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Revision 3

Documented Safety Analysis for the 216-Z-9 Waste Storage Crib Facility

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

CH2MHILL
Plateau Remediation Company

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HNF-58818, Rev. 3

Documented Safety Analysis for the 216-Z-9 Waste Storage Crib Facility

Prepared by:

CH2M HILL Plateau Remediation Company
Richland, Washington

October 2019

Executive Summary

ES.1 Facility Background and Mission

Plutonium Finishing Plant (PFP) was built in 1948 and began processing plutonium in mid-1949 with the Tank 241-Z-361 as part of the low salt waste disposal path from all PFP processes, including the incinerator, the Plutonium Reclamation Facility, and the Waste Treatment Facility. If the plutonium content was analyzed to be more than 10 g per batch, generally the batch was reprocessed. Below the plutonium discard limit, caustic was added and the material was sent to the cribs. The 216-Z-9 Crib received mixed aqueous and organic waste streams from the PFP Recovery of Plutonium and Uranium by Extraction (RECUPLEX) process between 1955 and 1962. During its operational period, the 216-Z-9 Crib received approximately 3.8E+06 L (1.0E+06 gal) of liquid wastes, which contained 27.4 kg of plutonium by accountability records. Based on analysis of the soil, the plutonium content of the crib soil was estimated to range from 50 to 150 kg. At the end of the operational period, the 216-Z-9 Crib was isolated from the RECUPLEX process through blanking its inlet lines in the 234-5Z Building tunnel; as part of PFP Deactivation and Decommissioning (D&D) activities, these drain lines have been grouted.

After 216-Z-9 Crib was isolated, activities included excavation of the top 30 cm of soil, construction of 216-Z-9A, 216-Z-9B, and 216-Z-9C support buildings, de-energization and removal of utility equipment, equipment removal, and surveillance and maintenance (S&M). After deactivation activities were performed, 216-Z-9 Crib transitioned to the Decommissioning phase of the facility life-cycle, with only S&M in the current work scope.

The 216-Z-9 Crib is shut down and isolated in S&M mode normally, but limited D&D activities are allowed. There are no process operations occurring or planned. However, it is expected that additional characterization activities may be required in the future, as 216-Z-9 Crib remediation plans are finalized.

ES.2 Facility Overview

The 216-Z-9 Waste Storage Crib is a tailings crib designed as an enclosed trench. The crib was built in 1955 and is located approximately 500 ft east of and outside the current security fence surrounding PFP. The crib is almost entirely underground, but has a reinforced-concrete-slab roof 9-in.-thick at grade level. The roof is approximately 120 ft long by 90 ft wide. The underground walls slant inward to a rectangular bottom that is one-sixth the size of its roof (60 ft by 30 ft). It is approximately 20 ft deep. The concrete roof is supported by footings around the perimeter and by 6 concrete columns located at the corners of the floor area and midway along each of the 60-ft sides. In addition, a girder-tension I-beam support system was installed on the roof for additional support over areas with increased weight and where holes had been drilled in the concrete cover. The 216-Z-9 Waste Storage Crib operations support building (216-Z-9A) sits next to and on top of the crib. It houses equipment used during the filling and plutonium mining operations. The support building is actually two connected buildings. The structure is located on the east side of the crib with a part of it extending onto the crib roof. It is approximately 1,000 ft^2, houses a soil packaging glovebox, soil assaying equipment, in-process drum storage, a personnel entryway to the crib, and a personnel change room. The portion of the building sitting next to the crib cover is made of reinforced concrete with insulated sheet-metal siding. It is connected to the structure extending over the crib via an airlock.

There are no fire detection, alarm, or suppression systems installed at the 216-Z-9 Crib Facility. The 216-Z-9 Complex is currently dormant and buildings are not accessed except for periodic monitoring and assessment tours. Building 216-Z-9 is not accessible without a confined space permit. Building 216-Z-9 is effectively a maintenance enclosure without any significant personnel access. Buildings 216-Z-9A and 216-Z-9B are both currently locked and require special permission for access. All existing lighting and other life-safety systems are out of service and provide no support for general occupancy.

The 216-Z-9 Crib was isolated from the RECUPLEX process through blanking its inlet lines in the 234-5Z Building tunnel; these drain lines have been grouted. The 216-Z-9 Crib has no electrical utilities attached. The 216-Z-9A Building, and the crib trench, are fitted with High-Efficiency Particulate Air (HEPA) breather filters to allow passive atmospheric pressure driven air exchange ("breathing").

ES.3 Facility Hazard Categorization

The 216-Z-9 Crib is a Hazard Category 2 nuclear facility.

ES.4 Safety Analysis Overview

The 216-Z-9 Crib is isolated in S&M mode normally, but limited D&D activities are allowed. No process operations are occurring or planned. The activities analyzed here for the 216-Z-9 Crib include the surveillance, maintenance, limited D&D activities, and limited characterization of contents in support of the containment of hazardous materials and future area restoration projects.

The significant hazards associated with the 216-Z-9 Crib are a crib roof collapse with fire, crib design basis seismic event, and a beyond design basis seismic event. The consequence for the crib roof collapse with fire and seismic event scenarios do not exceed the consequence thresholds used in the hazards analysis.

The Technical Safety Requirement (TSR) controls include: Material Management (SAC 5.6.1), Safety Management Programs (AC 5.5.1), Nuclear Criticality Safety (AC 5.7.1), Waste Acceptance Program (AC 5.7.2), and Traffic Control Program (AC 5.7.3).

ES.5 Organization

The contractor responsible for maintenance of 216-Z-9 Crib and development of this Documented Safety Analysis (DSA) is CH2M HILL Plateau Remediation Company (CHPRC).

ES.6 Safety Analysis Conclusions

The 216-Z-9 Crib Facility safety basis is appropriate and no issues have been identified that are significant to the 216-Z-9 Crib Facility safety basis.

ES.7 DSA Organization

This DSA complies with the 2016 revision of DOE-STD-1120, *Preparation of Documented Safety Analysis for Decommissioning and Environmental Restoration Activities*, supplemented with DOE-STD-3009-2014, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis*.

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Terms

A	anticipated
AC	Administrative Control
ACM	Asbestos-containing Material
ARF	Airborne Release Fraction
BEU	Beyond Extremely Unlikely
BEBA	Beyond Evaluation Basis Accident
CHPRC	CH2M HILL Plateau Remediation Company
CPRM	Central Plateau Risk Management
CSER	Criticality Safety Evaluation Report
CSP	Criticality Safety Program
CW	Collocated Worker
D&D	Deactivation and Decommissioning
DA	Directive Action
DBP	Dibutyl phosphate
DF	Design Feature
DID	Defense-in-Depth
DOE	U.S. Department of Energy
DR	Damage Ratio
DSA	Documented Safety Analysis
EG	Evaluation Guideline
EPP	Emergency Preparedness Program
ERDF	Environmental Restoration Disposal Facility
EU	Extremely Unlikely
FHA	Fire Hazards Analysis
FW	Facility Worker
HA	Hazard Analysis
HID	Hazard Identification
HC	Hazard Category
HE	Hazard Evaluation
HEPA	High Efficiency Particulate Air
ICRP	International Committee on Radiological Protection
ISMS	Integrated Safety Management System
KA	key attribute
LCO	Limited Condition for Operation
LLW	Low-Level Waste
LLMW	Low-Level Mixed Waste
LPF	Leak Path Factor
MAR	material at risk
MBP	Monobutyl phosphate

MDSA	Master Documented Safety Analysis
MOI	Maximally-exposed Offsite Individual
NDA	Nondestructive Assay
NPH	natural phenomena hazard
PAC	Protective Action Criteria
PFP	Plutonium Finishing Plant
QA	Quality Assurance
RF	Release Fraction
RO/RO	Roll-on/Roll-off
RPP	Radiation Protection Program
SARAH	Safety Analysis and Risk Assessment Handbook
S&M	Surveillance and Maintenance
SAC	Specific Administrative Control
SIH	Standard Industrial Hazard
SMP	Safety Management Program
SC	Safety Class
SS	Safety Significant
SSC	Structure, System, or Component
SWOC	Solid Waste Operating Complex
TBP	Tributyl phosphate
TED	Total Effective Dose
TRU	Transuranic
TSR	Technical Safety Requirement
U	Unlikely
USQ	Unreviewed Safety Question
WAP	Waste Acceptance Program
χ/Q'	(Chi over Q) Atmospheric Dispersion Factor

1.0 Introduction

1.1 Summary

The 216-Z-9 Crib facility has been in Surveillance and Maintenance (S&M) since 1962. DOE-STD-1120-2016, *Preparation of Documented Safety Analysis for Decommissioning and Environmental Restoration Activities*, supplemented with DOE-STD-3009-2014, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis*; where referenced, is an approved "safe harbor" methodology for facilities undergoing decommissioning provided in 10 CFR 830 Subpart B Appendix A, Table 2.

As a U.S. Department of Energy (DOE) nuclear facility transitions from operations through the decommissioning process, the facility undergoes many life cycle changes and the safety basis is required to be maintained whenever the hazard category is 1, 2, or 3. The following sequential phases are described for this transition: deactivation, decommissioning, decontamination, and demolition.

Per DOE-STD-1120-2016, decommissioning is defined as, "Takes place after deactivation and includes surveillance and maintenance, decontamination and/or dismantlement. These actions are taken at the end of the life of a facility to retire it from service with adequate regard for the health and safety of workers and the public and for the protection of the environment. The ultimate goal of decommissioning is unrestricted release or restricted use of the site."

The 216-Z-9 has been deactivated from service, currently in S&M mode as part of the decommissioning phase, and waiting for direction of future decontamination/demolition activities.

1.2 Facility Overview

The 216-Z-9 Waste Storage Crib is an isolated nuclear waste disposal facility located approximately 150 m (500 ft) east of the Plutonium Finishing Plant (PFP) site. See Figures 1-1 and 1-2. The 216-Z-9 Crib received mixed aqueous and organic waste streams from the PFP RECUPLEX ("Recovery of Plutonium and Uranium by Extraction") process between 1955 and 1962.

The 216-Z-9 Waste Storage Crib is a tailings crib designed as an enclosed trench. The crib was built in 1955 and is located approximately 500 ft east of and outside the current security fence surrounding PFP. The crib is almost entirely underground, but has a reinforced-concrete-slab roof 9-in.-thick at grade level. The roof is approximately 120 ft long by 90 ft wide. The underground walls slant inward to a rectangular bottom that is one-sixth the size of its roof (60 ft by 30 ft). It is approximately 20 ft deep. The concrete roof is supported by footings around the perimeter and by 6 concrete columns located at the corners of the floor area and midway along each of the 60-ft sides. In addition, a girder-tension I-beam support system was installed on the roof for additional support over areas with increased weight and where holes had been drilled in the concrete cover. The 216-Z-9 Waste Storage Crib operations support buildings 216-Z-9A, 216-Z-9B, and 216-Z-9C are supported by the I-Beam frame that extends across the trench 216-Z-9A is located on the east side of the crib with a part of it extending onto the crib roof. It is approximately 1,000 ft^2, houses a soil packaging glovebox, soil assaying equipment, in-process drum storage, a personnel entryway to the crib, and a personnel change room. The portion of the building sitting next to the crib cover is made of reinforced concrete with insulated sheet-metal siding. It is connected to the structure extending over the crib via an airlock. The 216-Z-9C enclosure houses the excavating equipment used during the filling and plutonium mining operations. The 216-Z-9B Mining Operator Station Building, near the west end of the crib, projects down through the concrete slab into the trench area to provide a view of the mining equipment for the operator controlling the mining arm. These buildings were used in the past for extracting plutonium and are inactive. The 216-Z-9 crib soil is contaminated with approximately 50 kg of plutonium.

All utilities have been physically disconnected from the 216-Z-9 Crib, support buildings, and ventilation system. The facility is normally in S&M mode, but limited D&D activities are allowed when in D&D mode.

1.3 Summary of Facility Hazard Categorization

Nondestructive Assay (NDA) measurements (memorandum M2410-07-072, "NDA Results for Z-9 Duct System," [Appendix C.2] and memorandum M2100-07-044, "NDA Results for 216-Z-9A Glovebox" [Appendix C.1]) indicate that there are approximately 8 g (0.28 oz) of dispersible material at risk (MAR) in the 216-Z-9 Glovebox (located in Building 216-Z-9A), and approximately 15 g of dispersible MAR in the K-1-9 and K-1-10 high efficiency particulate air (HEPA) filter housings and K1-8-1 and K1-8-2 exhaust fans in the 216-Z-9 Crib support buildings.

Based on data and measurements taken during soil mining in 1977 (HNF-31792, *Characterization Information for the 216-Z-9 Crib at the Plutonium Finishing Plant*), the soil beneath the 216-Z-9 Crib Trench is assumed to be contaminated with approximately 48,000 g of the < 10 percent ^{240}Pu mixture (see Subsection 3.1.1).

Based on the inventory thresholds defined in DOE-STD-1027-92, *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports*, the 216-Z-9 Crib is categorized as a Hazard Category 2 nuclear facility.

1.4 Summary of Safety Analysis Results

The hazard and accident analyses for the 216-Z-9 Crib Facility are described in detail in Chapter 3.0 of this DSA. The DSA presents analysis of the two bounding accidents: the 216-Z-9 Crib Facility Seismic Event and the 216-Z-9 Facility External Event Impact plus Fire. An analysis of a Beyond Evaluation Basis Accident (BEBA), "Seismic Event Plus Fire," is also presented in Section 3.4.3. Consequences for the Seismic event are "low" (Risk Bin III) to the Facility Worker (FW), Collocated Worker (CW), and Maximally-exposed Offsite Individual (MOI) receptors. Consequences for the External Event Impact with Fire event are "low" to both the CW and MOI receptors. Therefore, no Safety Significant (SS) structures, systems, and components (SSCs) are required to be designated as controls for the 216-Z-9 Crib Facility.

The 216-Z-9 Crib Facility structures, including the 216-Z-9 Crib Trench walls and roof; the 216-Z-9A and 216-Z-9B support buildings (including the 216-Z-9A Glovebox); and the K-1-8, K-1-9, and K-1-10 ventilation system components are classified as Defense-in-Depth (DID) structures providing confinement of hazardous materials. The soil within the 216-Z-9 Crib Facility boundary (see Figure 2-2) is designated as a DID Design Feature (DF) (see Table 4-3) to prevent releases of potentially-contaminated soils directly beneath the 216-Z-9 Crib Facility.

Five Technical Safety Requirements (TSRs) are implemented to protect accident assumptions and reduce the risk of these events:

- The Material Management Specific Administrative Control (SAC) protects accident assumptions by ensuring that the MAR is not increased.
- The Safety Management Program (SMP) Administrative Control (AC) reduces the risk of these events by implementing applicable SMPs.
- The Nuclear Criticality Safety (AC) establishes a Criticality Safety Program and provides measures that ensure Criticality Safety Program key elements are in place to prevent an accidental criticality at the 216-Z-9 Crib Facility.
- The Waste Acceptance Program (AC) defines measures to protect the assumptions associated with waste container-related accidents.
- The Traffic Control Program (AC) defines measures, restrictions, and actions to prevent or minimize the occurrence of vehicle or other heavy-equipment, impact-related accidents at the 216-Z-9 Crib Facility.

1.5 Rationale for DSA Methodology

DOE-STD-1120-2016, Chapter 1.0 “Introduction,” Section 1.1 “Purpose” states:

> This Department of Energy (DOE) Standard (STD), DOE-STD-1120-2016, describes a methodology for preparing a Documented Safety Analysis (DSA) for decommissioning of hazard category (HC) 1, 2, or 3 nuclear facilities, as well as HC-2 or HC-3 environmental restoration (ER) activities that involve work not done within a permanent structure or the decommissioning of a facility with only low-level residual fixed radioactivity.

As a Hazard Category 2 nuclear facility currently in S&M mode, the 216-Z-9 Crib falls within this scope of work, therefore the DSA methodology and form given in DOE-STD-1120-2016 has been selected for the 216-Z-9 Crib DSA.

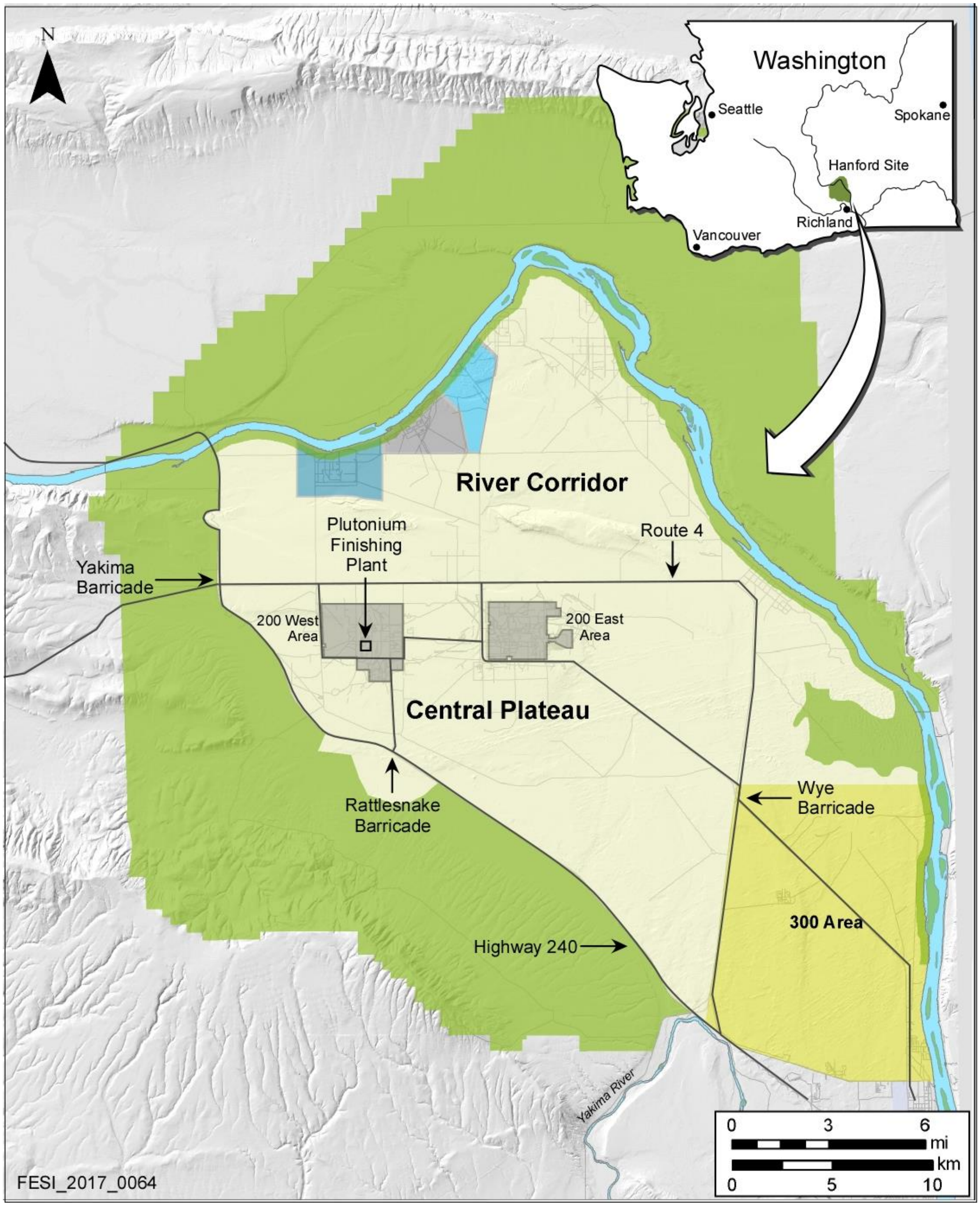

Figure 1-1. Hanford Site, Showing Location of the PFP Complex

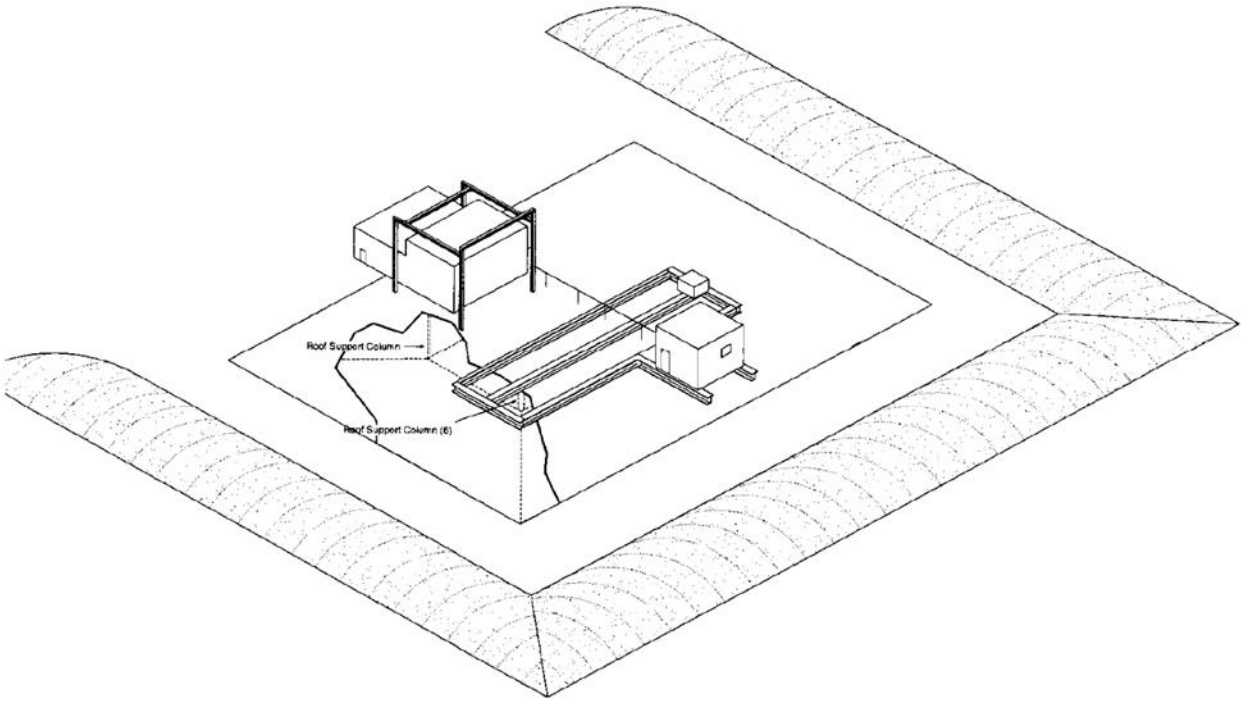

Figure 1-2. 216-Z-9 Waste Storage Crib

2.0 Facility Description

2.1 Facility Description

The 216-Z-9 Crib was completed in 1955 for the disposal of both organic and aqueous plutonium waste solutions from the RECUPLEX Plutonium Scrap Recovery Facility in the 234-5Z Building at PFP.

The 216-Z-9 Crib Trench is a rectangular excavation 6.1 m (20 ft) deep, which measures 27.5 m (90 ft) by 36.6 m (120 ft) at the surface, with trench walls that slope inward and downward to a floor area of 9.1 m (30 ft) by 18.3 m (60 ft). The trench is covered by a 23 cm (9 in.)-thick concrete slab, supported by six concrete columns spaced around the active floor area of the trench. See Figure 2-1. A load-bearing girder-tension I-Beam frame rests on footings at the top edge of the trench and bears the load of the 216-Z-9A and 216-Z-9B Buildings, the 216-Z-9C mechanical enclosure, and reinforces the roof at the locations where penetrations had been made.

The 216-Z-9A and 216-Z-9B Buildings, along with their associated ventilation systems and the 216-Z-9C enclosure, were built beginning in 1973 to support removal of contaminated soil from the crib (see Section 2.2). The 216-Z-9A Building is constructed of reinforced concrete and sheet metal, approximately 93 m^2 (1,000 ft^2). The portion of the building extending over the surface of the crib (supported on the I-Beam frame) connects with the rest of the building through an airlock; this portion of the building allows for personnel entry to the crib trench. The 216-Z-9B Building is constructed of sheet metal, approximately 11.4 m^2 (123 ft^2), and is supported on the I-Beam frame which is suspended over the concrete trench cover. The 216-Z-9C mechanical enclosure is also supported on the I-Beam frame at the south riser opening.

2.1.1 Facility Operational History

2.1.2 Operational Period

The 216-Z-9 Crib was in service, receiving mixed "high-salt" aqueous and organic waste streams from the PFP RECUPLEX process, between 1955 and 1962; among the organic solutions included in the waste stream were carbon tetrachloride, tributyl phosphate, and dibutyl butyl phosphate.

During its operational period, the 216-Z-9 Crib received approximately 3.8E+06 L (1.0E+06 gal) of liquid wastes, which contained 27.4 kg of plutonium by accountability records. Based on analysis of the soil, the plutonium content of the crib soil was estimated to range from 50 to 150 kg. At the end of the operational period, the 216-Z-9 Crib was isolated from the RECUPLEX process through blanking its inlet lines in the 234-5Z Building tunnel; as part of PFP Deactivation and Decommissioning (D&D) activities, these drain lines have been grouted. After isolation, the 216-Z-9 Facility remained inactive and underwent periodic surveillance, including NDA of the soil from the crib.

2.1.3 Soil Removal Period

Based on the results of the NDA following isolation in 1973, a decision was made to remove the top 30 cm of contaminated soil (also referred to as "mining") as a means of reducing the risk of environmental contamination and potential criticality. Prior to the initiation of excavation activities, the 216-Z-9A Operations Support Building and its associated HEPA-filtered ventilation system was constructed next to and on top of the east end of the crib. The 216-Z-9B Mining Operator Station Building was constructed near the west end of the crib, projecting down through the concrete slab into the trench area to provide a view of the mining equipment for the operator controlling the mining arm. Mining of the enclosed Z-9 trench began in August 1976 and was completed in July 1978 with the removal of a total of 58 kg of plutonium (in 5,222 10 L [2.6 gal] canisters, which were loaded into a total of 653 208 L [55-gal] drums).

Soil was removed from the floor of the crib using a remote-controlled clamshell excavator on a rotating arm. The retrieved soil was deposited into a bucket conveyor for packaging, NDA, staging, and shipping. The upper mechanical portion of the excavator is housed within the 216-Z-9C mechanical enclosure and projected above the concrete slab. The clamshell excavator and arm were originally placed in the north. Once the maximum amount of soil possible was removed the clamshell excavator and arm were relocated to the south riser and mining activities were completed. The clamshell excavator and arm remain in the south riser (see Figure 2-1).

2.1.4 Surveillance and Maintenance Period

The 216-Z-9 Crib was transitioned into S&M following the completion of soil removal, packaging, and shipping. Deactivation activities included the cleanout of the 216-Z-9A Glovebox and the removal of all utilities from the facility.

The Central Plateau Risk Management (CPRM) organization assumed responsibility for S&M of the 216-Z-9 Crib Facility in 2016.

2.2 Facility Life Cycle Planned Activities

The 216-Z-9 Crib Facility is inactive and normally in S&M mode, but limited D&D activities are allowed when in D&D mode. No operations other than S&M and limited D&D activities are authorized.

The scope of work activities taking place at the 216-Z-9 Crib during S&M mode are those intended to maintain confinement of hazardous materials and protect workers. These include pre-approved activities for surveillance and maintenance, as well as activities anticipated to occur, but are not already defined by pre-approved procedures.

D&D mode activities, such as grout structural stabilization, are authorized. General deactivation activities, such as large-scale removal of facility equipment, is not planned as part of S&M, but may be performed in direct response to indications of degradation of confinement barriers, and in response to the spread of contamination that might impact continued safe operation. This equipment removal may also be performed in preparation for proposed future grouting operations.

Programmatic SMP controls described in Chapter 7.0 are in place to ensure that S&M activities are conducted safely.

The Unreviewed Safety Question (USQ) Process is a programmatic control used in configuration control of the facility Safety Basis. Routine procedures are screened and evaluated in accordance with USQ requirements, and work instructions will be screened and evaluated as required under the USQ Process. Surveillance reports, audits, and similar documents will be reviewed to determine if they meet the entry criteria for USQ screenings and evaluations in accordance with discovery requirements of the USQ Process.

Planned activities are discussed in the following sections.

2.2.1 Surveillance

Surveillances encompass the routine facility tours to perform any TSR-related surveillances and ensure there is no significant degradation of the facility structure or condition.

To ensure safe operations on the 216-Z-9 Crib roof (e.g., related to Crib sampling activities), load testing may be performed. The 216-Z-9 Crib roof load testing shall be performed in accordance with an approved load test procedure, and may involve the use of robotic equipment. Load testing procedures and technical work instructions will be reviewed under the USQ program.

Inspections of the crib roof may be performed from the exterior (atop the crib structure), or from within the crib trench. These activities might include establishment and removal of radiological access points to support facility inspection. This would entail the generation and management of waste consistent with the requirements of the Radiological Control Program and Administrative Control (AC) 5.7.2. Past load-testing activities are documented in HNF-27424, *Hazard Analysis and Control Decision for the 216-Z-9 Crib Load Test and Thermal Exchange Monitoring*.

2.2.1.1 Surveillance and Maintenance of Barriers and Postings

Inspection of barriers and postings are conducted as part of S&M activities. Barriers and postings are used to prevent access to hazardous areas and to inform personnel of conditions that exist at the 216-Z-9 Crib Facility. Examples of barriers and postings used to prevent access to hazardous areas to display facility conditions include locks, tags, door locks, fencing, confined space postings, and radiological area postings. Discrepant conditions regarding barriers or postings are identified on associated data/inspection sheets. Maintenance activities will address discrepant conditions, as applicable.

Note that the barriers referred to here are not the physical barriers denoted in AC 5.7.3 “Traffic Control Program,” described in Subsection 4.5.4 below.

2.2.1.2 Radiological Surveys

Radiological surveys are performed to support S&M activities and are performed in accordance with Radiation Protection Program, HNF-11724, Chapter 7.0.

2.2.1.3 Inspection for and Response to Spills

Accessible areas of the 216-Z-9 Crib Facility are surveilled routinely for indications of spills of hazardous wastes. If a spill is discovered, the affected area will be isolated to prevent personnel exposure, corrective measures will be determined, and the spilled material will be packaged and shipped to an appropriate disposal facility compliant with the requirements of the Hazardous Material Protection Program, HNF-11724, Chapter 8.0.

2.2.1.4 General Inspections and Tours

General inspections and tours may be performed separately from S&M activities. Inspection and tours will be conducted in accordance with appropriate regulatory drivers, SMPs, and procedures.

2.2.2 Grouting Structural Stabilization

Grouting consists of making physical preparations and filling in the crib with concrete. The placement of grout into the crib (beneath the slab) could involve the use of a delivery truck, pump truck, and hose equipment. Access to the crib may be through existing penetrations already in the slab, or by drilling new holes in the slab to pour the grout. The use of an existing penetration would require part of a structure to be removed (e.g. such as through the opening occupied by the viewing room or the stairwell). Equipment and structure removal would be performed using general D&D operations that include the use of an excavator with shears, and/or by manual removal methods.

General D&D activities include the use of spray fixatives to control airborne contamination while dismantling structures and equipment.

2.2.3 Maintenance

This category of activities could include repairs or maintenance on facility superstructures to maintain their integrity, repairs of any glovebox or duct deterioration that might lead to a spill event, and securing or removing hazardous materials such as asbestos, etc. These activities might include establishment and removal of radiological access points to support the facility maintenance. This would entail the generation and management of waste consistent with the requirements of the Radiological Control Program, HNF-11724, Chapter 7.0, and AC 5.7.2 "Waste Acceptance Program."

2.2.3.1 Equipment Calibration, Testing, Maintenance, and Repair

Maintenance and repairs are performed as necessary to maintain equipment. Proposed changes are evaluated individually to determine if they are within the bounds of the safety analysis as required by the work control and USQ Programs.

2.2.3.2 Repair and Upgrades of Confinement Systems

Maintenance and repair of the 216-Z-9 Crib Facility confinement systems are performed as necessary to maintain system capability. Upgrades or physical changes to these systems may be undertaken if the changes provide restoration of damaged confinement to original specifications, or an equivalent or improved confinement.

2.2.3.3 Repair and Upgrades of Structural Components

Structural components necessary to ensure confinement will be repaired or upgraded as needed to maintain control of hazardous wastes.

2.2.4 Removal of Equipment

Equipment (e.g., abandoned conduits, deactivated electrical equipment, etc.) may be removed from the 216-Z-9 Crib Facility to reduce the risks from known hazards, or to redeploy obsolete equipment as spares or replacements (e.g., switchgear, motor control centers). Legacy waste, such as expired fire extinguishers and failed light bulbs may be removed from the 216-Z-9 Crib Facility and disposed of in accordance with the Hazardous Material Protection Program, HNF-11724, Chapter 8.0.

General deactivation activities, such as large-scale removal of facility equipment where the removal itself is the primary purpose, are not anticipated activities given the current work scope. Equipment may be removed in response to indications of degradation of equipment or spread of contamination that impacts continued, safe S&M, including filter changes.

2.2.5 Nondestructive Assay Waste Characterization and Sampling Activities

There may be a future need to perform some sampling activities of soils from the 216-Z-9 Crib to support remediation planning. These activities will be performed consistent with Hanford Site Sampling and Radiological Control programs. Performance of sampling activities might include establishment and removal of radiological access points to support the facility maintenance. This would entail the generation and management of waste consistent with the requirements of the Radiological Control Program, HNF-11724, Chapter 7.0.

The waste characterization, NDA, and sampling may be performed in the 216-Z-9 Crib Facility. The activities will be performed in accordance with established programs and procedures, and will comply with the Safety Basis. These activities may be performed to better identify and characterize radioactive material inventory and location, determine quantity and makeup of newly discovered material, or support planning for eventual disposition.

Characterization activities, such as recording radiation and contamination levels, photography and making video recordings, and sampling residues are authorized and allowed. The use of in-situ destructive assay techniques are not authorized, however, characterization sampling in small quantities (i.e., gram quantities) may be performed within the crib structure per approved procedures. Characterization, sampling, and geophysical logging activities may include the insertion, setup, sampling, and (if needed) decommissioning of boreholes (wells), specifically excluding the use of "Jet-Shot" (or equivalent) explosive charges. The boreholes (wells) are to be located and operated such that they do not compromise the function or integrity of any facility Structure, System, or Component (SSC) or program credited with a safety function.

2.2.6 Waste Handling Operations

Waste containers could be generated as a result of the activities discussed above.

The waste would typically be packaged in metal drums, but could also be placed into other acceptable containers as well. Waste containers used for shipping radiological waste from the facility meet the requirements of DOE/RL-2001-36 Revision 2, *Hanford Sitewide Transportation Safety Document*. Waste handling activities are managed consistent with applicable requirements of the following SMPs: Radioactive and Hazardous Waste Management, HNF-

11724 Chapter 9.0; Hazardous Material Protection, HNF-11724 Chapter 8.0; Operational Safety, HNF-11724 Chapter 11.0; Fire Protection, HNF-11724 Section 11.4; and Radiation Protection, HNF 11-724 Chapter 7.0, and with AC 5.7.2 "Waste Acceptance Program."

2.2.6.1 Generating Waste

Waste may be generated at the 216-Z-9 Crib to support those operations described above. Waste containers are temporarily stored at the point of generation until ready to be moved to container staging areas:

- In-process waste containers are waste containers that are in the process of being loaded, containers that are partially loaded and waiting to be finished (with temporary lids or lids set in place), or containers that are full and are waiting for final closure (bag out closures, lids set in place).
- In-process waste containers generated outside confinement areas (e.g., containers generated to support step-off-pad activities) may be loaded and sealed outside confinement areas.
- Once a waste container is filled, waste crew personnel put on and lock the lids, transport the containers to a central area where the lids are tightened (e.g., bolts are torqued, tabs are crimped), move the containers to staging areas, and finish required paperwork. Waste containers may be moved within the facility from generation points to storage or staging areas using pallet jacks, hand trucks, forklifts, dollies, etc. Filled waste containers are not staged or stored at the point of their generation, and are moved to designated staging or storage areas as soon as practical after being filled.

2.2.6.2 Staging Waste Containers Inside Facility

Staging areas have not been defined within the 216-Z-9 Crib Facility. It is assumed that waste will be staged in areas outside the 216-Z-9 Crib Facility structures for a limited time prior to shipment to an acceptable location. Full waste containers will be moved to a designated waste staging or storage area as soon as practical.

2.2.6.3 Staging Waste Containers Outside Facility and Shipping

From the internal waste generating areas or staging areas, waste may be moved to outside staging areas to await transport to disposal facilities. The waste being generated internally is from the above ground structures or from other approved activities. For the purposes of analysis, it was assumed that waste is staged on a pad.

Waste moving and handling activities from generation to staging areas outside the facilities may involve use of carts, dollies, forklifts, cranes, etc.

DOE/RL-2001-36 outlines the hazards and controls for transporting waste containers on transportation vehicles inside and outside of the 216-Z-9 Crib Facility area. Any hazardous waste removed from the 216-Z-9 Facility may, after proper waste designation, be disposed of at the Environmental Restoration Disposal Facility (ERDF), or at another approved disposal facility, as appropriate. Wastes will be packaged and shipped to an appropriate disposal facility compliant with requirements of the Hazardous Material Control Program and AC 5.7.2.

2.2.6.4 Container Management

Normally, relatively small volumes of Low-Level Waste (LLW) are accumulated during S&M activities. Risk reduction actions or other non-routine activities provide the need for conservative contingency plans. Designated areas may be used to accumulate waste before shipping. The addition of fissile or radiological material from other facilities to the current 216-Z-9 Crib Facility inventory is not allowed under this DSA; this requirement does not apply to non-waste items such as instrument check sources, calibration check sources, or contaminated tools or equipment required to conduct operations. Transuranic (TRU) waste[1] staged for transport is placed in waste containers that comply with applicable shipping and disposal requirements.

Surveillance activities include inspecting existing containers, and sampling, identifying, and labeling unlabeled containers. TRU waste containers are removed and transported to a permitted storage facility for treatment, storage, and/or disposal. Periodic container inspections are performed to identify container deterioration or signs of leakage. If a deteriorating or leaking container is found, the situation is evaluated, and actions are taken based on the severity of the situation; for example, the container may be monitored, repackaged, or moved to an appropriate treatment/disposal facility. Corrective action is taken, when applicable, to prevent recurrence. The activities are managed consistent with applicable requirements of the Hazardous Material Protection Program, Work Control Program, Fire Protection Program, and Radiation Protection Program and AC 5.7.2 “Waste Acceptance Program.”

Occasional use of ERDF roll-on/roll-off (RO/RO) waste boxes or other containers designated LLW or Low-Level Mixed Waste (LLMW) is anticipated. No accident analysis or controls are required for this minimal LLW or LLMW stream. The activities are managed consistent with applicable requirements of the following SMPs: Radioactive and Hazardous Waste Management, HNF-11724 Chapter 9.0; Hazardous Material Control, HNF-11724 Chapter 8.0; Work Control, HNF-11724 Chapter 11.0; Fire Protection, HNF-11724 Section 11.4; and Radiation Protection, HNF-11724 Chapter 7.0.

2.2.7 Administrative Activities

Administrative activities are performed to support the facility’s operation. These activities are primarily administrative, training, and technical support activities that do not deal directly or indirectly with hazardous materials. Administrative activities will be conducted for all CPRM facilities. The following is a non-comprehensive list of examples of administrative activities:

- Managing records and controlling documents dealing with the facility
- Preparing, providing, and tracking required training for facility personnel
- Planning work activities
- Maintaining the facility Safety Basis and evaluating new activities
- Managing the facility and providing technical support to Operations

[1] Waste materials contaminated with 100 nCi/g of TRU materials having half-lives of longer than 20 years.

- Monitoring work status and tracking system configurations
- Maintaining databases associated with chemical, hazardous material, and waste inventories

2.3 Structures, Systems, and Components

2.3.1 Confinement Ventilation

A deactivated HEPA-filtered exhaust ventilation system, used during soil removal activities, is connected to the 216-Z-9A Building, the glovebox in the building, and thus the crib trench. The exhaust ventilation system is deactivated, and electrical power to the system has been permanently removed. The 216-Z-9A Building, and the crib trench, are fitted with HEPA breather filters to allow passive atmospheric pressure-driven air exchange ("breathing").

2.3.2 Utilities

The 216-Z-9 Crib has no utilities provided. If electrical power is required to support S&M activities, it will need to be supplied from an outside source.

2.3.3 Fire Protection

There are no fire detection, alarm, or suppression systems installed at the 216-Z-9 Crib Facility.

The 216-Z-9 Complex is currently dormant and buildings are not accessed except for periodic monitoring and assessment tours. Building 216-Z-9 is not accessible without a confined space permit. Building 216-Z-9 is effectively a maintenance enclosure without any significant personnel access. Buildings 216-Z-9A and 216-Z-9B are both currently locked and require special permission for access. All existing lighting and other life-safety systems are out of service and provide no support for general occupancy.

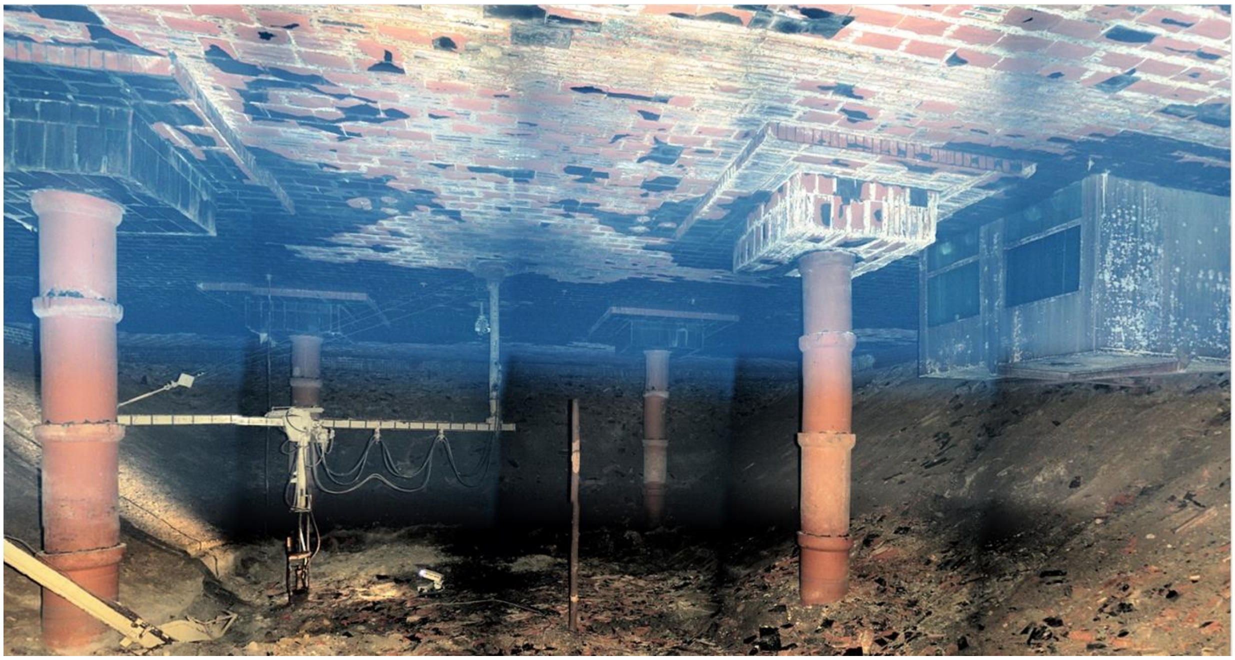

Figure 2-1. 216-Z-9 Crib Trench Interior (2007), Looking South

Figure 2-2. 216-Z-9 Crib Facility Boundary

3.0 Hazard and Accident Analysis

3.1 Summary of Remaining Hazards

The 216-Z-9 Waste Storage Crib was previously evaluated as a sub-element of the PFP Facility, and was included in the PFP Hazards Analysis (HNF-15501, *Plutonium Finishing Plant Deactivation & Decommissioning Hazard Analysis*) and Safety Basis documents (HNF-15500, *Plutonium Finishing Plant Deactivation and Decommissioning Documented Safety Analysis*, and HNF-15502, *Plutonium Finishing Plant Deactivation and Decommissioning Technical Safety Requirements*). HNF-15501 was used as a starting point to reexamine and validate the originally identified, analyzed hazards and to specifically analyze current S&M activities at the 216-Z-9 Crib Facility. This hazards analysis is documented in CP-58905, *216-Z-9 Waste Storage Crib S&M Hazard Analysis*.

3.1.1 216-Z-9 Crib Facility Radiological Inventory

Data analysis from the isotopic distribution and mass of thousands of containers of Pu generated by or shipped to PFP over the decades of that facility's operations (WHC-SD-CP-TI-190, *Technical Basis for Characterization of Plutonium for PFP Safety Analyses*) showed that PFP inventory may reasonably be characterized by two isotopic inventories: a "< 10 percent ^{240}Pu mixture," applicable during weapons plutonium production processing periods, and a "> 10 percent ^{240}Pu mixture," applicable to fuels-grade production processing periods.

The 216-Z-9 Crib was isolated in June 1962, prior to large-scale production of fuels-grade plutonium from N Reactor fuel. Therefore, Pu inventory in the 216-Z-9 Crib is best represented by the less than 10 percent ^{240}Pu mixture (shown in Table 3-1), and this mixture is used for accident analysis.

Table 3-1. < 10% ^{240}Pu Mix Composition

Isotope	Normalized Mass Fractions
^{238}Pu	9.99E-05
^{239}Pu	9.36E-01
^{240}Pu	6.04E-02
^{241}Pu	2.00E-03
^{242}Pu	3.00E-04
^{241}Am	1.50E-03
Total	1.00E+00

NDA results for the K-1-9 and K-1-10 HEPA filter housings and K1-8-1 and K1-8-2 exhaust fans in the 216-Z-9 Crib support buildings at the 216-Z-9 Crib Facility are documented in Memoranda M2100-07-044 and M2410-07-072. These results are given in Table 3-2. The inventory value for the below-grade 216-Z-9 Crib Trench is also listed in Table 3-2, and is based on 1977 data from the soil removal period.

Table 3-2. Summary of Plutonium Inventory in the 216-Z-9 Crib Facility

Location	NDA: Total Pu (g)	DSA-Assumed (g)
K-1-8, K-1-9, & K-1-10 Exhaust System Components	4	15
216-Z-9A Glovebox	4.7	7.81
Below-Grade Crib Trench	N/A	48,000

3.1.2 216-Z-9 Crib Facility Chemical Inventory

The 216-Z-9 Crib received mixed aqueous and organic waste streams from the PFP RECUPLEX process between 1955 and 1962. Descriptions of the RECUPLEX process are found in HNF-EP-0924, *History and Stabilization of the Plutonium Finishing Plant (PFP) Complex, Hanford Site*, Section 8.0 "Recovery and Recycle of Plutonium-Bearing Scrap at PFP," and Section 9.0 "RECUPLEX Facility at PFP."

There have been a number of efforts to determine the amounts of materials discharged to the 216-Z-9 Crib Facility. HNF-33138, *216-Z-9 Soil Removal Structures and Equipment Sampling and Analysis Plan*, gives the following table of inputs to the 216-Z-9 Trench:

Table 3-3. RECUPLEX Inputs to the 216-Z-9 Trench[a]

Contaminant	Form	Quantity
Aluminum	$Al(NO_3)_3$, $Al(OH)_3$, $A1F(OH)_2$; small amounts of $A1_2O_3$, $A1_3O_2$, $A1_3(SO_4)_2$, and $A1C_3$	100 tons
Nitrate	Total	1500 tons
Magnesium	$Mg(NO_3)_2$, $Mg(OH)_2$, possibly some $MgSO_4$, $MgCO_3$, and $MgCl_2$	35 tons
Calcium	$Ca(NO_3)_2$, $Ca(OH)_2$, CaF_2, small amounts of $CaSO_4$ and $CaSO_3$	30 tons
Iron	$Fe(NO_3)_3$, $Fe(OH)_3$, FeF_3, small amounts of $Fe_2(CO_3)_3$ and $Fe_2(SO_4)_3$	25 tons
Chromium, Lead, and Nickel	Nitrates and hydroxides	2.35 tons
Cadmium	$Cd(NO_3)_2$, and $Cd(OH)_2$	0.9 tons
Organic	15 - 25% TBP in $CC1_4$, DBBP, and trace MBP	120 tons
Organic	Lard Oil (CCl_4 - 50% and Lard Oil - 50%)	60 tons
Chlorine	$CC1_4$, deteriorating to HCl, CO, and CO_2	100 tons
Fluorine	$A1F^{+2}$	30 tons
Solids	SiO_2, $A1_2O_3$, $Fe_2(DBP)_3$, $CaSO_4$, $A1_2(CO_3)_3$, $MgSiO_2$, carbonaceous material, and other metallic DBPs such as chromium	6 tons

Table 3-3. RECUPLEX Inputs to the 216-Z-9 Trench[a]

Contaminant	Form	Quantity
Sulfate	$CaSO_4$, $A1_2(SO_4)_3$, and $Pu(SO_4)_2$	2 tons
Plutonium	PuO_2, $Pu(SO_4)_2$, $Pu(OH)_x$, PuF_4, $PuC1_4$, $Pu(CO_3)_2$ and $Pu(NO_3)_4$	~ 100 kg
Americium	Am_2O_3, $Am(NO_3)_3$, and $Am(OH)_3$	~ 2.5 kg

[a] Estimates from Letter Bruns, L.E., to R.E. Isaacson, 10 April 1973, *Recuplex Inputs to Z-9 Trench*.

Terms:

DBP Dibutyl phosphate

MBP Monobutyl phosphate

TBP Tributyl phosphate

Other efforts are documented in HNF-31792. Per HNF-31792, the following chemical constituents were found in the 216-Z-9 Crib Trench soil.

Table 3-4. Chemical Constituents found in 216-Z-9 Crib Trench

^{228}Ra	^{232}Th	$^{233,234,235}U$	^{241}Am	^{99}Tc
acetone	ammonia	arsenic	carbon tetrachloride	chlorobenzene
chloroform	copper	hexavalent chromium	lead	mercury
methylene chloride	nickel	nitrate	nitrite	oil and grease
polychlorinated biphenyl	selenium	silver	sulfate	tetrachloroethene
tributylphosphate	trichloroethene			

Carbon tetrachloride is the only hazardous material which might exceed threshold quantities specified in the following:

- 29 CFR 1910.119, "Process Safety Management of Highly Hazardous Chemicals"
- 40 CFR 68, "Chemical Accident Prevention Provisions"
- Threshold planning quantities of 40 CFR 355, "Emergency Planning and Notification"
- Reportable quantities of 40 CFR 302.4, "Designation of Hazardous Substances"

All other hazardous materials are expected to occur in limited or trace quantities.

Note that, beginning in 1992, soil vapor extraction operations began to extract carbon tetrachloride from the vadose zone beneath PFP waste sites, including the 216-Z-9 Crib Facility. By 2015, over 176,000 lb of carbon tetrachloride had been removed from the 216-Z-9 Well

Field, the remaining amounts were determined to meet the required levels for closure, and the soil vapor extraction project was declared complete.

In the more than 50 years since waste was last sent to the 216-Z-9 Crib Facility, and the 40 years since soil removal activities occurred, there have been no identified chemical compatibility issues. Contamination or waste remaining in the 216-Z-9A Glovebox has had 40 years to slowly react and oxidize; no adverse conditions have been seen. Therefore, chemical compatibility issues are not considered credible, but are conservatively evaluated in the Hazard Analysis (HA) as initiators for fires and overpressure events that could drive releases causing harm to the Facility Worker (FW).

Chemicals that are needed to support S&M activities will be managed in accordance with the Chemical Management System, which implements a comprehensive process for procurement, inventory tracking, storage, and disposal of hazardous chemicals. These chemicals pose a hazard only to the facility workers, not to onsite workers or the offsite public.

3.1.3 Work-related Industrial Hazards

Planned work activities at the 216-Z-9 Crib Facility consist of S&M and limited D&D activities, which are primarily industrial activities performed in accordance with an approved technical work instruction or procedure, with radiological controls imposed where needed to control spread of contamination. Essentially all of these activities represent SIH. Worker protection for SIH hazards is provided through the implementation of SMPs (See Chapter 7.0). Each technical work instruction goes through a detailed job hazard analysis prior to use in the field in accordance with CHPRC work practices, as well as evaluation through the USQ process.

3.2 Nuclear Facility Hazard Categorization

3.2.1 Hazard Category

NDA measurements (Memoranda M2100-07-072 and M2410-07-044) indicate that there are approximately 8 g of dispersible MAR in the 216-Z-9 Glovebox (located in Building 216-Z-9A), and approximately 15 g of dispersible MAR in the K-1-9 and K-1-10 HEPA filter housings and K1-8-1 and K1-8-2 exhaust fans in the 216-Z-9 Crib support buildings.

From data and measurements taken during soil mining in 1977 (HNF-31792), the soil of and beneath the 216-Z-9 Crib Trench is assumed to be contaminated with approximately 48 kg of Pu.

Based on the inventory thresholds defined in DOE-STD-1027-92 (greater than 900 g ^{239}Pu, and greater than 16 g ^{241}Am), the 216-Z-9 Crib is categorized as a Hazard Category 2 nuclear facility.

3.2.2 Criticality

The 216-Z-9 Crib Facility is classified as a limited control facility. This designation means that the crib contains greater than one-half of a minimum critical mass of fissile material, a criticality is documented to be incredible, and limits and controls are required to maintain incredibility. TSR AC 5.7.1 "Nuclear Criticality Safety" implements the criticality safety program at the 216-Z-9 Crib Facility.

3.3 Hazards Analysis

The 216-Z-9 Waste Storage Crib was previously evaluated as a sub element of the PFP Facility and was included in the PFP D&D DSA and TSR documents – HNF-15500 and HNF-15502, respectively.

HNF-15501 was used as a starting point to re-examine and validate the originally identified, analyzed hazards, and to specifically analyze the currently planned 216-Z-9 Crib S&M activities. This analysis is documented in CP-58905.

3.3.1 Hazard Identification

During the validation HA sessions, the Hazard Identification (HID) process identified approximately 1,800 hazards expected to be encountered during S&M activities (CP-58905). Of these, approximately 50 were screened out during the HID process as SIH or inconsequential radiological hazards, which are considered controlled by existing SMPs.

The HID checklist is given in Appendix A "216-Z-9: S&M Activities Hazard Identification Checklist" of CP-58905.

3.3.2 Hazard Evaluation

The Hazard Evaluation (HE) process consists of assigning frequency, consequences and risk rankings to each scenario, as described below, to those events from HID that have not been screened out as SIH or inconsequential hazards. These remaining hazards (approximately 1,750) underwent HE to determine the relative risk involved in each hazardous condition for the MOI and CW receptors, and the FW. Of these evaluated hazardous events, approximately 1,300 hazards were determined to have no significant radiological or chemical exposure, and their hazards are considered controlled by existing SMPs.

The results of the HE were used to select a representative set of bounding, risk dominant, or otherwise significant scenarios that will encompass all identified S&M activities and hazards in subsequent Accident Analyses. These included all Risk Bin I and II events. A range of FW, CW, and MOI Risk Bin III events were also identified for accident analysis, to ensure that a complete spectrum of low-consequence accidents which are anticipated to occur during the S&M phase of the 216-Z-9 Crib life were considered during the control selection process.

Approximately 60 of the evaluated hazards were found to represent significant worker hazards (FW consequence = "Yes," see Table 3-5). Twenty-three (23) of the 60 evaluated hazards are associated with criticality hazards. NOTE: The 216-Z-9 Crib has been found to be Criticality Incredible, and is designated as a Limited Control Facility. The representative accident scenarios were grouped by type (fires, explosions, loss of confinement (spills), inadvertent criticalities, external events, and natural phenomena) and consequence level, in accordance with guidance from PRC-STD-NS-8739, *CHPRC Safety Analysis and Risk Assessment Handbook (SARAH)*, to facilitate control set selection.

3.3.2.1 Frequency

The unmitigated frequency category represents a qualitative estimation of frequency of occurrence for the hazardous condition without the application of any identified controls. Frequency categories were assigned based on the criteria in Table 3-5.

Table 3-5. Frequency Categories Used in the Hazard Analysis

Estimated Annual Frequency	Description: Based on the initiating event(s) postulated
Anticipated (A) 1E-02/yr < to < 1E+00/yr	The hazardous condition has occurred or is likely to occur during the lifetime of the facility.
Unlikely (U) 1E-04/yr < to < 1E-02/yr	The hazardous condition is foreseeable, but unlikely to occur during the lifetime of the facility.
Extremely Unlikely (EU) 1E-06/yr < to < 1E-04yr	The hazardous condition is perhaps possible, but extremely unlikely to occur during the lifetime of the facility.
Beyond Extremely Unlikely (BEU) < 1E-06/yr	The hazardous condition is considered too improbable to warrant further consideration.

3.3.2.2 Consequences

A primary objective of HE is to qualitatively estimate the potential radiological and chemical consequences of hazardous conditions for the public (MOI receptor), the worker (FW/CW receptor), and the environment. Consequence categories were assigned based on the criteria given in Table 3-6, which was taken from DOE-STD-3009-2014, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis*.

Table 3-6. Consequence Thresholds Used in the Hazard Analysis

Consequence Level	Public[1,4]	Co-located Worker[2,4]	Facility Worker[3]
High	≥ 25 rem TED or ≥ PAC[5]-2	≥ 100 rem TED or ≥ PAC-3	Prompt death, serious injury, or significant radiological and chemical exposure
Moderate	≥ 5 rem TED or ≥ PAC-1	≥ 25 rem TED or ≥ PAC-2	No distinguishable threshold
Low	< 5 rem TED or < PAC-1	< 25 rem TED or < PAC-2	No distinguishable threshold

[1] Maximally-exposed Offsite Individual (MOI) – A hypothetical individual defined to allow dose or dosage comparison with numerical criteria for the public. This individual is an adult typically located at the point of maximum exposure on the Department of Energy (DOE) site boundary nearest to the facility in question (ground-level release), or may be located at some farther distance where an elevated or buoyant radioactive plume is expected to cause the highest exposure (airborne release) – see DOE-STD-3009-2014, Section 3.2.4.2. The MOI used here is not the same as the Maximally Exposed Individual or the Representative Person used in DOE Order 458.1 for demonstrating compliance with DOE public dose limits and constraints.

[2] A co-located worker at a distance of 100 m from a facility (building perimeter) or estimated release point.

[3] A worker within the facility boundary and located less than 100 m from the release point.

[4] Although quantitative thresholds are provided for the MOI and co-located worker consequences, the consequences may be estimated using qualitative and/or semi-quantitative techniques.

[5] DOE's Protective Action Criteria are defined by Advanced Technologies and Laboratories International, Inc. in "Protective Action Criteria (PAC): Chemicals with AEGLs, ERPGs, & TEELs," Rev. 27, February 2012. This is available at energy.gov/ehss/protective-action-criteria-pac-aegls-erpgs-teels-rev-29-chemicals-concern-may-2016.

Using the scenario frequency and consequence categories assigned by the HA team, the overall scenario risk is determined by Table 3-7, which is taken from DOE-STD-3009-2014.

Table 3-7. Risk Bin Values

	Beyond Extremely Unlikely Below 10E-06/yr	**Extremely Unlikely 10E-04 – 10E-06/yr**	**Unlikely 10E-02 – 10E-04/yr**	**Anticipated Above 10E-02/yr**
High Consequence	III	II	I	I
Moderate Consequence	IV	III	II	II
Low Consequence	IV	IV	III	III

3.3.2.3 Evaluation Guideline

Per DOE-STD-3009-2014, the Evaluation Guideline (EG) is the criterion for the dose of ionizing radiation to the MOI that the safety analysis evaluates against to identify the need for and evaluate the effectiveness of Safety Class (SC) controls. The EG is set at 25 rem; MOI dose values between 5 and 25 rem are considered to challenge the EG, and accidents with those consequences require the consideration of SC controls.

3.3.2.4 Facility Worker

Impacts of evaluated hazards on the FW were considered. A qualitative evaluation of the unmitigated consequence to the FW was performed based on the criteria specified in DOE-STD-3009-2014, Section 3.1.3.1.

3.3.2.5 Chemical Consequence Levels

In those cases where significant chemical releases are postulated, chemical consequences and threshold levels would be developed using DOE-STD-3009-2014. However, the HA team did not identify any hazards that would result in significant chemical releases.

3.3.2.6 Environmental Consequence Levels

The team qualitatively assessed impacts to the environment based on the criteria in Table 3-8. See CP-58905. There are no events with environmental “Y” consequences.

Table 3-8. Environmental Consequence Categories Used in Hazard Analysis

Consequence Category	Environmental Effects
Y	The release is qualitatively judged to create potential for significant future groundwater contamination or create the need for significant offsite soil remediation (e.g., 1.0 rem MOI per PRC-STD-NS-8739, Section 2.3.5).
N	Lesser radiological releases are marked "N" because typical hazards at CHPRC facilities result in the hazards to the environment tracking consistently with the impacts to the FW, CW, and MOI, and the hazard controls established for the FW, CW, and MOI are also effective for the environment.

3.3.3 Hazards Evaluation Summary

A summary of the bounding and bounded accidents resulting from the HE process for the 216-Z-9 Crib Facility are given in Table 3-8; note that the MAR values given in Table 3-9 represent the values used in the "Scoping Calculations" made at the time of the HE, not the values used in this DSA's accident analyses given in Section 3.4. The full HE table is given in CP-58905, Appendix B, "216-Z-9: S&M Activities Hazards Table."

Table 3-9. Hazards Analysis Summary

Scenario/Case	Bounding or related events	MAR (Pu Used in "Scoping Calculations")	Frequency	Unmitigated Risk Bin	
				MOI	CW
Scenario: Fire					
Case F-1: TRU Waste Staging Area Fire Outside Building Containment	Bounded by Case E-4 (K-2)	50 g Pu in "uncontained, combustible, contaminated material"	Anticipated	III	III
Case F-1: TRU Waste Staging Area Fire Outside Building Containment	Bounded by Case E-4 (K-2)	50 g Pu in "uncontained, combustible, contaminated material"	Anticipated	III	III
Case F-3: Fire in Below-Grade Structure	Bounded by Case K-2 (fire)				
Scenario: Explosions					
Case E-1: TRU Waste Drum Explosion Outside	Bounded by Case E-4 (K-2)	50 g Pu in "uncontained, combustible, contaminated material"	Anticipated	III	III
Case E-2: TRU Waste Drum Explosion Inside	Bounded by Case E-1 (K-2)	50 g Pu in "uncontained, combustible, contaminated material"	Anticipated	III	III
Case E-3: Gasoline Expanding Vapor Explosion	Bounded by Case E-4 (K-2)	50 g Pu in "uncontained, combustible, contaminated material"	Anticipated	III	III
Case E-4: Room Explosion - Expanding Vapor Explosion	Bounded by Case K-2	50 g Pu in "uncontained, combustible, contaminated material"	Anticipated	III	III
Scenario: Spills					
Case SP-1: TRU Waste Container Spill Outside Confinement	Bounded by Case E-4 (K-2)	50 g Pu in "uncontained, combustible, contaminated material"	Anticipated	III	III
Case SP-2: Energetic Dispersal of Holdup Material - Unconfined Area	Bounded by Case E-4 (K-2)	50 g Pu in "uncontained, combustible, contaminated material"	Anticipated	III	III

Table 3-9. Hazards Analysis Summary

Scenario/Case	Bounding or related events	MAR (Pu Used in "Scoping Calculations")	Frequency	Unmitigated Risk Bin	
				MOI	CW
Scenario: Collapse					
216-Z-9 Crib Roof Structure Collapses Due to Aging	Bounded by Case K-2	50,000 g Pu Case K-2 Crib Impact	Anticipated	III	III
Scenario: Loss of Confinement					
Case D-1: Glovebox or Duct Loss of Confinement	Bounded by Case E-4 (K-2)	50 g Pu in "uncontained, combustible, contaminated material"	Anticipated	III	III
Scenario: External Events					
Case K-1: 216-Z-9 Crib Impact	Bounded by Case K-2	50,000 g Pu Case K-2 Crib Impact	Anticipated	III	III
Case K-2: 216-Z-9 Crib Impact with Fire	Bounding Event for Facility	50,000 g Pu Case K-2 Crib Impact	Anticipated	III	II
Case K-3: Aircraft Crash	BEU events exempted per DOE-STD-3014	50,000 g Pu Case K-2 Crib Impact	Beyond Extremely Unlikely *	IV	IV
Scenario: Natural Phenomena Events					
Case NP-1: 216-Z-9 Crib Seismic Event	Bounding NPH Event for Facility	50,000 g Pu Case K-2 Crib Impact	Unlikely	III	III
Case NP-1.1: TRU Waste Staging Area Seismic Event	Bounded by Seismic Event NP-1				
Case NP-2: Winds	N/A	N/A			
Case NP-3: Floods	N/A	N/A			
Case NP-4: Ash/Snow	Bounded by Seismic Event NP-1				
Scenario: Criticality Events					
Case M-1: Criticality Events	N/A	N/A	Beyond Extremely Unlikely	IV	IV

Table 3-9. Hazards Analysis Summary

Scenario/Case	Bounding or related events	MAR (Pu Used in "Scoping Calculations")	Frequency	Unmitigated Risk Bin	
				MOI	CW

*This frequency was recorded at the time of the initial HA in 2015; In 2016, CP-59723 *Assessment of Aircraft Impact on CP S&M Nuclear Facilities in the 200 East and West Areas* was issued, which quantifies the aircraft crash probability for the 216-Z-9 Crib Facility as 3.27E-07, which is "Beyond Extremely Unlikely," and confirms the original, qualitative HA estimate.

Note: Accidents described above involving 50 g Pu in "uncontained, combustible, contaminated material" are using a conservative MAR value comprised of the above ground structures (DSA assumed 22.81 g Pu, Table 3-2) and waste generated during approved activities.

3.4 Accident Analysis

The potential dose consequences of the 216-Z-9 accidents selected for analysis are determined using RADIDOSE Version 3.0, a dose consequence spreadsheet for the Hanford Site.

The following information applies to both selected accident scenarios.

Releases are modeled as ground-level, point releases with no plume or building wake effects.

Leak Path Factor (LPF) and Damage Ratio (DR) values of 1.0 are used.

Airborne Release Fractions (ARFs) and Release Fractions (RFs) were developed using guidance from DOE-HDBK-3010-94, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*.

The dose to the CW is evaluated at 100 m (328 ft) from the 216-Z-9 Crib Facility. The nearest site boundary, 12,500 m (7.8 mi) to the west of the 216-Z-9 Crib Facility (distance taken from HMAPS, part of the Hanford Geographic Information System), was used as the location for the MOI receptor.

The atmospheric dispersion factor, χ/Q', accounts for the effects of atmospheric dispersion of material released under postulated accident conditions at a specified receptor location. It is defined as the concentration in air per unit release rate of the material from an upwind source at a particular receptor location. The value of χ/Q' is a function of the type of release (elevated, buoyant, ground level, etc.), release duration, wind speed, atmospheric stability class, and distance from the source (only centerline or under-centerline, ground-level values are considered). The default RADIDOSE χ/Q value of 3.28E-02 s/m^3 is used for a ground-level, no-building-wake release evaluation at the 100 m (328 ft) CW receptor location; the 216-Z-9 Crib Facility is sufficiently separated from the residual 234-5Z structures so as to preclude wake effects from influencing any releases from 216-Z-9.

The material form is modeled as soluble; a soluble material produces a higher dose for the CW, the limiting receptor for the 200 Area facilities. Inhalation of soluble aerosols produces higher doses than inhalation of oxide for TRU material.

Dose conversion factors and breathing rates are taken from the International Commission on Radiological Protection (ICRP) Publication 68, *Dose Coefficients for Intakes of Radionuclides by*

Workers: A Replacement of ICRP Publication 61, and ICRP 71, *Age Dependent Doses to Members of the Public from Intake of Radionuclides, Part 4, Inhalation Dose Coefficients*.

Receptor doses are reported as Total Effective Dose (TED).

Copies of the output sheets from RADIDOSE calculations for the applicable accident analyses are given in Appendix A. The dose consequences to the CW and MOI receptors from the RADIDOSE sheets are summarized in each accident analysis description subsection. Dose consequences to the “onsite public” (i.e., along Highway 240, calculated to evaluate the need for further controls) are given in the Appendix B RADIDOSE output sheets for information, but are not repeated in the accident analysis description sections.

Analytical calculation elements for the analyzed 216-Z-9 Crib Facility accidents are as presented in Table 3-10. RADIDOSE output sheet extracts are given in Appendix B.

Table 3-10. Facility Accident Analysis Calculation Elements

Analyzed Accident / Section #		MAR (g)	χ/Q'	DR	LPF	ARF	RF
216-Z-9 Crib Seismic Event	3.4.1	Trench Impact-Affected Soil 9,258	3.28E-02 s/m^3	1.0	1.0	9.74E-06	0.25
		Glovebox and Exhaust System 22.81				1.0E-03	0.1
216 Z 9 Crib External Event: Crib Roof Collapse with Fire	3.4.3	Trench Impact-Affected Soil 9,258	3.28E-02 s/m^3	1.0	1.0	9.74E-06	0.25
		Fire-affected Soil 386		1.0	1.0	6.0E-03	1.0E-02
BEBA: Seismic Plus Fire	3.4.4	Sum of 3.4.1 + 3.4.2	3.28E-02 s/m^3	1.0	1.0	Values as in 3.4.1 and 3.4.2	

3.4.1 216-Z-9 Crib Seismic Event

This is a natural phenomenon event involving an earthquake that impacts the 216-Z-9 Crib Facility, including the 216-Z-9 Crib Trench, support buildings, and ventilation system.

3.4.1.1 Scenario Development

The frequency of a 0.26-g design basis seismic event is classified as "unlikely," consistent with the guidance provided in DOE-STD-1020-2016, *Natural Phenomena Hazard Analysis and Design Criteria for Department of Energy Facilities*. For this event, the 216-Z-9 Crib Trench roof is assumed to collapse into the trench and impact the contaminated soil, while the 216-Z-9 Facility support buildings and Ventilation System components (i.e., 216-Z-9A and 216-Z-9B support buildings, and the K-1-8, K-1-9, and K-1-10 ventilation system components) are assumed to fail due to seismic motions and release their contents.

3.4.1.2 Source Term Analysis

The accident assumes the total available radiological inventory of the 216-Z-9 Crib Facility, including the uppermost 1 ft of the 216-Z-9 Crib Trench soil, the 216-Z-9A and 216-Z-9B support buildings, and the K-1-8, K-1-9, and K-1-10 ventilation system components.

See Appendix B, Section B-3 for the technical basis for limiting the impact-affected Crib Trench soil to a 1 ft depth.

216-Z-9 Crib Trench Soil Impact Release

The MAR value for the 216-Z-9 Crib Trench soil impact release is given in Table 3-11.

Table 3-11. 216-Z-9 Crib Trench Soil Seismic Event Impact MAR

Release Source	MAR (g)
216-Z-9 Crib Trench Soil	9,258

The entire Pu inventory of the 216-Z-9 Crib Trench soil is 48,000 g of the < 10 percent ^{240}Pu mixture (see Table 3-1), as listed in Table 3-2. This inventory is contained in a large-volume plume that spreads far downwards and outwards beneath the floor of the 216-Z-9 Crib Trench. See Appendix B, Figures B-1 and B-2. Because it is physically impossible for any realistic impact to affect the entire volume of the contaminated soil beneath the 216-Z-9 Crib Trench, the 216-Z-9 Crib Trench soil impact MAR is only the amount of radiological material that may possibly be affected by the impact. Appendix B, Section B.2 provides the basis for why the MAR is only 9,258 g of the total 48,000 g inventory, thus the reduction in the amount of Pu released as a result of the impact of the 216-Z-9 Crib Trench roof falling into the trench and impacting the soil.

For the 216-Z-9 Crib Trench soil impact release for this event, an ARF of 9.74E-06 and an RF of 0.25 are used. Appendix B, Section B.1 provides the basis for the use of these ARF and RF values.

For the 216-Z-9 Crib Trench soil impact due to the seismic event, a point-source, ground-level release is assumed, and the RADIDOSE default χ/Q' value of 3.28E-02 sec/m^3 is used at the CW receptor 100 m (328 ft) location, with no building wake effects.

216-Z-9 Crib Facility Support Buildings and Ventilation System Release

The MAR values for the 216-Z-9A and 216-Z-9B support buildings (including the 216-Z-9A Glovebox), and the K-1-8, K-1-9, and K-1-10 ventilation system components seismic releases are given in Table 3-12.

Table 3-12. 216-Z-9 Crib Facility Support Buildings and Ventilation System Seismic Event MAR

Source	MAR (g)
K-1-8, K-1-9, & K-1-10 Exhaust System Components	15
216-Z-9A Glovebox	7.81
Total	**22.81**

The MAR is considered to be residual contamination from soil removal activities in the 216-Z-9A Glovebox (powdery residues), and the residual materials in the inactive K-1-8 exhaust fans, the K-1-9 and K-1-10 HEPA Filters, and the connecting ductwork that ventilated those structures.

For the 216-Z-9 Crib Facility Support Buildings and Ventilation System release for this event, an ARF of 1.0E-03 and an RF of 0.1 are used. These ARF and RF values were chosen consistent with DOE-HDBK-3010-94, Section 4.4.3.3.2, which describes the determination of the ARF and RF for the case where rocks are dropped onto open quart cans. The case of contamination in the K-1-8, K-1-9, & K-1-10 Exhaust System Components and 216-Z-9A Glovebox is similar to the case of contamination in a can. The exhaust fans, ducting, and filters may be considered similar in this case to a small can, and the 216-Z-9A Glovebox likewise to a moderate-sized can. DOE-HDBK-3010-94 states that the ARF and RF for the case where the material is surrounded by the can is less than that for the case of material in a pile in the open, due to interaction of the particles of powder with each other, shielding of the powder by other portions of the powder, and interaction with the surfaces of the can. The powdery residues assumed as the material within these components is expected to act in a similar fashion.

For the 216-Z-9 Crib Facility Support Buildings and Ventilation System releases due to the seismic event, a point-source, ground-level release is assumed, and the RADIDOSE default χ/Q' value of 3.28E-02 sec/m^3 is used at the CW receptor 100 m (328 ft) location, with no building wake effects.

3.4.1.3 Consequence Analysis

Table 3-13 provides the unmitigated dose consequences of the 216-Z-9 Crib Facility Seismic event to the CW and MOI receptors. RADIDOSE calculations are given in Appendix A, Figures A-1 and A-2.

Table 3-13. Seismic Event Consequences for the 216-Z-9 Crib Facility

Source	CW (rem)	MOI (rem)
216-Z-9 Crib Trench Soil	2.39E+00	2.11E-03
216-Z-9 Crib Facility Support Buildings and Ventilation System	2.42E-01	2.14E-04
Total	**2.63E+00**	**2.32E-03**

The TED to the CW is 2.63 rem, which corresponds to a "Low" consequence class. The TED to the MOI is 0.00232 rem, which corresponds to a "Low" Consequence Class. The frequency for the seismic event is "Unlikely" which, combined with these consequences, corresponds to a Risk Bin III to both the CW and MOI receptors.

3.4.1.4 Comparison to Evaluation Guideline

The estimated unmitigated dose to the MOI from a seismic event causing a collapse of the 216-Z-9 Crib Facility at the Site boundary is 0.00232 rem. The unmitigated dose value does not challenge the EG of 25 rem. Therefore, no SC SSCs are required for the collapse of the 216-Z-9 Crib Facility.

The estimated unmitigated dose to the CW from a seismic event causing a collapse of the 216-Z-9 Crib Facility is 2.63 rem. The unmitigated dose value does not challenge the 100 rem guideline for consideration of SS controls. Therefore, no SS SSCs are required to be designated as a control for the collapse of the 216-Z-9 Crib Facility.

3.4.1.5 Summary of Safety SSCs and TSR Controls

The CW Risk Bin for this event is III, which does not require consideration of SS controls.

The 216-Z-9 Crib Facility structures are considered DID for providing confinement, but are not classified as SS.

The following TSR controls are identified for this event:

- 5.6.1 Material Management (SAC): This SAC prohibits the addition of MAR to the 216-Z-9 Crib Facility inventory, which protects accident assumptions.
- 5.5.1 Safety Management Programs (AC): This AC ensures applicable SMPs are established, implemented, and maintained.

A specific SMP significant to this event is the Emergency Preparedness Program (EPP) which provides for assessing facility damage and potential releases of hazardous/radioactive materials if facility integrity is potentially impacted. The EPP also provides for appropriate notification of all personnel who may potentially be affected, including other contractor personnel.

3.4.2 Facility Collapse – Aging

The scenario evaluated is the collapse of the 216-Z-9 Crib Trench roof into the trench due to the failure of the aging structure, resulting in a release from the impact to the soil. While the initiation of this event is different from the seismic event NP-1, the accident assumes the same radiological inventory and analysis; however, the frequency is classified as "anticipated."

The TED to the CW is 2.63 rem, which corresponds to a "Low" consequence class. The TED to the MOI is 0.00232 rem, which corresponds to a "Low" Consequence Class. The frequency for the aging collapse event is "Anticipated" which, combined with these consequences, corresponds to a Risk Bin III to both the CW and MOI receptors.

Refer to the 216-Z-9 Crib Seismic Event NP-1 for the comparison to the evaluation guideline and summary of safety SSCs and TSR controls.

3.4.3 216-Z-9 Crib External Event: Crib Roof Collapse with Fire

The scenario evaluated is the collapse of the 216-Z-9 Crib Trench roof into the trench, followed by a fire, resulting in releases both from the action of the fire, and the impact to the soil.

3.4.3.1 Scenario Development

The event is initiated by a vehicle being driven on top of the crib roof due to operator error or mechanical failure, which results in the failure of the concrete 216-Z-9 Crib Trench roof. The trench roof collapses and, along with the vehicle, falls into the trench. The vehicle fuel tank ruptures, spilling its fuel, which ignites and burns, causing additional contaminated material to be released. It is assumed that the 216-Z-9 Crib Trench soils are involved in the accident.

3.4.3.2 Source Term Analysis

The accident assumes the total available MAR in the 216-Z-9 Crib Trench soil, defined as the inventory of the uppermost 1 ft of soil (9,258 g Pu) for impact events, and the uppermost 0.5 in. (386 g) for fire events. The bases for these values are provided in Appendix B, Section B.3 and B.4, respectively.

216-Z-9 Crib Trench External Event Soil Impact Release

The MAR values for the 216-Z-9 Crib Trench external event soil impact release are the same as for the seismic impact event, given in Table 3-11.

The entire Pu inventory of the 216-Z-9 Crib Trench soil is 48,000 g of the < 10 percent ^{240}Pu mixture (see Table 3-1), as listed in Table 3-2. This inventory is contained in a large-volume plume that spreads far downwards and outwards beneath the floor of the 216-Z-9 Crib Trench. See Appendix B, Figures B-1 and B-2. Because it is physically impossible for any realistic impact to affect the entire volume of the contaminated soil beneath the 216-Z-9 Crib Trench, the 216-Z-9 Crib Trench soil external event impact MAR is only the amount of radiological material that may possibly be affected by the impact. Appendix B, Section B.2 provides the basis for the reduction in the amount of soil affected, thus the reduction in the amount of Pu released as a result of the impact of the 216-Z-9 Crib Trench roof (and the vehicle) falling into the trench and impacting the soil; Section B.3 gives the technical basis for limiting the impact-affected Crib Trench soil to a 1 ft depth. The actual 216-Z-9 Crib Trench soil Pu MAR for the external event impact is 9,258 g of the < 10 percent ^{240}Pu mixture.

For the 216-Z-9 Crib Trench soil impact release for this event, an ARF of 9.74E-06 and an RF of 0.25 are used. Appendix B, Section B.1 provides the basis for the use of these ARF and RF values.

For the 216-Z-9 Crib Trench soil impact from a vehicle, a point-source, ground-level release is assumed, and the RADIDOSE default χ/Q' value of 3.28E-02 sec/m^3 is used at the CW receptor 100 m (328 ft) location, with no building wake effects.

216-Z-9 Crib Trench External Event Soil Fire Release

The MAR value for the 216-Z-9 Crib Trench external event soil fire release is given in Table 3-14.

Table 3-14. 216-Z-9 External Event Crib Trench Soil Fire MAR

Release Source	MAR (g)
216-Z-9 Crib Trench Soil	386

It is physically impossible for any realistic fire to affect the entire volume of the contaminated soil beneath the 216-Z-9 Crib Trench, thus the 216-Z-9 Crib Trench soil fire MAR is only the amount of radiological material within the soil that may possibly be affected by the fire. Appendix B, Section B.4 provides the basis for the fire-affected soil depth, thus the reduction in the amount of Pu released as a result of the fuel fire on the 216-Z-9 Crib Trench soil. The actual 216-Z-9 Crib Trench soil Pu MAR for the external event fire release is 386 g of the < 10 percent ^{240}Pu mixture.

For the 216-Z-9 Crib Trench soil external event fire release for this event, an ARF of 6.0E-03 and an RF of 1.0E-02 are used. These values were chosen per DOE-HDBK-3010-94, Section 4.4.1.1.

For the 216-Z-9 Crib Trench soil external event fire, a point-source, ground-level release is assumed, and the RADIDOSE default χ/Q' value of 3.28E-02 sec/m^3 is used at the CW receptor 100 m (328 ft) location, with no building wake effects.

3.4.3.3 Consequence Analysis.

Table 3-15 provides the unmitigated dose consequences of the 216-Z-9 Crib Facility Seismic event to the CW and MOI receptors. RADIDOSE calculations are given in Appendix A, Figures A-3 and A-4.

Table 3-15. External Event Crib Roof Collapse with Fire Consequences for the 216-Z-9 Crib Facility

Source	CW (rem)	MOI (rem)
216-Z-9 Crib Trench Soil Impact Release	2.39E+00	2.11E-03
216-Z-9 Crib Trench Soil Fire Release	2.46E+00	2.17E-03
Total	**4.85E+00**	**4.28E-03**

The TED to the CW is 4.85 rem, which corresponds to a "Low" Consequence Class. The TED to the MOI is 0.00428 rem, which corresponds to a "Low" Consequence Class. The frequency for the external event crib roof collapse plus a fire is "Anticipated" which, combined with these consequences, corresponds to a Risk Bin III for both the CW and MOI receptors.

3.4.3.4 Comparison to Evaluation Guideline

The estimated unmitigated dose to the MOI from an external event causing a collapse of the 216-Z-9 Crib Roof plus a fire at the Hanford Site boundary is 0.00428 rem. The unmitigated dose value does not challenge the EG of 25 rem. Therefore, no SC SSCs are required for the external event crib roof collapse plus a fire at the 216-Z-9 Crib Facility.

The estimated unmitigated dose to the CW from a seismic event causing a collapse of the 216-Z-9 Crib Facility is 4.85 rem. The unmitigated dose value does not challenge the 100 rem guideline for consideration of SS controls. Therefore, no SS SSCs are required to be designated as a control for the collapse of the 216-Z-9 Crib Facility.

3.4.3.5 Summary of Safety SSCs and TSR Controls

The CW Risk Bin for this event is III, which does not require consideration of SS controls.

The 216-Z-9 Crib Facility structures are considered DID for providing confinement, but are not classified as SS.

The following TSR controls are identified for this event:

- 5.6.1: Material Management (SAC): This SAC prohibits the addition of MAR to the 216-Z-9 Crib Facility inventory, which protects accident assumptions.
- 5.5.1: Safety Management Programs (AC): This AC ensures that applicable SMPs are established, implemented, and maintained.

A specific SMP significant to this event is the EPP which provides for assessing facility damage and potential releases of hazardous/radioactive materials if facility integrity is potentially impacted. The EPP also provides for appropriate notification of all personnel who may potentially be affected, including other contractor personnel.

- 5.7.3: Traffic Control Program (AC): This AC defines specific measures, policies, and actions to prevent or minimize the occurrence of vehicle or other heavy equipment impact-related accidents at the 216-Z-9 Facility.

The Traffic Control Program, consisting of the presence of traffic barriers within the 216-Z-9 Crib Facility boundary area (see Figure 2-2), serves to reduce the frequency of any vehicle interactions with the 216-Z-9 Crib Trench roof, or the 216-Z-9 ancillary structures. The traffic barriers, consisting of an array of Eco-blocks along with some large pieces of equipment arranged around the 216-Z-9 Facility, serve to greatly restrict access ways for a vehicle to drive on to the 216-Z-9 Crib Trench roof. By preventing a vehicle from driving onto the 216-Z-9 Crib Trench Roof, a non-natural phenomena hazard (NPH) initiator for a roof collapse is removed.

3.4.4 Beyond Evaluation Basis Accident Consideration

Per DOE-STD-1120-2016, the evaluation must consider a BEBA, as described in DOE-STD-3009-2014, Section 3 "Hazard Analysis, accident Analysis, and Hazard Control Selection," subsection 3.5 "Beyond Design/Evaluation Basis Accidents." A BEBA is defined as "An accident that exceeds the severity of the design/evaluation basis accident." Guidance provided in OE-1: 2013:01, *Improving Department of Energy Capabilities for Mitigating Beyond Design Basis Events*, requires the following BDBE be evaluated: seismic events, floods, fires, lightning, wind and tornadoes, snow and ice, ash fall, accidental aircraft crash, station blackout, and cascading effects of design basis events. Each of the BDBE prescribed in OE-1: 2013:01 have been evaluated. For the 216-Z-9 Crib Facility BEBA, a Seismic Event with a Fire in the 216-Z-9 Crib Facility is analyzed.

3.4.4.1 Scenario Development

A BEBA is postulated in which a significantly larger than expected seismic event happens.

A liquid-fueled vehicle parked in close proximity to the 216-Z-9 Crib is thrown by the seismic motions into the 216-Z-9 Crib Trench on top of the roof, which has collapsed due to the seismic movements. The vehicle strikes the floor of the trench, the fuel tank ruptures, releasing the fuel to the floor of the crib trench, and the fuel ignites and burns, causing additional contaminated material to be released. The accident assumes the total available radiological inventory of the 216-Z-9 Crib Facility, including the uppermost 3 ft of soil (impact release) and the uppermost 0.5 in. (fire release), the 216-Z-9A and 216-Z-9B support buildings, and the K-1-8, K-1-9, and K-1-10 ventilation system components are affected.

3.4.4.2 Source Term Analysis

For this BEBA scenario, the results of the unmitigated 216-Z-9 Crib Trench Soil Impact Release (as shown in Table 3-11), the 216-Z-9 Crib Facility Support Buildings and Ventilation System Release (as shown in Table 3-12), and the 216-Z-9 Crib Trench External Event Soil Fire Release (as shown in Table 3-14) were combined using a simple summation. In addition, the impact-affected soil depth was increased from 1 ft to 3 ft to match that of a standard aircraft impact (CP-59723).

3.4.4.3 Consequence Analysis

The consequences of the BEBA event would be a combination of the doses from the 216-Z-9 Crib Soil Impact release (increased to a 3 ft depth, see Figure A-5), the 216-Z-9 Crib Facility Support Buildings and Ventilation System Release, and the 216-Z-9 Crib Trench External Event Soil Fire Release. Summing the consequences of these releases, A-1, A-2, and A-5, results in dose consequences given in Table 3-16.

Table 3-16. BEBA Consequences for the 216-Z-9 Crib Facility

Source	CW (rem)	MOI (rem)
216-Z-9 Crib Trench Soil Impact Release	5.48E+00	4.85E-03
216-Z-9 Crib Trench Soil Fire Release	2.46E+00	2.17E-03
216-Z-9 Crib Facility Support Buildings and Ventilation System	2.42E-01	2.14E-04
Total	**8.18E+00**	**7.23E-03**

3.4.4.4 Comparison to Consequence Thresholds

This is a BEBA. The unmitigated frequency of occurrence for NPH events (seismic event) cannot be reduced; the lofting of a vehicle into the 216-Z-9 Crib Trench from beyond the physical barriers due to seismic motions is Beyond Extremely Unlikely, therefore the overall frequency for the BEBA event is Beyond Extremely Unlikely. There are no new SC SSCs, SS SSCs or other safety controls required, because this is a BEBA.

3.4.4.5 Summary of Safety SSCs and TSR Controls

The following controls are considered applicable to this BEBA, although not required:

- 5.6.1 Material Management (SAC): This SAC prohibits the addition of MAR to the 216-Z-9 Crib Facility inventory, which protects accident assumptions.
- 5.7.3 Traffic Control Program (AC): This AC defines specific measures, policies, and actions to prevent or minimize the occurrence of vehicle or other heavy equipment impact related accidents at the 216-Z-9 Facility, including traffic barriers which ensure a minimum distance between vehicles and the 216-Z-9 Crib Trench.

Applicable SMPs that reduce the risk of this event include the EPP, which provides for assessing facility damage and potential releases of hazardous/radioactive materials if building integrity is potentially impacted. The EPP also provides for appropriate notification of all personnel who may potentially be impacted, including other contractor personnel.

In addition, the soil within the 216-Z-9 Crib Facility boundary (see Figure 2-2) is considered a DID DF, to prevent releases of potentially contaminated soil. An inspection of the condition of the soil in this area has been added to the 216-Z-9 Annual Surveillance work instruction.

3.5 Safety Structures, Systems, and Components

The 216-Z-9 Crib Facility structures are considered DID for providing confinement, and the physical barriers placed around the crib are considered DID as they prevent vehicle impacts.

The soil within the 216-Z-9 Crib Facility boundary is considered a DID DF to prevent releases of potentially contaminated soil.

These structures are discussed in Section 4.1. There are no SC or SS SSCs designated for the 216-Z-9 Crib Facility.

3.6 Margin of Safety

This section addresses margins of safety to facilitate USQ evaluations for changes affecting the 216-Z-9 Waste Storage Crib. Based on the guidance in PRC-PRO-NS-062 *Unreviewed Safety Question Process*, the Safety Basis was reviewed to determine if there were instances of DOE-defined functional requirements for equipment that would provide a basis for the identification of margins of safety. There is no explicit margin of safety identified in this DSA. Margin of safety must be an explicit function between a design or assumed failure point and its associated safety limit. This DSA does not contain safety limits nor does it designate SC SSCs that, if they were to fail, would result in a potential release greater than 25 rem to the MOI. As such, there are no explicit or implicit margins of safety associated with the 216-Z-9 Waste Storage Crib Facility.

4.0 Hazard Controls

This chapter identifies the building features and control elements required for authorized S&M activities at the 216-Z-9 Waste Storage Crib Facility. It provides details about equipment and features that are necessary to provide DID, and that contribute to worker safety. The controls presented here are based on the results of the HA and accident analysis for S&M activities at the 216-Z-9 Crib Facility as described in Chapter 3.0.

4.1 Safety Structures, Systems, and Components

Determination of necessity of designating equipment to be SC or SS is based on the current criteria for selecting safety systems identified in PRC-PRO-NS-700, *Safety Basis Development*, (following DOE-STD-1189, *Integration of Safety into the Design Process*, requirements) and the guidance in PRC-STD-NS-8739. Specifically, any scenario with a risk bin value greater than III requires SC or SS controls to reduce the risk bin value to III or less. SC SSCs are identified to reduce risk to the MOI, and SS SSCs are identified to reduce the risk to the CW. SSCs are evaluated for DID status if they are below the criteria for SC and SS SSCs discussed above.

Potential consequences calculated for the design basis accidents evaluated in Section 3.4 are presented in Table 4-1. All postulated accidents result in potential consequences that are much less than 25 rem TED to the MOI (the EG) and less than 100 rem TED to the CW at 100 m (328 ft) from the facility (the guideline for consideration of SS controls).

Table 4-1. Accident Scenario Summary

Scenario (unmitigated)	Frequency	Onsite (CW) TED (rem)	Offsite (MOI) TED (rem)	Risk Bin Values
Seismic Event	Unlikely	2.63E+00	2.32E-03	III
External Event Crib Roof Collapse with Fire	Anticipated	4.85E+00	4.28E-03	III
Facility Collapse – Aging	Anticipated	2.63E+00	2.32E-03	III

4.1.1 Safety Class SSCs

All of the accident analyses in Chapter 3.0 identified “Low” consequences to the MOI receptor, and as such, no SC SSCs are required or identified at the 216-Z-9 Crib Facility.

4.1.2 Safety Significant SSCs

None of the accident analyses in Chapter 3.0 identified consequences to the CW receptor that challenged the 100 rem guideline for consideration of SS controls. There are no SS SSCs required or identified at the 216-Z-9 Crib Facility.

4.2 Design Features

This section identifies and describes the passive DFs that, if altered or modified, would have a significant effect on safety.

4.2.1 216-Z-9 Crib Facility Soil Overburden – Impact- or Fire-Related Releases

The 216-Z-9 Crib Facility Soil Overburden is designated as a DID DF to prevent releases of potentially-contaminated soil. The soil overburden adjacent to the facility is designated as an Inactive Waste Site (assumed to be less than Hazard Category 3 facility) in accordance with PRC-PRO-NS-8366, *Facility Hazard Categorization*. Removal of the soil or any soil disturbing activity must be evaluated in accordance with PRC-PRO-NS-062 to prevent inadvertent releases of potentially contaminated soils.

A preventive maintenance inspection for this passive DF is added to the 216-Z-9 Crib Facility annual surveillance work instruction. In addition, this passive DF is protected by the USQ process.

4.3 Specific Administrative Controls

A summary of the SACs credited for protecting accident analysis assumptions is given in Table 4-2.

Table 4-2. Summary of SACs

Control	Type	Accidents
TSR SAC 5.6.1 Material Management	Directive Action SAC	3.4.1 Seismic event 3.4.2 Facility Collapse – Aging 3.4.3 External Event Crib Roof Collapse with Fire

4.3.1 Material Management (SAC)

This Directive Action (DA) SAC provides controls to ensure that the radiological inventories assumed in the accident analyses will not be exceeded, which would place the facility in formally unanalyzed space.

4.3.1.1 Safety Function

This SAC ensures that the introduction of outside radiological waste material anywhere at the 216-Z-9 Facility is prohibited. The radiological inventory shall only decrease or remain constant.

4.3.1.2 Functional Requirements

The Material Management control is the initial underlying assumption for the accident analyses performed in Section 3.4. The MAR limit protects accident assumptions and ensures that the consequences are not invalidated, thereby placing the facility outside the analyzed Safety Basis.

4.3.1.3 SAC Evaluation

Prohibiting the addition of radiological material to the 216-Z-9 Crib Facility inventory (SAC 5.6.1 a) protects accident assumptions as documented in Chapter 3.0. The USQ process and implementing procedures adequately protect this SAC element.

4.3.1.4 TSR Requirements

This control has been written as a DA SAC in the TSRs.

4.4 Defense-In-Depth Systems, Structures, and Components

SSCs are evaluated for DID designation, if they are below the criteria for SC and SS.

DOE G 424.1-1B *Implementation Guide for use in Addressing Unreviewed Safety Question Requirements*, Section 1 “Introduction” states:

> For the purposes of this Guide, equipment important to safety should be understood to include any equipment whose function, malfunction, or failure can affect safety either directly or indirectly. This includes safety class and safety significant structures, systems, and components (SSCs), and other systems that perform an important defense-in-depth function, equipment relied on for safe shutdown, and in some cases, process equipment. Support systems to safety systems that are required for the safety function are also safety systems and should be included.

The 216-Z-9 Crib Facility structures are not credited in the accident analyses for providing a preventive or mitigative function; however, 216-Z-9 Crib Facility structures provide confinement of hazardous materials and are considered DID for that function. Table 4-3 describes these DID structures.

The physical traffic barriers emplaced around the 216-Z-9 Crib Facility are not credited in the accident analysis for providing a preventive or mitigative function; however, the physical traffic barriers provide a degree of prevention of vehicle impacts with the 216-Z-9 Crib Facility structures, especially the 216-Z-9 Crib Trench roof.

Changes to DID equipment are considered significant modifications. The USQ Process ensures that changes are appropriately analyzed and controlled so they do not adversely affect safe operation.

Table 4-3. Defense-in-Depth Equipment (General Service)

Element	Boundary Definitions and Safety Functions	Basis for DID and applicability
216-Z-9 Crib, K-1-8, K-1-9, & K-1-10 Exhaust System Components, 216-Z-9A Building and Glovebox, 216-Z-9B Building	**Boundary**: The physical boundary includes the 216-Z-9 Crib Trench Roof, Support Building walls and roofs, exhaust system housings and ductwork **Defense-in-depth (DID) safety function**: **Confinement** – The facility structures provide degree of confinement of the MAR within the facility during normal operations and some accident conditions	The structures perform an important DID function (DOE G 424.1-1B) The structure safety function is effective for multiple hazards (PRC-PRO-NS-700)
Physical traffic barriers around 216-Z-9 Crib Facility	**Boundary**: The physical boundary includes the traffic barriers (i.e., eco-blocks, Jersey barriers, etc.) surrounding the 216-Z-9 Crib Facility **DID safety function**: **Impact Protection** – The physical traffic barriers serve to prevent vehicle impacts with the 216-Z-9 Crib Facility structures, especially the 216-Z-9 Crib Trench roof	The structures perform an important DID function (DOE G 424.1-1B)
216-Z-9 Crib Facility Soil Overburden	**Boundary**: The physical boundary includes all soil within the 216-Z-9 Crib Facility boundary as shown in Figure 2-2 **DID safety function**: **Confinement** – To prevent the soil within the 216-Z-9 Facility boundary from being removed in sufficient amounts to potentially expose the contaminated soil of the plume to events which may cause a release	The structures perform an important DID function (DOE G 424.1-1B)

4.5 Administrative Controls

To ensure that assumptions of this DSA are maintained and to ensure continued safety management of the facility, the following ACs are provided. All ACs are applicable in 216-Z-9 Crib Facility S&M Mode.

4.5.1 AC 5.5.1: Safety Management Programs

AC 5.5.1 is identified to ensure implementation and assessment of applicable SMPs.

This AC is not classified as an SAC because it does not meet the criteria described in DOE-STD-1186-2016, *Specific Administrative Controls*, Section 2.1, "Identification of SACs." That is, the AC is not needed to prevent or mitigate an accident scenario, and the safety function would not be safety-class or safety-significant if the function were provided by an SSC. All accidents analyzed in Section 3.4 resulted in acceptable CW and MOI receptor consequences without the application of controls (i.e., did not challenge guidelines for consideration of SS or SC controls).

4.5.2 AC 5.7.1: Nuclear Criticality Safety

AC 5.7.1 is identified to establish a Criticality Safety Program, and provide measures that ensure Criticality Safety Program key elements are in place to prevent an accidental criticality at the 216-Z-9 Crib Facility. Elements include criticality limits and controls, engineered safety features, notifications, and reporting of criticality safety nonconformances.

The Criticality Safety Program is discussed in Section 6.

4.5.3 AC 5.7.2: Waste Acceptance Program

AC 5.7.2 is identified to define measures to protect the assumptions made associated with waste-container-related accidents. Specific elements include provisions for ensuring that waste containers created at the 216-Z-9 Crib Facility are consistent with the accident analysis assumptions and other regulatory requirements. Additionally, this AC ensures that waste containers have a path forward with respect to removal from the 216-Z-9 Crib Facility boundary.

The Waste Acceptance Program (WAP) defines measures used to manage newly-generated wastes such that noncompliance with the requirements of HNF-14741, *Solid Waste Operations Complex Master Documented Safety Analysis*, and HNF-15280, *Solid Waste Operations Complex Technical Safety Requirements*, is minimized. The WAP includes the use of approved containers, procedures for NDA, and a process for remediation of deficiencies. For further details (HNF-EP-0063, *Hanford Site Solid Waste Acceptance Criteria*).

Waste containers generated at the 216-Z-9 Crib Facility that meet the WAP requirements are acceptable for transportation as well as handling and storage at the Solid Waste Operations Complex.

4.5.4 AC 5.7.3: Traffic Control Program

AC 5.7.3 is identified to define measures, restrictions, and actions to prevent or minimize the occurrence of vehicle or other heavy-equipment impact-related accidents at the 216-Z-9 Crib Facility.

This administrative control reduces the risk of a radiological release due to the structural collapse of the crib due to overloading by controlling vehicle access. The AC 5.7.3 traffic controls are specific to reducing the likelihood of a vehicle breaching the 216-Z-9 Crib Trench roof by requiring physical traffic barriers.

Physical barriers may include Jersey barriers, elevated locations, embankments, large concrete “eco” blocks, a berm of several feet, other large heavy object (e.g., large abandoned process tank, large abandoned burial box) or items that create a spatial separation (buffer zone) such as fencing, to protect 216-Z-9 Crib Trench roof from vehicle access. These barriers reduce the likelihood of a vehicle driving onto the crib. This control reduces the frequency of the event.

The Key Attribute of the program with respect to the 216-Z-9 Crib is:

- Protection of the 216-Z-9 Crib with physical barriers.

The safety function of the program is to minimize the likelihood of a vehicle impact or fuel fire which could result in the release of radioactive material.

This AC is not classified as a Specific Administrative Control because it does not meet the criteria described in DOE-STD-1186-2016, Section 2.1, "Identification of SACs." That is, the AC is not needed to prevent or mitigate an accident scenario, and the safety function would not be SC or SS if the function was provided by an SSC.

5.0 Derivation of Technical Safety Requirements

There are no safety limits, limiting control settings, or limiting conditions for operation applicable to the 216-Z-9 Crib in the S&M mode.

5.1 TSR Coverage

This chapter describes the type of TSR coverage to be implemented for each control that is carried over to the separate TSR document. It summarizes all identified SC and SS SSCs, SACs, and programmatic ACs to be covered in the TSR document. Chapter 4 discusses the Safety-Significant and DID SSCs and SACs that were identified in Chapter 3. Chapter 4, Section 4.2 provides the complete discussion of the safety functions, functional requirements, performance criteria, and applicable TSR controls for the identified Safety-Significant SACs.

5.2 Derivation of Facility Modes

Facility modes are used to describe the applicability of Limiting Conditions for Operation (LCOs) and some SACs and ACs. This section describes, based on hazard analysis and accident analysis, where different facility modes are appropriately distinguished to facilitate application of identified LCOs and SACs or ACs. The 216-Z-9 Crib Facility currently has two modes authorized, S&M Mode and D&D Mode, and does not have any LCOs.

5.2.1 S&M Mode

The scope of work activities taking place at the 216-Z-9 Crib during S&M mode are those intended to maintain confinement of hazardous materials and protect workers. These include pre-approved activities for S&M, as well as activities anticipated to occur, but are not already defined by pre-approved procedures.

5.2.2 D&D Mode

The scope of work activities taking place at the 216-Z-9 Crib during D&D mode are those intended to support grouting and structural stabilization activities.

5.3 TSR Derivation

5.3.1 Limiting Conditions for Operation and Surveillance Requirements

Chapter 3 does not currently identify any TSR LCOs requiring coverage in the TSRs.

5.3.2 Administrative Controls

5.3.2.1 Material Management (SAC 5.6.1)

SAC 5.6.1 is established, implemented, and maintained to ensure that the initial MAR (source inventory) conditions assumed in the 216-Z-9 Facility Accident Analyses will not be exceeded, as described in Section 1.7 of DOE-STD-1186-2016.

During the current 216-Z-9 Waste Storage Crib S&M life-cycle phase, planned activities will consist primarily of S&M, the storage of supplies and materials related to S&M activities, and limited deactivation activities. The scope of work includes S&M activities that maintain confinement of hazardous wastes and protect the worker. This work scope includes activities for surveillance of the facility, preventative maintenance of selected equipment, and incidental storage of necessary supplies and equipment. The work scope also includes characterization, sampling, and geophysical logging, asbestos abatement actions, replacement, or upgrades of postings and barriers, container management, demand repairs to SSCs, spill response, characterization, and response or investigation of surveillance reports. All of these activities center on the 216-Z-9 Facility's existing inventory and do not include or authorize the introduction of any external source inventory.

5.4 Design Features

The 216-Z-9 Crib Facility Soil Overburden is designated as a DID DF, to prevent releases of potentially contaminated soil. The soil overburden adjacent to the facility is designated as an Inactive Waste Site (assumed to be less than Hazard Category 3 facility) in accordance with PRC-PRO-NS-8366. Removal of the soil or any soil disturbing activity must be evaluated in accordance with PRC-PRO-NS-062 to prevent inadvertent releases of potentially contaminated soils.

5.5 Interface with Technical Safety Requirements from Other Facilities

The WAP given in AC 5.7.2 defines measures used to manage newly-generated wastes such that noncompliance with the requirements of HNF-14741 and HNF-15280 is minimized. The WAP includes the use of approved containers, procedures for NDA, and a process for remediation of deficiencies.

There are no interfaces required with PFP TSRs as given in HNF-15502.

5.6 Step Out Criteria

The basis for the classification of the 216-Z-9 Waste Storage Crib Facility as a Nuclear Facility is the radioactive inventory in the 216-Z-9A Building and the below-grade 216-Z-9 Crib Trench. The 216-Z-9 Facility can be reclassified as below Hazard Category 3 when sufficient radioactive material is removed to lower the radioactive material inventory below the Hazard Category 3 threshold. Reclassification of the 216-Z-9 Waste Storage Crib Facility as a less than Hazard Category 3 Facility will require DOE approval and a formal Implementation Validation Review.

6.0 Prevention of Inadvertent Criticality

6.1 Introduction

This chapter provides the facility specific details of the CHPRC Criticality Safety Program (CSP) as specified by DOE-STD-3009-2014, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis*, Chapter 6, "Prevention of Inadvertent Criticality."

6.2 Governing Documents

The CHPRC CSP is described in PRC-NS-00004, *CH2M HILL Plateau Remediation Company Criticality Safety Program Description Document*. A summary of the CSP, including specific key attributes (KAs), is provided in Chapter 6 of HNF-11724, *CH2M HILL Plateau Remediation Company Safety Management Programs*. All KAs have been implemented for the 216-Z-9 Crib except for KA 6-6, "criticality alarm systems." Criticality alarm systems are not required in Limited Control Facilities. The Criticality Safety Program is implemented in HNF-7098, *Criticality Safety Program*, at the site level, and in PRC-PRO-NS-52334, *WMP-200-4.4, Criticality Safety*, for the 216-Z-9 Crib at the project level. This Project procedure provides details that reinforce HNF-7098 and identifies approved exceptions that may apply to the 216-Z-9 Crib.

6.3 Criticality Safety Program

The 216-Z-9 Crib is a Limited Control Facility per HNF-7098. A limited control facility is defined as a facility in which greater than half of a minimum critical mass is present, a criticality is documented to be incredible, and limits and controls are required to maintain incredibility. PRC-PRO-NS-52334 requires that all Criticality Safety Evaluation Reports demonstrate that a criticality is incredible to allow operation as a limited control facility. Specifically, criticality incredibility has been shown in the 216-Z-9 Crib for the introduction of a robot crawler, equipment removal, grouting activities, and possible man entry. No fissile material is allowed to be introduced into the 216-Z-9 Crib. These restrictions are documented in CHPRC-03737, *CSER 18-003: Criticality Safety Evaluation Report for the 216-Z-9 Crib*. TSR 5.7.1 "Nuclear Criticality Safety" ensures that a criticality safety program exists at the 216-Z-9 Crib. This makes certain that future activities are analyzed with respect to criticality safety requirements.

6.4 Supporting Safety Management Programs

Implementation of the CSP at the 216-Z-9 Crib is supported by several Safety Management Programs and processes.

CRD O 422.1, *Conduct of Operations*, is implemented at CHPRC through the specifications noted in Section 11.3 of HNF-11724. Each nuclear facility is required to establish an implementing matrix that addresses each of the guideline requirements from CRD O 422.1. These guidelines support mission success and promote worker, public, and environmental protection. It was stated in CRD O 422.1 that a Conduct of Operations Program supports Integrated Safety Management System (ISMS) by providing techniques and practices to implement the Core Functions of "Develop and Implement Hazard Controls" and "Perform

Work within Controls." It is stated in Section 1.2.3 of HNF-7098 that the CHPRC Criticality Safety Program applies the principles of ISMS in developing, authorizing, and implementing criticality safety documents.

The Quality Assurance (QA) Program is presented in Section 14 of HNF-11724. The QA Program establishes requirements for several activities as discussed in Section 14 of HNF-11724: work process, design, procurement, inspection and testing for acceptance, and assessments (management and independent). Section 1.4 of HNF-7098 assigns responsibilities to several groups within CHPRC. In particular, Section 1.4.9 assigns the Quality Assurance Program responsibility to verify equipment design features and installations essential to criticality safety, as requested by the CSR or criticality safety engineer, and to verify compliance with other criticality safety limits, upon request.

Section 17.4.2 of HNF-11724 states that CHPRC configuration control provisions are established by the QA Program and that engineering configuration control requirements are further described in engineering implementing procedures. One such implementing procedure is PRC-PRO-EN-20050, *Engineering Configuration Management*. Section 6.3 of HNF-7098 acknowledges use of PRC-PRO-EN-20050 in specifying safety significant engineered safety features from criticality safety evaluations on a safety equipment list.

The provisions of the Initial Testing, In-Service Surveillance, and Maintenance SMP are applicable to facility systems or equipment that provide a preventive and/or mitigative function as noted in the DSA hazard evaluation. Section 10 of HNF-11724 presents six key attributes of the CHPRC initial testing, in-service surveillance, and maintenance program that support the implementation of criticality safety limits and controls. Initial testing and subsequent surveillance and maintenance are specifically discussed for fixed neutron absorber systems and criticality accident alarm systems in HNF-7098. In addition, all other active, safety significant, engineered safety features, as detailed on the safety equipment list, must have operability conditions and surveillance specifications in the TSRs.

It is noted in Section 12.4 of HNF-11724 that CHPRC Training Program develops, implements, and manages a program that includes identification of known requirements, definition of training standards, implementation of program training classes, certification/qualification of required skills, and verification of ongoing job qualifications. Section 1.4.10 of HNF-7098 assigns the Training Program responsibility to provide a formal criticality safety training program for certified fissionable material handlers, qualified fissionable material operators, supervisors, CSRs, and support personnel as described in Section 3 of that document.

7.0 Safety Management Programs

7.1 Radiation Protection

The Radiation Protection Program (RPP) implements applicable regulatory (10 CFR 835 *Occupational Radiation Protection*) and other contractual requirements. The program is based on functional or operational organizations implementing the necessary requirements. The RPP is described in Chapter 7.0 of HNF-11724. No exceptions are taken to the key attributes as described in HNF-11724.

7.2 Fire Protection

The Fire Protection Program ensures that sufficient fire protection is provided to protect the health and safety of employees and the health and welfare of the public in the event of a fire, to prevent unacceptable delays in vital DOE Programs, and to prevent exceeding specific dollar-loss values should a fire occur.

The fire hazards are identified in CHPRC-02870, *Fire Hazards Analysis for 216-Z-9 Complex and Tank 241-Z-361*. Activities authorized by this DSA will be performed in compliance with the requirements of the site Fire Protection Program. Facility specific controls and recommendations are identified in the Fire Hazards Analysis (FHA). The Fire Protection Program is described in Chapter 11.4 of HNF-11724. The KA pertaining to fire protection, as described in HNF-11724 apply except for KA 11-5 "CHPRC fire alarm and suppression systems are functionally tested, inspected, and maintained to meet NFPA and DOE standards and requirements." There are no Safety Basis requirements for the deactivated facility fire suppression system. NFPA inspection, testing, and maintenance requirements are not applicable to this deactivated system.

7.3 Maintenance

The 216-Z-9 Crib Facility has been in the S&M phase of its life cycle with limited occupancy for S&M activities. The 216-Z-9 Crib Support Buildings are normally locked, and access is controlled by approved procedures of the CPRM organization. The scope of activities to be performed is summarized in Section 2.3. The Initial Testing, In-service Surveillance, and Maintenance Program is found in Chapter 10.0 of HNF-11724. No exceptions are taken to the KAs as described in HNF-11724.

7.4 Procedures

The procedure development program employs a graded approach to ensure that work processes are controlled by approved instructions, procedures, design documents, technical standards, or other hazard controls adopted to meet regulatory or contractual requirements appropriate to the specific tasks to be performed. A description of the procedures development and training programs may be found in HNF-11724, Chapter 12.0. No exceptions are taken to the KAs as described in HNF-11724.

7.5 Training

The training program provides employees, required to perform specified job requirements, with the training necessary to become qualified and maintain qualification. A description of the procedures development and training programs may be found in HNF-11724, Chapter 12.0. No exceptions are taken to the KAs as described in HNF-11724.

7.6 Conduct of Operations

Conduct of Operations provides a formal and disciplined method for safely performing work and operating site facilities. Conduct of Operations is based on the concept that workers are provided with adequate knowledge of requirements, and are disciplined in observing these requirements. It is founded on training, qualification, and use of procedures. It promotes implementation of a set of standards that establishes safe operations. Provisions of the program specify that appropriately-trained personnel using approved, adequate, and controlled procedures perform work; that this work is properly supervised; that prior approval is obtained for the work; and that accountability exists for work performance.

The Conduct of Operations Program is implemented at the 216-Z-9 Crib Facility consistent with the description provided in HNF-11724, which provides a summary description of Conduct of Operations applicable for use at the 216-Z-9 Crib Facility. The implementation of the Conduct of Operations Program at the 216-Z-9 Crib Facility is consistent with the program description in HNF-11724, Section 11.3. No exceptions are taken to the KAs as described in HNF-11724.

7.7 Quality Assurance

CHPRC implements a QA Program meeting the requirements of 10 CFR 830, Subpart A, "Quality Assurance Requirements," in accordance with PRC-MP-QA-599, *Quality Assurance Program*. The QA Program is described in Chapter 14.0 in HNF-11724. No exceptions are taken to the KAs as described in HNF-11724.

7.8 Emergency Preparedness

CHPRC implements the DOE Emergency Management Plan through its Emergency Preparedness Program. The implementing organization prepares and maintains hazard assessments and response plans for applicable facilities. Facility staff is trained and practice drills are used to ensure a timely and effective response should an emergency occur. While the CPRM Organization will perform drills annually, they will not be performed for every facility annually. The EPP is described in Chapter 15.0 of HNF-11724. No exceptions are taken to the KAs as described in HNF-11724.

7.9 Radioactive and Hazardous Waste Management

The Radioactive and Hazardous Waste Management Program is found in Chapter 9.0 of HNF-11724. No exceptions are taken to the KAs as described in HNF-11724.

7.10 Hazardous Material Protection

The Hazardous Material Control Program is found in Chapter 8.0 of HNF-11724. No exceptions are taken to the KAs as described in HNF-11724.

7.11 Provisions for Decontamination and Decommissioning

The process for D&D at the 216-Z-9 Crib Facility is regulated under the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA). A description of the D&D Program is provided in Chapter 16 of HNF-11724. Execution of the D&D SMP ensures that D&D activities are performed in compliance with applicable federal and state laws and regulations, provisions for D&D are developed, and that modifications to facilities or newly constructed facilities include features to simplify future D&D activities. No exceptions are taken to the KAs as described in HNF-11724.

7.12 Management, Organization, and Institutional Safety Provisions

The details of management, organization, and institutional safety policies are summarized in Chapter 17.0 of HNF-11724. The functional support organizations that provide services to projects outlined in Chapter 17.0 of HNF-11724 include: Safety, Health, Security, and Quality (SHS&Q), Environmental Program and Strategic Planning, Project Technical Services, Business Services, Prime Contracts and Project Integration, and Communications. No exceptions are taken to the KAs as described in HNF-11724.

8.0 References

10 CFR 830, Subpart A, "Quality Assurance Requirements," *Code of Federal Regulations.*

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Appendix A

RADIDOSE Spreadsheets

Appendix A
RADIDOSE Spreadsheets

RADIDOSE Version 3.0 (5-18-2005)			
Input Parameter	**User Input**	**Default**	**Description (based on user input)**
Facility/Material (1-14):		1	Plutonium Finishing Plant: < 10% Pu-240
Form of Material (1-10):	3		Non-combustible Contaminated Solids
Accident Type (1-6):	2		External Impact
Quantity at Risk (MAR):	9.26E+03		gram
Damage Ratio:		1	
Airborne Release Fraction:	9.74E-06		ARF
Respirable Fraction:	2.50E-01		RF
Leak Path Factor:		1	LPF (applies to particulate only)
HEPA Filter Factor:	1		DF = 1 (applies to particulate only)
Collocated Worker Dose Factor:		3	ICRP 68, 5 µm AMAD
Onsite & Offsite Public Dose Factor:		7	ICRP 72 for Adult
Material Solubility Class:		2	compounds are generally soluble
Hanford Processing Area (1-4):		2	200 Area
Distance or X/Q for Collocated Worker:		100	meters
Distance or X/Q for Onsite Public:		4,210	meters
Distance or X/Q for Offsite Public:		12,500	meters
Emission Source Type (1-4):		1	Point source at ground level
Release Duration (0 to 8760 h):		0.5	hours
Description of Accident Scenario:		Edit using function key F2. Carriage returns are not allowed.	

NPH-1 Soil component
ARF=9.74E-6 RF=0.25 per Section B.1
DR=1; LPF=1
Inventory = 48,000g; MAR = 9.26 kg (top 1 foot of soil) per Section B.2

Plutonium Finishing Plant: < 10% Pu-240 – New composition (2004)				
Non-combustible Contaminated Solids				
Point Source At Ground Level				**200 Area**
Total Respirable Release:	2.25E-02 gram			
Dose Factors:	ICRP 68, 5µm	ICRP 72 for Adult		Release
Receptor:	**Collocated Worker**	**Onsite Public**	**Offsite Public**	Duration 0.5 h
Distance:	100 m	4,210 m	12,500 m	
X/Q:	3.28E-02	7.77E-05	1.89E-05	s/m3
Breathing Rate:	3.35E-04	3.29E-04	3.29E-04	m3/s
Unit DCF:	9.65E+06	1.51E+07	1.51E+07	rem/gram
Total Dose:	**2.39E+00**	**8.68E-03**	**2.11E-03**	**rem**
Consequence:	Low	na	Low	

Figure A-1. 216-Z-9 Crib Facility Seismic Event Soil Impact Release Consequences

RADIDOSE Version 3.0 (5-18-2005)			
Input Parameter	**User Input**	**Default**	**Description (based on user input)**
Facility/Material (1-14):		1	Plutonium Finishing Plant: < 10% Pu-240
Form of Material (1-10):	3		Non-combustible Contaminated Solids
Accident Type (1-6):	2		External Impact
Quantity at Risk (MAR):	2.28E+01		gram
Damage Ratio:		1	
Airborne Release Fraction:	1.00E-03		ARF
Respirable Fraction:	1.00E-01		RF
Leak Path Factor:		1	LPF (applies to particulate only)
HEPA Filter Factor:	1		DF = 1 (applies to particulate only)
Collocated Worker Dose Factor:		3	ICRP 68, 5 µm AMAD
Onsite & Offsite Public Dose Factor:		7	ICRP 72 for Adult
Material Solubility Class:		2	compounds are generally soluble
Hanford Processing Area (1-4):		2	200 Area
Distance or X/Q for Collocated Worker:		100	meters
Distance or X/Q for Onsite Public:		4,210	meters
Distance or X/Q for Offsite Public:		12,500	meters
Emission Source Type (1-4):		1	Point source at ground level
Release Duration (0 to 8760 h):		0.5	hours

Description of Accident Scenario: Edit using function key F2. Carriage returns are not allowed.

NPH-1 Holdup component
ARF=1.0E-3 RF=0.1 per DOE-HDBK-3010 Section 4.4.3.3.2
DR=1; LPF=1
MAR = 22.81g

Dose Results for the Postulated Accident:

Plutonium Finishing Plant: < 10% Pu-240 -- New composition (2004)				
Non-combustible Contaminated Solids				
Point Source At Ground Level				200 Area
Total Respirable Release:	2.28E-03	gram		
Dose Factors:	ICRP 68, 5µm	ICRP 72 for Adult		Release Duration 0.5 h
Receptor:	**Collocated Worker**	**Onsite Public**	**Offsite Public**	
Distance:	100 m	4,210 m	12,500 m	
X/Q:	3.28E-02	7.77E-05	1.89E-05	s/m3
Breathing Rate:	3.35E-04	3.29E-04	3.29E-04	m3/s
Unit DCF:	9.65E+06	1.51E+07	1.51E+07	rem/gram
Total Dose:	**2.42E-01**	**8.78E-04**	**2.14E-04**	**rem**
Consequence:	Low	na	Low	

Figure A-2. 216-Z-9 Crib Facility Support Buildings and Ventilation System Seismic Event Release Consequences

RADIDOSE Version 3.0 (5-18-2005)			
Input Parameter	**User Input**	**Default**	**Description (based on user input)**
Facility/Material (1-14):		1	Plutonium Finishing Plant: < 10% Pu-240
Form of Material (1-10):	3		Non-combustible Contaminated Solids
Accident Type (1-6):	2		External Impact
Quantity at Risk (MAR):	9.26E+03		gram
Damage Ratio:		1	
Airborne Release Fraction:	9.74E-06		ARF
Respirable Fraction:	2.50E-01		RF
Leak Path Factor:		1	LPF (applies to particulate only)
HEPA Filter Factor:	1		DF = 1 (applies to particulate only)
Collocated Worker Dose Factor:		3	ICRP 68, 5 µm AMAD
Onsite & Offsite Public Dose Factor:		7	ICRP 72 for Adult
Material Solubility Class:		2	compounds are generally soluble
Hanford Processing Area (1-4):		2	200 Area
Distance or X/Q for Collocated Worker:		100	meters
Distance or X/Q for Onsite Public:		4,210	meters
Distance or X/Q for Offsite Public:		12,500	meters
Emission Source Type (1-4):		1	Point source at ground level
Release Duration (0 to 8760 h):		0.5	hours
Description of Accident Scenario:		Edit using function key F2. Carriage returns are not allowed.	

EE-1 Impact component
ARF=9.74E-6 RF=0.25 per Section B.1
DR=1; LPF=1
Inventory = 48,000g; MAR = 9.26 kg (top 1 foot of soil) per Section B.2

Plutonium Finishing Plant: < 10% Pu-240 – New composition (2004)				
Non-combustible Contaminated Solids				
Point Source At Ground Level				**200 Area**
Total Respirable Release:	2.25E-02	gram		
Dose Factors:	ICRP 68, 5µm	ICRP 72 for Adult		Release Duration 0.5 h
Receptor:	**Collocated Worker**	**Onsite Public**	**Offsite Public**	
Distance:	100 m	4,210 m	12,500 m	
X/Q:	3.28E-02	7.77E-05	1.89E-05	s/m3
Breathing Rate:	3.35E-04	3.29E-04	3.29E-04	m3/s
Unit DCF:	9.65E+06	1.51E+07	1.51E+07	rem/gram
Total Dose:	**2.39E+00**	**8.68E-03**	**2.11E-03**	**rem**
Consequence:	Low	na	Low	

Figure A-3. 216-Z-9 Crib Trench Soil External Event Impact Release Consequences

RADIDOSE Version 3.0 (5-18-2005)			
Input Parameter	User Input	Default	Description (based on user input)
Facility/Material (1-14):		1	Plutonium Finishing Plant: < 10% Pu-240
Form of Material (1-10):	3		Non-combustible Contaminated Solids
Accident Type (1-6):	1		Fire
Quantity at Risk (MAR):	3.86E+02		gram
Damage Ratio:		1	
Airborne Release Fraction:	6.00E-03		ARF
Respirable Fraction:	1.00E-02		RF
Leak Path Factor:		1	LPF (applies to particulate only)
HEPA Filter Factor:	1		DF = 1 (applies to particulate only)
Collocated Worker Dose Factor:		3	ICRP 68, 5 μm AMAD
Onsite & Offsite Public Dose Factor:		7	ICRP 72 for Adult
Material Solubility Class:	2		compounds are generally soluble
Hanford Processing Area (1-4):		2	200 Area
Distance or X/Q for Collocated Worker:		100	meters
Distance or X/Q for Onsite Public:		4,210	meters
Distance or X/Q for Offsite Public:		12,500	meters
Emission Source Type (1-4):	1		Point source at ground level
Release Duration (0 to 8760 h):		0.5	hours

Description of Accident Scenario: Edit using function key F2. Carriage returns are not allowed.

EE-1 Fire component
ARF=6E-3 RF=1E-2 per DOE-HDBK-3010-94 Section 4.4.1.1
DR=1; LPF=1
Inventory = 48,000g; MAR = 386.0g (top 0.5 inch of soil) per Section B.4

Plutonium Finishing Plant: < 10% Pu-240 – New composition (2004)				
Non-combustible Contaminated Solids				
Point Source At Ground Level				200 Area
Total Respirable Release:	2.32E-02	gram		
Dose Factors:	ICRP 68, 5μm	ICRP 72 for Adult		Release Duration 0.5 h
Receptor:	**Collocated Worker**	**Onsite Public**	**Offsite Public**	
Distance:	100 m	4,210 m	12,500 m	
X/Q:	3.28E-02	7.77E-05	1.89E-05	s/m3
Breathing Rate:	3.35E-04	3.29E-04	3.29E-04	m3/s
Unit DCF:	9.65E+06	1.51E+07	1.51E+07	rem/gram
Total Dose:	**2.46E+00**	**8.92E-03**	**2.17E-03**	**rem**
Consequence:	Low	na	Low	

Figure A-4. 216-Z-9 Crib External Event Trench Soil Fire Release Consequences

RADIDOSE Version 3.0 (5-18-2005)			
Input Parameter	**User Input**	**Default**	**Description (based on user input)**
Facility/Material (1-14):		1	Plutonium Finishing Plant: < 10% Pu-240
Form of Material (1-10):	3		Non-combustible Contaminated Solids
Accident Type (1-6):	2		External Impact
Quantity at Risk (MAR):	2.12E+04		gram
Damage Ratio:		1	
Airborne Release Fraction:	9.74E-06		ARF
Respirable Fraction:	2.50E-01		RF
Leak Path Factor:		1	LPF (applies to particulate only)
HEPA Filter Factor:	1		DF = 1 (applies to particulate only)
Collocated Worker Dose Factor:		3	ICRP 68, 5 µm AMAD
Onsite & Offsite Public Dose Factor:		7	ICRP 72 for Adult
Material Solubility Class:		2	compounds are generally soluble
Hanford Processing Area (1-4):		2	200 Area
Distance or X/Q for Collocated Worker:		100	meters
Distance or X/Q for Onsite Public:		4,210	meters
Distance or X/Q for Offsite Public:		12,500	meters
Emission Source Type (1-4):		1	Point source at ground level
Release Duration (0 to 8760 h):		0.5	hours
Description of Accident Scenario:		Edit using function key F2. Carriage returns are not allowed.	

NPH-1 Soil component
ARF=9.74E-6 RF=0.25 per Section B.1
DR=1; LPF=1
Inventory = 48,000g; MAR =21,237g (top 3 foot of soil) per Section B.2

Plutonium Finishing Plant: < 10% Pu-240 – New composition (2004)				
Non-combustible Contaminated Solids				
Point Source At Ground Level				**200 Area**
Total Respirable Release:	5.17E-02	gram		
Dose Factors:	ICRP 68, 5µm	ICRP 72 for Adult		Release Duration 0.5 h
Receptor:	**Collocated Worker**	**Onsite Public**	**Offsite Public**	
Distance:	100 m	4,210 m	12,500 m	
X/Q:	3.28E-02	7.77E-05	1.89E-05	s/m3
Breathing Rate:	3.35E-04	3.29E-04	3.29E-04	m3/s
Unit DCF:	9.65E+06	1.51E+07	1.51E+07	rem/gram
Total Dose:	**5.48E+00**	**1.99E-02**	**4.85E-03**	**rem**
Consequence:	Low	na	Low	

Figure A-5. 216-Z-9 Crib Trench BEBA Soil Impact Release Consequences

Appendix B

Bases for Source Term Parameters

Appendix B
Bases for Source Term Parameters

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Figures

B.1 Basis for 216-Z-9 Impact-Affected Soil ARF and RF Values

For accidents involving high energy impacts to the contaminated soil of the 216-Z-9 Crib Trench, the ARF/RF values are derived based on the ARF/RF discussion given in Section 5.3.2 of the DOE-HDBK-3010-94. For this calculation, the entire roof over the 216-Z-9 Crib is assumed to collapse due to a vehicle impact.

The impact of the crib roof on the contaminated surface of the floor of the crib is treated in a similar way as an explosive stress shock on a non-combustible, contaminated surface. The kinetic energy of the falling crib roof and vehicle are converted into a TNT-equivalent quantity. Then, following Section 5.3.2.1.2 of the DOE handbook for soil or soil-like powders (aggregated, compacted powder), the ARF and RF for the mass of soil suspended in the crib is calculated as 0.8 × TNT equivalent for the explosion, with an RF 0.25. The amount of the radioactive contaminant made airborne is estimated by multiplying the mass of soil made airborne by the concentration of the contaminant in the soil.

The mass impacting the crib floor is the sum of the mass of the concrete roof plus the mass of the vehicle. The mass of the concrete is found based on the volume of concrete falling into the crib times the density of the concrete. The ceiling area, above the active crib surface and within the perimeter of the six concrete columns, is 30 ft (9.1 m) by 60 ft (18.3 m) with a thickness of 9 in. (0.23 m) (ARH-2207, *216-Z-9 Crib History and Safety Analysis*, page 2). A density of 2,450 kg/m^3 is used for concrete. The mass of the concrete slab, $slab_{mass}$ is therefore:

$$slab_{mass} = (2{,}450\ kg/m^3)\ (9.1m)\ (18.3\ m)\ (0.23\ m) = 94{,}000\ kg$$

Assuming a vehicle weight of 16,000 kg (35,000 lb), the total mass falling into the crib is 110,000 kg.

The surface of the crib is about 20 ft (6.1 m) beneath the bottom of the concrete slab cover (ARH-2207, page 2). The kinetic energy of the falling material is equivalent to its initial potential energy or

$$\begin{aligned} E &= M \text{ x } H \text{ x } g_a \\ &= (110{,}000\ kg) \text{ x } (6.1\ m) \text{ x } (9.8\ m/s^2) \\ &= 6.5 \text{ x } 10^6\ J \\ &= 1.6 \text{ x } 10^6\ cal \end{aligned}$$

where:

E	=	the kinetic energy of the falling mass at impact (J or cal)
M	=	the combined mass of the falling concrete and vehicle, (kg)
H	=	the height above the waste surface, (m)
g_a	=	the acceleration of gravity, (9.8 m/s^2)

At a standard conversion of 1,100 cal/g of TNT (DOE-HDBK-3010-94, pages 7-59), this corresponds to a TNT equivalent of 1.42 kg. The amount of suspended soil is:

$$\begin{aligned} Soil_{suspended} &= 0.8 \text{ x } TNT_{eq} \\ &= 0.8 \text{ x } 1.42 \text{ kg} \\ &= 1.14 \text{ kg (soil)} \end{aligned}$$

RHO-LD-114, *Existing Data on the 216-Z Liquid Waste Sites* provides the following statement:

- Core samples from 1 to 8 ft below crib bottom had a concentration of about 0.1 g ^{239}Pu/L of soil

ARH-2915 *Nuclear Reactivity Evaluations of 216-Z-9 Enclosed Trench* confirms this value, however, a value of 0.17 g ^{239}Pu/L of soil was modeled.

This value was chosen as a review of ARH-2915 Appendix B sample data showed there were some samples around the 30 cm (almost 1 ft) level that were slightly higher, with 0.17 g ^{239}Pu/L being the highest. Around 1977, the top 12 in. of soil were removed from the crib. A concentration of 0.17 g ^{239}Pu/L of soil is expected to bound dose consequences associated with the 216-Z-9 Crib soil. Dividing 0.17 g ^{239}Pu by 93.6 percent ^{239}Pu mass fraction (per Table 3-1) returns 0.182 g of the 216-Z-9 plutonium mixture per liter of soil.

With a soil density, ρ_{soil}, of 2,300 kg/m^3, (ARH-2207, Table 2), the quantity of plutonium suspended is:

$$\begin{aligned} Pu_{suspended} &= (Soil_{suspended} / \rho_{soil}) \text{ x } Pu_{conc} \\ &= (1.14 \text{ kg} / 2{,}300 \text{ kg/m}^3) \text{ x } 0.182 \text{ kg/m}^3 \\ &= 9.02 \text{ x } 10^{-5} \text{ kg} \end{aligned}$$

For use in RADIDOSE calculation, the equivalent ARF is the ratio of estimated suspended plutonium mass divided by the initial material at risk (MAR), 9.26 kg, or

$$\begin{aligned} ARF &= Pu_{suspended} / MAR \\ &= (9.02 \text{ x } 10^{-5} \text{ kg}) / (9.26 \text{ kg}) \\ &= 9.74 \text{ x } 10^{-6} \end{aligned}$$

The basis for the initial MAR being 9.26 kg is provided in Section B.2.

B.2 Basis for 216-Z-9 Crib Impact-Affected Soil MAR

The radiological inventory in the soil in the 216-Z-9 Crib consists of approximately 48 kg (48,000 g) of the Pu isotope mixture defined in Table 3-1. This value was based on engineering judgment after the completion of mining activities, and can be found in reference document HNF-31792, *Characterization Information for the 216-Z-9 Crib at the PFP*.

Based on the facility inventory being a plume descending into the soil underneath the crib (Figures B-1 and B-2), it is not realistic to consider the entire inventory as being MAR. The MAR associated with impact events at 216-Z-9 is defined as the top 0.3048 m (1 ft) of soil in the crib.

The top 1 ft of soil was chosen as roof drops, crane load drops, or vehicles falling through the roof are only expected to impact the top 1 ft of soil, at most.

From H-2-15492, *Architectural Waste Disposal Facility Details*, the trench floor is 9.14 m (30 ft) by 18.29 m (60 ft). Using these values, liters of soil per cm of soil depth in the crib is calculated:

$$9.14 \text{ m} \times 18.29 \text{ m} = 167.2 \text{ m}^2$$

$$167.2 \text{ m}^2 \times 10{,}000 \text{ cm}^2/\text{m}^2 = 1{,}672{,}254.7 \text{ cm}^2$$

$$1{,}672{,}254.7 \text{ cm}^2 \times 1 \text{ cm} = 1{,}672{,}254.7 \text{ cm}^3$$

$$1{,}672{,}254.7 \text{ cm}^3 \times 0.001 \text{ L/cm}^3 = 1{,}672.3 \text{ L}$$

From the liters of soil per cm of soil depth, the total number of liters in the top 0.3048 m (1 ft) of soil is calculated:

$$1{,}672.3 \text{ L/cm} \times 30.48 \text{ cm} = 50{,}972 \text{ L}$$

RHO-LD-114, *Existing Data on the 216-Z Liquid Waste Sites* provides the following statement:

- Core samples from 1 to 8 ft below crib bottom had a concentration of about 0.1 g ^{239}Pu/L of soil

ARH-2915 confirms this value, however, a conservative value of 0.17 g ^{239}Pu/L of soil was modeled. This value was chosen as a review of ARH-2915 Appendix B sample data showed there were some samples around the 30 cm (almost 1 ft) level that were slightly higher, with 0.17 g ^{239}Pu/L being the highest. A concentration of 0.17 g ^{239}Pu/L of soil is expected to bound dose consequences associated with the 216-Z-9 Crib soil.

Using this information, multiplying the 50,972 L of soil with the 0.17 g ^{239}Pu/L of soil provides a value of 8,665 g of ^{239}Pu. Dividing 8,665 by 93.6 percent ^{239}Pu mass fraction (per Table 3-1) returns 9,258 g (9.26 kg) of the 216-Z-9 plutonium mixture.

Therefore, for impact events, the MAR for is stated as 9,258 g of the total 48,000 g inventory.

B.3 Basis for 216-Z-9 Crib Impact-Affected Soil Depth

Calculation of the depth of soil affected by the collapsing roof of the 216-Z-9 Crib Trench is similar to calculations of projectile penetrations into soil. Equations developed and described in SAND97-2426, *Penetration Equations*, and U.S. Army Technical Report S-78-4, *Depth and Motion Prediction for Earth Penetrators* show that the depth of soil penetration by a projectile is dependent primarily on: the type of material being penetrated (e.g., sand, clay, rock, concrete, etc.); the area of impact of the projectile; and the projectile shape (e.g., cone, ogive, cylindrical, etc.).

A calculation (B.3.1, below) for the depth of soil affected by the collapse of the 216-Z-9 Crib Trench roof (including the mass of a large vehicle, see Section B-1), and choosing worst case conservative conditions shows a penetration depth (thus the depth of soil affected by the impact) of 0.28 m (0.91 ft).

The calculated impact occurs over only 10 percent of the surface area of the Crib Trench, the soil type is chosen to have the largest penetrability factor, and a projectile shape is chosen which yields the greatest penetration.

Therefore, the 1 ft. soil penetration depth assumed for calculation of accident consequences is conservative and bounding for all collapse accidents involving the roof of the 216-Z-9 Crib Trench.

B.3.1 Penetration Depth, Assumptions Optimized for Penetration

From SAND97-2426:

$D = (0.3)(S)(N)(W/A)^{0.7} \ln(1+2V^2 10^{-5})$ [ft.]

D	=	Depth of penetration in soil [ft.]
S	=	Penetrability of target, S-number [dimensionless]
N	=	Nose Performance Coefficient [dimensionless]
W	=	Weight of penetrator [lbs.]
A	=	Cross sectional area [in^2]
V	=	Impact velocity [fps]
V	=	$V_i^2 - 2g(y-y_0)^{0.5}$ = impact velocity [ft./s]
V_i	=	initial velocity [ft./sec]
g	=	Gravitational constant [$ft./s^2$]
y	=	Ground height [ft.]
y_0	=	Height of falling object [ft.]

Penetration depth, conservative assumptions optimized for penetration

S	=	20	(Ref. SAND97-2426, page 20, silt and clay)			
N	=	1.33	(Ref. WES-TR-78-4, Table 2, cone)			
W	=	110,000 [kg]	=	242,508 [lbs.]		
A	=	(167.2/10)[m^2]	=	16.72 [m^2]	=	25,916 [in^2]
V_i	=	0 [ft./sec]				
V	=	35.886 [ft./sec]				

Therefore

$D = (0.3)(20)(1.33)(242{,}508/25{,}916)^{0.7} \ln(1+2*35.886^2 10^{-5})$

$D = 0.908$ [ft.]

B.4 Basis for 216-Z-9 Crib Fire-Affected Soil MAR

The total radiological inventory in the soil in the 216-Z-9 Crib consists of approximately 48 kg (48,000 g) of the Pu isotope mixture defined in Table 3-1. This value was based on engineering judgment after the completion of mining activities, and can be found in reference document HNF-31792, *Characterization Information for the 216-Z-9 Crib at the PFP*.

B.4.1 Basis for 216-Z-9 Crib Fire-Affected Soil Depth

In CHPRC-02870, *Fire Hazards Analysis for 216-Z-9 Complex and Tank 241-Z-361*, Section 11.4.1 states:

> The potential for fire-based dispersal of radiological materials at the 216-Z-9 Complex would be fires that involve the 216-Z-9A glovebox or the HEPA filters in the associated ventilation system. The remainder of the contamination of the inhabitable buildings is relatively limited. The largest quantity of material is in the soils within the 216-Z-9 trench, which is only a minor dispersion in a fire environment since only surface quantities might be lofted in a fire plume.

Based on the facility inventory being a plume descending into the soil underneath the crib (Figures B-1 and B-2), it is not realistic to consider the entire inventory as being MAR. Since "surface quantities" is not quantitative, the MAR associated with soil fire events at 216-Z-9 is defined as the inventory contained in the top 1.27 cm (0.5 in.) of soil across the entire surface of the crib. The 1.27 cm (0.5 in.) fire-affected soil depth assumption is justified as follows.

This analysis assumes that the vehicle that falls into the 216-Z-9 Crib Trench with the collapsing roof has a fuel tank filled with 189.27 L (50 gal) of diesel fuel, that spills in its entirety, and spreads evenly across the entire surface of the Crib Trench floor.

From H-2-15492, *Architectural Waste Disposal Facility Details*, the trench floor is 9.14 m (30 ft) by 18.29 m (60 ft) (equals 167.2 m^2 [1,799.41 ft^2]).

The areal volume of the spilled diesel fuel pool is:

$$189.27 \text{ L} / 167.17 \text{ m}^2 = 1.13 \text{ L} / \text{m}^2$$

The density of diesel fuel is 0.832 kg / L, therefore the areal density of the spilled diesel fuel pool is:

$$(1.13 \text{ L} / \text{m}^2) * (0.832 \text{ kg} / \text{L}) = 0.94 \text{ kg} / \text{m}^2$$

Per *The SFPE Handbook of Fire Protection Engineering* (1st Edition), the burn rate of diesel fuel is 0.039 kg / m^2 / s. Therefore, the total burn time of the spilled diesel fuel pool on the 216-Z-9 Crib Trench floor is:

$$(0.94 \text{ kg} / \text{m}^2) / (0.039 \text{ kg} / \text{m}^2 / \text{s}) = 24.15 \text{ s}$$

Takeuchi, T., Tsuruda, T., Isizuka, S. and Hirano, T., "Burning Characteristics of a Combustible Liquid Soaked in Porous Beds" (See Appendix C.3) determined the affected depth of a bed of glass beads saturated with methanol. This is known as the "dry region boundary," as only the vaporized liquid fuel burns, not the fuel itself. As the burn time extends, the dry region boundary progresses deeper into the substrate into which the liquid fuel is soaked; there is some indication that the rate of progression is greater as particle size decreases.

In the Takeuchi, et. al., paper, the largest size of glass beads used as a substrate was 0.2 mm; Figure 7 of the paper shows that, at 600 seconds, the dry region boundary was 20 mm below the surface of the bead-particle bed. Scaling from these results to the burn time of the 216-Z-9 Crib Trench determined above gives:

$$24.15 \text{ s} / 600 \text{ s} = 0.04, \text{ and}$$

$$0.04 * 20 \text{ mm} = 0.805 \text{ mm}$$

Per ARH-2207 Section III "216-Z-9 Crib – A Description and History," the soil in the 216-Z-9 Crib Trench is classified as "medium to coarse grained sand." The "Pavement Interactive" website "ASTM Aggregate and Soil Terminology" states: "The basic reference for the Unified Soil Classification System is ASTM [American Society for Testing and Materials] D 2487. Terms include: . . . Medium Sand: Material passing a 2.00-mm sieve (No. 10) and retained on a 0.475-mm (No. 40) sieve."

As there may be a correlation of rate of dry zone penetration into the substrate with decreasing particle size, the 0.805 mm depth of flame-affected soil associated with the 0.2 mm beads from the Takeuchi, et. al., report is bounding for the 0.475 mm minimum size of the medium sand reported for the 216-Z-9 Crib Trench floor.

The 0.805 mm affected depth is 6.3 percent of the assumed 12.7 mm (0.5 in.) flame-affected soil depth in the 216-Z-9 Crib Trench fire release analysis, therefore remains conservative and bounding for even a great excess of spilled diesel fuel above the assumed 189.27 L (50 gal) diesel fuel spill.

B.4.2 Basis for MAR in 216-Z-9 Crib Fire-Affected Soil Depth

In addition, the area of the Crib Trench floor allows the total liters of soil per cm of soil depth in the crib to be calculated:

$$9.14 \text{ m} \times 18.29 \text{ m} = 167.2 \text{ m}^2$$

$$167.2 \text{ m}^2 \times 10{,}000 \text{ cm}^2/\text{m}^2 = 1{,}672{,}254.7 \text{ cm}^2$$

$$1{,}672{,}254.7 \text{ cm}^2 \times 1 \text{ cm} = 1{,}672{,}254.7 \text{ cm}^3$$

$$1{,}672{,}254.7 \text{ cm}^3 \times 0.001 \text{ L/cm}^3 = 1{,}672.3 \text{ L}$$

From the liters of soil per cm of soil depth, the total number of liters in the top 1.27 cm (0.5 in.) of soil is calculated:

$$1{,}672.3 \text{ L/cm} \times 1.27 \text{ cm} = 2{,}123.8 \text{ L}$$

RHO-LD-114, *Existing Data on the 216-Z Liquid Waste Sites* provides the following statement:

- Core samples from 1 to 8 ft below crib bottom had a concentration of about 0.1 g ^{239}Pu/L of soil

ARH-2915 confirms this value; however, a conservative value of 0.17 g ^{239}Pu/L of soil was modeled. This value was chosen as a review of Appendix B Sample data showed there were some samples around the 30 cm (almost 1 ft) level that were slightly higher, with 0.17 g ^{239}Pu/L being the highest. A concentration of 0.17 g ^{239}Pu/L of soil is expected to bound dose consequences associated with the 216-Z-9 Crib soil.

Using this information, multiplying the 2,123.8 L of soil with the 0.17 g ^{239}Pu/L of soil provides a value of 361.05 g of ^{239}Pu. Dividing 361.05 by 93.6 percent ^{239}Pu mass fraction (per Table 3-1) returns 385.7 g (0.386 kg) of the 216-Z-9 plutonium mixture.

Therefore, for fire events involving the 216-Z-9 crib soil, the MAR is stated as 386 g of the total 48,000 g inventory.

B.5 Figures

The following images provided in 2017 by the Soil and Groundwater Remediation Project depict the contamination plume as it exists under the 216-Z-9 Crib Trench.

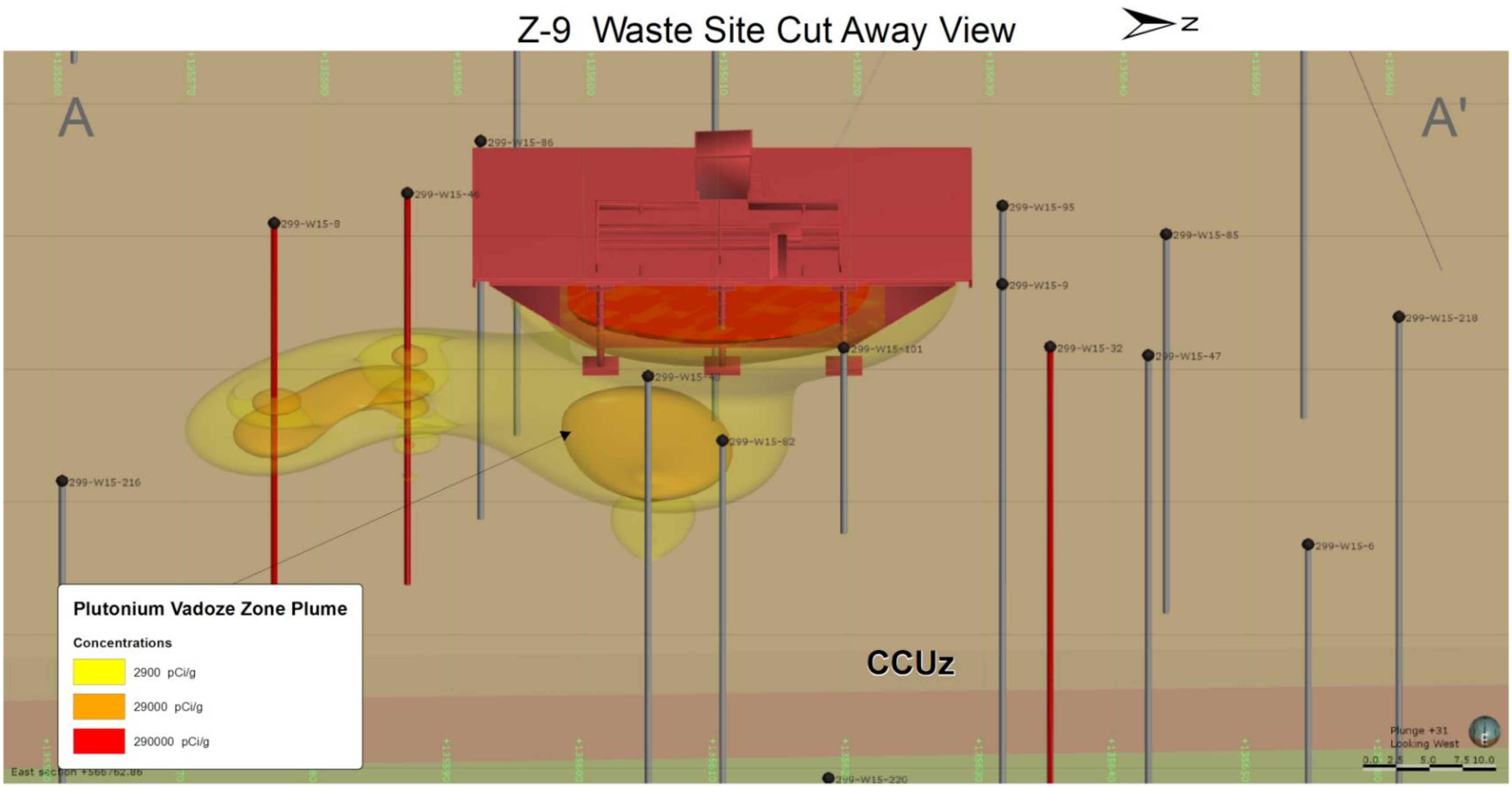
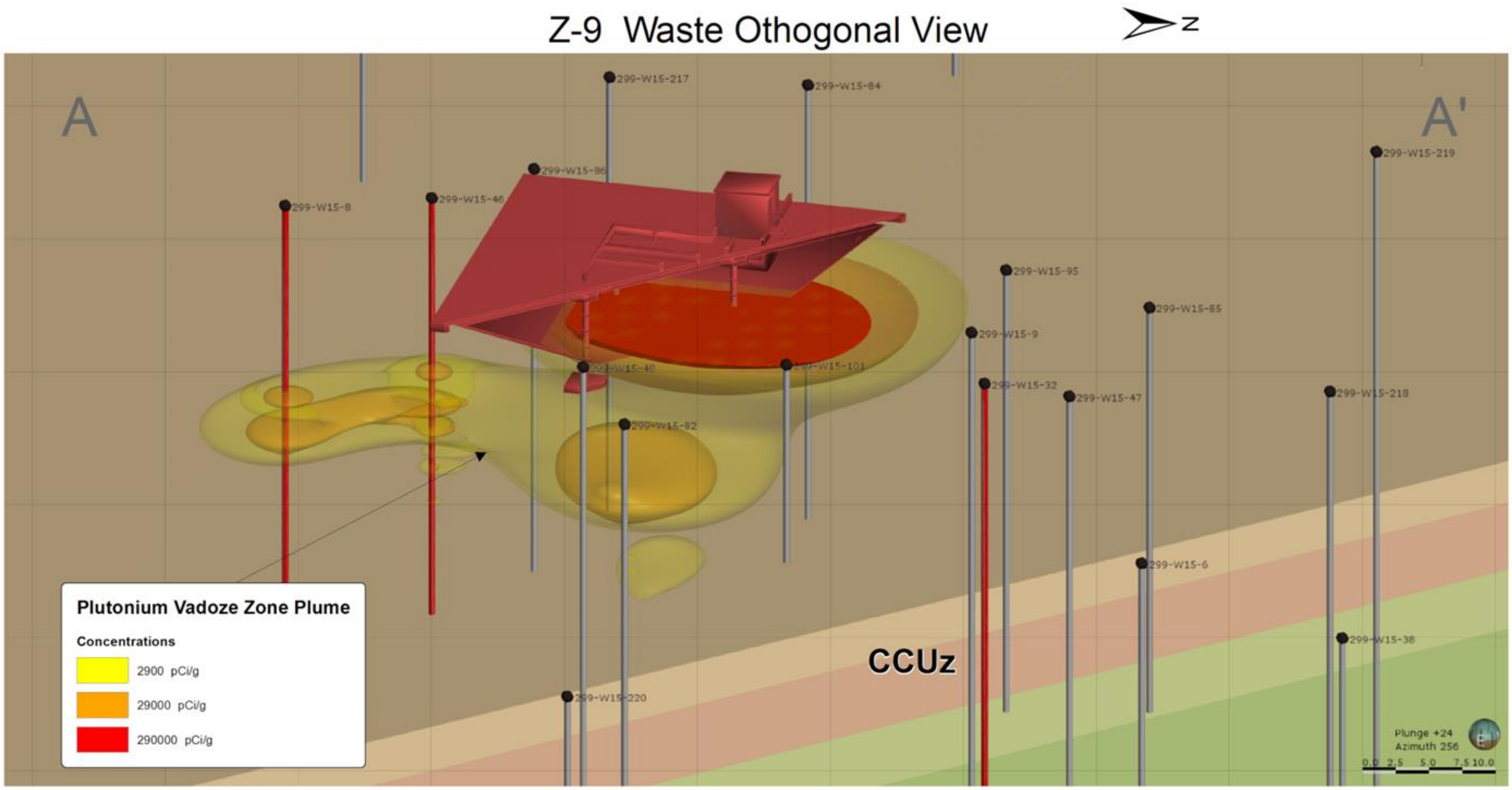


Figure B-1. Z-9 Waste Site Cut Away View



(Note: Misspelling is in the source graphic).

Figure B-2. Z-9 Waste Site Orthogonal View

B.6 References

ARH-2207, 1971, *216-Z-9 Crib History and Safety Analysis,* Rev. 0, Atlantic Richfield Hanford Company, Richland, Washington.

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Bernard, Robert S., 1978, U.S. Army Technical Report S-78-4, *Depth and Motion Prediction for Earth Penetrators,* U.S. Army Engineer Waterways Experiment Station Soils and Pavements Laboratory, Vicksburg, Mississippi.

CHPRC-02870, 2016, *Fire Hazards Analysis for 216-Z-9 Complex and Tank 241-Z-361*, Rev. 1, CH2M HILL Plateau Remediation Company, Richland, Washington.

DOE-HDBK-3010-94, 1994, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities,* U.S. Department of Energy, Washington, D.C.

DOE-STD-1120-2016, *Preparation of Documented Safety Analysis for Decommissioning and Environmental Restoration Activities,* U.S. Department of Energy, Washington, D.C.

H-2-15492, 1953, *Architectural Waste Disposal Facility Details*, Rev. 0, General Electric Company, Richland, Washington.

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RHO-LD-114, 1981, *Existing Data on the 216-Z Liquid Waste Sites,* Rockwell Hanford Operations, Richland, Washington.

SAND97-2426, 1997, *Penetration Equations*, Sandia National Laboratories, Albuquerque, New Mexico.

Takeuchi, T., Tsuruda, T., Isizuka, S. and Hirano, T., 1991. "Burning Characteristics of a Combustible Liquid Soaked in Porous Beds." *Fire Safety Science – Proceedings of the Third International Symposium*, International Association for Fire Safety Science, London, England.

Appendix C

Reference Documents

Appendix C
Reference Documents

C.1 Memorandum M2100-07-044 "NDA Results for 216-Z-9A Glovebox"

Fluor Hanford
P. O. Box 1000
Richland, WA 99352

FLUOR

Memorandum M2100-07-044

To:	C. S. Sutter	T4-32	Date:	March 29, 2007
From:	B. D. Keele B.D. Keele Non Destructive Assay	T4-20	Telephone:	373-4690
cc:	E. W. Curfman	T5-05	M. T. Jansky	H8-40
	D. G. Erickson	T5-54	H. R. Risenmay	T4-32
	B. E. Hey	T4-32	T. L. Welsh	L4-20
	A. M. Hopkins	H8-12	Letterbook	

Subject: NDA RESULTS FOR 216-Z-9A GLOVEBOX

This letter and attachments reports results for 216-Z-9A glovebox. NDA measurements were performed using the In-Situ Object Counting System (ISOCS) software to quantify the contained Pu-239 activity. Further NDA measurements were performed using the Multi Group Analysis (MGA++) software to quantify the isotopic ratios to account for the contained transuranic isotopes not directly quantified by ISOCS. Isotopic results are in table 1 and ISOCS results are attached.

ISOCS measurements were performed on February 14, 2007 by D. R. Sorenson and D. L. Sorenson using high purity germanium detector 8096 in accordance with ZA-503-303, *In-Situ Object Counting System (ISOCS) Gamma Spectroscopy Routine Operations*. Data was reduced by J. Pestovich Jr in accordance with HNF-22051, *Total Measurement Uncertainty Calculation Reference for ISOCS Gamma-Ray Spectroscopy NDA Measurements.* Measurements were reviewed by J. A. Pestovich and B.D. Keele.

A single MGA measurement was taken starting on March 15, 2007 and ending on March 16, 2007 by K. T. Brasel and D. L. Sorenson using high purity germanium detector 862A in accordance with ZA-948-329, *Plutonium Isotopic System Operation with ORTEC Analyzers.* Measurements were reviewed by B. D. Keele.

The ISOCS detector was calibrated by Canberra Industries. Validation of the calibration was performed by the Analytical Laboratories and is documented on letter M2610-05-066, *Validation of ISOCS Detector 8096*, from B. D. Keele to L. M. Sheehan on May 24, 2005. A calibration verification count was performed prior to and upon completion of the measurement in accordance with ZA-503-303, *In-Situ Object Counting System (ISOCS) Gamma Spectroscopy Routine Operations,* and ZQ-150-304, *Laboratory Quality Control Procedure.*

MGA determines an "intrinsic efficiency function" for each spectrum that includes absorption of the emitted gamma radiation by the plutonium and other absorbers and detector efficiency. A system calibration is not required. Validation of the system operation was performed by the Analytical Laboratories and is documented on letter M2F00-04-070, *Qualification of Multi Group Analysis (MGA++) Software ORTEC Version 1.6*, from B.D. Keele to T.L. Welsh on August 8, 2004. A calibration verification count was performed prior to and upon completion of the measurement in accordance with ZQ-948-304, *Quality Control of Gamma Isotopic Systems,* and ZQ-150-304, *Laboratory Quality Control Procedure.*

The ISOCS measurements were performed of the glovebox from outside of the facility. Measurement locations were selected so that the assay results would be similar regardless of where the actual deposit was located within the glovebox. The assay value is representative of the actual plutonium content. The analysis of the data is such that the uncertainty and upper limit (criticality value) is bounding of the contents, regardless of the actual location of the plutonium deposit within the glovebox. The locations were selected based on information provided by H. R. Risenmay and derived from engineering drawings. The 216-Z-9A glovebox was determined to be 12 ft long, 38 inches wide, with the top at 9 ft 11 inches above the floor. A foundation holds the bottom of the glovebox 10 inches above the floor. The glovebox runs northeast to southwest with the southwest end of the glovebox being 3 ft 7 inches inside the southwest end of the building. The building walls were measured to be 3" thick hollow core steel walls. The measurements were taken at a distance from the detector to the glovebox wall of 101 inches. The attached photographs depict the location of the glovebox within the building. The white stickers indicate the aim point of the ISOCS measurements. Note that on the southeastern wall, the upper locations stickers are near a steam line.

The MGA measurement was performed on contact with the building at the lower left assay point on the northwestern wall of the facility. The location was near at the ISOCS measurement location containing the highest amount of activity.

The glovebox weight was estimated by D. W. Jeppson on March 22, 2007 and reviewed by S. A. Christensen on March 22, 2007.

Quality assurance documents which pertain to these measurements include: HNF-14055, PFP *Analytical Laboratory Quality Assurance Plan*; FSP-PFP-5-8, Vol. 2 Chapter 15.1, *Quality Assurance Program Plan*; and HNF-RD-10484 Rev. 2, *Nondestructive Assay Management Program*.

Please contact my office if you have any questions concerning these measurements.

Table 1. Glovebox isotopic fraction.

Isotope	Mass fraction relative to total plutonium (%)	1 σ uncertainty, (%)
Pu-238	0.00602	21.82
Pu-239	94.21344	0.12
Pu-240	5.70819	1.98
Pu-241	0.04940	2.87
Pu-242 (estimated)	0.02294	(10)
Am-241	0.36824	1.17

ISOCS Item Report

Item ID:	Z-9 GB
Date Assayed:	2/14/07
Item Mass, kg:	1,956
Isotopic Source:	Measured MGA

Isotope	Assigned Mass Fraction (% of tot-Pu)	Activity (uCi)	Code*	Total Uncrtnty (uCi)	Upper Limit (uCi)	Isotope Mass (g)	Total Uncrtnty (g)	Upper Limit (g)
Pu-238	0.0060%	4.91E+03	I	1.51E+03	7.93E+03	2.87E-04	8.82E-05	4.63E-04
Pu-239	94.2134%	2.79E+05	M	8.90E+04	4.56E+05	4.49E+00	1.43E+00	7.36E+00
Pu-240	5.7082%	6.17E+04	I	1.90E+04	9.97E+04	2.72E-01	8.36E-02	4.39E-01
Pu-242	0.0229%	4.33E+00	I	1.33E+00	6.99E+00	1.09E-03	3.36E-04	1.76E-03
Np-237								
Am-241	0.3682%	6.02E+04	I	1.85E+04	9.73E+04	1.75E-02	5.40E-03	2.83E-02
Other TRU								
U-235								
U-238								
Pu-241	0.0494%	2.43E+05	I	7.48E+04	3.93E+05	2.35E-03	7.23E-04	3.80E-03
Other								

* Code
M = Reported activity directly measured,
I = Reported activity infered from measured Pu-239 and isotopic abundance.

Total Pu, g**	4.765E+00
Total Uncertainty, g	1.522E+00
Upper Limit, g Pu	7.810E+00

** Based on Pu-239 and isotopic fraction of Pu-239

Total TRU Activity, uCi	4.05E+05
Total Uncertainty, uCi	1.27E+05
Upper Limit, uCi	6.60E+05

TRU Specific Activity, nCi/g	2.07E+02
Total Uncertainty, nCi/g	6.50E+01
Upper Limit, nCi/g	3.37E+02

Total Activity (TRU + non-TRU), uCi	6.49E+05
Total Uncertainty, uCi	2.01E+05
Upper Limit, uCi	1.05E+06

Calculated [signature] Date 3/29/07

Reviewed [signature] Date 3/29/07

PFP ISOCS V1.00.xlt

C.2 Memorandum M2410-07-072, "NDA Results for Z-9 Duct System"

Fluor Hanford
P. O. Box 1000
Richland, WA 99352

FLUOR

Memorandum

M2410-07-072

To:	C. S. Sutter	T4-32	Date:	August 21, 2007
From:	B. D. Keele B.D. Keele Non Destructive Assay	T5-20	Telephone:	373-4690
cc:	S. A. Christensen E. W. Curfman D. G. Erickson B. E. Hey	T5-55 T5-05 T5-54 T4-32	A. M. Hopkins H. R. Risenmay T. L. Welsh Letterbook	H8-12 T4-32 L4-20

Subject: NDA RESULTS FOR Z-9 DUCT SYSTEM

This letter reports radionuclide values for the 216-Z-9A ventilation duct system. Measurements were performed from June 14, 2007 thru June 26, 2007 by D. L. Sorenson and T. B. Bates using high purity germanium detector 8096 in accordance with ZA-503-303, *In-Situ Object Counting System (ISOCS) Gamma Spectroscopy Routine Operations*. Data was reduced by J.A. Pestovich in accordance with HNF-22051, *Total Measurement Uncertainty Calculation Reference for ISOCS Gamma-Ray Spectroscopy NDA Measurements*. Measurements were reviewed by J. Pestovich Jr. and B.D. Keele.

The measurements were performed on the HEPA filter housings, exhaust fans and sections of the duct. The attached sketch depicts the items assayed and measurement locations.

Measurements of the HEPA filter housings (K1-9-1, K1-9-2, K1-10-1 & K1-10-2) and exhaust fans (K1-8-1 & K1-8-2) were taken at locations selected such that the assay results would be similar regardless of where the actual deposit is located within the HEPA filter or housing. The assay value is representative of the actual plutonium content. The analysis of the data is such that the uncertainty and criticality value is bounding of the actual contents regardless of the actual location of the plutonium deposit within the HEPA filter housings and exhaust fans.

The ventilation duct was considered to be comprised of 4 sections: Section 1 Duct (12.75" Diameter Duct from Crib to K1-10 HEPA Housings), Section 2 Duct (12.75" Diameter Duct from K1-10 HEPA Housings to K1-9 HEPA Housings), Section 3 Duct (18" Diameter Duct from K1-9 HEPA Housings to K1-8 Fans & 18" Diameter Stack downstream from K1-8 Fans), and Section 4 (16" Diameter & Square Duct from K1-9 HEPA Housing to Roof). Measurements were also performed on a ventilation duct drain line (K1-10 HEPA Housings to Crib). Measurement locations were selected to represent areas that are thought to have higher levels of holdup. These measurement shots were assumed to represent the entire length of duct, therefore the results may be biased high.

A positive indication of contained activity was observed in two HEPA filter housings (K1-10-1 & K1-10-2), one section of ventilation duct (Section 1 Duct (12.75" Diameter Duct from Crib to K1-10 HEPA Housings), and the drain line (K1-10 HEPA Housings to Crib).

A positive indication of contained activity was not observed in any of the other HEPA filter housings, exhaust fans or duct measurements. Therefore, no further attempts were made to perform assay measurements along the entire length of duct.

In all cases, Pu-239 was measured directly by an ISOCS NDA measurement. The other isotopes listed were inferred from the isotopic distribution. The isotope fractions are based on a measurement of the 216-Z-9A Glovebox and previously reported on letter M2100-07-044, *NDA Results for 216-Z-9A Glovebox*, from B. D. Keele to C. S. Sutter on March 29. 2007. The isotopic fractions are listed in the attached Table 1.

The 216-Z-9A ventilation duct system weights and lengths were calculated by S. A. Christensen on and reviewed by D. W. Jeppson on August 3, 2007. Item weights used in these calculations for the TRU specific activity calculation are in the attached Table 2.

The radioactivity content for the ventilation duct sections, drain line, HEPA filter housings and exhaust fans are listed in the attached Table 3.

The ISOCS detector was calibrated by Canberra Industries. Validation of the calibration was performed by the Analytical Laboratories and is documented on letter M2610-05-066, *Validation of ISOCS Detector 8096*, from B. D. Keele to L. M. Sheehan on May 24, 2005. A calibration verification count was performed prior to and upon completion of the measurement in accordance with ZA-503-303, *In-Situ Object Counting System (ISOCS) Gamma Spectroscopy Routine Operations,* and ZQ-150-301, *Laboratory Quality Control Procedure.*

Quality assurance documents which pertain to these measurements include: HNF-14055, PFP *Analytical Laboratory Quality Assurance Plan*; FSP-PFP-5-8, Vol. 2 Chapter 15.1, *Quality Assurance Program Plan*; and HNF-RD-10484 Rev. 2, *Nondestructive Assay Management Program*.

Please contact my office if you have any questions concerning these measurements.

Date: August 21, 2007
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Table 1. Isotopic fraction.

Isotope	Mass fraction relative to total plutonium (%)	1 σ uncertainty, (%)
Pu-238	0.00602	21.82
Pu-239	94.21344	0.12
Pu-240	5.70819	1.98
Pu-241	0.04940	2.87
Pu-242 (estimated)	0.02294	(10)
Am-241	0.36824	1.17

Table 2. Weight basis for calculations:

	Weight
12.75" Diameter Duct (Section 1, Crib to K1-10 HEPA Housings)	12.12 lbs/ft
Drain Line (K1-10 HEPA Housings to Crib)	0.84 lbs/ft
K1-10-1 & K1-10-2 HEPA Housings	420 lbs each
12.75" Diameter Duct (Section 2, K1-10 to K1-9 HEPA Housings)	10.65 lbs/ft
K1-9-1 & K1-9-2 HEPA Housings	1140 lbs each
18" Diameter Duct (Section 3, K1-9 HEPA Housings to K1-8 Fans & Stack Downstream K1-8 Fans)	19.77 lbs/ft
K1-8-1 & K1-8-2 Fans	250 lbs each
16" Diameter & Square Duct (Section 4, K1-9 HEPA Housings to Roof)	15.16 lbs/ft

Table 3. Contained radioactivity.

Description		Pu-238	Pu-239	Pu-240	Pu-242	Am-241	Pu-241	Total TRU Activity	Total Activity	Total Pu	TRU Specific Activity
12.75" Diameter Duct (Section 1, Crib to K1-10 HEPA Housings)	Value	2.33E+01	1.32E+02	2.93E+02	2.05E-02	2.41E+02	1.15E+03	1.88E+03	3.03E+03	2.260E-02	3.42E+02
	1σ	6.93E+00	4.29E+02	5.95E+01	4.63E-03	8.97E+01	2.36E+02	5.84E+02	8.38E+02	7.336E-03	1.06E+02
	UL	3.72E+01	2.18E+03	4.12E+02	2.98E-02	4.20E+02	1.63E+03	3.05E+03	4.71E+03	3.727E-02	5.54E+02
	Units	uCi/ft	uCi/ft	uCi/ft	uCi/ft	uCi/ft	uCi/ft	uCi/ft	uCi/ft	g/ft	nCi/g
Duct Section 1 Total (33 ft)	Value	7.69E+02	4.36E+04	9.66E+03	6.77E-01	7.95E+03	3.81E+04	6.20E+04	1.00E+05	7.46E-01	3.42E+02
	1σ	2.29E+02	1.42E+04	1.96E+03	1.53E-01	2.96E+03	7.78E+03	1.93E+04	2.76E+04	2.42E-01	1.06E+02
	UL	1.23E+03	7.19E+04	1.36E+04	9.83E-01	1.39E+04	5.36E+04	1.00E+05	1.55E+05	1.23E+00	5.54E+02
	Units	uCi	uCi	uCi	uCi	uCi	uCi	uCi	uCi	g	nCi/g
Drain Line (K1-10 HEPA Housings to Crib)	Value	7.62E-01	4.32E+01	9.57E+00	6.71E-04	3.25E+02	3.77E+01	3.79E+02	4.16E+02	7.387E-04	9.94E+02
	1σ	1.94E-01	1.94E+01	1.26E+00	1.10E-04	4.85E+01	5.04E+00	5.79E+01	6.22E+01	3.318E-04	1.52E+02
	UL	1.15E+00	8.20E+01	1.21E+01	8.92E-04	4.22E+02	4.78E+01	4.94E+02	5.41E+02	1.402E-03	1.30E+03
	Units	uCi/ft	uCi/ft	uCi/ft	uCi/ft	uCi/ft	uCi/ft	uCi/ft	uCi/ft	g/ft	nCi/g
Drain Line Total (25 ft)	Value	1.90E+01	1.08E+03	2.39E+02	1.68E-02	8.13E+03	9.43E+02	9.47E+03	1.04E+04	1.85E-02	9.94E+02
	1σ	4.84E+00	4.85E+02	3.16E+01	2.76E-03	1.21E+03	1.26E+02	1.45E+03	1.56E+03	8.29E-03	1.52E+02
	UL	2.87E+01	2.05E+03	3.02E+02	2.23E-02	1.06E+04	1.19E+03	1.24E+04	1.35E+04	3.51E-02	1.30E+03
	Units	uCi	uCi	uCi	uCi	uCi	uCi	uCi	uCi	g	nCi/g
K1-10-1 HEPA and Housing	Value	1.17E+02	6.65E+03	1.47E+03	1.03E-01	1.31E+03	5.81E+03	9.55E+03	1.54E+04	1.14E-01	5.01E+01
	1σ	5.44E+01	5.02E+03	6.04E+02	4.36E-02	1.09E+03	2.38E+03	7.36E+03	1.05E+04	8.60E-02	3.86E+01
	UL	2.26E+02	1.67E+04	2.68E+03	1.90E-01	3.50E+03	1.06E+04	2.43E+04	3.64E+04	2.86E-01	1.27E+02
	Units	uCi	uCi	uCi	uCi	uCi	uCi	uCi	uCi	g	nCi/g
K1-10-2 HEPA and Housing	Value	2.10E+02	1.19E+04	2.64E+03	1.85E-01	1.37E+03	1.04E+04	1.61E+04	2.65E+04	2.04E-01	8.46E+01
	1σ	9.74E+01	7.90E+03	1.08E+03	7.80E-02	8.78E+02	4.27E+03	1.19E+04	1.77E+04	1.35E-01	6.23E+01
	UL	4.05E+02	2.77E+04	4.80E+03	3.41E-01	3.13E+03	1.89E+04	3.98E+04	6.20E+04	4.74E-01	2.09E+02
	Units	uCi	uCi	uCi	uCi	uCi	uCi	uCi	uCi	g	nCi/g
12.75" Diameter Duct (Section 2, K1-10 to K1-9 HEPA Housings)	Value	<9.39E-01	<5.32E+01	<1.18E+01	<8.27E-04	<1.15E+01	<4.65E+01	<7.74E+01	<1.24E+02	<9.103E-04	<1.60E+01
	1σ	3.12E-01	1.33E+01	2.96E+00	2.23E-04	2.89E+00	1.17E+01	1.95E+01	3.12E+01	2.281E-04	4.03E+00
	UL	<1.56E+00	<7.99E+01	<1.77E+01	<1.27E-03	<1.73E+01	<6.99E+01	<1.16E+02	<1.86E+02	<1.366E-03	<2.41E+01
	Units	uCi/ft	uCi/ft	uCi/ft	uCi/ft	uCi/ft	uCi/ft	uCi/ft	uCi/ft	g/ft	nCi/g
Duct Section 2 Total[1] (31 ft)	Value	<2.91E+01	<1.65E+03	<3.66E+02	<2.56E-02	<3.57E+02	<1.44E+03	<2.40E+03	<3.84E+03	<2.82E-02	<1.60E+01
	1σ	9.67E+00	4.13E+02	9.19E+01	6.92E-03	8.97E+01	3.63E+02	6.03E+02	9.66E+02	7.07E-03	4.03E+00
	UL	<4.84E+01	<2.48E+03	<5.49E+02	<3.95E-02	<5.36E+02	<2.17E+03	<3.61E+03	<5.77E+03	<4.24E-02	<2.41E+01
	Units	uCi	uCi	uCi	uCi	uCi	uCi	uCi	uCi	g	nCi/g

Date: August 21, 2007
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M2410-07-072

Description		Pu-238	Pu-239	Pu-240	Pu-242	Am-241	Pu-241	Total TRU Activity	Total Activity	Total Pu	TRU Specific Activity
K1-9-1 HEPA and Housing[1]	Value	<3.01E+01	<1.71E+03	<3.78E+02	<2.65E-02	<3.69E+02	<1.49E+03	<2.48E+03	<3.98E+03	<2.92E-02	<4.80E+00
	1σ	1.99E+01	1.09E+03	2.36E+02	1.67E-02	2.30E+02	9.29E+02	1.56E+03	2.49E+03	1.86E-02	3.03E+00
	UL	<6.98E+01	<3.88E+03	<8.50E+02	<6.00E-02	<8.29E+02	<3.35E+03	<5.61E+03	<8.95E+03	<6.64E-02	<1.09E+01
	Units	uCi	uCi	uCi	uCi	uCi	uCi	uCi	uCi	g	nCi/g
K1-9-2 HEPA and Housing[1]	Value	<2.80E+01	<1.59E+03	<3.52E+02	<2.47E-02	<3.44E+02	<1.39E+03	<2.31E+03	<3.70E+03	<2.72E-02	<4.47E+00
	1σ	1.85E+01	1.02E+03	2.19E+02	1.56E-02	2.14E+02	8.65E+02	1.46E+03	2.32E+03	1.75E-02	2.83E+00
	UL	<6.50E+01	<3.63E+03	<7.91E+02	<5.58E-02	<7.71E+02	<3.12E+03	<5.24E+03	<8.34E+03	<6.21E-02	<1.01E+01
	Units	uCi	uCi	uCi	uCi	uCi	uCi	uCi	uCi	g	nCi/g
18" Diameter Duct (Section 3, K1-9 HEPA Housings to K1-8 Fans & Stack Downstream K1-8 Fans)	Value	<7.16E-01	<4.06E+01	<8.99E+00	<6.31E-04	<8.77E+00	<3.54E+01	<5.91E+01	<9.45E+01	<6.942E-04	<6.61E+00
	1σ	2.38E-01	1.02E+01	2.26E+00	1.70E-04	2.21E+00	8.94E+00	1.48E+01	2.38E+01	1.739E-04	1.66E+00
	UL	<1.19E+00	<6.09E+01	<1.35E+01	<9.71E-04	<1.32E+01	<5.33E+01	<8.87E+01	<1.42E+02	<1.042E-03	<9.93E+00
	Units	uCi/ft	uCi/ft	uCi/ft	uCi/ft	uCi/ft	uCi/ft	uCi/ft	uCi/ft	g/ft	nCi/g
Duct Section 3 Total[1] (43 ft)	Value	<3.08E+01	<1.74E+03	<3.87E+02	<2.71E-02	<3.77E+02	<1.52E+03	<2.54E+03	<4.06E+03	<2.985E-02	<6.61E+00
	1σ	1.02E+01	4.37E+02	9.72E+01	7.32E-03	9.48E+01	3.84E+02	6.38E+02	1.02E+03	7.479E-03	1.66E+00
	UL	<5.12E+01	<2.62E+03	<5.81E+02	<4.17E-02	<5.67E+02	<2.29E+03	<3.82E+03	<6.11E+03	<4.481E-02	<9.93E+00
	Units	uCi	uCi	uCi	uCi	uCi	uCi	uCi	uCi	g	nCi/g
16" Diameter & Square Duct (Section 4, K1-9 HEPA Housings to Roof)	Value	<8.14E-01	<4.61E+01	<1.02E+01	<7.17E-04	<9.98E+00	<4.03E+01	<6.71E+01	<1.07E+02	<7.893E-04	<9.77E+00
	1σ	2.70E-01	1.39E+01	2.57E+00	1.93E-04	2.51E+00	1.02E+01	1.85E+01	2.81E+01	2.376E-04	2.70E+00
	UL	<1.35E+00	<7.39E+01	<1.54E+01	<1.10E-03	<1.50E+01	<6.06E+01	<1.04E+02	<1.64E+02	<1.264E-03	<1.52E+01
	Units	uCi/ft	uCi/ft	uCi/ft	uCi/ft	uCi/ft	uCi/ft	uCi/ft	uCi/ft	g/ft	nCi/g
Duct Section 4 Total[1] (95 ft)	Value	<7.73E+01	<4.38E+03	<9.71E+02	<6.81E-02	<9.48E+02	<3.83E+03	<6.38E+03	<1.02E+04	<7.498E-02	<9.77E+00
	1σ	2.57E+01	1.32E+03	2.44E+02	1.84E-02	2.38E+02	9.66E+02	1.76E+03	2.67E+03	2.257E-02	2.70E+00
	UL	<1.29E+02	<7.02E+03	<1.46E+03	<1.05E-01	<1.42E+03	<5.76E+03	<9.90E+03	<1.55E+04	<1.201E-01	<1.52E+01
	Units	uCi	uCi	uCi	uCi	uCi	uCi	uCi	uCi	g	nCi/g
K1-8-1 Fan	Value	<4.28E+00	<2.43E+02	<5.38E+01	<3.77E-03	<5.25E+01	<2.12E+02	<3.53E+02	<5.65E+02	<4.15E-03	<3.12E+00
	1σ	1.82E+00	8.82E+01	1.96E+01	1.42E-03	1.91E+01	7.73E+01	1.29E+02	2.06E+02	1.51E-03	1.13E+00
	UL	<7.91E+00	<4.19E+02	<9.30E+01	<6.62E-03	<9.07E+01	<3.67E+02	<6.11E+02	<9.77E+02	<7.17E-03	<5.38E+00
	Units	uCi	uCi	uCi	uCi	uCi	uCi	uCi	uCi	g	nCi/g

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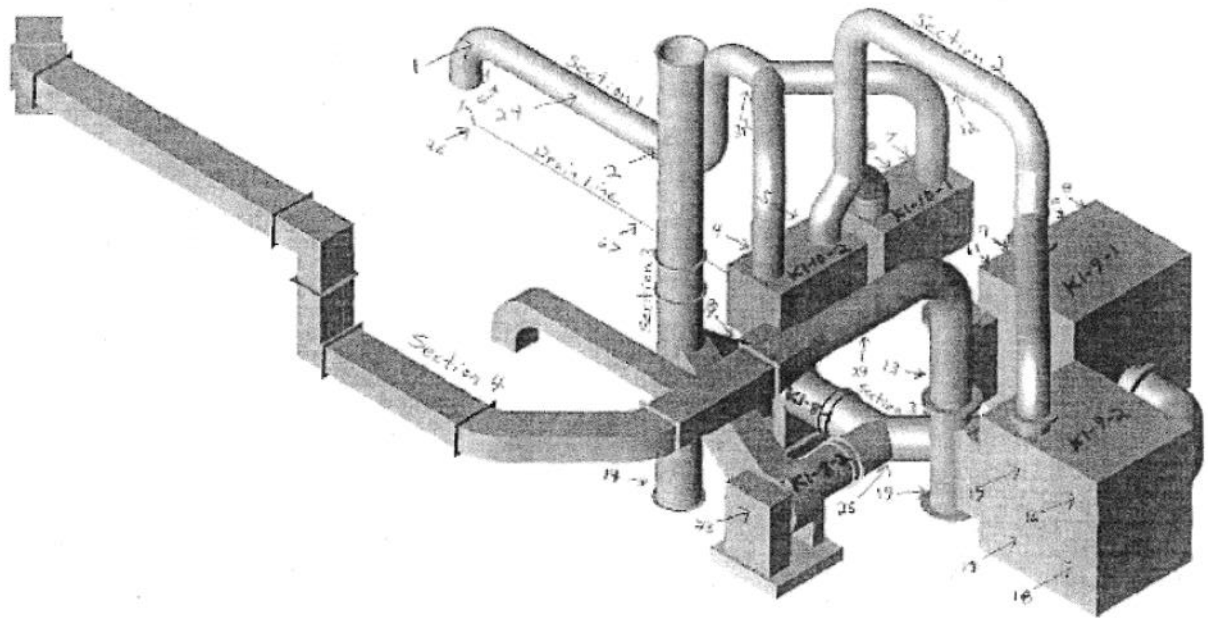
Description		Pu-238	Pu-239	Pu-240	Pu-242	Am-241	Pu-241	Total TRU Activity	Total Activity	Total Pu	TRU Specific Activity
K1-8-2 Fan	Value	<2.47E+00	<1.40E+02	<3.11E+01	<2.18E-03	<3.03E+01	<1.23E+02	<2.04E+02	<3.27E+02	<2.40E-03	<1.80E+00
	1σ	1.05E+00	5.10E+01	1.13E+01	8.22E-04	1.10E+01	4.47E+01	7.43E+01	1.19E+02	8.72E-04	6.55E-01
	UL	<4.57E+00	<2.42E+02	<5.37E+01	<3.82E-03	<5.24E+01	<2.12E+02	<3.53E+02	<5.65E+02	<4.14E-03	<3.11E+00
	Units	uCi	uCi	uCi	uCi	uCi	uCi	uCi	uCi	g	nCi/g

Table Note 1. MDA values and their associated uncertainties are included in the average as if the value was actually detected. Thus, the reported average and system total is overestimated. The reported total uncertainty may be underestimated or overestimated, depending on the true activity value of the measurements reported as a MDA value. Calculations show that the upper limit is conservatively maximized with the methodology used in this letter.

Z-9 Ventilation Duct + Drain Line (ISOCS Shot Locations)



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Checked by: D. Jeppsen

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Z-9 Section Weights	Weight	Length
trench outlet to primary filter inlet excluding valves	400 lb	33 ft
primary filter housing including filter and inlet and outlet isolation valves	420 lb each	-
primary filter housings to secondary filter housings excluding valves	330 lb	31 ft
secondary filter housing including filters and isolation valves	1140 lb each	-
secondary filter outlet to fan inlet	370 lb	21 ft
fans	250 lb each	-
stack	480 lb	22 ft
building to secondary filter inlet excluding valves	1440 lb	95 ft
damper between filter housings	24 lb	-

Prepared By: S. Christensen [signature] 8/3/07
Checked By: D. Jeppsen David W. Jeppsen 8-3-07

Z-9 Ventilation Duct Weight Calculation

Trench to Primary Filter		
duct diameter	12.75 in	
perimeter	40.06 in	
wall thickness - 16 ga	0.06 in	
length	33 ft	270 lb
angle qty	18	73 lb
1/2 pipe length	25 ft	
weight	0.85 lb/ft	21 lb
support quantity	4	
weight	10 lb	40 lb
Total weight		404 lb
Primary Filter to Secondary Filter		
duct diameter	12.75 in	
perimeter	40.06 in	
wall thickness - 16 ga	0.06 in	
length	31 ft	253 lb
angle qty	16	65 lb
support quantity	1	
weight	20 lb	20 lb
weight		338 lb
Secondary Filter to Fan		
duct diameter	18 in	
perimeter	56.55 in	
wall thickness - 20 ga	0.036 in	
length	21 ft	145 lb
angle qty	22	127 lb
damper	2	
weight	35 lb	70 lb
support quantity	3	
weight	10 lb	30 lb
weight		372 lb

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Building to Filters		
length	35 ft	
perimeter - 18x12	60 in	
thickness - 20 ga	0.036 in	257 lb
angle qty	25	153 lb
length	15 ft	
perimeter - 13x8	42 in	
thickness - 20 ga	0.036 in	77 lb
angle qty	10	42 lb
length	35 ft	
perimeter - 16" diameter	50.3 in	
thickness - 20 ga	0.036 in	215 lb
angle qty	13	66 lb
filter inlet valves - 2@16" dia	520 lb	520 lb
inlet plenums	3264 in^2	
thickness - 16 ga	0.06 in	111 lb
		1441 lb
Fan		
weight - fan & motor only	250 lb	250 lb
		250 lb
Stack		
length	22 ft	
diameter	18.00 in	
perimeter	56.55 in	
thickness - 18 ga	0.048 in	203
angle qty	10	57
length	6 ft	
perimeter	64 in	
thickness - 10 ga	0.135 in	176
angle qty	8	52
		488
Damper - 12'x12'x12'		
area	576 in^2	
thickness	0.036 in	5
flanges	9.8 lb	10
shafts	1.2 lb	1
damper blades	3.1 lb	3
misc	5 lb	5
		24 lb

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Prepared By: S. Christensen A. [signature] 8/3/07 Page 3 of 3
Checked By: D. Jeppsen David W. Jeppson 8-3-09 8/3/2007

Primary Filter Box			
area - approx. 2'x2'x4'	42 ft^2		
thickness - 18 ga	0.048 in	82	
angle	42 ft	51	
filters - qty 1	30 lb	30	
isolation valves - 2@12" dia	260 lb	260	
		423	

Secondary Filter Box			
area - approx. 5'x5'x4'	140 ft^2		
thickness - 18 ga	0.048 in	274	
angle - 2x2x1/8	150 ft	247	
filters - qty 4	30 lb	120	
isolation valve - 1@12" dia	130 lb	130	
isolation valves - 1@18" dia	375 lb	375	
		1146	lb

Reference Information	
density of steel	0.284 lb/in^3
1 1/2 x 1 1/2 x 1/8 angle	1.227 lb/ft
2 x 2 x 1/8 angle	1.653 lb/ft
12" valve	130 lb
16" valve	260 lb
18" valve	375 lb

C.3 Burning Characteristics of a Combustible Liquid Soaked in Porous Beds

Burning Characteristics of a Combustible Liquid Soaked in Porous Beds

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ABSTRACT

An experimental study has been made on the burning characteristics of liquid methanol soaked in porous beds of glass beads. In order to study the effects of the soil properties on the burning characteristics, experiments were carried out for several bead diameters. The consumption rates of methanol and the temperature profiles in the porous beds were measured.

The results showed that the total weight of the methanol consumed was only about half of the initial weight and the consumption rate decreased with time. The total weight of the consumed methanol and the consumption rate of methanol increased with decreasing bead diameter.

The temperature profiles indicated that the dry region in a porous bed, in which only methanol vapor was assumed to exist, expanded downward with time. The discrepancy between the lower boundary of the dry region and the liquid level evaluated on the basis of methanol consumption for small beads suggested that the liquid moved upward by a capillary force.

A simplified heat transfer model was proposed for large beads and the predicted results agreed qualitatively with the experimental ones. The consumption rate on large beads bed was inferred to be controlled mainly by the heat transfer in the porous bed.

KEY WORDS: liquid combustion, burning characteristics, fuel soaked porous bed.

INTRODUCTION

When a storage tank of liquid fuel is accidentally damaged or corroded, the liquid fuel leaks from the tank and soaks into soil. If it is ignited, a fire will occur. The scale and intensity of the fire depend not only on the amount of soaked liquid, but also on the properties of the soil. In order to predict the damage in such a hazard, it is important to study the effects of the soil properties on the burning characteristics of the liquid. Although the flame spread mechanisms over porous solids soaked with combustible liquid have been extensively studied [1-4], the burning characteristics such as the burning time or the burning rate have not yet been studied in detail. Thus, we study the burning characteristics of a combustible liquid soaked in porous materials using a bed of glass beads.

EXPERIMENTAL METHODS AND MATERIALS

A schematic diagram of the experimental apparatus is shown in Fig. 1. A stainless-steel cylindrical vessel with a diameter of 0.1 m and a height of 0.1 m was used. As in the previous studies [1,3], glass beads of various diameters were packed in the vessel and used as a porous bed. The diameters of the bead (d) were 0.2, 0.5, 1.4, 3, and 5 mm. Methanol (99% pure) was used as a combustible liquid. The porosities of the beds are about 35-36% for d=0.2,0.5,1.4 and 3 mm and 38.5% for d=5 mm. The vessel was counter-balanced by a weight and the variation of the methanol weight in the vessel was measured by using a strain-gauge.

The temperature distributions in the porous beds were measured by C-A thermocouples (wire diameter 0.1mm) installed in the vessel. In order to obtain the axial temperature profiles, four thermocouples were installed on the center axis of the vessel at the points of z=0,-6.5,-11.5,and -20 mm (z is the distance upward from the surface). In order to obtain the radial temperature profiles, four thermocouples were installed at the positions of r=0,17,33 and 46 mm (r is the radial distance from the center) at a plane 6.5 mm beneath the surface.

Experiments were made under a natural convection condition and at room temperature (296-300 K).

RESULTS

Appearance of Flame

When ignited, a flame immediately spreads over the bed and a blue diffusion flame is established. The flame is anchored at the rim of the vessel and the flame shape is almost conical. Initially, the flame height is over 20 cm and the flame is flickering with a frequency of 5 6 Hz. As the combustion proceeds, the flame height gradually decreases, i.e., the flame approaches the surface of the bed, resulting in a flat-shaped flame on the surface. Later, the flame is locally extinguished and some parts of the bed become uncovered with the flame. Finally, the flame completely extinguishes. The times from the ignition to the complete extinction are

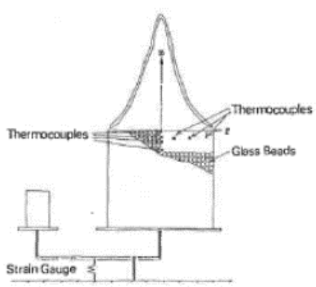


FIGURE 1. Schematic diagram of experimental apparatus

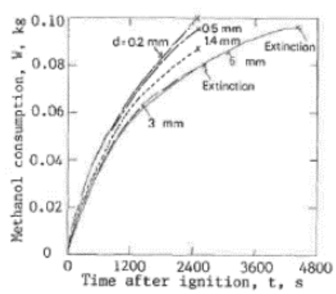


FIGURE 2. Methanol consumption at various bead diameters

almost the same (about 2500 s) for d=0.2,0.5,1.4 and 3mm, but the time is longer (about 4500 s) for d=5mm.

Consumption Rate of Methanol

Figure 2 shows the methanol consumption for various bead diameters. With increasing the bead diameter, the rate of the decrease of the methanol weight gradually decreases.

Near extinction, the methanol weights consumed are 0.1 kg for d=0.2 mm, 0.08 kg for d=3 mm (at t≈2500 s), and d=0.092 kg for d=5 mm (at t≈4500 s). Several runs were made for each bead diameter. The scatters in the methanol weights consumed were very small (within 3%) for each bead diameter. Since the initial weight of the methanol in the vessel was about 0.2 kg, these values indicate that only about a half of the initial methanol was burned on the bed.

Based on the results in Fig.2, the consumption rates of methanol, R were derived and shown in Fig.3. It is seen in Fig.3 that the consumption rates decrease with time. The consumption rates at ignition are about $8x10^{-5}$ kg/s and those at extinction are about $1.5x10^{-5}$ kg/s. If we evaluate the linear regression rates of the methanol in the vessel by dividing the consumption rate (R) by the density of methanol and by the cross sectional area of the pore of the vessel, the values are $3x10^{-5}$ m/s and $0.6x10^{-5}$ m/s at ignition and extinction, respectively. These linear regression rates are about the same order of the linear regression rate at liquid methanol burning in a 0.1 m diameter pool ($1.7x10^{-5}$m/s) [5-9]. It is interesting to note that except for d=5 mm, the value of R becomes larger as the bead diameter is decreased in the range of conditions at the present experiments.

Figure 4 shows the relation between the flame height, h and the consumption rate, R. The values at t=120, 300, 600, and 900 s are indicated in Fig.4. It is seen in Fig.4 that the flame height almost linearly decreases with the decreasing consumption rate.

Temperature Distribution in the Porous Bed

Figure 5 shows the variation of temperature in the 5 mm beads bed

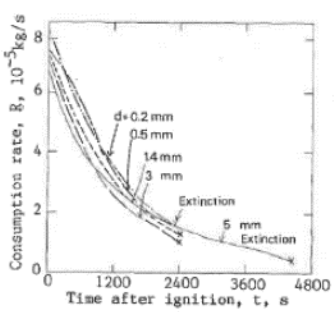


FIGURE 3. Consumption rate of methanol

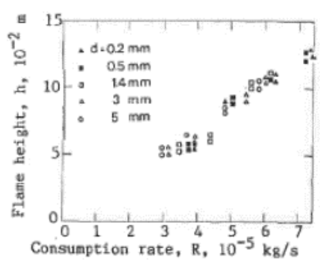


FIGURE 4. Relation between flame height and consumption rate

measured by the four thermocouples installed on the center axis of the vessel (r=0 mm). The temperature on the surface (z=0 mm) immediately rises after ignition, attains its maximum of 740 K at t=2100 s and then decreases. At 6.5 mm beneath the surface, the temperature first increases rapidly, but the rate of increase slows down around 335 K, and then the temperature increases rapidly again. At a much deeper position (z=-11.5 mm), the temperature increases first, but again the rate of increase slows down around 335 K, and then steeply increases. The retardation of the temperature increase around 335 K is seen also in the temperature profile at z =- 20 mm. The fact that the temperature (335 K) at which the retardation occurs is very close to the boiling point of methanol (337.9 K at 1.01×10^5 Pa) implies that the abrupt temperature increase is due to the completion of the methanol evaporation in the region of the thermocouple. This suggests that the region in which the temperature is higher than about 335 K is a dry region [3] in which only methanol vapor exists in the pore.

From the temperature-time records, the axial and radial temperature profiles in the bed are obtained. Figure 6 shows the result, with elapsed time as a parameter. As can be seen in the radial temperature profile (Fig.6(a)) at t=270 s, when the flame is anchored at the rim, the temperature near the center at z=-6.5 mm is almost uniform and increases near the wall. At t=600 s, an overall temperature profile is similar to that at t=270 s except for the absolute value of the temperature which increases with time. As the combustion process proceeds, the flame height decreases and the rate of the temperature increase in the near-wall region becomes smaller than that in the central region. The temperature increase in the near-wall region stops at t≈1000 s, when the flame base starts to leave the rim. During t=1000~2000 s, the wall temperature stays constant, while the temperature except for the near-wall region continues to increase.

In the axial temperature profile (Fig.6(b)), we can find that the temperature at r=0 mm increases with the distance to the surface decreases. At t=270 s, the temperature at z=-6.5 mm is very close to the boiling point of methanol and the temperature gradient between z=0 mm and a=-6.5 mm is much larger than that between z=-6.5 mm and z=-20 mm. This suggests that the bed is roughly divided into two regions by a surface, above which only methanol vapor exists. The position where the temperature is the boiling point of methanol is considered to correspond to the surface of the liquid. The surface is seen to be located around z=-6.5 mm at t=270 s and around z=-11.5 mm at t=600 s.

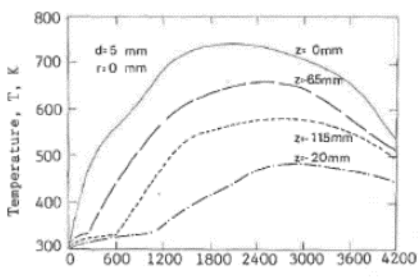
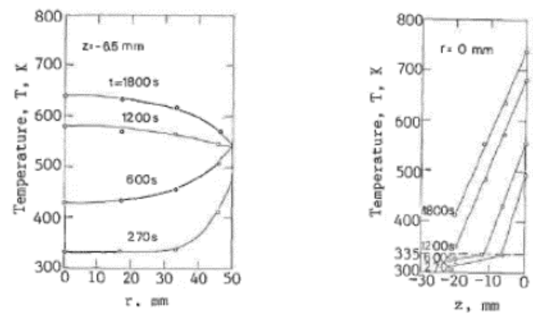


FIGURE 5. Variation of the temperature in the porous bed

At t=1200 s, the four points fall on a straight line. Further, the radial temperature profile (at z=-6.5 mm) in Fig.6(a) is almost uniform at t=1200 s. These facts imply that the heat transfer in the region is steady and one-dimensional. Based on the similar phenomena at t=1800 s, also the heat transfer can be assumed to be steady and one-dimensional.



(a) Radial temperature profile (b) Axial temperature profile

FIGURE 6. Temperatrue distributions in the porous bed

Lower Boundary of the Dry Region

From the temperature distributions, it is found that the porous bed can be divided into two layers by the surface above which only methanol vapor exists. Therefore this surface can be considered to be the lower boundary of the dry region. Since the surface seems to be almost horizontal, we consider that the position of 335 K on the center axis is that of the surface. The positions of the surface at the various bead diameters are shown in Fig.7. For comparison, the liquid levels in the porous solids are evaluated on the basis of results on the methanol consumption (Fig.2) and shown by broken lines in this figure. In this evaluation, we assume that the bed is divided into two regions, the upper dry region where only vapor exists and the lower region where only liquid methanol exists in the pore of the beads, and the boundary between the two regions can be simply obtained by dividing the weight of methanol consumed by the cross-sectional area of the pore of the vessel.

It is seen in Fig.7 that when the bead diameter is large (d = 3 mm and 5 mm) the liquid level simply evaluated from the methanol consumption agrees well with the boundary obtained from the temperature distribution.

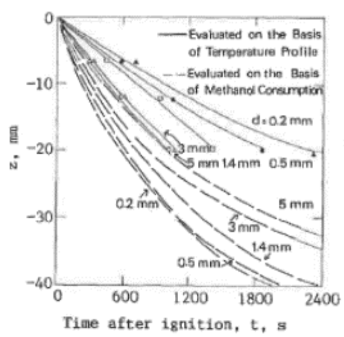


FIGURE 7. Positions of the dry region boundary at various bead diameters

When the bead diameter is small(d= 0.2 mm, 0.5 mm, and 1.4 mm), however, they do not coincide with each other. This suggests that when the bead diameter is large, a liquid layer and a vapor layer are clearly divided and when the bead diameter is small, however, the division is not so clear; the liquid can move upward owing to a capillary force and there exists a region where liquid methanol and methanol vapor coexist in the bed. As the bead diameter is decreased, the capillary force becomes larger, thus the location of the lower boundary of the dry region is considerably raised up. The difference in the liquid behavior leads to the difference of the burning characteristics with bead diameters observed in Fig.2.

Simplified Model

When the bead diameter is large, the porous bed can be divided into two regions; the upper region filled with vapor and the lower region filled with liquid. It can be assumed that the boundary between the two regions is almost flat and that the location moves with time. Although the total weight of consumed methanol or the consumption rate varies about 25% in the range of the conditions at the present experiments, we propose a simplified model to predict the consumption rate of methanol in the bed.

The model adopted here is schematically shown in Fig.8. In this model, we consider only heat conduction in the porous bed and neglect the motion of liquid induced by a capillary force in the bed. For simplicity, the following assumptions are made.

(1) Only heat conduction in the axial (z) direction is considered and heat conduction in the radial (r) direction is neglected. This assumption may be valid especially when several minutes are passed after ignition (see Fig.6(a) and Fig.6(b)).
(2) The beads bed in the vessel is divided into two regions; the upper region (dry region) where only methanol vapor exists and the lower region only liquid methanol exists.
(3) The temperature at the boundary surface between the upper region and the lower region equals to the boiling point of methanol θ_b.
(4) The temperatures at the top and the bottom of the bed are constant and given as θ_f and θ_0, respectively.
(5) Based on the fact that the temperature increase at the bottom is very small (less than 1 K), the bottom of the bed is assumed to be situated in the infinity.

Based on the above assumptions, the governing equations for the upper region and the lower region are given by

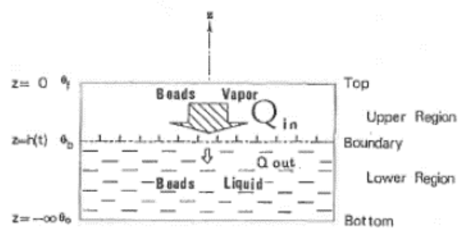


FIGURE 8. Schematic diagram of the model

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$$\frac{\partial \theta_1}{\partial t} = a_1 \frac{\partial^2 \theta_1}{\partial z^2}, \tag{1}$$

$$\frac{\partial \theta_2}{\partial t} = a_2 \frac{\partial^2 \theta_2}{\partial z^2}, \tag{2}$$

and the boundary conditions and the initial condition are

at $z=0$; $\qquad \theta_1(t,z)=\theta_f$, (3)

at $z=h(t)$; $\qquad \theta_1(t,z)=\theta_2(t,z)=\theta_b$, (4)

as $z\to-\infty$; $\qquad \theta_2(t,z)=\theta_0$, (5)

and

for $t=0$; $\qquad \theta_1(t,z)=\theta_2(t,z)=\theta_0$, (6)

where $\theta_1(t,z)$ and $\theta_2(t,z)$ are the temperatures of the upper region and the lower region, respectively, a_1 and a_2 are the thermal diffusivities of the upper region and the lower region, respectively, and $h(t)$ is the location of the boundary surface between the two regions.

The solutions, $\theta_1(t,z)$ and $\theta_2(t,z)$, can be determined by solving the second order partial differential equations with individual set of two boundary conditions ($\theta_1(t,0)$ and $\theta_1(t,h)$ for θ_1, $\theta_2(t,h)$ and $\theta_2(t,-\infty)$ for θ_2) and an initial condition. However, note that the location of the boundary $h(t)$ is not specified. To determine the solutions uniquely, we need an additional condition, which is given as follows. During a fraction Δt of time t, a heat Q_{in} conducted from the upper region into the boundary surface through a total cross-sectional area S of the vessel is $\lambda_1(\partial\theta_1/\partial z)S\Delta t$ and a heat Q_{out} conducted away from the boundary surface into the lower region is $\lambda_2(\partial\theta_2/\partial z)S\Delta t$. As the net heat is used to vaporize the methanol at the boundary surface, the following relation can be held at the boundary surface.

$$\lambda_1 \frac{\partial \theta_1}{\partial z} - \lambda_2 \frac{\partial \theta_2}{\partial z} = \varepsilon \rho q \frac{\Delta z}{\Delta t}, \tag{7}$$

where λ_1 and λ_2 are the thermal conductivities of the upper region and the lower region, respectively, ε is the porosity of the beads, ρ is the density of the methanol, and q is the latent heat of methanol.

If we introduce a nondimensional coordinate $\eta=z/2(a_1t)^{1/2}$ and assume the solutions with function of η, i.e. $\theta_1(\eta)$ and $\theta_2(\eta)$, Eqs.(1) and (2) are reduced to the following ordinary differential equations:

$$\theta_1''+2\eta\theta_1'=0, \tag{8}$$

$$\frac{a_2}{a_1}\theta_2''+2\eta\theta_2'=0, \tag{9}$$

where (′) denotes the differentiation with respect to η. The boundary conditions (3), (4), and (5) and the initial condition (6) are reduced to the following three conditions:

at $\eta=0$; $\qquad \theta_1(\eta)=\theta_f$, (10)

at $\eta=\dfrac{h(t)}{2\sqrt{a_1 t}}$; $\qquad \theta_1(\eta)=\theta_2(\eta)=\theta_b$, (11) as $\eta \to -\infty$; $\theta_2(\eta)=\theta_0$, (12)

From Eq.(8), the solution which satisfies the boundary condition (10) is given as

$$\theta_1(\eta)=k_1\int_0^{\eta} \exp(-x^2)dx+\theta_f, \tag{13}$$

and also, from Eq.(9), the solution which satisfies the boundary condition (12) is given as

$$\theta_2(\eta)=k_2\sqrt{a_2/a_1}\int_{-\infty}^{\sqrt{a_1/a_2}\,\eta} \exp(-x^2)dx+\theta_0, \tag{14}$$

in which k_1 and k_2 are constants to be determined by the conditions at the boundary .

By substituting the boundary condition (11) into Eqs.(13) and (14), we obtain a relation

$$k_1\int_0^{h(t)/2\sqrt{a_1 t}} \exp(-x^2)dx+\theta_f=k_2\sqrt{a_2/a_1}\int_{-\infty}^{\sqrt{a_1/a_2}\,h(t)/2\sqrt{a_1 t}} \exp(-x^2)dx+\theta_0=\theta_b. \tag{15}$$

Since Equation (15) has to be satisfied for all values of the time, h(t) must be proportional to $\sqrt{t}$. Therefore, the location of the boundary surface h(t) is given as

$$h(t)=2\alpha\sqrt{a_1 t}, \tag{16}$$

where α is a constant.

From Eqs.(15) and (16), k_1 and k_2, are given as follows:

$$k_1=\frac{\theta_b-\theta_f}{\int_0^{\alpha} \exp(-x^2)dx}, \tag{17}$$

$$k_2=\sqrt{a_2/a_1}\,\frac{\theta_b-\theta_0}{\int_{-\infty}^{\sqrt{a_1/a_2}\,\alpha} \exp(-x^2)dx}. \tag{18}$$

Note that these equations involve an unknown constant α which should be determined by the matching condition at the boundary (7). By substituting Eqs.(13), (14), (16), (17), and (18) into Equation (7), we obtain a relation

$$\frac{\exp(-\alpha^2)}{\int_{\alpha}^{0} \exp(-x^2)dx}-\frac{\lambda_2}{\lambda_1}\sqrt{a_1/a_2}\,\frac{\exp(-a_1\alpha^2/a_2)}{\int_{-\infty}^{\sqrt{a_1/a_2}\,\alpha} \exp(-x^2)dx}\,\frac{\theta_b-\theta_0}{\theta_f-\theta_b}=\frac{2\varepsilon\rho\alpha q}{C_p\rho_b(\theta_f-\theta_b)}, \tag{19}$$

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where ρ_b is the density of the upper region and C_p is the specific heat of the upper region.

The values of α can be numerically obtained from Eq.(19). Therefore, the location of the boundary surface $z=h(t)$ is predicted by using Eq.(16). Figure 9 shows the variations of the boundary surface predicted using Eq.(16), with θ_f as a parameter. Thermal conductivities of the upper region and the lower region are given by a theoretical formulation [10] and the values of λ_1 and λ_2 used are 0.23 W/m.K and 0.36 W/m.K. The values of a_1 and a_2 used are 2.4×10^{-7} m²/s and 2.3×10^{-7} m²/s, respectively. For comparison, the liquid level estimated using the methanol consumption in Fig.2 is also indicated by a solid line. Based on the results in Fig.9, the variations of methanol consumption are also evaluated and shown in Fig.10. For comparison, the experimental result is also indicated by a solid line.

As can be seen in Figs.8 and 9, the predicted results are qualitatively in good agreement with the experimental one. At an early stage of burning (t=0~1200 s) the temperature on the surface rises from 300 K to about 700 K (see Fig.4). Comparing the predicted value for θ_f=500 K with the experimental one, they are fitted within 30% at t=600 s. As for the period of t=1200~2400 s, the temperature on the surface is about 740 K. The difference between the predicted value for θ_f=740 K and the experimental one is only 20%. Therefore, this simplified heat transfer model can well describe the experimental results not only qualitatively but also quantitatively. It seems that when the bead diameter is large, the consumption rate of the methanol in the bed is mainly controlled by the heat transfer in the porous bed.

CONCLUSIONS

The burning characteristics of methanol soaked in porous beds were experimentally investigated. The consumption rates of methanol and the the temperature distributions in the porous beds were measured. The following conclusions were obtained:

(1) Extinction occurred at 2500~4500 s after ignition. Only half of the initial methanol was consumed during combustion.

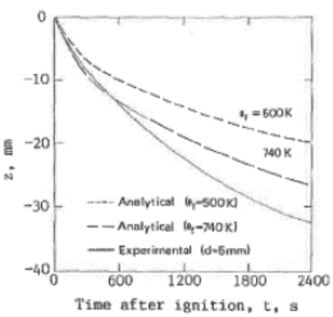

FIGURE 9. Variation of the predicted boundary surface

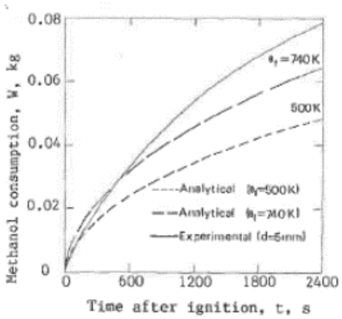

FIGURE 10. Methanol consumption evaluated

(2) The consumption rates of methanol were about $8x10^{-5}$ kg/s at ignition. They decreased with time, and they were about 1.5 kg/s at extinction.

(3) The linear regression rates of the methanol were estimated to be $3x10^{-5}$ m/s and $0.6x10^{-5}$ m/s at ignition and extinction, respectively.

(4) Total weight of the methanol consumed and the consumption rate of the methanol seemed to increase with decreasing bead diameter.

(5) The temperature-time records indicated that the dry region expanded from the surface towards the bottom in the bed with time. The lower boundary of the dry region agreed with the liquid level evaluated in a simple way from the variations of weight for the large diameter beads, whereas they did not agree for the small diameter beads. This discrepancy in the bed of small beads seems to be due to the capillary force.

(6) A simplified model based on one-dimensional heat transfer was proposed to predict the consumption rate of methanol for large beads. The predicted results were in qualitative agreement with the experimental results. Therefore, the fuel consumption rate on the large beads bed was found to depend mainly on the heat transfer in the bed.

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