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FIRE HAZARDS ANALYSIS FOR SOLID WASTE BURIAL
GROUNDS

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7. Abstract

This document comprises the fire hazards analysis for the solid waste burial grounds, including TRU trenches, low-level burial grounds, radioactive mixed waste trenches, etc. It analyzes fire potential, and fire damage potential for these facilities. Fire scenarios may be utilized in future safety analysis work, or for increasing the understanding of where hazards may exist in the present operation.

8.

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FIRE HAZARD ANALYSIS
FOR
SOLID WASTE BURIAL GROUNDS

WHC-SD-WM-FHA-015, Rev. 0

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ABBREVIATIONS, ACRONYMS, AND INITIALISMS

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A	Area
ARF	Airborne Release Fraction
atm	atmosphere
BTU	British Thermal Unit(s)
C	Centigrade
cal	calorie
cm	centimeter(s)
Ci	curies
CH	contact-handled
dia.	diameter
DBE	Design Basis Earthquake
DBF	Design Basis Fire
DOE	U.S. Department of Energy
EBR	Experimental Breeder Reactor
EPA	U.S. Environmental Protection Agency
F	Fahrenheit
FHA	Fire Hazards Analysis
ft	foot or feet
ft ²	square foot (feet)
ft ³	cubic foot (feet)
g	gram(s)
G	gravitational constant
gal	gallon(s)
HAZMAT	Hazardous Materials
HEPA	High Efficiency Particulate Air
HFD	Hanford Fire Department
HLW	high-level waste
h, hr	hour(s)
in.	inch(es)
in ²	square inch(es)
INEL	Idaho Nuclear Engineering Laboratories
kJ	kilojoules
kg	kilogram(s)
km ²	square kilometer(s)
kPa	kilopascals
kW	kilowatt(s)
L	liter
LLMW	low-level mixed waste
lbf	pounds-feet
LLW	low-level waste
m	meter(s)
m ²	square meter(s)
m ³	cubic meter(s)
MCFL	Maximum Credible Fire Loss
mi ²	square mile(s)
min	minute(s)
MPFL	Maximum Possible Fire Loss
mph	miles per hour

ABBREVIATIONS, ACRONYMS, AND INITIALISMS
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mrem	millirem
MW	mixed waste
nCi	nanocuries
NFPA	National Fire Protection Association
OSHA	Occupational Safety and Health Administration
PFP	Plutonium Finishing Plant
psi	pounds per square inch
PUREX	Plutonium-Uranium Extraction Facility
PUTDR	Pilot Unvented TRU Drum Retrieval
RCRA	Resource Conservation and Recovery Act of 1976
RCT	Radiological Control Technician (formerly Health Physics Technician, HPT)
RH	remote-handled
s	second(s)
SRC	Submarine Reactor Compartments
SWBG	Solid Waste Burial Grounds
SWITS	Solid Waste Information Tracking System
TRIGA	Training, Research and Isotope Production, General Atomics
TRU	transuranics
UBC	Uniform Building Code
Westinghouse Hanford	Westinghouse Hanford Company
yr	year(s)

1.0 INTRODUCTION

This Fire Hazards Analysis (FHA) addresses fire hazards or fire-related concerns in accordance with DOE Order 5480.7A (DOE 1993), resulting from or related to the Solid Waste Burial Grounds (SWBG). It is intended to comprehensively assess the risk from fire to ensure that there are no undue fire hazards to site personnel and the public, that the potential for the occurrence of a fire is minimized, that process control and safety systems are not damaged by fire or related perils, and that property damage from fire and related perils does not exceed an acceptable level.

The FHA analyzes and evaluates the SWBG with respect to existing and documented proposed conditions to ascertain whether the objectives of DOE Order 5480.7A Fire Protection are met. The graded FHA contains the following elements:

- Description of construction,
- Description of operations,
- Protection of essential safety class equipment,
- Fire protection features,
- Description of fire hazards,
- Life safety considerations,
- Critical process equipment,
- High value property,
- Damage potential: Maximum Credible Fire Loss (MCFL) and Maximum Possible Fire Loss (MPFL),
- Fire Department/Brigade response,
- Recovery potential,
- Potential for a toxic, biological and/or radiation incident due to a fire,
- Emergency planning,
- Security considerations related to fire protection,
- Natural hazards (earthquake, flood, wind) impact on fire safety, and
- Exposure fire potential, including the potential for fire spread between fire areas.

Assumptions and Limitations

Assumptions regarding combustible contents in containers, curie contents in containers, disposal practices, etc. are intended to be representative of actual conditions that exist during actual operations of the SWBG as documented in the referenced materials of this report. Drawings, Operating Procedures, Waste Acceptance Criteria as well as Interim Safety Analyses were used to supplement the field surveys and helped provide the basis for the FHA. Changes in procedures, acceptance criteria or conditions such as increasing the maximum curie content per container, increasing the height of the disposal array, introduction of waste retrieval operations, introduction of additional fuels or fuel sources, etc. may require additional analyses to assess whether these changes impact the conclusions of this analysis. Fire hazards resulting from deliberate acts of sabotage are not considered within the scope of this analysis.

Burial grounds which are classified as inactive or retired are no longer open to receive wastes and are outside the scope of the SWBG fire hazard analysis.

This analysis updates WHC-SD-WM-FHA-009, *Preliminary Fire Hazard Analysis for the PUTDR and TRU Trenches in the Solid Waste Burial Grounds* (WHC 1994f). When the fire hazards have remained unchanged, sections of this FHA incorporate analysis from WHC-SD-WM-FHA-009 (WHC 1994f).

The FHA of the Low Level Mixed Waste Trenches 31 and 34 have been previously analyzed and documented in WHC-SD-WM-FHA-010, Rev. 0 (WHC 1995c). This FHA incorporates analysis from WHC-SD-WM-FHA-010, Rev. 0 (WHC 1995c).

This analysis utilizes source term, release fraction, and methodologies developed by others to evaluate the potential loss and consequences of various postulated fires.

There are a number of areas where personnel entry/access is restricted or controlled. In areas not physically surveyed, relevant information relating to the FHA was obtained through document review and interviews with SWBG personnel.

2.0 SUMMARY AND CONCLUSIONS

This document represents the Fire Hazards Analysis for the SWBG. The FHA was developed in accordance with the criteria contained in DOE Order 5480.7A (DOE 1993) and is intended to address the major fire hazards inherent to the operation of the SWBG. The fire hazards of waste package/containers considered to be representative of the fire hazards in the SWBG are analyzed.

Waste package requirements/restrictions cited in the Hanford Site Solid Waste Acceptance Criteria effectively limit the consequences of an exposure fire. Waste packages which are covered with backfill material are not considered a fire hazard. Postulated flammable liquid pool fires exposing TRU drums are expected to result in limited drum-to-drum propagation. Postulated fires involving accumulated tumbleweeds do not result in TRU or MW container failure. There are no scenarios postulated which result in a caisson fire. There are no scenarios postulated that result in failure of a submarine reactor compartment waste package. Fires in open trenches involving tumbleweeds do not result in container failure for TRU drums and noncombustible MW packages.

Damage potential of the larger postulated fires have been analyzed. The Maximum Possible Fire Loss (MPFL) resulting from a flammable liquid fire within Burial Ground 218-W-4C exposing an array of TRU drums in Trench 29 has been estimated at \$924,753. The MPFL resulting from a fire in a 218-W-5 Mixed Waste trench has been estimated at \$283,852. The MPFL resulting from a fire in a 218-W-5 Low Level Waste trench has been estimated at \$20,715,607. Damage resulting from a "credible" fire scenario in a 218-W-5 Low Level Waste trench has been estimated at \$4,285,084.

TRU drums being retrievably stored in Burial Ground 218-W-4C, Trenches 1, 20, and 29 may contain unvented propane containers or other volatile hazardous waste which could result in violent container failure in an exposure fire. Cognizant Fire Department Personnel have been alerted to ensure that any pre-fire planning concerns can be addressed. The burial grounds building emergency plan has been revised to similarly address potential concerns that could impact worker safety.

In order to enable early notification of a fire event, procedures have been revised to ensure that all workers have a reliable means of notifying emergency services while working in a SWBG trench.

In order to minimize the potential for a fuel spill and/or fire involving equipment from becoming an exposure fire hazard to uncovered waste in the MW trenches (Trenches 31 and 34), written procedures have been developed to ensure that operators are adequately trained in the use of the applicable equipment, use of hand-held extinguishers, response in the event of a fire, refueling, maintenance and storage of the equipment.

Operational procedures have been revised to ensure that tumbleweeds and any other unplanned transient combustible that enter the trench are removed or covered if there is uncovered waste present.

3.0 DESCRIPTION OF CONSTRUCTION

The Solid Waste Burial Grounds are located in the 200 West and East Areas of the 1,450 km² (560 mi²) U.S. Department of Energy (DOE) Hanford Site, illustrated in Figure 1.

The purposes of the Solid Waste Burial Grounds (SWBG) are to permanently dispose of low-level waste and mixed waste and retrievably store transuranic waste. The SWBG are also used to dispose of remote-handled (RH) mixed wastes and store RH transuranic wastes on a case-by-case basis. The mixed wastes will be disposed in trenches that meet regulatory requirements such as the Resource Conservation and Recovery Act of 1976 (RCRA) (WHC 1994c).

Low-level waste (LLW) is defined in U.S. DOE Order 5820.2A as waste that contains radioactivity and is not classified as high-level waste (HLW), transuranic waste, spent nuclear fuel, or by-product material. Test specimens of fissionable material irradiated for research and development only, and not for the production of power or plutonium, may be classified as low-level waste, provided the concentration of transuranic is less than 100 nCi/g (DOE 1988).

Relative to the SWBG, LLW packages are categorized by nuclide activity limits as either Category 1 or Category 3. Category 1 waste is categorized as waste with very low concentrations of long-lived radionuclides whose concentrations do not exceed the values in Table 3-1 Column 1 of WHC-EP-0063-4 (WHC 1993b). Category 3 waste is categorized as waste with low to moderate concentrations of long-lived radionuclides whose concentrations do not exceed the values in Table 3-1 Column 2 of WHC-EP-0063-4 (WHC 1993b). LLW waste with nuclide activity limits that are higher than Category 1 waste must be stabilized prior to disposal (WHC 1993b).

Mixed waste (MW) or radioactive mixed waste is defined as radioactive waste that also contains dangerous waste as defined in the Washington Administrative Code, WAC 173-303-040 (WHC 1994c).

Transuranic (TRU) waste is defined as radioactive waste that is contaminated with alpha-emitting transuranium radionuclides with half-lives greater than 20 yr and concentrations greater than 100 nCi/g. Heads of DOE Field Elements can determine that other alpha contaminated wastes, peculiar to a specific site, must be managed as TRU waste. At the Hanford Site, TRU waste also includes ²³³U contaminated waste and ²²⁶Ra sources (WHC 1994c).

The SWBG receive wastes generated at the Hanford Site in support of operation (primarily decontamination, decommissioning, waste management, and environmental restoration activities) of the various chemical processing and nuclear reactor facilities. Wastes are also received for storage or disposal from other Hanford Site contractors and other U.S. Department of Energy (DOE) facilities throughout the United States.

In addition, the SWBG is the location for disposal of the U.S. Department of Transportation Type B compliant waste packages in support of the U.S. Navy (WHC 1994c). Additional details on the types and quantities of radioactive and mixed wastes currently in the active SWBG, as well as wastes expected to be received in the future, are described below.

The design of the SWBG accommodates a wide variety of waste characteristics, including RH and contact-handled (CH) waste packages of various sizes. The trench designs provide flexibility to receive commonly-used waste packages, such as a 208-L (55-gal) drum, as well as large waste packages, such as defueled submarine reactor compartments and reactor pressure vessels. Bulk wastes, such as contaminated soils and debris, may also be placed in the SWBG. The trench designs are intended to provide permanent near-surface confinement of LLW and MW and to provide retrievable storage for TRU waste. MW will be disposed in RCRA-compliant landfills. Radionuclide confinement is provided by the SWBG trench cover.

HANFORD AREA
SITE PLAN
SCALE: NONE

Figure 1. Solid Waste Burial Grounds Locations - 200 West Area, 200 East Area

The excavated trenches and soil backfill placed over filled trenches provide confinement by preventing precipitation from contacting and degrading the waste packages and also serve to retard radionuclide migration from failed waste packages. The soil backfill also protects the waste packages from heavy equipment accidents, earthquakes, range fires, etc. The soil provides shielding to reduce the radiation dose rates emitted from the trenches (WHC 1994c).

The trenches in the SWBG are non-Category 1 structures, i.e. they are facilities that do not perform a function required for nuclear criticality safety or whose failure will result in a significant release of radioactive, hazardous, or toxic materials as defined by DOE Order 5480.5, *Safety of Nuclear Facilities* (WHC 1994c).

The active SWBG include eight burial grounds comprised of a number of trenches. Six burial grounds are located in the 200 West Area (Figure 2) and two are located in the 200 East Area (Figure 3). A current assessment of their status and a brief assessment of the types of waste in each burial ground is provided in Table 3-1 (WHC 1995a). An inventory of wastes being stored or disposed of in the SWBG is contained in Appendix A.

Table 1. Active Burial Grounds (WHC 1995a)

Burial Ground	Location	Waste Types
218-E-10	200 East	MW, LLW
218-E-12B	200 East	MW, LLW, TRU ^a
218-W-3A	200 West	MW, LLW, TRU
218-W-3AE	200 West	MW, LLW
218-W-4B	200 West	MW, LLW, TRU ^b
218-W-4C	200 West	MW, LLW, TRU
218-W-5	200 West	MW, LLW
218-W-6	200 West	Has not received waste

^aIncludes submarine compartments in Trench 94 of this burial ground.

^bIncludes 12 caissons, of which five are alpha caissons (only four are used), six beta/gamma caissons, and one caisson that is plugged.

MW = mixed waste

LLW = low-level waste

TRU = transuranic waste

The applicable design criteria are those for existing burial ground facilities and equipment. DOE Order 6430.1A, *General Design Criteria*, which includes special nonreactor nuclear facility requirements, has been reviewed for applicability to the burial ground operations addressed in this safety analysis (DOE 1989). No special requirements are found to be directly applicable to the waste packages, burial grounds, or handling equipment (WHC 1994c).

Figure 2. Solid Waste Burial Ground Locations - 200 West Area

Figure 3. Solid Waste Burial Ground Locations - 200 East Area

3.1 BACKGROUND

Before 1970 all radioactive solid wastes at the Hanford Site, regardless of radionuclide content, were placed in trenches and covered with earth to prevent release of contamination. Since then the DOE has required that radioactive solid waste be segregated by categorizing as either TRU or LLW. The DOE directed that the TRU waste be placed in retrievable storage and the LLW be placed in nonretrievable disposal sites (WHC 1995b).

Until 1987 mixed waste packages were placed in trenches. In 1987 mixed waste burial was halted with the exception of the disposal of mixed waste containers with a dose rate greater than 200 mRem/h at the container surface, U.S. Navy defueled submarine reactor compartments (SRCs), and the Shippingport reactor vessel (WHC 1995b).

Active burial grounds are burial grounds that are currently receiving waste or may receive wastes in the future. Within an active burial ground there may be open trenches and trenches that have been backfilled, i.e. covered with soil (WHC 1995b).

3.2 BURIAL GROUND 218-E-10 (Figure 4)

This burial ground has been in service since 1960 and is mostly used for the receiving of RH waste. There are 14 trenches oriented north to south containing RH TRU waste and LLW. Trenches 9 and 12 contain some mixed waste. The waste has been received from the Plutonium-Uranium Extraction (PUREX) Facility, B Plant, and 100-N Area. The waste was received in mostly large concrete, and a few wooden, boxes. The boxes contained failed equipment and filters. Trench 9 was used prior to November 1987, and still has room for a few waste containers. This burial ground has received 21,764 m³ of waste. (WHC 1995b).

The open portions of trenches and the types of waste (if any) being stored or disposed are identified below.

Table 2. Open Trenches of Burial Ground 218-E-10

Trench No.	Width (ft)	Length (ft)	Waste Type
9	16	360	Empty
14	16	640	Empty

3.3 BURIAL GROUND 218-E-12B (Figure 5)

This burial ground, in service since 1962, has been used primarily for LLW but contains three trenches of TRU waste (Trenches 16, 17, and 27). This burial ground has 40 trenches. While most trenches are oriented in a north-to-south direction, Trench 94 is oriented from east to west. There are 39 trenches filled, of which two are partially filled. Trench 94 is used for the disposal of U.S. Navy defueled SRCs composed of various types of steel and contains approximately 392 tons of lead shielding. Most of the waste received in this burial ground has been generated by facilities in the 200 East Area with the exception of naval waste. This burial ground has received 78,740 m³ of waste (WHC 1995b).

Figure 4. Burial Ground 218-E10

The open portions of trenches and the types of waste (if any) being stored or disposed are identified below.

Table 3. Open Trenches of Burial Ground 218-E-12B

Trench No.	Width (ft)	Length (ft)	Waste Type
32	5	800	Empty
36	5	890	Empty
42	5	1140	Empty
94	200	1600	MW

Note: Trench 94 (Figure 6) has been excavated to an approximate depth of 53 ft. The floor of Trench 94 is approximately 200 ft in width at the narrow end and 250 ft at the wide end. It is approximately 1,600 ft in length.

3.4 BURIAL GROUND 218-W-3A (Figure 7)

This burial ground has been in service since 1970 and contains TRU waste, LLW, TRU mixed waste, and low-level mixed waste. Trenches 9S, 1, 4, 5, 6, 8, 10, 15 and 17 contain LLW and TRU waste. Trench 14 has 10 large concrete boxes of low-level radioactive soil from a tank farm cleanup in 1973. Trench 17 contains TRU fiberglass reinforced polyester plywood boxes related to the decommissioning of the weapons programs. Trench 7S contains waste from the cleanup effort at the Three-Mile Island Nuclear Plant. In Trench 8 there are some buried irradiated fuel elements. Trenches 40 and 49 contain LLW equipment, large boxes, and drums.

This burial ground has 57 trenches, one of which is partially filled. This burial ground has been used by most onsite and offsite DOE contractors. This burial ground has received 100,000 m³ of waste (WHC 1995b).

The open portions of trenches and the types of waste (if any) being stored or disposed are identified below.

Table 4. Open Trenches of Burial Ground 218-W-3A

Trench No.	Width	Length	Waste Type
49	36	560	Empty

3.5 BURIAL GROUND 218-W-3AE (Figure 8)

This burial ground was placed in service in 1981. It was to be used for RH LLW in support of the 100 Areas and the 200 West Area. Trenches 2 and 3 have received RH LLW. Trench 16 is being prepared to receive RH LLW. Trenches 5 and 10 are wide-bottom stacking trenches, which contain some mixed waste. Trench 26 was dug with a wide bottom to dispose of LLW railroad cars and large tanks. The trenches are oriented from east to west. A total of 21,900 m³ of waste has been received (WHC 1995b).

Figure 8. Burial Ground 218-W-3AE

The open portions of trenches and the types of waste (if any) being stored or disposed are identified below.

Table 5. Open Trenches of Burial Ground 218-W-3AE

Trench No.	Width (ft)	Length (ft)	Waste Type
3	16	150	Empty
8	100	1050	LLW
13	161	1150	Empty
16	161	1100	Empty
26	60	130	LLW

3.6 BURIAL GROUND 218-W-4B (Figure 9)

This burial ground was placed in service in 1968 and has received unsegregated TRU waste, segregated TRU waste, and TRU mixed waste. Trenches 1, 2, 3, 4, 5, 6, 8, 9, 10, and 12 contain unsegregated TRU waste/TRU mixed waste. Trench 7 contains TRU waste on an asphalt pad; the containers are mostly 55-gal drums with a few boxes. This trench is CH waste. The TRU waste in Trench 11 can contain either RH or CH waste; there is no asphalt pad in this trench. Trench 14 has 12 caissons, which are vaults or tanks underground, for the disposal of 1- to 5-gal cans of RH waste. There are five alpha caissons but only four have been used; they were used from 1970 to 1979. There are six beta/gamma caissons which are filled, and one caisson that is plugged; these were used from 1968 to 1979. No additional wastes are planned to be placed in the caissons. This burial ground has received a total of 10,466 m³ of waste (WHC 1995b).

There are no trenches that remain open.

3.7 BURIAL GROUND 218-W-4C (Figure 10)

This burial ground was placed in service in 1978. The most northern trench, or trench NC, contains naval core barrels. Trench 1 contains mostly noncombustible TRU waste, including the 216-Z-9 Crib drums containing plutonium-contaminated soil. Trench 4 contains mostly combustible TRU waste and little noncombustible TRU waste. Trench 7 contains TRU boxes, organic waste in drums, and drums of Training Research and Isotope Production, General Atomics (TRIGA) irradiated fuel. Additional TRU waste in boxes and drums is located in Trenches 19, 20, and 29. LLW is located in Trenches 19, 23, and 28. There are several remaining trenches in this burial ground to be used when needed. This burial ground has received waste from onsite and offsite DOE contractors. There has been a total of 15,666 m³ of waste received in the 218-W-4C burial ground (WHC 1995b).

The open portions of trenches and the types of waste (if any) being stored or disposed are identified below.

Table 6. Open Trenches in Burial Ground 218-W-4C

Trench No.	Width (ft)	Length (ft)	Waste Type
1	24	140	TRU
14	192	85	LLW
20	26	409	TRU
24	26	552	LLW
33	20	680	LLW
37	16	710	Empty
29	26	392	TRU
48	5	500	Empty
53	5	500	Empty

3.8 BURIAL GROUND 218-W-5 (Figure 11)

This burial ground became operational in 1986 for disposal of LLW and mixed waste. Trenches 3, 9, 13, 14, 21, 24, and 27 are full and have been backfilled. Trenches 31 and 34 are mixed waste lined trenches with leachate collection systems and will be used for burial of containerized and bulk mixed waste. Existing trenches in W-5 are oriented from east to west. Space is available for additional mixed waste trench units. This burial ground receives waste from offsite DOE contractors. A total 36,310 m³ of waste has been placed in this burial ground (WHC 1995b).

The open portions of trenches and the types of waste (if any) being stored or disposed are identified below.

Table 7. Open Trenches in Burial Ground 218-W-5

Trench No.	Width (ft)	Length (ft)	Waste Type
8	15	120	LLW
29	50	1000	LLW
33	120	1150	Empty
31	120	270	Empty (scheduled for MW)
34	120	270	Empty (scheduled for MW)

3.9 BURIAL GROUND 218-W-6

Trenches in this burial ground will be used for LLW and low-level mixed waste. All the monitoring wells have been installed and testing of the wells has started. This burial ground could have trenches in place as needed (WHC 1995b). To date, this burial ground has not received any waste. There are no open trenches.

4.0 DESCRIPTION OF OPERATIONS

Wastes received for storage or disposal in the SWBG must meet appropriate acceptance requirements specified by WHC-EP-0063 and be processed and handled in accordance with applicable Plant Operating Procedures appropriate for the waste type and waste container (WHC 1993b). These procedures are briefly summarized by waste type and/or container below.

4.1 LOW-LEVEL WASTE

Waste that contains radioactivity and is not classified as high-level waste, TRU, spent nuclear fuel, or by-product material is termed low-level waste (LLW). LLW is packaged in a wide variety of approved containers (steel drums, wood boxes, steel boxes, concrete burial vaults, etc.) and disposed of in waste burial trenches. Packages may be secured to pallets. Retrieval of LLW is not anticipated.

Upon receipt of LLW waste packages, the information listed on all shipping and storage forms is compared to the corresponding waste packages to verify agreement.

Any discrepancies between the information listed and the waste packages are noted with the supervisor. Each container is visually checked to verify that containers are free from bulging, punctures, dents, scratches that penetrate paint/coating, loose lids or locknuts, corrosion, signs of containment breach (WHC 1993a).

LLW waste packages are typically moved by means of a truck into the trench area (WHC 1993a). After a survey by the Radiological Control Technician (RCT), waste packages are transported via truck into the trench area. They are then off loaded by means of a qualified drum lift fixture, typically either a crane or forklift and stacked in the trench. The maximum height of stacked waste may not exceed 20 ft and drum stacks no higher than four tiers (WHC 1993a). Irrespective of these limitations the waste must be placed so that it may be covered by a minimum of 8 ft of soil (WHC 1995a). Low-level waste are covered with earth by the end of the day when any of the following conditions apply:

- When adequacy of containment is doubtful,
- When dose rate reaches 100 mRem/hr at edge of trench,
- When animal waste has been buried,
- When containers are unweighted or light weight and could be scattered by wind, or
- When waste is classified (some waste is considered classified for security reasons).

It should be noted that LLW packages defined as Category 3 are stored/disposed at specified trench locations and are not commingled with Category 1 waste (WHC 1993a). Typical disposal configuration of LLW waste packages is shown in Figures 12 and 13.

4.2 MIXED WASTE

Radioactive waste with hazardous constituents as defined by EPA regulations (40 CFR 261, 1990) is termed mixed waste (MW). Packages of TRU, spent fuel, or LLW that contain MW must be further segregated into compatible hazard classes and stored/disposed of in designated MW storage units. Waste packages are also designated remote-handled (RH) or contact-handled (CH), depending on the dose rate at the surface of the package. Mixed waste that exceeds 200 mRem/hr is disposed of in trenches on a case by case basis, whereas MW below this limit is stored at the Central Waste Complex.

MW is currently disposed of in Burial Ground 218-E-12B, Trench 94, and is scheduled to be disposed of in Burial Ground 218-W-5, Trenches 31 and 34. Operations within Trench 94 are described in Section 4.4. The receipt of waste at current MW disposal trenches does not vary in significant detail from the receipt of

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Figure 12. Illustration of Typical Disposal Within a Trench (WHC 1995a)

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Figure 13. Typical Stacking of Waste Containers Within a Trench (WHC 1995a)

wastes in other trenches (WHC 1995a). Waste, other than bulk waste, is received and disposed of in containers. The containers are required to be constructed of metal and meet container criteria prescribed (WHC 1993b). The containers that are most likely to be used are 55-gal drums. Waste may be received on pallets; however, the waste will be removed from the pallets prior to the waste being disposed in the trench. The pallets will not be disposed of in the trench (WHC 1994e).

Bulk waste refers to noncontainerized waste products such as soils, vegetation, building rubble, and other relatively homogeneous materials. In Trenches 31 and 34, bulk waste will be received in containers but will not remain in the container for disposal.

For Trenches 31 and 34, the maximum height of the waste will be limited to one layer of containers. Once the horizontal depth of waste container rows approaches the reach of a frontloader with the bucket (approximately a depth of three drum rows), backfill material will be placed on top of and between the waste containers. Backfill material may be clean fill or loose granular bulk waste. A nonflammable/noncombustible fixing agent may be applied to the bulk waste to reduce the spread of waste material. Once the voids between containers have been filled, they will be covered with 0.7 m (2 ft) of clean soil. The maximum number of drums or equivalent drum volumes that may be exposed without 0.7 m (2 ft) of soil cover is limited by procedure to 1,400 drums. Once a layer of waste has been placed and covered, the clean soil will be compacted by running the loader over the cover. Additional soil will be added as needed to maintain the 0.7 m (2 ft) depth. As the trench is filled, the ramp will be covered (WHC 1994e).

4.3 TRANSURANIC WASTE

As stated earlier, transuranic (TRU) waste is waste that contains greater than 100 nCi of transuranic radionuclides per gram of waste matrix. TRU waste is packaged (usually in 55-gal drums) and stored intact and in a contamination-free condition, so it is retrievable after a minimum of 20 yr (WHC 1991).

TRU wastes are retrievably-stored in the SWBG until facilities are available to process, treat, and dispose of these wastes, either onsite or elsewhere. To satisfy shipping requirements, the TRU waste packages must meet, at a minimum, the Type A package requirements identified in 49 CFR 173.412 (49 CFR 173, 1992). These include external surface free from protrusions, ability to withstand normal transport conditions, physical/chemical compatibility of package and associated structures a containment system which retains the contents under reduction of pressure to 24.1 kPa (3.5 psi), and capability to withstand the tests defined by 49 CFR 173.465 for water spray, free drop, compression test, and penetration test (WHC 1995a).

4.3.1 Backfilled TRU Waste Packages

The bulk of retrievably-stored TRU waste packages are located in backfilled trenches in the active SWBG in a variety of containers. In past practice, TRU waste packages have been stacked up to five layers high in the trenches, with each layer covered with 0.25-in. thick plywood. The retrievably stored TRU waste trenches have been backfilled with a minimum of 1.2-m (4-ft) thick layer of soil to reduce radiation dose rates and minimize any possible spread of contamination from the trench. A diagram of a typical backfilled TRU waste trench is illustrated in Figure 14.

Note: With the noted exception of classified TRU waste packages, the present operations practice is to store TRU waste packages in open trenches without backfill.

Operations in backfilled trenches are currently limited to routine maintenance and surveillance activities, including removal of combustible material, typically tumbleweeds, repairing subsidence, and groundwater monitoring (WHC 1995a).

Figure 14. Typical Covered Transuranic Waste Trench (WHC 1995a)

4.3.2 Retrievable Storage of Contact-Handled TRU Waste Packages

Uncovered TRU waste packages are stored in the 218-W-4C Burial Ground in Trenches 1, 20, and 29. The trenches incorporate an asphalt pad for waste package stacking and stability (WHC 1995a). Existing drum containers are stacked as high as four tiers. Other containers are typically placed within the trench on pallets. The maximum height of stacked waste may not exceed 20 ft.

With the noted exception of classified TRU waste and previously covered TRU waste packages, TRU trenches will remain open until the wastes are retrieved from the trenches for further processing and ultimate disposal. Uncovered TRU waste packages are inspected on a weekly basis for signs of corrosion and degradation. Classified TRU waste packages are covered with a minimum of 4 ft of backfill. Per discussions with Solid Waste Personnel and documented in the Interim Safety Analysis (WHC 1995a) no additional TRU waste packages in the form of 55-gal drums are expected to be received for storage at the SWBG.

4.3.3 Retrievable Storage of Remote-Handled TRU Waste Packages

There are two main types of Remote Handled (RH) TRU waste operations in the SWBG: irradiated fuel wastes and wastes in the alpha caissons.

4.3.3.1 Irradiated Fuel Waste Retrievable Storage

A number of different types of containers provided shielding and containment of radioactive wastes to meet retrievable storage requirements. Various types of irradiated reactor fuel wastes, including irradiated Training, Research and Isotope Production, General Atomics (TRIGA), Light Water Reactor, and Fast Flux Test Facility irradiated fuel wastes have been placed in the SWBG. These wastes, which in many cases are small fragments and pellets, are within sealed containers that are placed within the waste package. Irradiated fuel waste packages exist in both covered and uncovered conditions and include wastes from the Experimental Breeder Reactor No. 2 (EBR-II). Uncovered irradiated fuel wastes are placed within either single- or double-encapsulated containers before being placed within what is called an EBR II cask (Figure 15). The EBR-II cask is a cylindrical steel vessel with outer dimensions of 44.5 cm (17.5 in.) in dia. by 151 cm (59.5 in.) in length. EBR-II waste containers must be placed via crane and rigging crew, on an asphalt pad with at least a 5-ft separation center-to-center and at least 5 ft away from any other fissile containers. There are EBR-II casks which have been used for covered storage of irradiated fuels. However, the practice of covering irradiated fuel waste packages is no longer performed at the Hanford Site. The other type of waste package used for covered retrievable storage of irradiated fuel waste was concrete burial containers (Figure 16). These waste packages contain irradiated mixed plutonium oxide and enriched uranium oxide wastes from destructive testing and examination of fuels in the 1960s and 1970s at the General Electric Company. These wastes are placed within aluminum waste liners that are in turn placed within concrete burial containers.

4.3.3.2 Transuranic Waste Storage Caissons

Underground caissons, referred to as alpha caissons, are used for storage of small packages of TRU wastes with high levels of radiation. The caissons are reinforced-concrete cylinders buried approximately 4 m (13 ft) below grade, as shown in Figure 17. The caissons have approximate 1 m (3-ft) dia. inlet chutes that have been offset to eliminate direct radiation shine from the stored wastes. The caissons are provided with exhaust systems that include high-efficiency particulate air (HEPA) filters. Originally, the caissons had been provided with electrically driven exhaust fans to pull air through the inlet chutes into the caisson when the caissons are being loaded. Most caissons have been changed to breather filters and the exhaust fans have been removed.

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Figure 15. Illustration of an EBR-II Cask (WHC 1995e)

TOP VIEW

SIDE VIEW

LINER CONTAINER

Figure 16. Illustration of a Concrete Burial Container for Long Waste (WHC 1995a)

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Figure 17. Illustration of a Typical Caisson (Alpha) (WHC 1995a)

A specially designed bottom opening cask is used to load waste materials into the caissons. Waste containers on the caissons include 3.8-, 7.6-, and 18.9-L (1-, 2-, and 5-gal) cans containing RH (high dose rate) irradiated fuel and nonfuel scrap from hot cell examinations. The can lids may not be intact and waste materials may be dispersed with the caissons. TRU Waste Storage Caissons containing TRU wastes are no longer receiving new wastes. Routine monitoring, surveillance, and maintenance of the caissons continues in accordance with existing procedures. TRU waste from the alpha caissons is expected to be retrieved in the future. However, present activities are limited to surveillance and maintenance and includes HEPA filter change out (WHC 1995a).

4.4 SUBMARINE REACTOR COMPARTMENTS

The Submarine Reactor Compartment (SRC) unit is a section of a submarine that contains the sealed defueled reactor compartment, associated components, bulkheads, and hull sections. The transport and placement of submarine reactor compartments within Trench 94 of the 200 East 218-E-12B Burial Ground are performed by the Department of the Navy and its subcontractors. Westinghouse Hanford's responsibilities relative to placement of the compartments within the trench include watering, grading and compacting the trench, and staging heavy equipment to assist should the reactor compartment transporter become stuck in the trench bottom. Westinghouse Hanford also manages the construction of the SRC foundations and support columns in accordance with a design supplied by the Navy. Westinghouse Hanford issues welding and cutting permits to the Department of the Navy contractors but is not responsible for performing welding and cutting activities relating to the placement of the compartments on foundations within the trench. Westinghouse Hanford also provides emergency response services to the 200 East Area Burial Grounds in support of actual and/or suspected environmental releases (WHC 1995a).

The SRC units, once placed, are managed in the same manner as any other LLW. Because of its structural characteristics, the SRC waste package is considered impervious to wind, rain, dust, fire, and so forth (WHC 1995a).

5.0 FIRE PROTECTION FEATURES

There are no fixed fire protection systems serving Solid Waste Burial Grounds. A trained, fully staffed fire department is maintained at the Hanford Site which is staffed on a 24-hr per day, seven days per week basis. The response time of the fire department to the various burial ground areas is estimated to be 5 to 10 min.

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6.0 DESCRIPTION OF FIRE HAZARDS

6.1 GENERAL

The fire hazards associated with the SWBG are defined as conditions or practices related to fire that have the potential to contribute to or directly cause injury, illness, on-site or off-site release of radiological and/or other hazardous material, property damage, or mission impairment.

6.1.1 SWBG Fire History

Information relating to Hanford Fire Department responses to the 200 West Area between January 1985 and August 1994 was reviewed. The information provided between 1991 and 1994 is coded to more clearly identify the type and cause of each fire. There were no incidents of fires within SWBG trenches or involving SWBG packages/containers within the burial grounds identified.

6.1.2 Containers/Packages

The inventory of waste packages contained within the SWBG is included as Appendix A and identifies each waste package, waste type, waste status (covered or uncovered), weight, radiological inventory, material form, and location by trench and burial ground.

Containers/packages which have been covered or backfilled with earth represent the most common condition of container storage or disposal within the SWBG. From a fire protection perspective, this condition represents a protected unexposed condition since containers covered with 2 to 4 ft of earth are insulated from exposure to any external fire or external ignition source. Additionally, air available for combustion is limited to the air volume which may exist within the container severely limiting the potential for a fire within a container to develop as a result of spontaneous combustion. It is concluded that containers which are backfilled or covered in accordance with SWBG operating procedures do not pose a fire hazard.

Uncovered containers/packages may present a fire hazard. This is dependent upon container/package type, container/package contents, and the type of fire exposure. Their fire hazard potential is considered in the following sections below.

6.2 CONTAINER/PACKAGE REQUIREMENTS

6.2.1 Current Requirements for LLW, MW, and TRU Wastes

Pertinent regulatory requirements applicable to the wastes which may be stored or disposed of are cited in the Hanford Site Solid Waste Acceptance Criteria (WHC 1993b). Requirements which are considered to impact the waste flammability/explosive potential or the consequence of an exposure fire are cited below.

Low-Level Waste

- Packages used for disposal of LLW with the exception of plastic wrap shall be constructed of metal or be fire retardant.
- All exterior surfaces of wooden packages are required to be treated for fire retardation with a fire-retardant material having a maximum flame-spread index of 25 when tested to American Society for Testing Materials Standard E-84-89a.

- Liquids in excess of 1% of the volume of the waste, or 0.5% of the volume of waste processed to a stable form will not be accepted for disposal.
- Waste capable of detonation or of explosive decomposition or reaction at normal pressure and temperatures or of explosive reaction with water will not be accepted for disposal.
- Waste capable of generating toxic gases, vapors, or fumes harmful to persons handling the waste will not be accepted for disposal.
- Gaseous waste will not be accepted for disposal if it is packaged at a pressure in excess of 1.5 atm.
- LLW with the potential to generate sufficient nonradioactive gas to pressurize the waste package greater than 1.5 atm or reach explosive concentrations of hydrogen and oxygen or other explosive gases shall be vented. Vents shall be sized to ensure adequate passage of generated gas.
- Wastes capable of gas generation shall be vented or contain catalyst packs for the recombination of hydrogen and oxygen.
- Pyrophoric waste will not be accepted for disposal.
- Unidentified, uncharacterized, or poorly characterized waste will not be accepted.

Mixed Waste (storage criteria only)

- Packages for MW shall be constructed of metal or other noncombustible material.
- Waste capable of detonation or of explosive decomposition or reaction at normal pressure and temperatures or of explosive reaction with water will not be accepted for disposal.
- Packages of MW with the potential for gas generation or to reach explosive concentrations of hydrogen and oxygen may require vents or hydrogen-oxygen recombinant catalysts to deplete free oxygen and hydrogen.
- Waste capable of generating toxic gases, vapors, or fumes harmful to persons handling the waste will not be accepted for disposal.
- Gaseous waste packaged in excess of 1.5 atm will not be accepted for disposal.
- LLW with the potential to generate sufficient nonradioactive gas to pressurize the waste package greater than 1.5 atm or reach explosive concentrations of hydrogen and oxygen or other explosive gases shall be vented. Vents shall be sized to ensure adequate passage of generated gas.
- Wastes capable of gas generation shall be vented or contain catalyst packs for the recombination of hydrogen and oxygen.
- Pyrophoric waste will not be accepted for disposal.

Transuranic Waste

- All newly generated TRU waste shall be placed in noncombustible containers.
- TRU waste shall not be in free-liquid form. Minor residual liquids remaining in well-drained inner packages shall not exceed 1% volume and the total liquid in the waste package shall not exceed 1% volume.
- Liquids will be solidified, absorbed, or otherwise bound in the waste matrix by an inert material. The resultant waste matrix will not be capable of spontaneous combustion, decomposition, desorption, explosion, or affecting the integrity of the package.
- Pyrophoric materials, other than radionuclides, shall be rendered safe by mixing them with chemically stable materials or shall be processed to remove their hazardous properties. Not more than 1% by weight may be pyrophoric forms of radionuclides, and these shall be generally dispersed in the waste.
- TRU waste shall contain no explosives or compressed gases.
- All TRU-contaminated corrosive, reactive, and ignitable materials shall be treated to remove the hazardous characteristics.
- No pressurized vessels shall be permitted in TRU waste. Pressure vessels (such as aerosol cans and other gas cylinders) must be permanently vented (WHC 1993b).

These regulatory requirements for LLW, MW, and TRU wastes limit the fire potential of the container/package and limit the consequences of an exposure fire.

6.2.2 Previous Requirements for LLW, MW, and TRU Wastes

Prior to November 23, 1987, hazardous constituents in TRU drums were not characterized to current waste acceptance criteria and tracked in the Solid Waste Information Tracking System (SWITS). The preliminary FHA for the PUTDR and TRU trenches identified the potential for the existence of propane bottles. A SWITS search was conducted in order to determine the potential for the existence of propane bottles in the exposed containers of the Low-Level Burial Ground Trenches. The following was determined:

- A SWITS check for any container assigned to PFP that may have propane identified two containers which are both stored at Central Waste Complex.
- A SWITS check of open trenches identified four trenches which contain exposed containers that were placed prior to November 1987. These are Trench 1, 14, 20, and 29 in Burial Ground 218-W-4C. Only Trenches 1, 20 and 29 contain exposed TRU drums. (Trench 14 contains the Shippingport Reactor Vessels and the Disposable Solid Waste Casks.)
- The SWITS check confirmed that all other exposed waste in the open trenches was placed after November 23, 1987 and therefore meets current waste acceptance criteria (WHC 1995d).

The original issuance of WHC-EP-0063, *Hanford Radioactive Solid Waste Packaging, Storage and Disposal Requirements*, dated September 1988, was reviewed to identify any significant differences that could impact existing fire hazards within the open trenches (WHC 1988). No criteria differences deemed significant to this analysis were identified.

6.3 ACCIDENT ANALYSIS

6.3.1 General

Based on review of the trench operations performed, two potential fire hazards have been identified. They are:

- A flammable liquids spill from a truck, loader, or forklift in the vicinity of the storage array or disposal package and a subsequent fire. This fire could expose the container array to significant heat and flame.
- The accumulation of tumbleweeds within the trenches and along the edges of the drum/container array. The tumbleweeds are considered a potential fuel source which, if ignited, could expose the container array to significant heat and flame.

Note: A third potential fire hazard exists within the RH caissons due to the unknown quantities of flammable/combustible materials that are being stored. This potential hazard is discussed in the caisson section below.

These fire hazards and postulated scenarios are addressed by waste type/container section below. The objectives of the fire scenario analysis are to determine:

- Whether the scenarios are likely to result in container failure,
- Whether the fire will continue to propagate and involve other containers, and
- Whether the container exposed to the fire will result in a release of radiological or other hazardous material.

6.3.2 TRU Storage/Package Accidents

From evaluation of the various storage conditions for the TRU containers/packages, the storage array involving drums stacked 12 wide, 4 high and 12 deep in Trench 1 of Burial Ground 218-W-4C is considered to be the most significant single fire exposure. Similar arrays were analyzed in the *Preliminary Fire Hazard Analysis Report for the PUTDR and TRU Waste Burial Ground* (WHC 1994f). The analysis evaluated three fire scenarios in the SWBG that were candidates of the Design Basis Fire (DBF). These are:

Scenario No. 1.	Diesel Fuel (50 gal) was spilled at the edge of a drum array as a result of an accident involving drum handling equipment. The pool ignites, exposing the drum array;
Scenario No. 2.	During drum removal as part of the Pilot Unvented TRU Drum Retrieval Effort, a void in the drum array measuring 8 ft by 8 ft was created in the array which was originally soil covered. Diesel fuel (50 gal) was spilled in the void exposing the drum array; and
Scenario No. 3.	Tumbleweeds accumulate along the edge of the drum array within the trench. The tumbleweeds are ignited and fire propagates along the drum array edge, exposing the drum array.

6.3.3 TRU Storage/Package Container Failure Criteria

The referenced analysis (WHC, 1994F) provides a technical basis for drum container failure. This analysis defines two types of drum container failures, lid loss failure, and lid seal failure. From review of available literature, the analysis concludes that a 3-min fire exposure criterion is conservative for loaded drums. It also establishes a basis for assuming that 0.95 kg of diesel fuel must be burned per drum in the tight-packed array configuration to cause lid failure.

The referenced analysis determined that the mechanisms for involvement of drum combustible contents are violent lid loss due to fire induced overpressurization of the drum and damage to the drum/lid due to mechanical forces associated with falling drums. While some additional release may occur due to the loss of lid seal integrity without lid loss, these contributions were shown to be minor compared to burning of drum contents from drums which experience lid loss. While the analysis showed that the drum arrays may be stable and may resist toppling due to drum lid releases, the plywood used between tiers of the array is considered critical to this stability. In an alternate scenario, drums directly exposed to flames are assumed to fail due to plywood burnout and subsequent layer instability. However, tests conducted by Idaho Nuclear Engineering Laboratories (INEL) on two by two by four tier tall array of drums exposed to a pool fire result in plywood burnout between tiers. Yet the drum array remained in place throughout the whole test. The plywood alone is insufficient as a fuel to cause drum lid failures. For the packing densities generally found in these drums, the heat release rates are modest (75 kW/drum), but the duration is quite long (3 hr).

6.3.4 TRU Storage/Package Drum-to-Drum Fire Propagation

The referenced analysis considered the possibility of drum-to-drum propagation, via radiation, expulsion of burning contents, and as a result of the presence of hazardous materials following a pool fire exposure which caused lid failure.

6.3.4.1 Drum-to-drum fire propagation via radiation. The impact of incident radiation from a fire involving the contents of three drums on an adjacent target drum as well as the incident radiation from a fire involving the contents of one drum on an adjacent target drum was evaluated. Both situations were determined to generate overpressures in the target drum below the pressure needed to cause lid loss. The analysis concludes that fire propagation from drum-to-drum via radiation is not expected.

6.3.4.2 Drum-to-drum fire propagation via expulsion of burning contents. In Lawrence Livermore National Laboratories' tests of 10 kg waste in drums, when a lid was lost, the contents were expelled from the drum. It is unclear whether this would occur with higher more realistic drum loadings, but in the absence of any data, it is assumed that the contents may be expelled from a drum when lid loss occurs. The referenced analysis states that it is highly unlikely that drum lid losses will result if the contents burn on top of the drum array. However, if the contents contain polyethylene, which melts and flows, this fuel may flow both onto the drum lid and onto the plywood at the base of the drum. This effectively creates a pool fire exposure sufficient to cause lid failure. The referenced analysis postulates that only half of the expelled contents actually fall onto uninvolved drums, and that 3.25 target drums are exposed per one source drum. Based on a probability for violent lid loss of 0.26, the analysis determines that each drum failure leads to 0.42 drum lid losses ($0.5 \times 3.25 \times 0.26$). The analysis determines the probability for one lid loss to lead to additional lid losses to be 1.7. Therefore, each top tier drum which burns due to initiating source heating is expected to lead to 1.7 drum lid losses (including itself). This extent of drum-to-drum propagation is considered to be quite modest (WHC 1994f).

6.3.4.3 Impact of hazardous materials. The analysis (WHC 1994f) cites WHC-SD-W306-TI-001, Rev. 1 as a basis for concluding that approximately 15% of drums may contain 2.2 kg toluene and 200 g xylene (WHC 1994d). Interviews with Plutonium Finishing Plant employees are cited as a basis for assuming that 1% of

drums may contain a 1-lb. propane tank. It is not known whether the propane tanks are vented empty and how many are sealed and partially filled. Therefore, the analysis assumes that 16% of the drums contain hazardous materials (WHC 1994f).

The analysis states that the heat content of the hazardous materials is not of any great significance, (presumably, as it related to its contribution to container failures) noting that fireballs resulting from violent venting of a propane tank produce moderate heat fluxes of very limited duration. However, the analysis concludes that thermal conditions evaluated for the drum-to-drum propagation cited above would be expected to generate overpressures sufficient to cause lid loss. Since the actual location of drums containing hazardous materials (HAZMAT) is not known, the analysis concludes that propagation of the fire from drum-to-drum on the top tier of the array may be possible in the presence of 16% HAZMAT drums. The analysis states that with 16% HAZMAT drums, and a probability of lid loss of 25%, about 4% of the top tier drums will burn and 12% of the top tier HAZMAT drums will experience lid seal failure without lid loss (WHC 1994f).

Hazardous materials as used in this section refers solely to identified volatile materials which could impact the potential of the fire to propagate from drum-to-drum. The identified hazardous materials were packaged within the waste containers and stored prior to implementation of the current Waste Acceptance Criteria. It should be noted that the cited hazardous materials are not expected to be present in newly generated LLW and MW since such materials are expressly prohibited by current SWBG Waste Acceptance Criteria and/or by RCRA treatment requirements.

6.3.5 Evaluation of TRU Storage/Package Postulated Accident Scenarios

6.3.5.1 Scenario No. 1. Scenario No. 1 postulates diesel fuel (50 gal) spilled at the edge of a drum array which ignites exposing the drum array. The 50 gal of diesel fuel yields a 69-m long line fire exposing 112 drum stacks for a total exposure of 448 drums. It is conservatively postulated that a line type pool fire occurs whose flame height is to the top of the array and last 3 min (to conservatively estimate lid failure) exposing 448 drums. Based on available testing, the analysis utilizes a value of 0.26 as the fraction of drums which fail with lid loss. Lid loss is only postulated on the top tier drums. Therefore, 29 drums are expected to experience lid loss and the burning of their contents, and the remaining 419 are to experience lid seal failure. Lower tier exposed drums are expected to experience lid seal failure only, due to the stability of the array. The mass loss for this scenario is 754 kg burned (26 kg/drum x 29 drums) and 419 kg lost via seal failure (1 kg/drum x 419 drums). Note that the combustible loading per drum is based on detailed contents survey by Joyce (WHC 1993c), which determined the average combustible load in a drum to be 26 kg.

Since the largest array of TRU drums stored in an open trench is an array 4 drums high, 12 drums wide, and 22 drums deep, the consequences of this scenario is not considered to be applicable to existing conditions. However, it is illustrative of how a fire on the edge of a drum array can expose drums on all tiers to heat from a fire.

6.3.5.2 Scenario No. 2. Scenario No. 2 determined in the referenced analysis (WHC 1994f) to represent the worst case scenario, resulting in the burning of the contents of up to 56 drums. Scenario No. 2 postulated a 50-gal spill of diesel fuel in an 8-ft by 8-ft void in the drum array, and was based on operations and conditions which were part of the Pilot Unvented TRU Drum Retrieval (PUTDR) project. This project has been completed (without fire incident). Since there are no similar projects scheduled or planned for this fiscal year or the foreseeable future, the conditions and assumptions relating to the scenario no longer apply to the SWBG as they are currently operated.

6.3.5.3. Scenario No. 3. Scenario No. 3 evaluated the burning of tumbleweeds along the edge of the drum array. The collection of tumbleweeds along the edge of the drum array is a known phenomenon. In the event of ignition of the tumbleweeds by a wildland fire or other cause, the full length of the drum array could be

exposed to a tumbleweed fire. The referenced analysis (WHC 1994f) evaluated this event and concluded that the duration of burning is not sufficient to cause failure of exposed drums. This conclusion was supported by cited research involving the burning of wood sticks. The research results indicated that an active burning duration of 3 min requires a stick thickness of approximately 1.2 cm. Since, the typical stick thickness of tumbleweed is less than 1.2 cm and the density of tumbleweed is less than wood, it was concluded that the duration of burning is not sufficient to cause failure of exposed drums. This scenario is considered to be applicable to existing SWBG conditions. However, since no container failures result from this fire exposure, no further evaluation is deemed necessary.

6.3.5.4 Postulated Scenario Based on Existing Conditions, Trench 1. Under present SWBG operations, there are no current plans to receive additional TRU drums for storage. Using the methodology described in the Preliminary Fire Hazards Analysis for PUTDR and TRU Trenches in the Solid Waste Burial Ground (WHC 1994f), and cited in Section 6.3.5.1, Scenario No. 1, one possible worst case scenario involves the existing TRU drum array stacked 12 wide, 4 high and 22 deep in Burial Ground 218-W-4C, Trench 1. Revising Scenario No. 1 in the referenced analysis to reflect existing conditions results in a fire exposing 88 drums. Of these, only the top 22 drums could experience lid loss. Using the referenced analysis value of 0.26 as the fraction of drums which fail with lid loss due to the initial pool fire, results in 6 drums which are expected to experience lid loss and have their contents burn. The remaining 82 drums are expected to experience lid seal failure. Accounting for possible drum-to-drum propagation due to expulsion of combustibles from failed drums (initial number of drums expected to experience failure by lid loss $\times 1.7$) increases the number of drums which fail and experience lid loss to 10. Assuming that 16% of the top tier drums contain hazardous materials, the number of additional HAZMAT drums postulated to experience lid loss is 10 (0.04×254). The number of HAZMAT drums expected to experience lid seal failure is 39 (0.16×244).

The total number of drums postulated to result in lid failure and the burning of their contents is 20. The mass loss for the scenario is 520 kg ($26 \text{ kg/drum} \times 20$) burned and 121 kg ($121 \times 1 \text{ kg}$) lost via seal failure. Using the same heat release rate/drum assumptions as the referenced analysis, an average heat of combustion of 30 kJ/g for mixed cellulosic and plastics (15 kJ/g for cellulose and 40 kJ/g for common plastics) is assumed. Similarly, the cited burning rate (Tewarson 1988) of 2.35 g/s is assumed. This results in a burning time of about 3 hr ($26 \text{ kg} \times 1000 \text{ g/kg} \div 2.35 \text{ g/s} \div 1 \text{ hr/3600 s}$). The heat release rate is determined by the size of the fuel source in terms of its diameter and the packing density of the material. Assuming a drum dia. of 0.6 m, a 26-kg fuel load, and a packing density of 92 kg/m³, the referenced analysis cites a heat release rate correlated by Babrauskas (Babrauskas 1988) of about 75 kW/drum. Using the same heat release rate/drum assumptions as the referenced analysis, this equates to a heat release rate of 1.5 megawatts for 3 hr ($75 \text{ kW} \times 20$).

6.3.5.5 Postulated Scenario Based on Existing Conditions, Trench 29. Another possible worst case scenario involves the existing TRU drum array stacked 12 wide, 3 high, and 25 deep in Burial Ground 218-W-4C, Trench 29. Revising Scenario No. 1 in the referenced analysis to reflect existing conditions results in a fire exposing 75 drums. Of these, only the top 25 could experience lid loss. Using the referenced analysis value of 0.26 as the fraction of drums which fail with lid loss due to the initial pool fire, results in 7 drums which are expected to experience lid loss and their contents burn. The remaining 68 drums are expected to experience seal failure. Accounting for possible drum-to-drum propagation due to expulsion of combustibles from failed drums (initial number of drums $\times 1.7$) increases the number of drums which fail and experience lid loss to 12. Assuming that 16% of the top tier drums contain hazardous materials, the number of additional HAZMAT drums postulated to experience lid loss is 12 (0.04×288). The number of HAZMAT expected to experience lid seal failure is 44 (0.16×276).

The total number of drums postulated to result in lid failure and the burning of their contents is 24. The mass loss for this scenario is 624 kg ($26 \text{ kg/drum} \times 24$) burned and 112 kg ($112 \times 1 \text{ kg}$) lost via seal

failure. Using the same heat release rate/drum assumptions as the referenced analysis, this equates to a heat release rate of 1.8 megawatts for 3 hr.

Considering that present operations involving the TRU drum storage array are limited to weekly inspections for corrosion and degradation, the initial conditions which must exist for this scenario to occur increase the conservativeness of the fire scenario.

Note: There are life safety concerns associated with the potential presence of unvented propane containers exposed to a flammable liquids fire. These are addressed in Section 12.0, Fire Department/Brigade Response.

6.3.6 Transuranic Waste Storage Caissons

The TRU waste storage caissons contain suspect flammable/combustible material in unknown quantities (WHC 1995a). However, there are no operational conditions identified that would introduce an ignition source, or pose a fire hazard. Note that the exhaust fans have been removed and replaced by breather filters. Further, waste packages are no longer transferred to the RH TRU caissons. In the absence of a credible ignition source, no credible fire scenario is postulated for the TRU waste storage caissons. However, in the absence of a credible accident scenario, consequence analysis for a fire involving the entire radiological inventory of each caisson is provided in WHC-SD-WM-SARR-028, Rev. 1 (WHC 1995a).

6.3.7 Submarine Reactor Compartments

The Submarine Reactor Compartments (SRC) packages meet the Nuclear Regulatory Commission and U.S. Department of Transportation criteria for a Type B container (WHC 1995a). U.S. Department of Transportation requirements for a Type B container include a requirement for maintaining its shielding and integrity when subjected to an exposure for not less than 30 min to heat flux not less than that of 800°C (1474°F) with an emissivity coefficient of at least 0.9 (10 CFR 71 1992 and 49 CFR 173 1992). This requirement ensures reasonable resistance to fire exposures involving accidental fuel spills or tumbleweeds.

6.3.8 Mixed Waste

Fire Hazards associated with LLMW disposed in Trenches 31 and 34 of Burial Ground 218-W-5 have been previously analyzed (WHC 1995c). The plans, operations and conditions for these trenches have not changed. Consequently, no changes to the fire scenarios that have been postulated are warranted.

The analysis evaluated several potential fire scenarios (WHC 1995c). These are listed below:

Scenario No. 1.	Instantaneous fuel spill involving 50 gal of diesel fuel and a subsequent fire,
Scenario No. 2.	Continuous fuel spill involving 50 gal of diesel fuel and a subsequent fire,
Scenario No. 3.	Worse case fuel spill of 50 gal of diesel fuel and a subsequent fire,
Scenario No. 4.	Fire involving accumulation of tumbleweeds along the edge of the container array, and
Scenario No. 5.	Fire involving bulk waste.

Supporting calculations from the referenced report are included as Appendix C.

6.3.8.1 Scenario No. 1. Scenario No. 1, an instantaneous fuel spill and fire is theoretical and intended to bound the maximum area of a pool fire involving 50 gal of diesel fuel. The analysis concludes that Scenario No. 1 results in a fire with insufficient fuel/container density to result in a container failure.

6.3.8.2 Scenario No. 2. Scenario No. 2 is a localized fuel spill and fire initiated from a fuel tank leak or a ruptured fuel line which results in a release of 50 gal of fuel at a spill rate of 10 gpm. The analysis concludes that Scenario No. 2 could involve 16 drum containers of which four are expected to experience lid loss and burn. Using the previously referenced probability for one lid loss leading to an additional lid loss to be 1.7, the total number of drums expected to experience lid loss is 7 (1.7×4). The number of drums expected to experience lid seal failure is 11.

6.3.8.3 Scenario No. 3. Scenario No. 3 determines by calculation, a worst case exposure scenario resulting from a localized fuel spill and fire involving 50 gal of diesel. The analysis cites as criteria for drum container failure a fuel density of 0.95 kg/drum and a fire which burns for at least 3 min. The scenario results in an exposure of 82 drums of which 33 are assumed to fail. Of the 33 assumed to fail, nine are expected to experience lid loss and have the combustible contents burn due to exposure from the pool fire. Using previously referenced probability for one lid loss leading to an additional lid loss to be 1.7, the total number of drums expected to experience lid loss is 15 (1.7×9). The number of drums expected to experience lid seal failure is 18.

The mass loss for the scenario is 390 kg (15×26 kg/drum) burned and 18 kg (18×1 kg) lost via lid seal failure. Using the same heat release rate/drum assumptions as Section 6.3.5.4, an average heat of combustion of 30 kJ/g for mixed cellulosic and plastics (15 kJ/g for cellulose and 40 kJ/g for common plastics) is assumed. Similarly, the cited burning rate (Tewarson 1988) of 2.35 g/s is assumed. This results in a burning time of about 3 hr ($26 \text{ kg} \times 1000 \text{ g/kg} \div 2.35 \text{ g/s} \div 3600 \text{ s}$). As noted in Section 6.3.5.4, the heat release rate is determined by the size of the fuel source in terms of its diameter and the packing density of the material. Assuming a drum diameter of 0.6 m, a 26 kg fuel load and a packing density of 92 kg/m³, the heat release rate was determined to be about 75 kW/drum. Using the same heat release rate/drum assumptions, this equates to a heat release rate of 1.1 megawatts for 3 hr ($75 \text{ kW} \times 15$).

6.3.8.4 Scenario No. 4. Scenario No. 4, a fire involving accumulation of tumbleweeds along the edge of the container array, is considered by the referenced analysis not to cause failure of exposed drum containers.

6.3.8.5 Scenario No. 5. Scenario No. 5, a fire involving bulk waste is assumed by the analysis to involve vegetative debris and burn in a manner similar to the tumbleweeds fire. The referenced analysis concludes that this fire does not result in failure of exposed drums/containers.

6.3.9 Low-Level Waste (LLW)

LLW disposed in fire retardant plywood containers are considered vulnerable to failure from fire due to the inherent combustibility of the container. Fire development in plywood container storage arrays consistent with SWBG operational procedures has been separately analyzed and is included as Appendix D. However, it should be noted that the data used in the analysis was for non-fire retardant plywood containers. Since fire retardants are generally effective in improving ignition resistance, it is expected that the fire retardant plywood would perform better in lateral flame spread than normal plywood.

Fire development resulting from the two scenarios described in section 6.3.1, a flammable liquids spill and fire, and a fire involving tumbleweeds are considered. Assumptions include an array of containers constructed of 3/4-in. plywood of dimensions 4 ft by 4 ft by 8 ft, stacked three high, 6 across and 25 deep resting on soil within a burial ground trench. This equates to 450 containers that are potentially exposed. The plywood boxes are filled with combustible waste contaminated with radiological material. The containers are

tightly packed with separation between containers of 2 in. or less. The containers rest on 4 in. by 4 in. wooden skids so the horizontal spacing between the containers is approximately 3.5 in.

6.3.9.1 Diesel Fuel Spill and Fire Scenario

The initiation of a trench fire by 50 gal. of diesel fuel spilled at the edge of the array presents a significant threat to the array. A pool fire that is 7.6 m in length and 1 m wide has been determined to be sufficient to initiate flue space fires and burn through the exposed face of the boxes. Burn through time has been estimated to be approximately 12 min. Flue space flame spread, i.e. flame spread between, has been shown to dominate fire development. The analysis concludes that under the assumption that the plywood boxes are not fire retardant and the flue space width within the array is about 2 in., burn through of all plywood boxes within the array can occur (Appendix D).

6.3.9.2 Tumbleweeds Fire Scenario

The collection of tumbleweeds along the edge of the disposal array within a trench is a known phenomena. In the event of ignition of the tumbleweeds by a wildland fire or other cause, the full length of the array could be exposed to a tumbleweed fire. Burning duration for tumbleweeds has been previously estimated. It is expected that non-fire retardant treated plywood exposed to the tumbleweed fire will be ignited. However, on burn out of the tumbleweed these surfaces will not be able to sustain flaming combustion without external energy input. However, it is also expected that ignition of the flue space will occur to some distance from the exposed face of the boxes. Due to the burning of the opposite face of the flue, the burning within the flue is expected to be self-sustaining. It has been concluded that the tumbleweed is a sufficiently potent initiating source to result in a loss of the full array. In the sense that accumulation of tumbleweeds along the whole array edge is expected to occur, and spilling diesel fuel along the full length of the array may not occur for all or even most fuel spills, the tumbleweed scenario is a higher risk initiating source than the fuel spill fires (Appendix D).

Both tumbleweed and diesel fuel fire scenarios may result in the burn through of all the LLW plywood containers in the exposed array.

6.3.10 Accident Analysis Conclusions

- Waste package requirements/restrictions cited in the Hanford Site Solid Waste Acceptance Criteria effectively limit the consequences of an exposure fire.
- Waste packages which are covered with backfill material are not considered a fire hazard.
- Postulated flammable liquid pool fires exposing TRU drums are expected to result in limited drum-to-drum propagation.
- Plywood layers placed between tiers of TRU drums are considered to be insufficient as a fuel by itself to cause drum lid failures.
- Postulated fires involving accumulated tumbleweeds within the trenches are not expected to result in TRU or MW container failure.
- There are no scenarios postulated which result in a caisson fire.

- There are no scenarios postulated that result in failure of a submarine reactor compartment waste package.
- Both tumbleweed and diesel fuel fire scenarios may result in the burn through of all the LLW plywood containers in the exposed array.
- The following revisions to SWBG written procedures are in keeping with DOE 5480.7A's objective and Westinghouse Hanford's commitment to minimize the potential for the occurrence of a fire or related perils.
 - Requirements for the operator of the wheel loader, truck, forklift or other waste package operations equipment to have current training in the following areas:
 - Use of this type of equipment,
 - Use of hand-held fire extinguishers, and
 - response in the event of a fire.
 - Requirements for the Mixed Waste Trenches which stipulate that all refueling be performed at least 18.3 m (60 ft) from any uncovered waste and any refueling tank greater than 416.41 L (110 gal) shall not enter the trench during refueling operations. Also, attachment changing on waste package operations equipment shall be performed at least 9.1 m (30 ft) from any uncovered waste. Parking of the operations equipment when not in use shall be at least 9.1 m (30 ft) from any exposed waste. These requirements minimize the potential for a fuel spill and/or fire involving the operations equipment from becoming an exposure fire hazard to uncovered waste.
 - Requirements to ensure that tumbleweeds or any other unplanned transient combustible that enters the trenches shall be removed or covered if there is uncovered waste present. (If all waste in the trench is covered, there is no need to remove or cover the tumbleweeds or other unplanned transient combustibles).

6.4 RADIOLOGICAL RELEASE POTENTIAL

The evaluation and acceptability of radiological releases to the environment resulting from accidental fires is addressed in applicable safety analysis documentation, namely the *Solid Waste Burial Grounds Interim Safety Basis* (WHC 1995b) and the *Solid Waste Burial Grounds Interim Safety Analysis* (WHC 1994c). These documents include evaluation of postulated accidents, including fires, to determine if the radiological and hazardous material exposures will be acceptable from an overall health and safety standpoint to the worker, the onsite personnel, the public, and the environment.

Fires which have been analyzed as part of this FHA include postulated releases of radiological material. The postulated releases are based on methodologies developed by others and are used to estimate contaminated ground areas as part of the Maximum Possible Fire Loss (MPFL) determination. These releases are documented in the Appendices of this FHA.

7.0 PROTECTION OF ESSENTIAL SAFETY CLASS SYSTEMS

Safety Class 1 equipment is defined as systems structures, or components including primary environmental monitors and portions of process systems, whose failure could adversely affect the environment, or the safety and health of the public. Safety Class 2 equipment is defined by WHC as systems, components, or structures including portions of process systems, not identified as Safety Class 1, whose failure could adversely affect the health and safety of onsite workers. Safety analyses of the SWBG has not determined a need for Safety Class 1 or Safety Class 2 components (WHC 1995a). Consequently, there is no safety class equipment within the SWBG.

8.0 LIFE SAFETY CONSIDERATIONS

The SWBG is comprised of open air facility configurations, i.e. trenches, and are not subject to classification by NFPA 101, *Code for Safety to Life from Fire in Buildings and Structures* (NFPA 1994). Egress out of the trenches is normally via the trench access ramp or trench opening.

In a fire event, it is likely that existing trench openings would provide free egress. Though not intended for egress, select trenches, such as the LLMW Trenches 31 and 34 within Burial Ground 218-W-5, have sides with a slope ratio of 1 (rise) to 3 (run) and may enable able-bodied personnel to evacuate in a fire emergency.

Irrespective of fire hazard concerns, there are OSHA regulations governing the means of egress for specific trenches. Trenches whose depth is greater than the width and whose width (measured at the bottom) is not greater than 15 ft meet the definition of a trench as defined by OSHA Part 1926.650 and are required to have a stairway, ladder, ramp or other safe means of egress be located not more than 25 ft of lateral travel from employees (29 CFR 1926). SWBG trenches which meet the OSHA Part 1926.650 definition may need to be evaluated for applicability of this requirement.

9.0 CRITICAL PROCESS EQUIPMENT

There are no critical process equipment within the SWBG.

10.0 HIGH VALUE PROPERTY

High value property is defined as property with worth of \$1,000,000 or more. There are no high value property within the SWBG. Costs associated with a fire incident are primarily repackaging and remediation costs.

11.0 DAMAGE POTENTIAL

11.1 MAXIMUM CREDIBLE FIRE LOSS (MCFL)

DOE Order 5480.7A defines MCFL as the property damage that would be expected from a fire, assuming that:

- All installed fire protection systems function as designed, and
- The effect of emergency response is omitted except for post-fire actions such as salvage work, shutting down water systems, and restoring operation.

Since the trenches do not have any active fire protection systems, nor is it expected that the Wheel Loader, truck, forklift, or other equipment will have automatic fire suppression, the MCFL equals the Maximum Possible Fire Loss (MPFL) determined in Section 11.2.

11.2 MAXIMUM POSSIBLE FIRE LOSS (MPFL)

DOE Order 5480.7A defines MPFL as the value of property, excluding land, within a fire area, unless a Fire Hazards Analysis (FHA) demonstrates a lesser (or greater) loss potential (DOE 1993). This assumes the failure of both automatic fire suppression systems and manual fire fighting efforts.

In determining the MPFL, it is necessary to also define what is meant by "fire loss." Per DOE Order 5480.7A, fire loss refers to the dollar cost of restoring damaged property to its pre-fire condition (DOE 1993). In determining loss, the estimated damage to the facility and contents shall include replacement cost less salvage value. Losses exclude property that is scheduled for demolition and property decommissioned and not carried on books as a value. The loss determination includes the cost of decontamination and cleanup and the loss of production or program continuity.

DOE Order 5480.7A stipulates that structures having an MPFL in excess of \$1,000,000 shall be provided with complete automatic fire suppression systems designed in accordance with applicable MPFL standards (DOE 1993). Since the term "structure" is not defined in this order, DOE Order 6430.1A was referenced (DOE 1989). DOE Order 6430.1A, Section 0110-6, Fire Protection, states that definition, fire resistance rating, and type of construction shall be as contained in the Uniform Building Code (UBC 1994). The 1994 UBC defines a structure as "that which is built or constructed, an edifice or building of any kind or any piece of work artificially built up or composed of parts joined together in some definite manner".

The trenches being evaluated are not buildings or edifices and are not composed of parts joined together. Therefore, they are not considered to be structures. Consequently, the requirement for automatic fire suppression for structures having an MPFL in excess of \$1,000,000 is not applicable to the SWBG trenches.

For the SWBG, all waste is assumed to have zero property value. Consequently, in a trench fire, the likely property of value that could be damaged is a wheel loader, truck, or forklift being used to place or move the SWBG waste packages.

A method for estimating ground areas contaminated by a postulated fire in a facility containing radioactive material has been developed (WHC 1994g). It is used to estimate the ground contamination potential from a fire involving the combustible and radiological contents of the containers. The results are highly approximate and can vary by more than an order of magnitude under a given set of conditions (WHC 1994g). It is important to note that the methodology does not purport to model the worst case contamination

area that could occur. Rather, it predicts results based on realistic meteorological conditions. As such, they provide a reasonable means for estimating contaminated ground areas.

The methodology is explained in the previously cited reference. Key method assumptions are identified below:

- Estimation of releases are a function of particle fall velocity and is based on available data from experiments where simulated contaminated waste packages were burned under controlled conditions.
- Estimation of the equilibrium plume height is determined by calculating total fire heat generation rate and using an established buoyant plume model. This estimated plume height is used as the release height for the large particle dispersion model.
- Meteorological conditions are pasquill F stability¹ with a reference elevation of 10 m and wind speed of 1 m/s.
- The fire's rate of heat release per unit area is assumed to be:

$$Q'/A = 397 \text{ kW/m}^2 \text{ or } 9.48 \text{ E} + 04 \text{ cal/m}^2\text{s} \text{ (35 BTU/ft}^2\text{s)}.$$

This analysis makes use of calculations developed for a fixed set of meteorology which are approximated by simple functions of fire area (heat release rate). Assumptions and variables utilized in this analysis depend upon the fire being postulated and the radiological at risk inventory.

The equation for determining the downwind extent of the contour corresponding to a minimum contamination level C is:

$$x_L = [(64.9 \times (I/C) \times A_F^{0.847})]^{-1/m}$$

where:

- x_L = maximum downwind extent
- I = at risk inventory curies
- C = minimum contamination level
- A_F = fire area
- m = $-(0.02940 \ln(A_F) + 3.248)$

The equation for determining the area of the contour corresponding to the minimum contamination level, C, is:

$$A_C = 0.0713 (-m)^{1/2} x_L^{1.903}$$

11.3 LOW-LEVEL MIXED WASTE

The MCFL/MPFL for a fire within Burial Ground 218-W-5, Trench 31 or 34 has been estimated using the ground contamination method described above (WHC 1995c). Using Westinghouse Hanford soil cleanup

¹ Pasquill stability classes are used to define meteorological atmospheric conditions and typically are categorized from A to F. For materials with a deposition velocity of zero and release point at or very near ground level, the maximum concentration is always associated with "F" stability (Lawrence Livermore National Laboratories, 1994). For his formulation, Hines has 'arbitrarily' selected "F" stability, and suggests that other combinations of meteorology conditions could produce somewhat larger contaminated areas, but also indicates that the results are highly approximate estimates and that the source term contributes the greatest uncertainty.

cost estimate of \$5.49/m² (WHC 1993d), the cost of soil contamination cleanup is estimated to be \$133,852. Accounting for damage to the loader estimated to be \$150,000. The MCFL/MPFL was estimated to be \$283,852. An explanation of the calculation is provided in the Appendix C.

11.4 TRU Waste

Burial Ground 218-W-4C, Trench 29, has the greatest concentration of TRU/drum and is the basis for determining the MPFL for the estimated TRU waste. The ground contamination method described above was utilized to estimate the extent of ground contamination.

Using Westinghouse Hanford soil cleanup cost estimate of \$5.49/m², the cost of soil contamination cleanup is estimated to be \$609,153. Accounting for cost of replacement of equipment of values and the cost of repacking and restacking the drums results in an MPFL/MCFL estimated to be \$924,753. An explanation of the calculation is provided in Appendix B.

This estimate excludes any cost associated with collection of fire department runoff within the trench, decontamination of surrounding drums or equipment, inspection/repacking of drums which did not fail, and reassembly of the drum arrays.

11.5 LOW LEVEL WASTE

The MCFL/MPFL for LLW disposal in plywood boxes has been estimated for a fire involving a disposal array of 450 (4ft by 4ft by 8ft) containers, using the ground contamination method described above (WHC 1995c). Using Westinghouse Hanford soil cleanup cost estimate of \$5.49/m², the cost of soil contamination cleanup is estimated to be \$20,565,607. Accounting for damage to the loader estimated to be \$150,000. The MCFL/MPFL was estimated to be \$20,715,607. An expansion of the calculation is provided in Appendix E.

It should be noted that rapid fire suppression by the fire department could further limit the release of radiological material and thereby limit the fire loss attributed to ground area contamination.

Estimation of "Credible fire loss":

The MCFL/MPFL, in determining the inventory at risk (I) utilized the maximum radiological inventory that could be placed within each plywood container and remain contact handled. A more "credible" estimate is to base the inventory at risk (I) on the "expected" radiological inventory to be disposed in the LLW trenches. One means to estimate the "credible" inventory is to take the average Curie content of previous plywood boxes disposed in the LLW Burial Grounds and consider the average to be representative of future plywood container inventories. This results in a "credible fire loss of \$4,285,084. It should be noted that this "credible fire loss" does not meet the definition of the Maximum Credible Fire Loss (MCFL) as defined in DOE 5480.7A, but is provided to be a more realistic indicator of the resulting ground contamination that would be accounted as "fire loss potential"

This credible fire loss is still considered conservative since it assumes all of the inventory at risk is ⁶⁰Co, all of the exposed containers burn (i.e. no credit for fire retardant container characteristics), and there is no credit for Hanford Fire Department mitigation efforts.

12.0 FIRE DEPARTMENT/BRIGADE RESPONSE

12.1 BACKGROUND

The HFD consists of four fire stations covering the 1450 km² (560 mi²) Hanford Site. These stations are strategically located across the site to ensure minimum response time to all facilities. Front-line engines in all stations are aerial device/ pumpers, with additional pumpers for backup. HFD maintains 39 vehicles representing a diversified range of capabilities. Of these, 29 are specifically equipped fire/emergency response apparatus, 24 are first-line apparatus, and five are listed as backup (reserve) apparatus.

The present scenario for a Hanford Site Fire Emergency Response is to dispatch a single aerial device/pumper from the fire station closest to the incident with a backup aerial device/pumper from the next closest fire station to the incident. This provides a two-engine response. The first engine due constitutes what is termed "Initial Attack Response Capability."

First response will be for fire unless the initial alarm or call to HFD indicates another emergency. Other responses are for a medical emergency or for a hazardous material emergency.

HFD has an established mutual/automatic aid agreement with the surrounding jurisdictions. The agreement enables (and obligates) the HFD to augment its own fire and emergency medical resources in case of large fires, conflagrations, or other disasters. This agreement, known as the "Tri-Cities Mutual Aid Agreement," has been in existence at least since 1985 and includes the cities of Richland, Kennewick, and Pasco and the Fire Protection Districts of Benton County No. 1, Benton County No. 2, Benton County No. 3, Benton County No. 4, Benton County No. 5, Benton County No. 6, Franklin County No. 3, and Walla Walla County No. 5. Participation in the agreement is delivered using existing labor and equipment.

12.2 FIRE DEPARTMENT RESPONSE TO TRENCH FIRE

The response time of the fire department to the various burial ground areas is estimated to be 5 to 10 min. From discussions with HFD representatives, a fire in the trench would most likely be fought with hand held extinguishers or hose streams. For most trench fires, lay-in of fire department hand-held hose lines (if deemed necessary) would most likely occur from outside the trench. Water supplies for hose lines would have to be provided via fire department pumper/tanker due to the absence of fire hydrants in the vicinity of nearly all SWBG trenches.

TRU drums being retrievably stored in Burial Ground 218-W-4C, Trenches 1, 20, and 29 may contain unvented propane containers or other volatile hazardous waste which could result in violent container failure. Violent container failure could impact firefighter safety and possibly worker safety. The Hanford Fire Department has been alerted to this condition so that appropriate precautions can be taken should an event involving unvented containers or other volatile hazardous wastes occur and require controlling or mitigative action.

13.0 RECOVERY POTENTIAL

Since the SWBG is a storage/disposal site for waste, the resumption of operations is not considered to be a significant concern. Any postulated fire within a trench would be limited to that specific trench. However, contamination of other trenches due to dispersion of radiological material from a trench fire could occur. Beyond the initial fire department actions, recovery activities required include securing the remaining containers' contents, repackaging these contents, decontamination of the surrounding soil and containers, inspection of nearby containers, possible collection of fire department water runoff within the trench, and reassembly of the container arrays. For fires of the magnitude postulated in Section 6.0, these tasks could require a major effort extending over a period of many months.

14.0 POTENTIAL FOR A TOXICOLOGICAL, BIOLOGICAL, AND/OR RADIOLOGICAL INCIDENT DUE TO A FIRE

For TRU and MW, a significant exposure fire would have to be present to cause a hazardous or radiological incident. Precautions in the form of procedures or recommendations in this report are advised to minimize the exposure fire hazard to waste. Safeguards to eliminate or minimize an incident due to a fire include:

- Limiting the amount of waste that is left uncovered,
- Maintaining a fire break between the trenches and the surrounding areas,
- Limiting the quantity of tumbleweeds that accumulate in open trenches containing waste,
- Ensuring operations personnel are trained to minimize the risk of fire, and
- Ensuring operations equipment, the primary ignition and fuel source of an accidental fire in the trench, is only near the waste during operations.

Estimates of release of radiological material resulting from postulated fire scenarios are provided in Section 6.0, Description of Fire Hazards. Estimates of ground contamination resulting from the postulated fire scenarios are addressed in Section 11.0, Damage Potential. Dose impact to the public and onsite workers for similar postulated fires is addressed in *Solid Waste Burial Grounds Interim Safety Analysis* (WHC 1995a).

15.0 EMERGENCY PLANNING

The *Building Emergency Plan for the Burial Grounds* (WHC 1994b) was reviewed. The emergency plan covers the following buildings/structures or areas: 200 West Area Burial Grounds, 200 East Area Burial Grounds, 2727-W (Sodium Storage, Tanks), MO-223 (200 West Area Burial Ground Trailer), and the Radioactive Mixed Waste Land Disposal Facility (Trench 31).

Provisions addressing fires were reviewed.

The document has been revised to address the fire concerns associated with propane cylinders and volatile hazardous wastes that may be contained in the TRU drums. The following text changes/revisions were added:

- Section 6.1.5, Hazardous Material Spill, paragraph 2, "Fires or Explosions Involving Hazardous Materials:"

"A SWITS check of open trenches identified four trenches which contain exposed containers that were placed prior to November 23, 1987. Burial Ground 218-W-4C, Trenches 1, 20, and 29 contain exposed TRU drums which are suspected of containing unvented propane cylinders and/or other volatile hazardous materials. These drums, when exposed to an intense fire, may fail violently."

- Section 7.2.4, Fire and/or Explosion, paragraph 2:

"Due to danger of violent container failure, fires in the vicinity of TRU containers located in Trenches 1, 20, and 29 should not be fought by operations personnel. Rather, personnel should evacuate the trench immediately and notify the Fire Department."

Early notification of the fire department of a fire incident is critical to limiting the size of the fire and the release of radiological material. In order to ensure early notification of a trench fire during operations, written procedures have been modified to require that a reliable means for notifying emergency services be available to workers while working in the trenches.

16.0 SECURITY AND SAFEGUARDS CONSIDERATIONS RELATED TO FIRE PROTECTION

No security or safeguard barriers or procedures were noted that might compromise fire safety for these landfills; therefore, there are no security or safeguard issues related to fire protection for the SWBG. Classified waste is covered by the end of each shift. This action enhances fire safety.

17.0 NATURAL HAZARDS IMPACT ON FIRE SAFETY

17.1 FLOODS

The 200 West Area is located on a plateau 53 to 69 m (175 to 225 ft) above the highest elevation of the probable maximum flood postulated by the U.S. Army Corp of Engineers. The probable maximum flood in this situation requires severe climatic conditions in combination with a breach of Grand Coulee Dam. This breach scenario for the Grand Coulee Dam is from a hypothetical nuclear attack and is not projected to occur from any known natural event. It would result in a brief duration maximum flow of 227,000 m³/s (8,000,000 ft³/s) and flood elevations of 143 to 148 m (469 to 486 ft) in the 100 Areas. The 100 and 300 Areas as well as downstream cities along the Columbia River would be flooded. However, the 200 Area plateau would not be affected. With the 200 Area Fire Station on the 200 Area plateau, there is no postulated flood that would compromise fire safety.

17.2 TORNADOES

Hanford Meteorological Station and the National Severe Storm Forecast Center database list 21 tornadoes within a 161-km (100-mi) radius of the Hanford Site between 1916 and 1982. The recurrence interval cited is one per 146,000 yr. However, at least two tornadoes have been sighted within a 161-km (100-mi) radius since 1982. Maximum wind speeds for a design basis tornado used at the site are 145 km/h (90 mph). The differential pressure is equivalent to a 0.75 lbf/in² ambient pressure drop in three seconds, held for one second and returned to ambient at the same rate.

With the low frequency of tornadoes on the Hanford Site, no additional fire safety precautions are warranted to protect against tornadoes.

17.3 EARTHQUAKES

The Design Basis Earthquake (DBE) is taken to have a return period of 1,000 yr, which means the annual occurrence is 1.0 E-03. The repository siting group selected an application that gave 0.25 and 0.40 G as suggested preliminary maximum horizontal peak accelerations with 50% and 16% exceedance levels for use in preliminary design estimates. The Hanford Plant Standards specify a 0.13-G horizontal acceleration for the design basis earthquake for non-reactor structures having a moderate- or low-hazard safety classification.

Near-surface liquefaction is not expected as a result of a lack of saturated surface materials and the grading and compaction techniques that have been used. Landslides have and may continue to occur in the neighboring anticlines, but there is no evidence of this type of activity in the vicinity of the SWBG.

Earthquakes may cause toppling of the uncovered TRU drum arrays. If a fire and an earthquake did occur simultaneously, it is reasonable to assume that the drums breached by earthquake induced toppling would be burned and would be in addition to any fire induced container failure and burning. However, there is insufficient information available to assess the interaction of the combined effects of earthquakes and fire on the drum array. WHC-SD-WM-SARR-028, Rev. 1, suggests that a seismic event followed by an ensuing fire is considered to be extremely unlikely if not incredible (WHC 1995a).

18.0 EXPOSURE FIRE POTENTIAL

Range fire is the only postulated exposure fire potential to open trenches within the SWBG. Exposure fire potential risk is minimized by controlling tumbleweeds and other unwanted transient combustibles in trenches, and limiting the amount of uncovered waste. Fire propagation from one trench to an adjacent trench cannot be supported based on the very limited heat release rates, the substantial separation distance, and the geometry of the trenches, i.e. the separation of trenches by earth mounds.

19.0 RECOMMENDATIONS

Several issues of concern were identified as a result of the fire hazard analysis process and have been dispositioned as summarized below:

(1) It was identified that TRU drums being retrievably stored in Burial Ground 218-W-4C, trenches 1, 20, and 29 may contain unvented propane containers or other volatile hazardous waste which could result in violent container failure in an exposure fire. Cognizant Fire Department Personnel have been alerted to ensure that any pre-fire planning concerns can be addressed. The burial grounds building emergency plan has been revised to similarly address potential concerns that could impact worker safety.

(2) In order to enable early emergency service notification of a fire event within a trench, procedures have been revised to ensure that all workers have a reliable means of notifying emergency services while working in a SWBG trench.

(3) In order to minimize the potential for a fuel spill and/or fire involving equipment from becoming an exposure fire hazard to uncovered waste in the MW trenches (trenches 31 and 34), written procedures have been developed to ensure that operators are adequately trained in the use of the applicable equipment, use of hand-held extinguishers, response in the event of a fire, refueling, maintenance and storage of the equipment.

(4) Operational procedures have been revised to ensure that tumbleweeds and any other unplanned transient combustibles that enter the trench are removed or covered if there is uncovered waste present.

20.0 REFERENCES

- 10 CFR 71, 1992, Transportation of Radioactive Material, Code of Federal Regulations.
- 29 CFR 1926, 1993, General Requirements, Code of Federal Regulations.
- 40 CFR 261, 1990, Identification and Listing of Hazardous Waste, Code of Federal Regulations.
- 49 CFR 173, 1992, General Requirements for Shipments and Packagings, Code of Federal Regulations.
- Babrauskas, V., 1988, "Burning Rates", Section 2, Chapter 1, The SFPE Handbook of Fire Protection Engineering, P. DiNenno, Editor-in-Chief, National Fire Protection Association, Quincy, Massachusetts.
- DOE, 1988, Radioactive Waste Management, DOE Order 5820.2A, U.S. Department of Energy, Washington, D.C.
- DOE, 1989, General Design Criteria, DOE Order 6430.1A, U.S. Department of Energy, Washington, D.C.
- DOE, 1993, Fire Protection, DOE Order 5480.7 A, U.S. Department of Energy, Washington, D.C.
- NFPA 101, 1994, Code for Safety to Life from Fire and Buildings and Structures, National Fire Protection Association, Quincy, Massachusetts.
- Tewarson, A., 1988, "Generation of Heat and Chemical Compounds in Fires", Section 1, Chapter 13, The SFPE Handbook of Fire Protection Association, Quincy, Massachusetts.
- UBC, 1994, Uniform Building Code, International Conference of Building Officials, Whittier, California.
- WHC, 1988, Hanford Radioactive Solid Waste Packaging, Storage and Disposal Requirements, WHC-EP-0063, September 29, 1988.
- WHC, 1991, Contact-Handled Transuranic Waste Characterization Based on Existing Records, WHC-EP-0225, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1993a, Solid Waste Plant Operating Procedure. Receive and Store and/or Bury Radioactive Waste, SW-100-050, June 30, 1993, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1993b, Solid Waste Acceptance Criteria, WHC-EP-0063-4, November 1993, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1993c, Joyce, J.P., Solid Waste Burial Grounds Fire Hazard Analysis for Combustible Loadings for TRU 55-Gallon Drums, October 13, 1993, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1993d, Interim Stabilization of Radioactive Surface Contamination Associated with UN-216-E-44, WHC-SD-DD-TI-078, Rev. 0), April 1993, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1994a, Building Emergency Plan for Burial Acceptance and Receiving Trenches, WHC-IP-0263-BART, Draft September 15, 1994, Westinghouse Hanford Company, Richland, Washington.

- WHC, 1994b, Building Emergency Plan for Burial Ground, WHC-IP-0263-BF, September 17, 1994, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1994c, Solid Waste Burial Grounds Interim Safety Analysis, WHC-SD-WM-SARR-028, Rev. 0, September 1994, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1994d, Radiological and Chemical Source Terms for Solid Waste Operations Complex/A5228, WHC-SD-W306-TI-001, Rev. 1, November 10, 1994, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1994e, Solid Waste Plant Operating Procedure, SW-100-171, December 29, 1994, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1994f, Preliminary Fire Hazards Analysis for PUTDR and TRU Trenches in the Solid Waste Burial Ground, WHC-SD-WM-FHA-009, Rev. 0, December 1994, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1994g, A Method for Estimating Ground Areas Contaminated by a Postulated Fire in a Facility Containing Radioactive Material, WHC-SD-GN-TI-20004, Rev. 0, September 1994, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1995a, Solid Waste Burial Grounds Interim Safety Analysis, WHC-SD-WM-SARR-028, Rev. 1, March 1995, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1995b, Solid Waste Burial Grounds Interim Safety Basis, WHC-SD-WM-ISB-002, Rev. 0, March 1995, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1995c, Fire Hazard Analysis of the Radioactive Mixed Waste Trenches, WHC-SD-WM-FHA-010, Rev. 0, April 13, 1995, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1995d, Solid Waste Information Tracking System (SWITS) Search for the Fire Hazard Analysis for the Low Level Burial Ground, Internal Memo No. 87250-95-040 from L.J. Gaschott, June 30, 1995, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1995e, Solid Waste Plant Operating Procedures, SW-100-330, February 6, 1995, Westinghouse Hanford Company, Richland, Washington.

APPENDIX A

Solid Waste Burial Grounds Inventory

(WHC-SD-SARR-028, Rev. 1)

Low-Level Waste Packages

Waste package name	Waste type	Dimensions	Weight (kg)	Rad Inventory	Material form	Additional Information
Glove boxes	LLW Category 1 Uncovered*	28 glove boxes of various sizes total 3,776 ft ³ (107 m ³)	Total weight 15,545 kg (34,200 lb)	6 boxes contain 0.01 g Pu total; 12 boxes contain 0.02 g Pu total; 5 boxes contain 0.03 g Pu 5 boxes contain 0.05 g Pu total; 0.11 g Pu	Stainless steel glove boxes and exhaust tunnel sections; ports and windows covered with plywood; double-plastic wrapped; 57X steel, 1X wood, 2X plastic	Units are bonded to skids and boxed. Units have been decontaminated to non-ILW levels. Placed in 218-U-4C, trench 14 in 1984-85 Sources: SIMQ records
Steam generator	LLW Category 1 Uncovered*	3.7 m (12-ft) diameter, 13.7 m (45 ft) long 118.9 m ³ (4,200 ft ³)	Total weight 219,539 kg (484,000 lb)	60 Cl ⁶⁰ Co	10X stainless steel 90X steel	Self-contained cask. Placed in 218-U-4C, trench 14 in 1987 Sources: SIMQ records
Boxes	LLW Uncovered*	151 boxes 541 m ³ (19,105 ft ³)	Total weight 159,532 kg (351,700 lb)	93,946 Cl, ⁶⁰ Co, and ¹³⁷ Cs gr	50X combustible 50X noncombustible	Buried in 218-U-5, trench 27 Sources: SIMQ records
Drums	LLW Uncovered*	446 208-L (55-gal) drums 94 m ³ (3,308 ft ³)	Estimated total weight 30,345 kg (66,900 lb)	13,025 Cl, primarily ¹³⁷ Cs and ⁶⁰ Co	50X combustible 50X noncombustible	Buried in 218-U-5, trench 22 Sources: SIMQ records
Equipment bulk waste	LLW Uncovered*	9 items of various sizes 30 m ³ (1,362 ft ³)	Total weight 102,377 kg (225,703 lb)	0.095 Cl 30 g depleted U	50X combustible 50X noncombustible	Placed in 218-U-3A, trench 49 Sources: SIMQ records
Shipping port reactor vessel	LLW Uncovered*	1 cask, 5.4 m (17 ft 8 in) in diameter by 12.4 m (40 ft 7 in) long 9,946 ft ³	Total weight 815,575 kg (1,798,000 lb)	18,467 ⁶⁰ Co, ⁵⁴ Mn, ⁶⁵ Ni	49X heavy metal 50X concrete 1X lead	Placed in 218-U-4C, trench 14 Sources: SIMQ records
Pu glovebox hoods in steel boxes	LLW Uncovered*	2 boxes 15.2 m ³ (536 ft ³)	Total weight 4,872.1 kg (10,730 lb)	18,000 Cl, primarily ¹³⁷ Cs (as of 9-81)	90X metal 5X plastic 5X glass	Placed in 218-U-4C, trench 14 Sources: SIMQ records
KAPL Casks	LLW Uncovered*	7 casks, 2.4 m (8 ft) in diameter by 2.6 m (8 ft 8 in) high 81 m ³ (2,859 ft ³)	Total weight 202,305.6 kg (446,000 lb)	28 Cl, primarily ⁶⁰ Co	80X concrete 3X metal 12X resin	Placed in 218-U-4C, trench 14 Sources: SIMQ records

Low-Level Waste Packages

Waste package name	Waste type	Dimensions	Weight (kg)	Rad inventory	Material form	Additional information
100'W storage tank	LLW Uncovered ^a	1 tank, 3.7 m (12 ft) in diameter by 30.1 m (15 in) high, 48 m ³ (1,696 ft ³)	Total weight 1,816.4 kg (4,000 lb)	0.1 Ci tank covered with asbestos insulation	98% metal 2% cloth	Placed in 21B-W-4C, trench 14 Source: SWBG records
REDOX tanks	LLW One tank is uncovered ^a	4 tanks, 7.6 m (25 ft) in diameter by 5.3 m (17.5 ft) high, 945.2 m ³ (33,380 ft ³)	Total weight 23,587.2 kg (52,000 lb)	19,051 g Th 9.0 Ci	90% metal 8% silica gel 2% absorbent	Buried in 21B-W-4C, trench 14 Source: SWBG records
FFTF casks	LLW Uncovered	3 casks, 2.1 m (7 ft) in diameter by 4.3 m (14 ft) high, 45.8 m ³ (1,616.3 ft ³)	Total weight 136,080 kg (300,000 lb)	58,095 Ci, primarily ⁶⁰ Co	95% concrete 5% metal	Placed in 21B-W-4C, trench 14 Source: SWBG records
Classified waste Naval core barrels	LLW Covered	65 containers of various sizes 52,336 ft ³ (1,482 m ³)	Total weight (3,175,456 kg (7,000,682 lb)	1,107,157 Ci, primarily ⁶⁰ Co	100% noncombustible	Buried in 21B-W-4C, trench NC Source: SWBG records
Classified waste Naval pumps	LLW Uncovered ^a	37 containers, 1.1 m (3.5 ft) in diameter by 2.7 m (8 ft, 10 in) long, 333 m ³ (11,759.7 ft ³)	Total weight 374,255 kg (825,077.2 lb)	15 Ci, primarily ⁶⁰ Co and ⁵⁵ Fe	39% metal 5% nonmetal 2% plastic 5% absorbent 49% pyrofoam	Placed in 21B-E-4C, trench NC Source: SWBG records
Classified waste Naval core baskets	LLW Uncovered ^a	2 containers, 2.9 m (9 ft 7 in) in diameter by 5 m, (16.5 ft), 68 m ³ (2,401 ft ³)	Total weight 320,588 kg (706,763.7 lb)	138,000 Ci, primarily ⁶⁰ Co, ⁶³ Ni, and ⁵⁵ Fe	96% metal 4% absorbent	Placed in 21B-W-3AE, trench 08 Source: SWBG records
Classified waste Naval closure heads	LLW Uncovered ^a	2 containers, 3.1 m (10 ft 1 in) in diameter by 2.2 m (7 ft 4 in) long, 44 m ³ (1,554 ft ³)	Total weight 70,766 kg (156,009.7 lb)	4 Ci, primarily ⁵⁵ Fe	100% metal	Placed in 21B-W-3AE, trench 08 Source: SWBG records
IMI casks	LLW Covered	16 liners, 6.34 m ³ (224 ft ³) 16 casks, 184 m ³ (6,496 ft ³)	Weight - liners 8,201 kg (18,080 lb) Weight - casks 477,456 kg (1,052,610 lb)	495,387 Ci, primarily ¹³⁷ Cs and ⁹⁰ Sr	95% concrete 5% metal	Buried in 21B-W-3A, trench 37 Source: SWBG records

Low-Level Waste Packages

Waste package name	Waste type	Dimensions	Weight (kg)	Rad inventory	Material form	Additional information
Canoga Park MALLAM casks	LLW Covered	3 containers, 12.7 cm (5 in) in diameter by 4.3 m (14 ft) long, 1.03 m ³ (36.3 ft ³)	Total weight, 1,315.4 kg (2,900 lb)	120 Ci, primarily ¹³⁷ Cs and ¹³⁴ Cs	98X metal 2X cardboard	Buried in 218-W-3A, trench 51 Source: SWBG records
Ion exchange cylinders from 100-W	LLW Covered	About 41 shipments 1.8 m ³ (64 ft ³) per shipment	Weight, 2,177 kg (4,800 lb) per shipment	18 to 180 Ci per shipment primarily ¹³⁷ Cs and ⁹⁰ Sr	10X metal 90X resins	Buried in 218-W-3A, trenches Source: SWBG records
Drag-off concrete boxes from 100-W (West burial)	LLW Covered	14 total drag-off boxes, 476 m ³ (23,856 ft ³)	Total weight, 501,473 kg (1,106,000 lb)	Dose rate of 60 to 4,000 mrem/h	3X combustible 97X noncombustible	Buried in 218-W-3AE, trench 02 Source: SWBG records
Samarium ball casks from 100-W	LLW Covered	5 total concrete casks, 36.4 m ³ (580 ft ³)	Total weight, 81,647 kg (180,000 lb)	2,255 Ci primarily ¹⁵⁴ Eu and ¹⁵² Eu	10X metal 90X concrete	Buried in 218-W-3A, trench 40 Source: SWBG records
Reactor fuel cask	LLW Covered	3 total casks, 12 m ³ (405 ft ³)	Total weight, 76,204 kg (168,000 lb)	135 Ci primarily ⁶⁰ Co and Zr/ ⁹⁵ Nb	100X noncombustible	Buried in 218-W-3A, trench 40 Source: SWBG records
Unit 1 calsion	LLW Partial covered and plugged	1 calsion containing 2 shipments, 2 m ³ (53 ft ³)	Total weight, 618 kg (1,362 lb)	123 Ci primarily ⁶⁰ Co, ¹⁵⁴ Eu, and ¹⁵² Eu	100X noncombustible	Buried in 218-W-4B, trench 14 Calsion unit #1 Source: SWBG records
Graphite blocks in boxes	LLW Covered	1 208-L (55-gal) drum, 0.21 m ³ (7.4 ft ³)	Total weight, 589.7 kg (1,300 lb)	0.05 Ci primarily ¹⁴ C, ⁶⁰ Co, and ¹³⁷ Cs	88X concrete 10X metal 1X graphite block 1X plastic	Buried in 218-W-5, trench 22 Source: SWBG records
Mitman casks	LLW Covered	Mitman liner, 1.4 m (4.6 ft) in diameter by 1.5 m (5.1 ft) high, 30.2 m ³ (1,066 ft ³)	Total weight, 71,860 kg (158,424 lb)	17,824 Ci primarily ¹³⁷ Cs and ⁹⁰ Sr dose rates from 8 to 760,000 mrem/h	31X metal 1X plastic 2X rubber 66X grout	Buried in 218-W-3AE, trench 02 Source: SWBG records
Drag-off concrete boxes from 100-W (East burial)	LLW Covered	31 concrete boxes in various sizes, 373 m ³ (13,175 ft ³)	Total weight, 179,169 kg (395,000 lb)	Dose rate from 4.5 to 9,000 mrem/h primary isotope is ⁶⁰ Co	100X noncombustible	Buried in 218-E-10, trenches 04, 06, 07, 08, 09, 11, 12, 16 Source: SWBG records

Low-Level Waste Packages

Waste package name	Waste type	Dimensions	Weight (kg)	Rad inventory	Material form	Additional Information
Drag-off concrete boxes from 221 B (East Burial)	LLW Large equipment, filter, and drummed waste Covered	68 concrete boxes in various sizes 3,493 m ³ (123,367 ft ³)	Total weight 1,785,733 kg (3,936,868 lb)	Dose rates from MA to 10,000,000 mrem/h primarily isotopes are Cs and Sr	80% noncombustible combustible	Buried in 218-E-10, trenches 04, 06, 07, 08, 09, 11, 12, 16 Source: SMO records
Drag-off concrete boxes from 225 B (East Burial)	LLW Large equipment, filter, and drummed waste Covered	8 concrete boxes in various sizes 250 m ³ (8,840 ft ³)	Total weight 159,211 kg (351,000 lb)	Dose rates from 50 to 200,000 mrem/h primarily isotopes are Cs and Sr	100% noncombustible	Buried in 218-E-10, trenches 04, 06, 07, 08, 09, 11, 12, 16 Source: SMO records
Drag-off concrete boxes from PUMEX (East Burial)	LLW Large equipment, filter, and concrete blocks Covered	46 concrete items in various sizes 2,531 m ³ (89,380 ft ³)	Total weight 1,332,509 kg (2,937,480 lb)	Dose rates from MA to 60,000 mrem/h, primary isotopes are Cs and Sr	50% metal 50% concrete	Buried in 218-E-10, trenches 04, 06, 07, 08, 09, 11, 12, 16 Source: SMO records
Drag-off concrete boxes from Tank farm (East Burial)	LLW Large equipment, filter, and concrete blocks Covered	14 concrete items in various sizes 495 m ³ (17,484 ft ³)	Total weight 253,177 kg (558,160 lb)	Dose rate from MA to 5,000 mrem/h, primary isotopes are Cs and Sr	100% noncombustible	Buried in 218-E-10, trenches 04, 06, 07, 08, 09, 11, 12, 16 Source: SMO records
Large equipment burial in concrete boxes from 221F5 (cleaned)	LLW Covered	2 concrete boxes in various sizes 79 m ³ (2,800 ft ³)	Total weight 35,562 kg (78,400 lb)	Dose rates from 1 to 5,000 mrem/h, primarily Cs	100% noncombustible	Buried in 218-E-10, trenches 04, 06, 07, 08, 09, 11, 12, 16 Source: SMO records

Low-Level Waste Packages

Waste package name	Waste type	Dimensions	Weight (kg)	Rad inventory	Material form	Additional information
Hazardous waste, case-by-case	LLW Covered	72 208-L (55-gal) drums, 35 322-L (65-gal) drums, 1 cask, 1 metal box, 27 m ³ (947 ft ³)	Total weight 31,698 kg (69,882 lb)		Xylene, methanol, tar, mercury, beryllium, naphthylamine tritium, pseudocumene, oil, lead shielding, barium, chromium, naphthalene, cadmium, acetonitrile, toluene, cyclohexane, and lead	Buried in 218-W-3A, trench 16 Source: SWSG records
Hazardous waste, case-by-case	LLW Covered	61 wooden boxes, 49 208-L (55-gal) drums, 15 casks, 2 concrete boxes, 4 metal boxes, 225 cardboard boxes, 20 filters, 296 m ³ (10,452 ft ³)	Total weight 461,620 kg (1,017,700 lb)		Lead, lead shielding, zirconium, chromium, uranium hexafluoride, mercury, vinyl chloride, paint thinner, etched lime, and asbestos	Buried in 218-W-4C, trenches 48, 53, 58 Source: SWSG records
183N hazardous waste	LLW Covered	3,291 55-gal drums, 693 m ³ (24,459 ft ³)	Total weight 880,514 kg (1,941,200 lb)	126,567 g enriched uranium	10X poly 70X sludge 15X metal 3X plastic	Buried in 218-W-3AE, trench 05 Source: SWSG records
Tank farm pumps and jumpers	LLW Covered	58 pumps and jumpers, 348 m ³ (12,444 ft ³)	Total weight of items with lengths up to 52 ft, 48,736 kg (107,441 lb)	Dose rate range from 0.5 to 18,000 mrem/h, 6,302 Ci primarily ¹³⁷ Cs and ⁹⁰ Sr	15X noncombustible 85X combustible	Buried in 218-W-3A Buried in 218-E-12a Source: SWSG records
Category 3 waste	LLW or TRU Uncovered	447 208-L (55-gal) drums, 94 m ³ (3,306 ft ³)	Estimated total weight 38,526 kg (84,930 lb)	3.6695 g Pu 0.02289 g ²³⁸ Pu	50X combustible 50X noncombustible	Stored in 218-W-4C, trench 24 Source: SWSG records
Organic-free liquid	LLW Retrievable Covered	37 208-L (55-gal) drums, 8 m ³ (275 ft ³)	Total weight 3,187 kg (6,850 lb)	0.0002 g Pu	18X oil 1X metal 75X absorbent 6X poly	Stored in 218-W-4C, trench 07 Source: SWSG records
K-3 filters in concrete boxes - grouted (upcoming work)	LLW To be backfilled*	2 boxes, 332 m ³ (4,651 ft ³)	Total weight 52,345 kg (115,400 lb)	Dose rate of 3,000 mrem/h, 800 Ci, primarily ¹³⁷ Cs and ⁹⁰ Sr	5X combustible 95X noncombustible	To be buried in 218-E-10, trench 09 **

* "Backfilled" means "covered".

** "Buried" means "placed".

Low-Level Waste Packages

Waste package name	Waste type	Dimensions	Weight (kg)	Rad inventory	Material form	Additional information
Low-level casks	LLW Covered	6 casks containing 3.0- to 18.9-L (1 to 5-gal.) cans, 29" (1.021 ft.)	Total weight 25,471 kg (56,155 lb)	1,748 g Pu, 2,974,465 g U, 64,232 g Th, 139,969 g fissionable Cs, Sr, and Co	100% noncombustible	Buried in 218-U-4B, trench 14 casks 1 to 6 Source: SWMG records
Alaska casks	LLW Uncovered	2 casks, 0.9 m (3 ft) in diameter by 1.2 m (4 ft) high, 2 m ³ (73 ft ³)	Total weight 3,662 kg (8,074 lb)	24 Ci as of 1988, 55 primary isotopes Cs, Sr, and Co	100% metal, 2,812-kg (6,200-lb) lead shielding	Placed in 218-U-4C, trench 14 Source: SWMG records
Ion Exchange Modules	LLW Uncovered	11 total cement modules 1.2 m (4 ft) high, 2 m ³ (73 ft ³)	420,861 lb (190,990 kg)	1,400.4 curies primarily Cs and Sr	Ion Exchange Resins = 10X Concrete = 50X Metal = 40X	Buried in 218-U-4C Trench 25 ***
Irradiated Waste	LLW Covered	~100 sleeves in MICs with volume of 1.2 m ³ (42.4 ft ³)	1,910 kg (4,200 lb)	Up to 18,000 Ci ³ h	Sorbed onto a molecular sieve within a stainless steel container and placed into a MIC	Ongoing work - MICs to be placed in 218-U-3AE, trench 26E, or other trenches in 200 West Area burial grounds

*to be backfilled

FFIF = Fast Flux Test Facility
MIC = high integrity containers.
KAPL = Knolls Atomic Power Laboratory.
LLW = low-level waste.
PUREX = Plutonium-Uranium Extraction (facility).
REDOX = Reduction Oxidation (facility).
SMWG = Solid Waste Burial Ground.
TNI = Three Mile Island.
TU = transparent.

** Table revised to indicate 8 total cement modules instead of 11.
*** "Buried" means "placed".

Mixed Waste Packages

Waste package name	Waste type	Dimensions	Weight	Rad Inventory	Material form	Additional Information
Classified waste Naval submarine reactor compartment	HM Uncovered*	Cylinder containing nominal per unit 900 m ³ (32,000 ft ³)	Nominal weight per unit 910,000 kg (2,000,000 lb)	Nominal per unit 12 kg PCB 12,000 kg asbestos 91,000 kg lead 53,000 Ci HFP 86 mCi isotopes	96% metal 1% lead 2% asbestos 1% PCB and absorbents	Placed in 210-E-129, trench 96 Source: SMSG records
Mixed waste	HM Uncovered*		--	--	--	Placed in 210-U-5 HM disposal trenches 31, 32 (future operation)

*to be backfilled.
HFP = mixed fission products.
HM = mixed waste.
PCB = polychlorinated biphenyl.
SMSG = Solid Waste Burial Ground.

Mixed Waste Packages

Waste package name	Waste type	Dimensions	Weight	Rad Inventory	Material form	Additional Information
IRU fuel waste in shielded drums	IRU Retrievable Covered	13 208-L (55-gal) drums; 2.7 m ³ (96 ft ³)	Total weight, 13,572 kg (29,921 lb)	13 g Pu total, 17,174 g U, 364 Ci HfP	50% concrete 10% metal 40% lead	Stored in 208-L (55-gal) drums in 218-U-4C, trench 07, covered with 1.2 m (4 ft) of dirt Source: SMD records
Irradiated fuel waste in concrete liners (GE liners)	IRU Retrievable Covered	22 concrete vaults, total 110 m ³ (3868 ft ³)	Total weight, 252,774 kg (558,000 lb)	4,704 g Pu total 1,500 g Nat U 20,900 g Enr U 18,100 g Dep U 237,000 Ci HfP	100% noncombustible	Stored in concrete vaults in 218-U-3A, trench 0A, covered with 1.2 m (4 ft) of dirt Source: SMD records
IRU waste in 416-L (110-gal) drums (two 208-L (55-gal) drums welded end to end)	IRU Retrievable Covered	21 416-L (110-gal) drums; 0.8 m ³ (310.8 ft ³)	Total weight, 3,404 kg (7,945 lb)	7,900 g Pu total	100% noncombustible	Stored in 416-L (110-gal) drums in 218-U-4C, trench 01, covered with 1.2 m (4 ft) of dirt Source: SMD records
IRU waste in bird cages in 416-L (110-gal) drums (55-gal) drums welded end to end)	IRU Retrievable Covered	15 416-L (110-gal) drums; 6.3 m ³ (222 ft ³)	Total weight, 2,041 kg (4,500 lb)	6,287 g Pu total	100% noncombustible	Stored in 416-L (110-gal) drums in 218-U-4C, trench 01, covered with 1.2 m (4 ft) of dirt Source: SMD records
IRU drums	IRU Retrievable Uncovered	2,056 208-L (55-gal) drums; 432 m ³ (15,247 ft ³)	Estimated total weight, 177,191 kg (390,640 lb)	26,199 g Pu total, 73,307 Ci HfP, 15,894 g Dep U, 6,105 g Enr U, 1 g 241Am	50% combustible 50% noncombustible	Stored in 208-L (55-gal) drums in 218-U-4C, trenches 01, 20, 29 Source: SMD records
IRU boxes	IRU Retrievable Uncovered	24 boxes various sizes, 128 m ³ (4,460 ft ³)	Total weight, 40,560 kg (89,356 lb)	2,023 g Pu total	50% combustible 50% noncombustible	Stored in boxes in 218-U-4C, trenches 01, 20, 29 Source: SMD records
IRU Caissons (4)	IRU Retrievable Covered	4 caissons containing 3.8-L (1-gal) paint cans, 23 m ³ (824 ft ³)	Total weight, 20,557 kg (45,320 lb)	6,175 g Pu, 87,340 g U, 17,870 g Th, 99,410 Ci (80% naturally 90Sr, 137Cs, Co, and 99Sr)	100% noncombustible	Stored in 218-U-4B, trench 14 Caissons Alpha 1 to Alpha 4 Source: SMD records
ENR-II casks	IRU Retrievable Covered	5 casks, 3.5 m ³ (123 ft ³)	Total weight, 11,315 kg (24,945 lb)	9,811 g Pu, 31,646 g U, 98,908 Ci HfP	100% metal including lead	Stored in 218-U-3A, trench 16 Source: SMD records

Transuranic Waste Packages

Waste package name	Waste type	Dimensions	Weight	Rad inventory	Material form	Additional information
EAH-II casks Irradiated fuel waste from IMEL, FTRF, and CEIS	TRU Retrievable Uncovered	34 casks, 23.6 m ³ (833 ft ³)*	Total weight, 84,823 kg (187,000 lb)	32,441 g Pu, 151,278 g U	100% metal including lead	Stored in 21B-U-4C, trench 01 Source: SIMO records
Zr Muffle casks	TRU Retrievable Covered	10 casks, 4.2 m ³ (150 ft ³)	Total weight, 2,903 kg (6,400 lb)	16 g Pu 2,000 g enriched U, 36,000 cf (157 Ca)	50% Zr muffle 25% lead 25% metal	Stored in 21B-U-4C, trench 01 Source: SIMO records
105 M cask	TRU Retrievable Uncovered	1 cask, 3 m ³ (28.5 ft ³)	Total weight, 3,277 kg (7,225 lb)	48 g 243Am 48 g 242/243Pu 6 g 238Pu 69 g 239Pu 150 cf HFP	100% noncombustible	12 Am target elements; stored in 21B-U-4C, trench 01 Source: SIMO records
Ion exchange drums 100 M	TRU Retrievable Covered	Containers, drums, and boxes 50 m ³ (1,764 ft ³)	Total weight, 22,871 kg (50,422 lb)	9,102 g Pu	Water (filters placed in 200-L (55-gal) drums and wooden boxes	Stored in 21B-U-3A, trenches 23, 30, 32, 34 Source: SIMO records
PA cans	TRU Retrievable Uncovered	79 containers of various sizes, 13 m ³ (462 ft ³)	Total weight, 9,824 kg (21,658 lb)	22 g Pu	100% metal	Stored in 21B-U-4C, trench 20 Source: SIMO records
2-9 drums	TRU Retrievable Covered	702 200-L (55-gal) drums 147 m ³ (5,195 ft ³)	Total weight, 51,436 kg (113,396 lb)	59,400 g Pu	95% soil 4% metal 1% plastic	Stored in 21B-U-4C, trench 01 Source: SIMO records
TRU FFP boxes	TRU Retrievable Covered	112 boxes of various sizes 2,965 m ³ (104,720 ft ³)	Total weight, 1,094,972 kg (2,414,000 lb)	6,925 g Pu	10% combustible 90% noncombustible	Stored in 21B-U-3A, trench 17 Source: SIMO records
TRU FFP boxes	TRU Retrievable Covered	73 boxes of various sizes 1,917 m ³ (67,713 ft ³)	Total weight, 343,844 kg (755,930 lb)	8,471 g Pu	10% combustible 90% noncombustible	Stored in 21B-U-4C, trench 07 Source: SIMO records
Babcock tanks	TRU Retrievable Covered	22 boxes or tanks, 120 m ³ (4,235 ft ³)	Total weight, 40,443 kg (89,135 lb)	1,372 g Pu	100% noncombustible	Stored in 21B-U-4C, trench 20 Source: SIMO records

* Table revised to indicate 31 casks instead of 34.

Transuranic Waste Packages

Waste package name	Waste type	Dimensions	Weight	Rad inventory	Material form	Additional information
Classified TRU	TRU Retrievable Covered	1,036 208-L (55-gal) drums, 218 m ³ (7,683 ft ³)	Total weight, 122,920 kg (270,993 lb)	2,116 g Pu, 53,005 g Nat U, 13,847,010 g Dep U, 1,026 g Enr U	15% combustible 85% noncombustible	Stored in 218-W-4B, trench 07 Stored in 218-W-3A, trenches 04, 05, 08, 14, 19 Source: SWBG records
Ra-Ba neutron source	TRU Retrievable Uncovered	One 208-L (55-gal) drum, 0.21 m ³ (7.5 ft ³)	Total weight, 148 kg (325 lb)	0.25 g ²²⁶ Ra	28% noncombustible 72% combustible (lead shielding 91 kg)	Stored in 218-W-4C, trench 01 Source: SWBG records
Ra-Ba neutron source	TRU Retrievable Covered	One 0.53-m- (1.7-ft-) dia by 0.64-m (2.1 ft) cask 0.57 m ³ (20.1 ft ³)	Total weight, 1,570 kg (3,461 lb)	2.5 g radium 2 Ci radon	100% metal 0.745 kg cadmium 0.165 kg beryllium 1,520 kg lead	Stored in 218-W-3A, trench 16 Source: SWBG records
Pu-Ba sources	TRU Retrievable Uncovered	One 208-L (55-gal) drum, 0.21 m ³ (7.5 ft ³)	Total weight, 93 kg (205 lb)	7.9 g Pu, ²³⁸ Pu 1.14 g ²³⁸ Pu	45% vermiculite 5% plastic 50% metal	Stored in 218-W-4C, trench 04 Source: SWBG records
Category 3 waste	LLW or TRU Retrievable Uncovered	447 208-L (55-gal) drums 94 m ³ (3,308 ft ³)	Estimated total weight, 30,524 kg (67,930 lb)	3.6695 g Pu, ²³⁸ Pu 0.02259 g ²³⁸ Pu	50% combustible 50% noncombustible	Stored in 218-W-4C, trench 24 Source: SWBG records
Organic-free liquid	TRU Retrievable Covered	30 208-L (55-gal) drums, 6 m ³ (223 ft ³)	Total weight, 3,173 kg (6,995 lb)	161 g Pu	Poly containers with oils absorbed on pads 100% combustible	Stored in 218-W-4C, trench 07 Source: SWBG records

EBR-II = Experimental Breeder Reactor No. 2.

FFTF = Fast Flux Test Facility.

FRP = fiberglass-reinforced plastic.

GE = General Electric.

GETR = General Electric test reactor.

INEL = Idaho National Engineering Laboratory.

LLW = low-level waste.

MFP = mixed fission product.

PR = Product Receiver.

SWBG = Solid Waste Burial Ground.

TRIQA = Training, Research and Isotope production Reactor-General Atomic.

TRU = transuranic.

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APPENDIX B

**Estimation of Radiological Release Potential,
Ground Area Contamination, and Cleanup Costs
Associated with a Flammable Liquid Pool Fire
in TRU Trench 29**

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Estimation of Radiological Release Potential and Ground Area Contamination Resulting From Flammable Liquid Pool Fire in Burial Ground 218-W-4C, TRU Trench 29

Step (1) Determine curie content release potential by determining

- Radionuclide Concentration/Container,
- Number of Containers, and
- Inventory as risk (I) in curies.

For purposes of estimating radionuclide release, it is assumed that the fire involves 100% of the curie content of all the containers which experience lid loss. Twenty-six kg of combustible contents are assumed to be present in each container. For lid seal failure, 1 kg of combustibles are expected to be lost due to pyrolysis but without active burning (LLNL 1993). There was no explicit guidance identified for accounting for the release of radiological material associated with lid seal failure as it relates to ground contamination. In the absence of guidance, it is assumed that 1/26 (0.04) of the drum radiological inventory is released.

Postulated for Trench 29: 24 drums experience lid loss
 114 drums experience lid seal failure

From review of the report on Radiological and Chemical Source Terms for Solid Waste Operations Complex (WHC 1994a) and consultation with knowledgeable Solid Waste Management Facility personnel, the estimated plutonium equivalent curies (PECi) value of 0.175 PECi/g TRU is used to estimate the curie content of the TRU within the TRU drums. From review of the report (WHC 1994a), the average 55-gal TRU drum contains 24 g of TRU. However, WHC-SD-SARR-028, Rev. 1 indicates that the bin-weighted average for Trench 29, Module 6 is 37.7 g of TRU (WHC 1995). Using this value,

The total curie inventory considered to be at risk, I, is given by:

$$\begin{aligned} I &= (\text{quantity of TRU in grams}) \times (\text{PECi/gram}) \times (\text{no. of drums}) \\ &= (37.7\text{g}) \times (0.175 \text{ PECi/g}) \times (24) + \\ &\quad (37.7\text{g}) \times (0.175 \text{ PECi/g}) \times (0.04 \times 112) \\ &= 158.34 + 29.56 \\ I &= 187.9 \text{ PECi} \end{aligned}$$

Step (2) Determine Minimum Contamination Limit, C, in Ci/m² for 200 West Area. The Minimum Contamination Limit, if exceeded, would require cleanup.

From review of the referenced report (WHC 1994a), Pu-239 represents 83.95 of the weight percent of the source term and Pu-240 represents 12.97% of the weight percent of the source term. From consultation with knowledgeable Solid Waste Management Facility personnel, the accessible solid concentration limits for Pu-239 are used as the minimum contamination limit, which is also the value for Pu-240. This value, identified in WHC-CM-7-5 (WHC 1994c), is given as 1.9E+02 pCi/g.

$$\begin{aligned} C &= (1.9\text{E}+02 \text{ pCi/g}) \times (1.6 \text{ g/cm}^3 \times 10^{-12} \text{ Ci/pCi}) \times (10^4 \text{ cm}^2/\text{m}^2) \\ &\quad \text{for a soil depth of 1 cm} \end{aligned}$$

$$C = 3.04 \text{ E-}06 \text{ Ci/m}^2$$

Step (3) Determine area of contamination.

Utilize methodology developed by D. Himes (WHC 1994b),

Method Assumptions:

- Estimation of releases as a function of particle fall velocity,
- Estimation of equilibrium plume height, by calculation fire heat generation rate and using an established plume model,
- Meteorological conditions are pasquill F stability with a reference (10m) wind speed of 1 m/s. Note that pasquill stability classes are used to define meteorological atmospheric conditions and typically range from A to F. For materials with a deposition velocity of zero and release point at or very near ground level, the maximum concentration is always associated with "F" stability (LLNL 1994). For his formulation, Himes has 'arbitrarily' selected "F" stability, and suggests that other combinations of meteorology conditions could produce somewhat larger contaminated areas, but also indicates that the results are a highly approximate estimate and that the source term contributes the greatest uncertainty.
- Fire's rate of heat release = $Q'/A = 397 \text{ kw/m}^2$ or $9.48\text{E}+04 \text{ cal/m}^2\text{s}$ (35 BTU/ft²s)

Problem Assumptions

- Fire area equals the number of container lid areas postulated to fail. Note that the flammable liquids spill/fire does not contain radiological material. The flammable liquid fuel fire is presumed to be fully consumed at or about the time of container failure, and, thus, is not included as part of the fire area assumed for this calculation.
- Minimum level of Contamination, C, is determined from accessible soil concentration limits identified above. This is the radiological concentration limit. Concentrations above this limit require cleanup. Concentrations below this limit do not.
- I is the radiological at-risk inventory identified above.

From Himes, the equation for determining the downwind extent of the contour corresponding to a minimum contamination level, C, is:

$$x_L = [64.9 \times (I/C) \times A_F^{0.8407}]^{-1/m} \quad (\text{Equation 1})$$

where:

x_L = maximum downwind extent (m)

I = at-risk inventory (Curies)

C = minimum contamination level (Ci/m²).

A_F = area of fire, assumed to be the no. of container lid areas postulated to fail (24 x 0.27 m²)

$$= 6.48 \text{ m}^2$$

m = unitless value determined by:

$$m = -(0.02940 \ln A_F + 3.248) \quad (\text{Equation 2})$$

Solving Equation 2:

$$m = -3.303$$

Solving Equation 1:

$$x_L = 1,300.2 \text{ m}$$

From Himes, the equation for determining area of the contour corresponding to a minimum contamination level, C , is:

$$A_C = 0.0724[(-m)^{0.5} (x_L^{1.903})] \quad (\text{Equation 3})$$

Solving Equation 3:

$$A_C = 110,957 \text{ m}^2$$

Using the same unit cost value as that referenced in WHC-SD-GN-TI-20004 (WHC 1994b), a clean up unit value of \$5.49/m² is assumed.

At \$5.49/m², initial clean-up costs are calculated to be: \$609,153.

Other Costs Associated with Cleanup Include:

- Cost of repacking and restacking drums within the trench which were damaged as a result of the fire,
- Cost of repackaging contaminated soils which, due to the high concentration of TRU, must be treated as TRU waste, and, thus, are subject to TRU packaging and storage procedures, and
- Cost of replacement of equipment of value.

Excluded are costs associated with collection of fire department liquid runoff within the trench. At this time, it is unclear whether runoff within the trench would actually necessitate cleanup. Due to the depth and relatively large size of the trench, it is expected that the runoff would be limited to the confines of the trench.

Cost of Repacking and Restacking of Drums

Every drum which is expected to experience lid loss and/or lid seal failure will require repacking and restacking. Additionally, it is expected that drums adjacent to drums which experience lid loss and/or lid seal failure are susceptible to some degree of container damage which would require repacking and restacking. It is assumed that fire damage which results in container bulging, punctures, dents, scratches that penetrate painting/coating, loose lids, corrosion, or signs of containment breach would require repackaging. It is unclear how many drums would actually experience this degree of damage. Therefore, it is estimated an additional two drums would have to be repacked and restacked for every drum which experiences lid loss and/or lid seal failure. Since 138 drums are postulated to experience lid loss and/or lid seal failure, 414

drums are estimated to require repacking and restacking. Solid Waste Management personnel have estimated the cost of repacking and restacking TRU drums at \$400.00 per drum. This cost includes material and labor consisting of a crane and rigging crew, two operators and one radiological control technician.

The estimated cost to repack and restack 414 drums is \$165,600.

Cost of Repackaging Contaminated Soils Which Due to the High Concentration of TRU

An estimate of the quantity of contaminated soil which must be handled, packaged, and stored as TRU waste can be determined.

Using Himes methodology, the area which must be assumed to be contaminated at TRU contamination levels can be estimated. The estimation is based on the assumption that soil concentrations in excess of 100nCi/g will necessitate cleanup as TRU waste. The minimum contamination level, C, is given by:

$$C_{TRU} = (100 \text{ nCi/g}) \times (1.6 \text{ g/cc}) \times (10^{-9} \text{ Ci/nCi}) \times (10^4 \text{ c}^2/\text{m}^2)$$

for 1 cm soil depth:

$$C_{TRU} = 1.6 \text{ E-3 Ci/m}^2$$

from previous calculation,

$$m = -3.303$$

$$A_F = 6.48 \text{ m}^2$$

$$I = 119.95 \text{ PECi}$$

$$\text{from Equation 1: } x_L = [64.9 \times (I/C_{TRU}) \times A_F^{0.8407}]^{-1/m}$$

Solving:

$$x_{LTRU} = 170.3 \text{ m}$$

$$\text{from Equation 3: } A_{CTRU} = 0.0724[(-m)^{0.5} (x_{LTRU}^{1.903})]$$

Solving:

$$A_{CTRU} = 2,318 \text{ m}^2$$

For a depth of 1 cm (0.01 m), the volume of contamination requiring packaging and storage as TRU waste is 23.2 m³. For a drum volume of 0.22 m³, this equates to 105.4 drum volumes or 106 drums of contaminated soil which would be packaged and stored as TRU waste. It should be noted that the area estimate refers to contaminated soil assumed to be a depth of 1 cm. Actual cleanup of contaminated soil is expected to result in the mixing of several centimeters of clean soil. From discussion with Solid Waste Management personnel, this inherent mixing of clean and contaminated soils is expected to reduce the curie content below the level defining the contamination as TRU waste (100 nCi/g). Consequently, the waste is expected to be disposed as low-level waste.

Cost of Replacement of Equipment of Value

All TRU waste and waste containers are assumed to have zero property value. Consequently, the wheel loader/forklift is the property of value within the trench that could be damaged as a result of a trench fire. Damage to the wheel loader/forklift is postulated to equal the value of the wheel loader estimated to be \$150,000.

Summary of MPFL Costs

Contamination of nearby soils	\$609,153
Repackaging and restacking of drums	\$165,600
Equipment loss	\$150,000

Total Estimated MPFL Costs	\$924,753
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It should be noted that rapid fire suppression by the fire department could further limit the release of radiological material and thereby limit the fire loss attributed to ground area contamination. It should also be noted that no additional TRU drums are expected to be received. Limiting operations involving flammable liquid fueled equipment within the trench significantly reduce the likelihood of a flammable liquid fire occurring within the trench.

APPENDIX B REFERENCES

- DOE, 1993, Fire Protection, DOE Order 5480.7A, U. S. Department of Energy Washington, D.C.
- LLNL, 1993, Hasagawa, H.K., Stagges, K.J., Doughty, S.M. Fire Testing of 55 Gallon Metal Waste Drums for Dry Waste Storage, UCRL-CR-115037, Lawrence Livermore National Laboratory, Livermore, California.
- LLNL, 1994, Homann, Steven G., HOTSPOT, Health Physics Codes for the PC, March 1994, Lawrence Livermore National Laboratory, Livermore, California.
- WHC, 1994a, Radiological and Chemical Source Terms for Solid Waste Operations Complex/A5228, WHC-SD-W306-TI-001, Rev. 1, November 10, 1994. Westinghouse Hanford Company, Richland, Washington.
- WHC, 1994b, A Method for Estimating Ground Areas Contaminated by a Postulated Fire in a Facility Containing Radioactive Material, WHC-SD-GN-TI-20004, September 1994, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1995, Solid Waste Burial Grounds Interim Safety Analysis, WHC-SD-WM-SARR-028, Rev. 1, March 1995, Westinghouse Hanford Company, Richland, Washington.

APPENDIX C

**Supporting Analyses for the Mixed Waste Trenches,
Solid Waste Burial Grounds Fire Hazard Analysis,
Estimation of Radiological Release Potential,
Ground Area Contamination, and Cleanup Costs
Associated with a Flammable Liquid Pool Fire
in a Mixed Waste Trench**

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1.0 Identified Fire Hazards For The Mixed Waste Trenches

Fire hazards of concern that exist for Mixed Waste (MW) Trenches 31 and 34 are defined as conditions or practices related to fire that have the potential to contribute to or directly cause injury, illness, onsite or offsite release of radiological and other hazardous material, property damage, or mission impairment. Two potential fire scenarios that may represent fire hazards have been identified. They are:

- A flammable liquids spill in the vicinity of the container disposal array and a subsequent fire. This fire could expose the drum/container array to significant heat.
- The accumulation of tumbleweeds within the trenches and along the edges of the drum/container array. The tumbleweeds are considered a potential fuel source which, if ignited, could expose the drum/container array to significant heat.

The potential fire scenarios are considered to be significant fire hazards if they result in container failure and a subsequent uncontrolled release of radiological or other hazardous material.

The objectives of the fire scenario analysis are to determine:

- Whether the scenarios result in container failure,
- Whether the fire will continue to propagate and involve other containers, and
- Whether the container will result in a release of radiological or other hazardous material.

Methods and calculations used in the analysis are summarized in the sections below.

Container Failure Criteria

Similar scenarios have been previously analyzed in the FHA for the TRU Trenches (WHC 1994a). In the referenced FHA, 50-gal drum containers (Figure C-1) are considered to fail if they are exposed to a flammable liquids pool fire of at least 3 min duration. This failure criteria is based on full scale fire tests of drums at Sandia National Laboratories, INEL, and LLNL. The referenced FHA also cites heat transfer analysis which indicates that 0.95 kg of fuel must be burned per drum in a tight-packed array configuration (with void areas as shown in Figure C-2) to cause container failure. There are no failure criteria for the metal box container 7A Type A (Figure C-3) being proposed. In the absence of specific failure criteria, it is assumed that drum failure is the worst case container failure.

As reported in the referenced FHA (WHC 1994a), there are two common modes of drum failure that have been observed. Violent lid failure which results in the loss of the drum lid and may also result in the expulsion of the drum contents. This mode of failure exposes and/or may violently expel the contents of the drum. Burning of the combustible contents is expected. The other is lid seal failure. Lid seal failure describes a rupture of the seal without the loss of the lid. In this event gases produced as a result of the heat exposure are vented from the container. However, due to container overpressure, air is not able to enter the drum. Consequently, there is no flaming combustion within the container. Ignition of pyrolysis gases has been observed in full scale fire tests of drum containers conducted by Sandia Laboratories (SNL 1979) and Lawrence Livermore National Laboratories using a flammable liquids exposure fire (LLNL 1993). Based on Lawrence Livermore National Laboratory fire tests of 55-gal metal waste drums for drum waste storage, drums which experienced lid seal failure resulted in a mass loss of approximately 1 kg/drum (LLNL 1993).

3.4.7 Tolerances

Diameter over rolling hoops.....	23-13/32 in (595 mm) minimum 23-15/32 in (596 mm) maximum
Overall height.....	34-3/4 in $\pm 1/8$ in (883 mm ± 3.18 mm)
All other height dimensions	$\pm 1/8$ in (± 3.18 mm)
Center-to-center fitting	17-1/2 in $\pm 1/4$ in (444 mm ± 6.35 mm)
Convexity of each head	9/16 in $\pm 3/16$ in (14.3 mm ± 4.76 mm)
All other dimensions.....	$\pm 1/16$ in (± 1.59 mm)

NOTES:

- (1) All metric units are rounded, where required, in accordance with the procedure given in 2.2.1.2.
- (2) This dimension is applicable to both the top and bottom heads.

Figure C-1. ANSI MH2-1991 DOT 17C Drum Dimensions

Figure C-2. Drum Container and Void Areas (WHC 1994a)

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Table I

Type	Height		Width		Length		Volume	
	Inner Dimensions $\pm 0.01\text{m}$ ($\pm 4\text{in}$)							
	m	in	m	in	m	in	m ³	ft ³
MB-I	1.02	40	1.30	51	1.30	51	1.72	60
MB-II	1.12	44	1.12	44	2.22	88	2.78	99
MB-III	1.52	60	1.52	60	2.74	108	6.33	225
MB-IV	Buyer Supplied in Purchase Order							

Note: The Seller shall provide proposals for the above containers rated for pay loads of 800, 1200, 1600, and 2000kg/m³ (50, 75, 100, and 125 lb/ft³).

Figure A

Figure C-3. DOT 7A Type A Container

2.0 ACCIDENT ANALYSIS

2.1 Fuel Spill

Based on the Trench 31 and 34 operational procedures, placement of containers for disposal may be accomplished by use of a Caterpillar 936F Wheel Loader or equivalent. Backfill operations will most likely be accomplished by a frontloader with a bucket. This analysis assumes that an accidental fire resulting from a fuel spill involving a wheel loader is a credible event. The worst case wheel loader fire is analyzed as a fuel spill and subsequent fire.

The classification of flammable liquid spills and resulting fires fall into one of the following three categories:

- Instantaneous spills in which all of the spill occurs in a very "short time,"
- Continuous spills in which the spill continues at a specified finite rate for a "long time," and
- Quasicontinuous spills where a given volume of liquid is spilled over a given duration of time. This rate of release is finite, but can vary with time.

Although most spills may fall into the third category of quasicontinuous spills, analytical expressions describing such a scenario are not available (SFPE Handbook 1988). For this analysis, instantaneous spills, continuous spills, and postulated "worst case" spills are considered.

2.1.1 Instantaneous Fuel Spill and Fire

For purposes of conservative accident analysis, a volume of 50 gal (189 L) of fuel originating from a vehicle within the trench and occurring at the edge of the container row is postulated to be spilled instantaneously and would serve as the fuel source for an accidental fire. The maximum pool diameter is calculated below and is determined to be 12.2 m and cover a maximum theoretical area of 105.68 m² assuming no absorption into the soil. The trench floor soil surface is considered to be sufficiently level to assume that the spill spreads the same distance in all directions from the point of spill origin but allows fuel to flow under drums and containers that have not been backfilled. Since backfill operations occur after the drum/containers reach three rows in depth, it is assumed that three rows of drums are exposed at the time of the spill. Drums which may be covered with soil/backfill material at the time of the spill are assumed not to have sufficient void area to allow for fuel spread within covered areas.

Determine Number of Container Failures

The containers are assumed to be stored one high, i.e. no stacking. As assumed in the referenced FHA and illustrated in Figure C-2, each drum container and void space is assumed to encompass an area of 0.37 m² (0.61 m by 0.61 m). Since the spill occurs at the edge of the container row, only half of the theoretical fuel spill area will potentially involve containers. Since the container rows are only three deep, the spill would be limited to a depth of three containers or 1.83 m. If it is assumed that the spill will not extend beyond its maximum theoretical diameter, the maximum number of drum containers that could be involved would be 60.

Containers which are within the pool area are assumed to fail if the pool fire described burns 0.95 kg of kerosene per drum and burns for at least three min (WHC 1994a). Based on the theoretical pool diameter of 12.2 m, determined from the following formula:

$$D_m = 2[V_L^3 g'/y'^2]^{1/3}$$

where: V_L = Volume spilled (m^3) = 50 gal (0.1893 m^3)

g' = effective acceleration = 1.25 m/s^2

y' = burning rate = 0.000067 m/s

The mass of fuel available to each drum is determined below:

Theoretical pool diameter:	12.2 m (40 ft)
Theoretical pool area:	116.9 m^2 (1258.3 ft^2)
Area of drums involved:	$1/2(116.9) = 58.45 m^2$
Volume of fuel spilled:	189.27 L (50 gal) $\approx$ 155 kg (for diesel/kerosene)
Density of fuel per area:	$155 kg/116.9 m^2 = 1.33 kg/m^2$
Fuel/drum ratio:	$1.33 kg/m^2 \times 0.37 m^2/drum = 0.49 kg/drum$

For a drum and void area of dimensions 0.61 m by 0.61 m with an area of 0.37 m^2 (Figure C-2), this equates to a fuel/drum ratio of 0.49 kg/drum. This is below the ratio of 0.95 kg/drum needed for container failure. Therefore, under conditions of an instantaneous fuel spill and subsequent fire, it is concluded that the containers are not expected to fail.

2.1.2 Continuous Spill and Fire

A more credible exposure scenario is a localized fuel spill and fire initiated from a fuel tank leak or a ruptured fuel line which results in a release of 50 gal (189.27 L) of fuel at a specified rate for a fixed time. In the case of a continuous burning spill, the liquid will spread and increase the burning area until the total burning rate is equal to the spill rate. It is assumed that the burning rate is constant and that the mass balance is maintained within the pool; therefore, the loss of liquid due to percolation through the soil is not included. For most hydrocarbons these terms tend to be small compared to the burning rate (SFPE Handbook 1988).

A fuel spill rate of 10 gal/min (37.85 L/min) has been arbitrarily selected to represent a spill resulting from a fuel tank or fuel line rupture. It should be noted that spill rates less than 10 gal/min result in pool fires of smaller areas. The condition is given by the following equation:

$$D_{eq} = 2[V'_L/\pi y']^{0.5}$$

where: D_{eq} = steady state equilibrium diameter of the pool, m

V'_L = liquid spill rate, m^3/s (assume $6.175 \times 10^{-4} m^3/s$)

y' = liquid burning rate, m/s (0.000067 m/s) (SFPE Handbook 1988)

Solving,

$$D_{eq} = 3.4 m (11.15 ft).$$

As in the instantaneous fuel spill, the continuous burning fuel spill is assumed to occur at the edge of the container row, and, thus, only half of the theoretical fuel spill area is postulated to potentially involve containers. The trench floor soil surface is considered to be sufficiently level to assume that the spill spreads the same distance in all directions from the point of spill origin but allows fuel to flow under drums and containers that have not been backfilled. Since backfill operations occur after the drum/containers reach three

rows in depth, it is assumed that three rows of drums are exposed at the time of the spill. Drums which may be covered with soil/backfill material at the time of the spill are assumed to not have sufficient void area to allow for fuel spread within covered areas. The maximum drums to be involved is determined below and illustrated in Figure C-4.

Steady-state pool diameter:	3.4 m (11.15 ft)
Theoretical pool area:	9.2 m ² (99.1 ft ²)
Maximum area of drums involved:	4.6 m ²
Number of drums involved:	16
Volume of fuel spilled:	118.27 L (50 gal) $\approx$ 155 kg (for diesel/kerosene)
Density of fuel per area:	155 kg/9.2 m ² = 16.8 kg/m ²

For a drum and void area of dimensions 0.61 m x 0.61 m (0.3721 m²), this equates to fuel/drum ratio of 6.3 kg/drum. This is well above the ratio of 0.95 kg/drum needed for container failure. Therefore, under conditions of a continuous fuel spill and subsequent fire, it is concluded that all exposed containers are expected to fail.

Determine Type of Container Failure

As stated earlier, there are two common modes of drum failure that have been observed. Violent lid failure which results in the loss of the drum lid and may also result in the expulsion of the drum contents. The other is lid seal failure. Lid seal failure describes a rupture of the seal without the loss of the lid. The referenced FHA (WHC 1994a) cites fire test results of Hasegawa and Hunter that show only 15 percent of the drum lids were actually removed from the drum due to lid venting and defines the probability (p) that the drums will fail with lid loss as 0.26. Thus, for the 16 drums involved in the continuous spill and subsequent pool fire, four are expected to experience lid loss and burn.

2.1.3. Postulated Worst Case Fuel Spill and Fire

The previous scenario assumes a constant burn rate over the entire spill area. Since the fuel spill rate was arbitrarily selected, the number of exposed containers subject to a fuel/drum ratio resulting in container failure in the above scenario may not be conservative. Therefore, a worst case exposure scenario may involve a localized fuel spill and fire which results in a release of 50 gal of fuel such that the fuel/drum ratio is equal to or greater to the ratio determined for container failure, i.e. 0.95 kg/drum, and results in a fire which burns for at least 3 min.

Postulated Worst Case Fuel Spill and Subsequent Fire

Conditions for Failure:

1. Fuel/drum density $\geq$ 0.95 kg/drum (fuel density which results in drum failure) AND
2. Burn time $\geq$ 3 min.

Step (1) Determine area of pool fire which results in 0.95 kg/drum

Failure density:

$$\text{fuel/area} = (0.95 \text{ kg/drum}) \times (1 \text{ drum}/0.3721 \text{ m}^2) = 2.55 \text{ kg/m}^2$$

Figure C-4. Drum Container Exposure to Postulated Continuous Burning Fuel Spill (Not to Scale)

Given:

Volume of fuel = 155 kg

Failure density = 2.55 kg/m²

Area of pool fire determined by

$$\begin{aligned} (V_{\text{fuel}}) / (A_{\text{fire}}) &= \text{failure density} \\ (155 \text{ kg}) / (\pi D^2/4) &= 2.55 \text{ kg/m}^2 \end{aligned}$$

Solving:

$$D, \text{ dia. of pool fire,} = 8.79 \text{ m}$$

and

$$A_{\text{fire}} = 60.78 \text{ m}^2$$

Step (2) Determine number of containers expected to fail

Since half of the area of the spill occurs outside the drum inventory, the number of drums that could possibly be exposed is determined by:

$$\begin{aligned} \text{No. of drums} &= (1/2 A_{\text{fire}}) (1 \text{ drum}/0.3721 \text{ m}^2) \\ &= 81.67 \\ &\approx 82 \text{ drums} \end{aligned}$$

Step (3) Estimate burn time

Burn time (t) can be estimated by:

$$\begin{aligned} t &= V_{\text{fuel}}/(\text{burn area})(\text{burn rate}) \\ t &= 0.1893 \text{ m}^3 / [(82 \times 0.1 \text{ m}^2) + 1/2 (A_{\text{fire}})] \times (0.000067 \text{ m/s}) \\ t &= 73 \text{ s} = 1.2 \text{ min} \ll 3 \text{ min} \end{aligned}$$

Conclusion:

Burn time is not sufficient to cause container failure.

Step (4) Determine the number of drums that could fail based on burn time

As indicated above, burn time and burn area can be estimated by:

$$t = V_{\text{fuel}}/(\text{burn area})(\text{burn rate})$$

For a burn time of 180 s, burn area, X, can be expressed as:

$$X = 0.1893 \text{ m}^3 / (180 \text{ s}) (0.000067 \text{ m/s})$$

Solving:

$$X = 15.7 \text{ m}^2$$

For purposes of determining burning area, X, corresponds to the sum of 1/2 the fuel spill area and the no. of containers, b, multiplied by 0.1 m² or

$$X = 15.7 \text{ m}^2 = 1/2 A_{\text{fire}} + (b \times 0.1 \text{ m}^2) \quad (\text{Equation 1})$$

The area of the fire, A_{fire}, can be expressed in terms of the maximum number of containers expected to fail by:

$$1/2 A_{\text{fire}} = 0.37 b \quad (\text{Equation 2})$$

Substituting and Solving Equations 1 and 2 simultaneously, below:

$$\begin{aligned} A_{\text{fire}} &= 0.74 b \\ 15.7 &= (1/2) \times (0.74 b) + 0.1 b \\ b &= 33.4 \approx 33, \text{ and} \\ A_{\text{fire}} &= 24.7 \text{ m}^2 \end{aligned}$$

For A_{fire} = 24.7 m², the fuel/drum density is calculated by:

$$\begin{aligned} &(V_{\text{fuel}})/(A_{\text{fire}}) \times (0.37 \text{ m}^2/\text{drum}) \\ &(155 \text{ kg}/24.7 \text{ m}^2) \times (0.37 \text{ m}^2/\text{drum}) = 2.3 \text{ kg/drum} \geq 0.95 \text{ kg/drum} \end{aligned}$$

Therefore, all 33 drums are expected to fail.

Given a probability, p, of 0.26 for lid loss, 9 drums are expected to experience lid loss and subsequent burning of the combustible contents.

As in the previous scenarios, the above calculations assume that only half of the pool area exposes the drum inventory, resulting in a fire with a sufficient fuel drum density (2.32 kg/drum) to result in failure of 33 drums. Using the probability for lid loss of 0.26, nine drums are expected to experience lid loss and have the combustible contents burn.

The remaining 24 drums are expected to experience a mass loss of 1 kg due to the evolution of pyrolysis gases.

Determine Extent of Fire Propagation

Using the previously referenced probability for one lid loss leading to an additional lid loss to be 1.7, the total number of drums predicted to experience lid loss and the burning of contents is 15.

Backfilled Containers

Containers which have already been backfilled are assumed to be invulnerable to fire propagation. This is due to the backfill limiting the air available for combustion as well as the insulating value that would limit or prevent the containers from being exposed to the heat from the fire and thus prevent or greatly limit the amount of energy transferred from the fire to the containers.

Containers Adjacent to the Pool Fire

In order for the fire to propagate beyond the area of the pool fire, sufficient radiant heat must be transferred from fires involving drum contents to adjoining drums to result in violent lid seal failure. The

referenced analysis cites a drum survey by Joyce that documented the average combustible load in a drum of 26 kg (WHC 1994a).

The referenced analysis (WHC 1994a) has analyzed the potential for fire to propagate due to radiant heat transfer from burning drums to adjoining drums. The radiant heat transfer from burning drums to adjoining drums can generate overpressures in the range of 5.4 to 7 psig. These overpressures are significantly below the 20 psig criteria for failure. Therefore, fire propagation beyond the area of the pool fire is not expected.

2.2 Tumbleweeds Fire

The accumulation of tumbleweeds within the trenches and along the edges of the drum/container array is a known phenomenon. Tumbleweeds, if allowed to accumulate into a drift, are fuel for a fast developing hot fire. They contain a very large surface area and the volume of the fuel package has plenty of entrained combustion air. Tumbleweeds represent a potential fuel source and, if ignited, could expose the uncovered drum/containers. Such a fire could result from a wildland fire or other ignition source. This event has been previously analyzed in the referenced analysis (WHC 1994a) and determined not to cause failure of exposed drums. Nevertheless, tumbleweeds represent a likely fuel source for a fire within a trench.

2.3 Bulk Waste Fire

Bulk waste is noncontainerized waste products such as soils, vegetation, building rubble, and other relatively homogeneous materials. The potential for a bulk waste fire is difficult to assess given the limited waste characterization. *Solid Waste Acceptance Criteria* indicates that most organic chemicals are excluded from disposal due to liner compatibility requirements (WHC 1993). For purposes of this analysis, it is assumed that the combustible components of bulk waste are the vegetative debris. This type of combustible may be easily ignitable, but in a fire condition is expected to burn in a manner similar to the tumbleweeds fire. It is expected that a bulk waste fire will lack sufficient energy to cause drum/container failure.

2.4 Radiological Ground Contamination Potential

The methodology developed by Himes (WHC 1994b) for estimating ground contamination by a postulated fire in a facility containing radioactive material expresses the release fraction as a function of gravitational drift velocity and is presented below:

$$F = 5.0E-02v_g^{1.35}$$

where: F = Release Fraction

v_g = Gravitational drift velocity (m/s)

The author indicates that release fractions between 1.0E-04 and 5.0E-02, where the upward forced convection is 0.01 m/s and 1.0 m/s, respectively, fit the data reasonably well. The data refer to actual fractional release experiments performed by Mishima and Schwendiman and documented in DOE-HDBK-3010-YR (DOE 1994). The handbook also cites two sets of experimental data for uncontained, cellulosic waste or largely cellulosic mixed waste which resulted in ARFs ranging from 7E-5 to 1E-2. It states that the radionuclides were freshly applied and emphasized the goal of maximizing release.

For purposes of estimating radionuclide release, it is assumed that the fire involves 100 percent of the curie content of all of the containers which experience lid loss. In the case of containers which are postulated to experience lid seal failure, the referenced analysis (WHC 1994a) assumes that 1 kg of out of the assumed 26

kg combustible contents are consumed due to pyrolysis but without active burning. There was no explicit guidance identified for accounting for the release of radiological material associated with lid seal failure as it relates to ground contamination. In the absence of guidance, it is assumed that 1/26 (0.04) of the drum radiological inventory is at risk.

The postulated release is conservatively assumed to be based on the maximum expected radionuclide concentration with combustible waste. The concentration of isotopes in containers such as steel drums are limited to the *Waste Acceptance Criteria* (WHC 1993) Category 1 concentration limits for any large array of containers. Category 3 waste must be stabilized and covered thereby limiting their potential for possible involvement in fire. Greater than Category 3 wastes are no longer disposed of in the burial grounds. Any fire involving a large number of drums must also consider packaging criteria in addition to the Category 1 limits that will effectively limit the concentration of isotopes in these containers. A significant limitation on gamma emitters such as ^{60}Co is the requirement that contact handled packages have surface dose rates of no more than 200mrem/hr. Packages with higher dose rates are remote handled and require coverage of soil after receipt to limit personnel exposures.

This limit on contact handled waste was evaluated in the referenced document to determine the actual concentration of the primary gamma source (^{60}Co) and beta source (^{90}Sr) that will result in the worst consequences in terms of maximum area contamination from a fire. Two possibilities were evaluated. The first considered essentially uniform distribution of the wastes as would be expected in a container of contaminated combustible wastes. The second evaluated the maximum quantity that could be at the center of the container as might occur from a single source. Note that this maximum quantity would not be expected since it would require remote handling just to place it in a container while material that was uniformly contaminated could potentially be placed at concentrations near these levels by operating personnel.

Based on the referenced work, the quantity of ^{60}Co would be limited by the dose rate for contact handled containers to the value calculated for uniformly distributed materials for typical waste distributions. This value has been determined to be: 0.043 Ci.

Thus, the postulated radiological inventory is given by the following:

$$I = \text{Radionuclide/container} \times \text{No. of containers}$$

Solving for the worst case fuel spill and fire:

$$\begin{aligned} I &= 0.043 \times (15) + 0.043 \times (24) \times (0.04) \\ &= 0.645 + 0.041 \end{aligned}$$

$$I = 0.686 \text{ Ci (for } ^{60}\text{Co)}$$

The extent of ground contamination is estimated utilizing the methodology developed by Himes:

Method Assumptions

- Estimation of releases, a function of particle fall velocity.
- Estimation of equilibrium plume height, by calculating fire heat generation rate and using an established buoyant plume model.

- Meteorological conditions are pasquill F stability with a reference (10 m) wind speed of 1 m/s. Note that pasquill stability classes are used to define meteorological atmospheric conditions and typically range from A to F. For materials with a deposition velocity of zero and release point at or very near ground level, the maximum concentration is always associated with "F" stability (LLNL 1994). For his formulation, Himes has 'arbitrarily' selected "F" stability, and suggests that other combinations of meteorology conditions could produce somewhat larger contaminated areas, but also indicates that the results are a highly approximate estimate and that the source term contributes the greatest uncertainty.
- Fire's rate of heat release = $Q'/A = 397 \text{ kw/m}^2$ or $9.48 \text{ E}+04 \text{ cal/m}^2\text{s}$ (35 BTU/ft²s).

Problem Assumptions

- Fire area equals the number of container lid areas postulated to fail. Note that the flammable liquids fuel spill/fire does not contain radiological material. The flammable liquid fuel fire is presumed to be fully consumed at or about the time of container failure, and thus is not included as part of the fire area assumed for this calculation.
- Minimum level of Contamination, C, is determined from assessable soil concentration limits identified for the 200 West Area in WHC-CM-7-5 (WHC 1994c), and
- I is the radiological at risk inventory.

From Himes, equation for determining downwind extent of the contour corresponding to a minimum contamination level, C, is:

$$x_L = [64.9 \times (I/C) \times A_F^{0.8407}]^{-1/m} \quad (\text{Equation 1})$$

where: x_L = maximum downwind extent (m)

I = at risk inventory curies

C = minimum contamination level (Ci/m²).

The accessible soil concentration limit for cobalt 60 is $7.1 \text{ E}+00 \text{ pCi/g}$ from WHC-CM-7-5, Table 6-2 (WHC 1994c):

$$C = 7.1 \text{ E}+00 \text{ pCi/g} \times 1.6 \text{ g/cc} \times 10^{-12} \text{ Ci/pCi} \times 10^4 \text{ c}^2/\text{m}^2$$

For 1 cm depth:

$$C = 1.13 \text{ E}-07 \text{ Ci/m}^2$$

A_F = area of fire, assumed to be the no. of container lid areas postulated to fail (15 x 0.27)

$$= 4.05 \text{ m}^2$$

m = unitless value determined by:

$$m = - (0.02940 \ln A_F + 3.248) \quad (\text{Equation 2})$$

Solving Equation 2:

$$m = - 3.289$$

Solving Equation 1:

$$x_L = 587.05 \text{ m.}$$

From Himes, equation for determining area of the contour corresponding to a minimum contamination level, C, is:

$$A_c = 0.0724[(-m)^{0.5} (x_L^{1.903})] \quad (\text{Equation 3})$$

Solving Equation 3:

$$A_c = 24,381 \text{ m}^2$$

Using the same unit cost value as that referenced in WHC-SD-GN-TI-20004 (WHC 1994b), a clean up unit value of \$5.49/m² is assumed.

At 5.49/m², clean-up costs are calculated to be: \$133,852.

In order to identify the "worst" case, strontium 90 (⁹⁰Sr) was also considered. From the referenced analysis, the concentration limit for ⁹⁰Sr material is the category 1 maximum given in the reference to be 8.9E-4 Ci per drum.

Thus, the postulated radiological inventory is given by the following:

$$I = \text{Radionuclide/container} \times \text{No. of containers}$$

Solving for the worst case fuel spill and fire:

$$\begin{aligned} I &= 8.9\text{E-}4 \times (15) + 8.9\text{E-}4 \times (24) \times (0.04) \\ &= 0.01335 + 0.00085 \end{aligned}$$

$$I = 0.0142 \text{ Ci (for } ^{90}\text{Sr)}$$

The accessible soil concentration limit for ⁹⁰Sr = 2.8E+03 pCi/g (WHC 1994c),

$$C = 2.8\text{E+}03\text{pCi/g} \times 1.6 \text{ g/cc} \times 10^{-12} \text{ Ci/pCi} \times 10^4 \text{ c}^2/\text{m}^2$$

for depth of 1 cm:

$$C = 4.48 \times 10^{-5} \text{ Ci/m}^2$$

The I/C value for ⁹⁰Sr is approximately 316. The I/C value for ⁶⁰Co is approximately 6,070,796. Since the I/C value for ⁹⁰Sr is much less than the I/C value for ⁶⁰Co, it can be intuitively concluded that the contamination area resulting from the same type of fire is less for ⁹⁰Sr than for ⁶⁰Co. Therefore, the MPFL is best represented by a postulated loss of ⁶⁰Co.

Other Costs

For Trenches 31 and 34, all low-level mixed waste is assumed to have zero property value. Consequently, the wheel loader is the only property of value that could be damaged as a result of a trench fire. This analysis assumes that the fire loss associated with a trench fire will be comprised of damage incurred to the wheel loader and the decontamination and cleanup costs associated with an uncontrolled release

of radiological material. It is assumed that there the waste that was exposed or released from the container but remained in the trench would be covered with soil without any further repackaging.

Damage to the loader is postulated to equal the value of the Wheel Loader estimated to be \$150,000. Therefore, the fire loss is estimated to be \$283,852.00.

These estimated losses are within the acceptable loss criteria prescribed by DOE 5480.7A for the MPFL (DOE 1993). It should be noted that rapid fire suppression by the fire department could further limit the release of radiological material and thereby limit the fire loss attributed to ground area contamination.

APPENDIX C REFERENCES

- DOE-HDBK-3010-YR, 1994, DOE Handbook, Airborne Release Fractions/Rates and Respirable Fractions For Nonreactor Nuclear Facilities, October, 1994.
- LLNL, 1993, Hasagawa, H.K., Stagges, K.J., Doughty, S.M, Fire Testing of 55 Gallon Metal Waste Drums for Dry Waste Storage, UCRL-CR-115037 Lawrence Livermore National Laboratory, Livermore, California.
- LLNL, 1994, Homann, Steven G., HOTSPOT, Health Physics Codes for the PC, March 1994, Lawrence Livermore National Laboratory, Livermore, California.
- SNL, 1979, Summary of Research and Development Activities in Support of Waste Acceptance Criteria for WIPP, SAND79-1305, Sandia National Laboratories, Albuquerque, New Mexico.
- SFPE Handbook 1988, Society of Fire Protection Engineers Handbook of Fire Protection Engineering, 1988, National Fire Protection Association, Quincy, Massachusetts.
- WHC, 1993, Solid Waste Acceptance Criteria, WHC-EP-0063-4, November 1993, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1994a, Fire Hazards Analysis for PUTDR and TRU Trenches in the Solid Waste Burial Ground, WHC-SD-WM-FHA-009, Rev. 0, December 1994, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1994b, A Method for Estimating Ground Areas Contaminated by a Postulated Fire in a Facility Containing Radioactive Material, WHC-SD-GN-TI-20004, September 1994, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1994c, Environmental Compliance, WHC-CM-7-5 Release 2, Westinghouse Hanford Company, Richland, Washington.

APPENDIX D

Analysis of Fire Development

In Plywood Container Disposal Arrays

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Propagation of Fire in Plywood Disposal Arrays

by

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Propagation of Fire in Plywood Disposal Arrays

1.0 Introduction

Fire development in plywood waste disposal arrays may be initiated by a diesel fuel spill associated with trench operations or by tumbleweeds which blow into the trench and accumulate against the disposal array. Fire development resulting from each of these two initiating sources will be analyzed and modeled. Prior to assessment of these scenarios, previous work concerning the performance of plywood box arrays will be reviewed, and analytical methods required for the assessment will be reviewed and/or developed.

2.0 Available Testing of Plywood Box Arrays

Fire development in plywood storage containers has been studied by Beitel (1978) and by Brown (1979). In both investigations, the boxes were nominally the same size as the boxes used in the trenches under study, but the plywood was coated with glass reinforced polyester (GRP). The difference in the exterior surface requires analysis to allow the test results to be applied to the present problem.

The first Beitel test used a 2x4x4 box high array for testing. The boxes were 4x4x7 feet and were arranged to form a nine inch wide flue space between the two rows of boxes (see Figure 1). This formed a flue space four boxes tall and four box lengths long. The goal of the work was to assess the burning behavior of the storage boxes and to assess the potential for fire propagation along the flue space in the array. A 10x12 ft initiating diesel/gasoline mixture pool fire (164 gallons) was placed at the end of the array with the pool fire extending 5 ft into the flue array. This initiating source directly exposed the exterior and flue surfaces of the first row of the box array and initiated fire propagation in the flue space. The fire spread along the flue space, ultimately involving all of the boxes. The time required to thermally penetrate the boxes exposed to the pool fire was six minutes. Penetration times were not given for other boxes. The flame spread rate in the flue was not reported directly. Based on observations reported,

Figure 1. Beitel Test 1 - Experimental Configuration.

regarding the time of ignition of various stacks, a flue flame spread rate of about 2.5 mm/s is estimated.

In Beitel's second test, the boxes were configured in an ell shape, again four boxes in height (see Figure 2). The fire was initiated in the corner formed by the boxes using the same pool fire source as used in the first test. Thermal penetration of boxes exposed by the pool fire source occurred seven minutes into the test. Since no connecting flues were formed in this configuration, spread did not occur by this mechanism though burning was most intense within the existing flues. No propagation away from the stacks exposed directly by the pool fire was reported during the 100 minute test.

The Brown testing was performed subsequent to the Beitel testing to address other storage configurations. In these two tests, the boxes were formed into an ell configuration to a height of three boxes. In the corner of the ell, 55 gallon drum storage containers were stacked within a pan in which diesel fuel was spilled as the initiating source.

In the first test, the pan contained 15 gallons of fuel, and the pan contained salt as was anticipated to be present in storage for the WIPP site. As expected, the salt reduced the burning rate of the pool fire below that expected for a free pool. The pool fire duration was approximately 41 minutes, and the fire was extinguished with fuel remaining. Based on the description of the storage array and the photos in the report, the flues between boxes were as small as was practical though no dimensions are reported. The pool fire exposure was sufficient to initiate sustained burning on the exposed box surfaces. Some flaming was noted in the horizontal flue formed by the 4x4 inch timbers used to form the base of the boxes. However, this did not result in sustained burning on the bottom of the box and flame propagation to the unexposed side of the storage boxes did not occur. The fire was terminated at 41 minutes when the exposed boxes were judged to be burning in a self-sustaining mode. The box surfaces which did sustain burning faced onto the flue space formed by the boxes on one side and the drums on the other. The investigators reported that the drums were significant in terms of sustaining the burning of the plywood. This is consistent with the general observation that wood does not

Figure 2. Beitel Test 2 - Experimental Configuration.

sustain flaming combustion without external radiative feedback. The plywood of the boxes did not burn through during the period of the test, and boxes did not contain any simulated wastes.

In the second test, the same fuel configuration was used as in the first test except that the salt was not included in the fuel pan and four gallons of fuel were used. The second test used the same boxes as were used in the first test with all boxes turned 180 degrees to expose fresh fuel surfaces. This indicates the minimal damage to the boxes sustained in the first test. Without the salt, the pool fire burned more vigorously and for a shorter duration (15 minutes). In this test, the boxes did not reach self-sustained burning, and the fire self-extinguished without fire propagation and without plywood burn through. The test was terminated at 75 minutes.

There is additional testing of the flame spread and burning behavior of wood and plywood surfaces which is relevant to this analysis, but which do not involve storage box configurations. Cone calorimeter data were reported by Janssens (1991) for a number of wood products, including douglas fir and yellow pine plywood. Additional wood cone test results are available from Babrauskas (1982), who used red oak as a test material in the development of the cone calorimeter. These test results will be used here to assess the time required to burn through the plywood boxes to expose the box contents.

Further testing of plywood was conducted by Quintiere and Harkleroad (1985) in the development of the LIFT test method. This test method provides experimental test procedures and data analysis methods which can be used to model the lateral flame spread in the flue spaces of the box array. No data are available for fire retarded plywood in their work. In as much as fire retardants are generally effective in improving ignition resistance, it would be expected that fire retardant plywood would perform better in lateral flame spread than normal plywood. Jianmin (1992) reported incomplete ignition and flame spread test results for a fire retarded plywood. The nature of the fire retardant was not reported, and the plywood was only 4 mm thick. The report also included data for a 9 mm thick birch faced plywood. These results indicated that except at very low heat fluxes, the flame spread on the birch plywood and the fire retardant plywood were very similar.

3.0 Flue Space Flame Spread

Flame spread in the flues is the major mechanism for spreading the fire. Due to the importance of flue spaces to the development of a fire in the disposal arrays, it is useful to employ stacking methods which minimize the extent of flue spaces in the array. This appears to be particularly possible for the plywood crate array where stacking can be very tight due to the crate geometry. While there has not been any systematic study of the effect of flue space gap size on lateral flame propagation, it is clear that very large and very small gaps can limit flame spread. Wide gaps reduce the external radiation provided by the opposing surface. Very small gaps do not allow sufficient air flow to support vigorous flame spread. Because vertical flame spread in the flues is much more rapid than lateral spread, this analysis will focus on the prediction of lateral spread along the flue. Full involvement of the full stack height will be assumed to occur very early in the fire growth process.

The experiments of Beitel demonstrated the critical importance of flue space lateral flame spread. Unfortunately, since the boxes studied by Beitel were faced with GRP and the flue dimension was greater than exists in this facility, the results cannot be directly applied. As such, a lateral flame spread model is used to predict flue space flame spread. This model will be compared with the Beitel data for validation of the approach.

Based on the Beitel and other data, it is clear that radiation is of critical importance to sustained burning in flues and to lateral flame spread in this geometry. The dominant radiative heat source in the flue is the burning surface itself. During active burning, the surface temperature of cellulosic materials is generally about 600°C (Atreya et al. (1986)). Given the extensive lengths of parallel surfaces for purposes of flame spread calculations, the radiation from the burning surfaces to the not yet burning surfaces can be calculated using a 600°C blackbody radiation source, which spans the flue at the flame front. The geometry for this configuration factor is a rectangular emitter to a strip element in the plane 90 degrees to the emitter element. The configuration factor for this geometry is given by Blackshear (1974) as

$$F_{12} = \frac{1}{2} \left[1 - \frac{X/H}{(1 + (X/H)^2)^{0.5}} \right] \quad (1)$$

where H is the dimension of the radiating source (the flue width in this analysis), and X is the distance of the target from the source.

Using this description of the radiative heating of the unburnt container surfaces ahead of the flame, the flame spread rate can be predicted using a counterflow flame spread model applicable to the lateral flame spread geometry. The material heating and flame spread model used in this evaluation is taken from Quintiere and Harkleroad (1985). The heating algorithm was generalized for variable heat fluxes using standard Duhammel's integral methods. The lateral flame spread rate is given by

$$V = \frac{\Phi}{k \rho c (T_{ig} - T_s)^2} \quad (2)$$

where Φ is a material property group, which includes flame foot heat transfer properties, $k\rho c$ is the thermal inertia of the material, T_{ig} is the ignition temperature of the material, and T_s is the surface temperature of the material just ahead of the flame foot. The surface temperature is raised above ambient by the radiant flux to the unburnt fuel ahead of the flame. This is given by

$$T_s = T_\infty + \int_0^t \frac{\dot{Q}''(\tau)}{(\pi k \rho c (t - \tau))^{1/2}} d\tau \quad (3)$$

Here the integration is over the time required for the flame to propagate over the preheating length provided by the radiation. The heat flux, $\dot{Q}''$, is known as a function of distance from the flame foot, x . The equation is actually solved by transforming coordinates from temporal to spatial coordinates, using $x = V t$. The flame spread rate is calculated by postulating a spread rate, calculating the surface temperature, and then calculating the spread rate. This is repeated until the trial velocity matches the calculated velocity. This is then the flame spread velocity. This model was implemented as a MathCad model.

Calculations were performed using the following material properties for plywood and GRP:

MathCad is a Registered Trademark of Autodesk, Inc.

<u>Material</u>	<u>Φ (kW)²/m³</u>	<u>kpc ((kW/m²K)²s)</u>	<u>T_g(°C)</u>
Plywood	12.9	0.54	390
GRP	9.97	0.32	390

All properties taken from Quintiere and Harkleroad (1985).

GRP was included because the boxes studied by Beitel were coated with GRP and can be used to validate the predictive method. Plywood data were used in the absence of any known material properties for fire retarded plywood. Results of calculations for the two materials are summarized in the following table for a flue spacing of 9 inches as was used in the Beitel tests.

<u>Material</u>	<u>Flame Spread Rate (mm/s)</u>
Plywood	1.7 mm/s
GRP	2.6 mm/s

The calculated GRP flame spread rate of 2.6 mm/s compares very favorably to the 2.5 mm/s flame spread rate deduced from the Beitel data. While this is a one point calibration/validation of the method, the basis of the model physical principles and the limited validation data do give some credibility and confidence in the model. This model of flue space flame spread developed by Hughes Associates, Inc. has been used in two SAR's developed for storage of pondcrete and saltcrete at Rocky Flats in 1992. In as much as such analyses are often applied to other facilities without the involvement of the original authors/developers, the analysis results may have been applied to additional facilities since that time.

4.0 Plywood Burn Through

While flame spread is required to allow involvement of waste stored in the plywood boxes, burn through of the box wall is subsequently required. The burn through time is dependent on the material, the wall thickness, and the incident heat flux. Babrauskas (1982) has subjected 0.75 in. thick red oak to external heat fluxes of 25, 50, and 75 kW/m², resulting in burning durations of 1600, 1000, and 750 seconds, respectively. Janssens (1991) measured burning times for a wide range of woods and wood products, including douglas fir plywood, southern yellow pine plywood, and fire retarded southern yellow pine plywood. The results are shown in the following table.

Burning Duration (sec)

Wood Product	Thickness	External Heat Flux (kW/m ²)				
		25	35	50	65	75
Red Oak	19 mm	1600		1000		750
Red Cedar	18 mm	1082	1051	818	656	
Radiata Pine	18 mm	1133	1057	903	872	
Victorian Ash	17 mm	1403	1160	953	884	
Blackbutt	18 mm	1588	1337	1147	991	
Douglas Fir	17 mm	1056	930	776	732	
Douglas Fir PW	13 mm	735	660	534	481	
(extrap.)	19 mm	1077	967	782	705	
Yellow Pine PW	11 mm	566	512	478	402	
(extrap.)	19 mm	978	884	826	694	
Fire Retardant Yellow						
Pine PW	12 mm		461	444	427	
(extrap.)	19 mm		730	703	676	

Sources: Babrauskas (1982), Janssens (1991)

While there are variations in burning time with species and product, the burn time is generally related to the density of the wood with lower density products (cedar, pine, and fir) like softwoods having the shorter burning time. Plywood products constructed of low density woods have particularly short burn times in the table due to their reduced thickness in the testing performed by Janssens. In the table, the thinner plywood sample burning times are also extrapolated to 19 mm by assuming burning time is linearly dependent on thickness. This correction for thickness largely eliminates the apparent differences between softwood and softwood plywoods. The comparison of Yellow Pine plywood and Fire Retardant Yellow Pine plywood indicates that the fire retardant has little effect on burning time.

Heat fluxes associated with full pool fire immersion are typically about 120 kW/m^2 . This is roughly twice the maximum heat flux shown in the above table. Burn through of boxes exposed to the pool fire in Beitel's first and second tests were observed at 6 and 7 minutes, respectively. This is about half the burn time of the plywood samples at 65 kW/m^2 in the above table. As such, these two very different data sources seem to be in nominal agreement. It should be noted that the burn through time determined in the Beitel tests was indicated by elevated temperatures in the interior of the box. Actual structural collapse of the boxes occurs significantly later after the pool fire exposure had reduced or terminated.

In the flue space burning geometry, one finds significantly lower external radiative fluxes. As noted in the flame spread model development, the burning surfaces are at about 600°C and provide about 32 kW/m^2 radiative flux to the opposing surface. Further, the wall flame contributes approximately 15 kW/m^2 based on total flux measurements by Quintiere (1986) and by Hasemi (1984) of $20\text{-}30 \text{ kW/m}^2$ of which about 10 kW/m^2 is convective. Thus, an external radiative flux from the opposing surface and radiation from the opposing surface flame is about 47 kW/m^2 . For purposes of this analysis, we will use 50 kW/m^2 . Based on the plywood data extrapolated to 19 mm thickness, the burning time is in the range 700-825 seconds. For purposes of this analysis, a burn time of 12 minutes (720 s) will be used.

5.0 Contents Burning Rate

The contents of the plywood boxes in this facility are very similar in content to that contained in 55 gallon drum waste storage at WHC and studied by Rhodes et al. (1995). In those tests, drums with similar contents were burned in the open. For loading densities of about 100 kg/m^3 with mixed plastic and cellulosic wastes, average burning rates, and heat release rates of $3\text{-}5 \text{ g/m}^2\text{s}$ and $120\text{-}160 \text{ kW/m}^2$, respectively, were observed. These results are about twice the values for trash fires compiled by Lee and reported by Babrauskas (1988) of $50\text{-}75 \text{ kW/m}^2$ for similar densities. These trash fire data are dominated by cellulose which may be the cause of their lower burning rates relative to the Rhodes et al. mixed cellulosic and plastic materials.

Based on the bulk density of 100 kg/m^3 and the burning rate per unit area of $4 \text{ g/m}^2\text{s}$ from the Rhodes et al. data, the regression rate is about $4 \times 10^{-5} \text{ m/s}$. Thus, to burn through the contents of a 1.2 m deep box requires in excess of 8 hours. If both sides of the box burn through, this may be reduced to about 4 hours. Clearly, burning through the contents of the box is not a viable fire spread mechanism except where very long time scales are appropriate. Flame spread rates in flues are about two orders of magnitude more rapid than contents burn through.

In terms of burning rates and heat release rates, the Rhodes et al. results should properly only be applied to surfaces with access to air. As boxes collapse, the flue spaces will be lost, and only exterior surfaces have access to air. Of course, these surfaces may not have been exposed to a flue fire or pool fire, and as such, the wood surface may not have been burned. This would be expected to further reduce the burning rate below that indicated by the Rhodes et al. data used in conjunction with the exterior surface area of the burning plywood box array.

6.0 Evaluation of Diesel Fuel Spill Scenarios

The initiation of the trench fire by 50 gallons of diesel fuel spilled at the edge of the array presents a significant threat to the array. The burning rate of the diesel fuel is bounded by the kerosene pool burning rate of 1.6 MW/m^2 for fuel spilled on a nonporous surface (Babrauskas (1988)). Lower burning rates can be expected on porous surfaces. Taking a pool the full 7.6 m length of the array edge and 1 m wide, the burning rate is 12 MW for a duration of 500 s. The 1 m pool width is sufficient to yield an optically thick flame. This is sufficient to initiate flue space fires and burn through the exposed face of the boxes. As flue space flame spread has been shown to dominate fire development, the analysis focuses on this mechanism.

The flue space flame spread model described in Section 3 is used to assess the flame spread along the plywood box flues. The material flame spread data used in Section 3 are used in the analysis in the absence of data for fire retarded plywood. Using these properties with a 2 inch (0.05 m) flue width yields a flame spread rate of 0.7 mm/s (0.0007 m/s). With a flue length of 7.6 m (25 ft), the flame is expected to traverse the full length of the flue in about 3 hours. Since the plywood burn through time is far less than this time, it is expected that the line fire initiation along one full array edge will involve all boxes within three hours.

While the above fuel spill fire configuration is certainly not the only possible spill configuration, it is certainly plausible and more than enough to initiate flue space fires in all flues. Longer spill lengths with reduced width may well be able to initiate additional flue space ends. Encroachment of the spill into the flues would further reduce the amount of fuel required to initiate each flue fire. Using the model for flue flame spread, it is possible to assess the heating length ahead of the flame foot that is significant in terms of material preheating and hence flame spread. Using the base case of a 0.05 m wide flue, the flame spread rate is only reduced by 5 percent if heating out to only 0.1 m ahead of the flame, two flue widths are included. This indicates that the length of flue space, which needs to be ignited by the initiating source need only be several flue widths long to initiate sustained flue flame spread.

Another method to gain some understanding of the potential for fire propagation in the array is to consider ignition of a single flue space. One may estimate the potential extent of fire propagation within three hours by tracing all flue paths which are within 7.6 m (the spread distance in three hours) of the initiation site via the flue spaces available. This results in burning of more than half of the array.

It is important to note that the calculations used here assume a 0.05 m flue space and assume that there is no slowing or stopping of the flame when the flame reaches the end of a box length and is faced with a 0.05 m gap. While strict application of the modeling principles used in the flue flame spread model would indicate that the flame may not be able to jump the 0.05 m flue gap created by the cross-flue, the experimental results of Beitel provide no support for this conclusion. As such, it appears that no credit can be taken for cross-flue gaps.

Taken together, the results presented here indicate that for the diesel fuel spill initiation scenario, all of the boxes in the array may be burned through within three hours of fire initiation. It must be remembered that this conclusion is based on non-fire retarded plywood and a uniform flue width of 0.05 m.

7.0 Evaluation of Tumbleweed Fire Scenarios

The collection of tumbleweeds along the edge of the drum arrays is a known phenomena. In the event of ignition of the tumbleweeds by a wildland fire or other cause, the full length of a box array could be exposed to a tumbleweed fire. The intensity of such fires is well known and results from the dry thin fuel elements. The thin fuel yields high heat release rates but also results in relatively short fire duration. Gross (1962) and Thomas (1974) have studied the burning of wood sticks. Their results indicate that an active burning duration of 3 minutes requires a stick thickness of approximately 1.2 cm. While this is probably somewhat large for typical tumbleweed, a burning duration for a tumbleweed of 2-3 minutes cannot be specifically eliminated as a possibility.

Based on the plywood ignition data of Quintiere and Harkleroad (1985), heat fluxes of only 20-25 kW/m² are required to ignite plywood in 2-3 minutes. As such, there can be no doubt as to the fact that the faces of the plywood exposed to the tumbleweed fire will be ignited. However, on burn out of the tumbleweed, these surfaces will not be able to sustain flaming combustion without external energy input. However, it is also expected that ignition of the flue space will occur to some distance from the exposed face of the boxes. Due to the burning of the opposite face of the flue, the burning within the flue is expected to be self-sustaining.

As noted in Section 5, the pre-heating length ahead of the flame foot is two flue widths or less in steady flame spread in the base case. Using the 0.7 mm/s flame spread rate and a heating length of 100 mm (two flue widths) yields a heating time of about 140 s. Thus, a 2-3 minute exposure at the end of the flue with the same emissive power as the burning wood surface (32 kW/m^2) would be sufficient to establish the steady flame spread pre-heat zone temperatures. It is quite clear that the emissive power of a substantial tumbleweed fire must be far in excess of this emissive power due to the substantial flame contribution. Thus, a tumbleweed fire propagating along the edge of the array is expected to ignite flue space fires which will propagate at the 0.7 mm/s flame spread rate established in Section 5. In essence, the tumbleweed is a sufficiently potent initiating source that the same loss of the full array within three hours is expected as was determined for the diesel fuel. In the sense that accumulation of tumbleweed along the whole array edge is expected to occur and spilling diesel fuel along the full length of the array may not occur for all or even most fuel spills, the tumbleweed scenario is higher risk initiating source than fuel spill fires.

8.0 Conclusions

Under the assumption that the plywood boxes are not fire retarded and the flue space width within the array is about 0.05 m (2 inches), burn through of all plywood boxes within an array can occur. While manual firefighting intervention after three hours would be expected to prevent the consumption of all the contents, a substantial fraction of the contents is expected to be consumed. Without intervention, the results of this work indicate that all of the box contents could be consumed in a fire incident.

9.0 References

- Atreya, A., Carpentier, C., and Harkleroad, M. (1986), "Effect of Sample Orientation on Piloted Ignition and Flame Spread," *Fire Safety Science—Proceedings of the First International Symposium*, Hemisphere Publishing, NY, 1986, pp. 97-109.
- Babrauskas, V. (1982), "Development of the Cone Calorimeter—A Bench-Scale Heat Release Rate Apparatus Based on Oxygen Consumption," NBS 82-2611, National Bureau of Standards, Washington, D.C., November 1982.
- Babrauskas, V., (1988) "Burning Rates", Section 2/Chapter 1, *The SFPE Handbook of Fire Protection Engineering*, P. DiNenno, Editor-in-Chief, National Fire Protection Association, Quincy, MA.
- Beitel, J.J. (1978), "Full-Scale Fire Testing of DOT-7A Boxes Utilized for Solid Water Storage," Final Draft, prepared for EG&G Idaho, Inc., October 1978.
- Blackshear, P.L. (1974), *Heat Transfer in Fires*, Scripta Book Company, Washington DC, pp. 413.
- Brown, R. (1979), "DOT 7A FRP Box Fire Test at the INEL," EG&G Idaho, Inc., TREE-1367, 1979.
- Gross, D. (1962), "Experiments on the Burning of Cross Piles of Wood," *Journal of Research of the National Bureau of Standards—C. Engineering and Instrumentation*, Vol. 66C, No. 2, April-June 1962.
- Hasemi, Y. (1984), "Experimental Wall Flame Heat Transfer Correlations for the Analysis of Upward Flame Spread," *Fire Science and Technology*, 4(2).
- Janssens, M. (1991), "Fundamental Thermophysical Characteristics of Wood and their Role in Enclosure Fire Growth," Ph.D. Dissertation at University of Gent (Belgium).
- Jianmin, Q. (1992), "Prediction of LIFT Data from Cone Calorimeter Measurements", *Heat Release in Fire*, Babrauskas and Grayson, ed., Elsevier Science Publishers, Ltd, England, pp 293-306.

- Quintiere, J. and Harkleroad, M. (1985), "New Concepts for Measuring Flame Spread Properties," *Fire Safety: Science and Engineering, ASTM STP 882*, T.Z. Harmathy, ed., American Society for Testing and Materials, Philadelphia, PA, 1985, pp. 239-267.
- Quintiere, J. et al. (1986), "Wall Flames and Implications of Upward Flame Spread", *Combustion Science and Technology*, 48, pp. 191-222.
- Rhodes, B.T., Beitel, J.J., Gottuk, D.T., Beyler, C.L., Rosenbaum, E.R., and Haecker, C.F. (1995), "Analytical and Experimental Evaluation of Solid Waste Drum Fire Performance, Volume I," Hughes Associates, Inc., WHC-SD-WM-TRP-233 REV.0, Westinghouse Hanford Company, April 28, 1995.
- Thomas, P.H. (1974), "The Effect of Crib Porosity in Recent CIB Experiments," Fire Research Note No. 999, Fire Research Station, Borehamwood, UK, February 1974.

Appendix A
Flue Flame Spread Model Sensitivity Analysis

The basic flue flame spread scenario is a 2 inch (0.05 m) wide plywood flue space. It is of interest to assess the sensitivity of the calculated flame spread rate to major variables. The most obvious variables are the flue space width which is inherently variable and the emissive power of the burning wall which has nominally been taken as 32 kW/m² in the present model, corresponding to a surface temperature of 600°C.

Table A-1 shows the variation in flame spread rate with flue width in the model. While the variations in flame spread rate are not insignificant, the results indicate that moderate variations in the flue width will not affect the results to a significant extent.

Table A-1. Sensitivity of the Base Flame Spread Rate Calculation to Flue Width

Flue Width (m)	Flame Spread Rate (mm/s)
0.0125	0.38
0.025	0.50
0.05	0.70
0.10	1.0
0.15	1.25
0.20	1.5
0.23	1.7

Table A-2 shows the variations in flame spread rate with the emissive power of the burning surfaces which is driving the flame spread. As noted in the model development, 32 kW/m² (600°C surface temperature) was selected based on typical wood surface burning temperatures and resulting surface emissive power. Somewhat lower emissive powers (surface temperatures) are possible, and higher values may be possible based on the inclusion of flame radiation. For instance, at the edge of the array where the pool fire is burning, an emissive power of around 150 kW/m² (1000°C) is reasonable. Here again, based on these results, it is difficult to rationalize flame spread rates much below the base case rate of 0.7 mm/s used in the analysis.

Table A-2. Sensitivity of the Base Flame Spread Rate
Calculation to Emissive Power/Burning Surface Temperature

Temperature (C)	Emissive Power (kW/m ²)	Flame Spread Rate (mm/s)
400	12	0.3
500	20	0.45
600	32	0.7
700	51	1.1
800	75	1.8
1000	149	5.08

APPENDIX E

**Supporting Analyses for the Low Level Waste Trenches,
Solid Waste Burial Grounds Fire Hazard Analysis,
Estimation of Radiological Release Potential,
Ground Area Contamination, and Cleanup Costs
Associated with a Plywood Container Array Fire
in a Low Level Waste Trench**

Estimation of Radiological Release Potential and Ground Area Contamination Resulting From a Plywood Container Array fire in a Low Level Waste Trench

Step (1) Determine curie content release potential by determining

- Radionuclide Concentration/Container,
- Number of Containers, and
- Inventory as risk (I) in curies.

For purposes of estimating radionuclide release, it is assumed that the fire involves 100% of the curie content of all the containers. Assumptions include an array of containers constructed of 3/4-in. plywood of dimensions 4 ft by 4 ft by 8 ft, stacked three high, 6 across and 25 deep resting on soil within a burial ground trench. This equates to 450 containers that are potentially exposed. The plywood boxes are filled with combustible waste contaminated with radiological material. The containers are tightly packed with separation between containers of 2 in. or less. The containers rest on 4 in. by 4 in. (nominal dimensions) wooden skids so the horizontal spacing between the containers is approximately 3.5 in. The postulated release is conservatively assumed to be based on the maximum expected radionuclide concentration with combustible waste. The concentration of isotopes in containers such as plywood containers are limited to the *Waste Acceptance Criteria* (WHC 1993) Category 1 concentration limits for any large array of containers. Category 3 waste must be stabilized and covered thereby limiting their potential for possible involvement in fire. Greater than Category 3 wastes are no longer disposed of in the burial grounds. Any fire involving a large number of plywood containers must also consider packaging criteria in addition to the Category 1 limits that will effectively limit the concentration of isotopes in these containers. A significant limitation on gamma emitters such as ^{60}Co is the requirement that contact handled packages have surface dose rates of no more than 200 mRem/hr. Packages with higher dose rates are remote handled and require coverage of soil after receipt to limit personnel exposures.

This limit on contact handled waste was evaluated in the attached analysis to determine the actual concentration of the primary gamma source (^{60}Co) and beta source (^{90}Sr) that will result in the worst consequences in terms of maximum area contamination from a fire. Two possibilities were evaluated. The first considered essentially uniform distribution of the wastes as would be expected in a container of contaminated combustible wastes. The second evaluated the maximum quantity that could be at the center of the container as might occur from a single source. Note that this maximum quantity would not be expected since it would require remote handling just to place it in a container while material that was uniformly contaminated could potentially be placed at concentrations near these levels by operating personnel.

Based on the referenced work, the quantity of ^{60}Co would be limited by the dose rate for contact handled containers to the value calculated for uniformly distributed materials for typical waste distributions. For a 4 ft x 4 ft x 8 ft plywood container this value has been determined to be: 0.59 Ci (for ^{60}Co).

Thus, the postulated radiological inventory is given by the following:

$$I = \text{Radionuclide/container} \times \text{No. of containers}$$

$$I = 0.59 \times 450$$

$$I = 265.5 \text{ Ci}$$

The extent of ground contamination is estimated utilizing the methodology developed by Himes:

Method Assumptions

- Estimation of releases, a function of particle fall velocity.
- Estimation of equilibrium plume height, by calculating fire heat generation rate and using an established buoyant plume model.
- Meteorological conditions are pasquill F stability with a reference (10 m) wind speed of 1 m/s. Note that pasquill stability classes are used to define meteorological atmospheric conditions and typically range from A to F. For materials with a deposition velocity of zero and release point at or very near ground level, the maximum concentration is always associated with "F" stability (LLNL 1994). For his formulation, Himes has 'arbitrarily' selected "F" stability, and suggests that other combinations of meteorology conditions could produce somewhat larger contaminated areas, but also indicates that the results are a highly approximate estimate and that the source term contributes the greatest uncertainty.
- Fire's rate of heat release = $Q'/A = 397 \text{ kw/m}^2$ or $9.48 \text{ E}+04 \text{ cal/m}^2\text{s}$ (35 BTU/ft²s).

Problem Assumptions

- Since all the containers and contents are expected to burn, the fire area is assumed to equal the area of the array. This is approximately 48 ft x 100 ft or 4,800 ft² (446 m²). Note that neither the tumbleweed fire nor the flammable liquids fuel spill/fire contains radiological material. Both the tumbleweed and the flammable liquid fuel fire are presumed to be fully consumed at or about the time of container failure, and thus are not included as part of the fire area assumed for this calculation.
- Minimum level of Contamination, C, is determined from assessable soil concentration limits identified for the 200 West Area in WHC-CM-7-5 (WHC 1994b), and
- I is the radiological at-risk inventory.

From Himes, equation for determining downwind extent of the contour corresponding to a minimum contamination level, C, is:

$$x_L = [64.9 \times (I/C) \times A_F^{0.8407}]^{-1/m} \quad (\text{Equation 1})$$

where: x_L = maximum downwind extent (m)

I = at-risk inventory (Curies)

C = minimum contamination level (Ci/m²)

The accessible soil concentration limit for cobalt 60 is 7.1 E+00 pCi/g from WHC-CM-7-5, Table 6-2 (WHC 1994b):

$$C = 7.1 \text{ E}+00 \text{ pCi/g} \times 1.6 \text{ g/cm}^3 \times 10^{-12} \text{ Ci/pCi} \times 10^4 \text{ cm}^2/\text{m}^2$$

For a 1 cm depth:

$$C = 1.13 \text{ E-07 Ci/m}^2$$

$$A_F = \text{area of fire, assumed to be the area of the container array} \\ = 446 \text{ m}^2$$

$$m = \text{unitless value determined by:}$$

$$m = -(0.02940 \ln A_F + 3.248) \quad (\text{Equation 2})$$

Solving Equation 2:

$$m = -3.427$$

Solving Equation 1:

$$x_L = 8184 \text{ m}$$

From Himes, equation for determining area of the contour corresponding to a minimum contamination level, C , is:

$$A_C = 0.0724[(-m)^{0.5} (x_L^{1.903})] \quad (\text{Equation 3})$$

Solving Equation 3:

$$A_C = 3,746,012 \text{ m}^2$$

Using the same unit cost value as that referenced in WHC-SD-GN-TI-20004 (WHC 1994a), a clean up unit value of \$5.49/m² is assumed.

At \$5.49/m², clean-up costs are calculated to be: \$20,565,607.

In order to identify the "worst" case, strontium 90 (⁹⁰Sr) was also considered. From the referenced analysis the concentration limit for ⁹⁰Sr material is the Category 1 maximum given in the reference to be 1.6E-2 Ci per box.

Thus, the postulated radiological inventory is given by the following:

$$I = \text{Radionuclide/container} \times \text{No. of containers}$$

Solving for the worst case fuel spill and fire:

$$I = 1.6\text{E-2}(450)$$

$$I = 7.2 \text{ Ci (for } ^{90}\text{Sr)}$$

The accessible soil concentration limit for ⁹⁰Sr = 2.8E+03 pCi/g (WHC 1994b),

$$C = 2.8\text{E+03 pCi/g} \times 1.6 \text{ g/cm}^3 \times 10^{-12} \text{ Ci/pCi} \times 10^4 \text{ cm}^2/\text{m}^2$$

for depth of 1 cm:

$$C = 4.48 \times 10^{-5} \text{ Ci/m}^2$$

The I/C value for ^{90}Sr is approximately 160,714. The I/C value for ^{60}Co is approximately 8,849,558. Since the I/C value for ^{90}Sr is much less than the I/C value for ^{60}Co , it can be intuitively concluded that the contamination area resulting from the same type of fire is less for ^{90}Sr than for ^{60}Co . Therefore, the MPFL is best represented by a postulated loss of ^{60}Co .

Other Considerations

All low-level mixed waste is assumed to have zero property value. This analysis assumes that the fire loss associated with a low level trench fire that involves all exposed plywood boxes would only result in an event where no fire department intervention has occurred. For a fire initiated by a tumbleweeds fire, this is a plausible event. It is assumed that the waste that was exposed or released from the container but remained in the trench would be covered with soil without any further repackaging.

No other significant costs have been identified. Therefore, the fire MPFL is estimated to be \$20,565,607.

It should be noted that rapid fire suppression by the fire department could further limit the release of radiological material and thereby limit the fire loss attributed to ground area contamination.

Estimation of "Credible fire loss":

The MPFL in determining the inventory at risk (I) utilized the maximum radiological inventory that could be placed within each plywood container and remain contact handled. A more "credible" estimate is to base the inventory at risk (I) on the "expected" radiological inventory to be disposed in the LLW trenches. One means to estimate the "credible" inventory is to take the average curie content of previous plywood boxes disposed in the LLW Burial Grounds and consider the average to be representative of future plywood container inventories. A SWITS search of Burial Ground 218-W-5, trench 27 revealed 2,035 plywood containers with a total inventory of 26.6 Ci. This results in an average curie content of 0.013 Ci/plywood container. A SWITS search of Burial Ground 218-W-5, trench 22, revealed 715 plywood containers with a total inventory of 24 Ci. This results in an average curie content of 0.034 Ci.

The larger average value 0.034Ci/plywood container is assumed to be reasonably representative of future waste inventory. For purposes of estimating ground contamination, it is conservatively assumed that the total inventory at risk is ^{60}Co . The same type of fire as was used in calculating the MPFL is used in estimating the "credible fire loss". It should be noted that this "credible fire loss" does not meet the definition of the Maximum Credible Fire Loss (MCFL) as defined in DOE 5480.7A, but is provided to provide a more realistic indicator of potential fire loss.

Thus, the postulated radiological inventory is given by the following:

$$I = \text{Radionuclide/container} \times \text{No. of containers}$$

$$I = 0.034 \text{ Ci/plywood container} \times 450$$

$$I = 15.3 \text{ Ci}$$

As noted above:

$$A_F = 446 \text{ m}^2$$

$$C = 1.13 \text{ E-07 Ci/m}^2$$

$$m = -3.427 \text{ (equation 2)}$$

Solving Equation 1:

$$x_L = 3561 \text{ m}$$

Solving Equation 3:

$$A_c = 768842 \text{ m}^2$$

At 5.49/m², clean-up costs are calculated to be: \$4,220,942.

This credible fire loss is considered conservative since it assumes all of the inventory at risk is ⁶⁰Co, all of the exposed containers burn (i.e. no credit for fire retardant container characteristics), and there is no credit for Hanford Fire Department mitigation efforts.

APPENDIX E REFERENCES

- DOE, 1993 Fire Protection, DOE Order 5480.7A, U.S. Department of Energy, Washington, D.C.
- LLNL, 1994, Homann, Steven G., HOTSPOT, Health Physics Codes for the PC, March 1994, Lawrence Livermore National Laboratory, Livermore, California.
- WHC, 1993, Solid Waste Acceptance Criteria, WHC-EP-0063-4, November 1993, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1994a, A Method for Estimating Ground Areas Contaminated by a Postulated Fire in a Facility Containing Radioactive Material, WHC-SD-GN-TI-20004, September 1994, Westinghouse Hanford Company, Richland, Washington.
- WHC 1994b, Environmental Compliance, WHC-CM-7-5 Release 2, Westinghouse Hanford Company, Richland, Washington.

APPENDIX F

Shielding Calculations for Plywood Storage Box and a Steel Drum

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Y2

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Introduction to Appendix F

Isotope limits for containers to be placed for disposal in the Solid Waste Burial Grounds have been developed for ^{60}Co and ^{90}Sr . These values have been used as the basis for estimating the radiological material at risk for each container in the calculation of the Maximum Possible Fire Loss for the Mixed Waste and Low Level Waste Trenches.

Determination of radionuclide content limits in the Solid Waste Burial Ground Trenches in the Solid Waste Burial Ground trenches are subject to a number of factors. The concentration of isotopes in containers such as plywood boxes or steel drums are limited to the Waste Acceptance Criteria (WHC-EP-0063-4) Category 1 concentration limits for any large array of containers. Category 3 waste must be stabilized and covered thereby limiting their potential for possible involvement in fire. Greater than Category 3 wastes are no longer disposed of in the burial grounds. The TRU waste remaining in the burial grounds is a greater than Category 3 waste but has known concentrations of radionuclides for the existing stored waste for use in the determination of the MPFL for the TRU waste.

There are packaging criteria in addition to the Category 1 limits that effectively limit the concentration of isotopes in plywood boxes and steel drums. A significant limitation on gamma emitters such as ^{60}Co is the requirement that contact handled packages have surface dose rates of no more than 200 mRem/hr. Packages with higher dose rates are remote handled and require coverage by soil after receipt to limit personnel exposures.

The limit on contact handled waste was evaluated to determine the actual concentration of the primary gamma source ^{60}Co and ^{90}Sr that will result in the worst consequences in terms of maximum contamination area from a fire. A 4 ft x 4 ft x 8 ft plywood box was evaluated to determine the maximum content of each isotope that could be contained in the box assuming typical contents for LLW containers. Two possibilities were evaluated. The first considered essentially uniform distribution of the waste as would be expected in a container of contaminated combustible wastes. The second evaluated the maximum quantity that could be at the center of the box as might occur from a single source. This maximum quantity would not be expected since it would require remote handling just to place it in a box while material that was uniformly contaminated could potentially be placed at concentrations near these levels by operating personnel. The same calculations were made for 55-gal drums to determine the possible maximum quantities of wastes in these containers without provision of additional shielding. The results of the calculations are presented in the following table. The actual calculations are included as this Appendix.

Isotope	⁶⁰ Co (Ci)	⁹⁰ Sr (Ci)
Activity Uniform Over Box	0.59	85
Activity Centered in Box	29	64,000
Category 1* Maximum in Box	279	1.6E-2
Activity Uniform Over Drum	0.043	12.8
Activity Centered in Drum	0.127	136
Category 1* Maximum in Drum	16	8.9E-4

* Category 1 values are presented as Ci/m³ in WHS-SD-SARR-028, Rev 1, Table 6-3. The total number of curies for the plywood box is based on a volume of 3.62 m³ (4 ft x 4 ft x 8 ft). The total number of curies for the drum is based on a volume of 0.2 m³.

Table values in bold print represent the values utilized to estimate the MPFL for the LLW and MW trenches.

Westinghouse
Hanford Company

Internal
Memo

From: Consequence Analysis
Phone: 376-2920 H4-64
Date: September 8, 1995
Subject: SHIELDING CALCULATION FOR STORAGE BOX

8M400-JCVK-95005

To: D. R. Porten H4-70
cc: T. Chiao H4-64
JCVK File/LB

The calculation of the maximum activities to produce a 200 mr/h dose rate at a storage box surface has been performed. The results are summarized below and are described in the attachments.

Activities Required to Produce a 200 mr/h Dose
Rate at the Surface of a 4 ft by 4 ft by 8 ft Wood
Box with Self Shielding based on Drum Contents.

Isotope	Activity spread uniformly over box (Ci)	Activity concentrated in center of box (Ci)
Co-60	0.59	29
Sr-90	85	64,000

J. C. Van Keuren
Senior Principal Engineer

gjr

Attachments 2

Concurrence
D. S. Leach, Manager

ATTACHMENT 1
to
8M400-JCVK-95005

SHIELDING CALCULATION FOR STORAGE BOX ANALYSIS DESCRIPTION Page 137 of 162

The activity contents of boxes containing radioactive waste are limited by the quantities assumed in the safety analyses of events such as a release from dropping of a box or a fire that results in release. It is necessary to determine the maximum activities in the box to perform these analyses. The dose rate at the box surface is limited to 200 mr/h. A conservative calculation has been made of the maximum isotope content that could be in the storage box, and not result in a 200 mr/h dose rate at the surface of the box being exceeded. Four calculations were requested (Porten 1995): 1) assume Co-60 is uniformly spread throughout the inside of the box, 2) assume the Co-60 source is concentrated at the center of the box, 3) assume a Sr-90 source uniformly spread throughout the inside of the box, and 4) assume the Sr-90 is concentrated at the center of the box.

The box dimensions are 4 ft by 4 ft by 8 ft (1.22 m by 1.22 m by 2.44 m). The box is wood 0.75 inch (1.91 cm) thick. The content of the box is waste consisting of mixtures of wood, rubber, metal and plastics. The exact mixture will vary from box to box. The contents of the box are important because the contents provide self shielding. This analysis is based on assumptions that maximize self shielding effects since the purpose of the calculation is to determine the maximum radioactive content that would not result in the 200 mr/h dose rate at the box surface being exceeded.

The waste in the box is similar to that normally contained in solid waste drums. The self shielding from the material inside the box was modelled based on samples taken from drums. A content profile of the drums was determined for WRAP-1 (Joyce 1993). This profile indicates 22% of the contents are metal, and the remainder is lower density material. In this calculation, the metal was modelled as iron with an effective density of $0.22 \times 7.83 = 1.72 \text{ g/cm}^3$. The rest of the waste was assumed to be combustible. Calculation for the SWBG ISB indicated that the combustible loading in a drum is a maximum of 200 kg in a 0.208 m^3 volume. The combustible waste was modelled as carbon with a density of $200,000 \text{ g}/(0.208 \text{ m}^3 \times 10^6 \text{ cm}^3/\text{m}^3) = 0.97 \text{ g/cm}^3$. This is a conservative estimate of the box content since it implies that there is essentially zero void volume in the box, and that the mass of the contents of the box is about 9800 kg (21,000 lbm). The mass of an average box is expected to be about 1400 kg (3000 lbm). The wood walls of the box were assumed to be carbon with a density of 0.5 g/cm^3 .

The computer code ISOSHL (Lourant, 1990) was used to calculate the dose rates. A box geometry was assumed for the two cases with source spread uniformly over the box. The dose rates were calculated at a surface of the box perpendicular to the 8 ft length of the box. That is, the dose was calculated in the center of one of the 8 ft x 4 ft surfaces. Doses from bremsstrahlung were included as this is dominant dose effect from Sr-90 since the beta from Sr-90 will not penetrate the box walls. Since Sr-90 exists in equilibrium with Y-90, the box was assumed to contain Y-90 equal to the Sr-90.

The calculation with the source located in the center of the box was modelled as a point source with slab shields equal to half the thickness of the box and the box wood wall placed between the source and the detector.

The computer code outputs are given in Attachment 2. The results are summarized in Table 1 below.

Table 1 Activities Required to Produce a 200 mr/h Dose Rate at the Surface of a 4 ft by 4 ft by 8 ft Wood Box with Self Shielding based on Drum Contents.

Isotope	Activity spread uniformly over box (Ci)	Activity concentrated in center of box (Ci)
Co-60	0.59	29
Sr-90	85	64,000

The values in Table 1 are based on specific assumptions of box content and should be used with care. The assumptions are conservative but a box containing higher metal fractions or box with a hot spot of radioactive waste shielded by high density material might contain higher radioactive inventories, and still meet the 200 mr/hr dose rate limit.

References

Joyce 1993, Memo from J. P. Joyce to C. B. Evans, "SWBG FHA Combustible Loadings for TRU 55 Gallon Drums," JPH-29540-93-001.

Porten, 1995 Memo from D. Porten to J. C. Van Keuren, "Shielding Calculation for Waste in a Storage Box."

Lourant, 1990. Validation of the ISOSHL-PC on the IBM-PC (PS-2/AT/XT). EDT-109878, WHC-SD-SQA-CWSD-303.

ATTACHMENT 2
to
8M400-JCVK-95005

COMPUTER CODE OUTPUTS

ISOSHL-D-II (RIBD removed)
IBM PC/AT Version 1.5, August 1987
Radiological Analysis
Westinghouse Hanford Company
Richland, WA 99352

box 4x4x8

Table of Source Activity:

Scale Factor = 1.000E+00

Isotope	Name	Curies	Adjusted Curies
CO-60		5.90E-01	5.900E-01

Shield Composition, g/cc

Shield 1 Shield 2 Shield 3 Shield 4 Shield 5

CARBON	IRON
9.700E-01	5.000E-01
1.720E+00	0.000E+00

Group Linear Attenuation Coefficients (Last region is air)

1	7.737E+01	7.260E-01	4.424E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2	2.141E+01	1.528E-01	6.542E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
3	9.983E+00	1.055E-01	3.504E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
4	4.712E+00	9.275E-02	2.715E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5	2.671E+00	8.675E-02	2.405E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
6	1.831E+00	8.300E-02	2.247E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
7	1.347E+00	8.000E-02	2.137E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
8	1.014E+00	7.750E-02	2.049E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
9	8.324E-01	7.550E-02	1.985E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
10	4.818E-01	6.750E-02	1.725E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
11	3.472E-01	5.750E-02	1.474E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
12	2.701E-01	5.075E-02	1.312E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
13	2.393E-01	4.575E-02	1.183E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
14	2.077E-01	4.325E-02	1.118E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
15	1.770E-01	3.475E-02	8.986E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
16	1.627E-01	3.175E-02	8.210E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
17	1.438E-01	2.865E-02	7.408E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
18	1.308E-01	2.575E-02	6.658E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
19	1.231E-01	2.390E-02	6.180E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

20	1.150E-01	2.250E-02	5.818E-05	0.000E+00	0.000E+00	0.000E+00
21	1.104E-01	2.125E-02	5.495E-05	0.000E+00	0.000E+00	0.000E+00
22	1.050E-01	2.035E-02	5.262E-05	0.000E+00	0.000E+00	0.000E+00
23	1.026E-01	1.935E-02	5.004E-05	0.000E+00	0.000E+00	0.000E+00
24	9.884E-02	1.850E-02	4.784E-05	0.000E+00	0.000E+00	0.000E+00
25	9.394E-02	1.695E-02	4.383E-05	0.000E+00	0.000E+00	0.000E+00

Box Co 60 source 0.59 Ci

Source Shields Distance to Detector, X = 1.239E+02 cm
Slab Slab Volume = 3.624E+06 cc
Thickness = 1.219E+02 cm Height = 2.438E+02 cm Width = 1.219E+02 cm
Integration Specs: NTHETA = 25 NPSI = 25 DELR = 6.417E+00 cm
Total Intervals: 1.187E+04

Shield Thickness, cm 1.219E+02 1.910E+00
Taylor Buildup Data for Shield 1 with Effective Atomic Number 11.5

Group	Average Energy, Mev	Bremsstr. photons/sec	Source Total photons/sec	Energy Flux Mev/sq.cm/sec	Dose Rate R/hr
1	1.500E-02	1.062E+08	1.062E+08	3.135E-01	2.580E-05
2	2.500E-02	3.240E+07	3.240E+07	4.444E-01	7.687E-06
3	3.500E-02	2.015E+07	2.015E+07	4.906E-01	3.115E-06
4	4.500E-02	1.194E+07	1.194E+07	4.242E-01	1.391E-06
5	5.500E-02	7.674E+06	7.674E+06	3.566E-01	8.166E-07
6	6.500E-02	5.474E+06	5.474E+06	3.162E-01	5.980E-07
7	7.500E-02	3.781E+06	3.781E+06	2.654E-01	4.549E-07
8	8.500E-02	2.736E+06	2.736E+06	2.298E-01	3.716E-07
9	9.500E-02	2.001E+06	2.001E+06	2.030E-01	3.254E-07
10	1.500E-01	3.647E+06	3.647E+06	5.836E-01	1.009E-06
11	2.500E-01	1.487E+05	1.487E+05	4.788E-02	9.384E-08
12	3.500E-01	4.127E+04	4.127E+04	2.230E-02	4.594E-08
13	4.750E-01	2.599E+04	2.599E+04	2.118E-02	4.320E-08
14	6.500E-01	1.131E+04	1.131E+04	1.321E-02	2.748E-08
15	8.250E-01	2.709E+03	2.186E+06	3.330E+00	6.660E-06
16	1.000E+00	9.440E+02	9.440E+02	1.838E-03	3.547E-09
17	1.225E+00	1.072E+02	4.366E+10	1.095E+05	2.014E-01
18	1.475E+00	2.828E+01	2.828E+01	8.830E-05	1.554E-10
19	1.700E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
20	1.900E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
21	2.100E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
22	2.300E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
23	2.500E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
24	2.700E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
25	3.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

TOTALS 1.962E+08 4.386E+10 1.095E+05 2.015E-01

Note that 2.015E-01 R/hr = 1.444E-08 amp/kg

Scale Factor = 1.000E+00

WHC-SD-WM-FHA-015, Rev. 0
Page 142 of 162

Isotope Name	Curies	Adjusted Curies
SR- 90	8.50E+01	8.500E+01
Y - 90	8.50E+01	8.500E+01

SOURCE =Strontium 90 Y90 85 Ci

Source Slab Shields Slab Distance to Detector, X = 1.239E+02 cm
Volume = 3.624E+06 cc
Thickness = 1.219E+02 cm Height = 2.438E+02 cm Width = 1.219E+02 cm
Integration Specs: NTHETA = 25 NPSI = 25 DELR = 6.417E+00 cm
Total Intervals: 1.187E+04

Shield Thickness, cm 1.219E+02 1.910E+00
Taylor Buildup Data for Shield 1 with Effective Atomic Number 11.5

Group	Average Energy, Mev	Bremsstr. photons/sec	Source Total photons/sec	Energy Flux Mev/sq.cm/sec	Dose Rate R/hr
1	1.500E-02	1.797E+11	1.800E+11	5.314E+02	4.374E-02
2	2.500E-02	9.893E+10	9.893E+10	1.357E+03	2.347E-02
3	3.500E-02	5.969E+10	5.969E+10	1.453E+03	9.228E-03
4	4.500E-02	4.091E+10	4.091E+10	1.454E+03	4.768E-03
5	5.500E-02	2.945E+10	2.945E+10	1.369E+03	3.134E-03
6	6.500E-02	2.550E+10	2.550E+10	1.473E+03	2.786E-03
7	7.500E-02	2.319E+10	2.319E+10	1.628E+03	2.790E-03
8	8.500E-02	2.108E+10	2.108E+10	1.770E+03	2.863E-03
9	9.500E-02	1.898E+10	1.898E+10	1.925E+03	3.085E-03
10	1.500E-01	8.636E+10	8.636E+10	1.382E+04	2.388E-02
11	2.500E-01	2.808E+10	2.808E+10	9.042E+03	1.772E-02
12	3.500E-01	1.360E+10	1.360E+10	7.349E+03	1.514E-02
13	4.750E-01	1.001E+10	1.001E+10	8.153E+03	1.663E-02
14	6.500E-01	5.772E+09	5.772E+09	6.744E+03	1.403E-02
15	8.250E-01	2.071E+09	2.071E+09	3.155E+03	6.311E-03
16	1.000E+00	1.348E+09	1.348E+09	2.625E+03	5.067E-03
17	1.225E+00	6.521E+08	6.521E+08	1.635E+03	3.009E-03
18	1.475E+00	2.009E+08	2.009E+08	6.272E+02	1.104E-03
19	1.700E+00	4.310E+07	1.500E+08	5.607E+02	9.587E-04
20	1.900E+00	8.462E+06	8.462E+06	3.670E+01	6.092E-05
21	2.100E+00	4.535E+05	4.856E+06	2.354E+01	3.766E-05
22	2.300E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
23	2.500E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
24	2.700E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
25	3.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TOTALS		6.456E+11	6.459E+11	6.673E+04	1.998E-01

Note that 1.998E-01 R/hr = 1.432E-08 amp/kg

***> end of run

Finish run at 13:31:37 09/05/95

Contents of Input file, box.in

```
0      2    box 4x4x8
rect co 60 source 0.59 Ci
&INPUT NEXT=1, IGEOM=10, X=123.87, Y=243.84, ISPEC=3,
NSHLD=2, JBUF=1, T(1)=121.92, 1.91, SLTH=121.91, DELR=6.1,
NTHETA=25, NPSI=25,
WEIGHT(472)=0.59 &
      6      0.97      0.5
I      9      1.72
SOURCE =Strontium 90 Y90 85 Ci
&INPUT NEXT=2, WEIGHT(472)=0.0, WEIGHT(82) =85.0, WEIGHT(84)=85.0 &
end of run
&input next=6 &
```

Start run at 13:34:56 09/05/95

WHC-SD-WM-FHA-015, Rev. 0
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ISOSHL-D-II (RIBD removed)

IBM PC/AT Version 1.5, August 1987
Radiological Analysis
Westinghouse Hanford Company
Richland, WA 99352

POINT SOURCE

Table of Source Activity:

Scale Factor = 1.000E+00

Isotope Name	Curies	Adjusted Curies
CO- 60	2.90E+01	2.900E+01

Shield Composition, g/cc

	Shield 1	Shield 2	Shield 3	Shield 4	Shield 5
CARBON	9.700E-01	5.000E-01			
IRON	1.720E+00	0.000E+00			

Group	Linear Attenuation Coefficients (last region is air)				
1	7.737E+01	7.260E-01	4.424E-03	0.000E+00	0.000E+00
2	2.141E+01	1.528E-01	6.542E-04	0.000E+00	0.000E+00
3	9.983E+00	1.055E-01	3.504E-04	0.000E+00	0.000E+00
4	4.712E+00	9.275E-02	2.715E-04	0.000E+00	0.000E+00
5	2.671E+00	8.675E-02	2.405E-04	0.000E+00	0.000E+00
6	1.831E+00	8.300E-02	2.247E-04	0.000E+00	0.000E+00
7	1.347E+00	8.000E-02	2.137E-04	0.000E+00	0.000E+00
8	1.014E+00	7.750E-02	2.049E-04	0.000E+00	0.000E+00
9	8.324E-01	7.550E-02	1.985E-04	0.000E+00	0.000E+00
10	4.818E-01	6.750E-02	1.725E-04	0.000E+00	0.000E+00
11	3.472E-01	5.750E-02	1.474E-04	0.000E+00	0.000E+00
12	2.701E-01	5.075E-02	1.312E-04	0.000E+00	0.000E+00
13	2.393E-01	4.575E-02	1.183E-04	0.000E+00	0.000E+00
14	2.077E-01	4.325E-02	1.118E-04	0.000E+00	0.000E+00
15	1.770E-01	3.475E-02	8.986E-05	0.000E+00	0.000E+00
16	1.627E-01	3.175E-02	8.210E-05	0.000E+00	0.000E+00
17	1.438E-01	2.865E-02	7.408E-05	0.000E+00	0.000E+00
18	1.308E-01	2.575E-02	6.658E-05	0.000E+00	0.000E+00
19	1.231E-01	2.390E-02	6.180E-05	0.000E+00	0.000E+00

20	1.150E-01	2.250E-02	5.818E-05	0.000E+00	0.000E+00	0.000E+00
21	1.104E-01	2.125E-02	5.495E-05	0.000E+00	0.000E+00	0.000E+00
22	1.050E-01	2.035E-02	5.262E-05	0.000E+00	0.000E+00	0.000E+00
23	1.026E-01	1.935E-02	5.004E-05	0.000E+00	0.000E+00	0.000E+00
24	9.884E-02	1.850E-02	4.784E-05	0.000E+00	0.000E+00	0.000E+00
25	9.394E-02	1.695E-02	4.383E-05	0.000E+00	0.000E+00	0.000E+00

Source Point Shields Slab Distance to Detector, X = 6.287E+01 cm
Offset from Normal, Y = 0.000E+00 cm

Shield Thickness, cm 6.096E+01 1.910E+00
Taylor Buildup Data for Shield 1 with Effective Atomic Number 11.5

Group	Average Energy, Mev	Bremsstr. photons/sec	Source Total photons/sec	Energy Flux Mev/sq.cm/sec	Dose Rate R/hr
1	1.500E-02	5.219E+09	5.219E+09	0.000E+00	0.000E+00
2	2.500E-02	1.593E+09	1.593E+09	0.000E+00	0.000E+00
3	3.500E-02	9.905E+08	9.905E+08	0.000E+00	0.000E+00
4	4.500E-02	5.869E+08	5.869E+08	0.000E+00	0.000E+00
5	5.500E-02	3.772E+08	3.772E+08	0.000E+00	0.000E+00
6	6.500E-02	2.690E+08	2.690E+08	0.000E+00	0.000E+00
7	7.500E-02	1.858E+08	1.858E+08	5.077E-30	8.701E-36
8	8.500E-02	1.345E+08	1.345E+08	3.401E-21	5.500E-27
9	9.500E-02	9.836E+07	9.836E+07	2.194E-16	3.517E-22
10	1.500E-01	1.792E+08	1.792E+08	7.208E-08	1.246E-13
11	2.500E-01	7.310E+06	7.310E+06	5.307E-06	1.040E-11
12	3.500E-01	2.028E+06	2.028E+06	1.100E-04	2.265E-10
13	4.750E-01	1.278E+06	1.278E+06	4.584E-04	9.351E-10
14	6.500E-01	5.559E+05	5.559E+05	1.187E-03	2.470E-09
15	8.250E-01	1.332E+05	1.074E+08	9.233E-01	1.847E-06
16	1.000E+00	4.640E+04	4.640E+04	8.717E-04	1.682E-09
17	1.225E+00	5.269E+03	2.146E+12	1.102E+05	2.028E-01
18	1.475E+00	1.390E+03	1.390E+03	1.436E-04	2.528E-10
19	1.700E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
20	1.900E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
21	2.100E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
22	2.300E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
23	2.500E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
24	2.700E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
25	3.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

TOTALS 9.645E+09 2.156E+12 1.102E+05 2.028E-01

Note that 2.028E-01 R/hr = 1.453E-08 amp/kg

Table of Source Activity:

Scale Factor = 1.000E+00

Isotope Adjusted
FHA of the Solid Waste Burial Grounds

September 27, 1995

Name	Curies	Curies
SR- 90	6.40E+04	6.400E+04
Y - 90	6.40E+04	6.400E+04

WHC-SD-WM-FHA-015, Rev. 0
Page 146 of 162

SOURCE =Strontium 90 Y90

Source Point Shields Slab Distance to Detector, X = 6.287E+01 cm
Offset from Normal, Y = 0.000E+00 cm

Shield Thickness, cm 6.096E+01 1.910E+00
Taylor Buildup Data for Shield 1 with Effective Atomic Number 11.5

Group	Average Energy, Mev	Bremsstr. photons/sec	Source Total photons/sec	Energy Flux Mev/sq.cm/sec	Dose Rate R/hr
1	1.500E-02	1.353E+14	1.355E+14	0.000E+00	0.000E+00
2	2.500E-02	7.449E+13	7.449E+13	0.000E+00	0.000E+00
3	3.500E-02	4.494E+13	4.494E+13	0.000E+00	0.000E+00
4	4.500E-02	3.080E+13	3.080E+13	0.000E+00	0.000E+00
5	5.500E-02	2.218E+13	2.218E+13	0.000E+00	0.000E+00
6	6.500E-02	1.920E+13	1.920E+13	0.000E+00	0.000E+00
7	7.500E-02	1.746E+13	1.746E+13	4.769E-25	8.174E-31
8	8.500E-02	1.587E+13	1.587E+13	4.014E-16	6.491E-22
9	9.500E-02	1.429E+13	1.429E+13	3.187E-11	5.109E-17
10	1.500E-01	6.502E+13	6.502E+13	2.615E-02	4.518E-08
11	2.500E-01	2.115E+13	2.115E+13	1.535E+01	3.009E-05
12	3.500E-01	1.024E+13	1.024E+13	5.550E+02	1.143E-03
13	4.750E-01	7.535E+12	7.535E+12	2.703E+03	5.515E-03
14	6.500E-01	4.346E+12	4.346E+12	9.284E+03	1.931E-02
15	8.250E-01	1.559E+12	1.559E+12	1.340E+04	2.680E-02
16	1.000E+00	1.015E+12	1.015E+12	1.907E+04	3.681E-02
17	1.225E+00	4.910E+11	4.910E+11	2.522E+04	4.640E-02
18	1.475E+00	1.513E+11	1.513E+11	1.563E+04	2.751E-02
19	1.700E+00	3.245E+10	1.130E+11	1.888E+04	3.229E-02
20	1.900E+00	6.372E+09	6.372E+09	1.705E+03	2.830E-03
21	2.100E+00	3.414E+08	3.657E+09	1.286E+03	2.058E-03
22	2.300E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
23	2.500E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
24	2.700E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
25	3.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TOTALS		4.861E+14	4.864E+14	1.078E+05	2.007E-01
Note that 2.007E-01 R/hr = 1.438E-08 amp/kg					

***> end of run

Finish run at 13:35:02 09/05/95

Contents of Input file, point.in

```
0      2  POINT SOURCE
Co 60 source 29 Ci
&INPUT NEXT=1, IGEOM=1, X=62.87, ISPEC=3,
NSHLD=2, JBUF=1, T(1)=60.96, 1.91, Y=0.0,
WEIGHT(472)=29.0 &
      6      0.97      0.5
1      9      1.72
SOURCE =Strontium 90 Y90
&INPUT NEXT=2, WEIGHT(472)=0.0, WEIGHT(82) =64000.0, WEIGHT(84)=64000. &
end of run
&input next=6 &
```


CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed: SHIELDING CALCULATION FOR STORAGE BOX

Scope of Review:

Yes	No	NA	
☐	☐	☒	Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
☒	☐	☐	Problem completely defined.
☐	☐	☒	Accident scenarios developed in a clear and logical manner.
☒	☐	☐	Necessary assumptions explicitly stated and supported.
☒	☐	☐	Computer codes and data files documented.
☒	☐	☐	Data used in calculations explicitly stated in document.
☒	☐	☐	Data checked for consistency with original source information as applicable.
☐	☐	☒	Mathematical derivations checked including dimensional consistency of results.
☒	☐	☐	Models appropriate and used within range of validity or use outside range of established validity justified.
☒	☐	☐	Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
☒	☐	☐	Software input correct and consistent with document reviewed.
☒	☐	☐	Software output consistent with input and with results reported in document reviewed.
☐	☐	☒	Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
☒	☐	☐	Safety margins consistent with good engineering practices.
☒	☐	☐	Conclusions consistent with analytical results and applicable limits.
☒	☐	☐	Results and conclusions address all points required in the problem statement.
☐	☐	☒	Format consistent with appropriate NRC Regulatory Guide or other standards
☒	☐	☐	Review calculations, comments, and/or notes are attached.
☒	☐	☐	Document approved.

Reviewer (Tang Chiao)

9-8-95
Date: September 8, 1995

Any notes and/or comments should be attached.

Westinghouse
Hanford Company

Internal
Memo

From: Consequence Analysis
Phone: 376-2920 H4-64
Date: September 20, 1995
Subject: SHIELDING CALCULATION FOR DRUM

8M400-JCVK-95006

To: D. R. Porten H4-70
cc: T. Chiao
JCVK File/LB

A calculation of the maximum activities to produce a 200 mr/h dose rate at the center of the curved surface of a 17C 55 gallon steel drum has been performed. The results are summarized below, and are described in detail in the attachments.

Activities Required to Produce a 200 mr/h Dose
Rate at the Surface of a 17C 55 Gallon Steel Drum.

Isotope	Activity spread uniformly over drum (Ci)	Activity concentrated in center of drum (Ci)
Co-60	0.043	0.128
Sr-90	12.7	136

J. C. Van Kauren
Senior Principal Engineer

gjr

Attachments 2

Concurrence:

D. S. Leach, Manager

Date 9/21/95

ATTACHMENT 1

to

8M400-JCVK-95006

SHIELDING CALCULATION DESCRIPTION

SHIELDING CALCULATION DESCRIPTION

The activity contents of drums containing radioactive waste are limited by the quantities assumed in the safety analyses of events such as a release from dropping of a drum or a fire that results in release. It is necessary to determine the maximum activities in the drum to perform these analyses. The dose rate at the drum surface is limited to 200 mr/h. A conservative calculation has been made of the maximum isotope content that could be in the drum, and not result in a 200 mr/h dose rate at the surface of the drum being exceeded. Four calculations were requested (Porten 1995): 1) assume Co-60 is uniformly spread throughout the inside of the drum, 2) assume the Co-60 source is concentrated at the center of the drum, 3) assume a Sr-90 source uniformly spread throughout the inside of the drum, and 4) assume the Sr-90 is concentrated at the center of the drum.

The drum dimensions are 22.5 inch (57.3 cm) diameter and 33.25 inch (84.5 cm) in length. The drum wall are 16 gauge steel which has a thickness of 0.06 inches (0.15 cm.). The content of the drum is waste consisting of mixtures of wood, rubber, metal and plastics. The exact mixture will vary from drum to drum. The contents of the drum are important because the contents provide self shielding. This analysis is based on assumptions that maximize self shielding effects since the purpose of the calculation is to determine the maximum radioactive content that would not result in the 200 mr/h dose rate at the drum surface being exceeded.

The self shielding from the material inside the drum was modelled based on samples taken from drums. A content profile of the drums was determined for WRAP-1 (Joyce 1993). This profile indicates 22% of the contents are metal, and the remainder is lower density material. In this calculation, the metal was modelled as iron with an effective density of $0.22 \times 7.83 = 1.72 \text{ g/cm}^3$. The rest of the waste was assumed to be combustible. Calculation for the SWBG ISB indicated that the combustible loading in a drum is a maximum of 200 kg. The report by Joyce assumed a 0.208 m^3 volume. The combustible waste was modelled as carbon with a density of $200,000 \text{ g}/(0.208 \text{ m}^3 \times 10^6 \text{ cm}^3/\text{m}^3) = 0.97 \text{ g/cm}^3$. This is a conservative estimate of the drum content since the density is based on the assumption of essentially zero void volume in the drum. The walls of the drum are assumed to be iron with a density of 7.8 g/cm^3 .

The computer code ISOSHL (Lourant, 1990) was used to calculate the dose rates. A cylindrical geometry was assumed for the two cases with source spread uniformly over the drum. The dose rates were calculated at the midpoint of the curved surface of the drum. Doses from bremsstrahlung were included as this is dominant dose effect from Sr-90 since the beta radiation from Sr-90 will not penetrate the drum walls. Since Sr-90 exists in equilibrium with Y-90, the drum was assumed to contain Y-90 equal to the Sr-90.

The calculation with the source concentrated in the center of the drum was modelled as a thin cylinder source (0.02 cm long and a 0.01 cm diameter) surrounded by two cylindrical shields. The first shield modelled the contents of the drum, and the second the wall of the drum. Dimensions were the same as above.

The computer code outputs are given in Attachment 2. The results are summarized in Table 1 below.

Table 1 Activities Required to Produce a 200 mr/h Dose Rate at the Surface of a drum.

Isotope	Activity spread uniformly over the drum (Ci)	Activity concentrated in center of drum (Ci)
Co-60	0.043	0.128
Sr-90	12.7	136

The values in Table 1 are based on specific assumptions of box content and should be used with care. The assumptions are conservative but a box containing higher metal fractions or box with a hot spot of radioactive waste shielded by high density material might contain higher radioactive inventories, and still meet the 200 mr/hr dose rate limit.

References

Joyce 1993, Memo from J. P. Joyce to C. B. Evans, "SWBG FHA Combustible Loadings for TRU 55 Gallon Drums," JPH-29540-93-001.

Porten, 1995 Memo from D. Porten to J. C. Van Keuren, "Shielding Calculation for Waste in a Metal Drum," September 8, 1995.

Lourant, 1990. Validation of the ISOSHL-PC on the IBM-PC (PS-2/AT/XT). EDT-109878, WHC-SD-SQA-CWSD-303.

ATTACHMENT 2
to
8M400-JCVK-95006
COMPUTER CODE OUTPUT

COMPUTER CODE OUTPUTS

ISOSHL-D-II (RIBD removed)

IBM PC/AT Version 1.5, August 1987
Radiological Analysis
Westinghouse Hanford Company
Richland, WA 99352

Table of Source Activity:

Scale Factor = 1.000E+00

Isotope Name	Curies	Adjusted Curies
CO- 60	4.30E-02	4.300E-02

Shield Composition, g/cc

	Shield 1	Shield 2	Shield 3	Shield 4	Shield 5
CARBON	9.700E-01	0.000E+00			
IRON	1.720E+00	7.800E+00			

Group Linear Attenuation Coefficients (last region is air)

1	7.737E+01	3.445E+02	4.424E-03	0.000E+00	0.000E+00	0.000E+00
2	2.141E+01	9.576E+01	6.542E-04	0.000E+00	0.000E+00	0.000E+00
3	9.983E+00	4.434E+01	3.504E-04	0.000E+00	0.000E+00	0.000E+00
4	4.712E+00	2.055E+01	2.715E-04	0.000E+00	0.000E+00	0.000E+00
5	2.671E+00	1.135E+01	2.405E-04	0.000E+00	0.000E+00	0.000E+00
6	1.831E+00	7.574E+00	2.247E-04	0.000E+00	0.000E+00	0.000E+00
7	1.347E+00	5.405E+00	2.137E-04	0.000E+00	0.000E+00	0.000E+00
8	1.014E+00	3.918E+00	2.049E-04	0.000E+00	0.000E+00	0.000E+00
9	8.324E-01	3.111E+00	1.985E-04	0.000E+00	0.000E+00	0.000E+00
10	4.818E-01	1.591E+00	1.725E-04	0.000E+00	0.000E+00	0.000E+00
11	3.472E-01	1.069E+00	1.474E-04	0.000E+00	0.000E+00	0.000E+00
12	2.701E-01	7.784E-01	1.312E-04	0.000E+00	0.000E+00	0.000E+00
13	2.393E-01	6.825E-01	1.183E-04	0.000E+00	0.000E+00	0.000E+00
14	2.077E-01	5.616E-01	1.118E-04	0.000E+00	0.000E+00	0.000E+00
15	1.770E-01	4.969E-01	8.986E-05	0.000E+00	0.000E+00	0.000E+00
16	1.627E-01	4.586E-01	8.210E-05	0.000E+00	0.000E+00	0.000E+00
17	1.438E-01	4.001E-01	7.408E-05	0.000E+00	0.000E+00	0.000E+00
18	1.308E-01	3.666E-01	6.658E-05	0.000E+00	0.000E+00	0.000E+00
19	1.231E-01	3.479E-01	6.180E-05	0.000E+00	0.000E+00	0.000E+00
20	1.150E-01	3.237E-01	5.818E-05	0.000E+00	0.000E+00	0.000E+00

21	1.104E-01	3.136E-01	5.495E-05	0.000E+00	0.000E+00	0.000E+00
22	1.050E-01	2.972E-01	5.262E-05	0.000E+00	0.000E+00	0.000E+00
23	1.026E-01	2.948E-01	5.004E-05	0.000E+00	0.000E+00	0.000E+00
24	9.884E-02	2.855E-01	4.784E-05	0.000E+00	0.000E+00	0.000E+00
25	9.394E-02	2.769E-01	4.383E-05	0.000E+00	0.000E+00	0.000E+00

Co 60 source 0.043 Ci

Source Shields Distance to Detector, X = 2.873E+01 cm
Cylindrical Cylindrical Volume = 2.168E+05 cc
Source Length = 8.450E+01 cm Distance Along Cylinder, Y = 4.225E+01 cm
Integration Specs: NTHETA = 25 NPSI = 25 DELR = 1.429E+00 cm
Total Intervals: 1.250E+04

Shield Thickness, cm 2.858E+01 1.500E-01
Taylor Buildup Data for Shield 1 with Effective Atomic Number 11.5

Group	Average Energy, Mev	Bremsstr. photons/sec	Source Total photons/sec	Energy Flux Mev/sq.cm/sec	Dose Rate R/hr
1	1.500E-02	7.739E+06	7.739E+06	5.665E-23	4.662E-27
2	2.500E-02	2.362E+06	2.362E+06	1.131E-06	1.957E-11
3	3.500E-02	1.469E+06	1.469E+06	8.089E-04	5.136E-09
4	4.500E-02	8.702E+05	8.702E+05	1.228E-02	4.028E-08
5	5.500E-02	5.593E+05	5.593E+05	3.613E-02	8.275E-08
6	6.500E-02	3.989E+05	3.989E+05	7.000E-02	1.324E-07
7	7.500E-02	2.755E+05	2.755E+05	1.022E-01	1.752E-07
8	8.500E-02	1.994E+05	1.994E+05	1.358E-01	2.196E-07
9	9.500E-02	1.458E+05	1.458E+05	1.527E-01	2.447E-07
10	1.500E-01	2.658E+05	2.658E+05	3.921E-01	6.776E-07
11	2.500E-01	1.084E+04	1.084E+04	4.034E-02	7.906E-08
12	3.500E-01	3.008E+03	3.008E+03	2.104E-02	4.333E-08
13	4.750E-01	1.894E+03	1.894E+03	2.054E-02	4.190E-08
14	6.500E-01	8.242E+02	8.242E+02	1.320E-02	2.746E-08
15	8.250E-01	1.974E+02	1.593E+05	3.279E+00	6.559E-06
16	1.000E+00	6.880E+01	6.880E+01	1.815E-03	3.504E-09
17	1.225E+00	7.812E+00	3.182E+09	1.086E+05	1.998E-01
18	1.475E+00	2.061E+00	2.061E+00	8.724E-05	1.535E-10
19	1.700E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
20	1.900E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
21	2.100E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
22	2.300E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
23	2.500E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
24	2.700E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
25	3.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

TOTALS 1.430E+07 3.196E+09 1.086E+05 1.998E-01

Note that 1.998E-01 R/hr = 1.432E-08 amp/kg

Table of Source Activity:

Scale Factor = 1.000E+00

Isotope Name	Curies	Adjusted Curies
SR- 90	1.27E+01	1.270E+01
Y - 90	1.27E+01	1.270E+01

SOURCE =Stontium 90 Y90 12.7 Ci

Source Shields Distance to Detector, X = 2.873E+01 cm
Cylindrical Cylindrical Volume = 2.168E+05 cc
Source Length = 8.450E+01 cm Distance Along Cylinder, Y = 4.225E+01 cm
Integration Specs: NTHETA = 25 NPSI = 25 DELR = 1.429E+00 cm
Total Intervals: 1.250E+04

Shield Thickness, cm 2.858E+01 1.500E-01
Taylor Buildup Data for Shield 1 with Effective Atomic Number 11.5

Group	Average Energy, Mev	Bremsstr. photons/sec	Source Total photons/sec	Energy Flux Mev/sq.cm/sec	Dose Rate R/hr
1	1.500E-02	2.685E+10	2.689E+10	1.968E-19	1.620E-23
2	2.500E-02	1.478E+10	1.478E+10	7.080E-03	1.225E-07
3	3.500E-02	8.918E+09	8.918E+09	4.912E+00	3.119E-05
4	4.500E-02	6.112E+09	6.112E+09	8.626E+01	2.829E-04
5	5.500E-02	4.401E+09	4.401E+09	2.843E+02	6.511E-04
6	6.500E-02	3.810E+09	3.810E+09	6.686E+02	1.264E-03
7	7.500E-02	3.464E+09	3.464E+09	1.285E+03	2.203E-03
8	8.500E-02	3.150E+09	3.150E+09	2.145E+03	3.469E-03
9	9.500E-02	2.835E+09	2.835E+09	2.968E+03	4.758E-03
10	1.500E-01	1.290E+10	1.290E+10	1.904E+04	3.290E-02
11	2.500E-01	4.196E+09	4.196E+09	1.562E+04	3.061E-02
12	3.500E-01	2.032E+09	2.032E+09	1.421E+04	2.927E-02
13	4.750E-01	1.495E+09	1.495E+09	1.621E+04	3.307E-02
14	6.500E-01	8.624E+08	8.624E+08	1.382E+04	2.874E-02
15	8.250E-01	3.094E+08	3.094E+08	6.371E+03	1.274E-02
16	1.000E+00	2.015E+08	2.015E+08	5.316E+03	1.026E-02
17	1.225E+00	9.744E+07	9.744E+07	3.325E+03	6.119E-03
18	1.475E+00	3.002E+07	3.002E+07	1.270E+03	2.236E-03
19	1.700E+00	6.440E+06	2.242E+07	1.132E+03	1.937E-03
20	1.900E+00	1.264E+06	1.264E+06	7.408E+01	1.230E-04
21	2.100E+00	6.775E+04	7.256E+05	4.728E+01	7.565E-05
22	2.300E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
23	2.500E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

24	2.700E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
25	3.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

TOTALS		9.646E+10	9.651E+10	1.039E+05	2.007E-01
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Note that 2.007E-01 R/hr = 1.439E-08 amp/kg

***> end of run

Contents of Input file, drum.in

```

0      2  drum
Co 60 source 0.043 Ci
&INPUT NEXT=1, IGEOM=7, X=28.73, Y=42.25, ISPEC=3,
NSHLD=2, JBUF=1, T(1)=28.58, 0.15, SLTH=84.5, DELR=1.4,
NTHETA=25, NPSI=25, SSV1=0.0,
WEIGHT(472)=0.043 &
      6      0.97
1      9      1.72      7.8
SOURCE =Stontium 90 Y90 12.7 Ci
&INPUT NEXT=2, WEIGHT(472)=0.0, WEIGHT(82) =12.7, WEIGHT(84)=12.7 &
end of run
&input next=6 &

```

Start run at 13:38:36 09/12/95

ISOSHL-D-II (RIBD removed)

IBM PC/AT Version 1.5, August 1987
Radiological Analysis
Westinghouse Hanford Company
Richland, WA 99352

thin drum centered

Table of Source Activity:

Scale Factor = 1.000E+00

Isotope Name	Curies	Adjusted Curies
CO- 60	1.28E-01	1.280E-01

Shield Composition, g/cc

	Shield 1	Shield 2	Shield 3	Shield 4	Shield 5
CARBON	9.700E-01	9.700E-01			
IRON	1.720E+00	1.727E+00			

Group Linear Attenuation Coefficients (last region is air)

1	7.737E+01	7.768E+01	4.424E-03	0.000E+00	0.000E+00	0.000E+00
2	2.141E+01	2.150E+01	6.542E-04	0.000E+00	0.000E+00	0.000E+00
3	9.983E+00	1.002E+01	3.504E-04	0.000E+00	0.000E+00	0.000E+00
4	4.712E+00	4.731E+00	2.715E-04	0.000E+00	0.000E+00	0.000E+00
5	2.671E+00	2.681E+00	2.405E-04	0.000E+00	0.000E+00	0.000E+00
6	1.831E+00	1.838E+00	2.247E-04	0.000E+00	0.000E+00	0.000E+00
7	1.347E+00	1.352E+00	2.137E-04	0.000E+00	0.000E+00	0.000E+00
8	1.014E+00	1.018E+00	2.049E-04	0.000E+00	0.000E+00	0.000E+00
9	8.324E-01	8.352E-01	1.985E-04	0.000E+00	0.000E+00	0.000E+00
10	4.818E-01	4.833E-01	1.725E-04	0.000E+00	0.000E+00	0.000E+00
11	3.472E-01	3.481E-01	1.474E-04	0.000E+00	0.000E+00	0.000E+00
12	2.701E-01	2.708E-01	1.312E-04	0.000E+00	0.000E+00	0.000E+00
13	2.393E-01	2.399E-01	1.183E-04	0.000E+00	0.000E+00	0.000E+00
14	2.077E-01	2.082E-01	1.118E-04	0.000E+00	0.000E+00	0.000E+00
15	1.770E-01	1.774E-01	8.986E-05	0.000E+00	0.000E+00	0.000E+00
16	1.627E-01	1.631E-01	8.210E-05	0.000E+00	0.000E+00	0.000E+00
17	1.438E-01	1.442E-01	7.408E-05	0.000E+00	0.000E+00	0.000E+00

18	1.308E-01	1.311E-01	6.658E-05	0.000E+00	0.000E+00	0.000E+00
19	1.231E-01	1.234E-01	6.180E-05	0.000E+00	0.000E+00	0.000E+00
20	1.150E-01	1.153E-01	5.818E-05	0.000E+00	0.000E+00	0.000E+00
21	1.104E-01	1.107E-01	5.495E-05	0.000E+00	0.000E+00	0.000E+00
22	1.050E-01	1.053E-01	5.262E-05	0.000E+00	0.000E+00	0.000E+00
23	1.026E-01	1.028E-01	5.004E-05	0.000E+00	0.000E+00	0.000E+00
24	9.884E-02	9.910E-02	4.784E-05	0.000E+00	0.000E+00	0.000E+00
25	9.394E-02	9.419E-02	4.383E-05	0.000E+00	0.000E+00	0.000E+00

Co 60 source thin drum center 0.128 Ci

Source Shields Distance to Detector, X = 2.874E+01 cm
Cylindrical Cylindrical Volume = 6.283E-06 cc
Source Length = 2.000E-02 cm Distance Along Cylinder, Y = 1.000E-02 cm
Integration Specs: NTHETA = 25 NPSI = 25 DELR = 2.000E-03 cm
Total Intervals: 3.125E+03

Shield Thickness, cm 1.000E-02 2.858E+01
Taylor Buildup Data for Shield 2 with Effective Atomic Number 11.5

Group	Average Energy, Mev	Bremsstr. photons/sec	Source Total photons/sec	Energy Flux Mev/sq.cm/sec	Dose Rate R/hr
1	1.500E-02	2.304E+07	2.304E+07	0.000E+00	0.000E+00
2	2.500E-02	7.030E+06	7.030E+06	0.000E+00	0.000E+00
3	3.500E-02	4.372E+06	4.372E+06	0.000E+00	0.000E+00
4	4.500E-02	2.590E+06	2.590E+06	0.000E+00	0.000E+00
5	5.500E-02	1.665E+06	1.665E+06	2.143E-29	4.907E-35
6	6.500E-02	1.187E+06	1.187E+06	8.033E-19	1.519E-24
7	7.500E-02	8.202E+05	8.202E+05	9.254E-13	1.586E-18
8	8.500E-02	5.936E+05	5.936E+05	1.341E-08	2.169E-14
9	9.500E-02	4.341E+05	4.341E+05	2.440E-06	3.911E-12
10	1.500E-01	7.912E+05	7.912E+05	8.555E-04	1.478E-09
11	2.500E-01	3.226E+04	3.226E+04	1.406E-03	2.756E-09
12	3.500E-01	8.953E+03	8.953E+03	3.232E-03	6.657E-09
13	4.750E-01	5.639E+03	5.639E+03	5.539E-03	1.130E-08
14	6.500E-01	2.453E+03	2.453E+03	5.923E-03	1.232E-08
15	8.250E-01	5.877E+02	4.742E+05	2.166E+00	4.332E-06
16	1.000E+00	2.048E+02	2.048E+02	1.439E-03	2.777E-09
17	1.225E+00	2.326E+01	9.472E+09	1.093E+05	2.011E-01
18	1.475E+00	6.135E+00	6.135E+00	1.015E-04	1.786E-10
19	1.700E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
20	1.900E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
21	2.100E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
22	2.300E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
23	2.500E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
24	2.700E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
25	3.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

TOTALS 4.257E+07 9.515E+09 1.093E+05 2.011E-01
Note that 2.011E-01 R/hr = 1.441E-08 amp/kg

Table of Source Activity:

Scale Factor = 1.000E+00

Isotope Name	Curies	Adjusted Curies
SR- 90	1.36E+02	1.360E+02
Y - 90	1.36E+02	1.360E+02

SOURCE =Strontium 90 Y90 136 Ci

Source Shields Distance to Detector, X = 2.874E+01 cm
Cylindrical Cylindrical Volume = 6.283E-06 cc
Source Length = 2.000E-02 cm Distance Along Cylinder, Y = 1.000E-02 cm
Integration Specs: NTHETA = 25 NPSI = 25 DELR = 2.000E-03 cm
Total Intervals: 3.125E+03

Shield Thickness, cm 1.000E-02 2.858E+01
Taylor Buildup Data for Shield 2 with Effective Atomic Number 11.5

Group	Average Energy, Mev	Bremsstr. photons/sec	Source Total photons/sec	Energy Flux Mev/sq.cm/sec	Dose Rate R/hr
1	1.500E-02	2.876E+11	2.879E+11	0.000E+00	0.000E+00
2	2.500E-02	1.583E+11	1.583E+11	0.000E+00	0.000E+00
3	3.500E-02	9.550E+10	9.550E+10	0.000E+00	0.000E+00
4	4.500E-02	6.546E+10	6.546E+10	0.000E+00	0.000E+00
5	5.500E-02	4.713E+10	4.713E+10	6.065E-25	1.389E-30
6	6.500E-02	4.080E+10	4.080E+10	2.760E-14	5.220E-20
7	7.500E-02	3.710E+10	3.710E+10	4.185E-08	7.174E-14
8	8.500E-02	3.373E+10	3.373E+10	7.622E-04	1.232E-09
9	9.500E-02	3.036E+10	3.036E+10	1.706E-01	2.735E-07
10	1.500E-01	1.382E+11	1.382E+11	1.494E+02	2.582E-04
11	2.500E-01	4.493E+10	4.493E+10	1.958E+03	3.838E-03
12	3.500E-01	2.176E+10	2.176E+10	7.853E+03	1.618E-02
13	4.750E-01	1.601E+10	1.601E+10	1.573E+04	3.208E-02
14	6.500E-01	9.235E+09	9.235E+09	2.230E+04	4.638E-02
15	8.250E-01	3.314E+09	3.314E+09	1.514E+04	3.027E-02
16	1.000E+00	2.157E+09	2.157E+09	1.516E+04	2.926E-02
17	1.225E+00	1.043E+09	1.043E+09	1.204E+04	2.215E-02
18	1.475E+00	3.214E+08	3.214E+08	5.315E+03	9.354E-03
19	1.700E+00	6.896E+07	2.401E+08	5.195E+03	8.884E-03

20	1.900E+00	1.354E+07	1.354E+07	3.733E+02	6.196E-04
21	2.100E+00	7.255E+05	7.770E+06	2.487E+02	3.980E-04
22	2.300E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
23	2.500E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
24	2.700E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
25	3.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

TOTALS .. 1.033E+12 1.034E+12 1.015E+05 1.997E-01
Note that 1.997E-01 R/hr = 1.431E-08 amp/kg

***> end of run

Finish run at 13:39:17 09/12/95

Contents of Input file, drumc.in

```

0      2  thin drum centered
Co 60 source thin drum center 0.128 Ci
&INPUT NEXT=1, IGEOM=7, X=28.74, Y=0.01, ISPEC=3,
NSHLD=2, JBUF=2, T(1)=0.01, 28.58, 0.15, SLTH=0.02, DELR=0.05,
NTHETA=25, NPSI=25, SSV1=0.0,
WEIGHT(472)=0.128 &
      6      0.97      0.97
1      9      1.72      1.72      7.8
SOURCE =Stontium 90 Y90 136 Ci
&INPUT NEXT=2, WEIGHT(472)=0.0, WEIGHT(82) =136.0, WEIGHT(84)=136.0 &
end of run
&input next=6 &

```

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed: SHIELDING CALCULATION FOR DRUM DESCRIPTION

Scope of Review:

Yes	No	NA	
☐	☐	☒	Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
☒	☐	☐	Problem completely defined.
☐	☐	☒	Accident scenarios developed in a clear and logical manner.
☒	☐	☐	Necessary assumptions explicitly stated and supported.
☒	☐	☐	Computer codes and data files documented.
☒	☐	☐	Data used in calculations explicitly stated in document.
☒	☐	☐	Data checked for consistency with original source information as applicable.
☐	☐	☒	Mathematical derivations checked including dimensional consistency of results.
☒	☐	☐	Models appropriate and used within range of validity or use outside range of established validity justified.
☒	☐	☐	Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
☒	☐	☐	Software input correct and consistent with document reviewed.
☒	☐	☐	Software output consistent with input and with results reported in document reviewed.
☐	☐	☒	Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
☒	☐	☐	Safety margins consistent with good engineering practices.
☒	☐	☐	Conclusions consistent with analytical results and applicable limits.
☒	☐	☐	Results and conclusions address all points required in the problem statement.
☐	☐	☒	Format consistent with appropriate NRC Regulatory Guide or other standards
☒	☐	☐	Review calculations, comments, and/or notes are attached.
☒	☐	☐	Document approved.

Reviewer (Tang Chiao)

Date: September 19, 1995

Any notes and/or comments should be attached.