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Re-evaluation of the 1995 Hanford Large Scale Drum Fire Test Results

J. M. Yang

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Re-evaluation of the 1995 Hanford Large-Scale Drum Fire Test Results

A large-scale drum performance test was conducted at the Hanford Site in June 1995, in which over one hundred (100) 55-gal drums in each of two storage configurations were subjected to severe fuel pool fires. The two storage configurations in the test were pallet storage and rack storage. The description and results of the large-scale drum test at the Hanford Site were reported in WHC-SD-WM-TRP-246, "Solid Waste Drum Array Fire Performance," Rev. 0, 1995. This was one of the main references used to develop the analytical methodology to predict drum failures in WHC-SD-SQA-ANAL-501, "Fire Protection Guide for Waste Drum Storage Array," September 1996.

Three drum failure modes were observed from the test reported in WHC-SD-WM-TRP-246. They consisted of seal failure, lid warping, and catastrophic lid ejection. There was no discernible failure criterion that distinguished one failure mode from another. Hence, all three failure modes were treated equally for the purpose of determining the number of failed drums. General observations from the results of the test are as follows:

- Trash expulsion was negligible.
- Flame impingement was identified as the main cause for failure.
- The range of drum temperatures at failure was 600°C to 800°C. This is above the yield strength temperature for steel, approximately 540°C (1,000°F).
- The critical heat flux required for failure is above 45 kW/m².
- Fire propagation from one drum to the next was not observed.

The statistical evaluation of the test results using, for example, the student's *t*-distribution, will demonstrate that the failure criteria for TRU waste drums currently employed at nuclear facilities are very conservative relative to the large-scale test results. Hence, the safety analysis utilizing the general criteria described in the five bullets above will lead to a technically robust and defensible product that bounds the potential consequences from postulated fires in TRU waste facilities, the means of storage in which are the Type A, 55-gal drums.

1.0 Introduction

A large-scale drum performance test was conducted at the Hanford Site in June 1995, in which over one hundred (100) 55-gal drums in each of two storage configurations were subjected to severe fuel pool fires. The two storage configurations in the test were pallet storage and rack storage. The description and results of the large-scale drum test at the Hanford Site were reported in WHC-SD-WM-TRP-246, "Solid Waste Drum Array Fire Performance," Rev. 0, 1995 (Reference 1).

Three drum failure modes were observed from the test reported in WHC-SD-WM-TRP-246. They consisted of seal failure, lid warping, and catastrophic lid ejection. There was no discernible failure criterion that distinguished one failure mode from another. In addition, there was no discernible correlation in the failure data among the location, heat flux, temperature, and pressure.

A statistical analysis on the failure data was not performed in WHC-SD-WM-TRP-246. Hence, the failure data in WHC-SD-WM-TRP-246 are re-examined in this paper to determine the degree of conservatism associated with the safety analysis commonly performed on TRU waste storage facilities in DOE/EM. Re-examination of the data in WHC-SD-WM-TRP-246 is mainly focused on the pallet storage configuration, which is the predominant storage configuration in the DOE/EM complex. In particular, a statistical analysis, based on the Student's *t*-distribution, is performed to estimate the conservative failure criteria for the heat flux and the temperature when subjected to a severe fuel pool fire.

2.0 The Hanford large-scale drum fire test

A large-scale drum performance test was conducted at the Hanford Site in June 1995, in which more than one hundred (100) 55-gal drums in each of two storage configurations were subjected to severe fuel pool fires. The two storage configurations in the test were pallet storage and rack storage. This test was a continuation in a series of tests, which were small scale and involved only a few drums, performed at SNL, LLNL, and INEEL. The summary of these tests is provided in Appendix A to WHC-SD-WM-TRP-233, "Analytical and Experimental Evaluation of Solid Waste Drum Array Fire Performance," Rev. 0, 1995.

The description and results of the large-scale drum test at the Hanford Site were reported in WHC-SD-WM-TRP-246, "Solid Waste Drum Array Fire Performance," Rev. 0, 1995 (Reference 1). This was one of the main references used to develop the analytical methodology to predict drum failures in WHC-SD-SQA-ANAL-501, "Fire Protection Guide for Waste Drum Storage Array," September 1996. The analytical approach in WHC-SD-SQA-ANAL-501 is in turn used to perform the accident analysis involving TRU waste drums in the DOE/EM complex.

Three drum failure modes were observed from the test reported in WHC-SD-WM-TRP-246. They consisted of seal failure, lid warping, and catastrophic lid ejection. There was no discernible failure criterion that distinguished one failure mode from another. Hence, all three failure modes were treated equally for the purpose of determining the number of failed drums. General observations from the results of the test are as follows:

- Trash expulsion was negligible.
- Flame impingement was identified as the main cause for failure.

- The range of drum temperatures at failure was 600°C to 800°C.
- The critical heat flux required for failure is above 45 kW/m².
- Fire propagation from one drum to the next was not observed.

A complete set of the measured data from the large-scale fire tests for rack storage and pallet storage configurations is excerpted and summarized in Table 1 at the end of the document. The test results for the two drum storage configurations are summarized below.

2.1 Pallet storage test

Of the twenty-two failed drums that failed in one of the three failure modes, only seven drums were instrumented and yielded the failure flux data. For those seven drums, the measured radiant heat flux at failure ranged from 77 kW/m² to 200 kW/m². The measured temperature at failure ranged from 526°C to 951°C. Observations and recommendations for the pallet storage test in Reference 1 are as follows:

- A total of 135 liters (36 gal) of diesel was used that was spread over an area of 9.3 m². In addition, 9.5 gal of gasoline was added to ensure even combustion.
- 144 drums on pallets, four drums on a pallet, were stacked three-level high.
- The magnitude of the fire was 14.5 MW lasting approximately 5 minutes.
- Of the 144 drums, there were 24 drums directly inside the fuel pool as shown in Figure 1. Fourteen of the twenty-four (24) drums engulfed in the fuel pool fire failed.
- The total number of failed drums, including those with failed seals, was twenty-two (22) as shown in Tables 9 and 11 of WHC-SD-WM-TRP-246. This represents a 15% (22/144) failure rate.
- Only three drums, two in the fuel pool fire at the bottom two tiers and one adjacent to the fire at the bottom tier, failed by lid ejection. Of the remaining nineteen (19) failed drums, seal failure occurred in eleven drums (50% of the total failure).

Seven of the twenty-two failed drums in the pallet storage configuration were located outside the fuel pool fire. For the two failed drums with low measured temperatures at failure below 600°C, failure occurred well after the fuel pool fire was extinguished. Failure times were 363 seconds and 763 seconds at 538°C and 526°C for O831 and O743, respectively. The measured temperature and pressure for the failed drums on pallets are graphically shown in Figure 2. A histogram of the failure temperature data is shown in Figure 3.

2.2 Rack storage test

The total failure rate in the rack storage test is higher because of the increased fire severity. The magnitudes of the rack storage test fire is 25.6 MW, higher than 14.5 MW in the pallet storage test. The measured temperature at failure ranged from 339°C to 760°C. For the seven drums, the measured radiant heat flux at failure ranged from 64 kW/m² to 165 kW/m². Observations in Reference 1 are as follows:

- A total of 265 liters (70 gal) of diesel was spread over an area of 16.6 m². In addition, 5 gal of gasoline was added to ensure even combustion.

Figure 1. Pallet storage array fire test (Figure 6, Reference 1).

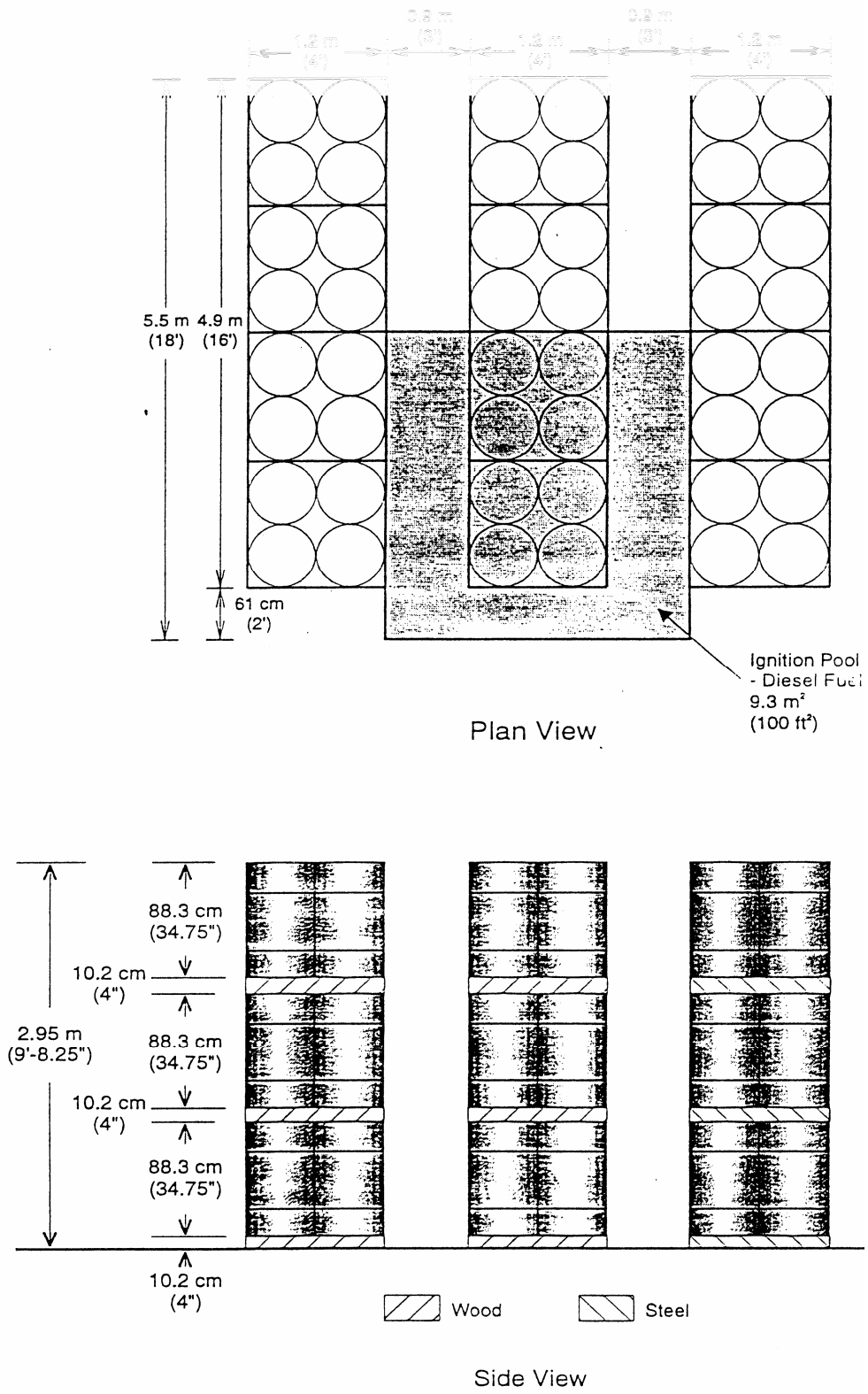
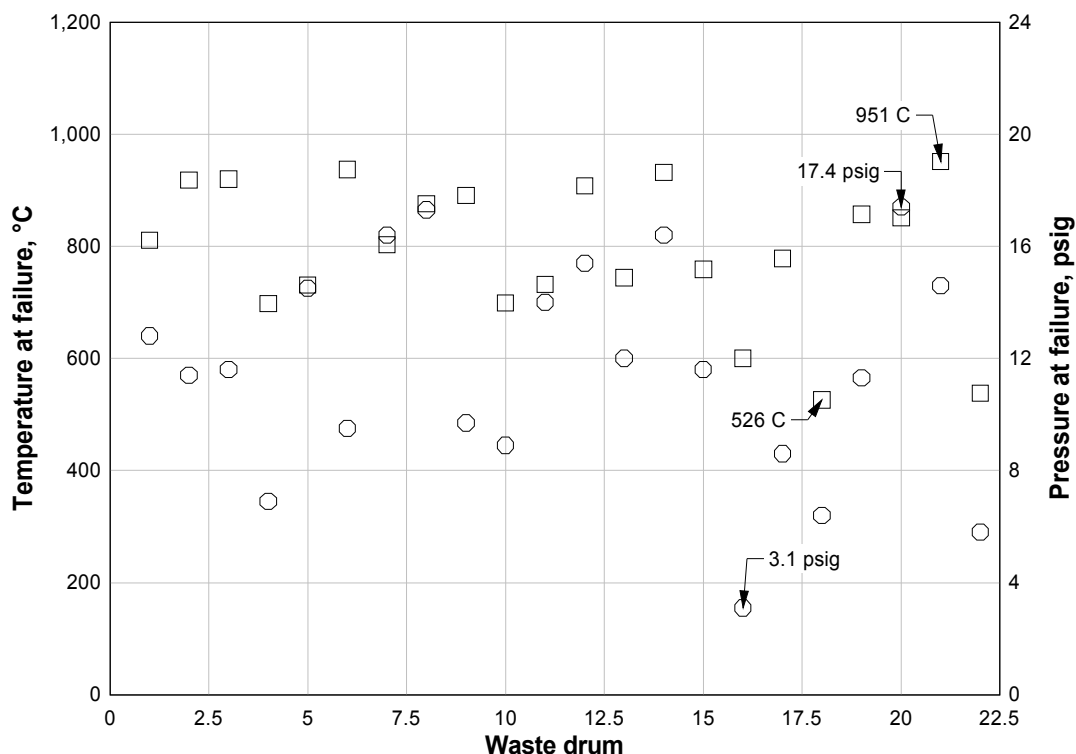


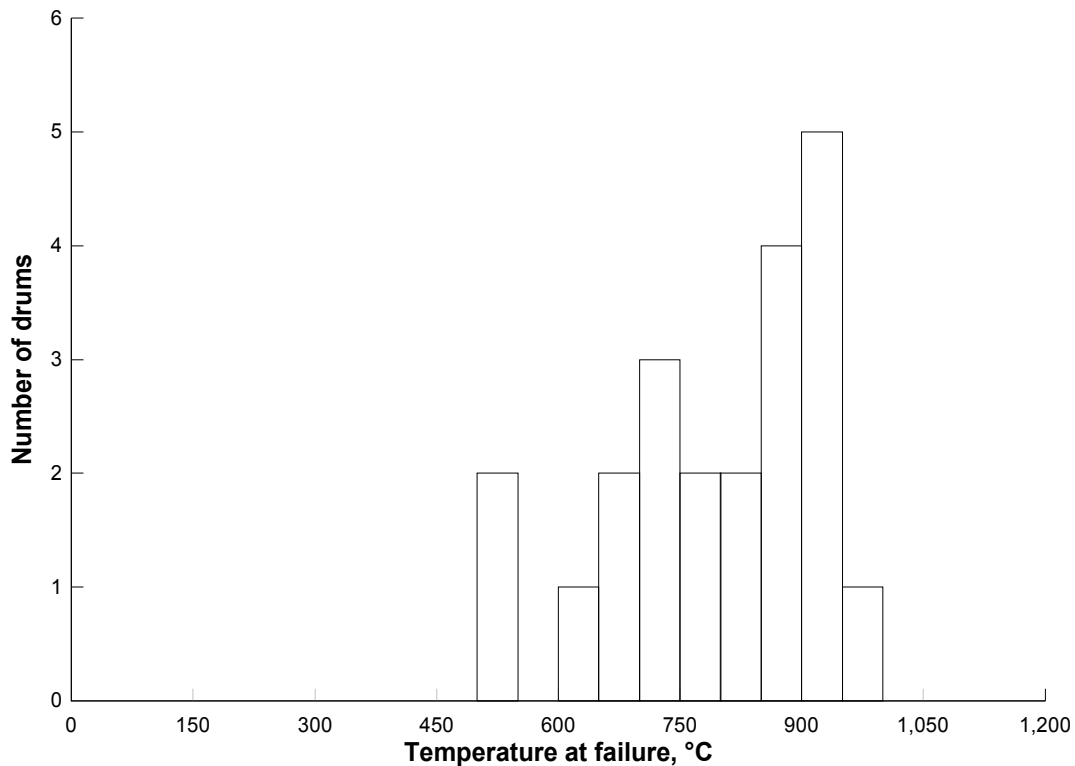
Figure 2. Pallet storage array fire test data.

- The magnitude of the fire was 25.9 MW lasting approximately 5 minutes.
- 144 drums in racks were arranged in six levels high.
- The text in Section 8.2.1 and Section 8.2.2, consistent with those in Figure 58 and Table 12, in WHC-SD-WM-TRP-246 states that a total of 37 drums failed. The number of failures also includes those due to seal failures. The resultant failure rate is 26% (37/144).
- 48 drums of the 144 drums were directly in the fuel pool fire, of which 35 drums failed.

Six instrumented drums in the rack storage configuration located outside the fuel pool did not fail. Of those, four instrumented drums—X251, X253, X254, and X352—located outside the fuel pool fire provided the heat flux data. The measured heat flux ranged from 23 kW/m² to 37 kW/m². The data associated with these drums that did not fail can provide additional assurance that the selected failure criterion for the heat flux is reasonable. Also, it appears that data for few of the failed drums are not provided in Reference 1.

The increased number of 37 failures in the rack storage test may be due to the increased magnitude of the fire. For both pallet and rack storage tests, the predicted failure rates prior to the tests were higher, at 48/144 and 45/144, respectively, than the test data as shown in Table 12 in Reference 1. While the fraction of failed drums engulfed in the fuel pool fire is higher at 64% (46/72), flooding a nuclear facility with gasoline or diesel is not credible. It would take a total of 410 gal of gasoline to flood a 40-ft×40-ft compartment to sustain a fire for 140 seconds. Hence, the failure rate of engulfed drums alone, which is higher, is not likely to be relevant for evaluating accident conditions in a TRU waste storage facility.

Figure 3. Distribution of the number of failed drums at measured temperature with an interval of 50°C from the pallet storage data.



3.0 Analysis using Student's *t*-distribution

A statistical distribution published by William Gosset in 1908. His employer, Guinness Breweries, required him to publish under a pseudonym, so he chose “Student.” Given N independent measurements x_i , let

$$t \equiv \frac{\bar{x} - \mu}{s / \sqrt{N}} \Rightarrow \mu = \bar{x} \pm t \frac{s}{\sqrt{N}} \quad (1)$$

where μ is the population mean, \bar{x} is the sample mean, and s is the estimator for the unknown population standard deviation, σ , or simply the sample standard deviation. The sample standard deviation is calculated from the sample variance, as follows:

$$s^2 = \frac{1}{N-1} \sum_{i=1}^N (x_i - \bar{x})^2 \quad (2)$$

The Student's *t*-distribution is defined as the distribution of the random variable t that is (very loosely) the “best” estimate without knowing σ . The Student's *t*-distribution assumes that the general population, from which the sample is drawn, is normally distributed. Based on Equation 1, the upper and lower limits of the true population mean, μ , can be estimated as follows:

$$\bar{x} - t \frac{s}{\sqrt{N}} \leq \mu \leq \bar{x} + t \frac{s}{\sqrt{N}}$$

The standard error of the mean of a sample from a population is the standard deviation of the sampling distribution of the mean, and may be estimated by the formula:

$$S_E = \frac{s}{\sqrt{N}}$$

where s is an estimate of the standard deviation, σ , of the population. N is the sample size. Using data in Table 1, the sample mean, the sample variance, and the sample standard deviation of the temperature at failure, \bar{x} , s^2 , and s , are 793.6°C, 16,054, and 126.7°C, respectively. The standard error of the sample mean, S_E , is 27.01. Results of the statistical analysis for the pallet storage test are shown in Table 2.

Table 2. Statistical analysis results of the measured drum temperature at failure based on the Student's t -distribution.

	Drum No.	Temperature at failure, °C	Radiant heat flux at failure, kW/m ²	$(x_i - \bar{x})^2$	
1	O831	538	85	65350	2070
2	O813	951	NM	24763	NC
3	O812	851	NM	3291	NC
4	O811	857	NM	4015	NC
5	O743	526	NM	71629	NC
6	O742	778	NM	244.5	NC
7	O741	600	NM	37495	NC
8	O723	759	NM	1200	NC
9	O722	932	NM	19144	NC
10	O721	744	NM	2464	NC
11	O713	908	NM	13079	NC
12	O711	732	NM	3799	NC
13	O641	699	77	8956	2862
14	O633	891	81	9480	2450
15	O632	876	135	6784	20.25
16	O631	803	166	87.68	1260
17	O612	937	NM	20553	NC
18	O611	731	NM	3923	NC
19	O541	698	NM	9146	NC
20	O533	920	124	15968	42.25
21	O532	918	176	15466	2070
22	O521	811	200	301.5	4830
sample mean, \bar{x}				793.6	130.5
sample size, N				22	8
sample variance, s^2				16054	2229
sample standard deviation, s				126.7	47.22

From Appendix D in Reference 4, the value of t for a sample size of 22, i.e., the degree of freedom of 21, with the 95% confidence level is 2.08. The estimate of the lower limit of the population mean, μ , of the temperature is then:

$$\mu \geq \bar{x} - t \frac{s}{\sqrt{N}} = \bar{x} - S_E t = 793.6 - 126.7 / \sqrt{22} \times 2.08 = 737.5$$

Similarly, the value of t for a sample size of 8 and the estimate of the lower limit of the mean heat flux at failure at the 99% confidence level are 3.499 and 72.08 kW/m², respectively. Results of the statistical analysis for the measured temperature and heat flux data at failure for the two storage configurations at 95% and 99% confidence intervals are summarized in Tables 3 and 4, respectively.

Table 3. Statistical analysis results of the measured drum temperature at failure based on the Student's t -distribution.

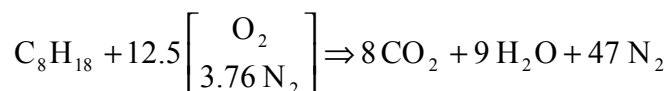
	Sample mean	Standard error of the mean	Sample size	Lower limit of the mean at 95% CL	Lower limit of the mean at 99% CL
Pallet storage	793.6	27.01	22	737.5	717.2
Rack storage	588.2	30.02	17	524.5	500.5
Combined	704.1	25.81	39	651.8	634.1

Table 4. Statistical analysis results of the measured heat flux at failure based on the Student's t -distribution.

	Sample mean	Standard error of the mean	Sample size	Lower limit of the mean at 95% CL	Lower limit of the mean at 99% CL
Pallet storage	130.5	16.69	8	91.03	72.08
Rack storage	101.8	10.67	11	78.05	68.02
Combined	113.9	9.662	19	93.59	86.08

4.0 Results and discussion

The adiabatic flame temperature from complete combustion of a stoichiometric air-octane mixture under ideal conditions was computed using Cheetah 2.0 (Reference 8) to confirm the experimental observation that flame impingement is the main cause for drum failure. Gasoline is octane with oxygenate or additives to reduce pollution. For simplicity, combustion of a stoichiometric octane-air mixture is shown below:



The computed adiabatic flame temperature is 2,238°K (1,965°C, Reference 2). A fuel pool fire would be rich in fuel, as evidenced by black smoke in most fuel pool fires, leading to a lower flame temperature. For example, an equivalence ratio of 2, i.e., twice as much fuel in the mixture as that in the stoichiometric mixture, yielded an adiabatic flame temperature of 1,512°K

(1,238°C). Even for a rich mixture, computed flame temperatures would indicate a significant thermal stress on the structural integrity of drums and appear to confirm that flame impingement is the main cause of the drum failure.

Figure 3-11.11 in Reference 3 shows a decreasing trend of the average emissive power with increasing diameters of fuel pool fires in open air. Data in Table 3-11.4 in Reference 3 show a wide range of measured emissive powers from 10 kW/m² for smoky fires to 280 kW/m². The average flame emissive power, \dot{q}''_{fl} , is computed using the equation below (Reference 3):

$$\dot{q}''_{fl} = 140 \times \exp\{-0.12 \times D_{eq}\} + 20 \times (1 - \exp\{-0.12 \times D_{eq}\})$$

The equivalent diameter of the 100-ft² diesel fuel pool is 3.44 m. The calculated flame emissive power of the fire in the large-scale fire test is 99 kW/m², consistent with the calculated results in Reference 1. The flame emissive power also appears to confirm that flame impingement is the main cause for failure.

4.1 Analysis of the combined test data

The sample size of the failed drums is relatively small even in the large scale fire test. There is also uncertainty associated with the assumed distribution of the failure data as presented in Figure 3 for the pallet storage configuration alone. It is therefore prudent to examine the combined failure data to derive the failure criteria for drums when subjected to a severe fuel pool fire. It is also prudent to use the 99% confidence level results because even the combined sample size is relatively small. The combined failure data are shown in Figure 4. Histograms of the heat flux and temperature at failure are shown in Figure 5 and Figure 6 at the end of the document, respectively.

The lower estimate of the heat flux at failure for a large population of drums on pallet when subjected to a severe fire is above 72 kW/m² with the 99% confidence level. In comparison, the lower estimate of the heat flux at failure for a large population of drums when subjected to a severe fire is above 68 kW/m² with the 99% confidence level for the rack storage. Both are clearly above 45 kW/m², commonly used as the failure criterion in the DOE/EM complex, as observed in Reference 1.

Because the magnitude of the fire in the rack storage test is greater than that of the pallet storage test, the difference in the mean values at failure may be statistically significant. To confirm this hypothesis, mean values of the heat flux and temperature at failure from the two storage configurations in the large-scale fire are tested. First, the heat flux data are tested from the two storage configurations, as follows:

$$s_{\bar{x}_1 - \bar{x}_2} = \sqrt{\frac{s_1^2}{N_1} + \frac{s_2^2}{N_2}} = \sqrt{\frac{2,229}{8} + \frac{1,251}{11}} = 19.81$$

Second, the Z value for the two tailed test is calculated to determine whether the difference in the two means is significant, as follows:

$$Z = \frac{\bar{x}_1 - \bar{x}_2}{s_{\bar{x}_1 - \bar{x}_2}} = \frac{130.5 - 101.8}{19.81} = 1.448 \leq 1.96 < 2.576$$

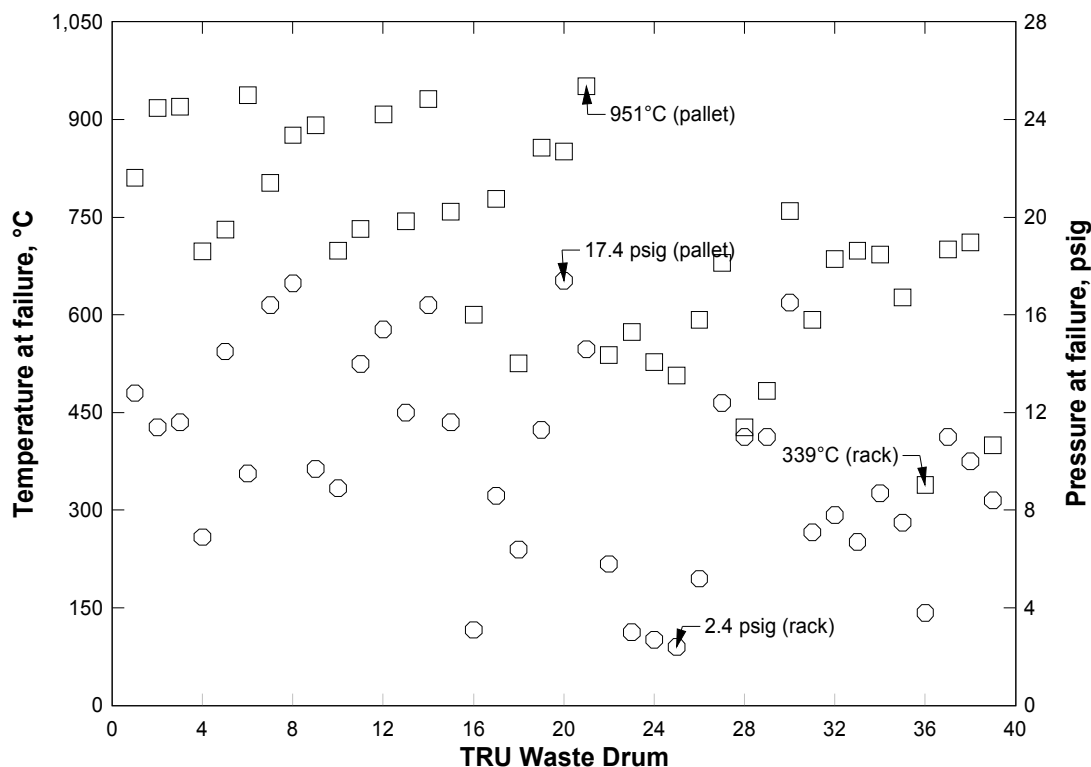
The result indicates that the difference between the two mean values is due to chance at a level of significance of 0.05 ($t_{\infty} = \pm 1.96$ from Appendix D in Reference 4) and 0.01 ($t_{\infty} = \pm 2.576$). Stated otherwise, the difference in the mean heat flux at failure is not sensitive to the storage configuration and the magnitude of the fire. Further, based on the statistical analysis, a better estimate of the conservative heat flux criterion for failure of TRU waste drums when subjected to a severe fire is 68 kW/m^2 with the 99% confidence level. This is above 45 kW/m^2 as observed in Reference 1.

As mentioned previously, there were four drums in the rack storage test—X251, X253, X254, and X352—located outside the fuel pool fire with measured heat flux data that did not fail. The measured heat flux ranged from 23 kW/m^2 to 37 kW/m^2 . The data associated with these drums that did not fail provide additional assurance that the selected failure criterion for the heat flux is reasonable.

For the pallet storage configuration alone, the lower estimate of the temperature at failure for a large population of drums when subjected to a severe 14.5-MW fuel pool fire is above 717°C with the 99% confidence level. This is clearly well within the failure temperature range of 600°C to 800°C stated in Reference 1.

For the rack storage configuration alone, however, the lower estimate of the temperature at failure for a large population of drums when subjected to a severe 25.9-MW fuel pool fire is above 500°C with the 99% confidence level. This is out of the failure temperature range discussed in Reference 1. Hence, the difference in mean values may be statistically significant.

Figure 4. Combined pallet storage and rack storage fire test data.



To test the hypothesis on the failure temperature, mean values from the two tests are tested:

$$\sigma_{\bar{x}_1 - \bar{x}_2} = \sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}} = \sqrt{\frac{16,054}{22} + \frac{15,318}{17}} = 40.38$$

Again, the Z value for the two tailed test is calculated to determine whether the difference in the two means is statistically significant, as follows:

$$Z = \frac{793.6 - 588.2}{40.38} = 5.088 \geq 2.576 > 1.96$$

The calculated value of Z is greater than 1.96 and 2.576, which indicates that the difference between the two mean values is statistically significant at a level of significance of 0.05 ($t_{\infty} = \pm 1.96$) and 0.01 ($t_{\infty} = \pm 2.576$). The test data do not allow a separate analysis to distinguish the effect of the magnitude of the test fire and the effect of the storage configuration. It is inferred that the temperature at failure is sensitive to the magnitude of the fire and, to a lesser extent, the storage configuration.

4.2 Effect of steel pallet

Little known or analyzed in the large scale drum fire test is the effect of the steel pallet on the drum failure in a fuel pool fire. One third of the drums in the pallet storage test was stored on steel pallets. These were on Rows 4 and 5. Of the 48 drums stored on steel pallets, only four drums failed: O521, O532, O533, and O541. Of the 48 drums stored on wooden pallets outside the fuel pool, only four drums failed: O831, O813, O812, and O811. The results are not statistically significant to be conclusive.

Although the benefit of the steel pallet is not apparent from the large scale test data, it is generally a good practice to maintain the combustible loading in TRU waste storage facilities at a low level. This is consistent with the recommendation in Section 8.2.2 in Reference 1.

5.0 Conclusion and recommendations

The sample size of the failed drums is relatively small even in the large scale fire test. Consequently, there is uncertainty associated with the assumed distribution of the failure data. As a result, it is prudent to establish conservative failure criteria for TRU waste storage. For added assurance, the failure criteria with a 99% confidence interval are recommended and used. In general, recommended failure criteria derived from on the statistical analysis compare favorably with the observations and recommendations in Reference 1. They are discussed as follows:

- **Trash expulsion was negligible.**
- **Flame impingement is the main cause for failure.**

The calculated flame emissive power of the fire in the large-scale fire test is 99 kW/m². The calculated adiabatic flame temperature for octane (a substantial constituent of gasoline) with an equivalence ratio of 2, i.e., twice as much fuel in the mixture as that in the stoichiometric mixture, is 1,512°K (1,238°C). The calculated adiabatic flame temperature and the flame emissive power appear to confirm that flame impingement is the main cause for failure.

- **The range of drum temperatures at failure was 600°C to 800°C.**

The test data do not allow a separate analysis to distinguish the effect of the magnitude of the test fire and the effect of the storage configuration. It is inferred from the analysis that the temperature at failure is sensitive to the magnitude of the fire and, to a lesser extent, the storage configuration. For TRU waste drums on pallets subjected to a severe fire with a magnitude equal to or less than 14.5 MW, the recommended failure criterion is 700°C. When subjected to a severe fire greater than 14.5 MW, the recommended failure criterion is 500°C.

- **The critical heat flux required for failure was above 45 kW/m².**

The heat flux at failure is not sensitive to the storage configuration and the magnitude of the fire. For predicting failures from exposure fires, the commonly used threshold radiant heat flux of 45 kW/m² appears to be low relative to the test data. Based on the analysis, a better estimate of the failure criterion is 68 kW/m².

- **The failure rate for drums on pallets was 15%.**

The total number of failed drums on pallets, including those with failed seals, was twenty-two (22) as shown in Tables 9 and 11 in WHC-SD-WM-TRP-246 (Reference 1). The failure rate includes seal failures, which constitute 50% of the failed drums on pallets. Seal failures of drums would not result in a significant release. The total failure rate conservatively rounded up to 20% represents a bounding estimate of the drum failure in the source term calculation.

Application of the recommended criteria for the heat flux and the temperature in an exposure fire, those not engulfed in a fuel pool fire as in Figure 1, will yield an extremely conservative source term. Those in a fuel pool fire, application of the recommended criteria will yield a conservative source term. Hence, the recommended failure criteria will lead to a technically robust and defensible safety analysis that bounds the potential consequences from postulated fires in TRU waste storage facilities involving the Type A, 55-gal drums.

References

1. WHC-SD-WM-TRP-246, "Solid Waste Drum Array Fire Performance," Rev. 0, Westinghouse Hanford Company, 1995.
2. UCRL-MA-117541, "Cheetah 2.0 User's Manual," Rev. 5, Lawrence Livermore National Laboratory, L.E. Fried, August 1998.
3. *The SFPE Handbook of Fire Protection Engineering*, 2nd ed., Society of Fire Protection Engineers, Boston, MA, 1996.
4. *Probability and Statistics*, Murray R. Spiegel, John Shiller, and R. Alu Srinivasan, Schaum's Outline, 2nd edition, McGraw-Hill, 2000.

Figure 5. Distribution of the number of failed drums at the measured heat flux with an interval of 10 kW/m² from the combined data.

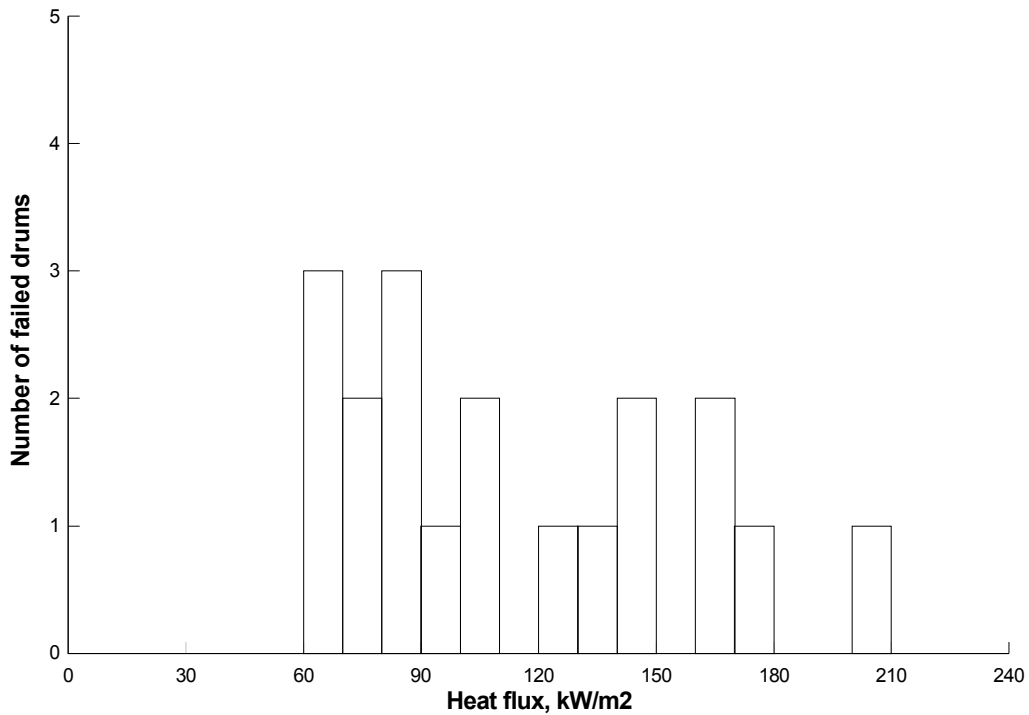


Figure 6. Distribution of the number of failed drums at the measured temperature with an interval of 50°C from the combined data.

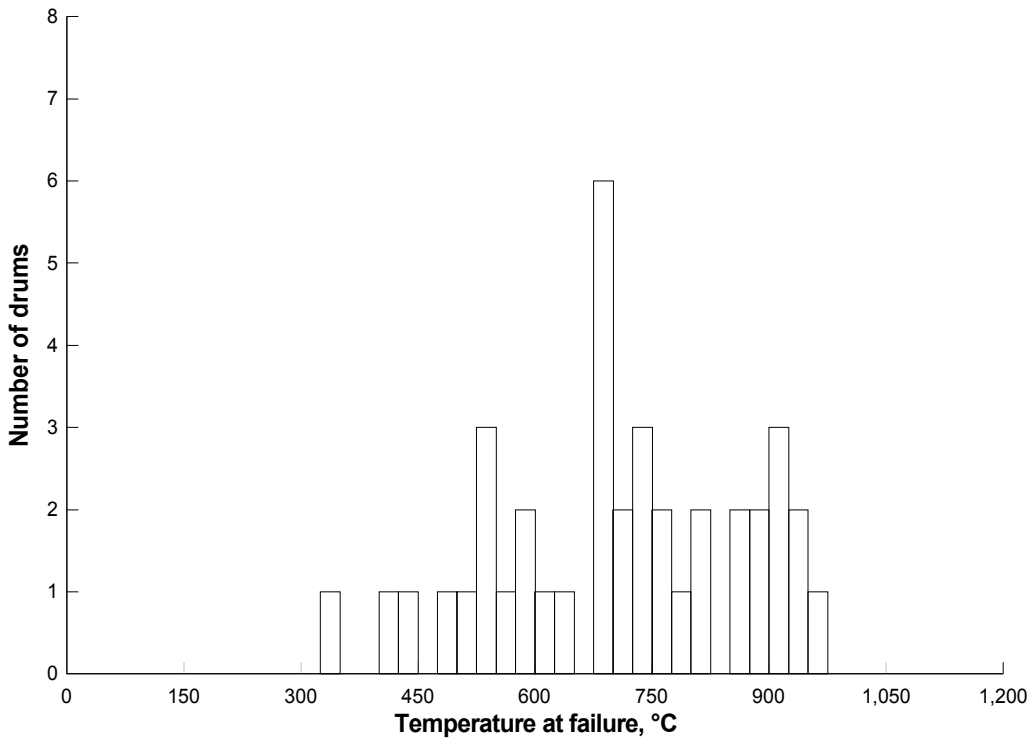


Table 1. Measured drum failure data from the combined rack storage configuration and pallet storage configuration tests.

	Drum No.	Lid Loss or Rupture	Time, s	Temperature, °C	Pressure, psig	Heat flux, kW/m ²	Out of/In Flame	Table No. [†]
1	O521	LID LOSS	203	811	12.8	200	Out	11
2	O532	VENT	212	918	11.4	176	Out	11
3	O533	VENT	254	920	11.6	124	Out	11
4	O541	VENT	292	698	6.9	NM*	Out	11
5	O611	LID RUPTURE	165	731	14.5	NM	In	9
6	O612	VENT	172	937	9.5	NM	In	9
7	O631	LID LOSS	147	803	16.4	166	In	9
8	O632	LID RUPTURE	156	876	17.3	135	In	9
9	O633	LID RUPTURE	245	891	9.7	81	In	9
10	O641	LID RUPTURE	197	699	8.9	77	In	9
11	O711	LID RUPTURE	159	732	14.0	NM	In	9
12	O713	VENT	154	908	15.4	NM	In	9
13	O721	VENT	160	744	12.0	NM	In	9
14	O722	VENT	169	932	16.4	NM	In	9
15	O723	LID RUPTURE	185	759	11.6	NM	In	9
16	O741	VENT	195	600	3.1	NM	In	9
17	O742	VENT	518	778	8.6	NM	In	9
18	O743	VENT	763	526	6.4	NM	In	9
19	O811	LID RUPTURE	156	857	11.3	NM	Out	11
20	O812	LID RUPTURE	152	851	17.4	NM	Out	11
21	O813	LID RUPTURE	175	951	14.6	NM	Out	11
22	O831	VENT	363	538	5.8	85	Out	11
23	X122	VENT	207	574	3.0	68	Out	8
24	X123	VENT	296	528	2.7	64	Out	8
25	X125	VENT	362	507	2.4	NM	Out	8
26	X131	VENT	166	592	5.2	95	Out	8
27	X211	LID RUPTURE	112	680	12.4	NM	In	6
28	X213	LID LOSS	119	427	11.0	NM	In	6
29	X214	LID LOSS	163	483	11.0	NM	In	6
30	X222	LID LOSS	98	760	16.5	142	In	6
31	X224	LID RUPTURE	211	592	7.1	75	In	6
32	X225	LID RUPTURE	236	686	7.8	88	In	6
33	X226	LID RUPTURE	275	699	6.7	109	In	6
34	X231	LID LOSS	162	693	8.7	165	In	6
35	X233	LID LOSS	273	627	7.5	147	In	6
36	X256	VENT	298	339	3.8	NM	Out	8
37	X312	LID RUPTURE	110	701	11.0	NM	In	6
38	X321	LID RUPTURE	122	711	10.0	101	In	6
39	X332	LID LOSS	249	400	8.4	66	In	6

\bar{x}	704.1	113.9
s^2	25975	1,774
s	161.2	42.12
Sample size	39	19
$t(0.025)^{**}$	2.025	2.101
$t(0.01)$	2.713	2.878
Lower limit of the mean at 95% CL	651.8	93.59
Lower limit of the mean at 99% CL	634.1	86.08

† From Reference 1

* Not measured

** From Reference 4