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T. E. Ehrenkranz
D. A. Dahl
E. H. Plassmann
R. Pogna
D. R. Smith

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87545

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SAFETY ANALYSIS OF THE MAIN VAULT AT TA-41, LASL

by

**T. E. Ehrenkranz, D. A. Dahl, E. H. Plasmann,
R. Pogna, and D. R. Smith**

ABSTRACT

Safety considerations discussed in this report show that special nuclear materials stored at a Los Alamos Scientific Laboratory facility (TA-41) present no inappropriate risk to workers or the public. The report addresses nuclear criticality, fire, and radioactive contamination potentials, as well as physical protection and material safeguards.

A. SCOPE

The Los Alamos Scientific Laboratory's (LASL's) TA-41 main vault falls within the scope of the May 10, 1972, document "AEC-LASL Interpretation of Criteria for Storage of Unirradiated Enriched Uranium," shown in Appendix A. According to paragraph D.4 of that document, the criteria may also be applied to storage facilities for other materials, such as plutonium. The section headings in this report correspond to those in the above-cited document.

B. PURPOSE

This report demonstrates the degree of public and plant safety, physical protection, materials safeguards, and limitation to the potential for personal injury or property loss.

C. DEFINITIONS

Terms defined in Appendix A will be used in the same sense in this report.

D. GENERAL DESCRIPTION

Area V is the main storage facility at TA-41. It is located completely underground within a canyon wall. It consists of a linear array of five reinforced concrete vaults in which unirradiated metallic uranium, uranium oxide, UF₆, plutonium, tritium, and weapon or test device components are stored.

Each vault, or cubicle, contains 48 bins (24 against each wall). The top eight bins usually are not used. The plutonium content in Area V is usually about 70 kg. Uranium content in October 1975 consisted of 290 kg of metal and 350 kg of oxide and fluoride.

E. SAFETY ANALYSIS

Sections F, G, and H constitute the safety analysis.

F. NUCLEAR CRITICALITY SAFETY

The potential for nuclear criticality during storage at TA-41 is small. The materials are placed

on strong, stable metal shelving. Storage limits are established on the assumption that the materials will be full-density metal spheres, although actual configurations are significantly less reactive. Criticality limits are posted.

Materials usually are encapsulated in a strong outer can, usually stainless steel, in configurations that would be subcritical if immersed in water. Some individual assemblies could become critical following prolonged submerision, but storage areas in TA-41 are not susceptible to flooding because they are >15 ft above the high water mark. The vaults are not used for storing solutions or large quantities of plutonium powders, chips, or turnings. A large amount of enriched uranium is stored as UF_4 powder (this was the subject of a special storage evaluation).

The metal shelving is compartmented so that each storage bin is 30 in. long by 30 in. wide and 18 in. deep. The maximum quantity of material stored in each bin is 4.5 kg of alpha-phase plutonium, 6 kg of delta-phase plutonium, or 20 kg of oralloy. Procedures also recognize storage of plutonium and oralloy parts for a single assembly in one storage bin. Most assemblies are stored in stainless steel containers; the smallest is the Type 2A, a 13-in. cube.

Only 32 bins per vault are used. Thirty-two Type 2A containers, each containing 6 kg of delta-phase or 4.5 kg of alpha-phase plutonium spheres, would not be critical if closely packed into a near-cubic array and water reflected. In addition, the usual quantity of fissile material on hand is less than one-fifth of capacity. Criticality is therefore a very remote possible result of an extreme earthquake. A LASL Engineering Department representative, who is a specialist in soil mechanics and seismic problems, states that a disturbance producing ground accelerations of about 0.1 g's would not displace objects in storage. For UF_4 , shelf restraints have been installed. (See discussion on earthquake considerations in Appendix B.) The gamma detectors in the storage vaults would signal a criticality event, although the need for this system is marginal for areas of such low potential risk.

G. FIRE PROTECTION

The vaults and the building in which they are located are made of fire resistant materials. The combustible loading within the vaults is low—a few thousand Btu (a few ounces of combustibles) per square foot. Fissile materials (except uranium fluoride) are contained in noncombustible packaging. Uranium fluoride is contained in polyethylene to prevent corrosion. The polyethylene bottles are sealed inside metal cans. The fire protection rating of the vault doors is for at least 2 h. The reinforced concrete walls, which separate stored materials from adjacent areas, are a minimum of 10 in. thick. Thus, the fire hazard from within the vault is low. There are no multiple exits, but the exitways are wide and kept free of obstructions. The ventilation system for the main vaults is electric, and thus does not constitute a possible source of flammable gases.

There is no automatic fire suppression system in view of the foregoing, but there are Fenwal heat detectors. The supervisory circuits of the heat detectors are checked monthly and the heads are checked every 2 yr. Response to emergencies is governed by a LASL Group WX-5 plan of October 11, 1974. Conceivable ignition sources are the 110-V gamma detectors and the one tritium counter within the No. 3 vault. However, such an electrical fire should be confined to the apparatus itself and not exceed a loss of about \$500.00. Fires would probably be fought with CO_2 or dry agents, thus obviating the need to impound water for monitoring (see Appendix C).

H. HEALTH AND SAFETY

The two classes of potential accidents involving the release of plutonium from the vaults are (a) physical damage, such as dropping, and (b) releases as a result of fire damage. Experience has shown that the release of material in particulate form from physical damage is minor and the resultant contamination is local. Containers are known to be subject to no corrosion or overpressure. Vault areas and

available assemblies, both open and packaged, are monitored monthly for alpha contamination. As discussed above, the combustible loading in the vaults is so low that it is doubtful that sufficient energy would be released to initiate a release of plutonium.

Calculations indicate that a maximum off-site (beyond the boundaries of the Laboratory) lung dose of 30 rem would be expected if the entire plutonium inventory in storage were to burn. These calculations recognize the absence of filters in the exhaust system, and demonstrate that filters are not necessary. In an abnormal situation, workers would enter with supplied air breathing devices and their doses should be negligible. Also, the ventilation system would be shut down. (See Appendix D.) Controls for this system are located at the tunnel entrance. Switches are labeled "Main Supply Fan" and "Area V Exhaust." Therefore, no back-up ventilation system is necessary. Wall and floor surfaces are smooth, lending themselves to effective decontamination.

Only very small quantities of plutonium might be released as a result of any credible accident. If the entire inventory were involved in a massive fire (an incredible event), the release might be relatively large, but it would not be larger than the postulated emergency dose criteria. The calculated doses are very conservative because not only has the amount of plutonium involved in, and released by, the fire been chosen conservatively, but no credit has been taken for deposition of plutonium in ductwork and in transit to the dose point. Loss of airborne plutonium by deposition would be significant.

I. PHYSICAL PROTECTION AND MATERIAL SAFEGUARDS

The TA-41 area (W-Site, housing Structure W-1) is a "Limited Security Area" that is enclosed by a security fence constructed of No. 11 American Wire Gauge woven fabric. This fence, topped by three strands of barbed wire on brackets angled outward, has an overall height of at least 8 ft. Entry into this area is controlled at all times by at least two members of the LAAO Protective Force. Unescorted en-

try is restricted to badged employees who have "Q" Access Authorization.

Area V is an underground vault within Structure W-1, with one access point equipped with a vault door that has two built-in combination locks. Inside this vault there are five separate vaults; each vault has a vault door with two built-in combination locks. The separate vault doors normally are not closed. The vault is constructed of poured reinforced concrete and has the following measurements: 24-in. sides, 17-in. back, 18-in. front, 24-in. ceiling, 8-in. floor, and 16-in. interior walls.

Access to the vault is controlled by designated site employees. Two site employees must be present to open this vault because the two built-in combination locks operate on different combinations. This requirement exists because the vault is under the "buddy-system."

Persons not directly employed in operations involving access to, or use, processing, storage, accountability, or protection of unclassified special nuclear materials (SNM) must sign in upon entering this area. Information required is name, date and time of visit, organization represented, and purpose of visit.

An ERDA-approved door contact alarm on the vault entrance door is activated when the area is unattended. This alarm is connected to the central alarm panel in the LAAO Protective Force headquarters. This panel is manned 24 hours per day, 7 days per week. Response to the alarm is made within 10 minutes by Protective Force personnel.

During nonoperating hours, lights surrounding the TA-41 area are turned on, search procedures are in effect at the controlled entrance, and security checks are conducted hourly by Protective Force personnel.

J. LOSS LIMITATION

Based on the information given in paragraphs D and G, the loss potentials would not exceed \$1 million if safety systems function, or \$25 million if safety systems fail.

K. SURVEILLANCE, INSPECTION, AND TESTING

The Fenwal heat detectors are tested every 2 yr, and the associated supervisory circuits are checked monthly. Gamma and tritium detection systems are tested monthly. Physical protection and safeguard circuits are tested weekly. Tritium and alpha monitors in the exhaust system are tested weekly and calibrated annually.

L. REFERENCES

Operation of the vault is consistent with all applicable ERDA Manual Chapters. No waivers or deviations from these requirements have been requested.

APPENDIX A

AEC-LASL Interpretation of Criteria for Storage of Unirradiated Enriched Uranium dated May 10, 1972

A. SCOPE

1. These criteria are applicable to storage facilities used for all forms and concentrations of unirradiated enriched uranium in significant quantity except those materials listed in A.2 below.
2. The criteria do not apply to:
 - (a) material specifically designated by the user as "in-use" or "in-process",
 - (b) an assembly cell where enriched uranium components for weapons or peaceful nuclear explosives assembly and storage are involved,
 - (c) material which is packaged for transport in accordance with requirements of AECM 0529.

B. PURPOSE OF CRITERIA

1. These criteria define minimum requirements for new and existing storage facilities to provide
 - (a) adequate public and plant safety,
 - (b) physical protection and materials safeguards,
 - (c) limitation of any potential for loss of life and property.

C. DEFINITIONS

1. "Enriched uranium," for purposes of these criteria, means all material above 5 weight percent enrichment in the isotope U-235 (based on the total uranium content).
2. "Form of enriched uranium" means the various chemical and physical conditions which may occur in finished products or interim stages thereof. These include gases, solids, solutions, slurries, sludges, or process residues, weapons components, scrap, waste, and reactor fuels. Form also means the degree of solubility, degree of encapsulation, degree of combustibility, and degree of dispersibility present.

3. "Significant quantity" means more than 350 grams of U-235, unless a safety analysis demonstrates a larger quantity is required to qualify as significant.
4. "Storage facility" means a room, building, or other location meeting the criteria of this document.
5. A "storage zone" or "compartment" means a region within a storage facility which is separated from other compartments by physical barriers as necessary to comply with these criteria.
6. "In-process" or "in-use" material means only material which is integral to laboratory operation or production processes, or is needed to maintain continuity of operations.
7. "Approved" means approved in writing by inclusion in a Safety Analysis Report or through separate documentation submitted to the Field Office Manager or his designated authorities.
8. "Periodic" means occurring at approved regular intervals.

D. GENERAL STORAGE REQUIREMENTS

1.
 - a. Enriched uranium shall be stored in approved storage facilities. The suitability of storage facilities shall be documented in a Safety Analysis Report.
 - b. Existing facilities intended for or already in use for storage of enriched uranium shall be reviewed by the operating contractor who shall prepare a safety analysis for consideration by the field office and approval of any justified exceptions or exemptions.
 - c. A specific Safety Analysis Report (SAR) for a facility may not be necessary if the hazards associated with storage have been addressed in a more comprehensive SAR, as for the plant in which the storage facility is located.
2. Storage facilities and their monitoring and engineered safety systems shall provide reasonable assurance that fire protection, physical protection, and material safeguards will be functional under all credible combinations of internal accidents and natural forces.

3. Storage facilities shall provide reasonable assurance that, under normal operating conditions, any release of stored material to plant or public environment will not exceed the limits on exposure and permissible concentrations established in AECM 0524 and shall be kept to the minimum practicable. Under postulated maximum credible accident conditions, exposure of off-site personnel shall not exceed 25 rem whole body or 300 rem to the thyroid, and the intake of uranium shall not exceed the maximum permissible body burden for workers as specified by the ICRP, taking into account the isotopic composition of the material being stored.*
4. Other material of greater potential hazard shall not be kept within enriched uranium storage facilities unless the presence of the other material has been evaluated in an approved SAR.
5. Process operations, storage of nonnuclear materials, or equipment which is not directly required for storage operations, and all other functions not directly a part of normal storage operations shall be excluded from the storage facility. Specific prior approval by the field office shall be required for any deviation.
6. All pyrophoric materials shall be converted to non-pyrophoric forms or inerted prior to storage or be stored in approved containers that will not permit spontaneous ignition or dispersal. All readily airborne dispersible materials shall be placed in approved containers that will minimize the possibility of dispersal under credible operating or accident conditions. All other forms of enriched uranium should also be stored in approved containers wherever operationally practicable.
7. All containers for enriched uranium shall be marked, tagged, or coded to indicate the type or category of

* It is felt that the use of the occupational body burden for this criterion is adequately safe considering both the unlikely nature of the event and the fact that uranium is not as tenaciously held in the body as plutonium so that the radiation dose rates will be more transitory. Also, for slightly enriched uranium, the effect is primarily one of chemical toxicity and the listed body burden is presumably below the toxic threshold.

material, amount, degree of enrichment, and curie level or radiation characteristics of contents. Containers shall be securely closed and positioned so as to prevent significant displacement and maintain criticality prevention requirements. Containers shall provide resistance to fire and maintain confinement under accident conditions. Form of material shall be taken into consideration in determining requirements for containers.

8. Enriched uranium shall be stored in racks or equivalent equipment (such as birdcages) capable of securely locating stored material to prevent displacement, to assure needed separation, and to meet safety design requirements under operational and credible accident conditions. Floor storage will be permitted only where criticality control is inherently provided by individual containers or physical restraints.
9. Where storage facilities use approved containers for all stored material and otherwise meet minimum requirements for criticality prevention, physical protection, material safeguards, and fire safety, no additional safety features (such as ventilation systems or confinement barriers) will be required. The need for monitoring systems for detecting leakage of container or facility contents (as required by Section H.2), fire, and criticality shall be evaluated in all cases. Inspections of approved type and frequency may be considered as a substitute for selected monitoring systems, provided this substitution is supported by appropriate safety analysis.
10. Storage facilities shall be compartmentalized so that no compartment contains material with a U-235 content of more than 600 kg unless a larger quantity is justified in an approved SAR.

Compartments shall be designed to prevent significant propagation of internal accident conditions between compartments.
11. Any outdoor storage shall be in approved containers (compatible, wherever feasible, with DOT standards) and shall provide physical protection and safety features to prevent unacceptable loss, damage, or dispersal as a result of accidents or natural forces.

E. SAFETY ANALYSIS

1. A Safety Analysis Report shall be prepared by the operating contractor to define and document:
 - a. *principal characteristics and design bases (such as structural loads and required equipment*

capacities) of storage containers, racks, structures or compartments, mechanical systems and components (including utilities), and the rationale for selection of design bases,

- b. form, type, and amount of material to be stored, and definitions used to distinguish such material from "in-process" material,
 - c. potential accidents (including fire, criticality, and explosions), and natural forces pertinent to the site, and their credible combinations,
 - d. potential hazards from operating and accident conditions (including personnel exposure and contamination of environment),
 - e. maximum accidental release from the storage facility of enriched uranium and fission products (and of other stored material), dispersal potential, and any associated personnel exposures and environmental contamination,
 - f. any design safety features included to prevent or cope with potential accidents,
 - g. review and approval procedures for criticality control, fire safety, physical protection, and periodic inspection and testing of equipment,
 - h. results of safety analyses, including objectives, margins of safety, and degree of conservatism employed, to demonstrate that the facility meets specified safety objectives.
2. Natural forces pertaining to the site such as floods, earthquakes, winds and tornados (and potential missiles), shall be assessed to define maximum credible natural events and consequent bases for design.* To select design bases, existing historical data shall be examined. Historic earthquake data shall be supplemented, as appropriate, by review of existing geologic data and the possible effects of local amplification of vibration and of local ground displacements where appropriate.

*The pertinent environmental situation shall be reviewed in all cases in the SAR as background for selection of design bases. However, for facilities where the inventory limits of D.10 are met, consideration may be given either to establishing minimized tornado and earthquake design requirements or to eliminating them as design requirements. Nevertheless, criticality control and requirements of Section D.3 must be maintained under all environmental conditions pertinent to the site.

3. Safety analyses shall (a) evaluate design bases consistent with the potential hazard inherent in the type, form and amount of stored material and (b) define safety margins consistent with the potential hazard and with any uncertainties in natural phenomena, maximum credible accidents, and the dispersal characteristics of any released material.
4. The Safety Analysis Report and the facility design shall be approved by the field office and reviewed by responsible Headquarters division(s) when deemed appropriate by the field office manager or as requested by Headquarters. Proposed deviations from these criteria shall be defined and justified in the Safety Analysis report. Any subsequently proposed significant deviations shall be approved by the field office and incorporated in a revised report. Copies of the report will be maintained at the site.

F. NUCLEAR CRITICALITY SAFETY

1. Nuclear criticality safety measures shall conform to and fully utilize AECM 0530 and AECM Appendix 0530 as minimum requirements in order to prevent an unplanned nuclear excursion under all natural and accident conditions pertinent to other requirements of this section. Limitation of these criteria to materials of 5% or greater enrichment in U-235 shall not negate AECM 0530 requirements for criticality control at other enrichment levels.
2. The "Double Contingency Principle" shall be applied to enriched uranium storage facilities. This principle requires that the design incorporate sufficient factors of safety to require at least two unlikely, independent, and concurrent changes to storage conditions before a nuclear excursion is possible. To accomplish this, the requirements given in AECM 0530 shall be followed. Necessary separation of units in storage shall be provided by physical means with minimum reliance on administrative control.
3. Storage Limits shall be posted in conspicuous places.
4. Criticality reviews, independent inspections, and documentation thereof shall be conducted according to the requirements of IAD 0530-27, "Contractor Internal Review System Requirements for Nuclear Criticality Safety." AEC personnel shall monitor these activities.
5. Systems for criticality detection and for nuclear accident dosimetry shall be provided. Monitoring and alarm systems for criticality detection shall meet, as a minimum, ANSI Standard N. 16.2-1969. Design parameters for nuclear accident dosimetry shall meet

the requirements of AECM 0545 and ANSI N 13.3-1969. Information for interpreting and responding to alarms shall be posted in conspicuous places. Systems shall remain operational under postulated accident conditions and include provision for emergency power. In the event of failure or disablement, signals shall annunciate the condition of the equipment.

G. FIRE AND EXPLOSION SAFETY REQUIREMENTS

1. Storage facilities shall be designed in accordance with AECM 0552, as a minimum. Where required by the safety analysis, manual or automatic fire suppression shall be provided.
2. Storage facilities shall prevent release of stored material in excess of the limits of Section D.3 in the events of credible fires and explosions.
3. Construction shall be non-combustible and fire-resistive. Alternative construction, if required, may be used only where shown acceptable by the safety analysis.
4. Automatic fire detection systems shall be provided. Alarms shall annunciate locally so as to be audible within storage areas, and at remote locations, and shall indicate the specific area initiating the alarm. Alarm systems shall indicate malfunctions.
5. A firefighting plan shall be developed, incorporated in the overall site fire plan, and exercised through drills which include use of emergency equipment. Signs providing basic information for interpretation of alarms and defining emergency procedures for evacuation shall be prominently displayed at strategic locations.
6. Where required by the safety analysis, automatic fire suppression systems shall be provided. Such systems shall be designed to minimize possibility of disablement as a result of any credible accident. Emergency power shall be provided as required.
7. First aid firefighting equipment shall be provided to facilitate manual fire suppression.
8. Storage facilities shall provide features to collect water used in firefighting, minimize contamination of surrounding areas, minimize loss and allow recovery of uranium which may be involved in a fire. Storage areas may be exempted from this requirement when justified by safety analysis. Any impounding capability

including floor drains and holding tanks, shall be designed for criticality safety and safe and efficient recovery of any enriched uranium which may be released in an emergency.

H. HEALTH AND SAFETY REQUIREMENTS

1. Storage facilities shall confine enriched uranium under normal operating or credible accident conditions so as to prevent exposure of the public and plant personnel exceeding requirements of Section D.3.
2. Automatic monitoring and alarm devices shall be considered in the SAR to detect the presence of significant levels of radioactivity or nonradioactive toxic materials, either released within the facility or escaping from it. Cautionary systems or interlocks to alert personnel prior to entry into hazardous areas shall be considered.
3. Container design shall be appropriate to the form of stored material. Criteria for container integrity shall be developed in the course of the required safety analysis and used in periodic inspection.
4. In multicompartimented facilities, multiple emergency exits shall be provided where necessary to permit safe egress without need for passage through hazardous areas. All safety alarms should annunciate inside and outside of the storage facility so as to identify hazardous areas.
5. The need for a ventilation system, and for protection of needed ventilation systems, shall be addressed in the Safety Analysis Report.
6. Emergency power, automatically activated on failure of normal supply shall be provided for all necessary systems, as defined in the SAR.

I. PHYSICAL PROTECTION AND MATERIAL SAFEGUARDS

1. Storage facilities shall conform to the requirements of AECM 2401, 2405, 2406 as applicable, and 7401, as a minimum to (a) prevent unauthorized access to and unauthorized removal or diversion of stored material, (b) facilitate detection of such removal, and (c) prevent significant damage to the facility from external causes.

J. LOSS LIMITATION

Facilities shall be provided with sufficient strength, fire resistance, compartmentalization, and engineered safety systems to limit property loss from any single credible accident (a) to less than \$1 million if safety systems function properly and (b) to less than \$25 million where such systems fail to function as designed. These limitations are not necessarily imposed on losses resulting from tornados or earthquakes.

K. SURVEILLANCE, INSPECTION, AND TESTING

Design shall facilitate the performance of periodic inspections and in situ tests by the user (in a manner approved by cognizant field office personnel) so as to ensure that safety systems and components necessary for criticality control, fire control, physical protection, materials safeguards, and detection and alarm systems are being properly maintained in readiness for use. Specific periods for inspection and testing shall be established in the Safety Analysis Report.

L. REFERENCES

Other AECM sections shall be reviewed for pertinent health, safety, physical protection, and fire protection criteria that may be required in addition to the requirements of these criteria (which have been derived for consistency with requirements of these other sections). In particular, reference is made to:

0524	Standards for Radiation Protection
0529	Safety Standards for the Packaging of Radioactive and Fissile Material
0530	Nuclear Criticality Safety
0544	Planning for Emergencies in AEC Operations
0545	Nuclear Accident Dosimetry Program
0550	Operational Safety Standards
0552	Industrial Fire Protection
2401	Physical Protection of Classified Matter and Information
2405	Physical Protection of Unclassified Special Nuclear Materials
2406	Protection of AEC Property
6203	Site Development Planning
6301	General Design Criteria
7401	Safeguards Control and Management of Nuclear Materials

APPENDIX B

EARTHQUAKE CONSIDERATIONS

The postulated 0.1 g's as a result of an earthquake corresponds to about 5.8 on the Richter scale.¹ A 1971 report² states that only one earthquake of magnitude 5 has been recorded in the Los Alamos area. This earthquake, recorded in 1952, caused only minor damage. Paper 366, cited in Ref. 3, states: "...that the boulder-capped pinnacles prevalent in

Los Alamos canyons could not survive a strong earthquake and that their existence indicates a long period of ground stability." A New Mexico Bureau of Mines and Mineral Resources document, also cited in Ref. 3, contains an estimate of a maximum shock of 3.5 (or about 0.006 g's) per 25-yr period for the Los Alamos area.

APPENDIX C

INSTRUCTIONS FOR FIRE DEPARTMENT AND PROTECTIVE FORCE REGARDING TA-41-1 VAULT AREAS AND ICE HOUSE (From an Orientation Tour Report)

ADMISSION TO ICE HOUSE AND VAULT AREAS

Contact Protective Force; all hours. Protective Force has by-pass key to Ice House and combinations for Day Vault and Main Vault locks.

USE OF WATER

In the Day Vault, water may be used if it can be assured that objects will not be displaced (moved about) by the water stream. In the Main Vault, water may be used only if it can be assured that objects stored on the shelves will not be wetted.

VENTILATION

System is normally "On." Switches labeled "Main Supply Fan" and "Area V Exhaust" are located at entrance to tunnel (Vault Areas).

RADIATION MONITORING

Before leaving, after having responded to a fire, call Group H-1, telephone 7878 (during working hours) or 4437 (after working hours). Do not leave area until H-1 has monitored personnel and equipment items.

APPENDIX D

POSSIBLE CONSEQUENCES OF PLUTONIUM RELEASE IN A FIRE AT TA-41

A fire in the storage facility at TA-41 could involve as much as 60 kg of plutonium. The consequences of such a fire, in terms of the possible release of plutonium as airborne material that could be inhaled by people living downwind, are of interest in establishing design criteria for the control of such an emission. The permanently inhabited area closest to the site is about 1000 ft to the south at an elevation approximately 350 ft higher. Additionally, uncontrolled occupationally inhabited areas are located 625 ft to the north, again at an elevation about 350 ft higher. At the same elevation as the site is the Omega West Reactor, about 1500 ft to the east.

People working at the site constitute a controlled population. In case of a serious fire in the storage area, actions would be responsive to the situation as it developed. The building ventilation system could be shut down if it were found to be introducing alpha activity into the facility. An alarm system, manually initiated, signals personnel to evacuate the site. This system is exercised annually in accordance with Laboratory policy.

Because of these considerations, the following evaluation of the consequences of a possible plutonium release concentrates on the impact on people off-site.

PLUTONIUM RELEASE

The assessment of the quantity of plutonium potentially released was made chiefly from two reports. The first⁴ is a literature review in which the ignition data are based primarily on the British work reported by Stewart. The second⁵ describes an experiment in which large pieces of plutonium (from 450 to 1770 g) were ignited and allowed to burn in a stream of air at a velocity of about 5.25 m/s.

The first report describes a British experiment in which 200-g rods of plutonium were suspended in a chimney and heated by a gasoline fire. Stewart's conclusions from this experiment were that beyond 200 yards no significant inhalation hazard would exist from burning several kilograms of plutonium and that a release value of 0.5% is a satisfactory, safe

value for estimating the airborne hazard downwind. Stewart also correlated the results of other British laboratory work by arriving at what he calls the "effective source strength," which is the quantity released from ignition in various particle size ranges weighted by the effective retention in the lung of that particle size. He quotes the effective source strength from these experiments as 2000 $\mu\text{Ci/kg}$ for burning under static conditions and as 10 000 $\mu\text{Ci/kg}$ for burning under dynamic conditions.

The difference between the static and dynamic conditions is related to the air velocity passing the specimen and the possibility of entrainment of the oxide produced in this air stream. Because 1 Ci of ²³⁹Pu is equal to about 16 g of plutonium, the effective source strength is about 0.0032% for static conditions and about 0.016% for dynamic conditions.

In the second report, the first two runs were with alpha-phase plutonium in which the metal was allowed to burn once ignited, with no additional heat source. The release on these two runs was 0.049% and 0.014%. In the third experiment, about 1 kg of delta-phase plutonium was burned with no additional heat source once ignited. The release from this specimen was about 0.0034%. In the fourth experiment, the alpha-phase plutonium was covered with magnesium-oxide sand once the piece was ignited. The release was 0.00039%.

From these data, 0.03% release was chosen as a conservative value for combustion under static conditions. This would amount to 0.33 g of airborne plutonium per kilogram of plutonium burned. In most of the experiments the particle size was relatively small in comparison to that of the oxide left, which could be entrained. For example, Mishima reports a value of about 4.3- μm mass median diameter for the experiment with the 1.7 kg, but the curve on log probability paper is not a straight line, with the deviation indicating that the distribution is skewed toward the smaller particle size.

The assessment of the quantity of plutonium released in a fire was based on the above reports.^{4,5} Later data⁶ indicate that in fires involving plutonium metal under static conditions, $<10^{-4}$ % of the burning metal will be released as an aerosol in the respirable size range. As the amount of disturbance increases (higher airflow and flow of molten metal), the quantity of aerosol increases from 0.01 to

0.05%. In the extreme, if droplets are formed and molten metal falls through space, spattering on impact, airborne release can increase to 1%. Overall, it appears that the 0.03% release remains a conservative assumption for the conditions that might exist in the vaults.

METEOROLOGICAL CONSIDERATIONS (By D. Dahl, H-8)

The location of TA-41 in Los Alamos Canyon introduces complex terrain effects into the meteorological considerations. Unfortunately, such terrain effects have not been an area of intensive investigation in meteorology. Therefore, there is little experimental or theoretical basis on which to model the effects of a plutonium release from the bottom of this canyon. The meteorological considerations, therefore, must be based on a subjective possibility, not objective probability analysis.

There is some evidence from the Omega West Reactor safety analysis⁷ that stable atmospheric conditions tend to occur frequently in the canyon. However, cross-canyon airflow also appears to predominate at the mesa level. This introduces the possibility of mutual air-mass entrainment and canyon flow rotation under certain atmospheric conditions. Moreover, the thick stand of tall trees on the canyon floor enhances the normal diffusion of a release. It therefore seems very risky to assume that an apparent inversion condition in the canyon would prevent material from reaching mesa levels. The existence of fire, with its thermal effects, would contribute to dispersal and further complicate calculations.

A list of possible release conditions is given below. These are not exhaustive but it is felt that they cover the range of possibilities. The intent of the analysis is to be conservative.

Case I: Significant thermal forcing (fire) in an otherwise stable canyon flow with low (1- to 2-m/s) mesa cross-canyon flow.

Case II: Strong cross-canyon flow (>4-m/s) during otherwise stable canyon flow causing canyon flow rotation or roll. No significant thermal forcing.

Case III: Stable down-canyon flow with weak cross-canyon mesa level winds (1- to 2-m/s). No significant thermal forcing.

Case IV: Unstable canyon flow (daytime) with weak cross-canyon winds (1- to 2-m/s). No significant thermal forcing.

Cases I and II serve as possible mechanisms for transport of material to mesa levels under otherwise stable conditions.

Cases III and IV are simpler because in Case III material is trapped in the canyon and in Case IV material is diffused as if no complex terrain were involved. Each case is analyzed below.

Test Case I—Fire at TA-41

Assumptions about fire:

Case (A): 1 ft³ of pine per hour

Heat potential = 5.68×10^7 cal/ft³

Based on 60-min burning time, the heat production (QH) rate is $\sim 1.6 \times 10^4$ cal/s.

Case (B): Input temperature = 0°C

Output temperature = 300°C

Altitude = 6800 ft

V output = 4-m/s

Diameter of stack = 0.5 m

Based on 60-min burning time, the heat production (QH) rate is 2.7×10^4 cal/s. (For Case B the assumptions are more severe than for the actual stack.)

Atmospheric conditions:

1. Stable inversion: 27°C/km (Ref. 7)
2. Mesa wind speed: 1-m/s

Plume rise (from Ref. 8): $\Delta h = CF_M^{1/4} S^{-1/4}$.

Case (A), where QH = 1.6×10^4 cal/s:

$\delta(^{\circ}\text{C}/\text{km})$	$\Delta h(\text{m})$	Dilution Factor (Air Mix)	
		$\Delta T 100^{\circ}\text{C}$	$\Delta T 300^{\circ}\text{C}$
27	54	78	237
10	68	98	294
0	89	113	340

Case (B), where QH = 2.7×10^4 cal/s:

$\delta(^{\circ}\text{C}/\text{km})$	$\Delta h(\text{m})$	Dilution Factor (Air Mix)	
		$\Delta T 100^{\circ}\text{C}$	
27	61	207	
10	78	258	
0	100	297	

Dilution factor is found by assuming air mix dilution to obtain stability at $\Delta h(\text{m})$.

$$D = \frac{\Delta T \times 10^3}{\Delta h(\delta/2 - \delta_a)}$$

where

- D = dilution factor
 ΔT = difference between entrance and exit temperature (C)
 Δh = calculated plume height (Briggs) meters
 δ = atmospheric lapse rate ($^{\circ}\text{C}/\text{km}$)
 δ_a = $-10^{\circ}\text{C}/\text{km}$ (adiabatic lapse rate).

From the calculations above, a plume that could reach the top of the canyon wall would have a dilution factor of about 250 (conservative). Using the existing stack parameters, the maximum dilution factor is calculated to be 158 rather than the 250 given above.

If, for the rest of its journey, the plume is assumed to be Pasquill Category F, we can use Gaussian plume equations to compute exposures.

Technique used:

1. Pasquill F
2. Distance 200 m
3. Divide X/Q by dilution factor

$$X/Q = 9.5 \times 10^{-8}$$

$$\begin{aligned} x &= 200 \text{ m} \\ \bar{u} &= 1 \text{ m/s} \\ h &= 0 \\ y &= 0 \\ z &= 0 \end{aligned}$$

$$X/Q \text{ corrected} = \frac{9.5 \times 10^{-8}}{250} = 3.8 \times 10^{-5}$$

If 0.03% of the 60 kg of plutonium is released to the exhaust during the burn, ~20 g would be released and the exposure would be $800 \mu\text{g-s}/\text{m}^3$ at 200 m. (Nearest occupational facility is to the north.)

For the Royal Crest Trailer Court (south)

$$X/Q = 4.6 \times 10^{-8}$$

Cat = F

$$\begin{aligned} x &= 300 \text{ m} \\ h &= 0 \\ y &= 0 \\ z &= 0 \\ \bar{u} &= 1 \text{ m/s} \end{aligned}$$

$$X/Q \text{ corrected} = 1.8 \times 10^{-5}$$

Exposure = $400 \mu\text{g-s}/\text{m}^3$ at 300 m.

Test Case II—Wind Roll (stable conditions)

Nearest habitations:

North - public facility (occupational)

South - Royal Crest Trailer Court

Approximate path lengths:

Flow to north ~600 m.

Flow to south ~500 m.

Time when condition may occur: Night during frontal passage (mostly winter)

Choice of model: Gaussian plume

Conditions:

Mesa wind velocity = 4-m/s cross canyon

Canyon wind velocity = 1-m/s

Stability = neutral

Pasquill Cat = D (high wind rough surface)

$$h = 0$$

$$y = 0$$

$$z = 0$$

Low thermal input (neglected):

$X/Q = 1 \times 10^{-4}$ to south (500 m)

$X/Q = 7.7 \times 10^{-5} = > 1 \times 10^{-4}$ to north (600 m)

For 20 g of plutonium released, exposure would be $2000 \mu\text{g-s}/\text{m}^3$ (to both north and south).

Test Case III—Stable Down-Canyon Flow

Nearest habitation: Omega West Reactor (occupational)

Distance downwind: 500 m

Times when condition generally occurs: Nights (most severe in winter) and heavily overcast days

Choice of model: Gaussian plume

Conditions:

Mesa wind velocity = ≤ 1 -m/s cross canyon

Canyon wind velocity = 1-m/s

Wind direction = from west

Stability = inversion

Pasquill Cat = E (caused by surface roughness)

$$h = 0$$

$$y = 0$$

$$z = 0$$

$$x = 500 \text{ m}$$

Low thermal input (neglected)

$X/Q = 7.35 \times 10^{-4} = > 1 \times 10^{-4}$ (conservative)

For 20 g of plutonium released, exposure would be $20000 \mu\text{g-s}/\text{m}^3$ at 500 m.

Test Case IV--Convective Canyon Conditions

Nearest habitations:

North: Public facility (occupational)

Distance: 200 m

South: Royal Crest Trailer Court

Distance: 300 m

Times when condition generally occurs: Daytime
(mostly in summer)

Choice of Model: Gaussian plume

Conditions:

Mesa wind velocity = 2-m/s cross canyon

Canyon wind velocity = <1-m/s

Wind direction = from east

Stability = moderately unstable

Pasquill Cat = B

$h = 0$

$y = 0$

$z = 0$

Low thermal input (neglected)

$X/Q = 2.1 \times 10^{-4} = >2 \times 10^{-4}$ (to north, $x = 200$ m)

$X/Q = 9.9 \times 10^{-4} = >1 \times 10^{-4}$ (to south, $x = 300$ m)

For 20 g of plutonium released, exposures would be:

4000 $\mu\text{g-s/m}^3$ at 200 m (to north) and 2000 $\mu\text{g-s/m}^3$
at 300 m (to south).

Exposure Summary (units = $\mu\text{g-s/m}^3$)

	North Facility	Royal Crest Trailer Court	Omega West Reactor
Case I	800	400	---
Case II	2000	2000	---
Case III	---	---	20 000
Case IV	4000	2000	---

DOSE CONSIDERATIONS

To estimate the dose and quantity inhaled, a breathing rate of 10 $\text{m}^3/8$ h (3.47×10^{-4} m^3/s) was used. The International Council on Radiation Protection Task Group lung model was used as a basis for calculation with an assumed 20% pulmonary deposition. (According to this model, a 1- μm particle would have a pulmonary deposition of about 25%, and a 4.3- μm mass median diameter particle would have a deposition of about 10 to 15%. In view of the uncertainty of particle size, the 20% deposition seems reasonable. In an actual situation, the plutonium may well be absorbed by smoke particles, which would probably lower its deposition.)

If, as a basis for calculating the dose, an exposure of 1000 $\mu\text{g-s/m}^3$ with 1 μg equivalent to 0.063 μCi is used, such an exposure would lead to the inhalation of 0.322 μCi . The pulmonary retention would be 0.0043 μCi . Forty per cent of this deposition will be eliminated with a half-life of 1 day, resulting in a dose of 0.0066 rem (Quality Factor of 10). The remainder will be cleared with a 500-day half-life to give a dose over the entire clearance period of 4.95 rem to the lung or a total of about 5 rem. Of the material deposited in the pulmonary region, 15% or 0.00065 μCi will be cleared to the lymph nodes with a half-life of 500 days, whereas two-thirds will be eliminated with a half-life of about 1 yr. This leaves a permanent deposit in the lymph nodes of 0.00022 μCi . Again, of the initial pulmonary deposition, 5% will be cleared to the blood with a half-life of 500 days, where it will be deposited in the liver and bone as a permanent burden. A slight additional quantity will be transferred to the blood from the deposits in the nasal and tracheobronchial regions, resulting in a total body deposit of 0.00025 μCi from the exposure to 1000 $\mu\text{g-s/m}^3$.

From these dose calculations and the integrated air concentrations, one can estimate the consequences of the postulated release under the various conditions estimated (see Table D-I).

CRITERIA

There are no established criteria from which we can judge the application of given doses in an accident situation such as this. Essentially, we are dealing with the question of a "once-in-a-lifetime" dose, which can be judged to have a low probability of occurrence. Further, we are dealing only with that part of the dose that will be received during the active phase of the accident. Following the accident, people will be evacuated until they can return with no further possibility of increased dose.

The only similar criteria available have been established by Title 10, Code of Federal Regulations (CFR) Part 100, which deals with the design of light-water reactors. These are dose criteria that the license applicant must show will not be exceeded even in the event of a design basis accident. If such an accident should occur, the design features of the reactor and the extent of an exclusion area must be such that these doses, applied to uncontrolled individuals, would not be exceeded.

These criteria require that the dose at the boundary of an exclusion area should not exceed 25 rem

TABLE D-1
ESTIMATED DOSE CALCULATIONS

Exposure ($\mu\text{g-s/m}^3$)	Total Lung Dose (rem)	Quantity to Lymph Nodes (μCi)	Permanent Body Deposit (μCi)
4000	20	8.8×10^{-4}	1×10^{-3}
2000	10	4.4×10^{-4}	5×10^{-4}
20 000	100	4.4×10^{-3}	5×10^{-3}

to the whole body or 300 rem to the thyroid if the individual spends 2 h at the boundary following onset of the postulated fission product release. There must be a low population zone of such size that an individual remaining at the boundary during the full period of the release will not receive more than 25 rem full body radiation or 300 rem to the thyroid. A population center distance of at least 1-1/3 times the distance to the outer boundary of the low population zone also is prescribed. There are no references, either direct or indirect, regarding acceptable lung doses in Title 10, CFR Part 100. However, an indirect reference is given in ERDA Appendix 0524 wherein the lung, under the category of "other organs," presumably is allowed an occupational dose commitment of 15 rem/yr.

The 25 rem whole body number, given in Title 10, CFR Part 100, is the same as that recommended by the National Council on Radiation Protection as the dose which, if received by workers in an accident, need not be entered in their exposure records to control their integrated exposure over the years. It also corresponds to five times the allowed annual accumulated dose commitment for workers occupationally exposed to ionizing radiation. It is noted that 300 rem for the thyroid is equal to 20 times the annual limit for workers. Therefore, for this calculation, a limit of either 5 or 10 times the annual dose for workers for individual organs can be used with the proviso that the total deposition retained in the body for the lifetime of the individual be <10% of the permissible body burden for workers. In view of the low population of Los Alamos and the

low population density, one can apply these figures to the nearest point of habitation, bearing in mind that the plant and the community are closely knit in their emergency procedures and that sizable areas could be evacuated during a fire if it became necessary. The doses and body burdens calculated for uncontrolled personnel constitute a considerable fraction of these criteria while still remaining within them. This is reasonable based on the extreme conservatism of the initial assumptions.

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