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Evaluation of OSRP Sealed Sources at TA-54, Area G

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HISTORY OF REVISIONS

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1.0 INTRODUCTION

The *Technical Safety Requirements (TSRs) for Technical Area (TA) 54, Area G*, planned to be fully implemented in the fall of 2004, originally limited the total above-ground material at risk (MAR) at Area G to 133,880 plutonium equivalent curies (PE-Ci). However, on June 29, 2003, preliminary testing of a computer-based inventory tracking system (conducted as part of the TSR implementation of the limiting condition for operation [LCO] on MAR) showed that the current total above-ground inventory at the Area G site was 141,500 PE-Ci, already exceeding the limit established in the soon-to-be implemented TSRs. The total above-ground inventory includes approximately 18,400 PE-Ci associated with Off-Site Source Recovery Project (OSRP) sealed sources containing low-level actinide sources and overpacked in pipe overpack containers (POCs). None of the individual container, truckload, or dome MAR limits are affected.

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The Los Alamos National Laboratory (LANL) Facility Waste Operations–Waste Facility Management (FWO-WFM) Group received permission from the National Nuclear Security Administration (NNSA) to increase the total above-ground MAR limit to the 150,000 PE-Ci evaluated in the TA-54, Area G Documented Safety Analysis (DSA). However, there is still a small margin (about 8500 PE-Ci, or 5%) between the current above-ground inventory and the revised TSR limit. Being able to separately address sealed sources in POCs from the total above-ground Area G MAR would result in a total above-ground inventory of 123,100 PE-Ci. This will provide the FWO-WFM Group with a larger margin (about 26,900 PE-Ci, or 18%) for continued critical mission operations.

The FWO-WFM Group is considering two options to address this issue:

1) Modify the Area G DSA and TSRs to allow for an increased total MAR allowed above-ground.
2) Request NNSA consideration to separately address sealed sources in POCs from the TSR limit.

The first option will be pursued at the next annual update. The second option is presented in this submittal, and will be an addendum to the Area G DSA.

2.0 INVENTORY LIMITS

The Area G TSRs administratively limit the total above-ground MAR at Area G to 150,000 PE-Ci. This limit was the originally approved total above-ground MAR limit for Area G and was based on an estimated average drum content of 2.0 PE-Ci per drum. However, on June 29, 2003, preliminary testing of a computer-based inventory tracking system (conducted as part of the TSR implementation of the LCO on the MAR allowed at Area G) showed that the current total above-ground inventory at the Area G site was 141,500 PE-Ci, already exceeding the limit established in the soon-to-be implemented TSRs. This inventory included approximately 18,400 PE-Ci associated with sealed sources in POCs.

FWO requested NNSA to consider (1) increasing the total above-ground MAR limit at Area G to the originally approved 150,000 PE-Ci; and (2) excluding the sealed sources from the considered inventory based on their meeting the exclusion requirements of U.S. Department of Energy (DOE) Standard (STD) 1027-92, *Hazard and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports*. Although the FWO-WFM Group received permission to return the total above-ground MAR limit to the 150,000 PE-Ci evaluated in the TA-54, Area G DSA, NNSA rejected FWO's request to exclude the sealed sources from the MAR limit because the standard is only used to determine the initial and final hazard categorization of nuclear facilities. In its response to FWO's request, NNSA replied that LANL would need to "prepare a defensible analysis for the sealed sources relative to their ability to withstand accident stressors like aircraft crash, fire, impact, etc., to show that under Evaluation Basis Accidents the Damage Ratio would effectively be low or zero."

Considering that the inventory at Area G is close to exceeding the 150,000 PE-Ci evaluated in the TA-54, Area G DSA and that Area G's ability to support LANL operations depends on their waste storage capacity, the FWO-WFM Group is requesting NNSA consideration for separately addressing sealed sources from the MAR limit. None of the individual container, truckload, or dome limits are affected. This request and supporting analysis is being submitted to allow Area G to continue accepting waste shipments until the next annual update of the DSA.

3.0 SEALED SOURCES IN STORAGE AT AREA G

The Low-Level Radioactive Waste Policy Amendments Act of 1985, Public Law (PL) 99-240, makes the NNSA responsible, in part, for disposal of Greater-Than-Class C (GTCC) radioactive waste (waste that exceeds the limits identified in Title 10 of the Code of Federal Regulations [CFR], Part 61.55 for Class C waste). Because NNSA has no disposal facility for sealed sources that contain GTCC waste, the OSRP is recovering and temporarily storing them at TA-54, Area G. The OSRP's specific aim is to gather unused, unwanted, and excess radioactive sealed sources containing actinides. Sealed sources associated with the

OSRP primarily contain ^{239}Pu, ^{238}Pu, or ^{241}Am, and may be combined with light elements, such as beryllium (Be). Table 1 identifies the major types of sources involved in this project.

Table 1. Major Types of Sources Associated with Off-Site Source Recovery Project

^{238}Pu and ^{239}Pu	^{241}Am
^{239}Pu Be general neutron sources	Am Be well-logging neutron sources
^{238}Pu Be well-logging neutron sources	Am Be general neutron sources
^{238}Pu medical pacemakers	Am Be & Cs (cesium) portable gauge sources
^{238}Pu batteries	Am Be portable gauge sources
^{238}Pu heat sources	Other Am gauge and calibration sources

3.1 INVENTORY

Currently, there are approximately 680 OSRP sealed actinide sources containing over 18,000 PE-Ci in above-ground storage at Area G. Although there are other non-actinide sources at Area G, they are not addressed in this evaluation (these sources are placed in below-ground shafts at Area G). The majority of the sealed sources, representing 98% of the total number of sealed sources in storage at Area G, are stored in Dome 283 (68%) and Dome 375 (30%). Table 2 identifies the locations of the sealed sources, and the number and amount of radioactivity in PE-Ci per dome. It is important to note that, even though the sealed sources are low-level waste (LLW) and do not meet the DOE definition of transuranic (TRU) waste, they are still considered contributing to the TRU inventory at Area G. As Table 2 shows, the maximum sealed source contains less than 110 PE-Ci, well below individual container TSR MAR limits.

Table 2. Sealed Sources in Storage at Area G

Location	Number		Radioactivity (PE-Ci)			
	Count	Percent*	Total	Percent*	Max. Drum	Avg. Drum
Dome 153	21	3.1	321	1.7	88.73	9.27
Dome 283	454	67.5	12,477.	67.7	80.55	31.63
Dome 375	193	28.7	5458	29.6	107.55	31.84
Dome 48	5	0.7	164	0.9	50.10	32.14
All Domes	673	100	18,420	100	107.55	31.63

* Percentages based on total number of OSRP sealed actinide sources in storage at Area G.

3.2 SEALED SOURCE THERMAL AND MECHANICAL CAPACITIES

Sealed sources shipped to the Area G facility from the OSRP meet U.S. Department of Transportation (DOT) requirements for special form material. Figure 1 illustrates a typical sealed source packaging configuration. Table 3 summarizes the various thermal and mechanical requirements that the OSRP sealed sources and packages are designed and tested to meet without loss of containment.

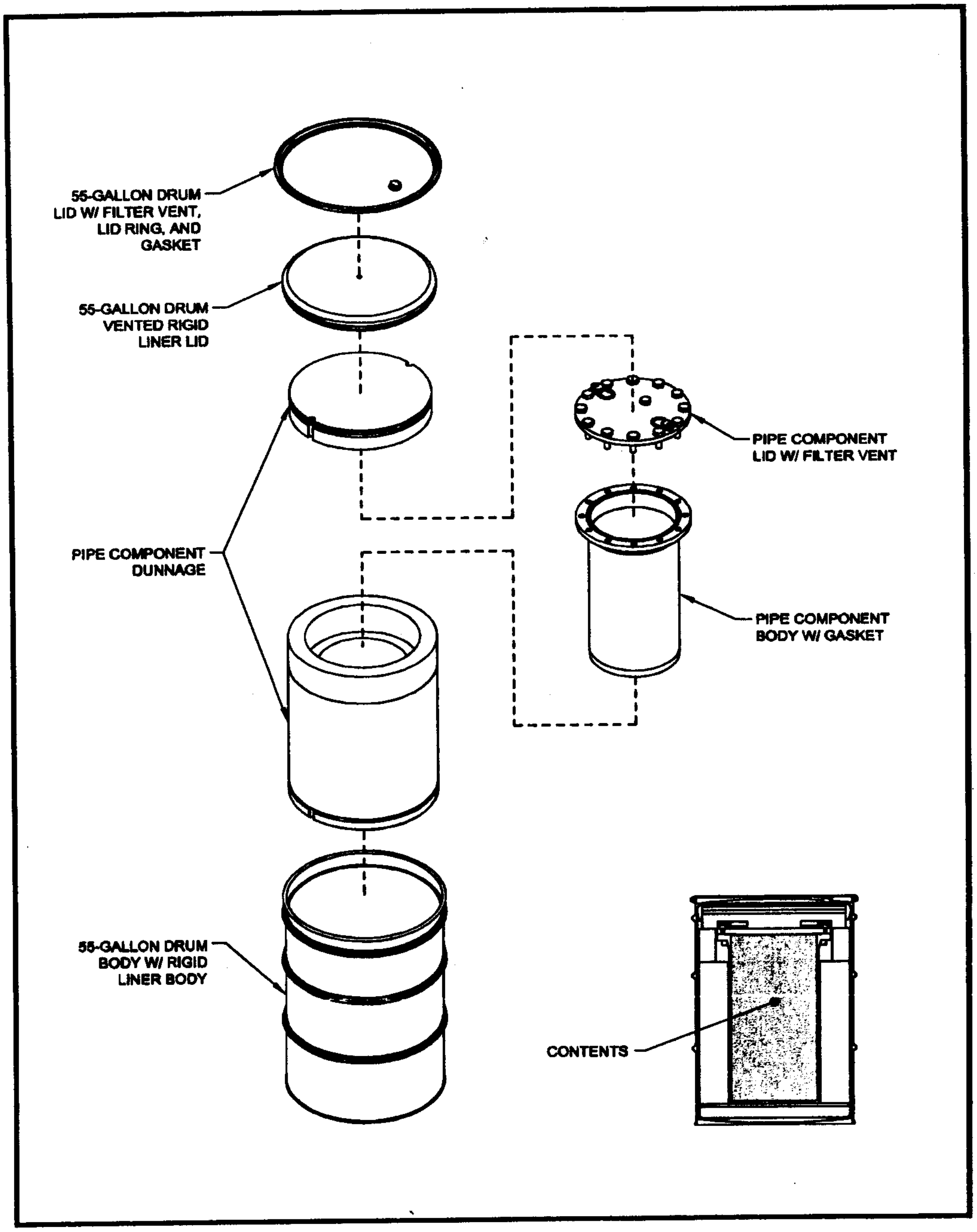

Figure 1. Typical Sealed Source Packaging Configuration

As Table 3 shows, OSRP sources meet DOT test requirements specified in 49 CFR 173.469, *Tests for Special Form Class 7 (Radioactive) Materials*, for special form material, which is defined as a single solid piece or material contained in a sealed capsule. OSRP sealed sources are packaged in POCs, which are described in the *Transuranic Package Transporter-II (TRUPACT-II) Authorized Methods for Payload Control* (TRAMPAC) as robust engineered containers that are designed to withstand hypothetical accident conditions similar to those experienced by DOT Type B TRUPACT-II shipping containers. These sealed sources are packaged inside POCs that are centered via protective packing material within a standard 55-gal Type A drum.

Table 3. Sealed Source and Pipe Overpack Container Characteristics

Item	Applicable Requirement Document	Thermal	Mechanical
Special form material	49 CFR 173.469	10 min exposure in air to a temperature of 800°C (1475°F)	Impact: 9 m (30 ft) free drop onto a flat, unyielding, horizontal surface Penetration: 1 m (3.3 ft) free drop of object 2.5 cm (1 in.) in diameter weighing 1.4 kg (3 lbs) onto specimen
POC	TRAMPAC[1]	30 min exposure to between 800°C (1475°F) and 1100°C (2012°F)	Impact: 9 m (30 ft) top and side impact drop of loaded POC onto a flat, unyielding, horizontal surface
	Sandia National Laboratories (SNL)[2, 3]		Crush: 9 m (30 ft) free drop of 500 kg (1102 lbs) steel plate onto POC
Type A drum[4]	49 CFR 173.410 (thermal) 49 CFR 173.465 (Impact)	Exposure to 70°C (158°F)	Impact: 1.2 m (4 ft) drop, onto a flat, unyielding, horizontal surface Penetration: 1 m (3.3 ft) free drop of object 3.2 cm (1.25 in.) in diameter weighing 6 kg (13.2 lbs) onto specimen
Type B container[5]	10 CFR 71.73	30 min exposure to 800°C (1475°F)	Impact: 9 m (30 ft) drop onto a flat, unyielding, horizontal surface Penetration: 1 m (40 in.) free drop of specimen onto a protruding bar 15 cm (6 in.) in diameter and 20 cm (8 in.) long

[1] POC thermal test documented in *Evaluation of Pipe Overpack Containers for TRU Waste Storage*.

[2] SAND97-0716/TTC-1477, *Testing in Support of Transportation of Residues in the Pipe Overpack Container*, April 1997.

[3] SAND97-0368/TTC-1476, *Testing in Support of Onsite Storage of Residues in the Pipe Overpack Container*, February 1997.

[4] Tests performed at LANL show that Type A drums weighing more than 300 lb fail the quadrant drop test.

[5] Test requirements for Type B container provided for comparison to the test requirements for POCs.

Table 4 evaluates the kinetic energy associated with the drop test requirements identified in Table 3, using the maximum Waste Isolation Pilot Plant (WIPP) weights allowed for POC containers and payloads, the kinematic equation associated with falling objects $1/2mv^2$ (where m is the mass of the object and v is the velocity of the object), and the equation $v_f^2 = v_i^2 + 2ad$ to determine the kinetic energy associated with falling objects (where v_i is the initial velocity of the object [zero for all cases evaluated], v_f is the final velocity of the object, a is 9.8 m/s^2, and d is the fall distance).

Table 4. Kinetic Energy Resulting from Drop Tests for OSRP Sealed Sources and Containers

Item	Weight (lb)	Weight (kg)	Fall Height (m)	Velocity $v_f = (2ad)^{0.5}$ (m/s)	Kinetic Energy[1] (kJ)
POC payload	225[2]	102	9	13.3	9
POC (TRAMPAC test)	407[3]	185	9	13.3	16
POC (SNL test)	1102	500[4]	9	13.3	44

[1] Determined by the equation $KE = 1/2mv^2$ for falling objects (where m is the mass of the object, and v is determined from $v_f^2 = 2ad$, where d is the fall distance, v_f is the final velocity of the object, and a is 9.8 m/s/s).

[2] Maximum allowable POC payload weight at WIPP.

[3] Maximum allowable POC weight at WIPP.

[4] Weight of steel plate in SNL test.

4.0 ACCIDENT CONDITIONS AT AREA G

The purpose of this evaluation is to determine how the inventory associated with sealed sources inside POCs would be impacted by the accident conditions postulated in the Area G DSA. The Area G DSA evaluated ten accident scenarios that included spills and fires resulting from operational, external, and natural phenomena events. Table 5 summarizes the accident conditions postulated in the Area G DSA.

Table 5. Accident Conditions Postulated in the Area G DSA

Accident	Accident Condition	Maximum MAR (PE-Ci)
1. Operational spill - TRU waste (Section 3.4.2.1)	Cases evaluated include single drum dropped/punctured, pallet of drums dropped, transport vehicle impacts drums	1100 (overpack) 300 (drum) 1100 (truck)
2. TRU waste transportation accident and fire (Section 3.4.2.2)	Transport vehicle accident with different heat release rates, drums remain or are spilled from vehicle	1100 (truck)
3. TRU waste drum deflagration accident (Section 3.4.2.3)	Deflagration of explosive mixture inside a single drum	637 (overpack) 300 (drum)
4. Waste storage dome fire (Section 3.4.2.4)	Eight cases analyzed to determine impact of fire size on analysis	50,000 (dome)
5. Brush/forest fire spreads to waste storage domes (Section 3.4.2.5)	Brush/forest fire spreads to waste storage domes	150,000 (Area G)
6. Earthquake (0.31 g) (Section 3.4.2.6)	Eight cases evaluated to determine impact of drum structural capability/banding on analysis	150,000 (Area G)
7. Waste storage dome structural failure from high wind (3.4.2.7)	Two cases analyzed: wind-driven missile, and major dome structural failure	50,000 (dome)

Accident	Accident Condition	Maximum MAR (PE-Ci)
8. Airplane crash into waste storage domes (Section 3.4.2.8)	Air taxi crash and subsequent fire impact storage arrays. Three cases evaluated with different fuel tank capacities, MAR inventories	50,000 (dome)
9. Fire in tritium waste sheds (Section 3.4.2.9)	Fire involving the tritium waste sheds	2.0 E+6 Ci (H-3)
10. Operational spill during shaft placement (Section 3.4.2.10)	Operational spill (crane drop) during shaft placement	1100 (overpack)

The maximum sealed source at Area G contains less than 110 PE-Ci, well below individual container TSR MAR limits. None of the individual container, truckload, or dome limits are affected. As Table 5 shows, the only accidents in which the entire MAR is at risk are Accident 5, Brush/forest fire spreads to waste storage domes, and Accident 6, Earthquake (0.31 g). The remaining accidents are only postulated to impact individual containers, truckloads, or domes whose MAR limits bound the MAR associated with OSRP sealed sources. However, for the sake of completeness, all of the accidents evaluated in the Area G DSA are evaluated below.

Accident 1: Operational Spill - TRU Waste

The accident is an operational spill. Table 6 identifies the four postulated cases evaluated and provides estimates of the kinetic energies associated with each case.

Table 6. Kinetic Energy Associated with Operational Spill Postulated Cases

Case	Weight (kg)	Fall Height (m)	Velocity v_f (m/s)	Kinetic Energy[1] (kJ)
1. Single drum dropped or punctured during handling [2]	658	1.2	4.8	8
2. Pallet of drums (4 drums) dropped [2]	658	1.2	4.8	8
3. Transport vehicle runs into a stack of drums [3]	13,100	N/A	11.2	819
4. Drums fall off transport vehicle [4]	658	1.0	4.4	6.4

[1] Determined by the equation $KE = 1/2mv^2$ for falling objects (where m is the mass of the object, and v is determined by $v_f^2 = 2ad$, where d is the fall distance, v_f is the final velocity of the object, and a is 9.8 m/s^2).

[2] Fall height is associated with 49 CFR 173.465 free drop test, and mass is maximum allowable 85-gal drum weight at Area G (although the current Area G waste acceptance criteria [WAC] restrict the total mass of any 55-gal container to 900 lbs and do not accept 85-gal containers except as overpacks, previous WAC for Area G allowed for 55-gal and 85-gal drums weighing up to 1000 and 1450 lbs, respectively).

[3] Assume a flatbed stake truck with a gross vehicle weight rating of 13,100 kg (OST 405-10-01), traveling at 25 mph.

[4] Assume a typical flatbed truck bed height of 1 m as was assumed in the Area G DSA.

As Table 6 shows, although the kinetic energy associated with the drop scenarios (Cases 1, 2, and 4) is well below the energy associated with the POC impact tests (44 kJ, as shown in Table 4), the kinetic energy associated with Case 3 is 819 kJ. Case 1-3 represents a truck colliding into a stack of drums. Because of the configuration of the storage array, this case is characterized as a semi-elastic collision. That is, the truck will lose speed as it penetrates the array, and deliver its momentum and a fraction of its kinetic energy into the array. This semi-elastic collision characterization does not mean that the POCs do not experience any damage from the initial impact; rather, as Appendix A shows, the truck is initially expected to directly impact 16 POCs (based on the dimension of the truck and the storage array). Once the truck impacts the 16 POCs, its speed is reduced to 9.1 m/s (less than the velocity associated with the impact tests), and the collision is not expected to breach any other POCs.

It is important to realize that, unlike the impact test conducted on the POCs (totally inelastic impact with all the energy being transferred to the POCs), the collision of the truck with the staged or stored POCs will only transfer a fraction of the collision energy to the POCs themselves. Some of the energy will be transferred to the vehicle itself (as structural damage or deformation), to the drums (as deformation), and as kinetic energy to the staged drums (including frictional losses). However, even though considerable energy is lost, it cannot be demonstrated that the impact energy received by the POCs will not exceed the test conditions (i.e., 44 kJ).

More realistically, of the initial 16 POCs impacted, it is assumed that one-half (8 POCs) are energetically breached (consistent with the assumptions in the Area G DSA), since 8 POCs will receive the direct impact from the truck, while the other 8 containers will be somewhat shielded by these POCs. In addition, because the individual sealed sources are lightweight special form material, and are overpacked in the POCs, it is unlikely that all of these sealed sources will fail. It is reasonable to expect that no more than 10% of the individual sealed sources in the POCs will rupture because significant deformation of the POCs must occur before the sealed sources inside the POCs will be damaged. This results in a final damage ratio (DR) of 5%.

Accident 2: TRU Waste Transportation Accident and Fire

The accident considered in this analysis is a vehicle crash that spills the waste containers and initiates a fire that spreads to the spilled waste containers. The following cases are evaluated:

- Case 1: Transport vehicle accident causes a fire; drums remain on the vehicle.
- Case 2a: Transport vehicle accident causes a fire and container spill (20 gal fuel).
- Case 2b: Transport vehicle accident causes a fire and container spill (40 gal fuel).

As described above, a transport vehicle accident is expected to result in a DR of less than 5%.

With respect to the ensuing fire, Appendix A evaluates a 50-gal fuel pool fire to in order to bound the 20 and 40 gal spills (Cases 2a and 2b) and determine the potential damage to the POCs from the fire. It was postulated that the transport vehicle fuel tank containing 50 gal of gasoline spills instantaneously as a result of the impact and is exposed to an ignition source, resulting in a fire of the fuel tank's contents. The computer model Fire Dynamics Simulator (Version 2) (FDS), developed by the National Institute of Standards and Technology (NIST), was used as an aid in determining the characteristics of the fire. The FDS model is a field model that is based on a computational fluid dynamics model of fire-driven fluid flow. This model divides the volumes into a user-selected number of discrete elements and numerically solves a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow with an emphasis on smoke and heat transport from fires.

Figure A2 in Appendix A shows maximum temperatures and heat fluxes associated with a 50-gal gasoline fire. As Figure A2 shows, assuming a catastrophic, instantaneous spill of gasoline with a pool thickness of about 1.8 mm covering an area of 106 m^2, the 50-gal fuel pool fire is expected to last no more than a few minutes. The estimated average and maximum fire temperatures are approximately 750°C and 875°C, respectively.

Tests performed by SNL on POCs show that POCs can withstand temperatures of between 800°C and 1100°C for 30 min. The SNL tests were performed on 6 in. and 12 in. pipes inserted in Type A containers, including both welded pipe and formed pipe bottoms for each pipe size, for a total of four POCs. The units were placed on an open support stand with 1 m spacing between them in a square array. The bottoms of the units were one meter above the surface of a 10 m^2 pool of jet fuel. The initial amount of fuel in the pool was slightly less than that required for a 30-min fire, but additional fuel was added as the fire progressed to support a 30-min fire duration. Of the POCs tested, only one lost its lid, which was attributed to the decomposition of the drum liner and fiberboard in the presence of the stainless steel housed carbon media filter in the drum lid. For the drums that kept their lids, passive thermal indicators showed a peak internal POC temperature of less than 200°F (93°C). Although all drums showed weight loss after the fire, all pipes (except for the one drum that lost its lid) were leak-tight following the fire test.

Based on the Appendix A fire model and the SNL test results, it is apparent that the POCs will withstand the insults associated with the 50-gal fuel pool fire. The sealed sources enjoy a triple layer of protection: the POC (shown by SNL to survive a 30-min fire); the pipe (designed to survive a 30-min exposure to fire of up to 1100 °C); and the source (designed to survive a 10-min fire of 800 °C). A fire would require a long duration in order to defeat each layer sequentially. These layers provide a cumulative thermal protection, i.e., each layer protects the next inner layer from the thermal insults of a postulated fire. Because of the geometrical configuration of the sealed sources, it is qualitatively assumed that a fire would have to last over 1 hr before the radioactive material from the sealed sources will be significantly challenged. Thus, the DR for the fire component of the vehicle crash is zero.

Accident 3: TRU Waste Drum Deflagration Accident

The accident considered in this analysis is a scenario in which an explosive mixture forms internally and is ignited by a mishandling accident. OSRP sealed sources are not subject to deflagration hazards. Furthermore, the worst-case deflagration accident with respect to sealed sources in POCs in drums is a deflagration that occurs either adjacent to a sealed source, or a deflagration that causes a fire that propagates to the stored sealed sources. Accident 2 above bounds any potential thermal insults created by a deflagration-induced fire.

Accident 4: Waste Storage Dome Fire

The accident considered in this analysis is a fire in an Area G waste storage dome. Eight cases (Cases 1 through 8) are analyzed, representing a spectrum of fire sizes and storage configurations. Cases 1 and 7 assume that only crates are involved; Cases 2 through 6 assume that drums are adjacent to burning crates; and Case 8 assumes that drums are fully engulfed by flames from a vehicle fuel pool fire.

The fuel pool fires evaluated in Accident 2 and Accident 8 bound the thermal insult posed by the various scenarios postulated for Accident 4. As described above, sealed sources overpacked in POCs are provided with multiple, independent layers of protection against thermal insults that protect the radioactive material encapsulated in the sealed sources. These layers of protection are expected to withstand the thermal insults associated with the scenarios. Thus, the DR for this scenario is zero.

Accident 5: Brush/Forest Fire Spreads to Multiple Waste Storage Domes

The accident considered in this analysis is a brush or forest fire that spreads to the waste storage domes. Two identical cases are evaluated to determine the potential dose from opposite ends of the site. The source terms for both cases were developed based on the TRU waste storage dome fire analysis worst-case scenario (Case 4 above) and the total MAR for the Area G site.

As described above, the fuel pool fire evaluated in Accident 2 bounds the thermal insults posed by the scenarios postulated for this accident. Sealed sources overpacked in POCs are provided with multiple, independent layers of protection against thermal insults to the radioactive material encapsulated in the sealed sources, and these layers of protection are expected to withstand the thermal insults associated with the scenarios. Thus, the DR for this scenario is zero. This credits controls already identified in the DSA (i.e., combustible loading).

Accident 6: Earthquake (0.31 g)

The accident considered in this analysis is an earthquake with a ground acceleration of 0.31 g. Eight cases are evaluated to determine the impact of drum structural capability and banding on the analysis:

- Case 1a: Drums are not banded; their performance is similar to drum drop test results.
- Cases 1b and 1c: Drums are not banded; degraded drums fail upon impact (different MAR values are used).
- Cases 2a, 2b, and 2c: Same as Cases 1a, 1b, and 1c, respectively, except that drums are banded.
- Cases 3a and 3b: Same as Cases 1a and 1b, respectively; fire is initiated.

As Appendix A shows, the kinetic energy (15.5 kJ) associated with the drop of a drum from the third level of the storage array is well below the energy associated with the POC impact tests (44 kJ) (see Table 4). That is, as Table 3 shows, both POCs and the sealed sources are expected to withstand a fall from 9 m (30 ft), which bounds the fall from the third tier of a storage array. In addition, the outer Type A packaging and packing material are likely to absorb much of the energy of the impact, thus protecting the inner pipe component and the sealed sources. Therefore, POCs are expected to withstand the fall scenarios, and a DR of 0 is assigned to the spill component.

Table 7. Kinetic Energy Associated with Drum Fall from Third Tier of Storage Array

Case	Weight (kg)	Fall Height (m)	Velocity v_f (m/s)	Kinetic Energy[1] (kJ)
Single drum dropped from 8 ft (2.4 m)	658[2]	2.4[3]	6.9	15.5

[1] Determined by the equation KE = $1/2mv^2$ for falling objects (where m is the mass of the object, and v is determined by $v_f^2 = 2ad$, where d is the fall distance, v_f is the final velocity of the object, and a is 9.8 m/s^2).

[2] Mass is maximum allowable 85-gal drum weight at Area G (although the current Area G WAC restrict the total mass of any 55-gal container to 900 lbs and do not accept 85-gal containers except as overpacks, previous WAC for Area G allowed for 55-gal and 85-gal drums weighing up to 1000 and 1450 lbs, respectively).

[3] Fall height associated with third level of a three-high storage array.

With respect to the fire component, the fuel pool fire evaluated in Accident 2 bounds the thermal insults posed by the various scenarios postulated for Accident 6. As described above, the sealed sources enjoy a triple layer of protection: the POC (shown by SNL to survive a 30-min fire); the pipe (designed to survive a 30-min exposure to fire of up to 1100°C); and the source (designed to survive a 10-min fire of 800°C). A fire would require a long duration in order to defeat each layer sequentially. These layers provide a cumulative thermal protection, i.e., each layer protects the next inner layer from the thermal insults of the postulated fires. Because of the geometrical configuration of the sealed sources, a fire with a temperature over 1100°C would have to last over an hour in order for the radioactive material inside the POCs to be significantly challenged. A fire of this magnitude and duration would require a significant source of fuel that is not present at Area G (although flammable liquid fueled vehicles are present at Area G, the amount of fuel associated with these vehicles is bounded by the flammable liquid fuel pool fires evaluated in Appendix A). Thus, sealed sources overpacked in POCs are expected to withstand the expected thermal insults associated with a seismically induced fire, resulting in a DR of zero for these scenarios.

Accident 7: Waste Storage Dome Structural Failure from High Wind

The accident considered in this analysis is a high wind event, in particular, winds exceeding Performance Category (PC)-2 wind speeds. Two cases are analyzed in this section:

- Case 1: A wind-driven missile is blown into the storage dome and impacts waste containers.
- Case 2: Major dome structural failure; drums in storage array impacted.

The DSA assumes that the missile is a storage dome door and determines the number of drums impacted as a function of the dimensions (e.g., height and width) of the door. For the purpose of this analysis, however, the weight and speed of a missile that a PC-3 facility would need to withstand is used to determine kinetic energy (per DOE-STD-1020-2002, the missile to be considered is a 2 x 4 timber plank, 15 lbs at 50 mph). The kinetic energy associated with a PC-3 wind-driven missile is 1.7 kJ, well below the kinetic energy associated with the drop criteria for sealed sources or POCs. In addition, the outer layers (POC, packing material, and Type A drums) are expected to protect the sealed sources and reduce the likelihood that waste from the sealed sources will be released upon impact. Thus, the DR for the sealed sources overpacked in POCs is reduced to zero.

Accident 8: Airplane Crash into Waste Storage Domes

The accident analysis addresses an airplane crash and fire that impact the storage arrays. Three cases are evaluated, all assuming a crash involving an air taxi airplane. Cases 1 and 2 are evaluated for two unique aircraft jet fuel tank capacities (100 gal and 300 gal), while Case 3 is evaluated for a maximum drum MAR inventory.

Appendix A evaluates the mechanical and thermal insults associated with an aircraft crash into the POCs arrays. Appendix A conservatively assumes that all POCs are staged or stored together. For the mechanical insult, Appendix A considers an aircraft impacting the drum array to be an inelastic collision because, upon impact, the aircraft is expected to deform, break apart, and press into the array, as opposed to the aircraft bouncing off the array like a rubber ball. As such, conservation of momentum requires that the initial momentum of the aircraft equal the final momentum of the aircraft plus that of the impacted POCs. For this analysis, the mass of the impacted POCs is limited to those POCs that form a solid cohesive mass (i.e., the mass against which the plane pushes). The entire mass is not initially involved because the storage array is subdivided by spaces and a central aisle. The POC mass that is directly impacted (i.e., the solid cohesive fraction of the array) depends on the angle of an aircraft impact. Two different angles are considered: one resulting from an aircraft impacting the *end* of the array, and the other resulting from an aircraft impacting the *side* of the array.

For the case in which the aircraft impacts the end of the array, Appendix A determines that a total of two rows containing 240 POCs are within the impact area. However, only a fraction of the POCs within the impact area will be breached. In reality, only a small fraction of the staged or stored drums will be directly impacted by the aircraft; that is, those in direct contact and in the direct path of the wings and the cabin. All other drums will be knocked down but not impacted by the aircraft itself. The energy and acceleration received by a drum during the impact varies from drum to drum, depending on its initial position in the array and the complicated set of action-reaction events that eventually unfold. Many of the drums initially impacted by the aircraft receive considerably more energy than that required to cause a breach. Many other affected drums do not receive sufficient energy to be breached, resulting in dents/damage to the drums with no major consequences. Consistent with the Area G DSA, it is conservatively assumed that one-half (120) of the POCs in the impact area are energetically breached. Of those, it is estimated that only 10% of the sealed sources within the POCs (12 sealed sources) will be breached. This is equivalent to 5% of the 240 POCs initially impacted.

For the case in which the aircraft impacts the side of the array, Appendix A determines that a total of two rows containing 600 POCs are within the impact area. However, only a fraction of the POCs within the impact area will be breached. As described above, consistent with the Area G DSA assumption for Type A drums, it is assumed that one-half (300) of the POCs in the impact area are energetically breached. Of those POCs, it is further estimated that only 10% of the sealed sources in the POCs will be breached. Thus, the final DR is 5% of the POCs initially impacted.

The Area G DSA airplane crash analysis originally assigned a DR of 0.10 (10%) to the scenario, based on the assumptions that 600 out of 3000 drums inside the storage dome would be impacted and that half of the drums impacted would be breached. It is clear that the DR for an airplane impacting sealed sources overpacked in POCs would be much smaller than 10%, due to the increased robustness of the sealed sources, pipes and POCs, and the multiple layers of protection provided for the sealed sources. Using the same methodology that was used in developing the Area G DSA, the DR for sealed sources in POCs impacted by an airplane crash can be estimated to be bounded by the DR originally estimated in the Area G DSA, namely 10%.

With respect to the ensuing fire, Appendix A analyzes both Case 1 and Case 2 identified above and described below in more detail (Case 3 does not affect the size of the fire and only the MAR is involved; therefore, it does not require analysis beyond what is evaluated here):

- Case 1: A pool fire of approximately 100 gal of JP5 jet fuel, normally utilized by turbo-prop airplanes likely to be found operating into and out of Los Alamos airport.
- Case 2: A pool fire of approximately 300 gal of JP5 jet fuel, normally utilized by airplanes such as the DeHavilland Twin Otter, which is believed to represent the type of air taxi flying into and out of Los Alamos.

As with the previous gasoline fire analysis, FDS was utilized to model the 100 gal and 300 gal jet fuel fires. The 100 gal flammable fuel fire lasts slightly over 2 min (with an area of 210 m^2, based on a calculated pool thickness of about 1.8 mm), with an average temperature of about 700°C and a maximum temperature of less than 800°C. The 300 gal flammable fuel fire lasts approximately 3 min (assuming a catastrophic, instantaneous spill having a diameter of about 28.3 m), with an average temperature of about 700°C and a maximum temperature of less than 800°C.

Based on the Appendix A fire models and the SNL test results, it is apparent that the POCs will withstand the insults associated with the 100 gal and 300 gal JP5 pool fires. Figures A4 and A6 in Appendix A show maximum temperatures and heat fluxes associated with the 100-gal JP5 pool fire and the 300-gal JP5 pool fire, respectively. As described earlier, the sealed sources enjoy a triple layer of protection: the POC, the pipe, and the source. These layers provide a cumulative thermal protection. A fire would require a long duration in order to defeat each layer sequentially. Because of the geometrical configuration of the sealed sources, it is qualitatively assumed that a fire would have to last over 1 hr before the radioactive material from the sealed sources will be significantly challenged. Thus, the DR for the fire component of the airplane crash is zero.

Accident 9: Fire in Tritium Waste Sheds

This section addresses the accident analysis associated with a fire involving the tritium waste sheds within Area G. The worst-case deflagration accident with respect to sealed sources in POCs is a fire that propagates to the stored sealed sources, and Accident 2 bounds any potential thermal insults created by the deflagration-induced fire.

Accident 10: Operational Spill during Shaft Placement

This section addresses an accident associated with an operational spill during shaft placement activities at Area G. An accident could be caused by a worker error or equipment failure that causes a crane-drop event. As discussed above, non-actinide sources at Area G that are placed in shafts and that are not packaged in POCs are not addressed in this evaluation. Therefore, the OSRP sealed actinide sources stored aboveground in POCs at Area G are not affected by this accident.

5.0 CONCLUSIONS

This evaluation shows that sealed sources are capable of withstanding most of the operational, natural phenomena, and external accident conditions evaluated in the Area G DSA, with the possible exception of a direct impact by a truck or an aircraft. For those accidents in which the kinetic energy associated with the mechanical insult exceeds the kinetic energy associated with the POC impact tests (Accidents 1, 2, and 8 in the Area G DSA), the DR is 5%. Because of the fire duration for a fuel spill resulting from a truck or airplane crash is well below the fire test durations the DR is practically zero for all fire conditions postulated in the Area G DSA. The sealed sources are protected by three layers of protection: the POC, the pipe, and the sealed source—each of which is designed and tested to withstand elevated mechanical and thermal insults. These layers provide a cumulative protection against both mechanical and thermal insults.

Considering that the inventory at Area G is close to exceeding the 150,000 PE-Ci evaluated in the TA-54, Area G DSA and that Area G's ability to support LANL operations depends on its waste storage capacity, the FWO-WFM Group is requesting NNSA consideration for separately addressing sealed sources inventory from the MAR limit. None of the individual container, truckload, or dome limits are affected. This request and supporting analysis is being submitted for Area G to continue accepting waste shipments until the next annual update of the DSA.

To preserve the analysis, and to ensure a significant margin of safety (conservatism), the following controls are being put forward as part of the TA-54, Area G operations:

1. Store all OSRP actinide sealed sources in POCs.
2. Maintain minimum of 2 ft spacing between columns containing stacked drums/POCs.
3. Minimize vehicle speeds around stacked drums/POCs.
4. Avoid storing or staging all of the POCs in a single dome.

These controls are implemented as elements of the Hazardous Material and Waste Management program.

6.0 REFERENCES

10 CFR 71.73, "Hypothetical Accident Conditions."

49 CFR 173.410, "General Design Requirements."

49 CFR 173.465, "Type A Packaging Tests."

49 CFR 173.469, "Tests for Special Form Class 7 (Radioactive) Materials."

American National Standards Institute. ANSI N43.6, *Sealed Radioactive Sources, Categorization.*

Hughes Associates, Inc. *Fire Protection Guide for Waste Drum Storage Arrays.* WHC-SD-SQA-ANAL-501. Rev. 0. Prepared for Westinghouse Hanford Company. 1996.

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Los Alamos National Laboratory. *Technical Safety Requirements (TSRs) for Technical Area 54, Area G.* ABD-WFM-002. Rev 0.3. April 23, 2004.

Los Alamos National Laboratory. "Unplanned TA-54 Area G MAR Increase Event and Conditional Safety Basis Approval of TSR Changes." NNSA memorandum. July 7, 2004.

Sandia National Laboratories. *Testing in Support of Transportation of Residues in the Pipe Overpack Container.* SAND97-0716/TTC-1477. April 1997.

Sandia National Laboratories. *Testing in Support of Onsite Storage of Residues in the Pipe Overpack Container.* SAND97-0368/TTC-1476. February 1997.

U.S. Department of Energy. *Airborne Release Fraction/Rates and Respirable Fractions for Nonreactor Nuclear Facilities.* DOE-HDBK-3010.

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Washington Hanford Co. *Drum Drop Test Report.* WHC-SD-WM-TRP-231. Rev. 0. February 27, 1995.

Waste Isolation Pilot Plant. *TRUPACT-II Authorized Methods for Payload Control* (TRAMPAC). Carlsbad, NM.

7.0 APPENDIX

Appendix A. "Evaluation of Pipe Overpack Container Ability to Survive Thermal/Mechanical Insults"

APPENDIX A. EVALUATION OF PIPE OVERPACK CONTAINER ABILITY TO SURVIVE THERMAL/MECHANICAL INSULTS

1.0 INTRODUCTION

The purpose of this appendix is to document the methodology or approach used to quantify the effects of thermal and mechanical insults evaluated in the Technical Area (TA)-54, Area G documented safety analysis (DSA) on sealed sources stored in pipe overpack containers (POCs) at Area G.

2.0 FIRE ANALYSIS

The computer model Fire Dynamics Simulator (Version 4) (FDS), developed by the National Institute of Standards and Technology (NIST), was used as an aid in determining the characteristics of the fires. The interested reader is referred to *Fire Dynamics Simulator* (*Version 4*) (*FDS*)*--User's Guide* for more information on this computer code.

The FDS model is a field model that is based on a computational fluid dynamics (CFD) model of fire-driven fluid flow. This model divides the volumes into a user-selected number of discrete elements and numerically solves a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow with an emphasis on smoke and heat transport from fires. The formulation of the equations and the numerical algorithm is contained in *Fire Dynamics Simulator* (*Version 4*)*--Technical Reference Guide.*

Three fires were conceptualized for this analysis: 50-gal, 100-gal, and 300-gal flammable fuel fires. A 50-gal flammable fuel pool fire is likely to involve a transport truck in which 50 gal of flammable fuel is typically found. Aircrafts generally found at the Los Alamos Airport have tanks that each holds 100 gal of aviation fuel. A 100-gal fuel pool fire is thought to represent a type of accident involving a typical aircraft at the Los Alamos Airport. Air taxi airplanes typically hold more fuel. A 300-gal pool fire is considered as a representative case to illustrate a fire involving a typical air taxi airplane that holds 300 gal of jet fuel.

In addition to FDS, hand calculations utilizing spreadsheets were used where necessary.

***Fire Scenarios*:** The hazard analysis of the DSA (Section 3.3) identified postulated bounding representative and unique fire scenarios. They became the starting point for the fire modeling. As mentioned above, the 50-gal pool fires were expected to be connected with vehicles, while the 100-gal and 300-gal pool fires were expected to be connected with airplanes, normally external to any facility in Area G.

***Rebaselining the Fire Size*:** The minimum fire sizes were determined using hand calculations and spreadsheets (combustible loadings and potential burning surface areas).

***Fire Characteristics*:** The fire size and duration were used as inputs to the fire compartment models and to the FDS computer code to determine the fire characteristics (e.g., fire temperatures and heat fluxes).

***Critical Equipment Protection*:** Because of the potential proximity of combustibles to critical equipment, a fire could still lead to ignition of adjacent combustibles with a room or area, even if no flashover conditions are reached. To determine the worst-case temperatures and heat fluxes and to represent actual conditions, one stack of three POCs was placed inside the fire to illustrate total engulfment by fire, one stack was placed at the periphery of the pool, and a single drum was placed at the periphery. Heat flux calculations consisting of view or shape factor calculations were performed to model fire geometry (e.g., cylinder, slab), and FDS heat-flux capabilities were then obtained.

Since the fires were initiated outdoors, there was no need to model access doors and ventilation vents. In FDS, the fire characteristics must be specified using two of the following parameters: heat of combustion, heat release rate, or pyrolysis rate. The two specifications chosen to describe all fires were the heat of combustion and the heat release rate. The heat of combustion used for all models was 43,700 kJ/kg for gasoline and 43,000 kJ/kg for JP5.

All FDS calculations must be performed within a rectangular domain on a rectilinear numerical grid. Because of this restriction, the circular pool surface area also has to be converted to an equivalent rectangular area. The size of the grid determines the accuracy of the results. The finer the mesh of the grid, the more computational cells exist, thereby giving more accurate results. The drawback of this technique is that the computer run time becomes longer as the number of computational cells increases. An effort was made to find a grid size that gives accurate results without causing unreasonably long computer run times.

In FDS, a fire is modeled as the ejection of pyrolyzed fuel from a solid surface or vent that burns when mixed with oxygen. This combination is the default mixture fraction model of combustion. The user specifies either a heat release rate per unit area or a heat of vaporization at the fuel surface. A solid surface with a heat release rate per unit area emanating from the surface was chosen to describe the fire. The fire's constant heat release rate area was then manipulated to follow a specified heat release rate curve. The area chosen to represent the fire was calculated using specific fire characteristics. The stoichiometry of the reaction was set by the parameter REACTION on the MISC line of the input file. All of the species associated with the combustion process are accounted for by way of the mixture fraction variable.

FDS was used to calculate heat fluxes and temperatures at pre-selected locations. FDS is an ideal tool for this purpose because it can calculate temperatures and fire characteristics at discrete locations. First, the critical heat flux to sensitive equipment and MAR was identified. Criteria for minimum heat fluxes depend on the individual scenario analyzed. Using appropriate heat release rate curves resulting from specific scenarios, heat fluxes were calculated and critical or minimum separation distances were found. Wherever possible, conservatism was built into the analysis to allow for a margin of safety. From the above calculations, the following calculations were performed:

1. The maximum fuel loading corresponding to a generated worst-case radiant heat or temperature environment was calculated based on temperatures of the maximum credible fire heat release rate. This information was then used to determine the environmental conditions to which critical equipment or MAR would be exposed and to evaluate the adequacy of controls or impact on MAR.
2. The minimum fuel loading corresponding to a worst-case radiant impingement was calculated based on the duration (and associated temperatures) of the maximum credible fire heat release rate.

2.1 MODELING OF FIRES

The following fire scenarios were chosen to be analyzed as representative cases of interest:

- A pool fire of approximately 50 gal of gasoline located outside on a concrete pad.

- A pool fire of approximately 100 gal of JP5 jet fuel, normally utilized by a turboprop airplane likely to be found operating into and out of the Los Alamos Airport.
- A pool fire of approximately 300 gal of JP5 jet fuel, normally utilized by an airplane like a DeHavilland Twin Otter, which is believed to represent the type of air taxi flying into and out of the Los Alamos Airport.

The following details describe the results of the calculations performed. Calculations were performed to establish maximum temperatures and heat fluxes at pre-selected locations where the POCs are expected to be located. It is important to note that fire characteristics associated with combustible loading depend on the amount, the arrangement, and the type of fuel involved. In analyzing fires associated with certain types of fuel (e.g., flammable liquids), it is not appropriate to convert them to "common combustibles" to estimate hazards. The fires analyzed must represent the fuel's fire characteristics to gain meaningful results.

2.1.1 Large 50-Gallon Pool Fire

An analysis was performed using FDS to investigate the fire hazards associated with the ignition of an instantaneous spill of 50 gal of gasoline. The postulated spill originated from a transport truck's fuel tank holding 50 gal of gasoline. It was estimated that the pool had an area of 106 m^2 based on the calculated pool thickness of about 1.8 mm (which is more conservative than the 1 cm pool depth recommended in the Environmental Protection Agency's *Risk Management Program Guidance for Offsite Consequence Analysis*, EPA 550-B-99-009). The fire lasted about two min and achieved an average temperature of about 750°C.

Figure A1 schematically illustrates the fire and its general layout and configuration. A stack of three drums was placed inside the fire to represent total engulfment by the fire. Another stack of three drums was placed at the periphery of the pool, and a single drum placed at the periphery. Thermocouples were also placed at the drums' locations to collect temperature and heat flux data. None of the drums was credited as providing heat sinks for the fire. Table A1 shows calculations performed to analyze the 50-gal fuel pool fire. Table A2 provides the FDS input data file for the 50-gal gasoline fuel pool fire. Figure A2 shows the hottest flame temperatures and severest heat fluxes experienced by the most impinged of the seven drums.

Tests performed by Sandia National Laboratories (SNL) on POCs have shown that these containers can withstand temperatures of between 800°C and 1100°C for 30 min. The POCs tested consisted of 6 in. and 12 in. containers. A total of four POCs with welded and formed pipe bottoms were tested. They were placed on an open support stand with 1 m spacing among them in a square array. The bottoms of the units were 1 m above the surface of a 10 m^2 pool of jet fuel. The amount of fuel initially in the pool was slightly less than the amount required for a 30-min fire, but as the fire progressed, more fuel was added to extend the duration to 30 min. Of the containers involved in this experiment, only one of them lost the lid. SNL attributed this result to the decomposition of the drum liner and fiberboard in the presence of the stainless steel housed carbon media filter in the drum lid. For the drums that kept the lids, passive thermal indicators showed a peak temperature of less than 200°F (93°C). Although all drums showed weight loss after the fire, all pipes (except for the one that lost its lid) were leak-tight following the test.

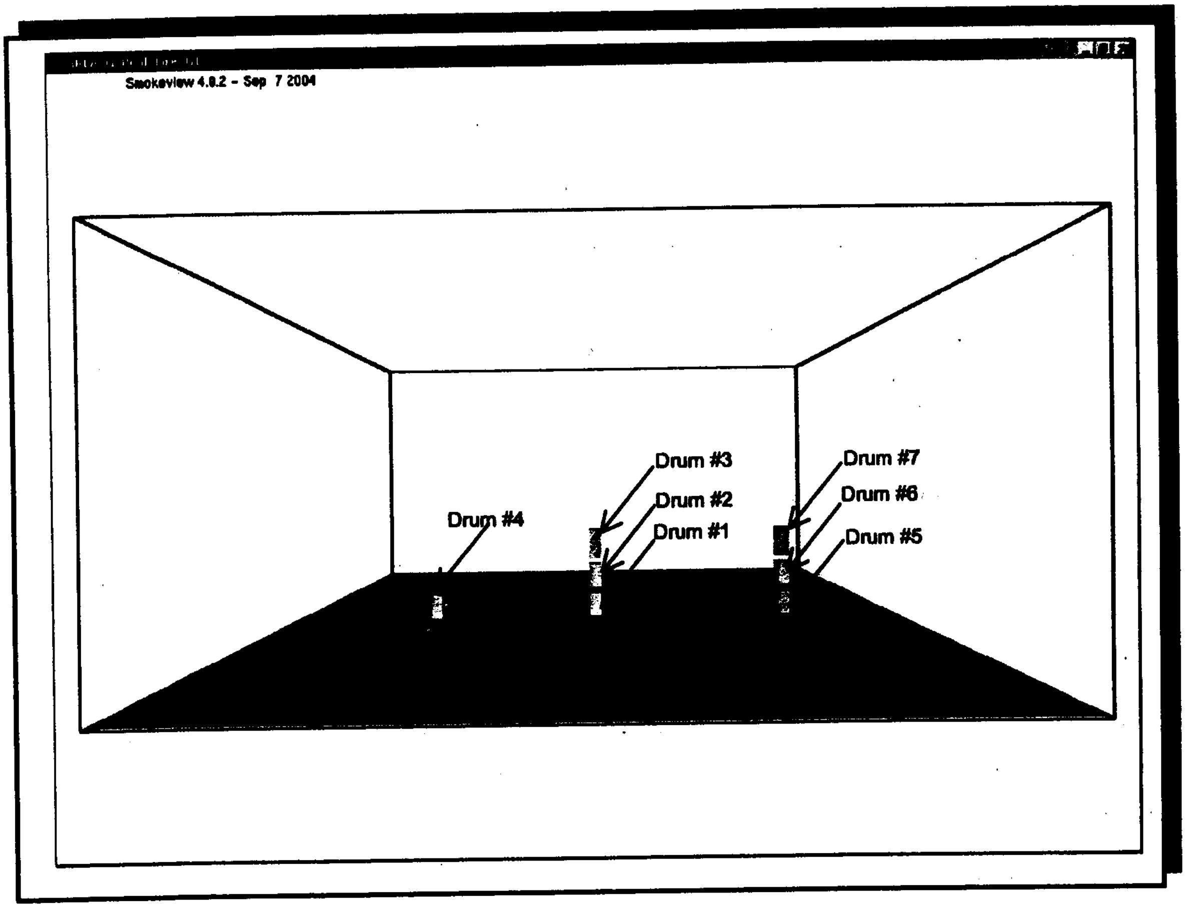

Figure A1. 50-Gallon Gasoline Fuel Spill Fire

Table A1. Hand Calculations Associated with the 50-Gallon Fuel Pool Fire

Determine the size and fire characteristics of a fuel spill:

First, the size of the spill is estimated using Equation 4b (page 2-300 of the SFPA handbook 3rd ed.), assuming that the release occurs instantaneously (i.e., the spill is nearly at its maximum diameter at the time of ignition) and is allowed to spread freely.

$V_{fuel} := 50gal$	Volume of fuel spilled
$AV := 0.36\frac{m^2}{L}$	Spill area per volume > 25 gal (95 L)
$A_s := AV \cdot V_{fuel}$	Equation 4b
$A_s = 68m^2$	Area of spill for 50 gal of gasoline

Per Equation 2 (page 2-298 of the SFPA handbook 3rd ed.), the maximum possible fire size is estimated

$A := 1.55 A_s$	Equation 2
$A = 106m^2$	Maximum possible fire size

Parameters for calculating the fire charistics:

$\Delta h_c := 43.7 \cdot 10^6 \frac{J}{kg}$	The heat of combustion for the fuel
$\rho_{fuel} := 740\frac{kg}{m^3}$	Density of the fuel
$m_{burnratepool} := 0.055\frac{kg}{m^2 \cdot s}$	Maximum burning rate per unit area for gasoline

The maximum mass burn rate per unit area for a spill fire is estimated to be one-fifth (page 2-311 of the SFPA handbook 3rd ed.) of the maximum pool burn rate per unit area, therefore the maximum burn rate per unit area for gasoline is

$m_{burnratespill} := 0.2 \cdot m_{burnratepool}$	Mass burn rate per unit area for a liquid fuel spill
$m_{burnratespill} = 0.011\frac{kg}{m^2 s}$	Mass burn rate per unit area for gasoline in a liquid fuel spill

Table A1. Hand Calculations Associated with the 50-Gallon Fuel Pool Fire (Continued)

From the mass burn rate per unit area, the heat release rate is calculated

$Q_{rate} := m_{burnratespill} \cdot A \cdot \Delta h_c$	Heat release rate
$Q_{rate} = 50.8 \times 10^6 W$	Heat release rate for gasoline

Assuming that the fuel spill burns at the maximum rate for the duration of the fire the following equation is used

$t_f := \dfrac{V_{fuel} \cdot \rho_{fuel}}{m_{burnratespill} \cdot A}$	Fire duration
$t_f = 121s$	Fire duration for 50 gal of gasoline

For FDS inputs the heat release rate per unit area (HRRPUA) and the equivalent area for a square (LW) must be calculated

$HRRPUA := \dfrac{Q_{rate}}{A}$	Heat release rate per unit area
$HRRPUA = 480.7 \dfrac{kW}{m^2}$	Heat release rate per unit area for 50 gal of gasoline
$LW := \sqrt{A}$	Length and width of an equivalent square
$LW = 10.3m$	Length and width of an equivalent square for a 50 gal spill

Table A2. FDS Input Data File for the 50-Gallon Gasoline Fuel Pool Fire

```
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&PDIM XBAR=20,YBAR=20,ZBAR=10 /
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/HEAT RELEASE RATE OF FIRE/
&SURF ID='FIRE',HRRPUA=480.7,PARTICLES=.TRUE.,RGB=1.0,0.0,0.0/

/Pool Fire/
&OBST XB=4.8500,15.1500,4.8500,15.1500,0.00,0.05,SURF_IDS='FIRE','INERT','INERT',RGB=1.0,0.0,0.0/

&VENT CB='XBAR' ,SURF_ID='OPEN' /
&VENT CB='XBAR0',SURF_ID='OPEN' /
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&OBST XB=9.7385,10.2615,9.7385,10.2615,2.0200,2.9030,SURF_ID='SHEET METAL'/ drum 3 center

&OBST XB=4.3270,4.8500,9.7385,10.2615,0.000,0.883,SURF_ID='SHEET METAL'/ drum 4 edge

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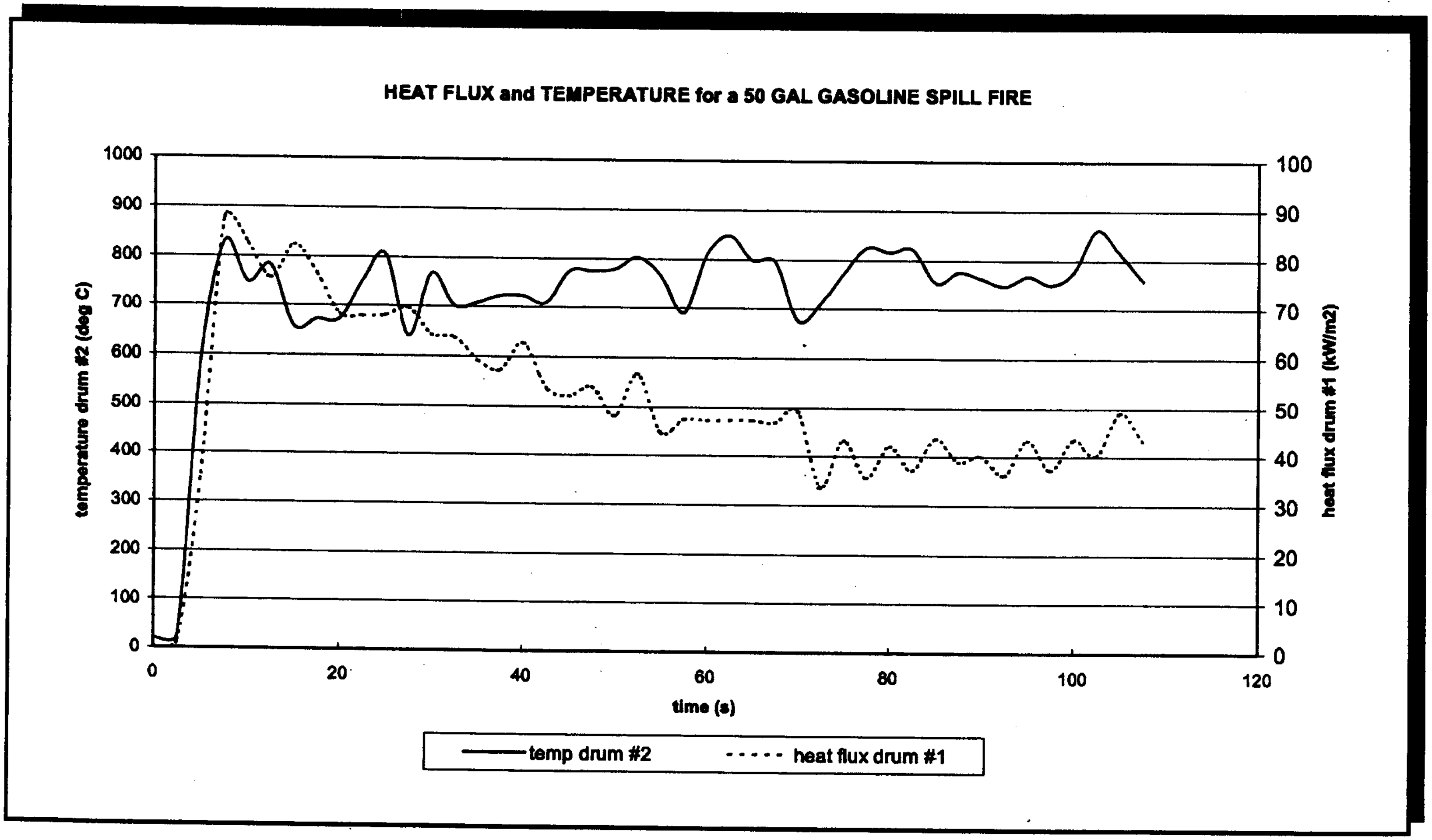

Figure A2. Maximum Temperatures and Heat Fluxes Associated with a 50-Gallon Gasoline Fire

2.1.2 Large 100-Gallon Pool Fire

Next, a fire associated with the spill of 100 gal of JP5 was investigated. This fire had an area of 210 m^2 and calculated pool thickness of about 1.8 mm. The fuel type chosen (JP5) is the representative fuel for most of the turboprop airplanes that are commonly found at the Los Alamos Airport. The amount of fuel (100 gal) was deemed appropriate to bound the tank capacities of these airplanes. The fire lasted slightly more than 3 min and achieved an average temperature of about 700°C.

Figure A3 below is a representation of the fire and its general layout and configuration. As in the previous analysis, a stack of three drums was placed inside the fire to represent total engulfment by the fire, another stack of three drums was placed at the periphery of the fuel pool, and a single drum was placed at the periphery. Thermocouples were also placed at the drums' locations to record temperature and heat flux information. Table A3 provides calculations performed for this fire scenario. Table A4 is the FDS input data used for this analysis. Figure A4 records the hottest flame temperatures and severest heat fluxes experienced by the most impacted of the seven drums. The POCs are expected to survive this fire.

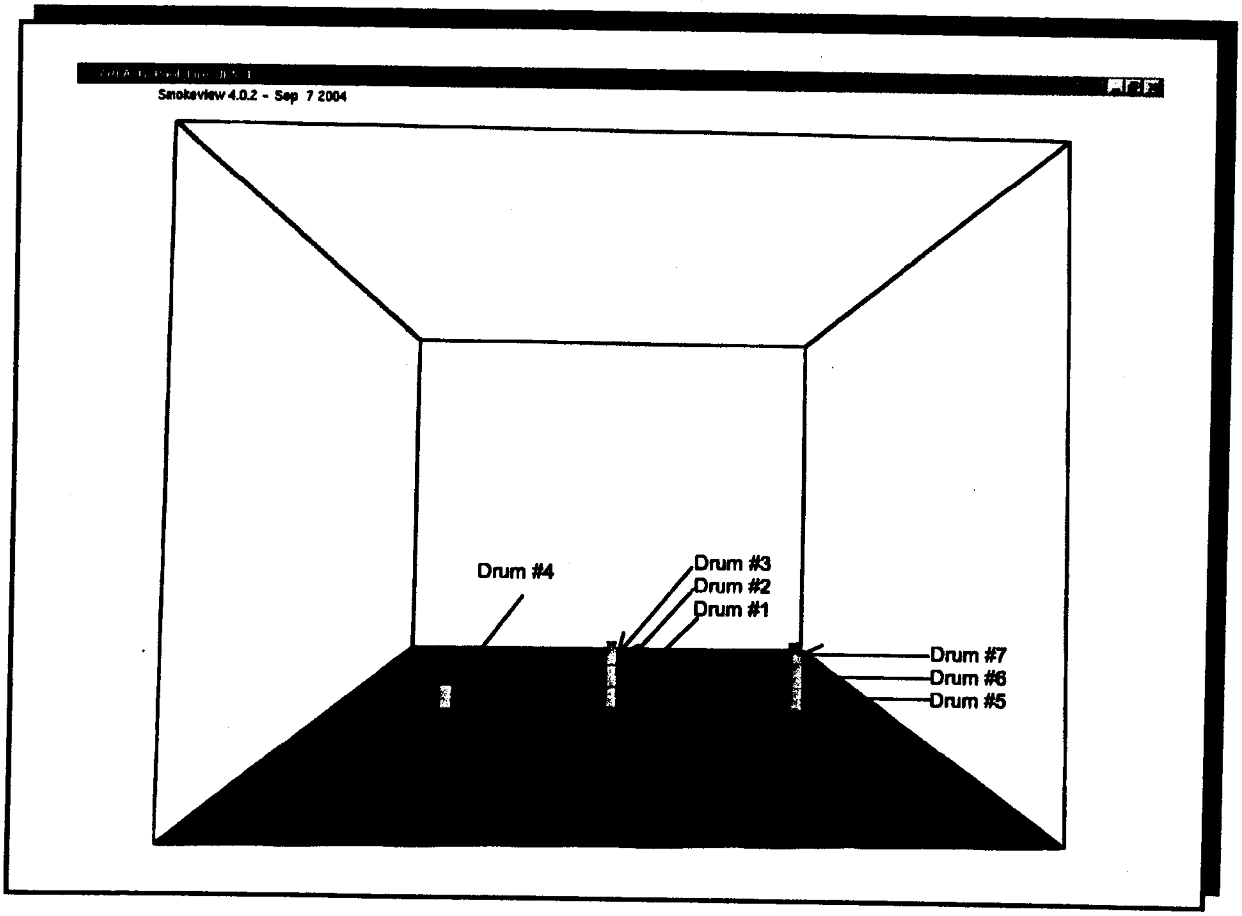

Figure A3. 100-Gallon JP5 Fuel Spill Fire Configuration

Table A3. Hand Calculations Associated with the 100-Gallon Fuel Pool Fire

Determine the size and firecharacteristics of a fuel spill:

First, the size of the spill is estimated using Equation 4b (page 2-300 of the SFPA handbook 3rd ed.), assuming that the release occurs instantaneously (i.e., the spill is nearly at its maximum diameter at the time of ignition) and is allowed to spread freely.

$V_{fuel} := 100gal$	Volume of fuel spilled
$AV := 0.36\frac{m^2}{L}$	Spill area per volume > 25 gal (95 L)
$A_s := AV \cdot V_{fuel}$	Equation 4b
$A_s = 136m^2$	Area of spill for 100 gal of JP5

Per Equation 2 (page 2-298 of the SFPA handbook 3rd ed.), the maximum possible fire size is estimated

$A := 1.55 A_s$	Equation 2
$A = 211m^2$	Maximum possible fire size

Parameters for calculating the fire charistics:

$\Delta h_c := 43.0 \cdot 10^6 \frac{J}{kg}$	The heat of combustion for the fuel
$\rho_{fuel} := 810\frac{kg}{m^3}$	Density of the fuel
$m_{burnratepool} := 0.054\frac{kg}{m^2 \cdot s}$	Maximum burning rate per unit area for JP5

The maximum mass burn rate per unit area for a spill fire is estimated to be one-fifth (page 2-311 of the SFPA handbook 3rd ed.) of the maximum pool burn rate per unit area, therefore the maximum burn rate per unit area for JP5 is

$m_{burnratespill} := 0.2 \cdot m_{burnratepool}$	Mass burn rate per unit area for a liquid fuel spill
$m_{burnratespill} = 0.011\frac{kg}{m^2 s}$	Mass burn rate per unit area for JP5 in a liquid fuel spill

Table A3. Hand Calculations Associated with the 100-Gallon Fuel Pool (Continued)

From the mass burn rate per unit area, the heat release rate is calculated

$Q_{rate} := m_{burnratespill} A \cdot \Delta h_c$	Heat release rate
$Q_{rate} = 98.1 \times 10^{6} \mathrm{W}$	Heat release rate for JP5

Assuming that the fuel spill burns at the maximum rate for the duration of the fire the following equation is used

$t_f := \dfrac{V_{fuel} \cdot \rho_{fuel}}{m_{burnratespill} A}$	Fire duration
$t_f = 134 \mathrm{s}$	Fire duration for 100 gal of JP5

For FDS inputs the heat release rate per unit area (HRRPUA) and the equivalent area for a square (LW) must be calculated

$HRRPUA := \dfrac{Q_{rate}}{A}$	Heat release rate per unit area
$HRRPUA = 464.4 \dfrac{\mathrm{kW}}{\mathrm{m}^2}$	Heat release rate per unit area for 100 gal of JP5
$LW := \sqrt{A}$	Length and width of an equivalent square
$LW = 14.5 \mathrm{m}$	Length and width of an equivalent square for a 100 gal spill

Table A4. FDS Input Data File for 100-Gallon JP5 Fuel Pool Fire

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&PDIM XBAR=25,YBAR=25,ZBAR=20 /
&TIME TWFIN=136. /

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REACTION='JP5',SMOKE3D=.TRUE.,BNDF_DEFAULT=.FALSE.,DTCORE=10.0/


/HEAT RELEASE RATE OF FIRE/
&SURF ID='FIRE',HRRPUA=464.4,RGB=1.0,0.0,0.0/

/Pool Fire/
&OBST XB=5.250,19.75,5.250,19.75,0.000,0.050,SURF_IDS='FIRE','INERT','INERT',
T_REMOVE=134.0,RGB=1.0,0.0,0.0/

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&VENT CB='YBAR0',SURF_ID='OPEN' /
&VENT CB='ZBAR' ,SURF_ID='OPEN' /

&OBST XB=12.2385,12.7615,12.2385,12.7615,0.0000,0.8830,SURF_ID='SHEET METAL'/ drum 1 center
&OBST XB=12.2385,12.7615,12.2385,12.7615,1.0100,1.8930,SURF_ID='SHEET METAL'/ drum 2 center
&OBST XB=12.2385,12.7615,12.2385,12.7615,2.0200,2.9030,SURF_ID='SHEET METAL'/ drum 3 center

&OBST XB=4.7270,5.2500,12.2385,12.7615,0.000,0.883,SURF_ID='SHEET METAL'/ drum 4 edge

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&OBST XB=20.7500,21.2730,12.2385,12.7615,1.0100,1.8930,SURF_ID='SHEET METAL'/ drum 6 outside
&OBST XB=20.7500,21.2730,12.2385,12.7615,2.0200,2.9030,SURF_ID='SHEET METAL'/ drum 7 outside

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&THCP XYZ=20.750,12.5000,2.4615,IOR=-1,QUANTITY='HEAT_FLUX',LABEL='HFlux 7'/

/Temperature/
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&THCP XYZ=12.7615,12.5000,2.4615,IOR=1,QUANTITY='TEMPERATURE',LABEL='Temp 3'/
&THCP XYZ=5.2500,12.5000,0.4415,IOR=1,QUANTITY='TEMPERATURE',LABEL='Temp 4'/
&THCP XYZ=20.750,12.5000,0.4415,IOR=-1,QUANTITY='TEMPERATURE',LABEL='Temp 5'/
&THCP XYZ=20.750,12.5000,1.4515,IOR=-1,QUANTITY='TEMPERATURE',LABEL='Temp 6'/
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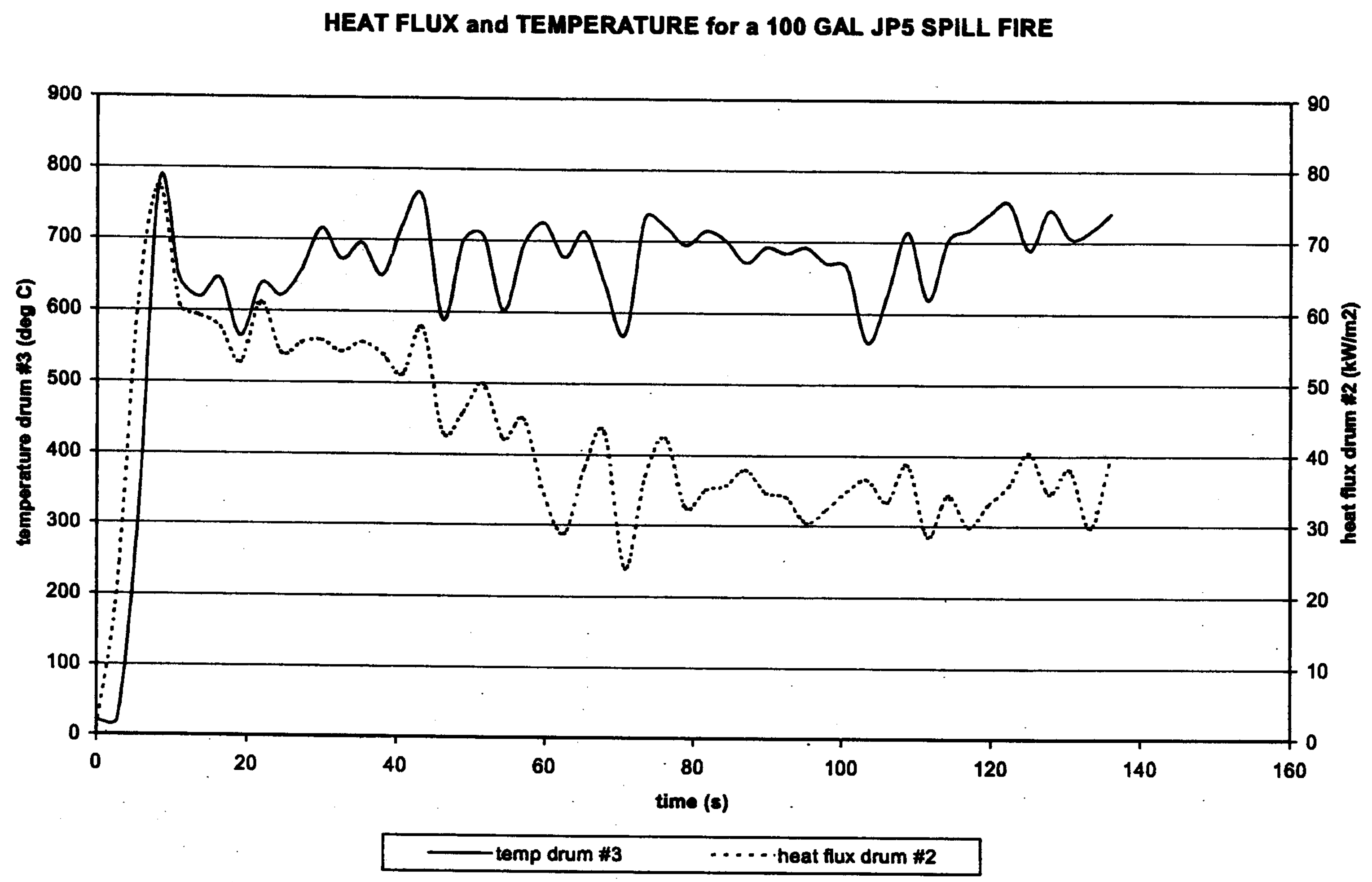

Figure A4. Maximum Temperatures and Heat Fluxes Associated with a 100-Gallon JP5 Fire

2.1.3 Large 300-Gallon Pool Fire

A 300-gal pool fire was also analyzed. As in the case of the 100-gal large pool fire, the type of fuel considered was JP5, but the amount of fuel was increased to 300 gal to represent a scenario involving a DeHavilland Twin Otter air taxi. DeHavilland Twin Otters have been seen providing air taxi services to and from the Los Alamos Airport. The fire was postulated to have an area of about 834 m^2 and achieve an average temperature of about 700°C.

Figure A5 shows this fire's configuration, and Tables A5 and A6 show the hand calculations and input files, respectively. Figure A6 shows the maximum temperature and heat flux experienced by the maximally-impinged drum. The fire lasted about 3 min and did not exceed the test temperatures for pipe damage. These results are consistent with the SNL testing that lasted 30 min.

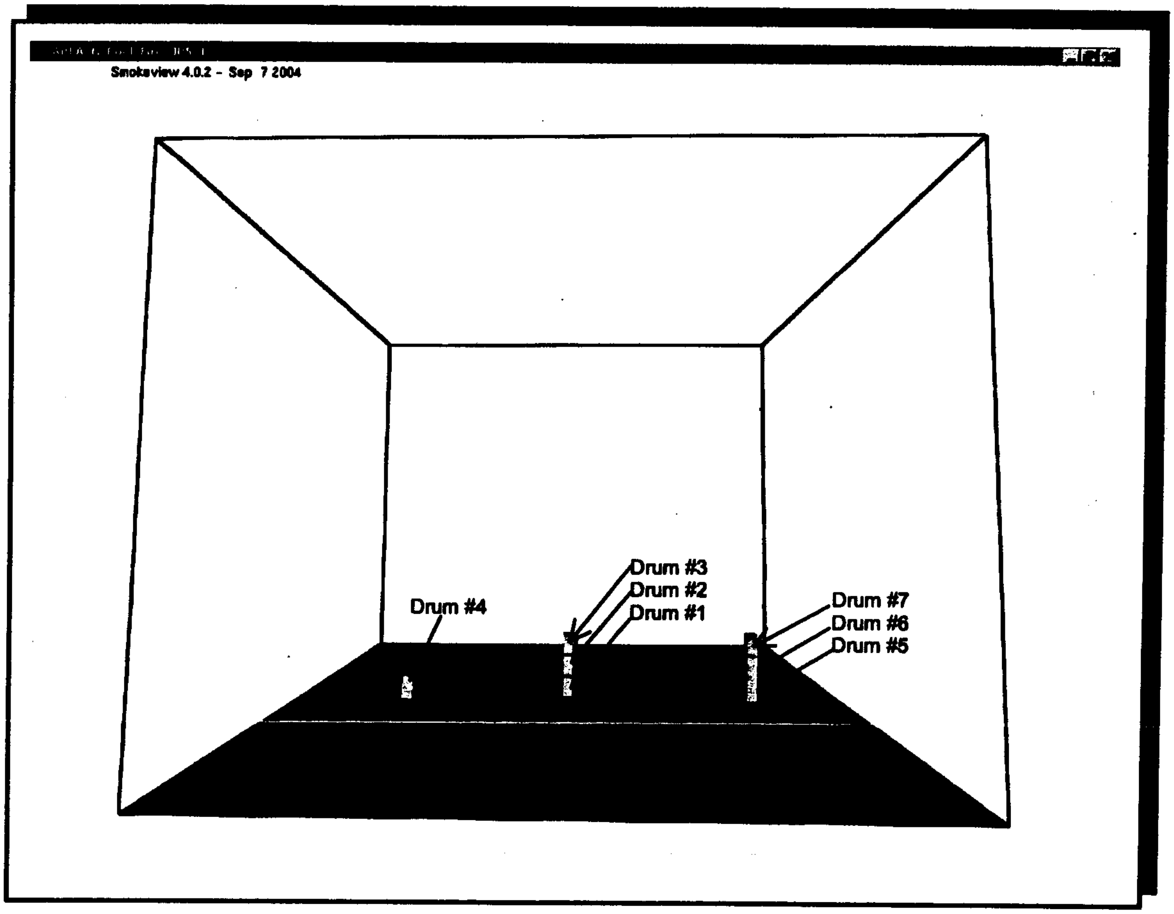

Figure A5. 300-Gallon JP5 Fuel Spill Fire

Table A5. Hand Calculations Associated with the 300-Gallon Fuel Pool Fire

Determine the size and fire characteristics of a fuel spill:

First, the size of the spill is estimated using Equation 4b (page 2-300 of the SFPA handbook 3rd ed.), assuming that the release occurs instantaneously (i.e., the spill is nearly at its maximum diameter at the time of ignition) and is allowed to spread freely.

$V_{fuel} := 300\text{gal}$	Volume of fuel spilled
$AV := 0.36\frac{\text{m}^2}{\text{L}}$	Spill area per volume > 25 gal (95 L)
$A_s := AV \cdot V_{fuel}$	Equation 4b
$A_s = 409\text{m}^2$	Area of spill for 300 gal of JP5

Per Equation 2 (page 2-298 of the SFPA handbook 3rd ed.), the maximum possible fire size is estimated

$A := 1.55 \cdot A_s$	Equation 2
$A = 634\text{m}^2$	Maximum possible fire size

Parameters for calculating the fire charistics:

$\Delta h_c := 43.0 \cdot 10^6 \frac{\text{J}}{\text{kg}}$	The heat of combustion for the fuel
$\rho_{fuel} := 810\frac{\text{kg}}{\text{m}^3}$	Density of the fuel
$m_{burnratepool} := 0.054\frac{\text{kg}}{\text{m}^2 \cdot \text{s}}$	Maximum burning rate per unit area for JP5

The maximum mass burn rate per unit area for a spill fire is estimated to be one-fifth (page 2-311 of the SFPA handbook 3rd ed.) of the maximum pool burn rate per unit area, therefore the maximum burn rate per unit area for JP5 is

$m_{burnratespill} := 0.2 \cdot m_{burnratepool}$	Mass burn rate per unit area for a liquid fuel spill
$m_{burnratespill} = 0.011\frac{\text{kg}}{\text{m}^2\text{s}}$	Mass burn rate per unit area for JP5 in a liquid fuel spill

Table A5. Hand Calculations Associated with the 300-Gallon Fuel Pool Fire (Continued)

From the mass burn rate per unit area, the heat release rate is calculated

$Q_{rate} := m_{burnratespill} \cdot A \cdot \Delta h_c$	Heat release rate
$Q_{rate} = 294.3 \times 10^6\,W$	Heat release rate for JP5

Assuming that the fuel spill burns at the maximum rate for the duration of the fire the following equation is used

$t_f := \dfrac{V_{fuel} \cdot \rho_{fuel}}{m_{burnratespill} \cdot A}$	Fire duration
$t_f = 134\,s$	Fire duration for 300 gal of JP5

For FDS inputs the heat release rate per unit area (HRRPUA) and the equivalent area for a square (LW) must be calculated

$HRRPUA := \dfrac{Q_{rate}}{A}$	Heat release rate per unit area
$HRRPUA = 464.4\,\dfrac{kW}{m^2}$	Heat release rate per unit area for 300 gal of JP5
$LW := \sqrt{A}$	Length and width of an equivalent square
$LW = 25.2\,m$	Length and width of an equivalent square for a 300 gal spill

Table A6. FDS Input Data File for 300-Gallon JP5 Fuel Pool Fire

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&PDIM XBAR=35,YBAR=35,ZBAR=23 /
&TIME TWFIN=136. /

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REACTION='JP5',SMOKE3D=.TRUE.,BNDF_DEFAULT=.FALSE.,DTCORE=10.0/


/HEAT RELEASE RATE OF FIRE/
&SURF ID='FIRE',HRRPUA=464.4/

/Pool Fire/
&OBST XB=4.9,30.1,4.9,30.1,0.0,0.01,SURF_IDS='FIRE','INERT','INERT',
T_REMOVE=134.0,RGB=0.85,0.5,0.25/

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&THCP XYZ=31.1,17.5,0.4415,IOR=-1,QUANTITY='HEAT_FLUX',LABEL='HFlux 5'/
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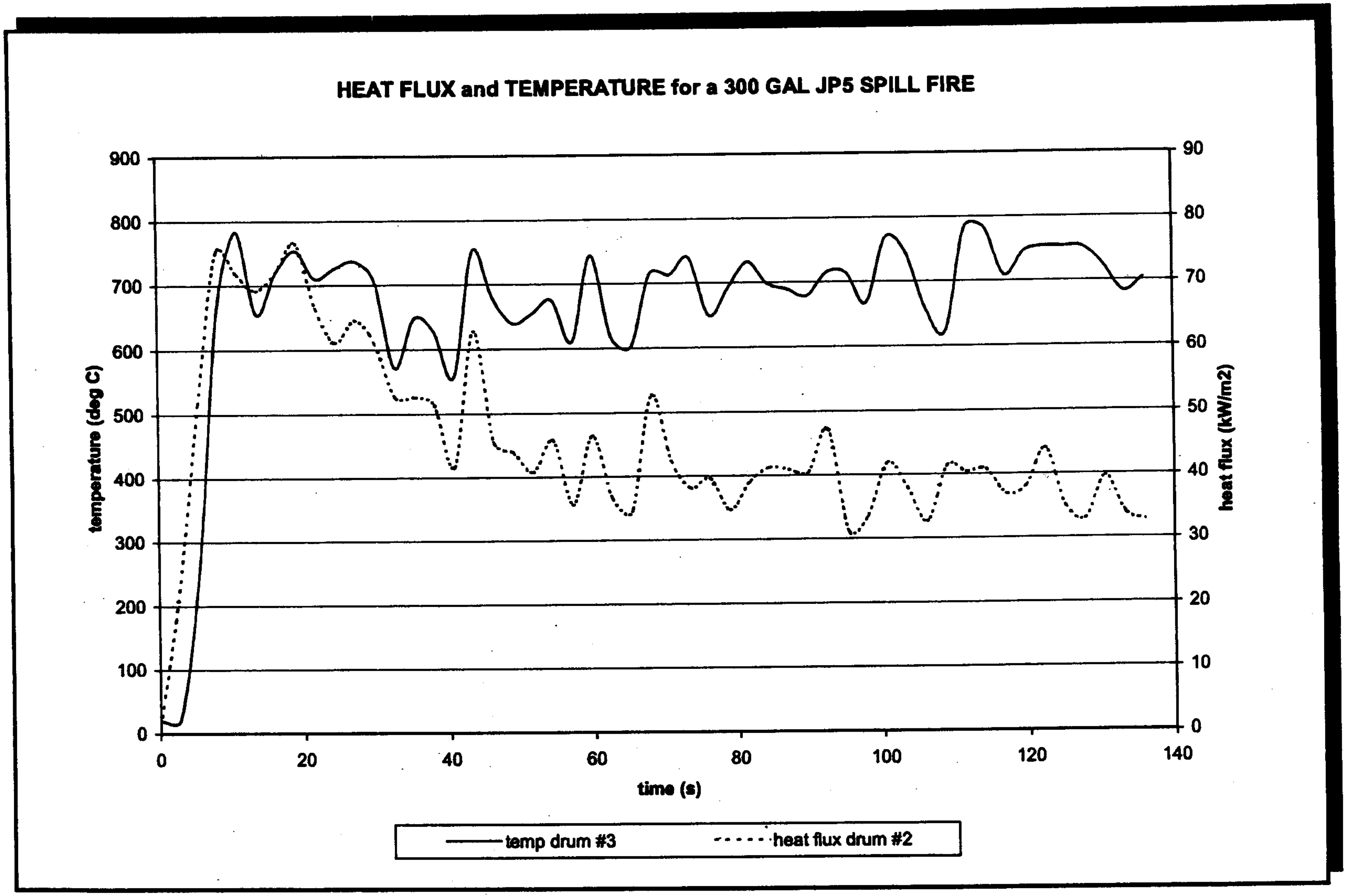

Figure A6. Maximum Temperatures and Heat Fluxes Associated with a 300-Gallon JP5 Fire

3.0 AIRPLANE IMPACTS

The Area G DSA accident analysis addresses an airplane crash that impacts the storage array.

Appendix 3E of the Area G DSA develops an estimate for the frequency of an airplane crash into the waste storage domes using the methodology of DOE-STD-3014-96. The analysis shows that, although the overall frequency of an airplane crash into a waste storage dome is greater than 1E-6 per yr, the frequency of a small airplane crash is much greater than the frequency of a crash of a larger airplane. The frequency of a crash of a general aviation (single engine) aircraft into a waste storage dome is on the order of 1E-5 per yr. For a commercial air taxi, the frequency is on the order of 1E-6 per yr. For a commercial airplane or large military aircraft, the frequency is on the order of 1E-8 per yr.

A crash of a commercial air taxi was selected as the evaluation basis accident (EBA) because it has the potential to result in consequences that are severer than those caused by a crash of a smaller airplane. A crash of larger aircraft has a *beyond extremely unlikely* frequency and is not considered an EBA.

The bounding crash scenario analyzed was that an air taxi crashes directly into the waste storage array in one dome. For the purpose of this Appendix, it was conservatively assumed that the array is composed of POCs only. In reality, the POCs are more likely to be interspersed among other drums, resulting in fewer POCs being impacted by the aircraft crash. The ensuing fire is evaluated in the fire section of this appendix.

The total aircraft crash frequency for a zone varied from 2.06E-6 to 3.35E-6 per yr, resulting in an overall frequency of 1.3E-5 per yr for all the storage domes. About 1/3 of this total frequency is from airport operations and 2/3 from non-airport operations. The frequency of a large airplane crash (commercial airplane or large military aircraft) into a waste storage dome is about 5E-8 per yr, a very small contributor to the overall frequency.

The frequency of an air taxi crash, the basis of this accident analysis, is about one order of magnitude less than that for a single-engine plane. However, its consequences are considered severer because the aircraft is larger. Although there was a commercial air taxi service to the Los Alamos Airport in the past, no such service is provided currently. This analysis assumes that this service will be reinstated in the future. The plane is assumed to be a twin turboprop that uses jet fuel. According to DOE-STD-3014, an average wingspan of an air taxi is considered 59 ft. Other aircraft parameters include a maximum take-off weight of 5000 kg, a maximum cruising speed of 180 kt, and a maximum fuel capacity of 300 gal (these parameters are from a DeHavilland Twin Otter). A smaller airplane found at the Los Alamos Airport is a Cessna Turbo Stationair, whose maximum landing weight is 1650 kg and wingspan 11 m. This aircraft was taken as the aircraft that represent general aviation aircrafts servicing to and from the Los Alamos Airport. This aircraft's fuel capacity is only 92 gal (rounded off to 100 gal). The insults to the POCs are, therefore, to be bounded by a crash of a DeHavilland Twin Otter.

3.1 PHENOMENOLOGICAL MODELS

3.1.1 Impact Model

The impact model conservatively assumes that all three levels of stacked drums are POCS and that the POCs will be impacted by the entire wingspan of the airplane. The airplane loses its speed as it penetrates the array, and delivers its momentum and a fraction of its kinetic energy into the array. The fractional amount is directly related to momentum considerations. The wings will likely shear upon impact, and the affected area and number of drums are expected to be less than that estimated by the following impact model. Therefore, this conservative model overestimates the number of drums that are impacted. As stated above, it is assumed that the aircraft directly impacts the drum array and potentially affects all 3000 drums. It is conservatively assumed that the drums in direct line of the aircraft crash are all POCs. In this analysis, the aircraft's energy/momentum is used to estimate the fraction of the array that is affected. As recommended in DOE-STD-3014, energy/momentum considerations are used to estimate the number of impacted/breached drums. The maximum energy available to breach the drums is the kinetic energy of the aircraft. This is conservatively maximized by assuming that the aircraft is fully fueled, at full takeoff weight, and impacts at a maximum cruising speed.

3.1.2 Energy Considerations

The POCs are designed to withstand the impact associated with a 9 m fall, which yields:

$$v_{impact} = \text{sqrt}\,(2gh) = \text{sqrt}\left[2\left(9.8\ \text{m/s}^2\right)\left(9\ \text{m}\right)\right] = 13.3\ \text{m/s}\ (29.7\ \text{mph})$$

where:

g = acceleration of gravity = 9.8 m/s^2
h = fall height = 9 m

Using this fall speed, the average energy of a falling POC (POC fail energy) is:

$$E_{Breach} = \frac{1}{2}m\left(v_{impact}\right)^2 = \frac{1}{2}\times 185\ \text{kg}\times\left(13.3\ \text{m/s}\right)^2 = 16{,}362\ \text{j}$$

Therefore, 16,362 j is the minimum amount of energy required to potentially breach a pipe. This energy is the energy corresponding to the drop test, which in reality does not represent the failure energy for the POCs. Since they not only survive such drop tests, but the actual failure energy is significantly larger (based on design philosophies for containers. Usually, a safety margin of 2 is used). Alternatively, it can be conservatively concluded that POCs that are accelerated through impact and subsequently achieve a speed of at least 13.3 m/s might potentially breach upon striking the ground or another hard solid object. In reality, the energy has to be greater to potentially cause a breach because the sealed source is protected by the pipe, the drum, and the fiberboard material. As indicated by the SNL test, the POCs can survive a 500 kg steel plate drop from 9 m (energy of about 44 kJ), with significant margin (no damage to POCs).

3.1.3 Momentum Considerations

An aircraft impacting into the drum array is considered to be an inelastic collision because, upon impact, the aircraft is expected to deform, break apart, and press into the array, as opposed to the aircraft bouncing off the array like a rubber ball or the array absorbing all of the impact energy. For this analysis, the array is considered consisting of POCs. As such, conservation of momentum requires that the initial momentum of the aircraft equal the final momentum of the aircraft plus that of the impacted POCs. This is expressed as:

$$m \times v_i = (m + M) \times v_f$$

where:

M = mass of POCs impacted

v_f = velocity of aircraft plus drums after impact

From this, the final velocity after the impact of the affected drum mass and aircraft is:

$$v_f = v_i \times m/(m + M)$$

For this analysis, the mass of the impacted POCs, M, is the mass of POCs that lie in front of the airplane's wings and is limited to those drums that form a solid cohesive mass (i.e., the mass against which the plane pushes). The entire mass in the array is not initially involved because the storage array is subdivided by spaces and a central aisle. Only a fraction of the array receives the initial impact. The array is 25 columns deep, and a 2-ft space is maintained between the columns. A central aisle runs down the length of the dome splitting the columns in two. The POC mass that is directly impacted (i.e., the solid cohesive fraction of the array) depends upon the angle of impact of the aircraft. Two angles of impact are considered: one resulting from the aircraft impacting the *end* of the array, and the other resulting from the aircraft impacting the *side* of the array.

3.2 THE AIRCRAFT IMPACTS THE END OF THE ARRAY

This scenario assumes that the aircraft impacts the end (short side) of the array. The initial impact is received by those POCs lying in the first (front) row in the path of the aircraft wingspan. From this angle, the solid cohesive mass impacted is a single row of POCs. Because the wingspan is greater than the width of a row, the entire first row is involved in the initial impact. This scenario is modeled as a series of successive independent collisions. It begins with the aircraft impacting the first row of POCs and ends with the speed of the aircraft plus impacted drums slowing down sufficiently to be considered stopped. In theory, there is always some residual speed regardless of the size of the impacted mass. Therefore, a threshold speed of 13.3 m/s (test speed) below which further damage to drums is not expected is applied.

Each storage array row contains ten 3-tier pallets, or a total of 120 drums (see Figure A7). The total mass of drums in the row is 2.2E4 kg, which assumes a single POC mass of 185 kg (maximum allowable 85-gal drum weight at Area G). The mass of the aircraft is assumed to be the maximum takeoff weight.

The air taxi parameters used are for a DeHavilland Twin Otter having a maximum takeoff weight of 5000 kg and a maximum cruising speed of 180 knots (93 m/s). For conservatism, an impact airspeed of 100 m/s is used to maximize the available energy. After impacting the first row, the resultant speed of the combination of the aircraft and first row drums is:

$$v_f = v_i \times m/(m + M) = 100 \text{ m/s} \times 5\text{E}3 \text{ kg}/(5\text{E}3 \text{ kg} + 2.2\text{E}4 \text{ kg}) = 18.5 \text{ m/s}$$

This speed is greater than the threshold speed of 13.3 m/s, and the crash penetrates the first row of POCs and impacts the second row of POCs. That is, the mass of first row of drums plus aircraft are assumed to impact the second row with a speed of 18.5 m/s. Following the second row impact, the resulting speed of two rows (240 drums) and aircraft further decreases to:

$$\begin{aligned} v_f &= v_i \times m/(m+M) \\ &= 18.5 \text{ m/s} \times (5\text{E}3 + 2.2\text{E}4 \text{ kg})/(5\text{E}3 \text{ kg} + 2.2\text{E}4 \text{ kg} + 2.2\text{E}4 \text{ kg}) \\ &= 10.2 \text{ m/s} \end{aligned}$$

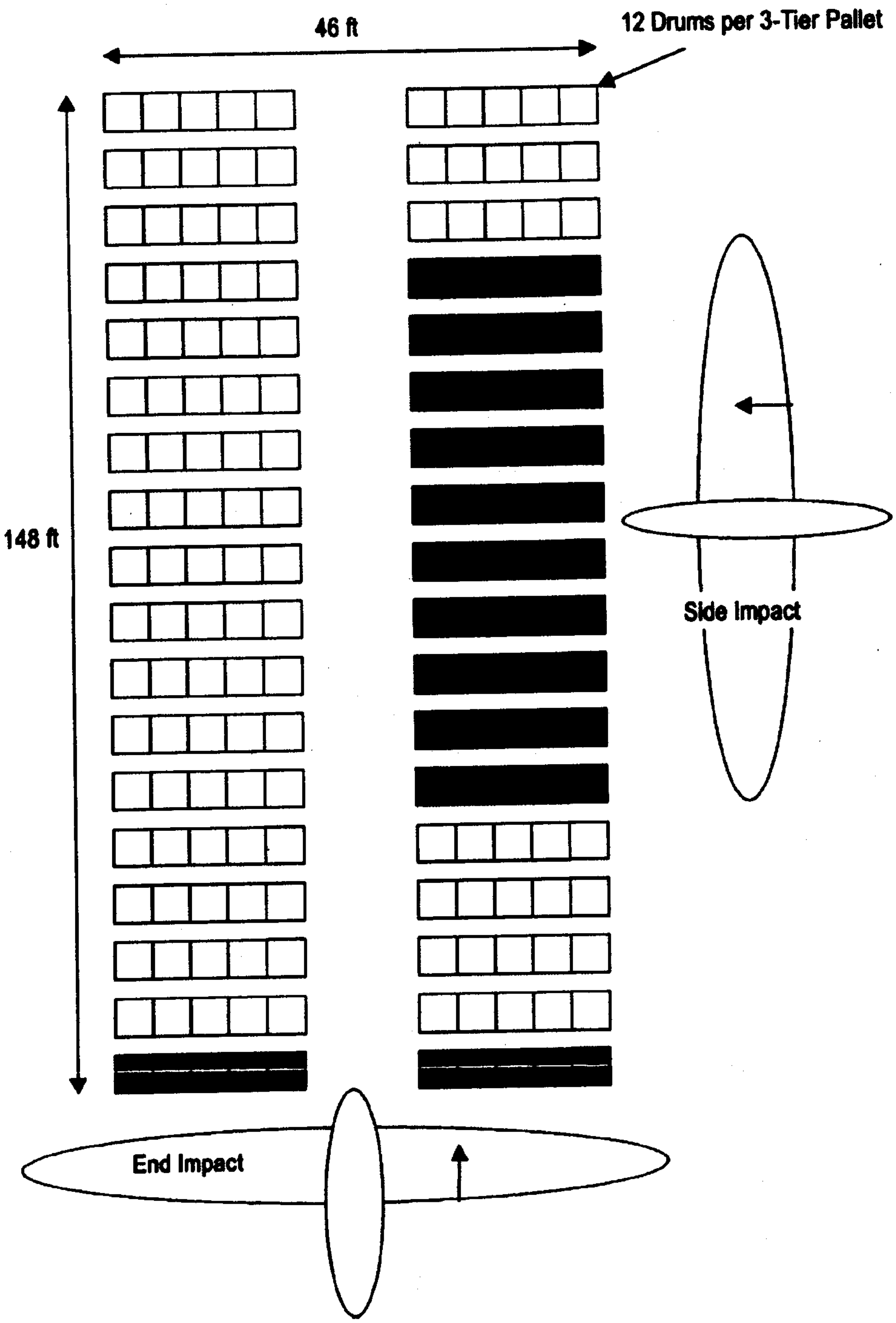

Figure A7. Aircraft Impact Accident Depiction (not to scale)

As shown in the above equation, the impacting mass, m, is now the mass of the aircraft and one row of POCs. The total mass, m + M, is the mass of the aircraft plus two rows of drums. The resulting speed after the impact is now smaller than the drum breach speed of 13.3 m/s. It is assumed that the third row is not penetrated.

Based on the above, a total of two rows containing 240 POCs are within the impact area. However, only a fraction of the POCs within the impact area will be breached. The energy and acceleration received by the drums during the impact varies from drum to drum, depending on the initial position in the array and a complicated set of action-reaction events that eventually unfold. Many of the drums initially impacted by the aircraft will receive considerably more energy than that required to breach them. Many other affected drums will receive insufficient energy to be breached, resulting in minor dents/damage with no major consequences. Consistent with the Area G DSA, it is assumed that one-half (120) of the POCs in the impact area are energetically breached. Of those POCs breached, it is estimated that only 10% of the sealed sources within the POCs are assumed to be breached. This corresponds to 5% of the sealed sources in POCs in the original impact area.

3.3 THE AIRCRAFT IMPACTS THE SIDE OF THE ARRAY

This scenario assumes that the aircraft impacts the long side of the array. As before, the impacted drums are those drums lying in front of the aircraft wingspan, extending from the edge of the array to the central aisle. These are the drums that form a cohesive mass against which the aircraft pushes upon impact. Given that the wingspan is 59 ft, the impact area includes 10 columns and 9 spaces totaling 58 ft (40 ft and 18 ft, respectively). A total of 50, 3-tier pallets of drums (12 drums/3-tier pallet × 50 = 600 drums) are within the impact area.

The mass of the impacted drums is 1.1E5 kg assuming an average drum mass of 185 kg (maximum allowable 85-gal drum weight at Area G). The mass of the aircraft is assumed to be 5E3 kg. From the above discussion, the speed of the aircraft and impacted drum mass combined after the impact is:

$$v_f = v_i \text{ x } m/(m+M) = 100 \text{ m/s} \times 5\text{E}3 \text{ kg}/(5\text{E}3 \text{ kg} + 1.1\text{E}5 \text{ kg}) = 4.3 \text{ m/s}$$

where v_i is the initial speed of the aircraft. Therefore, the result of impacting 600 drums reduces the combined speed of the aircraft plus drums to 4.3 m/s. The resultant speed is less than the drum breach speed of 13.3 m/s. It can be concluded that the initial impact with 600 drums will stop the aircraft. There will be no further collision or penetration.

In addition, only a fraction of the POCs within the impact area will be breached. It is assumed that one-half (300) of the POCs in the impact area will be energetically breached. Of those POCs breached, it is estimated that only 10% of the sealed sources in POCs are assumed to be breached. This corresponds to 5% of the sealed sources in POCs in the original impact area.

4.0 VEHICLE IMPACT SCENARIO

A vehicle is postulated to impact the array of POCs. The vehicle is a flatbed stake truck with a gross vehicle weight rating of approximately 28,800 lbs (13,063 kg) and a 26 ft long bed. It is assumed that this truck is loaded to its maximum capacity and traveling at 25 mph (11.2 m/s) when it strikes the POCs. Based on the dimensions of the front of the vehicle and the storage array, the impact area can only be 2 pallets wide and 2 drums high, resulting in a total of 16 POCs being actually impacted. The third (top) tier of drums will not be impacted; rather, these drums are expected to be expelled. The weight of the impacted POCs is estimated to be 2960 kg. Utilizing the same methodology as above, the v_f will be:

$$v_f = v_i \times m/(m+M) = 11.2 \text{ m/s} \times 1.3E4 \text{ kg}/(1.3E4 \text{ kg} + 2.96E3 \text{ kg}) = 9.1 \text{ m/s}$$

The resulting speed of the truck is smaller than the 13.3 m/s POC breach speed; therefore, only 16 POCs that receive the initial impact will be breached; the remaining POCs will not be breached.

As described above, it is conservatively assumed that one-half of the POCs in the impact area are considered energetically breached. Of those POCs, it is estimated that only 10% of the sealed sources within the POCs are assumed to be breached. This corresponds to 5% of the sealed sources in POCs in the original impact area, resulting in a DR of 5%.

5.0 CONSEQUENCES

In order to calculate potential consequences associated with accidents involving OSRP sealed sources stored aboveground in POCs, the maximum inventory of POCs aboveground at Area G is assumed to be 30,000 PE-Ci. In this analysis it is assumed that the damage ratio is 5% (as established above). Should the damage ratio increase, the doses will be increased accordingly, as the doses are directly scalable with respect to the damage ratio.

The ARF/RF values chosen for the POCs are those associated with sintered, composite solids (dispersible non-combustible materials). This is a conservative assumption since the majority of sealed sources at Area G are more than likely of metallic composition.

5.1 Aircraft Impact

As stated above, an aircraft impact could result in a fire or mechanical impact. Further, it is assumed for conservatism that the entire sealed source MAR of 30,000 PE-Ci is in a single dome and is thus available to the airplane impact. Based on this assumption, and on the material form and previously identified DR, Table A7 establishes the source terms for both the spill and fire components.

Table A7. Aircraft Impact Source Term Derivation

Directly Impacted POCs						
Release Component	**MAR (PE-Ci)**	**DR**	**ARF**	**RF**	**LPF**	**ST (PE-Ci)**
Impact	30,000	0.05	1E-3[1]	0.3[1]	1.0	0.45
Fire	30,000	0.05	6E-3[2]	1E-2[2]	1.0	.009

1. The ARF and RF were taken from Table 3-38 of the TA-54, Area G DSA for dispersible non-combustible material
2. The ARF and RF were taken from DOE-HDBK-3010-94, Change Notice 1, Page 4-61, for solids, powders.

Table A8 below presents the dose calculations for this scenario.

Table A8. Aircraft Impact Dose Calculations

Directly Impacted POCs			
Release Component	ST (PE-Ci)	Dose-to-source ratio (Rem/PE-Ci)1	Doses (Rem)
Impact	0.45	84.0	37.8
Fire	0.009	28.8	0.26
		Total	38.06

1. These values were taken from Table 3-24 of the TA-54, Area G DSA for non-buoyant releases and for 0.10 MW buoyant releases. Selection of the 0.1 MW fire introduces additional conservatism as it is the largest dose-to-source ratio.

As shown above, the dose associated with an airplane crash impacting sealed sources at Area G result in a dose of approximately 40 rem to the public. This dose, although exceeding the EG of 25 rem, is much less than the doses evaluated in the Area G DSA for an airplane crash, which range from 263 rem to 1795 rem. Thus, the doses associated with the sealed sources in POCs will represent less than one percent of the maximum dose for a similar scenario at Area G.

5.2 Truck Impact

It was shown in the analysis above that the truck can, at most, impact 16 POCs. If each POC contains 110 PE-Ci (the maximum amount a POC is currently loaded), the material at risk for this scenario is:

(16 POCs) (110 PE-Ci/POC) = 1,760 PE-Ci

Note that this amount exceeds the single truck limit at Area G; however, for conservatism this larger amount will be evaluated. Based on this assumption, and on the material form and previously identified DR, Table A9 establishes the source terms for both the spill and fire components.

Table A9. Vehicle Impact Source Term Derivation

Directly Impacted POCs						
Release Component	MAR (PE-Ci)	DR	ARF	RF	LPF	ST (PE-Ci)
Impact	1,760	.05	1E-3[1]	0.3[1]	1.0	0.026
Fire	1,760	.05	6E-3[2]	1E-2[2]	1.0	0.005

1. The values for the ARF and RF were taken from Table 3-38 of the TA-54, Area G DSA for dispersible non-combustible material.
2. The values for the ARF and RF values were taken from DOE-HDBK-3010-94, Change Notice 1, Page 4-61, for solids, powders.

Table A10 below presents the dose calculations for this scenario.

Table A10. Vehicle Impact Dose Calculations

Directly Impacted POCs			
Release Component	ST (PE-Ci)	Dose-to-source ratio (Rem/PE-Ci)1	Doses (Rem)
Impact	0.026	84.0	2.18
Fire	0.005	28.8	0.14
		Total	2.32

1. These values were taken from Table 3-24 of the TA-54, Area G DSA for non-buoyant releases and for 0.10 MW buoyant releases. Selection of the 0.1 MW fire introduces additional conservatism as it is the value with the largest dose-to-source ratio.

As shown above, the dose associated with a vehicle crash impacting sealed sources at Area G result in a dose of less than 5 rem to the public. As with the airplane crash scenario, this dose is much less than the doses evaluated in the Area G DSA for a vehicle crash, which range from 62 rem to 192 rem. Thus, the doses associated with the sealed sources in POCs will represent less than one percent of the maximum dose for a similar scenario at Area G.

6.0 CONCLUSIONS

An analysis was performed using FDS to investigate the fire hazards associated with the ignition of an instantaneous spill of 50 gal of gasoline, and of 100 gal and 300 gal of JP5 aviation fuel. The POCs are expected to survive the thermal insults associated with these three fuel fires. These results are consistent with the tests performed by SNL on POCs that demonstrated that the POCs are capable of withstanding temperatures of between 800 °C and 1100 °C for 30 min.

With respect to the mechanical impacts (for both vehicles and airplanes), based on conservation of momentum, the analysis shows that 240 POCs are in the impact area when an airplane impacts the end of the storage array, 600 POCs are in the impact area when an airplane impacts the side of the storage array, and 16 POCs are in the impact area when a vehicle impacts a storage array. For the purpose of this analysis, however, it was conjectured that the airplane is capable of impacting the entire dome inventory, while the truck can at most impact 16 POCs. It is important to note that the 600 POCs involved in the aircraft side impact could not all be loaded to 110 PE-Ci per POCs without violating the dome inventory of 50,000 PE-Ci limit as well as the stipulation that all POCs not be stored or staged within a single dome. However, in all of these cases, it is conjectured that the majority of the impact energy would be dissipated on contact, and that no more than 5% of the sealed sources in the POCs will be breached. It is also important to note that the consequences associated with these scenarios are considerably smaller than those associated with the same scenarios impacting waste drums evaluated in Area G.

7.0 REFERENCES

D. J. Ammerman, J. G. Bobbe, and M. Arviso, *Testing in Support of On-Site Storage of Residues in the Pipe Overpack Container*, Sandia National Laboratories, SAND97-0368, TTC-1476, February 1997.

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INTERIM CHANGE NOTICE

>>>Team Leader or Line Manager must notify the Training Coordinator of this ICN Change within TWO DAYS of its authorization.<<

ICN (to document below) No.

1. Process Owner

Document No.: TD-SWO-012 R.0.1__ (Current Revision)	**Process Owner: M Waller**	**Document Preparer: Mitch Waller**
Document Title: Evaluation of OSRP Sealed Sources at TA-54, Area G		**Today's Date:** 1 / 5 / 05

Proposed Changes:

Page	**Section**	**Change** **Attach document with requested page change(s)**	**Justification**
3/ 4/ 21	1/2/5	Change text from "excluding MAR"	NNSA direction

Process-related questions:

Is the change solely related to Area L, being non-nuclear in nature, with sufficient separation? Yes ☐ No ☒

If the answer to the question above is "Yes", Section 3 doesn't apply, because the processes are not related in any way to a change affecting any active Documented Safety Analysis (DSA).

Please check the box(s) for facility(ies) in which change is to occur: AREA G ☒ RLW ☐ RANT ☐ WCRR ☐ TWISP ☐

2. Team Leader

Team Leader Approval--Name (print) J. Minton-Hughes *Signature* *Date* 1 / 6 / 2005 ☐ Stop Work

3. USQ Applicability assessment (Reproduced Verbatim from OST 300-00-06B, R.3)

SECTION 1 [from OST 300-00-06B, Rev. 3]

a. Is this a replacement of equipment with an exact replacement? [8.2.1.a] Yes ☐ No ☒

b. Is this replacement of equipment with an approved equivalent part? [8.2.1b]
If yes, identify the supporting engineering analysis which provides the equivalency determination. Yes ☐ No ☒
Document No.: __________
Document Title: __________

c. Is this an SSC restoration to the existing design not in conflict with the existing approved DSA? [8.2.1.c] Yes ☐ No ☒

d. Is this simply an editorial change to a procedure or document? [8.2.1.d] Yes ☒ No ☐

If the answer to any of the questions in Section 1 is "Yes", the USQ screening and determination steps DOES NOT apply and NNSA review and approval is NOT REQUIRED; proceed to the applicability assessment summary. Otherwise, continue with SECTION 2 of OST 300-00-06B, Rev. 3, Applicability Assessment].

Does document change enter USQ process? ☐ **Yes** ☒ **No** *If NO, sign and date below* *If YES, sign, date, and report results below*

USQ Applicability Assessor or USQ Qualified Evaluator (QEV) Name (print) M. Waller *Signature* *Date* 1 / 6 / 05

Result of USQ process: ☐ USQS–Screened Out ☐ USQD–Negative ☐ USQD–Positive USQD No.

STOP: IF THE USQD IS POSITIVE, DOE APPROVAL IS REQUIRED FOR THIS DOCUMENT ACTION.

4. QA

Document meets QA standards ☒ Yes Comments:

QA Name (print) Manuel Martinez *Signature* *Date* 1 / 7 / 05

5. Group Leader

Group Leader Name (print) Gilbert Montoya. *Signature* *Date* 1 / 6 / 05

6. DM

a. ICN received and processed:	Yvette Branch	1 / 13 / 05
b. Changes made to electronic copy and posted with signed ICN:	Yvette Branch	1 / 13 / 05
	Signature	*Date*