1 of 1

2
AUG 08 1994

ENGINEERING DATA TRANSMITTAL

Page 1 of 1

1. EDT 118522

2. To: (Receiving Organization)

Waste Operations Safety Engineering

3. From: (Originating Organization)

Engineering Process Applications

4. Related EDT No:

5. Proj/Prog/Dept/Div:

Solid Waste Storage

6. Cog/Proj Engr:

W. O. Greenhalgh

7. Purchase Order No:

N/A

8. Originator Remarks:

Transmittal of "Combustion and Fuel Loading Characteristics of Hanford Site Transuranic Solid Waste", Doc. No. WHC-SD-WM-DTR-033 Rev0

9. Equip/Component No:

N/A

10. System/Bldg/Facility:

N/A

12. Major Assm Dwg No:

N/A

13. Permit/Permit Application No.

N/A

14. Required Response Date:

7/31/94

11. Receiver Remarks:

15 DATA TRANSMITTED

(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev No.	(E) Title or Description of Data Transmitted	(F) Impact Level	(G) Reason for Transmittal	(H) Originator Disposition	(I) Receiver Disposition
1	WHC-SD-WM-DTR-033	N/A	0	Combustion and Fuel Loading Characteristics of Hanford Site Transuranic Solid Waste	N/A	1,2		

16. KEY

Impact Level (F)	Reason for Transmittal (G)	Disposition (H) & (I)
1, 2, 3, or 4 see MRP 5.43 and EP-1.7	1. Approval 2. Release 3. Information 4. Review 5. Post-Review 6. Dist (Receipt Acknow. Required)	1. Approved 2. Approved w/comment 3. Disapproved w/comment 4. Reviewed no/comment 5. Reviewed w/comment 6. Receipt acknowledged

(G)	(H)	17. SIGNATURE/DISTRIBUTION (See Impact Level for required signatures)								(G)	(H)
Reason	Disp	(J) Name	(K) Signature	(L) Date	(M) MSIN	(J) Name	(K) Signature	(L) Date	(M) MSIN	Reason	Disp
	1	Cog./Proj. Eng	W. O. Greenhalgh	7/18/94	65-31						
	1	Cog./Proj. Eng. Mgr.	J. P. Hunter	7/20/94	65-31						
		QA									
		Safety									
	1	Waste Operation Safety Eng.	J. P. Estrellado Jr./W. Olson								

18.

Signature of EDT Originator
Date 7/18/94

19.

Authorized Representative for Receiving Organization
Date 7/20/94

20.

Cognizant/Project Engineer's Manager
Date 7/20/94

21. DOE APPROVAL (if required)

Ltr No.
☐ Approved
☐ Approved w/comments
☐ Disapproved w/comments

BD-7400-172 (2/89)

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Date Received: <u>7/21/94</u> <u>MB</u>		INFORMATION RELEASE REQUEST		Reference: WHC-CM-3-4	
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			ID Number (include revision, volume, etc.) WHC-SD-WM-DTR-033, Rev. 0		
			List attachments.		
			Date Release Required <u>7/27/94</u>		
Title <u>Combustion and Fuel Loading Characteristics of Hanford Site Transuranic Solid Waste</u>				Unclassified Category UC-	
				Impact Level <u>NA</u>	
New or novel (patentable) subject matter? ☒ No ☐ Yes If "Yes", has disclosure been submitted by WHC or other company? ☐ No ☐ Yes Disclosure No(s).			Information received from others in confidence, such as proprietary data, trade secrets, and/or inventions? ☒ No ☐ Yes (Identify)		
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Date(s) of Conference or Meeting		City/State		Will proceedings be published? ☐ Yes ☐ No Will material be handed out? ☐ Yes ☐ No	
Title of Journal					
CHECKLIST FOR SIGNATORIES					
Review Required per WHC-CM-3-4		Yes No		Reviewer - Signature Indicates Approval Name (printed) Signature Date	
Classification/Unclassified Controlled Nuclear Information		☐ ☐			
Patent - General Counsel		☐ ☒		<u>N/R ref. 9403446</u>	
Legal - General Counsel		☐ ☒			
Applied Technology/Export Controlled Information or International Program		☐ ☒			
WHC Program/Project		☒ ☐		<u>JP Estrellado, Jr. SEE JP JOYCE SIGNATURE</u>	
Communications		☐ ☒			
RL Program/Project		☒ ☐		<u>RF Guercia</u> <u>[Signature]</u> <u>7/22/94</u>	
Publication Services		☒ ☐		<u>DF Washburn Sr. [Signature]</u> <u>7/26/94</u>	
SAR Development		☒ ☐		<u>John P. Joyce [Signature]</u> <u>7/16/94</u>	
Information conforms to all applicable requirements. The above information is certified to be correct.					
References Available to Intended Audience		Yes No ☒ ☐		INFORMATION RELEASE ADMINISTRATION APPROVAL STAMP Stamp is required before release. Release is contingent upon resolution of mandatory comments.
Transmit to DOE-HQ/Office of Scientific and Technical Information		☒ ☐			
Author/Requestor (Printed/Signature) Date <u>W. O. Greenhalgh/ [Signature]</u>					
Intended Audience <u>6/28/94</u> ☐ Internal ☐ Sponsor ☒ External					
Responsible Manager (Printed/Signature) Date <u>J. A. Hunter/ [Signature]</u> <u>6/28/94</u>				Date Cancelled Date Disapproved	

SUPPORTING DOCUMENT		1. Total Pages x 39
2. Title Combustion and Fuel Loading Characteristics of Hanford Site Transuranic Solid Waste	3. Number WHC-SD-WM-DTR-033	4. Rev No. 0
5. Key Words Combustion, Fuel, Fuel loading, Characteristics, Solid Waste, Transuranic, Hanford Site, Retrieval storage	6. Author Name: W. O. Greenhalgh <i>Wilbur O. Greenhalgh</i> Signature Organization/Charge Code 8D670/A1520	
7. Abstract The document describes typical combustion and fuel loading characteristics of Transuranic waste in retrieval storage at the Hanford Site.		
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9. Impact Level NA		

*** APPROVED FOR
PUBLIC RELEASE**

M. Boston 7/26/94

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MASTER

**COMBUSTION AND FUEL LOADING CHARACTERISTICS
OF HANFORD SITE TRANSURANIC SOLID WASTE**

WHC-SD-WM-DTR-033 REV 0

May 1994

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LIST OF TERMS

BTU	British thermal unit
HEPA	high-efficiency particulate air (filter)
NPH	normal paraffin hydrocarbon
PFP	Plutonium Finishing Plant
PVC	polyvinyl chloride
TBP	tributyl phosphate
TRU	transuranic
WIPP	Waste Isolation Pilot Plant
WRAP	Waste Receiving and Processing
WRAP 1	Waste Receiving and Processing Facility Module 1

COMBUSTION AND FUEL LOADING CHARACTERISTICS OF HANFORD SITE TRANSURANIC SOLID WASTE

1.0 INTRODUCTION

The Waste Receiving and Processing (WRAP) Facility is being designed for construction in the north end of the Central Waste Complex. The WRAP Facility will receive, store, and process radioactive solid waste of both transuranic (TRU) and mixed waste (mixed radioactive-chemical waste) categories. Most of the waste is in 208-L (55-gal) steel drums. Other containers such as wood and steel boxes, and various sized drums will also be processed in the facility. The largest volume of waste and the type addressed in this report is TRU in 208-L (55-gal) drums that is scheduled to be processed in the Waste Receiving and Processing Facility Module 1 (WRAP 1).

Half of the TRU waste processed by WRAP 1 is expected to be retrieved stored waste and the other half newly generated waste. Both the stored and new waste will be processed to certify it for permanent storage in the Waste Isolation Pilot Plant (WIPP) or disposal. The stored waste will go through a process of retrieval, examination, analysis, segregation, repackaging, relabeling, and documentation before certification and WIPP shipment. Newly generated waste should be much easier to process and certify. However, a substantial number of drums of both retrievable and newly generated waste will require temporary storage and handling in WRAP. Most of the TRU waste is combustible or has combustible components. Therefore, the presence of a substantial volume of drummed combustible waste raises concern about fire safety in WRAP and similar waste drum storage facilities. This report analyzes the fire related characteristics of the expected WRAP TRU waste stream.

2.0 CHARACTERISTICS OF STORED SOLID WASTE

In 1970, the Atomic Energy Commission required TRU waste to be segregated from other waste categories. At the Hanford Site TRU waste was placed in retrievable near-surface burial trenches equipped with an asphalt pad (floor). The drums were stacked in an array, wrapped with plastic, and covered with soil for corrosion protection. When originally buried, most of the lids on the drums were tightly sealed with no vent. The drums that were not vented with a vent clip or other means are now being removed and vented with a small high-efficiency particulate air (HEPA) filter plug to allow hydrogen or other radiation produced flammable gases to escape. It is expected that all drums with reasonable physical integrity will be vented before placement in WRAP or other facilities for processing or certification.

The Plutonium Finishing Plant (PFP) was the largest Hanford Site generator of TRU solid waste accounting for approximately 55% of the present stored retrievable waste. The plant generated 33,546 containers of solid waste from 1970 through 1991 and about 66% of this was designated as TRU waste. Approximately 84% of the waste containers were 208-L (55 gal) steel drums. (Duncan et al. 1993) An estimate of 10% of the total TRU solid waste

was non-combustible judged from the type of containers generated. This is a conservative estimate since all of the drums were assumed to be combustible when in fact 5 to 30% might be non-combustible depending upon the reference year. It is expected that 10% of the drummed waste is actually all non-combustible (cement or concrete, soil, spent tools or equipment, etc.). The general make-up of the other 90% of the waste is hard to determine but the waste was known to contain the following types of materials:

- Polyethylene plastic sheeting and bags
- Polyvinyl chloride (PVC) plastic sheeting and bag out bags
- Neoprene rubber gloves
- Neoprene leaded rubber gloves
- Hypalon^{*} rubber gloves
- Hypalon leaded rubber gloves
- Paper wipes and tissues
- Cloth decontamination rags and wipes
- Plastic vials and bottles
- Contaminated or broken tools
- Failed equipment--small pumps
- Fuel or cladding materials
- Small HEPA filters and prefilters
- Contaminated lead shielding
- Sampling cans and containers
- Metal trash cans
- Broken and spent ceramic crucibles
- Furnace parts
- Broken and contaminated tools.

The percentage of the preceding various waste materials is unknown; although, a waste survey is expected to be done in the near future to obtain an estimate of the average waste composition. A survey has been done in the 308 Building, a fuels fabrication facility, and a primary generator of TRU waste in the 300 Area. The average composition of the 38 drums surveyed in the 308 Building is given in Table 1 (Cooley 1974).

The 308 Building survey found that the average weight of the waste drum packages was 58 kg (127 lb) and the average weight of the PFP drum packages was slightly higher at about 68 kg (150 lb). This difference meant the PFP drums contained about 45 kg (100 lb) of waste and the 308 Building drums would contain about 34 to 36 kg (75 to 80 lb) because an empty drum weighs 23 kg (50 lb). Based on that information, the average combustible fuel loading would be 17 kg (37 lb) for 308 Building TRU generated waste ($77 \times 0.48 = 17 \text{ kg [37 lb]}$). The rest of the waste would not contribute appreciably to any fire situation.

Most waste surveys and composition estimations are made on the basis of volume percent rather than weight percent. The conversion of weight percent to volume percent can be done if material densities are available. Data used to prepare the values in Table 1 was also used to estimate densities for the various materials discovered in the 308 Building survey, with the exception of wood and carbon tetrachloride. The density values for these materials were

*Hypalon is a trademark of E.I. du Pont de Nemours and Company.

Table 1. Transuranic Waste Survey Results from the 308 Building.*

Waste materials	Average drum content
Combustibles (total)	47.5
Plastic	34.0
Rubber	7.0
Paper	6.0
Cloth	0.3
Wood	0.2
Noncombustibles (total)	47.7
Metal	42.0
Ceramics	4.0
Fuel Pins	1.0
Glass	0.7
Liquids (total)	3.7
Water	4.0
Carbon	3.0
Tetrachloride	0.7
HEPA filters	0.8

*Cooley 1974.

HEPA = high-efficiency particulate air (filters).

taken primarily from laboratory measurements and estimations. Table 2 lists the densities of the materials and Table 3 shows a modification of Table 1 giving the percentages in volume percent.

The average TRU waste drum that contained about 48 wt% combustibles from the 308 Building survey is roughly equivalent to about 67 vol% combustibles.

The major fire fuel contributor found in the 308 Building survey results was the plastic component. Pacific Northwest Laboratory has determined or listed common waste materials and their resultant fuel combustion contribution. These common waste materials and their caloric content are provided below (Schneider 1974).

Waste Materials	Kcal/g	BTU/lb
Polyethylene plastic	11.00	19,790
Latex rubber	10.42	18,760
Neoprene rubber	4.83	8,690
PVC plastic	4.98	8,970
Tygon*	6.13	11,030
Tissue paper/rags (50/50 mixture)	3.99	7,170

*Tygon is a trademark of the U.S. Stoneware Company.

Table 2. Densities of Typical 308 Building Solid Waste Components.

Material item	Density (g/cc)
Paper	
Ice cream cartons	0.81
Brown towels	0.40
Teri towels	0.60
White cardboard	0.59
Diaper paper	0.77
Light cardboard (for gloves)	0.67
Average	0.64
Cloth	
Canvas gloves	0.73
Cheese cloth	0.80
Cleaning rags	0.75
Coveralls	0.68
Average	0.74
Rubber	
Canner gloves	1.03
Shoe covers	1.41
Rubber stoppers	1.39
Hypalon glovebox gloves	1.65
Leaded glovebox gloves	2.50
Average (without the leaded gloves)	1.37
Plastic	
Heavy poly bags	0.97
PVC sheeting	1.28
Reagent (poly) bottles	1.09
Poly tubing	0.85
PVC bags	1.39
Average	1.12
Tape	
Green cloth tape	1.00

PVC = polyvinyl chloride.

Table 3. Waste Composition Survey Summary for 308 Building.

Material item	Weight (%)	Density (g/cc)	Volume (%)
Combustibles			
Plastic	34	1.12	47.6
Rubber	7	1.37	8.0
Paper	6	0.64	14.7
Cloth	0.3	0.74	0.6
Wood	0.2	~0.5	0.6
Partial totals	48	--	67
Noncombustibles			
Metal	42	3.6	18.3
Ceramics	4	2.3	2.7
Fuel pins	1	10	0.2
Glass	0.7	1.9	0.6
Liquids			
Water	3	1.0	4.7
Carbon tetrachloride	0.7	1.6	0.6
HEPA filters			
Glovebox HEPA filters	0.8	0.86	1.4

HEPA = high-efficiency particulate air (filter).

Table 3 indicates that the composition of waste effects heat output during a fire. A 308 Building type drum, with only polyethylene plastic as a combustible material (17 kg [37 lb]), would potentially produce about 733,000 BTU's. However, most of the plastic in 308 Building waste drums is actually PVC which exhibits a lower fuel loading. Also, there are other fuel materials that make up the 17 kg (37 lb) of combustibles. From the original survey data, it appears that the plastic fraction is about 28% PVC and about 6% polyethylene. Using these figures we can then calculate a realistic fuel loading for an average 308 Building type combustible waste drum. The results are provided in Table 4.

A determination of the waste fuel loading, based on a realistic composition as shown in Table 4 has only about half the fuel content compared with estimating the heat output using the highest BTU waste fuel constituent. When determining waste fuel loading it is important to know the specific waste constituents.

A major offsite generator of the Hanford Site's stored TRU waste was Babcock and Wilcox (Bradley et al. 1978). They were a reactor fuel contractor for the Fast Flux Test Facility and supplied 20,000 finished fuel pins between 1972-75 for cores 1 and 2 and also later produced fuel for cores 3 and 4. Some of the early waste was segregated and placed in drums according to the material it contained. The weight and percent composition of the waste as a whole is listed in Table 5.

Table 4. Fuel Loading of an Average 308 Building Type Transuranic Waste.

Waste item	Content		BTUs available
	(%)	(lb)	
PVC plastic	28	21.8	195,600
Polyethylene	6	4.6	92,500
Rubber (neoprene)	7	5.5	47,400
Paper, cloth, and wood	6.5	5.1	36,300
Totals	47.5	37.0	371,800

PVC = polyvinyl chloride.

Table 5. Composition of Early Transuranic Waste Generated by Babcock and Wilcox.

Material	Weight (lb)	Percent of total
Plastic	12,500	52.2
Rubber	6,100	25.7
HEPA filters	2,200	9.1
Paper and cloth	2,100	8.7
Metal	700	3.0
Miscellaneous (spent equipment)	300	1.3

HEPA = high-efficiency particulate air (filter).

The information in Table 5 was collected from 298 drums and the weights were estimated by assuming an average of 36 kg (80 lb) of waste material for each drum, which is the average for the drummed line waste (Bradley 1978). There is no specifics on the makeup of the plastic material, but it is known that PVC, polyethylene, propylene, and other plastics were present. To estimate an average fuel loading per drum, it is assumed half the plastic was PVC and the other half polyethylene (polypropylene characteristics are very similar to polyethylene). The rubber is primarily from spent glovebox gloves and is primarily neoprene. The HEPA filters are made of asbestos panels and woven glass (noncombustible) assembled in a wooden frame with wood derived glue (combustible). It is assumed that half the weight of the HEPA's will be a wood type fuel, and the other half noncombustible. The results are given in Table 6.

Table 6. Average Per Drum Fuel Loading of the Fast Flux Test Facility Fuel Waste (see Table 7).

Material	BTU loadings	BTU/drum
Plastic	1.79 E+8	6.02 E+5
Rubber	5.35 E+7	1.79 E+5
HEPA filters	7.74 E+6	2.60 E+4
Paper and cloth	1.49 E+7	4.99 E+4
Totals	2.55 E+8	8.57 E+5

BTU = British thermal unit.

HEPA = high-efficiency particulate air (filter).

There was also waste characterization data available for about 1,182 drums of fuel production line waste representing 63.7 vol% of the retrievable waste sent to the Hanford Site for storage. In addition, there was 15 vol% crate waste and 21.3 vol% liquid wastes absorbed in a vermiculite material. The crated waste (room waste) is mostly noncombustible waste and includes spent HEPA filters, reject fuel cladding (metal tubing), spent equipment, and equipment components. The absorbed waste is either aqueous liquid, or oil. Drums of absorbed aqueous liquid would be noncombustible, the absorbed oil would be combustible with 1 volume of oil to 2 volumes of absorbent. The absorbent is a vermiculite type material and is noncombustible. The absorbed oil would have a maximum estimated fuel loading of about 2 million BTU/drum assuming the oil to exhibit about 18,500 BTU's/lb and the volume of the drum to contain a maximum of 33 vol% oil.

The estimate for the average fuel loading of the line waste is summarized in Table 7 for noncrated, nonabsorbed waste (Bradley 1978).

The fire fuel loading averaged for the noncrated, nonabsorbed line waste drums amounts to 757,000 BTU/drum using a net weight of 36 kg (80 lb), which is just slightly above the computed average for line type waste from Babcock and Wilcox. The fire fuel loading for all of the line waste is a maximum of 695,000 BTU/drum assuming half the absorbed liquid waste is oil and the balance aqueous material. The average waste weight (80 lb) indicates lower oil contents and a more realistic heat load value based on weight would be 535,000 BTU/drum.

Not all solid waste has combustible materials present. Three types of waste were generated that went either to TRU retrievable burial or direct trench disposal. The different types of waste and volume percentages are shown in Table 8. Drummed dry waste, a mixture of combustible and noncombustible materials, went primarily to TRU retrievable storage. The crated dry waste went both to retrievable storage and trench burial, but these wastes are primarily noncombustible. The drummed liquid waste contains both combustible and noncombustible residues. The noncombustible liquids from scrap recovery processes are primarily TRU, as are the laboratory wastes. The nonscrap recovery liquid wastes were primarily combustible residues, but they were buried (disposed) directly. It is estimated from the Table 8 information that about 75% of the waste went to retrievable storage. Of that 75%, 20% or about 1/4 of the total was noncombustible.

Table 7. Estimated Fire Fuel Loading of Babcock and Wilcox Line Waste.

Waste material	Volume (%)	Estimated weight (%)	Average weight (lb)	BTU/drum
Plastic	67.5	55	44	6.33 E+5
Paper	6.0	5	4	2.87 E+4
Rubber gloves	5.4	6	4.8	4.17 E+4
Mixed combustibles	3.6	4	3.2	3.20 E+4
				(10,000 BTU/lb)
Metal	3.6	18	14.4	0
Mixed Combustibles/ noncombustibles	6.0	5	4	2.00 E+4
				(5,000 BTU/lb)
Glass	1.7	4	3.2	0
Absorbent	1.3	2	1.6	0
Crucibles	0.6	1.0	0.8	0
Scrap	0.4	0.3	0.24	0
Vials and electrodes	0.4	0.3	0.24	1.12 E+3
Totals	100.0	100.6	80.0	7.57 E+5

BTU = British thermal unit.

Table 8. Distribution of Babcock and Wilcox Generated Wastes.

Types of waste	Volume (%)	Waste description
Drummed dry waste		
Production line waste	25.4	Small equipment items, rubber gloves, and plastic items
Laboratory	0.9	Miscellaneous small items
Nonproduction line	17.8	General housekeeping trash - cloth, plastic, paper, used containers, and wipes.
HEPA filters and filter bags	10.3	Smaller HEPA (12 in. x 12 in. x 18 in. maximum) plus adapters, and Jet Millfilter bags
Scrap materials and other waste	4.9	Spent equipment, tools, furnace brick, glove box windows and parts, and miscellaneous wastes
Total	59.3	
Crated dry waste		
Spent HEPAs	5.7	Large HEPAs (24 in. x 24 in. x 20 in.)
Scrap materials and miscellaneous	8.3	Reject fuel cladding, spent equipment and equipment parts
Total	14.0	
Drummed liquid waste		
Scrap recovery liquid and sludge	14.8	Absorbed liquid residues with high plutonium values
Analytical laboratory	1.9	Small items and residues
Nonscrap recovery liquids	9.9	Sump liquid, hydraulic oil, organic solvents, and lubricants
Total	26.6	

HEPA = high-efficiency particulate air (filter).

3.0 COMBUSTIBLE CHARACTERISTICS OF THE HANFORD SITE TRANSURANIC WASTE

A summary of Hanford Site TRU waste data has been compiled for the retrievable stored waste materials (Anderson et al. 1990). The weight of a typical TRU drum was estimated at 68 kg (150 lb) during the 1970 to 1977 time period because actual drum weights were not available. The steel drum containers used at this time were painted and weighed about 23 kg (50 lb), so the net weight of solid waste was estimated to be about 45 kg (100 lb). Actual survey measurements during this time show TRU waste drum weights at about 54 to 59 kg (120 to 130 lb) for combustible solid waste. Few truly combustible waste drums exceed the weight range to any extent, except for unusual construction type waste such as floor tile. The 68 kg (150 lb) weight if estimated accurately, would likely have included a number of drums containing soil, cement, or lead. Most of the early drums were based on 10 nCi/g TRU definition or were potential TRU. At the present >100 nCi/gm definition a number of TRU designated waste drums have been disposed as low-level waste when assays were found to be <100 nCi/g.

The average stored 208-L (55-gal) drum with combustible waste weighs about 68 kg (150 lb) and this appears to be conservative (Anderson et al. 1990). Empty painted steel DOT (E or H) spec. drums weigh 23 kg ($\approx$ 50lb), leaving 45 kg (100 lb) as the net waste weight. Approximately two-thirds of the material in the waste drum is considered combustible by volume, leaving a net combustible loading volume of about 67% or that is equalent to about 23kg (50lb) per drum when converted to weight from volume Anderson et al. 1990). Based on typical material densities and compositions provided in Table 1, a fuel loading of about 500,000 BTU/drum would be expected from the 68 kg (150 lb) waste drums.

The TRU waste drums received after 1977 were found to average 79 kg (174 lb). However, these drums were also known to have lead shielding, include noncombustible waste, and starting in 1982, galvanized drums were used that are heavier than the painted drums. Present galvanized drums weigh about 29 kg (65 lb). An estimation of the fire fuel loading of these drums is provided in Section 6.1.

4.0 BURN CHARACTERISTICS

The burn characteristics of drummed solid waste is a concern for the safety of stored waste drums. In the late 1970's and early 1980's, the Mound Laboratory (Alexander 1980) worked on the development and demonstration of the Cyclone Drum Incinerator. The Cyclone Drum Incinerator was developed for the combustion of solid waste containing plutonium, or TRU waste as it is termed today. The drum incinerator was designed to burn the waste in-situ to minimize waste handling. The waste was incinerated in an enclosure, using a cyclone air feed to produce more efficient combustion with high temperature, high air turbulence, and high excess oxygen. Typically, drum burns are difficult because the drum acts as a barrier to the inflow of oxygen that is needed to support combustion. Mound Laboratory measured exhaust temperatures,

burn times (rate), and other essential combustion data. This burn data and information may be of value in modeling conditions for in-drum fires.

From 1976 to 1980, more than 9 tons of 2:1-compacted waste was successfully burned. The average waste weight reduction was 90.8%. Waste contained paper, wood, rubber, polyethylene, polypropylene, polystyrene, and PVC. The composition of a typical feed is listed in Table 9.

Table 9. Typical Composition of Mound Cyclone Incinerator Feed.

Waste material	Submaterials	Weight (%)
Paper	--	34
Plastics		49
	PVC	9
	Polyethylene	31
	Polypropylene	9
Rubber	--	14
Cloth	--	3

PVC = polyvinyl chloride.

The Mound Laboratory TRU waste generators in fiscal years 1976 and 1976A produced 187,144 ft³ of TRU waste. However, 21.6% of this waste was categorized as combustible TRU waste. Table 10 shows the breakdown of the different categories of TRU waste received at the Mound Laboratory (Luthy et al.).

The largest volume of waste listed in Table 10 is equipment that will have little combustible material present for most items. In addition, only the categories listed as "combustibles" and "absorbed liquids" would have substantial quantities of combustible materials. Most truly cemented oil solids burn very little if at all, and the rest of categories contain little combustible material. The survey of the Mound TRU waste demonstrated that noncombustible waste contains little or no fire fuel unless it is packaged in a combustible container. The containers for this particular set of waste are given in Table 11.

Table 10. Categories of Mound Transuranic Waste Generated in Fiscal Year 1976.

Waste type	Volume (ft ³)	Waste examples
Equipment	81,568	Gloveboxes, equipment, tanks
Combustibles	40,438	Paper, rags, cloth, fabric,
Glovebox/laboratory	39,785	Hardware, metal, glass, HEPAs
Cemented wastes	10,765	Oils, caustics, solutions,
Dry sludges	7,832	Carrier precipitations
Absorbed liquids	6,697	Corrosives, organics, oils
Others	59	Contaminated soil

Table 11. Packaging for Mound Transuranic Waste (Fiscal Year 1976).

Waste containers	Volume (ft ³)
DOT 17H 55-gal steel drums	5,750
DOT 17C 55-gal steel drums	14,500
DOT 17C/high-density polyethylene liner 55-gal drums	28,300
30-gal steel drums	800
Fiberglass reinforced plywood boxes	125,100
Steel boxes	8,200
Corrugated metal pipe	4,500

DOT = U.S. Department of Transportation.

Most of the actual containers described in Table 11 (high-density polyethylene liners and fiberglass reinforced plywood boxes) add to the fire loading and represent 153,300 ft³ or 81.9% of the volume. The choice of containers substantially increases the potential fire threat. This demonstrates the potential problems in obtaining realistic fire analysis data, and how waste handling choices can either worsen or improve potential fire risks.

Early Cyclone Incinerator tests were performed with small drums, but the incinerator was later demonstrated with a 208-L (55-gal) drum (Klinger 1979). During incineration, the air enters the drum at a side angle with high volume (300 ft²/min) causing a downward spiral to occur. This was done to cool the drum wall and feed air across the burning fuel. The waste burns uniformly downward while combustion gases and excess air swirl upward inside the spiral. The drums are purposely not insulated so that radiant and convective heat can be dissipated. The composition of some typical incinerator feeds and the heat produced are given in Table 12.

Table 12. Typical Incinerator Feed Compositions and Heat Produced.

Material (wt%)	Incinerator feeds		
	Type I	Type II	Type III
Paper	32	2	48
Plastics			
PVC	9	23	1
Polyethylene	29	9	6
Polypropylene	8	2	--
Rubber	13	3	26
Cloth	3	61	6
Wood	--	--	7
Metal	6	--	6
Average heat produced (BTU/lb)	11,700	8,300	8,600
Average rate of heat (BTU/min)	10,700	7,600	7,900
Approximate heat to offgas scrubber (%)	46	31	31
Approximate heat lost by radiation and convection (%)	54	69	69

BTU = British thermal unit.

PVC = polyvinyl chloride.

Compacting the waste before incineration slows down the rate. Solid wastes were burned at a rate of 27 kg/h (59.5 lb/h). Uncompacted waste takes about 20 to 30 minutes to incinerate. Standard 208-L (55-gal) steel drums can make in excess of 30 burns, stainless steel drums can make up to 100 burns (Klingler 1979).

The Cyclone Drum Incinerator is composed of two primary parts, a 208-L (55-gal) drum and a burn chamber with an offgas system (Klingler 1979). Temperatures produced by the drum burns average 1,090 °C and a peak temperature of 1,320 °C has been recorded at the outlet of the combustion chamber. In these burns there is a 300% oxygen excess and a particulate loading of about 504.9 mg/m³. Combustion air flowrate is about 300 ft²/min maintained by the offgas blower downstream (Klingler 1978).

Other waste runs made in the Cyclone Drum Incinerator, on a continuous basis, showed average burn rates of 35.1 kg/h for one quarter and 26.1 kg/h for another quarter. The ash content of the feed averaged about 4 wt% for the 1,530 kg of waste that was burned (Klingler 1978).

5.0 CONTAINMENT

Certain materials, containers, walls, and space can act to contain or limit fire combustion. Documented items that have been shown to contain fire for solid combustible waste will be discussed in this section. Radioactive spent solvents, oils, and other combustible organics are often immobilized or solidified before storage. Babcock and Wilcox immobilized their liquid wastes including hydraulic oils, organic solvents with vermiculite absorbent (Bradley et al. 1978). Others producers have used absorbents, gypsum cement, and portland cement, to solidify flammable or combustible liquids (Greenhalgh 1986, Rosenstiel et al. 1984). One question to resolve is how much fire containment does an absorbent or a solidification agent provide to oils or solvents?

The bond of oil or most other liquids to an absorbent is relatively weak. Spraying water on absorbed oil or organics during a fire situation is not advised because water tends to readily displace the organics. However, the presence of the absorbent does tend to stabilize or minimize the flammability of the absorbed organics at lower temperatures and tends to reduce the burn rate. It should be noted that two volumes of absorbent or more are typically added to each volume of organic or liquid. More information on the affect of absorbents to reduce combustibility or rate of combustion is needed for further study.

Gypsum and portland cement typically bond much better to liquids, including organic liquids than do absorbents. An organic extraction liquid of 30% tributyl phosphate (TBP) in normal paraffin hydrocarbons (NPH), which is similar to kerosene was solidified in cement at 35 vol% (Greenhalgh 1986). The resultant product was self extinguishing at room temperature, which means it would burn only exposed to an open flame, extinguishing as the flame was removed (see Photos 1 and 2). The burn rate would be expected to be a function of the temperature to which the cement product was heated and diffusion rate of the organics. It is expected that burn rates would be substantially reduced in a fire if the waste exposed to the fire was solidified by some type of noncombustible cement such as portland cement, plaster of paris, or other material.

The potential fire containment effect of cementing combustible waste has been illustrated by placing such a drum in an oil-gasoline fire (Greenhalgh 1988). A galvanized steel DOT 17-C drum was filled with 86 kg (189 lb) of simulated shredded waste mixed with 109 kg (241 lb) of portland cement-water slurry then allowed to set and cure (see Photo 3). The product termed shred-grout was actually a shredded-waste concrete with the waste itself acting as the aggregate. The drum was fitted with a vent clip and the lid was sealed with a standard drum rubber gasket and the drum lid clamped. This drum of waste concrete was then transported to the 400 Fire Testing Area and the drum was placed in a large burn pan containing 50 gal of diesel oil and 50 gal of gasoline. The oil-gasoline mixture was ignited (see Photo 4) and burned for ≈ 20 minutes with flames averaging 10 to 15 ft high (see Photos 5 and 6) the fire died and was then extinguished. At no time did the drum burn. There were gases observed coming from the vent clip and the vented gases burned for a few minutes initially. Then the flame went out apparently because of an increasing ratio of water to organic gases. The waste drum

package lost 5 kg (11 lb) during the test burn and inspection of the waste concrete showed the inner surface to be charred and surface plexiglass to be melted, but the other contents showed little or no damage (see Photo 7). The galvanizing coating was destroyed but the steel container was intact and showed little or no damage. The waste contents were about 69.7 wt% combustible and included the addition of a small volume of oil. Temperatures of the burn were not measured but the drum surface had a red glow for at least 5 minutes, indicating an approximate surface temperature of 750 to 800 °C. The characteristics of the waste concrete, including an estimation of the fuel loading, is given in Table 13.

Table 13. Characteristics of Shred/Grout Used in Oil Fire Test.*

Waste constituent	Weight content (%)	Weight (lb)	BTUs
Plastic			
Plexiglass	10.2	19.3	366,700
PVC	13.4	25.3	226,900
Polyethylene	0.7	1.3	25,700
Plastic bags	0.7	1.3	25,700
Laundry	12.0	22.7	162,800
Paper	6.6	12.5	89,600
Wood	3.6	0.8	48,800
Rubber	15.7	29.7	258,100
Carbon steel	3.6	6.8	0
Aluminum	4.8	9.1	0
Conduit	9.8	18.5	0
Electrical wire	9.8	18.5	92,500
Glass	3.0	5.7	0
Iron oxide (plutonium tracer)	1.8	3.4	0
Oil	4.3	8.1	153,900
Totals	100%	189	1,450,700

*Greenhalgh 1988.

BTU = British thermal unit.

PVC = polyvinyl chloride.

6.0 TRANSURANIC WASTE STORAGE FACILITIES

The safe operation of WRAP and other waste handling facilities is based on keeping waste covered and contained in 208-L (55-gal) steel drum. Waste drums to be processed in WRAP 1 are at least half newly generated waste, and half retrieved waste. The retrieved drums, before entering WRAP, are required to be vented (vent clips or HEPA filters) and the inner air purged to remove any build up of flammable or combustible gases such as hydrogen. All waste drums are then kept sealed and covered until they are placed inside a glovebox for processing. Drums not requiring processing are kept covered. Because there is essentially no exposed waste to ignite, or to easily propagate fire, it is considered extremely unlikely that any of the contained waste will be involved in a fire without accidental breakage of the drum containment.

6.1 ESTIMATED FIRE FUEL LOADING FOR THE WASTE RECEIVING AND PROCESSING FACILITY

WRAP is designed to process about 6,825 drums a year of both newly generated and retrieved waste. Anticipated maximum waste drum inventories are 357 drums in the Shipping/Receiving area, 23 drums in the NDA/NDE assay area, and 40 drums in Special Processing, totaling 420 waste drums. WHC-EP-0225, *Contact-Handled Transuranic Waste Characterization Based on Existing Records* (Anderson et. al 1990) describes the general characteristics of contact-handled TRU wastes stored at the Hanford Site since 1977. Table 4-5 of the document approximates the average composition of the drummed solid waste. This composition is listed in volume percent and is listed in the following table in the first column. Volume percents are difficult to work with and are not readily used to estimate reproducible contents. Therefore, the density values listed below and averaged from in Table used to convert volume percent to weight percent: paper 0.64 g/cc, cloth 0.74, rubber (neoprene) 1.37, polyethylene plastic 0.97, PVC plastic 1.34, tape 1.00, metal (general such as aluminum) 3.6, stainless steel 7.0, dirt 2.3, filters 0.86, wood 0.5, concrete 2.2, cement 1.7, glass 1.0, and absorbent 1.0 g/cc.

The approximate drum volume for each specific waste was derived from the listed volume percent. The weight of that volume of material was tabulated using the listed densities. The material weights were added up, and the weight percent of each item was computed neglecting the effect of varying void volumes. WHC-EP-0225 lists the average waste drum weight generated after 1977 at 79 kg (174 lb). The empty weight of waste drums varies from 23 to 29 kg (50 to 65 lb), but most in storage are assumed to weight 23 kg (50 lb) and that would be the lowest weight value. Therefore, the net weight of waste would be 56 kg (124 lb). The weight content estimate for the average drum was then established by multiplying the constituent weight percents by 56 kg (124 lb). The results are given in Table 14 and the estimated fire fuel loading is estimated from the resulting weights.

The preliminary design report for WRAP determines the size of the building at 51,300 ft². and calls for a pre-engineered metal building with concrete flooring (DOE-RL 1991). A metal (steel) building with concrete floors exhibits a very low fire fuel loading. Fuel loading contributors

include paint and other protective coatings, electrical wiring, machinery and equipment including lubricants and hydraulic oils, and insulation, most of which contribute little to fire loading. The largest contributor, and the item that essentially sets the fire loading is the waste inventory. Assuming that the designed maximum of waste drums (420) are either stored or handled in the facility, then the BTU's available are calculated as the multiple of 420 by 484,000 giving a total of 2.03×10^8 BTUs. The average fire fuel loading for the facility would then be 2.03×10^8 BTUs divided by 51,300 ft². This gives a total fire fuel loading of 3,963 BTU/ft². The facility will store and handle other types of waste containers, but the drummed waste is the large volume item. The maximum fuel loading contribution from all of the waste would not be any larger than double the waste drum value or 7,925 BTU/ft². This is considered a very low fuel loading, and even if the maximum waste fuel loading was doubled to account for paint and other building items, the building would still be categorized as low fire fuel loading ($<1.0 \times 10^5$ BTU/ft²) (Lees 1980).

Table 14. Characteristics of the Average Transuranic Waste Drum.

Constituent	Volume (%)	Volume (cc)	Density (g/cc)	Weight (g)	Weight (%)	Weight (lb)	BTUs
Metal	19.0	39,520	3.6	142,272	38.9	48.2	0
Stainless steel	3.0	6,240	7.0	43,680	12.0	14.9	0
Dirt	4.0	8,320	2.3	19,136	5.3	6.6	0
Filters	1.0	2,080	0.86	1,789	0.5	0.6	2400
Wood	1.0	2,080	0.5	1,040	0.3	0.4	3200
Rubber (neoprene)	8.0	16,640	1.37	22,797	6.3	7.8	67,780
Plastic (poly) 50%	13.5	28,080	0.97	27,238	7.5	9.3	184,050
Plastic (PVC) 50%	13.5	28,080	1.34	37,627	10.3	12.8	114,820
Paper	20	41,600	0.64	26,624	7.3	9.0	64,530
Cloth	6	12,480	0.74	9,235	2.5	3.1	22,230
Concrete	1.0	2,080	2.2	4,576	1.2	1.5	0
Cement	1.0	2,080	1.7	3,356	1.0	1.2	0
Oxide	1.0	2,080	3	6,240	1.7	2.1	0
Glass	1.9	4,160	1.9	7,904	2.1	2.6	0
Absorbent	1.0	2,080	0.6	1,248	0.3	0.4	0
Other (tape, etc.)	5.0	10,400	1.0	10,400	2.8	3.5	25,100
Totals	99.9	208,000	--	--	100.0	124.0	484,110

BTU = British thermal unit.
PVC = polyvinyl chloride.

7.0 PRELIMINARY FIRE TEST

There are still facts and information to discover or determine concerning the combustion characteristics of solid waste. To help provide some of this data a fire test was planned and implemented.

The fire test was conducted on Tuesday, December 28, 1993 to assess the performance of steel drums in containing or protecting solid waste. Four drums of simulated solid waste were placed in a steel storage rack in a 2 by 2 (2 rows stacked 2 high) configuration. Two of the drums simulated waste loads consistent with Table 15 having a minimum of 20.8 kg (45.9 lb) of combustibles in each drum. The other two drums were 95 percentile (heavily loaded combustible) drums containing 1.962 times more combustibles than the average or a minimum of 40.9 kg (90.1 lb). Assuming a normal distribution of loaded waste drums, these 95 percentile drums would contain as much combustibles or more than any random 95 out of 100 waste drums. These drums were placed in an old wooden office building (1703-D) that was scheduled for a demolition burn. Wooden pallets were placed in the building to initiate the demolition burn. The addition of wood pallets placed the building into a medium category of fire fuel loading for a commercial building having at least 1.1×10^5 BTU/ft². Four piles of pallets were placed around the test rack (544 kg [1,200 lb]), a 45 kg (100 lb) of wood, and a pile of building debris also was placed in the rear of the rack. The burn was completed after 2 hours. A complete report on the fire test including results has been completed and released for distribution (Greenhalgh et al. 1994), highlights of the test are provided below.

Photos 7 through 9 show the building in the midst of the burn and Photo 10 shows the test rack with drums after the burn. The drums were vented, but all bulged from the heat of the burn. One lid bulged more than the rest and separated from the clamp ring exhibiting about a 4 to 5 in. long opening. However, none of the solid contents appeared to be lost during the burn. The heat caused waste vaporization, or pyrolysis, that vented to the outside of the drum and burned. This fire torch effect can be seen on video tapes of the event. Despite the vapor loss, recoveries on combustibles were 77 wt% or better. In addition, zirconium oxide placed randomly in each drum, to act as a chemical tracer in the event of a spill or leak, was recovered to better than 94 wt%. The residual tracer was not considered lost but was trapped in melted plastic residues that were difficult to isolate and analyze.

The steel drum containers used were galvanized. The fire burned, or melted off, most of the outside galvanizing material. Also, vented gases passing through the HEPA filter from inside the drum deposited substantial zinc, indicating a loss of inner galvanizing material but no appreciable zirconia. The steel drum wall thickness appeared to remain unchanged (no noticeable losses). Temperatures incurred in the fire test include up to 1,750 °F inside the drums and up to 1,837 °F on the middle rack and indicators of at least 2,000 °F on the top of the steel rack. In addition, some window glass of the 1703-D Facility was melted and deformed by the fire.

8.0 SUMMARY AND CONCLUSIONS

The following conclusions were reached from the information contained in this report:

- The average TRU combustible waste drum defined by document WHC-EP-0225 has more weight and includes more waste than the average waste drum from actual waste surveys (conservative estimate). However, the average line waste generated by Babcock and Wilcox had a higher fuel loading primarily because of the very high plastic content.
- The fire fuel loading of the average TRU waste drum in storage is just under 500,000 BTU/drum.
- Storage and handling of 420 drums or less in WRAP does not add appreciably to the fire fuel loading, and unless other combustible furnishings, equipment, lubricants, paints, or other materials are added to WRAP operations, it is expected to remain in the low fire loading rating for commercial buildings. It is recommended that this conclusion be confirmed by a professional fire engineer.
- The Mound incineration work, and the 1703-D fire test supports the use of a steel drum as a container that can hold waste and contain it in a low or medium fuel load fire situation.
- The steel drum containers in the Fire Test suffered lid bulging, loss of galvanizing, and one lid separated, but the drums remained otherwise intact and did not spill nor leak any solid materials.
- The fire test showed that except for fire torches, there was no indication of fire propagation with the drummed combustible waste in the 1703-D medium fuel load commercial fire situation.
- The common waste material presenting the greatest fire fuel loading value per pound is polyethylene plastic at just under 20,000 BTU's/lb. Fuel load minimization efforts such as replacing polyethylene plastic with PVC in radioactive operations should be considered and used when possible to enhance fire safety for drummed waste.

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Photo 1. 1703-D Fire Test in Progress.

Photo 2. Overall View of the 1703-D Demolition Burn.

Photo 3. View of the Test Rack and Drums During the Burn.

Photo 4. View of the Test Rack and Drums After the Fire Test.

Photo 5. Testing Drum of the Waste Receiving and Processing
Shred/Grout in Gasoline Diesel Fire. (sheet 1 of 4)

Photo 5. Testing Drum of the Waste Receiving and Processing
Shred/Grout in Gasoline Diesel Fire. (sheet 2 of 4)

Photo 5. Testing Drum of the Waste Receiving and Processing Shred/Grout in Gasoline Diesel Fire. (sheet 3 of 4)

Photo 5. Testing Drum of the Waste Receiving and Processing
Shred/Grout in Gasoline Diesel Fire. (sheet 4 of 4)

Photo 6. Igniting Cement Solid Containing 35% Tributyl
Phosphate-Normal Paraffin Hydrocarbon Solvent.

Photo 7. Ignited Cement Solid Containing 35% Tributyl
Phosphate-Normal Paraffin Hydrocarbon Solvent Goes
out When Ignition Burner is Extinguished.

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