MASTER

PROCEEDINGS

THIRD INTERNATIONAL SYMPOSIUM
PACKAGING AND TRANSPORTATION
OF RADIOACTIVE MATERIALS

AUGUST 16-20, 1971/RICHLAND, WASHINGTON, U.S.A.

SPONSORED BY • U.S. ATOMIC ENERGY COMMISSION AND THE FOLLOWING HANFORD CONTRACTORS
• ATLANTIC RICHFIELD HANFORD COMPANY • BATTELLE-NORTHWEST • DOUGLAS UNITED NUCLEAR, INC.
• ITT/FEDERAL SUPPORT SERVICES, INC. • J A JONES CONSTRUCTION COMPANY
• VITRO CORPORATION/HANFORD ENGINEERING SERVICES • WADCO CORPORATION

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

✓ LEAD REMELT EXPERIENCE WITH 60-TON CASK

E. C. Lusk

BATTELLE
Columbus Laboratories

ABSTRACT

The fabrication of large-size spent fuel shipping containers can result in a variety of unanticipated crises. During the fabrication cycle of the NFS-100 cask, (a 60-ton gross weight cask) there was a failure of the lead pouring equipment which necessitated the remelting of 80,000 lb of lead. Since the "lead pour" phase is near the end of a cask fabrication cycle, it was necessary to quickly establish a guaranteed success remelt operation which would result in a nonporous gamma shield. The size of this particular cask and a large number of heat rejection fins necessitated the set up of shroud-type furnace within the metal fabrication shop which would bring the entire cask up to the desired lead remelt temperature of approximately 680 F. Five 750,000 Btu rated liquid propane burners (oriented so the flame was directed tangential to the cask finned exterior) were positioned at several vertical levels and a successful remelt operation was carried out. This paper presents the details of that operation, as well as the temperature history of the cask. Temperatures were recorded by means of both external thermocouples welded to the cask and dip-type thermocouples employed within the lead volume to establish the liquid/solidus interface and its movement with time. The remelt operation required 27 hours to complete, was completed on site, and resulted in a void-free gamma shield. Specifics of this operation and associated temperature data are detailed in this paper.

CASK DESCRIPTION

The spent fuel shipping cask discussed in this paper is the NFS-M100 cask system which is shown mounted on a rail car in Figure 1. This cask is a multipurpose shipping cask designed and licensed by BCL, and which is capable of shipping either 12 Big Rock Point, 18 Pathfinder, or 18 Humboldt Bay spent fuel assemblies. Figure 2 provides an exploded view of the NFS-M100 cask and illustrates the major components. The cask weight, exclusive of the skid, is 60 tons and has an external diametric envelope of 70 inches (as established by the heat rejection fins) and an overall length of 130 inches. The biological lead shield weighs approximately 40 tons and has a radial thickness of 8.75 inches.

The heat rejection fins, which are required to dissipate an anticipated decay heat load of approximately 28 kw thermal, increase the cask surface area by more than a factor of three and were fabricated from a continuous strip of four-inch wide x 1/4-inch thick stainless steel. Attachment of the fins to the outer shell was accomplished by a continuous welding operation which resulted in 1/4-inch fillet welds on both sides. The fins are four inches high and are set on 1.75-inch axial centers. The outer shell of the cask is a composite plate comprised of a 1.75-inch thickness mild steel plate to which a roll bond clad 1/4-inch thickness Type 304 stainless steel plate has been joined. The interior fuel cavity has a 40 inch ID and is 103 inches deep. Eighteen square type permanent fuel assembly cavities are established by a means of the inner basket which is comprised of 1/2-inch thick copper plates which are bonded to themselves as well as to the walls of the inner cavity.

Lead Melt Background

The lead fill procedure utilized called for setting the cask in a vertical attitude and then positioning a lead kettle plus furnace apparatus at a higher level to effect a gravity feed of molten lead. During the first lead filling operation, a flow control valve on the lead fill line between the lead source kettle and the furnace froze in the closed position. During the time required to replace the stuck valve, the auxiliary heating equipment (which normally would maintain the overall cask system at the desired casting temperature) was unable to supply sufficient heat to hold the lead (which had already been cast) in a molten condition. Upon resumption of the lead filling (after the defective valve had been replaced) the cooling rate of the lead was too rapid and a void was formed at approximately 24 inches from the

bottom of the cask surface. Information obtained from the thermocouples which were placed on the cask to monitor the lead pour operation, indicated that the heat rejection fins were being too effective in shadow shielding the cask surface from the flame being produced by the liquid propane burners (as oriented for this initial casting operation). Since the cask would require extensive rework if the situation were not remedied quickly, the decision was made to set up an on-site remelt furnace. This is described in the next section.

Description of Remelt Equipment

A shroud-type furnace composed of 0.187-inch thick mild steel plates was erected on-site for the remelt operation. Scheduling and cost requirements precluded moving the cask. The furnace arrangement is shown in Figure 3, and since the cask fins increase the cask envelope by 8 inches resulted in a chimney diameter of approximately 80 inches. The cask was positioned vertically with the open end of the fuel cavity facing downward to permit heating of the cavity interior. A cover employing a controllable vent was provided for the top of the furnace shroud and the entire furnace assembly was then supported by steel legs resting on the floor of the fabrication shop. Ten burner openings were provided for in the sides of the furnace shell and were equally spaced circumferentially and vertically to permit desired burner placement for the purpose of heating up zones in a uniform fashion. These burner ports were also provided with a controlled air inlet vent and provision was made to direct the burner flame at a tangential angle with respect to the outer shell of the cask, thus utilizing the circumferential fins to, in effect, direct the flame front (see Figure 3). Baffle-type deflection plates were provided for the burner flame to impinge upon and to then provide for a swirling motion around the cask.

Details of Remelt Operation

Five 750,000 Btu rated propane burners were positioned within the furnace shroud to commence a uniform remelt heating cycle. In addition, a ring burner was positioned beneath the cask to heat the fuel assembly cavity and a standard "blast" burner was positioned at the top to heat the lead pour port. In addition, eight chromel-alumel thermocouples were welded to the outer shell of the cask between the fins for purposes of temperature monitoring during the heatup and cooldown cycles since the preceeding experience had shown the fins shadow shield the flame. These couples were positioned such

that there would not be direct burner flame impingement and were located at approximately one foot axial increments from bottom to top. A portable dip-type thermocouple was utilized to monitor temperatures within the lead cavity after the lead remelt had begun. As another backup, a portable contact pyrometer with a range of 0 to 1,200 F was utilized to check available surface temperatures of the furnace and cask. The pyrometer employed was a compensated, direct reading type pyrometer which had been calibrated prior to the operation against a bureau of standards related instrument.

The burners were lit at approximately 7 a.m. and commencement of temperature data recordings were initiated at 8 a.m. Burners were adjusted for maximum heat output and within a short time period were capable of maintaining the flame baffle plates and the outer edges of the cask fins in the area of the flame impingement at a cherry red color, which was measured via a thermocouple to read approximately 1,400 F. The operation proceeded quite smoothly with very little burner adjustment being required. The vent opening at the top of the furnace configuration was adjusted upward to provide for a blast burner to be directed down at the center of the vent opening onto the lead pour hole. Despite all of this deliberate heating, lead melt temperatures did not occur until approximately 9-1/2 hours after starting the heatup. The first indication of lead melting on the top was some 30 minutes later, or at 5 p.m. At six o'clock p.m. the internal "dip" thermocouple indicated molten lead at a depth of four feet. At this time, the top burners were cut back and at 12:15 a.m., or 17 hours after starting, all of the lead within the NFS cask was assessed to be in a molten condition.

The solidification process which followed required approximately ten hours. This operation was accomplished by opening the top vent, turning the burners down, and removing vertical sections of the furnace wall commencing at the bottom and proceeding upward. Following the cooldown period, a complete gamma scan of the cask surface was made on a three-inch grid. The results of this test proved that a solid condition of remelted lead gamma shielding existed. The detailed thermal history is summarized in Table 1.

Postmelt Evaluations and Comments

The preceding sections have described the successful remelting of a large volume of lead at a fabricator's shop. However, some additional insight as to the severity of postulated industrial fires, and their effect on a cask system, can be gleaned from this experience.

First of all, the remelting process took 17 hours, with the cask outer shell temperature reaching 620 F after ten hours. In addition, this heat up took place in a specially erected furnace which directed propane gases to sweep between the fins, with the gases having a very high energy content. This can be illustrated by the fact that 800 gallons of liquid propane (heating value of propane is 91,690 Btu/gal) were burned over a 17-hour period for a potential heat load of 73.4×10^6 Btu/hr.

The hypothetical fire which is defined in 10-CFR-Part 71 as a 1475 F radiant source having an effective emissivity of 0.9, and which regulation also stipulates that the receiver surface has an effective absorptivity of 0.8, permits utilization of the Stefan-Boltzmann equation to describe the heat transfer coupling, or

$$q_{\text{Fire}} = (\Sigma F_G A) (F_\epsilon) (\sigma T_{\text{Fire}}^4 - \sigma T_{\text{surface}}^4) \quad (1)$$

where F_G = geometric view factor

A = area receiving radiation energy

$$F_\epsilon = \text{emissivity factor} = \frac{1}{\frac{1}{\epsilon_{\text{fire}}} + \frac{1}{\epsilon_{\text{surface}}} - 1} .$$

If we neglect the countering effect of an increasing surface temperature, and utilize Equation (1) to calculate a "cold wall" heat input, we obtain the following heat inputs resulting from the hypothetical fire:

$$q_{\text{RAD}} = 2.12 \times 10^6 \text{ Btu/hr at } \epsilon_{\text{surface}} = 0.8 \quad (2a)$$

$$= 0.54 \times 10^6 \text{ Btu/hr at } \epsilon_{\text{surface}} = 0.2 \quad (2b)$$

$$= 0.4 \times 10^6 \text{ Btu/hr at } \epsilon_{\text{surface}} = 0.15 . \quad (2c)$$

The results shown in Equation (2a) when compared to 4.3×10^6 Btu/hr, as calculated from the heating value of liquid propane, would permit me to say that the remelt fire was more severe than the prescribed fire test. The latter two values illustrate the effect of a lower emissivity and since the cask fins and shell had already been polished to a 63 G micro finish, the lower values are justifiable for 304 stainless steel. More will be said regarding these lower values below.

Consideration of the thermal capacitance of the NFS-100 cask itself leads to the following tabulation and resulting thermal capacitance values:

$$80,000 \text{ lb of lead} \times 0.031 \text{ Btu/lb-F} = 2480 \text{ Btu/F} \quad (3a)$$

$$27,000 \text{ lb of steel} \times 0.11 \text{ Btu/lb-F} = 2970 \text{ Btu/F} \quad (3b)$$

$$4,000 \text{ lb of copper} \times 0.0915 \text{ Btu/F} = 366 \text{ Btu/F} \quad (3c)$$

$$(\rho \text{ VCp})_{\text{total}} = 5816 \text{ Btu/F} \quad (3d)$$

Exclusive of the heat of fusion of lead, the total heat required to raise this cask to 600 F above room temperature is then

$$Q = \rho \text{ VCp} \Delta T = 5816 \text{ Btu/F} \times 600 \text{ F} = 3.48 \times 10^6 \text{ Btu} \quad (4)$$

In addition, the heat of fusion of lead (10.5 Btu/lb) raises the total heat to 4.32×10^6 Btu, which is significantly lower than the 73.4×10^6 Btu cited for the propane previously. The logical question is where did this heat go? However, before we go on, if the capacitance calculated via Equation (4) is averaged over a ten-hour period (time lead melt temperature is reached, see Table 1), and a 17-hour period, heat transfer levels of 0.35×10^6 Btu/hr and 0.25×10^6 Btu/hr, respectively, are calculated. These latter numbers should be compared with the results shown in Equations (2b) and (2c), and the next questions is - how realistic is the absorptivity value of 0.8 (to be held constant through the 30-minute fire) stipulated by the regulations? It took ten hours in a specially designed furnace to reach melt temperatures, and another seven hours to complete melting of the lead. On the other hand, Serkiz⁽¹⁾ shows melt temperatures being approached in approximately 30 minutes with the fins "blocking" and lead melt occurring if the fins are removed. There would appear to be an inconsistency.

In an attempt to consolidate the above remarks, consider the following tabulation:

Heat load required to raise cask temperature 600 F and melt lead	= 4.32×10^6 Btu
Heat load contained in 800 gal of propane	= 73×10^6 Btu
Heat load dumped to external environment by 200 ft ² of furnace shell at 900 F*	= 18.5×10^6 Btu
	$\Delta = 54.5 \times 10^6$ Btu.

With 54.5×10^6 Btu of heat energy being potentially available to heat up the cask (and it is recognized that the burner gases took considerable energy out through the stack opening) why did it take ten hours to reach the lead

---

* Radiative coupling to the ambient environment only.

melting temperature, and then another seven hours to melt the 40,000 lb of lead? The hypothetical 30-minute fire heat level* (in comparison) calculated to be $0.27 \leftrightarrow 1.06 \times 10^6$ Btu. Obviously, convective coupling was not as effective as had been hoped for in a special furnace. Further speculation is left to the reader, but this remelt experience does raise some questions as to the actual interpretation of the effect of the fire test conditions on a shipping container. Needless to say, our analytical approaches appear to be quite conservative.

ACKNOWLEDGMENTS

Acknowledgment is extended to the Edward Lead Company, Scientific Advances, Inc., and Nuclear Fuel Services, Inc., for permission to use in this paper the information generated on this project.

REFERENCES

- (1) Serkiz, A.W., "Safety Analysis Report NFS-M-100 Cask", Battelle's Columbus Laboratories.
- (2) Perry, R., "Log of Lead Pour Operation NFS-M-100", Edward Lead Company.
- (3) Jones, S., Pictures and Drawings and NFS-M-100 Cask, Scientific Advances, Inc.

Table 1. Thermal History of Remelt Operation (Temperature, F)

Time	Thermocouple Number								Dip	Comments
	1	2	3	4	5	6	7	8		
8:00 a.m.	150	150	150	185	250	310	370	310		
10:00 a.m.	170	175	185	220	290	350	410	350		
12:00 a.m.	190	200	225	290	360	440	480	380		
2:00 p.m.	222	240	280	370	470	542	590	470		
4:00 p.m.	255	290	345	450	550	600	605	580		
5:00 p.m.	365	418	460	570	640	635	630	640		First lead melting
6:00 p.m.	430	470	515	600	645	640	630	615	610	Dip 4 ft. down
7:00 p.m.	460	540	570	640	655	660	655	615	610	Dip 7 ft. down
7:30 p.m.	500	670	630	630	635	665	670	650	620	Dip 9 ft. down
8:00 p.m.	520	682	650	635	645	675	680	635	655	
9:05 p.m.	545	635	640	635	660	690	690	605	670	Moved burner No. 3 to No. 4 and No. 2 to No. 3
10:00 p.m.	515	610	665	720	720	710	720	700	700	
11:00 p.m.	495	610	715	750	740	730	730	660	725	
12:25 a.m.	630	718	732	732	735	745	732	675	730	All lead melted Burners raised and set back
1:00 a.m.	550	680	755	770	770	760	740	675	740	
2:00 a.m.	500	635	720	760	770	765	760	670		Removed bottom panel
3:00 a.m.	--	602	675	730	755	760	750	560		Covered top vent hole
4:00 a.m.	--	--	660	730	770	780	780	670		Removed 2nd section of furnace
5:00 a.m.	--	--	620	715	765	780	780	675	780	
6:00 a.m.	--	--	593	660	725	755	760	760	760	Shut off No. 3 and 4 burner More sections of furnace removed
10:00 a.m.										Final lead solidification

Fig. 1. NFS-M100 Cask System

Fig. 2. Exploded View of NFS-M100 Cask System

Fig. 3. Furnace Arrangement.