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# Fire Analysis of the Shielded Container For the Waste Isolation Pilot Plant Carlsbad, New Mexico

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## Executive Summary

Transuranic waste is currently shipped to the WIPP from the U.S. Department of Energy generator sites. The contact-handled (CH) waste containers currently approved for disposal at WIPP include 55-gallon drums, 85-gallon drums, 100-gallon drums; standard waste boxes (SWBs); ten drum overpacks (TDOPs); and pipe configurations overpacked in 55-gallon drums (pipe overpack or POC). This evaluation focuses on the shielded container, a lead-lined 55-gallon drum, which is to be emplaced in the CH disposal array in 3-packs. The shielded container is proposed as an alternative to disposal of remote-handled (RH) waste in canisters in the walls of the disposal rooms. TRU waste that emits significant radiation (mostly gamma radiation) can be packaged within the lead shielded containers and the surface dose rate is reduced to levels for safe handling as a CH container. The shielded container will be shipped to WIPP in the Half-package Transporter (HalfPACT) transportation packages.

This paper documents a fire protection engineering analysis of the ability of the proposed shielded container to withstand postulated fires at the WIPP facility. The shielded container is compared, in some aspects, to a standard, 55-gallon TRU waste drum, and in other aspects, to a pipe overpack container (POC) as certain attributes of each of these known TRU waste container configurations are similar to attributes of the shielded container. Then, based on known fire-induced failure mechanisms of the standard TRU waste drum and POC, appropriate damage ratios and release estimate factors are derived for postulated fires involving the shielded container. It is anticipated that these damage ratios and release estimate factors will be used in subsequent safety analyses to evaluate potential releases from the lead shielded container.

This analysis focuses on two types of fires: (i) a fully engulfing pool fire, and (ii) a nearby pool or ordinary combustible exposure fire. This is appropriate because these types of fires provide the greatest thermal stress or the most uneven thermal stress on the shielded container, respectively. Shielded containers exposed to short-duration, fully engulfing pool fires are expected to have no release due to the uniform heating and the space available for thermal expansion of the outer container's lead lining. A short duration pool fire is defined as having a depth of 6.4 mm, or less, and lasting for about 2.5 minutes. Shielded containers exposed to nearby pool or ordinary combustible fires could experience uneven heating of the lead lining along with weakening of the outer container shell resulting ultimately, in breach of the container outer shell, and loss of lead lining through flow of melted lead through the breach. Shielded containers involved in a long-duration, fully engulfing pool fire could be breached in a similar manner. And, shielded containers which experience impact followed by fire would be expected to have the same consequences. A reasonable estimate of the release fraction (ARF x RF)[i] is 6.1E-08. This value should be used in safety analysis calculations for long duration, fully engulfing pool fires, exposure fires, and all fires preceded by impact to the shielded container.

A damage ratio (DR) of 0.5 should be applied to arrays of 10 or more shielded containers involved in an exposure or fully engulfing pool fire. A DR of 1.0 should be applied to arrays of less than 10 shielded containers

A summary of the shielded container's expected response to the various types of thermal insult postulated in this analysis is provided in Table 7-2 on page 25.

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[i] Airborne Release Fraction (ARF), Respirable Fraction (RF) and Damage Ratio (DR) values are used in safety analysis calculations to estimate the portions of involved radiological material that may be transported in air, inhaled, or impacted by accident-generated conditions, respectively ; see DOE-HDBK-3010-94 [19].

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## List of Acronyms

| | |
|---|---|
| ARF | airborne release fraction |
| Btu/lb | British thermal unit per pound |
| Btu/lb-ºF | British thermal unit per pound degree Fahrenheit |
| CFR | Code of Federal Regulations |
| CH | contact-handled |
| $cm^3/s$ | cubic centimeters per second |
| DOE | U.S. Department of Energy |
| DOT | U.S. Department of Transportation |
| DR | damage ratio |
| EPA | U.S. Environmental Protection Agency |
| FHA | fire hazards analysis |
| HalfPACT | half-package transporter |
| hr | hour |
| HRR | heat release rate |
| in | inch |
| $in^3$ | cubic inches |
| kPa | kilo-pascals |
| kW/hr | kilowatts per hour |
| $kW/m^2$ | kilowatts per square meter |
| $kW\text{-}hr/m^2$ | kilowatt-hours per square meter |
| lbm | pound (mass) |
| $lb/in^3$ | pounds per cubic inch |
| MgO | magnesium oxide |
| m | meter |
| min | minute |
| mm | millimeter |
| mm/min | millimeters per minute |
| mrem/hr | millirem per hour |
| NaCl | sodium chloride |
| POC | pipe overpack |
| Pu | plutonium |
| $PuO_2$ | plutonium oxide |
| rem/hr | rem per hour |
| RF | respirable fraction |
| RH | remote-handled |
| SCA | shielded container assembly |
| SWB | standard waste box |
| SwRI | Southwest Research Institute |
| TDOP | ten-drum overpack |
| TRU | transuranic (waste) |
| TRUDOCK | transuranic dock |
| TRUPACT | transuranic transporter |
| WAC | waste acceptance criteria |
| WHB | Waste Handling Building |
| WIPP | Waste Isolation Pilot Plant |
| WIPP WAC | *Transuranic Waste Acceptance Criteria for the Waste Isolation Pilot Plant* |
| WTS | Washington TRU Solutions LLC |
| ºF | degrees Fahrenheit |

## 1.0 INTRODUCTION

The Shielded Container Assembly (SCA) is proposed as an alternative for the disposal of remote-handled (RH) waste in canisters in the walls of the disposal rooms. The shielded container will contain RH waste but the shielding reduces the dose rate such that the container can be contact-handled (CH). The shielded container is shipped to the WIPP site from U.S. Department of Energy (DOE) generator sites in the Half-package Transporter (HalfPACT) transportation package.

The WIPP Fire Hazards Analysis (FHA, reference 1) evaluates receipt and storage operations associated with CH waste in TRU waste storage drums that are received in TRUPACT or HalfPACT shipping containers. The HalfPACT containers can carry one 7-pack drum assembly consisting of seven (7) 55 gallon drums banded together with shrink wrap or banding, one standard waste box (SWB), one pipe overpack (POC), one 3-pack drum assembly of 100 gallon drums, one 4-pack drum assembly of 85 gallon drums, or when approved for use, one 3-pack drum assembly of shielded containers.

This report evaluates the shielded containers as they could be involved in fire events postulated and analyzed in the FHA and determines the likely potential damage based on those of similar containers already documented.

## 2.0 INPUT

| Input | Property | Value | Units | Reference | Notes |
|---|---|---|---|---|---|
| 1. | Latent Heat of Fusion of Lead | 10.4 | Btu/lb | 5 | |
| 2. | Melting Point of Lead | 621.3 | ºF | 5 | |
| 3. | Specific Heat Capacity of Lead | 0.031<br>0.035 | Btu/lb-ºF | 5<br>5 | @77ºF<br>@621ºF (max) |
| 4. | Regression rate of diesel fuel | 0.039 | $kg/m^2$-s | 10,<br>Input 4.1 | Rate that fuel pool depth decreases during free-burning fire |
| 5. | Density of diesel fuel | 977 | $kg/m^3$ | 10,<br>Input 4.1 | |
| 6. | Height of Lead Liner | 32.718 | In | 3 | |

## 3.0 FACILITY AND PROCESS DESCRIPTION

The WIPP is located in southeastern New Mexico, 26 miles east of Carlsbad. This site is owned by the DOE and operated by the Washington TRU Solutions LLC (WTS). The purpose of the WIPP facility is to serve as a final repository for transuranic (TRU) waste generated at other DOE sites and to demonstrate the feasibility of safe disposal of radioactive wastes in deep underground salt formations. Plutonium (Pu) is the primary TRU isotope within the majority of waste to be disposed of at the WIPP.

Note: The WIPP facility and process descriptions in this evaluation represent the conditions currently anticipated at the facility during shielded container handling operations, and are provided as background information. This analysis focuses on the shielded container's expected response to varying thermal insults (fires) and is therefore irrespective of the facility design or waste handling practices, except as they relate to ensuring the full range of postulated fire events is considered.

Two categories of waste, CH and RH, are approved for disposal at the WIPP. Contact-handled waste containers have surface radiation levels of less than 200 millirem/hr (mrem/hr) and are handled directly by human operators. Remote-handled waste containers have surface radiation levels of 200 mrem/hr and up to 1,000 rem/hr. All waste received for placement in the WIPP facility must conform to the WIPP waste acceptance criteria (WAC)[2]. The WAC prohibits both pyrophoric and compressed gas containers in the waste and limits the amount of liquids. All waste containers disposed of at WIPP are also required [16] to be made of metal with installed vents.

Transporters carrying TRU waste arrive at the WIPP and are parked on the south side of the Waste Handling Building (WHB). After the CH TRU shipping package is inspected for contamination, the loaded shipping package is moved into the WHB. The WHB has two TRUDOCKs and four overhead cranes for opening and unloading the HalfPACT shipping packages. Each TRUDOCK is designed to handle up to two HalfPACTs. The CH bay provides space for transferring loaded facility pallets to the waste hoist via forklifts, a shielded holding area, a waste handling equipment battery recharge area, and temporary storage areas for waste containers.

Once at the TRUDOCKs, the shipping packages are opened and surveyed for radiation and contamination levels. Then the waste containers are removed and placed on a facility pallet. Figure 3-1 shows a 3-pack of shielded containers and a 7-pack of 55-gallon drums loaded onto a facility pallet for transport in the underground. This figure also illustrates the use of slipsheets. The 0.15-inch-thick polyethylene slipsheet is used to provide a mechanism for sliding the waste container(s) off the facility pallet and into a disposal location. The reinforcement plate shown in Figure 3-1 is a second polyethylene sheet. A facility pallet can hold up to four drum assemblies; but the shielded container assemblies are only stacked one high to ensure a stable configuration and because of weight limitations. The facility pallet is either transferred to the conveyance loading car, which is moved into the hoist cage for transfer to the underground repository for permanent disposal, or is temporarily stored in the WHB in a designated area for future transfer to the underground repository.

The WIPP underground disposal repository consists of eight panels and two panel equivalents mined from the Salado formation, a 2,000-foot-thick series of salt beds [approximately 95% sodium chloride (NaCl)]. The disposal level lies 2,150 feet below the surface, a little below the middle of the Salado formation. A typical underground panel contains seven rooms, each of which is 300 feet long, 33 feet wide and 13 feet high. The access drifts connect the rooms in a panel and provide an additional length of 33 feet on each end of the room for drum storage. A magnesium oxide (MgO) backfill is used in the WIPP to reduce actinide solubility in the unlikely event the facility is flooded. A “super sack” of MgO is placed on top of the waste container stack. The super sack of MgO per waste column consumes the carbon dioxide produced from microbial consumption of the cellulose, plastic, and rubber contained in the waste.

Underground waste is emplaced in a pattern designed so that 7-packs of 55-gallon drums, four-packs of 85-gallon drums, and 3-packs of 100-gallon drums all occupy the same “footprint.” A closely-packed hexagonal lattice is achieved for a 7-pack. 3-packs of shielded containers are smaller than this footprint and two 3-packs may be placed side by side in the footprint of a 7-

pack. The 3-packs may be stacked two high (one 3-pack on top of another 3-pack) with a super sack on top of the second tier in lieu of any other waste container on the third tier. More likely though, a single 3-pack will be placed on the top of other waste assemblies as the third tier.

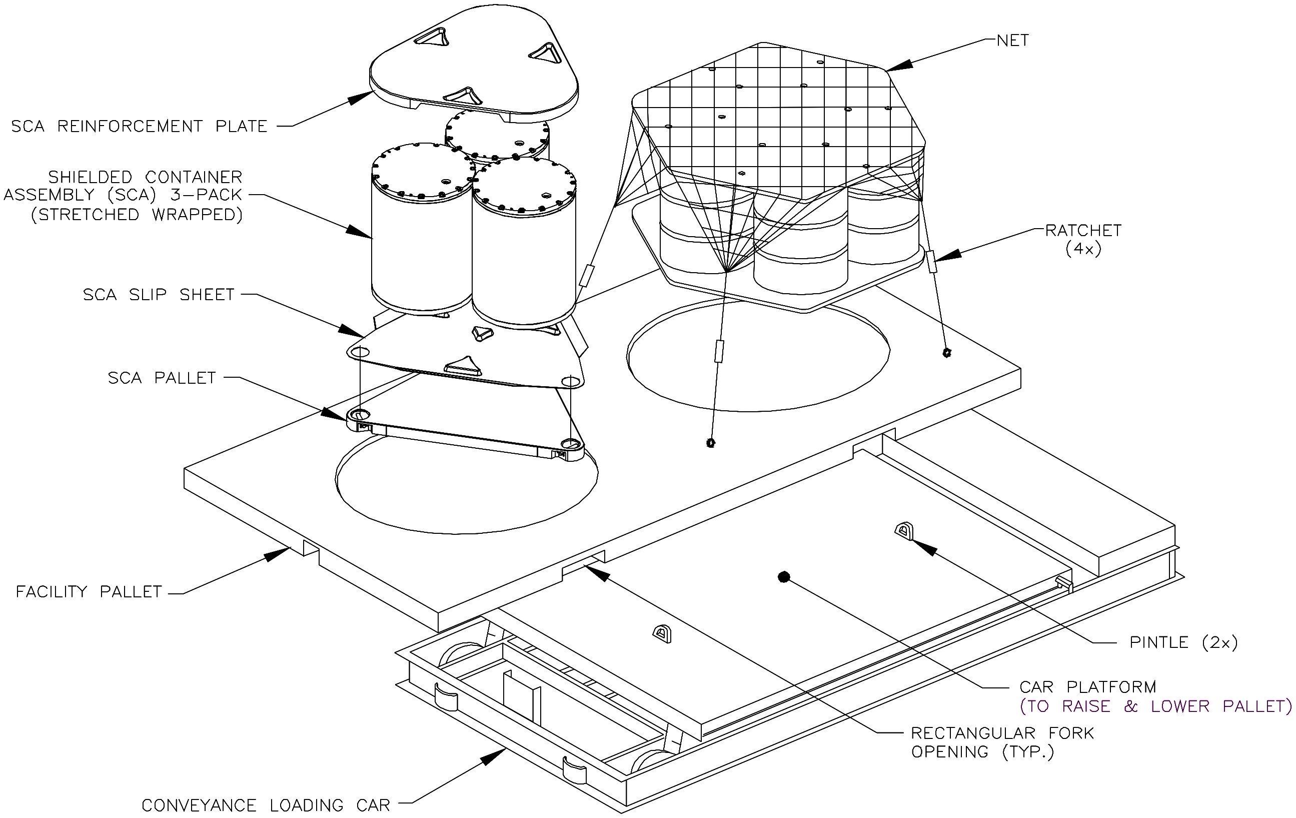

**Figure 3-1, Exploded View of a 3-Pack Shielded Container Drum Assembly and a 7-Pack 55 gallon Drum Assembly on a Facility Pallet**

## 4.0 DESCRIPTION OF SHIELDED CONTAINERS

The shielded container proposed for future RH waste shipments to WIPP is comparable in size, having approximately the same exterior dimensions, to a 55-gallon TRU waste drum. The shielded container however, is designed to carry one 30-gallon vented payload drum, and the cylindrical sidewall of the shielded container has nominal 1-inch-thick lead shielding sandwiched within a double-walled steel shell, as shown in Figure 4-1 and Figure 4-2. The external shell wall is 11 gauge steel and the internal shell wall is 7 gauge steel. The lid and the bottom of the container are made of carbon steel and are approximately 3 inches thick. The container has been tested to DOT Type 7A specifications [7], which will ensure that the container is robust. Type 7A containers must be subjected to test which simulate hypothetical accident conditions for heavy rain (water spray), impacts (drop, puncture), and compression (stacking). These containers are not tested for hypothetical fire conditions.

A comparison of the shielded container and a standard 55-gallon TRU waste drum (hereafter referred to as simply a TRU waste drum) dimensions is summarized in Table 4-1 [3].

**Table 4-1, Comparison of the Dimensions of a Shielded Container and a 55-gallon TRU Waste Drum***

| Dimension | 55-gallon Drums | | Shielded Container | |
|---|---|---|---|---|
| | (in.) | (cm) | (in.) | (cm) |
| Inner Height | 33.25 | 84.455 | 29.688 | 75.4063 |
| Inner Diameter | 22.5 | 57.15 | 20.446 | 51.9328 |
| Inner Steel Wall Thickness | N/A | N/A | 0.171 | 0.4343 |
| Lead Wall Thickness | N/A | N/A | 1.044 | 2.6518 |
| Outer Steel Wall Thickness | 0.0478 | 0.12141 | 0.112 | 0.2845 |
| Outer Diameter | 22.5956 | 57.3928 | 23.056 | 58.5622 |
| Lid/Bottom Thickness | 0.0478 | 0.12141 | 3.030 | 7.6962 |

* includes dimensional tolerances from reference 3.

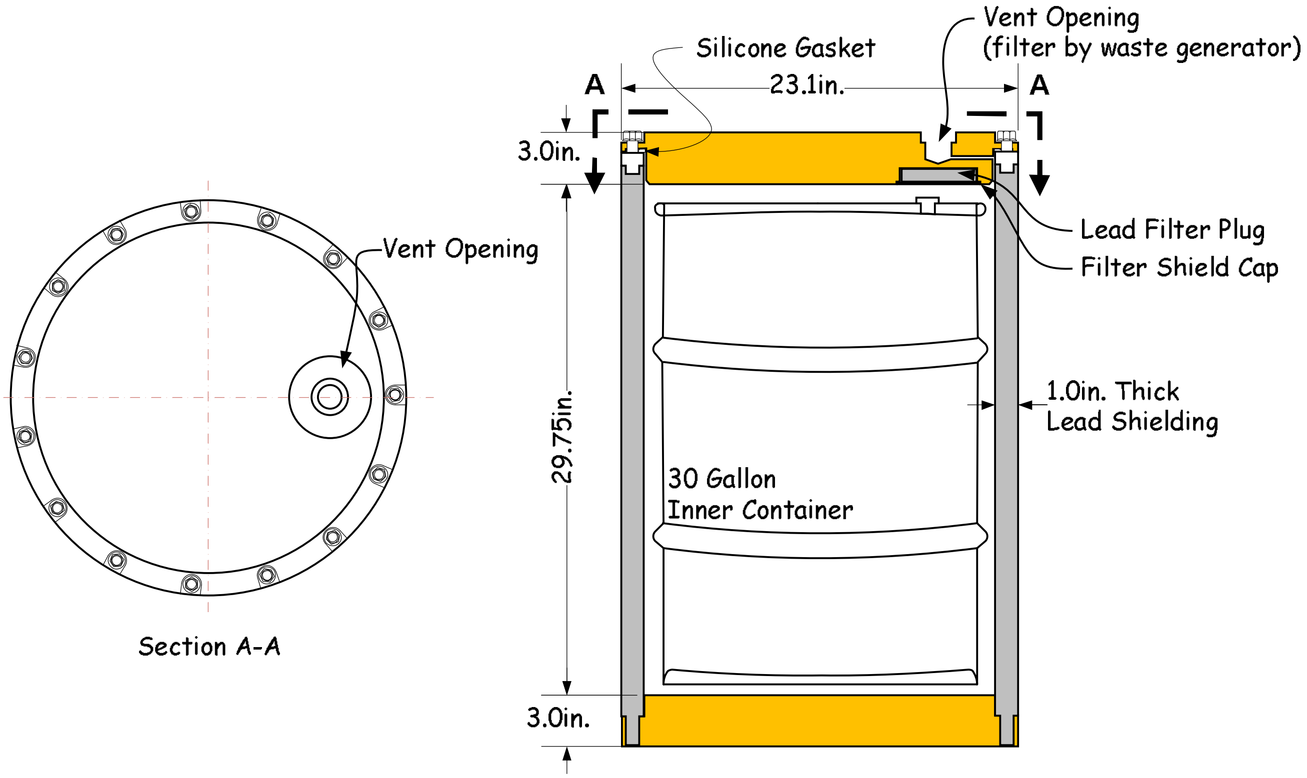

**Figure 4-1, Shielded Container Diagram**

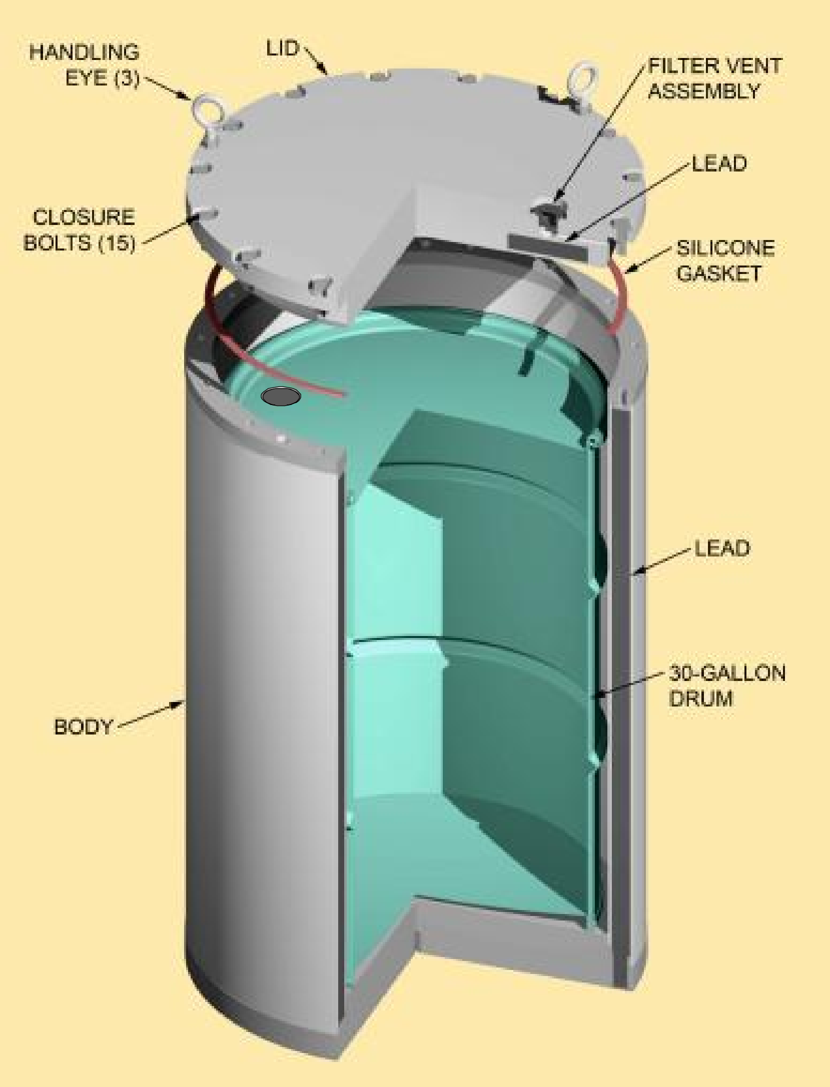

**Figure 4-2, Shielded Container Cut-Away Diagram**

## 5.0 COMPARISON OF ATTRIBUTES AFFECTING FIRE PERFORMANCE

Data are not available on which to directly base estimates of the performance capabilities of the shielded container exposed to fire conditions. However, the design and construction of the shielded container is similar to some of the physical attributes of other TRU waste containers that have been exposed to fire testing. Specifically, certain attributes of the shielded container are very much like certain attributes of both the TRU waste drum (Figure 5-1) and pipe overpack (POC, Figure 5-2). Shielded containers exposed to postulated fires in the WHB or Underground would be expected to be damaged to some extent. The inner 30 gallon drum portion of the shielded container is similar in design and construction to the TRU waste drum. Both the shielded container inner drum and the TRU waste drum are thin gauge (< 0.2 in.) steel drums equipped with a hoop-ring lid closure. And, both are provided with a filtered vent that is provided by the waste generator. The shielded container outer drum assembly, with a bolted lid design, is similar to the inner pipe component of the POC. The POC pipe is a thick-walled container. The shielded container outer drum is a double-walled thin gauge steel drum. But, it is provided with a 1” thick lead liner between its inner and outer surfaces, making it therefore, 3 layers thick and considered (provided the lead remains in place) as a thick-walled steel container, similar to the POC pipe component. The bottom plate and lid of the shielded container are 3-inch thick steel plate and though not layered, are also thick-walled components of the container. The outer shielded container drum is provided with a filtered vent (filter provided by waste generator); and the thick-walled POC inner container is also provided with a vent. Finally, the entire shielded container assembly (outer lead-lined drum and inner 30 gallon drum) is an overpacked assembly and as such, is similar to the overpacked assembly of the POC.

Table 5-1 provides a summary of this comparison.

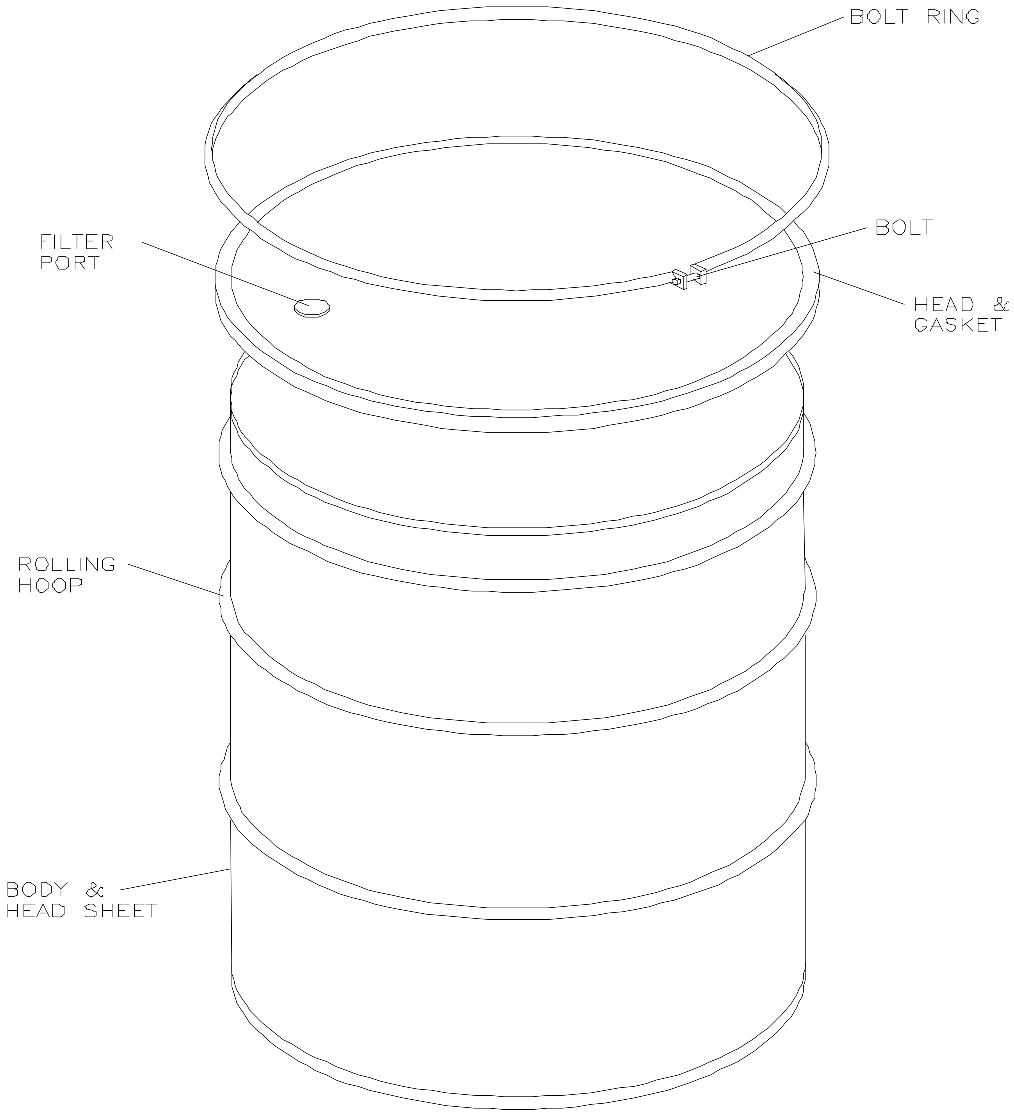

**Figure 5-1, Standard 55-Gallon TRU Waste Drum Diagram**

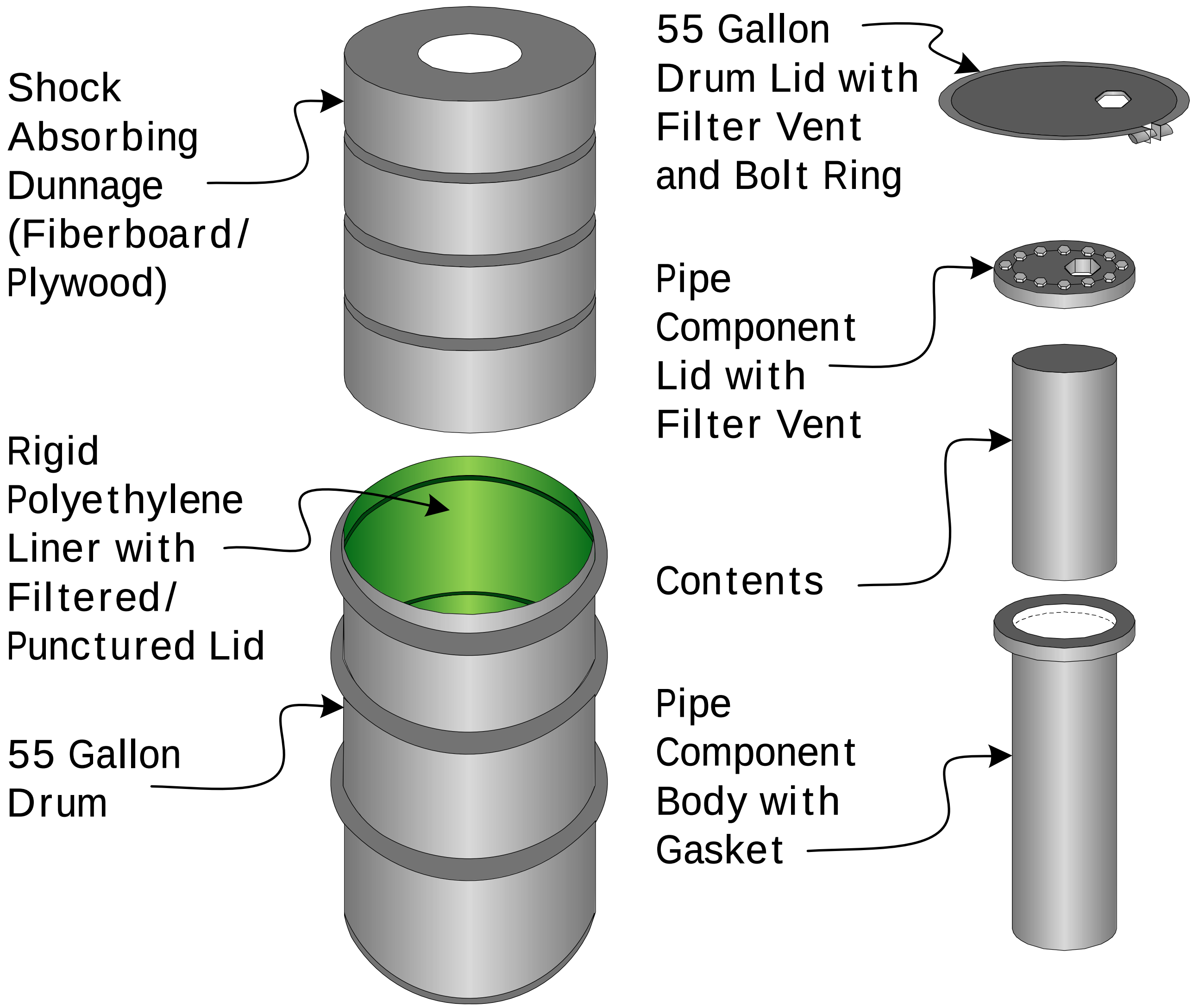

**Figure 5-2, Pipe Overpack Container (POC) Diagram**

**Table 5-1, Comparison of Selected Important Physical Attributes of the TRU Waste Drum, POC, and Shielded Container**

| Attribute | TRU Waste Drum | POC | Shielded Container |
|---|---|---|---|
| Thin-walled container | Yes | Outer | Inner |
| Thick walled container | No | Inner | Outer* |
| Hoop ring lid closure | Yes | Outer | Inner |
| Bolted lid | No | Inner | Outer |
| Vented | Yes | Inner & Outer | Inner & Outer |
| Overpacked assembly | No | Yes | Yes |

*Valid if lead shielding on the shielded container remains intact.

## 6.0 SUMMARY OF FIRE DAMAGE TO POC AND TRU WASTE CONTAINERS

DOE-STD-5506-2007 [4] summarizes damage estimates for both the POC and TRU waste containers used at WIPP. Pertinent attributes are described, for each container, below:

### 6.1 Pipe Overpack Damage in Fire

POCs consist of a thin-walled outer drum overpack housing a thick-walled inner pipe component, with insulating fiberboard insulation in between. The outer container has a hoop-ring lid closure, while the inner pipe component lid is bolted. Both the outer and inner containers are vented. For outer containers with a plastic vent, the outer vent melted in fire testing and left the bung hole open. The inner container in these drums survived intact with no leakage. A single POC tested [15] with a metal filter in the outer container experienced lid ejection of the outer container lid. It was surmised that the vent filter became plugged with soot generated from combustion of the fiberboard insulation. Along with the lid ejection, an upper cover of fiberboard insulation was also ejected with the lid. The inner pipe component was subject to fire temperatures in the test and was found afterward to be leaking. Associated leak rate testing of this POC showed a total leak rate of 24 $cm^3/s$ at a differential pressure of 87 kPa. This leak rate was later associated with an ARF of 6E-6 for the bounding material type in POCs (i.e., powder) [reference 4, Section 4.4.3]. The lid of the inner pipe component was not ejected.

### 6.2 TRU Waste Drum Damage in Fire

TRU waste drums are of thin-walled construction, with a hoop-ring closure. It is provided with a filtered vent and waste is directly loaded into the container. From Section 4.4.3 of DOE-STD-5506-2007, TRU waste drums subject to non-pool fire exposures can only experience seal failure. The combined ARF x RF for this type of failure is 5.0E-04 for a portion of the drums. For a fully engulfed pool fire, some portion of the drums are determined to experience lid loss due to over-pressurization of the container. And, some portion of the waste ejected in the lid loss is expected to continue burning and flexing in air (material traveling through the air that can shed particles due to the flexing of the substrate during the transmission). Waste burning in air (unconfined burning) is given an ARF x RF of 1.0E-02 and flexing in air contributes an additional ARF x RF of 1.0E-04. DOE-STD-5506-2007 permits use of a damage ratio based on the number of drums involved in the postulated fire. This analysis is based on the individual drums. Additional DR fractions applied to multiple container arrays should be applied as described in DOE-STD-5506-2007. The waste remaining in the drum is taken as burning in a confined manner and has the same dose contribution as that of drums experiencing seal failure.

# 7.0 SHIELDED CONTAINER FIRE ANALYSIS

## 7.1 Description of Postulated Fires

Since the shielded container permits contact handling of RH waste as CH waste, this evaluation will only consider fires postulated to directly involve CH waste containers. RH waste containers are of different type, handled remotely and in different portions of the WHB. The WIPP FHA [1] evaluated fires that directly involve CH waste containers as described below. Facility fires postulated to impact RH waste containers are not impacted by use of the new shielded containers and are not applicable to this analysis.

Surface Building Fire Scenarios

- Fire involving the 13-ton electric forklift carrying a fully loaded facility pallet amongst the CH bay waste array.
- Fire involving a 6-ton diesel forklift proximate to a non-palletized waste array.
- A loaded 13-ton electric forklift collision into a close-packed waste array and subsequent fire with another loaded 13-ton electric forklift that becomes involved in the same fire.
- A liquid-fueled manlift fire adjacent to the CH Bay rollup door with spilled fuel pooling under the door to expose CH waste.
- Fire scenarios involving other miscellaneous combustible concentrations including office area fires, fire involving palletized stacks of polyethylene or fiberboard slipsheets, combustible liquid spill fires (up to 5 gallons), miscellaneous transient combustible package fires, and a fuel tanker truck fire immediately outside the building.

Underground Disposal Circuit Fire Scenarios

- Fires involving a liquid-fueled transport or material handling vehicle adjacent to a stored waste array (at the waste face).
- Fires involving a liquid-fueled vehicle during waste drum transport from the waste hoist to the disposal panel.
- Fires involving a liquid-fueled vehicle during transport that occurs adjacent to the end of a filled panel fitted with either a temporary or permanent closure structure.
- Collision of a liquid-fueled vehicle (CH or RH waste handling equipment) into waste face, with and without another vehicle nearby, and a follow on fire.
- Collision of two liquid-fueled vehicles (eg UG Transporter and 6-ton diesel forklift) near waste face with follow-on fire.

It is important to note here that the failure mechanism for release of material from any TRU waste container (but, principally TRU waste drums) in an engulfing pool fire or in an exposure fire is different than the failure mechanism for release of material from a shielded container in similar fires.

A significant amount of fire testing of standard TRU waste drums indicates that drum failure, either through lid ejection or seal failure, is a prompt event that occurs very early in the development of the fire. As a result of this phenomena, the criteria for postulating fire exposure to the drums (as embodied in DOE-STD-5506-2007) is structured to encompass conservatisms related to the specific failure mechanisms involved. That is, the effects of fires directly impacting TRU waste storage arrays are maximized by employing analytical techniques which involve the use of thin pool depths resulting in short duration, larger diameter fires. Lid ejection is determined, by DOE-STD-5506-2007, to occur within 70 seconds and seal failure is determined to occur at the onset of sufficient incident heat flux from the fire to the side of the drum. The duration of the fire is irrelevant to the DOE-STD-5506-2007 prescribed methodology for evaluating TRU waste container damage (i.e., release) in a fire.

On the other hand as shown in this analysis, the shielded container is essentially impervious to short duration fire events. Lid ejection is not possible because of the overpack configuration (the outer container will prevent ejection of the inner container's lid and the waste inside) and failure of the inner 30-gallon drum seal or filter is not possible unless sufficient heat energy is applied to the shielded container to disable the protective capabilities of the 1-inch thick lead liner. The lead liner can only be disabled through longer term heatup and melting of the lead, breach of the outer container shell through expansion of the lead beyond the capabilities of the steel shell[2], and subsequent loss of molten lead through the breach. This is, compared to the TRU waste drum failure, a relatively long duration event. Therefore, reasonably conservative analysis of fire exposure to the shielded container must consider realistic phenomena which address failure under longer duration events. Since pool depth and pool diameter are not mutually-exclusive parameters directly related to pool volume, analysis of the shielded container in this evaluation is structured to maximize pool depth and extend fire duration at the expense of pool diameter. Stating this another way, short duration fires of thin pool depths are conservative for TRU waste drums and non-conservative for shielded containers. Therefore, this evaluation departs from the DOE STD-5506-2007 methodology for evaluating pool fires in order to develop reasonably conservative analysis that is targeted to the specific failure mechanisms of the shielded container in a pool fire environment; i.e., use of a maximum pool depth or otherwise long duration fire events. This methodology is captured quantitatively, in Section 7.2.

Non-pool fire exposure to the shielded container is also time-dependent. A qualitative evaluation of exposure fire damage to a shielded container is provided in Section 7.3 below.

For the purposes of this evaluation, fire analysis of shielded containers in either the WHB or Underground, may be subdivided into two general categories. They are; fully engulfing pool fires and exposure fires which can be either pool fires or non-pool fires. These two categories may be further subdivided into short duration and long duration fire events. Impact events with a follow-on pool or exposure fire are subsets of the general categories.

Liquid pool fires are typically characterized [9] as quickly reaching a steady state burning rate, or mass loss rate, that is principally dependent on the thermophysical properties of the burning fuel and the surface area of the pool. The fire duration, independent of fire diameter, is then proportional to the pool depth. The pool fire analysis methodology outlined in DOE STD 5506-2007, maximizes pool surface area, as described above, using an assumed uniform pool depth of 2.8 mm. This depth is representative of the average spill depth from empirical testing [9] of large (>25 gallons) hydrocarbon fuel spills on a flat smooth surface, as would be appropriate for the WHB. The duration of a burning diesel fuel pool fire of that depth is 70 seconds [10]. Since this is based on empirical testing, there are only two means by which it may be physically possible to consider a liquid fuel pool fire duration of greater than 70 seconds. They are: an increased pool depth such as could be created on an uneven surface like the WIPP Underground; and a non-static fuel spill such as would be created from a small breach in a fuel container that continues to add fuel to the fire until the container is depleted, a metered spill.

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[2] Impact-induced breach of the shielded container outer steel shell prior to involvement in a fire is also possible. Subsequent heatup and melting of the lead lining would be similar to the fire-then-breach scenario described here.

The expected response of the shielded container to fire scenarios is evaluated in this analysis, irrespective of their location. It is noted however, that long duration deep pool fires are not considered credible in the WHB (Section 7.2). Fires which result in lead loss will potentially increase the radiation dose to any worker who remains in the area. However, since the fire itself poses a greater immediate hazard it is considered that the workers will evacuate the area. This evaluation considers the potential magnitude of radiological release. Increased radiation dose due to direct radiation is outside the scope of this analysis.

## 7.2 Short Duration, Fully Engulfing Pool Fire

A shielded container exposed to an engulfing pool fire can be generally anticipated to behave in a certain manner based on what is known about the design and fabrication of the container. Lid ejection due to rapid heatup and pressurization of the inner container is not considered credible. So, the only mechanism for release of radiological material in the inner drum would be through compromise of the inner 30-gallon drum seal. The lead shielding would effectively prevent heat propagation to the inner drum for a significant time. But, the lead would melt and expand as it heats. The engulfing pool fire could be expected to heat the outer surface of the container uniformly. As the lead liner melts it will expand. Fabrication of the inner liner is done through successive pours [8] which allow for some contraction between pours. This approach is taken to ensure complete filling of the outer container interstitial space and avoid air gaps which would reduce shielding. When the final pour is made, the top of the liner is essentially just below its melting point of 621ºF (Input 2). But the bottom of the liner is also relatively hot (500ºF – 560ºF, Attachment 1). There would have been additional contraction as the liner cooled to room temperature. But the void space is substantially minimized as would be compared to use of a method employing a single pour.

When exposed to a pool fire it would be expected to essentially reverse the cooling / contracting process in order to heat / expand. The rate of change would likely be much faster, but the rate is unimportant as the lead is expected, in this scenario, to heat, melt and expand, uniformly filling the void space as it does. Because the void space was completely full at the end of the first pour, successive pours added more lead to the liner space so that when re-heated in this uniform engulfing fire, the liner void space is expected to be completely filled just shortly before the lead liner is fully melted. Additional heat input beyond the point at which the liner space is completely filled would serve to pressurize the interstitial space in the container. Volumetric expansion would continue until the lead reaches equilibrium with fire temperatures which are estimated to be as high as 2,000ºF or until the fuel is consumed and the fire self-extinguishes. As long as the container interstitial space contains the lead in a solid or liquid state, it is expected to attenuate heat influx to the inner container and provide adequate thermal shielding to prevent a breach of the inner container. The container's most likely response to an engulfing fire would be swelling of the inner liner walls due to expansion of the lead and softening of the outer steel shell. This type of response was observed (see Figure 7-1) during testing of stainless steel hollow panel doors filled with lead and water-extended polyester conducted by the Southwest Research Institute (SwRI) in 2007 [17]. The test actually involved two panel doors. The second door did not swell because a stiffener weld broke during the test allowing molten lead to spill out, and relieving internal pressure. The shielded container is not constructed with internal stiffeners and would not be expected to breach quickly. The only possibility for an opening to develop would be at the outer shell seam weld or at some anomalous imperfection (dent, gouge, etc.) that would inhibit or prevent uniform heat conduction throughout the shell. These conditions would represent credible, but very unlikely, failure mechanisms for short duration fires. It is therefore concluded that for the duration of the engulfing pool fire, until just before the lead mass is fully melted, no failure will occur. It is further determined that for a fire duration that fully melts the lead, and for some finite time after, the most likely container response would be swelling or bulging of the container shell with no breach of the outer steel shell so that no lead loss will occur. This portion of the fire analysis then, is structured to ascertain whether or not a short duration fire will melt (or approach melting) of all the lead in the liner cavity. This approach necessitates determining the conditions which define a short duration fully engulfing pool fire.

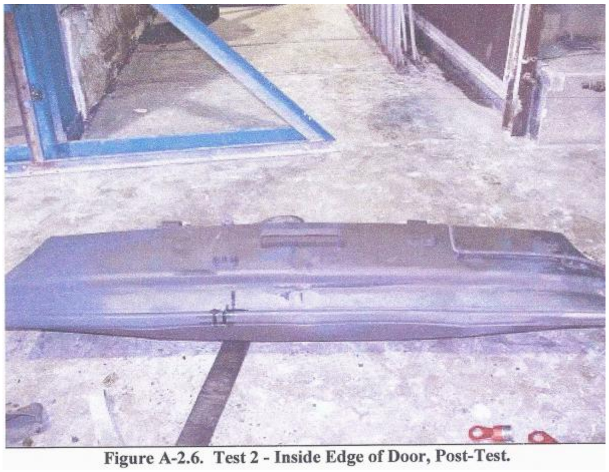


**Figure 7-1, Photo from SwRI Fire Test of Lead/Polyester Filled Door**

The analysis methodology for considering fully engulfing pool fires uses the following steps

a. Determine the duration of a postulated pool fire based on diesel fuel pool fire regression rates.
b. Determine the incident energy imposed by the postulated pool fire on a fully engulfed shielded container.
c. Determine the energy required to heat the mass of lead in the shielded container from room temperature to melting temperature.
d. Compare the energy imposed on the container by the postulated pool fire to the energy required for heatup of the lead liner to determine if sufficient energy exists to result in melting all the lead in the container.

### 7.2.1 Determine the duration of a postulated pool fire based on diesel fuel pool fire regression rates.

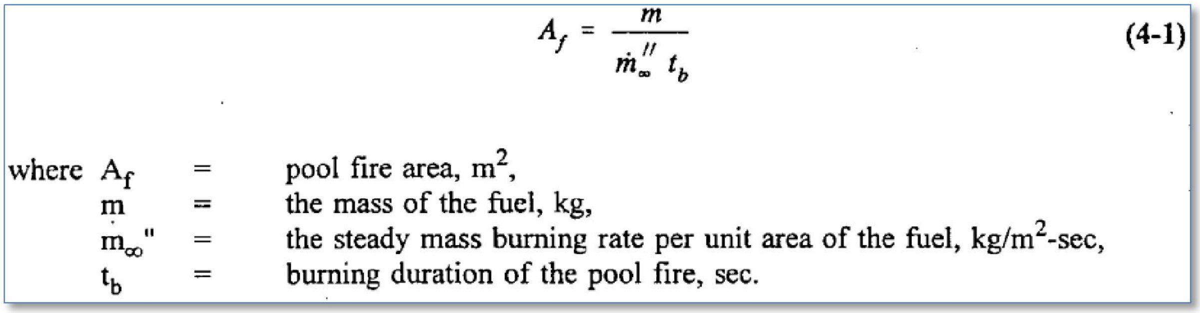
Pool fires are typically modeled, in accordance with DOE-STD-5506-2007, as short duration events where the fuel is completely consumed after approximately 70 seconds of burning. This methodology is based on the time it takes for drums to experience lid ejection due to rapid heatup of the drum contents. The approach maximizes pool fire diameters resulting in conservative results because it also maximizes the number of drums involved. The pool size developed for the 70 second duration fire coincides with pool spill diameter estimates developed from empirical fuel spill testing [9] on hard flat surfaces. That is, a typical hydrocarbon fuel spill has been shown, by empirical testing, to pool at a depth of about 2.8 mm on a hard flat surface and if ignited will burn for approximately 70 seconds.

Due to the manner in which pool fires burn, from the surface down and at a constant heat release rate, a greater pool depth results in a longer duration fire. The rate at which the pool surface lowers is the regression rate.

Unlike TRU waste drums, the shielded container would suffer little to no damage in a 70 second pool fire; first, because the bolted lid would not be ejected; second, because the lead shielding would not suffer significant damage, and third because the shielded container is an overpacked container with a steel inner container. However, engulfing pool fires of longer duration could cause substantial damage. Calculation WIPP-005 documents differing methodologies for determining the spill depth for hydrocarbon fuel spills. The methodology specified by DOE-

STD-5506-2007 is based on a pool depth of approximately 2.8 mm which maximizes pool diameter for a given spill volume. The U.S. Environmental Protection Agency (EPA) safety analysis methodology manual [13] cites 40 CFR 68 [14] as a basis for determining worst case accident conditions for both toxic and flammable liquid spills. These documents specify a uniform pool thickness of 1 cm (10 mm) for worst case spill events. Neither document offers a technical basis for the use of such a thick pool, but it is likely accurate to assert that soil absorption has been considered. The WIPP-005 calculation uses a median pool depth of 6.4 mm for pool fires on the compacted salt substrate of the mine underground. This value was chosen to determine a conservative maximum pool diameter, given that the WIPP underground surfaces are uneven, constantly changing, and at least partially absorptive.

DOE-STD-5506-2007 cites a methodology developed by Beyler and Gottuk [18], where the pool area is calculated based on the pool depth needed to result in consumption of the fuel in 70 seconds. Their equation 4-1 presents a correlation for the worst case area of a postulated pool fire with a given mass of fuel. It is reproduced as Figure 7-2 here:



$$A_f = \frac{m}{\dot{m}''_\infty \, t_b} \tag{4-1}$$

where $A_f$ = pool fire area, $m^2$,
$m$ = the mass of the fuel, kg,
$\dot{m}_\infty''$ = the steady mass burning rate per unit area of the fuel, $kg/m^2$-sec,
$t_b$ = burning duration of the pool fire, sec.

Figure 7-2, Beyler and Gottuk Correlation for Fuel Pool Burning

Substituting the mass loss rate of 0.039 $kg/m^2$-s [input 4] and the density of 977 $kg/m^3$[input 5] for diesel fuel into this equation, the duration of the pool fires evaluated in WIPP-005 can be determined as follows:

$$A_f = \frac{m}{\dot{m''} \times t_b} \qquad \text{so, } t_b = \frac{depth_{(in\ mm)}}{0.04}$$

| Depth, mm | 2.8 | 6.4 | 10 |
|---|---|---|---|
| Duration, sec | 70 | 160 | 250 |
| Duration, min | 1.17 | 2.67 | 4.17 |

{note: mass loss rate is rounded to 0.04 kg/m2-s}

### 7.2.2 Determine the incident energy imposed by the postulated pool fire on a fully engulfed shielded container.

Heat flux data for items immersed in a pool fire are documented by Russell and Canfield [11] and by Gregory, Keltner, and Mata [12]. These reports document empirical testing of the heat flux incident on items immersed in large pool fires. Time-averaged peak incident flux levels reported by Gregory et al, for a 30 minute fire are in the range of 40 to 160 $kW/m^2$. While Russell and Canfield report radiant only flux levels ranging from 16 to 175 $kW/m^2$.

Table 3 of Gregory, et.al. reports an average flux level 31.6 $kW\text{-}hr/m^2$ for all radiometers for all the tests. When averaged over the duration of the tests (30 min) the average flux is 63.2 $kW/m^2$.

The flux levels varied widely depending on the location of the flux meter within the flame and to what it was attached. Gregory, et al, presents specific data for calorimeters oriented vertically (up and down) and horizontally (sides) on the surface of a large pipe engulfed in the pool fire, their Table 3. The calorimeters oriented to point up and to the windward side of the fire were reported to be outside or just barely inside the flame perimeter for significant periods of time, principally due to the effects of the wind. For the purposes of this analysis, the flux received on the leeward side calorimeter is chosen to best-represent the conditions of a shielded container exposed to an engulfing pool fire. The calorimeter is reported to be constantly inside the flame and the flame is of a substantial thickness. Although the calorimeter oriented downward into the flame front indicated the highest flux levels, use of these values is considered unnecessarily conservative for this situation. The leeward calorimeter received an integrated peak flux of 39.1 kW-hr/m$^2$ over the 30 minute (0.5 hr) fire duration. But peak values of about 160 kW/m$^2$ are shown for the first few minutes. In fact the heat flux to the leeward calorimeter does not drop below 100 kW/m$^2$ during the first 5 minutes of burn time. This is seen in Figure 11 from Gregory, et. al. It is suggested that heat flux imparted to a calorimeter is at least partially influenced by the object to which the calorimeter is attached. Heat flux values are high until the object heats up and larger objects take longer to heat up. Since the shielded container has a significant lead mass, it is reasonable to consider heat flux input to the container is relatively high in the beginning stages of the fire. The fire would be expected to burn in a manner similar to the test pool fires documented by Gregory, et. al.; that is, shape of the heat release rate (HRR) curve would be similar. Except, the pool fires postulated here would burn out in a very short time, instead of burning for 30 minutes. The average heat flux over a short duration fire would be expected to be similar to the longer 30 minute burn; i.e., in the range of the 63.2 kW/m$^2$ value reported above. However higher fluxes are also expected for very short initial portions of fire as compared to the full pool fire burn time. For the simplified steady-state thermal analysis conducted here, it is necessary to determine a reasonably conservative heat flux value that would bound the postulated phenomena. It is considered overly conservative to assume the peak 160 kW/m$^2$ is constantly applied for the duration of the fire. It is also inappropriate to assume the minimum heat flux (40 kW/m$^2$) is applied for the entire duration. It would be appropriate to select the median heat flux value (63.2 kW/m$^2$) for this value. But for this analysis, a reasonably conservative heat flux value of 100 kW/m$^2$ is applied here as a constant incident flux over the entire vertical surface of the container and is considered sufficiently conservative to bound all accident conditions and address instrument uncertainties.

Using the dimensional data for a shielded container, the total surface area is the area of the cylinder, without the bottom and top. The bottom and top would receive much less flux than the sides and would not contribute to heating of the lead liner located at the periphery of the container. The outer steel shell would provide some protection to the lead. But steel is a good conductor of heat. And, since it is very thin and in direct contact with the lead, its contribution to limiting the amount or rate of heat transfer to the lead is neglected in this analysis. This approach is therefore conservative.

Area= 2*$\pi$*radius*height

Area = 2* $\pi$*11.528*32.718 = 2,369.8 in$^2$ (1.53 m$^2$)
{note: lead height scaled from sheet 1 of reference 3.}

At 100 kW/m$^2$, the incident energy imposed on the drum over the duration of the three types of fires postulated in WIPP-005 is:

$100\ \text{kW/m}^2 * 1.53\ \text{m}^2 * \text{duration, hr} = \text{flux, kW-h}$

Flux, kW-h = 153 * duration, hr

| Depth, mm | 2.8 | 6.4 | 10 |
|---|---|---|---|
| Duration, sec | 70 | 160 | 250 |
| Duration, min | 1.17 | 2.67 | 4.17 |
| Duration, hr | 0.019 | 0.044 | 0.069 |
| Flux, kW-h | 2.91 | 6.73 | 10.56 |

### 7.2.3 Determine the energy required to heat and melt the mass of lead in the shielded container from room temperature.

Porter [Attachment 2] defines the average mass of lead in the shielded container at 865 lb, based on data collected from nine container lead pours. Using an average specific heat capacity of 0.033 Btu/lb-°F (Input 3), the energy required to raise 865 lb of lead from room temperature (70°F) to melting temperature (621°F) is provided by Liley [6, page 4-3] as:

$$Q = mc\Delta T = 865\,lb \times 0.033\,{}^{Btu}/_{lb\text{-}°\mathrm{F}} \times (621°\mathrm{F} - 70°\mathrm{F}) = 15{,}728.3\,Btu = 4.61\,kW\text{-}h$$

Then, the latent heat of fusion (10.4 Btu/lb [Input 1]), required for melting of the lead:

$$865\,lb \times 10.4\,{}^{Btu}/_{lb} = 8{,}996\,Btu = 2.64\,kW\text{-}h$$

Adding the heat required to raise the temperature of the lead from 70°F to its melting temperature of 621°F (4.61 kW-h) to the heat required for a phase change (2.64 kW-h), the total heat required to melt the entire 1-inch thick lead liner of the shielded container is:

$$4.61\,kW\text{-}h + 2.64\,kW\text{-}h = 7.25\,kW\text{-}h$$

### 7.2.4 Compare the energy imposed on the container by the postulated pool fire to the energy required for heatup of the lead liner to determine if sufficient energy exists to result in melting all the lead in the container.

Section 7.2.1 above determined that 2.8 mm, 6.4 mm, and 10 mm would burn about 1.17 min, 2.67 min, and 4.17 min, respectively before being self-extinguished. Section 7.2.2 estimates that these pool fires could deliver about 2.91 kW-hr, 6.73 kW-hr, and 10.56 kW-hr, heat flux, respectively, to the outer surface of the container if the incident heat flux were a conservative $100\ \text{kW/m}^2$ applied equally and continually over the entire surface of the container. Finally, Section 7.2.3 determines that it would require approximately 7.25 kW-hr of incident flux to bring all the lead in the container to a liquid state. As stated in Section 7.2, the lead would occupy all interstitial space available at some point before the entire mass reaches a liquid state. At the point when the space is filled, the container would begin to pressurize. To analytically determine at what point a breach would occur is beyond the scope of this analysis. But, a qualitative engineering judgment can be made by considering the phenomenology involved (heating, swelling, and stretching of the heated outer container shell). A comparison of the pertinent parameters at this condition is summarized in Table 7-1.

**Table 7-1, Comparison of Energy Delivered to Shielded Container in a Short Duration Pool Fire to the Energy Required for Lead Melting**

| Pool depth, mm | Fire duration, min | Heat flux delivered to container, kW-hr, | Heat flux required to melt 865 lb of lead, kW-hr | Ratio: heat flux delivered to heat flux required | Container shell pressurized to breach? |
|---|---|---|---|---|---|
| 2.8 | 1.17 | 2.91 | 7.25 | 40.1 % | Not possible |
| 6.4 | 2.67 | 6.73 | 7.25 | 92.8 % | Very unlikely |
| 10.0 | 4.17 | 10.56 | 7.25 | 145.6 % | Likely |

From the above data, it is clear that a 2.8 mm deep pool fire, such as might be postulated for the WHB, would not challenge the integrity of the outer shell of the shielded container. Pool fires with a depth of 10 mm or greater should be assumed to fail the container as discussed in Section 7.3 below. In between these pool depths, the failure potential is less certain. At a pool depth of 6.4 mm, such as those postulated for the WIPP Underground, there is insufficient heat to fully melt all the lead. But in contrast, there is insufficient space in the outer container lining, to contain all the lead in a molten state without some pressurization of the container lining. Given the conservative use of a constant peak heat flux at a level of 100 kW/m$^2$, and the nature of the welded steel construction to withstand heating and expansion of the inner lining material (witness the SwRI panel door test), there is likely sufficient margin to consider that the outer shell would not fail. Or that, at worst, it could only fail at a time when fire extinguishment is imminent. Once the fire is extinguished, the lead would begin to solidify or "freeze" almost immediately. And, even if some lead were to be lost through a container breach, substantial loss of lead could not occur before freezing and then there would be minimal energy left to damage the inner container. So in either case, the outer shell of the shielded container would provide sufficient heat attenuation to prevent damage to the inner container, including its liner, vent, and waste material. This analysis therefore determines the following with respect to short duration pool fires:

1. A shallow, short duration pool fire is defined as 6.4 mm deep which burns for about 2.5 minutes or less;
2. A shielded container exposed to a shallow, short duration pool fire is very unlikely to breach. If a breach could occur, it would develop at, or imminently near, the point where the postulated pool fire is self extinguished due to lack of fuel. It would then begin to freeze immediately after the fire ceases to burn.
3. A shielded container exposed to a shallow, short duration pool fire will not result in damage to the inner steel container, or its contents; and no radiological release would occur.

## 7.3 Long Duration, Fully Engulfing Pool Fire

For the purposes of this analysis, long duration pool fires are defined as those with a pool depth greater than 6.4 mm and lasting longer than about 2.5 minutes. There are two mechanisms by which this type of fire could occur. The fuel spill could develop to a deeper depth. Or the fuel spill could be fed by additional fuel at a metered rate. A deeper fuel spill is only possible on uneven, or soft surfaces where the fuel can puddle or be otherwise contained. This is not considered possible on the smooth, flat concrete surface of the WHB and possible, though not likely, in the WIPP Underground. The mine surface is mined to be as level as possible. But the salt substrate is continually moving, being packed down by heavy equipment, and is somewhat absorbent. The absorbency of the salt has not been evaluated. It is considered more likely that the mine surface would have a slope than a depression. A metered spill could be postulated to result from an opening in a vehicle supply system such as a puncture or tear in a fuel tank or a ruptured fuel line. In this scenario, the fire duration would depend on the size of the opening, the volume available to leak out, and the geometry of the fuel container/tank. The leak volume could be driven by the vehicle fuel pump or by head pressure from the fuel tank if the fuel pump is not operating. Note that liquid fueled vehicles are prohibited from entering the WHB.

In order for a shielded container to be involved in a long duration pool fire, the fuel and the container would have to be situated in a depression in the mine underground at the same time the fuel spill occurs and is ignited. Or, the container would have to be near the liquid fueled vehicle when the fuel leak occurred and was ignited, and the leak would have to flow toward and around the container.

Although these chains of events are very unlikely, they are still considered plausible. Damage to individual drums could occur, but the robustness of the overpack container assembly would limit the possible release. Damage to the container is described as beginning with a breach in the skin of the outer shell, most likely at a seam. Once the skin is breached, melted lead would then pour from the opening. Continued melting would result in continued loss of lead lining from the outer container portion of the shielded container. The damage level would be expected to be very similar to a shielded container impacted by a severe exposure fire. These potential damages are described in more detail in the succeeding section of this analysis and consequential release fractions are evaluated in Section 7.5.

## 7.4 Shielded Container In An Exposure Fire

A severe exposure fire is defined here as any fire adjacent to one side of the shielded container that results in uneven heating of the container shell. The fire could be an adjacent pool fire, the burning solids portion of a vehicle fire, or a fire of ordinary combustible material in close proximity to the container and could extend for a significant duration. Uneven heating could be expected to heat a localized portion of the drum surface. With localized flame temperatures, the outer skin would be weakened, and as the lead expands in a localized spot it could cause a breach in the skin of the outer shell, particularly at a seam. This condition is considered unlikely, but possible. If the skin were to breach, melted lead could then pour from the opening. Continued melting would, depending on the location of the breach, result in continued loss of lead lining from the outer container portion of the shielded container. With loss of lead lining, heat-up of the inner steel container would occur. Lid ejection is not considered possible for two reasons. First the drum would not be heated quickly but slowly over time. As the lead is lost from the outer container heat transfer to the inner drum would increase. But the heating rate would be slowed by the steel structure of the outer container which is expected to remain intact. TRU waste drums similar to the shielded container inner drum only experience lid ejection when directly exposed to fully-engulfing pool fires. Second, the outer container portion of the shielded container is a bolted-lid assembly and will not lose its lid in a fire. It will therefore also prevent ejection of the inner container lid were that container to somehow receive significant rapid heat influx. Therefore, seal failure and loss of the vent filter is determined to be the worst type of damage that could occur to the inner container portion of the shielded container. Commensurate with DOE-STD-5506-2007, this type of damage is determined to permit an ARF x RF of 5.0E-04. This is considered over conservative because there is not expected to be any combustion of the contents of the 30 gallon inner container as there is with the TRU waste drum.

## 7.5 Estimate of Release Consequences for Postulated Fire Damages

Excepting the postulated breach of the outer container outer shell and loss of some of the lead liner, the remaining portions of the shielded container are expected to remain intact. This includes the inner shell of the outer container. That is, even with a loss of lead through a breach in the outer container shell, the drum-in-drum configuration is expected to be maintained. Therefore, no release of material is expected through the outer container unless the vent filter or seal is compromised. If the outer container filter is of a plastic material it is expected to melt out of the container in a severe exposure fire as postulated here. In that case, some portion of the material released through the failed seal or filter of the inner drum could leak out through the outer container seal and filter opening. Most of the material would be expected to plate out on the interior surfaces of both overpacked drums. This type of damage mechanism is similar to type of damage incurred by the pipe component of the POC that experienced lid loss because the heavy, bolted lid steel outer container of the shielded container is similar to the heavy, bolted lid steel pipe component of the POC.

Damage to the POC described in DOE-STD-5506-2007 was limited to the single container that experienced outer drum lid loss. The inner pipe component, which is most similar to the outer container portion of the shielded container, did not release any of the simulated oxide powder contained inside the test assembly. But it did show leakage in subsequent integrity testing. Associated leak rate testing of that POC showed a total leak rate of 24 $cm^3/s$ at a differential pressure of 87 kPa. Peterson [15], later associated this leak rate with an ARF of 6E-6 for the bounding material type in POCs (i.e., powder). His analysis considered that the radioactive component of material capable of being released consists of residues or other very fine particulate matter that is clinging or otherwise adhering to solid material in the container. With only heating of the waste in the inner 30 gallon drum of the shielded container (i.e., no combustion of the waste), Peterson's description of the POC release phenomenology is appropriate for this scenario. Measuring the POC's post-fire test leak rate under induced differential pressure, he applied the ARF for heating of Pu Oxide ($PuO_2$) powder under entrainment airflows as presented in Table 4-10 of Mishima [19]. Mishima presents data from empirical testing for two different airflow velocities (0.1 and 1.17 m/s) for two different temperatures (ambient and 800-900ºC [1,472-1,662ºF]) showing that of these two parameters, airflow velocity is the only one with significant influence on the measured release. Peterson cites Mishima as indicating that when $PuO_2$ powder is heated and air flows past it at a speed of 0.1 m /s for one hour, the total fraction of PuO2 released is 6.0E-06; this would be an airborne release rate and must therefore be multiplied by the duration of the heating to get the ARF. A one hour fire duration would yield an ARF of 6.1E-06. Peterson very conservatively estimated the velocity of air leakage past the POC pipe component O-ring and filter gasket (the filter itself did not fail) at somewhat less than 0.1 m/s. The outer container of the shielded container could experience damage through mechanisms similar to the POC. However if the shielded container's filter vent were to melt out or become deformed to create a larger opening in the outer container, it would result in a significantly decreased release flow rate due to the decreased potential for pressure buildup. The RF reported by Mishima is 0.01.

Considering the possibility of an fire lasting more than one hour, one must account for possible accumulations of ordinary combustible materials, vehicle tires, etc. Though possible, large quantities of these types of combustibles are not present in WIPP waste handling areas (where shielded container are transported and stored). If such an accumulation were to occur, it would be unlikely for a shielded container to be nearby if it were to ignite. And, only those containers directly exposed to the fire would receive any damage. With regard to a very deep pool fire, it is not possible in the WHB. Underground, the 41 ton diesel-powered forklift is described in WIPP-005 as containing 197 gallons of combustible liquid (fuel and hydraulic fluids). Using the correlations presented above, this volume of liquid, must be collected in a pool of about 8 ft. diameter and a depth of 140 mm in order to generate a pool fire that can continue burning for one hour. A localized depression in the mine floor of this depth (5.5 in) is extremely unlikely. For this scenario to occur, a shielded container would have to be placed in such a depression, then a fuel leak must occur and the fuel must be ignited. None the less, if it did occur, the ARFxRF would be expected to be 6.1E-08. This value is considered very conservative because it is based on a conservative application of the heated $PuO_2$ release fractions with no confinement. Peterson conservatively applied the ARF to the pipe component portion of the POC that had been directly exposed to the Type B test fire because of outer container lid ejection. Peterson did not apply the RF reported by Mishima simply because it was more conservative to not consider it.

This analysis applies both the RF and ARF from Mishima to the potential damage incurred by the outer portion of the shielded container exposed to a long duration fire. This approach only credits the 30 gallon inner drum to help prevent ignition of the waste in the container, no credit or reduction is taken to lower the overall container release fractions used. Additional conservatism is provided by application of an assumed leak rate (0.1 m/s) that is higher than is realistically possible.

When these conservatisms are taken together along with the likelihood of establishing the chains of events or occurrences which are necessary to lead to these conditions, it is considered appropriate to apply DOE STD 5506-2007-style damage ratios to larger populations of shielded containers. Therefore a DR of 0.5 should be applied to arrays of 10 or more shielded containers. Application of this DR recognizes that most pool fires would not damage the shielded container sufficiently to cause a breach in the outer shell and sufficient loss of lead to result in overheating of the contents of the inner container. Exposure fires could only expose containers in direct line of site with the fire. And even though the lead liner could heat up unevenly, there is still little to no chance that the contents of the inner container would be impacted. This DR should not be applied to shielded containers experiencing impact then fire.

## 7.6 Conclusions

This paper documents a fire protection engineering analysis of the ability of the proposed shielded container to withstand postulated fires at the WIPP facility. The shielded container is compared, in some aspects, to a TRU waste drum, and in other aspects, to a pipe overpack container (POC) as certain attributes of each of these known TRU waste container configurations are similar to attributes of the shielded container. Then, based on known fire-induced failure mechanisms of the TRU waste drum and POC, appropriate damage ratios and release estimate factors are derived for postulated fires involving the shielded container.

Shielded containers exposed to short-duration, fully engulfing pool fires are expected to have no release due to the even heating and the space available for thermal expansion of the outer container’s lead lining. A short duration pool fire is defined as having a depth of 6.4 mm, or less, and lasting for about 2.5 minutes. Shielded containers exposed to nearby pool or ordinary combustible fires could experience uneven heating of the lead lining along with weakening of the outer container shell resulting ultimately, in breach of the container outer shell, and loss of lead lining through flow of melted lead through the breach. Shielded containers involved in a long-duration, fully engulfing pool fire could be breached in a similar manner. And, shielded containers which experience impact followed by fire would be expected to yield the same consequences. A reasonable estimate of the overall effective release fraction (ARF x RF) is 6.1E-08.

A damage ratio (DR) of 0.5 should be applied to arrays of 10 or more shielded containers involved in an exposure or fully engulfing pool fire. A DR of 1.0 should be applied to arrays of less than 10 shielded containers, and to shielded containers which experience impact followed by fire.

These conclusions are summarized in

**Table 7-2, Summary of Expected Shielded Container Response to Thermal Insult**

| Insult | Expected Container Response | DR | ARF | RF |
|---|---|---|---|---|
| Short duration* engulfing pool fire | • Uniform lead heating/expansion;<br>• Loss of outer filter vent;<br>• Possible loss of inner filter vent;<br>• Insignificant heating of waste. | 0.0 | 0.0 | 0.0 |
| Long duration engulfing pool fire | • Lead heating/expansion,<br>• Loss of outer and inner filter vents;<br>• Breach of outer shell, loss of lead;<br>• Inner shell of outer container and inner container remain intact;<br>• Heating of waste without ignition. | 1.0, (<10 cntnr.)<br>0.5 (≥10 cntnr.) | 6.1E-06 | 1.0E-02 |
| Exposure fire (nearby pool fire or ordinary combustible fire) | • Uneven lead heating/expansion;<br>• Loss of outer and inner filter vents;<br>• Breach of outer shell, loss of lead;<br>• Inner shell of outer container and inner container remain intact;<br>• Heating of waste without ignition. | 1.0, (<10 cntnr.)<br>0.5 (≥10 cntnr.) | 6.1E-06 | 1.0E-02 |
| Impact with any type follow-on fire | • Breach of outer shell (from impact);<br>• Lead heating/expansion;<br>• Loss of outer and inner filter vents;<br>• Loss of lead;<br>• Inner shell of outer container and inner container remain intact;<br>• Heating of waste without ignition. | 1.0, (<10 cntnr.)<br>0.5 (≥10 cntnr.) | 6.1E-06 | 1.0E-02 |

* Short duration pool fire defined as having a depth of 6.4 mm, or less, and lasting for about 2.5 minutes.

## 8.0 REFERENCES

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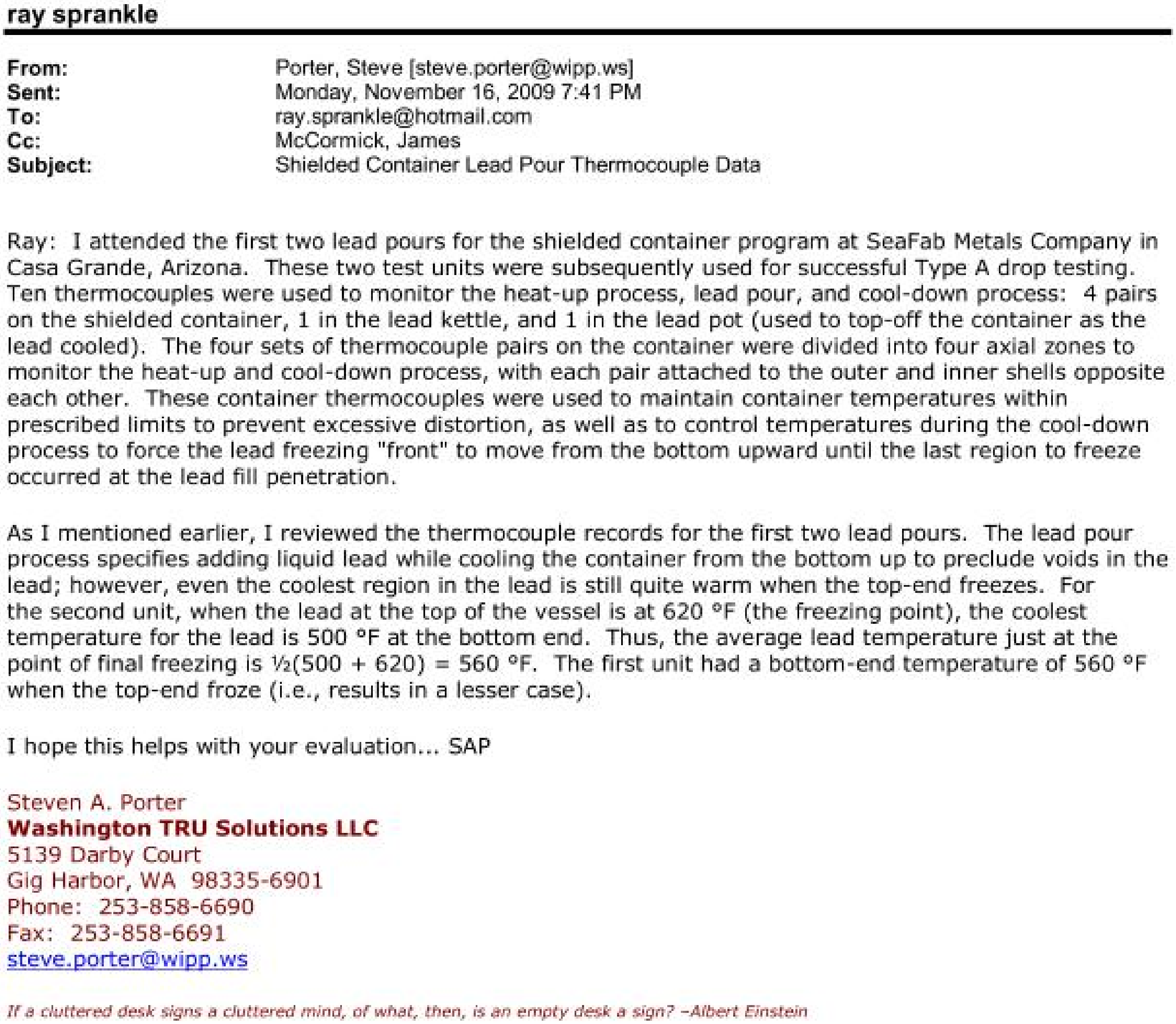
## Attachment 1 11/16/09 E-Mail, S. Porter to R. Sprankle Stating Lead Pour Details



**ray sprankle**

**From:** Porter, Steve [steve.porter@wipp.ws]
**Sent:** Monday, November 16, 2009 7:41 PM
**To:** ray.sprankle@hotmail.com
**Cc:** McCormick, James
**Subject:** Shielded Container Lead Pour Thermocouple Data

Ray: I attended the first two lead pours for the shielded container program at SeaFab Metals Company in Casa Grande, Arizona. These two test units were subsequently used for successful Type A drop testing. Ten thermocouples were used to monitor the heat-up process, lead pour, and cool-down process: 4 pairs on the shielded container, 1 in the lead kettle, and 1 in the lead pot (used to top-off the container as the lead cooled). The four sets of thermocouple pairs on the container were divided into four axial zones to monitor the heat-up and cool-down process, with each pair attached to the outer and inner shells opposite each other. These container thermocouples were used to maintain container temperatures within prescribed limits to prevent excessive distortion, as well as to control temperatures during the cool-down process to force the lead freezing "front" to move from the bottom upward until the last region to freeze occurred at the lead fill penetration.

As I mentioned earlier, I reviewed the thermocouple records for the first two lead pours. The lead pour process specifies adding liquid lead while cooling the container from the bottom up to preclude voids in the lead; however, even the coolest region in the lead is still quite warm when the top-end freezes. For the second unit, when the lead at the top of the vessel is at 620 °F (the freezing point), the coolest temperature for the lead is 500 °F at the bottom end. Thus, the average lead temperature just at the point of final freezing is ½(500 + 620) = 560 °F. The first unit had a bottom-end temperature of 560 °F when the top-end froze (i.e., results in a lesser case).

I hope this helps with your evaluation... SAP

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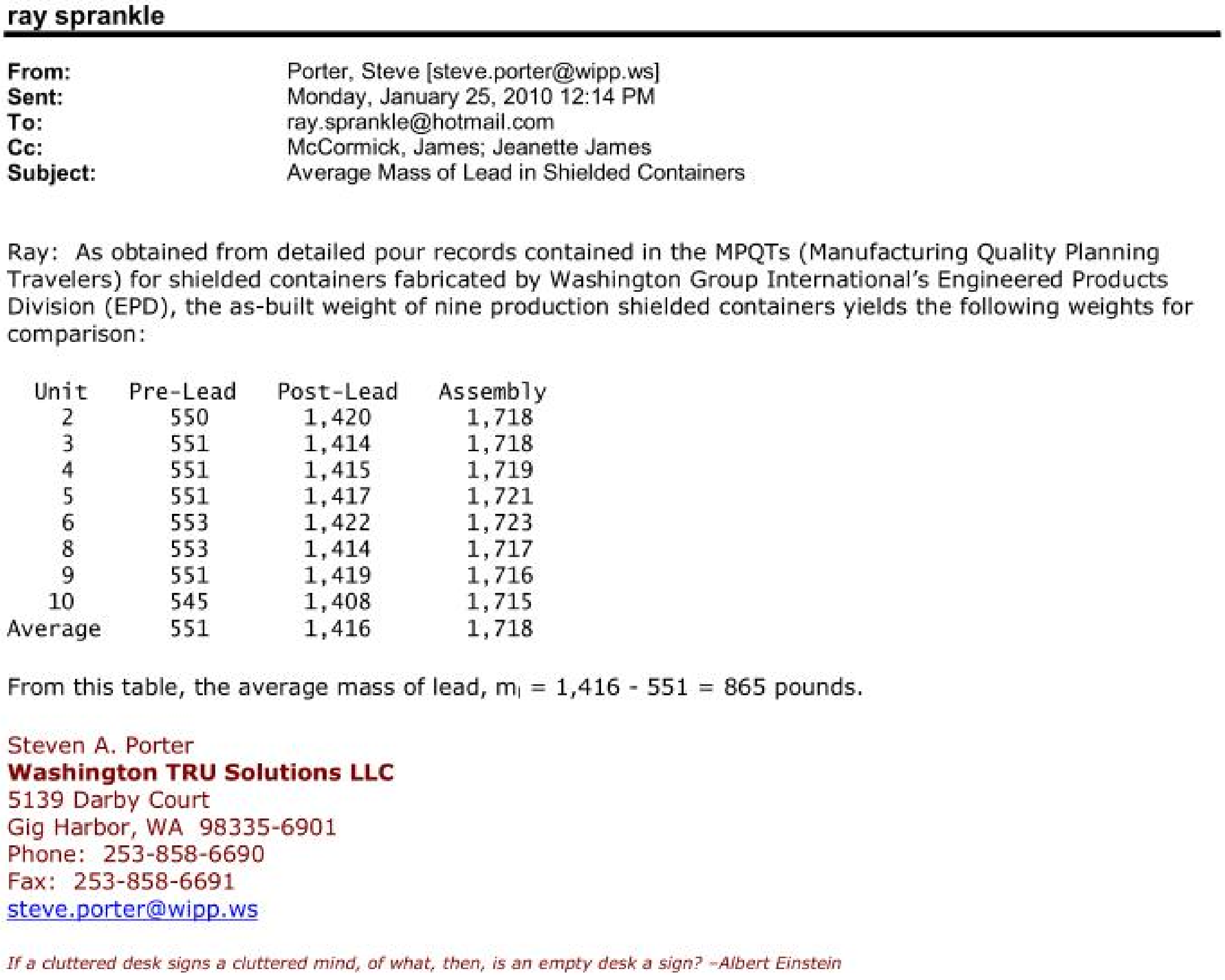
*If a cluttered desk signs a cluttered mind, of what, then, is an empty desk a sign? –Albert Einstein*

## Attachment 2 01/25/10 E-Mail, S. Porter to R. Sprankle Stating Average Lead Mass



**ray sprankle**

**From:** Porter, Steve [steve.porter@wipp.ws]
**Sent:** Monday, January 25, 2010 12:14 PM
**To:** ray.sprankle@hotmail.com
**Cc:** McCormick, James; Jeanette James
**Subject:** Average Mass of Lead in Shielded Containers

Ray: As obtained from detailed pour records contained in the MPQTs (Manufacturing Quality Planning Travelers) for shielded containers fabricated by Washington Group International's Engineered Products Division (EPD), the as-built weight of nine production shielded containers yields the following weights for comparison:

| Unit | Pre-Lead | Post-Lead | Assembly |
|---|---|---|---|
| 2 | 550 | 1,420 | 1,718 |
| 3 | 551 | 1,414 | 1,718 |
| 4 | 551 | 1,415 | 1,719 |
| 5 | 551 | 1,417 | 1,721 |
| 6 | 553 | 1,422 | 1,723 |
| 8 | 553 | 1,414 | 1,717 |
| 9 | 551 | 1,419 | 1,716 |
| 10 | 545 | 1,408 | 1,715 |
| Average | 551 | 1,416 | 1,718 |

From this table, the average mass of lead, $m_l$ = 1,416 - 551 = 865 pounds.

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