Lockheed Martin Energy Systems Engineering
Engineering Analysis

1700°F Fire
15 Min

ACCIDENT SIMULATIONS USING 6FIRE AND SUBLIME

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James C. Anderson

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Prepared by
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
managing the
Oak Ridge K-25 Site
Oak Ridge Y-12 Plant
under Contract DE-AC05-84OR21400
for the
U.S. DEPARTMENT OF ENERGY

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INTRODUCTION

This "Design Analysis Calculation" (DAC) has been prepared in support of the following projects:

1. Preparation of the K-25 Site Cylinder Storage Yard Final Safety Analysis Report (SAR).
2. Upgrade of the Gaseous Diffusion Plant Safety Analysis Reports (GDP SARs) for the Portsmouth and Paducah GDPs.
3. Preparation of the Depleted UF_6 Programmatic Environmental Impact Statement (PEIS).

The purpose of this DAC is to document the simulation of UF_6 cylinders engulfed in fire to determine the time to rupture, the amount of UF_6 released "instantaneously" at the time of rupture, and the time dependent release of UF_6 after the rupture. These simulations were made using 6FIRE and SUBLIME which have been documented by Williams *[WRW96]* and Anderson *[JCA96]*. Simulations have been limited to 2½-ton cylinders and larger. Smaller cylinders are assumed to fail with the complete release of their contents on the basis of tests conducted at the Oak Ridge Gaseous Diffusion Plant in 1966 *[AJM]*; those tests involved 3½-, 5-, and 8-in. cylinders.

MODELING ASSUMPTIONS

The following cylinders were identified for simulation based on the information provided in Table 1:

Thin-walled 14-ton cylinders (assumed to be 48G)
Thin-walled 10-ton cylinders (assumed to be 48T)
2½-ton cylinders (assumed to be 30A)
2½-ton cylinders (assumed to be 30B)
Thick-walled 14-ton cylinders (assumed to be 48Y)
Thick-walled 10-ton cylinders (assumed to be 48X)

Cylinder characteristics used in the analyses are defined in Table 2 and are derived from ORO-651, Rev.4 *[ORO/4]* except for materials of construction and the characteristics for the 48T cylinder. Characteristics for the thin-walled 48T cylinder were assumed equal to those of a thick-walled 48X cylinder except for wall thickness and cylinder weight. Information in Rev. 5 and 6 of ORO-651 *[ORO/5; ORO/6]* indicates specific steels used for constructing some of the cylinders. Information on cylinder procurement history and materials of construction also appear in a paper by Ziehlke and Barlow *[KTZ]*. This information demonstrates specifically for some cylinders—and the inference is drawn for other cylinders—a change in the material of construction used from A-285 to A-516 steel in the late 1970s. 30B and 48Y cylinders, which were procured after 1978 *[KTZ]*, are assumed to be constructed of A-516 steel; all other cylinders listed above are considered to be constructed of A-285. A-285 has a lower heat capacity and a lower ultimate stress than A-516, so assuming cylinders are constructed of A-285 steel should result in

Table 1. Summary of Cylinders in K-25 Cylinder Yards
(all numbers are based on information provided by C. L. Hedrick)

Cylinder Type	UF$_6$, lb	Depleted	Feed	Enriched	Totals
Full 14-ton thin-walled	> 6400	3220	40	-	3260
Partially full 14-ton thin-walled	125 - 6400	5	10	-	15
Partially full 14-ton thin-walled	50 - 125	-	5	-	5
Heel quantity 14-ton thin-walled	<50	-	15	-	15
Totals, 14-ton thin-walled cylinders		3225	70	-	3295
Full 10-ton thin-walled	> 4800	1450	5	-	1455
Partially full 10-ton thin-walled	50 - 125	-	-	5 †	5
Heel quantity 10-ton thin-walled	< 50	-	-	15 †	15
Totals, 10-ton thin-walled cylinders		1450	5	20	1475
Full 10-ton thick-walled	> 4800	5	10	-	15
Heel quantity 10-ton thick-walled	< 50	-	-	255 †	255
Heel quantity 14-ton thick-walled	< 50	-	-	65 †	65
Totals, thick-walled cylinders		5	10	320	335
Full 2½-ton	> 300	25	1	-	26
Partially full 2½-ton	75 - 300	5	-	-	5
Partially full 2½-ton	25 - 75	-	-	5	5
Heel quantity 2½-ton	< 25	5	-	250	255
Totals, 2½-ton cylinders ‡		35	1	255	291

† Enriched and depleted cylinders combined.
‡ Mostly 30A cylinders; totals include about ten 30B cylinders.

conservative estimates of the time to failure. Principal differences among the 48-in. cylinders are material of construction, wall thickness, and overall size (i.e., length, which impacts cylinder weight and UF$_6$ capacity).

Other assumptions utilized for these simulations include:

Cylinders are assumed to be nominally full (i.e., the mass of UF$_6$ would fill 95% of the volume of the cylinder at 250°F)

Cylinders are fully engulfed in fire

Table 2. Cylinder Characteristics Utilized in 6FIRE or SUBLIME

Characteristics	30A	30B	48G	48T	48X	48Y
Cylinder Characteristics Utilized in 6FIRE						
Inner diameter, in.	29.1875	29	48	48	48	48
Cylinder thickness, in.	0.406	0.5	0.3125	0.3125	0.625	0.625
Cylinder length, in.	66.24	68.02	132.74	103.99	103.99	136.27
Cylinder weight, lb	1400	1400	2600	2250	4500	5200
Material of construction	A-285	A-516	A-285	A-285	A-285	A-516
Cylinder Characteristics Utilized in SUBLIME						
Cylinder shell surface area, ft^2	51.47	52.21	164.1	134.0	134.0	167.8
UF_6 surface area, ft^2	39.16	19.80	126.3	101.7	101.7	129.3

Fire duration = 15 min (see Attachment 1)
Fire temperature = 1700°F (see Attachment 2)
Ambient temperature = 100°F
Initial temperature of cylinder and UF_6 equals ambient temperature
Emissivity of fire = 0.9 in 6FIRE, 1.0 in SUBLIME
Emissivity of cylinder = 0.8 (in both programs)
Failure mode: hoop stress exceeds ultimate stress (see Williams *[WRW96]* for ultimate stress data)

RESULTS

Results of the simulations for the six cylinder types identified in the preceding section are summarized in Table 3 and Figs. 1 through 3. Based on the results from 6FIRE, only 48Y cylinders would survive a 15-minute, 1700°F fire accident; failure times for the other cylinders ranged from approximately 6.4 minutes (48G cylinder) to 15.0 minutes (48X cylinder). Table 3 and Fig. 3 reflect data for a 48Y cylinder failure at 16.6 minutes in a 1700°F fire. Figures 1 though 3 show the cumulative mass of UF_6 released predicted by 6FIRE and SUBLIME from 2 1/2-ton, 10-ton, and 14-ton cylinders, respectively; Table 4 tabulates some of the data plotted in these figures.

Table 4 also provides information to support atmospheric dispersion analyses. That information includes the temperature and the vapor mass fraction of the UF_6 being released at the time of initial rupture as well as the temperature of the vapor subsequently sublimed. The initial release of UF_6 includes all vapor and liquid in the cylinder at the time of rupture; the liquid is assumed to flash and mix with the vapor forming a solid-vapor mixture at the sublimation temperature of UF_6 (solids formed upon flashing would be

Table 3. Summary of 6FIRE and SUBLIME Results†

	30A	30B	48G	48T	48X	48Y
6FIRE Results						
Initial UF_6 mass, lb	4951.1	5019.0	26833.5	21021.7	21021.7	27546.9
Time of rupture, min	11.52	13.03	6.42	6.67	15.00	16.60†
Composition at rupture, lb (%) Solid	3796.9 (76.7)	3733.9 (74.4)	24409.5 (91.0)	19054.0 (90.6)	16845.4 (80.1)	21693.0 (78.7)
Liquid	1100.4 (22.2)	1173.4 (23.4)	2193.0 (8.2)	1790.4 (8.5)	3986.6 (19.0)	5481.5 (19.9)
Vapor	53.9 (1.1)	111.8 (2.2)	231.1 (0.8)	177.3 (0.9)	189.7 (0.9)	372.6 (1.4)
Cylinder pressure at rupture, psia	264.3	446.1	165.0	164.9	230.1	305.5
Liquid temperature at rupture, °F	309.6	318.9	199.6	206.5	303.6	313.7
Vapor temperature at rupture, °F	819.1	680.6	763.3	780.9	922.7	785.8
Average shell temperature at rupture, °F	1275	1270	1234	1232	1288	1290
Initial release, lb	1154.3	1285.2	2424.1	1967.7	4176.3	5854.1
SUBLIME Results						
Time from rupture to end of fire, min	3.48	1.97	8.58	8.33	na	na
Vapor sublimated during remainder of fire, lb	228.8	125.0	1949.5	1521.1	na	na
Vapor temperature at end of fire, °F	1026.6	999.4	1050.4	1055.3	na	na
Vapor sublimated after fire, lb	706.5	799.0	1350.8	1160.4	2158.6	2909.1
Duration of post-fire release, min	158.3	179.9	92.2	98.0	195.0	206.9
Total UF_6 released, lb (% initial UF_6)	2089.6 (42.2)	2209.2 (44.0)	5724.4 (21.3)	4649.2 (22.1)	6334.9 (30.1)	8763.2 (31.8)

† The fire duration generally assumed for analysis purposes is 15 min. Because the 48Y cylinder did not fail within this time frame, the fire was extended to the time of failure to provide information on potential source terms for subsequent analyses.

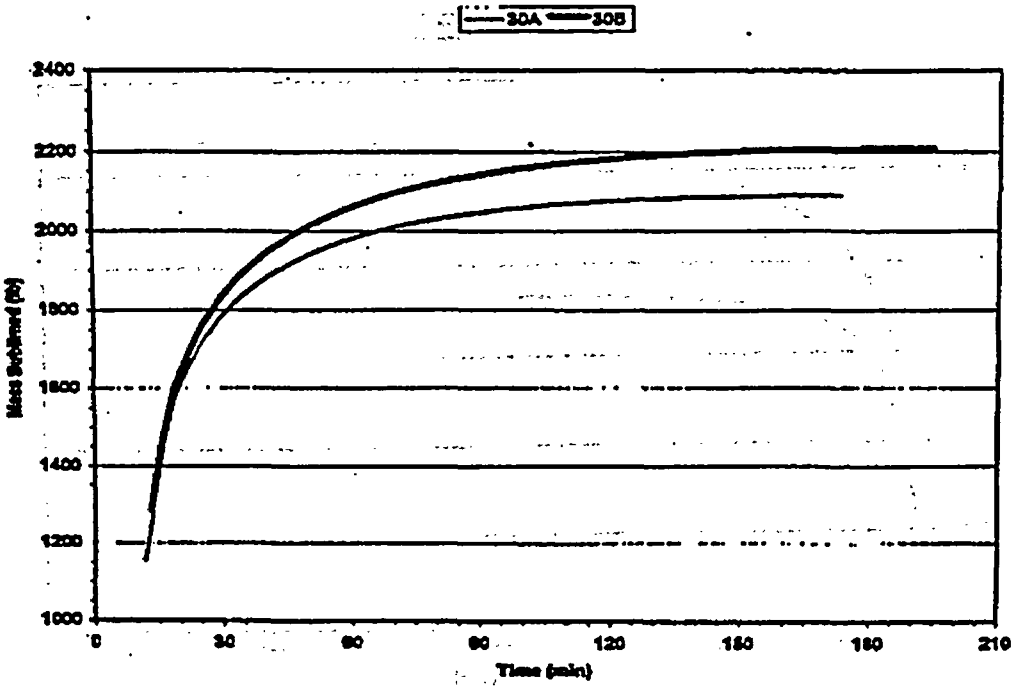

Fig. 1. Cumulative mass of UF_6 released from 2½-ton 30A and 30B cylinders exposed to a 1700°F, 15-min fire.

entrained in the plume). The equation used for calculating the vapor fraction is the following:

$$X = \{ [(m_{SHL}H_{SHL} + m_{SHV}H_{SHV}) / (m_{SHL} + m_{SHV})] - H_{S@T_s} \} / [H_{V@T_s} - H_{S@T_s}]$$

where X = vapor mass fraction
m = mass
H = enthalpy
SHL = superheated liquid
SHV = superheated vapor
$S@T_s$ = solid at sublimation temperature
$V@T_s$ = vapor at sublimation temperature

DISCUSSION OF RESULTS

The results presented in this DAC are predicated on an assumed fire temperature of 1700°F. It should be noted that fire temperatures in excess of 2000°F have been documented *[JHC96]*. Higher temperatures will result in shorter times to failure; however, algorithms yet to be completed in 6FIRE may extend times to failure *[WRW96]*. Results presented by Williams *[WRW96]* demonstrate that time to failure is a strong function of fire temperature: increasing the fire temperature to 2000°F would cut the time to failure by about half while decreasing the temperature to 1475°F would approximately double the time to failure.

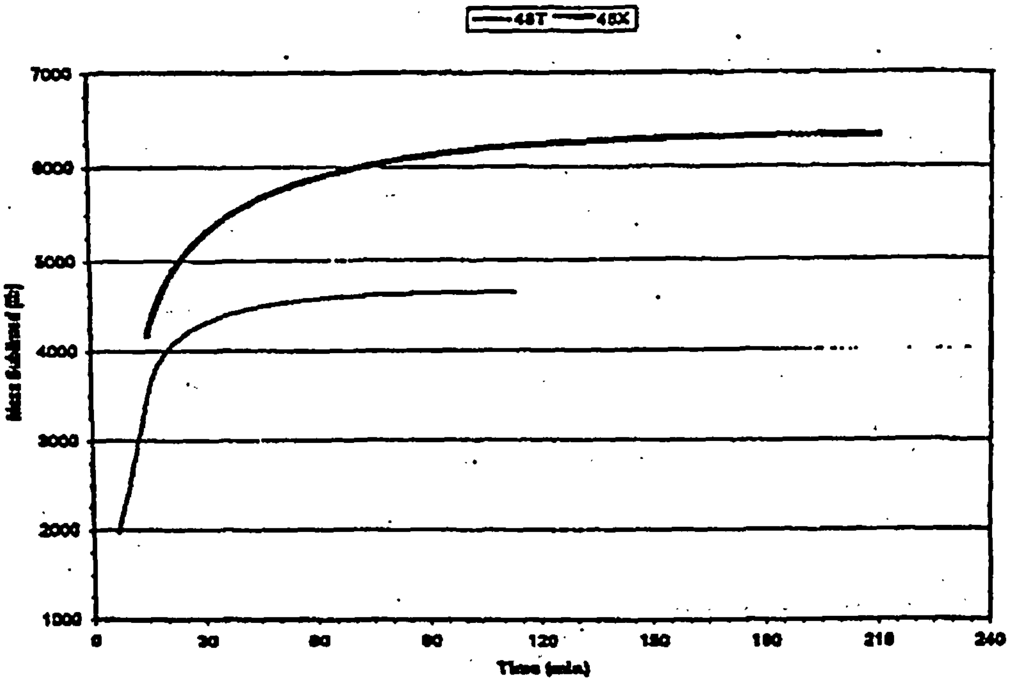

Fig. 2. Cumulative mass of UF_6 released from 10-ton 48T (thin-walled) and 48X (thick-walled) cylinders exposed to a 1700°F, 15-min fire.

The uncertainties introduced by fire temperature (an input) predominate over all other uncertainties, either in modeling or resulting from input (see *[WRW96]* for additional discussion of modeling uncertainties). Williams also presents results demonstrating that some partially filled cylinders may survive longer than nominally filled cylinders.

Table 5 compares the times to failure and rupture pressures predicted by 6FIRE to those presented by Luk and Webb in a companion study *[KHL96]*. The failure pressures predicted by Luk and Webb are based on stress-strain data at 1300°F derived from graphical information and are the result of finite element analyses of the Tresca stresses throughout the cylinder. Once failure pressure was determined, time-pressure information from 6FIRE was used to identify the time of failure. 6FIRE compares hoop stress to ultimate stress to determine failure; the ultimate stress is based on tabular temperature-stress data from the same source used by Luk and Webb (specific information on the data utilized by 6FIRE are given by Williams *[WRW96]*). When the wall temperature at the time of failure predicted by 6FIRE is essentially 1300°F, as is the case for 30A and 30B cylinders, the times of failure and rupture pressures are directly comparable (and within the uncertainty associated with the data). The differences shown in Table 5 for the other cylinders primarily result from the variation of ultimate stress with temperature.

At the elevated temperatures and pressures occuring in a fire, cylinder valves may leak or fail prior to the rupture of the cylinder resulting in the release of some UF_6; such failures were noted by Mallett *[AJM]*.

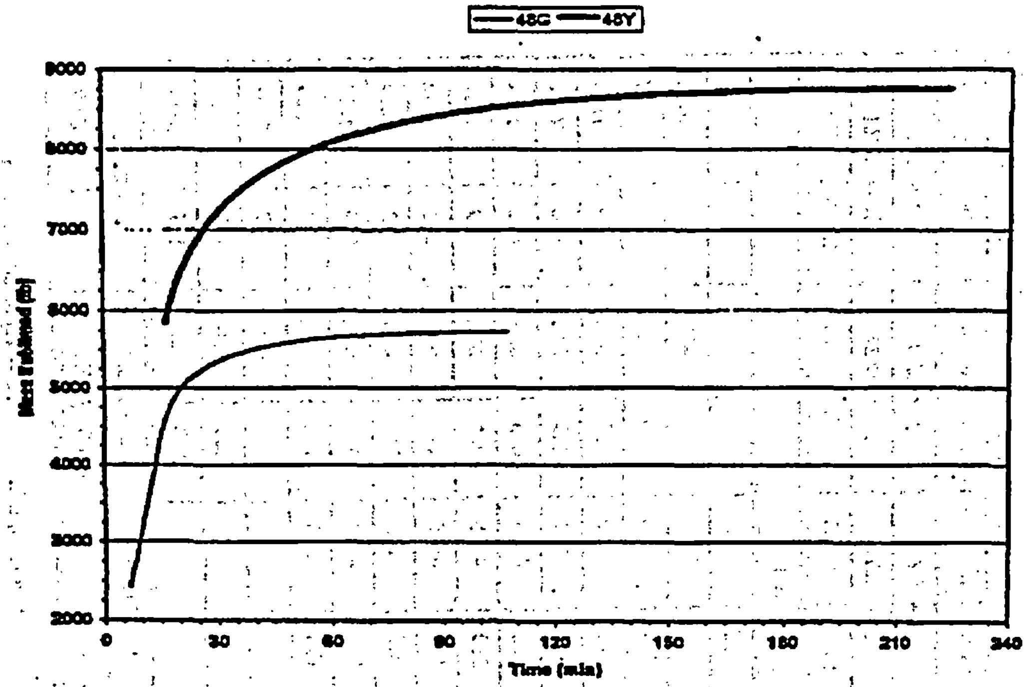

Fig. 3. Cumulative mass of UF_6 released from 14-ton 48G (thin-walled) and 48Y (thick-walled) cylinders exposed to a 1780°F, 15-min fire.

Elliott *[PGE]* provides information that valve leak rates of a few standard cubic feet per minute of nitrogen ($SCFM_{N2}$) or more might be expected under fire conditions (which *may* translate to about a pound per minute of UF_6 per $SCFM_{n2}$ based on a very cursory evaluation). Figure 2 of Elliott's paper indicates leakage exceeds 1 $SCFM_{N2}$ as the pressure approaches 100 psig (given a constant temperature of about 1450°F); Table 2 indicates leakage exceeds 0.5 $SCFM_{N2}$ as the valve temperature excedes the range of 800 to 1000°F (given a constant pressure of about 250 psig). Leakage should not be expected to preclude failure; also, the amount of material released prior to rupture is not expected to be significant relative to the overall release of material before, during, and after the failure of a cylinder.

It was assumed that the fire lasted 15 min; the fire then stopped and the cylinder cooled by convection and radiation to the environment. If the fire lasts longer than 15 min, then more UF_6 would be sublimated. On the other hand, if the fire is extinguished at 15 min (as opposed to the tacit assumption of simply burning out), then the process of extinguishing the fire may also quench the cylinder which would decrease the amount of UF_6 sublimated; however, the formation and release of HF by water introduced into a breached cylinder would then need to be evaluated.

The emissivity of the fire has been assumed to be 0.9 in 6FIRE. This is a reasonable value, which has been adopted for evaluating the effects of fire on packaging *[10CFR71]*, and it is consistent with a fire that has been tacitly assumed to have the footprint of the cylinder. It is noted that fire emissivity approaches

Table 4. Additional Information Provided to Support Atmospheric Dispersion Analyses

	30A		30B		48G		48T		48X		48Y	
	T, °F	m_{cum}, lb	T, °F	m_{cum}, lb	T, °F	m_{cum}, lb	T, °F	m_{cum}, lb	T, °F	m_{cum}, lb	T, °F	m_{cum}, lb
"Initial" conditions	t = 11.5		t = 13.0		t = 6.4		t = 6.7		t = 15.0		t = 16.6	
	X = 0.833		X = 0.884		X = 0.670		X = 0.679		X = 0.827		X = 0.861	
	133.8	1154.3	133.8	1285.2	133.8	2424.1	133.8	1967.7	133.8	4176.3	133.8	5854.1
t, min	*Transient conditions*, X = 1											
15	1027	1383	999	1410	1050	4374	1055	3489				
20	700	1601	715	1632	594	4963	609	3978	718	4728	779	6401
25	558	1713	579	1753	445	5199	459	4179	590	5043	631	6877
30	472	1785	495	1834	363	5339	376	4300	508	5260	539	7195
35	412	1838	436	1894	309	5434	321	4383	449	5423	476	7430
40	368	1879	391	1941	271	5504	282	4443	405	5551	428	7614
50	306	1938	327	2010	221	5596	230	4525	341	5742	359	7887
60	264	1979	284	2059	190	5651	197	4576	296	5879	312	8082
75	221	2021	239	2110	161	5698	167	4619	250	6023	263	8289
90	193	2047	209	2144	145	5718	149	4640	219	6122	229	8432
105	174	2065	187	2167	135	5724	138	4648	196	6192	205	8533
120	160	2076	171	2183					179	6242	187	8607
150	142	2088	150	2202					156	6301	162	8699
180			138	2209					142	6328	147	8744
"Final" conditions	t = 173.3		t = 194.9		t = 107.2		t = 113.0		t = 210.0		t = 223.5	
	133.8	2089.6	133.8	2209.2	133.8	5724.4	133.8	4649.2	133.8	6334.9	133.8	8763.2

T = temperature, °F m_{cum} = cumulative mass of UF_6 released, lb t = time, min X = vapor mass fraction

Table 5. Comparison of 6FIRE and FEA Results

Cylinder type	6FIRE Results			FEA Results		
	T_{cyl}, °F	P_{rupt}, psig	t_{rupt}, min	T_{cyl}, °F	P_{rupt}, psig	t_{rupt}, min
30A	1301	250	11.5	1300	242	11.5
30B	1293	431	13.0	1300	415	13.0
48G	1243	150	6.4	1300	122	5.5
48T	1243	150	6.7	1300	117	5.5
48X	1319	215	15.0	1300	240	15.3
48Y	1318	291	16.6	1300	317	16.7

1 as the flame thickness extends from 3 to 6 ft or more *[Buck]*. The emissivity of the fire (or environment) is 1 in SUBLIME; this value is conservative during the fire and appropriate for the postfire analysis when the cylinder radiates to the environment. An emissivity of 0.8 appears to be a reasonable estimate of cylinder emissivity. Higher emissivities would increase the rate of heat transfer and decrease the time to rupture.

The current evaluations consider cylinders fully engulfed in fire. If a cylinder is not fully engulfed (e.g., the cylinder extends only partially into a pool, it is resting on the ground, or it is partially shielded from direct radiation by other cylinders) then the time to failure will be increased.

This study has only considered "like-new" cylinders. Degradation due to corrosion or other damage may reduce estimated times to failure.

This study has determined best estimates of times to failure for 2½-, 10, and 14-ton cylinders. For thick-walled, 14-ton cylinders, one caveat should be noted ... if 48F cylinders are of concern, which are assumed to be constructed of A-285 steel due to their date of construction, then the time to failure would be less than that for 48Y cylinders. Other 48-in. diam. cylinders (48A, 48O, 48OM, 48H, and 48HX) can be compared to or bounded by calculations presented herein. Both types of 2½-ton cylinders (30A and 30B) have been evaluated.

The current evaluations have been limited to 2½-, 10-, and 14-ton cylinders. As noted in the introduction, it is assumed that smaller cylinders will fail with the complete release of their contents. Because of current limitations in the 6FIRE program (thought to be in subroutines evaluating physical properties near the triple point), it is not possible to obtain information on the masses and temperatures of the UF_6 phases at the time of failure for smaller cylinders. However, because the failure pressures increase as the cylinders become smaller, the amount of liquid formed relative to the total mass of UF_6 in the cylinder would increase as well as the temperature of the liquid. These considerations would be expected to lead to a greater release of vapor (upon flashing of the liquid) and a more buoyant plume as the cylinders become smaller. In the absence of complete computer runs for the smaller cylinders it is suggested that the source terms assume liquid UF_6 at 300°F flashes to a solid-vapor mixture at the sublimation point. This recommendation leads to a release temperature of 133.8°F and a vapor mass fraction of about 0.76 (solids formed upon flashing would be entrained in the plume).

REFERENCES

[10CFR71] 10 CFR Part 71.73(c)(3).

[AJM] A. J. Mallett, *ORGDP Container Test and Development Program: Fire Tests of UF_6-Filled Cylinders*, K-D-1894, January 12, 1966.

[Buck] Michael R. Buck and E. Bruce Belason, "ASTM Test for Effects of Large Hydrocarbon Pool Fires on Structural Members," *Plant/Operations Progress*, Vol. 4, No. 4, pp. 225-229, October 1985.

[JCA96] J. C. Anderson, *SUBLIME: A Model for Evaluating the Sublimation of UF_6 for a Ruptured/ Breached Cylinder During and After a Fire*, DAC-EA-710660-A002, July 1996.

[JHC96] J. H. Clinton, *Fire Duration Analysis and Characteristics*, DAC-EA-710060-A005, July 1996.

[KHL96] K. H. Luk and D. S. Webb, *UF_6 Cylinders Rupture Pressure Analysis*, DAC-EA-710660-A009, July 1996.

[KTZ] K. T. Ziehlke and C. R. Barlow, "Rupture Testing of UF_6 Transport and Storage Cylinders," *Uranium Hexaflouride—Safe Handling, Processing, and Transporting Conference Proceedings*, CONF-880558, May 24-26, 1988, pp. 97-101.

[ORO/4] *Uranium Hexafluoride: Handling Procedures and Container Criteria*, ORO-651, Rev. 4, April 1977.

[ORO/5] *Uranium Hexafluoride: Handling Procedures and Container Descriptions*, ORO-651, Rev. 5, September 1987.

[ORO/6] *Uranium Hexafluoride: A Manual of Good Handling Practices*, ORO-651, Rev. 6, October 1991.

[PGE] P. G. Elliott, *Testing of One-Inch UF_6 Cylinder Valves under Simulated Fire Condition*, paper contained in the Proceedings of the Second International Conference on Uranium Hexafluoride Handling, October 29-31, 1991, Oak Ridge, Tennessee, CONF-9110117, pp. 235-241.

[WRW96] W. R. Williams, *Overview of UF_6 Cylinder-Fire Modeling with Specific Discussion of 6FIRE*, DAC-EA-710660-A001, July 1996.

Attachment 1. e-mail re: FIRE DURATION

The following e-mail provides a basis for assuming a fire duration of 15 min:

Date: Tue, 21 May 1996 13:33:47 -0400 (EDT)
To: justra@ornl.gov, williamswr@ornl.gov, scarborougwr@ornl.gov
From: ajh@ornl.gov (John A. Hoffmeister)
Subject: Fire Department Reponse Time - Cylinder Yards
Cc: brockwr@ornl.gov, colemanda@ornl.gov

Robert:

I checked with David Coleman of K-25 Fire Protection and he informed me that the response time to the K-1065 Building next to the K-1066K yard is documented in the Fire Protection Engineering Assessment as 5 minutes with an additional 5 minutes until water is actually being sprayed on cylinders. He indicated that the first effort will be to cool any exposed cylinders and then to fight the fire. This time DOES NOT account for the time to detect and report the fire, which I would estimate to be a minimum of 1 minute up to 5 minutes or more if you consider the potential for accidents involving external vehicles or if operations can be performed with only one operator who might be incapacitated by the accident.

John Hoffmeister
John A. Hoffmeister
Building K-1035
MS 7212
Phone: 4-0261 Fax: 6-8184
hoffmeisteja@ornl.gov

Attachment 2. Letter re: FIRE TEMPERATURE, etc.

ROBERT J. O'LAUGHLIN, P.E., CSP
FIRE PROTECTION ENGINEER
CONSULTANT
7904 Livingston Drive
Knoxville, TN 37919
(423) 691-9932

April 30, 1996

Marcia Fischer
H&R Technical Associates
P. O. Box 4159
151 Lafayette Dr. Suite 220
Oak Ridge, TN 37831-4159

Re: K-25 Cylinder Yard Fire Hazards Analysis

Dear Marcia:

During a telephone conversation with John Hoffmeister of LM yesterday, he expressed a need for some basic fire characteristics of hydrocarbon pool fires. Once the pool fire data becomes available, LM will analyze the data for use with the UF_6 cylinder storage yard SAR.

Attached to this transmittal letter are the burning characteristics of combustible and flammable liquids that potentially could be used in the yard areas.

An excellent reference source for pool fires involving hydrocarbons is Chapter 2-4 in the SFPE Handbook of Fire Protection Engineering. This reference text includes a variety of fire protection parameters that would be beneficial to the engineers working on the FHA and the SAR. Some of the important parameters in this chapter include pool fire flame height, burning rates, liquid burning velocities, and flame temperatures, in addition to physical properties of pool fires.

Please convey this information to the engineers involved in the project.

Sincerely,

Bob O'Laughlin

Robert J. O'Laughlin, P.E.
Fire Protection Engineer

FIRE BURNING CHARACTERISTICS
OF
LARGE OPEN HYDROCARBON FIRES

Liquid Velocity Burning Rate (mm/min):
(Ref 1.)

Diesel Fuel: 2 mm/min with a pool diameter of 1 m
4 mm/min with a pool diameter of 3 m or greater

Gasoline: 4 mm/min with a pool diameter of 1 m
4 mm/min with a pool diameter of 3 m or greater

Flame Height (meter):
(Ref. 1)

Diesel Fuel: 1.7 m with a pool diameter of 1 m
3.9 m with a pool diameter of 3 m

Gasoline: 2.1 m with a pool diameter of 1 m
5.4 m with a pool diameter of 3 m

Heat Release Density (BTU/sec/ft$_2$):
(Ref. 2)

Diesel Fuel: 180

Gasoline: 200

Flame Temperature (K):
(Ref. 3)

Diesel Fuel: 1200 (1700 °F)
Gasoline: 1200
JP-4: 1200

Note 1: Hydraulic fluids have burning characteristics that are less severe than the above listed liquids.

Note 2: Assume pool size fire (diameter) is the length of the UF$_6$ cylinders (10 ton and 14 ton).

REFERENCES

1.0 P. J. DiNenno, Chief Editor, "*SFPE Handbook of Fire Protection Engineering*", pp 2-47, First Edition, September 1988.

2.0 NFPA 72E, "Automatic Fire Detectors", Table C-2.2.2.1(a), National fire Protection Association, Quincy, MA., 1984.

3.0 P. J. DiNenno, Chief Editor, "*SFPE Handbook of Fire Protection Engineering*", pp 2-51, First Edition, September 1988.

REVISION LOG

Original Issue .... July 1996

Revision 1 .... August 1996

Corrected DAC number appearing at the top of pages 2-17.

Added Revision Log.