containers. Material on shelves or laboratory floors is contained in drums or similar containers. Thus, nuclear material is not directly exposed in general, and the ARFs and RFs do not apply unless one assumes that the accident breaches the containers and spills all of their contents. If containers remain essentially intact, it was assumed conservatively that any release from the containers is less by an order of magnitude than that from exposed material. Some materials are encapsulated or in strong, sealed units that are tested against accident conditions. These materials are assumed not to be released at all by either a random, building-wide fire or a fire preceded by an earthquake.

2.3.2 RRFs for Non-Standard Material Forms

Where available, respirable release fractions were taken directly from the DOE Handbook. When applicable values were not available, extrapolations and interpolations were performed. As mentioned above, an extreme set of RRFs reflecting a complete breach and emptying of containers was developed. This set was applied in a first pass at developing the source term. Importantly, because the MASS database does not distinguish the dispersability of various physical forms of different chemical compounds, worst-case assumptions were made in assigning these release fractions to the inventory. In particular, all oxides were treated as fine powders even though it is known that some are in the form of granules and pellets that are effectively not dispersable as respirable aerosol.

2.3.3 Modifications to RRF

The first pass at developing the source term showed the SMT represented by ^{238}Pu to dominate by an order of magnitude. This situation motivated a more detailed look at the ^{238}Pu operations in PF-4, which led to a refinement of the RRFs for the ^{238}Pu SMT. LANL subject matter experts were consulted, and RRFs were assigned to the Mass Location Numbers identified in MASS according to the known material forms and processes at these locations. More detail on the ARFs and RFs is in a classified report by Hans Jordan on this issue written in 1999 (LA-CP-99-110).

2.4. LeakPath Factors (LPF)

A building-wide fire or a building-wide fire preceded by an earthquake is expected to provide direct leak paths to the outside.

It is expected that HEPA exhaust filters for both Zones I and II will plug with smoke and blow out if the ventilation systems are on. If the ventilation systems are off, it is likely that the heat generated by the fire will degrade the filter seals and filter medium binder enough to reduce the filtration efficiency of the HEPA filters to essentially zero.

As the respirable aerosol particles are transported out of the facility, it is likely that they will be attenuated by thermophoretic or other deposition mechanisms, but the degree of that attenuation is difficult to predict. For this analysis, such particle attenuation was assumed conservatively to be negligible. Therefore, the leak-path factor was taken as equal to one.

2.5 Building Source Term (BST)

The source term for each month of 1998 was calculated for each Summary Material Type, each Mass Location Number and each Item Description from the MASS data base by multiplying the inventory in dose-equivalent grams of ^{239}Pu (MAR) by the appropriate DR, RRF and LPF. The total source term for the month is the sum over all these individual source terms. The arithmetic mean over the last 12 months was calculated from these monthly source term values. The detailed calculations are presented in Jordan's report.

The results indicated that the major contributors to the ^{238}Pu source term are oxide powder in screw-top cans and combustible waste sealed in plastic bags contained in sealed drums. It does not appear reasonable that either of these containers would release more than 10% its contents by dropping from a shelf or glovebox in the event of an earthquake. The Department of Transportation (DOT) Type A 55-gal. drums that contain the combustible waste are certified to not release loose powder when dropped from a height of 4 ft and have been shown to remain intact for much higher falls. The contaminant on combustible material is much less dispersible by mechanical means than loose powder.

If the earthquake drops structural material from the ceiling onto the waste containers or the walls collapse onto them, it appears unlikely that more than 10% of the aggregate contents would be freely exposed to the fire. Powder containers would be shielded by gloveboxes in addition to their inherent integrity. Waste containers may deform but not fully expel material contained in sealed plastic bags and adhering to bulky material such as rags and paper towels.

Because of these considerations and consistent with the approach of the PRA, which looks at best estimates, a reasonable source term for ^{238}Pu is 56 g (^{239}Pu dose equivalent).

The source term for WG plutonium was calculated to be 113 g (^{239}Pu dose equivalent) assuming all forms of WG material are directly exposed to the fire. In fact, some of the material, such as oxide salts and powders (compounds), is in containers and unlikely to be exposed fully. It is reasonable to reduce their release by an order of magnitude as was done for ^{238}Pu. If this is done, the average source term for WG plutonium compounds is reduced from 51.2 g to 5.1 g, and the source term for all WG plutonium forms is reduced from 113 g to 67 g (^{239}Pu dose equivalent). This is the reasonable best-estimate source term for WG plutonium.

3. SUMMARY

This source-term study resulted in the following major findings.

- The radiological source term is dominated by ^{238}Pu and WG plutonium. All other isotopes in PF-4 contribute negligibly.
- The inventories of ^{238}Pu and WG Pu are remarkably constant throughout 1998 except for the month of November, for which they are down roughly by half. Therefore, the November data were discarded in estimating the likely future source term.
- The ^{238}Pu source term is 56 g (^{239}Pu dose equivalent).
- Roughly 50% of the ^{238}Pu source term is attributable to combustible waste and the ash from heat-treated waste.
- The source term attributable to WG Pu is 67 g (^{239}Pu dose equivalent)