DESIGN EVALUATION OF A LARGE CONCRETE CASK TO MEET IP-2 REQUIREMENTS

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INTRODUCTION

Oak Ridge National Laboratory (ORNL) has a large quantity of low-level waste, in the form of concrete monoliths, that are stored in large concrete vaults in ORNL's Melton Valley Storage Tanks (MVST). During FY 2000, a number of the monoliths were transferred from the concrete vaults to a Nuclear Regulatory Commission (NRC)-certified lead-shielded cask and shipped to the Nevada Test Site (NTS) for disposal. This activity has resulted in (1) increased radiation exposure both when the monoliths were transferred to the lead-shielded cask and when they were unloaded and buried at the NTS and (2) high cask rental and shipping costs for the program, and (3) the accumulation of empty vaults at ORNL which will also have to be disposed of at NTS, adding a significant additional transportation cost. As a result, Department of Energy (DOE)–Oak Ridge has been exploring ways to ship the MVST cask with its monolith to the NTS for disposal as a unit. To do this, the MVST cask would have to be self-certified as meeting IP-2 package requirements.

THE PACKAGE

The cask is a large concrete package that was originally designed to store radioactive waste, as a solid, on site. The contents consist of waste material thoroughly mixed with cement and solidified in 9,075-kg (20,000-lb) monolith, contained in a steel shell. Each monolith is loaded into a 18,150-kg (40,000-lb) outer concrete shield with a 4,537-kg (10,000-lb) concrete lid. Currently, there are approximately 150 MVST casks on the Oak Ridge Reservation which contain these monoliths.

The MVST cask, which weighs over 70,000 lb when loaded, was not designed initially to be shipped off-site. The concrete lid currently rests on the top of the cask body and is not fastened to it. Thus, to meet IP-2 requirements, a lid-retaining device (LRD) had to be designed and shown to retain the lid on the cask and retain the monolith within the shield under the test conditions specified for an IP-2.

An LRD was designed using the LS-Dyna structural program to show whether the LRD would meet those requirements. LS-Dyna showed that in a l-ft. drop, the lid and contents would both be retained and no significant increase in radiation levels would occur as a result of lid movement. The LRD also was designed to be capable of meeting the general design requirements prescribed in 49 CFR 173.410 and the test requirements specified in 49 CFR 173.465 (c) and (d), or to be evaluated against those tests by any of the methods authorized by 49 CFR 461 (a).

The LRD is a plate steel cap and a plate steel base held together by cables. The flat plates on the lid and the bottom are 6.4 mm (1/4 in.) thick, and the cylindrical portions are fabricated from 12.7-mm (½-in.) plate. There are eight 12.7-mm (½ in.) cables tying the lid to the bottom.

ORNL PHOTO 5874-2001

Fig. 1. **Melton Valley Storage Tank package with the steel lid-retaining device in place**.

CONTAINMENT

The concrete monolith forms the containment system for the low-level radioactive waste carried in the MVST cask provided by the steel body and lid of the monolith. Within each steel monolith shell is a concrete matrix, reinforced with the steel mixer blade assembly and the baffle assemblies that are used to ensure uniform mixing of the concrete prior to its solidification. The side of the steel shell is 10-gage sheet metal; the top and bottom are 8-mm-(0.3125 in.)-thick steel welded together to form a canister having an outside diameter of 1.89 m (74.4 in.) and a height of 1.83 m (71.9 in.). The top steel plate has four steel lugs welded to it which can be used to lift the monolith.

Since the lugs extend above the monolith lid closure, they also protect it from directly impacting the underside of the concrete MVST shield lid in an accident.

ANALYSIS OF TEST

The test was to determine if the LRD was properly designed and could, in fact, maintain the concrete MVST shield lid in place in a 30.5-cm (1-ft) drop as required in the regulations for an IP-2 package. Because of the weight of the package, it was decided to tip the package over, letting it fall and impact onto its side. This would obviate the need to raise and release the package from a mobile crane. In a tipover test, the velocity of the lid at the time of impact would be 320 cm/sec (126 in./sec) at the top end of the cask, greater than if the entire package were to be dropped in a horizontal attitude from a height of 30.5 cm (1 ft), impacting onto a buttress [244 cm/sec (96 in./sec)].

An analysis was conducted of various orientations the package could have at the time of impact in the regulatory free-drop test to determine the orientation most likely to dislodge the lid. The five different orientations that were considered (shown in Fig. 2) are:

1. Horizontal impact of the MVST cask onto its side with a buttress impacting the rigid surface;

2. Horizontal impact of the MVST cask onto its side between two buttresses;

3. Center-of-gravity over a lid corner, with the upper buttress corner impacting the rigid surface;

4. Slapdown impact with the bottom corner of a buttress impacting first, followed by the assembly rotation and the second impact with a buttress impacting the rigid surface;

5. Slapdown impact with the bottom corner between buttresses impacting first, followed by the assembly rotation and the second impact being between the buttresses.

ORNL DWG 2001-352

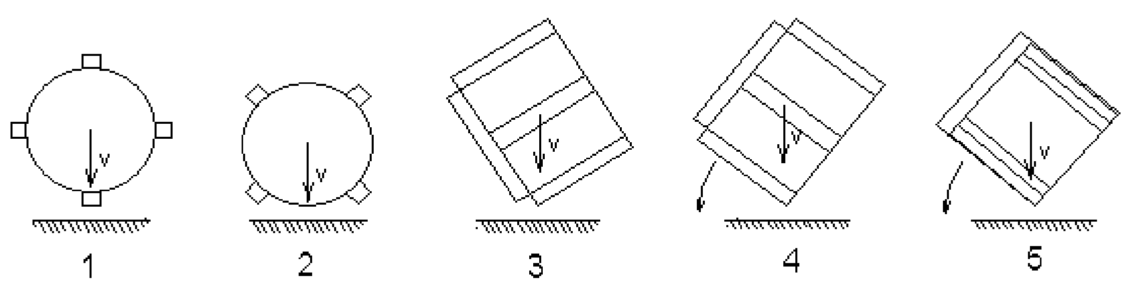

Fig. 2. Schematic of package orientations that were analyzed.

The 1-ft free-drop test impact simulations were made using the LS-Dyna non-linear software (ref. 1). The software TrueGrid (ref. 2) was used as a preprocessor, and LS-Taurus (ref. 3) was used as the postprocessor. All runs were made on a Silicon Graphics Octane workstation. The details of this analysis are reported in ref . 4.

A unique "worst case" did not stand out amongst the various impact orientations modeled; the cases that involved impact on the buttress tended to place the largest demand on the lid restraint device. Through-the-wall tensile pressures were noted in most of the impacts. Larger regions of through-wall tensile pressure tended to exist in the impacts between the buttresses. However, in no cases did the stresses reach or exceed the values required to cause failure of any of the package components. Thus, considering all factors, the slapdown onto the buttress side would be representative of a worst-case impact, particularly with regard to retaining the lid on the vault.

TEST RESULTS

With regard to the primary purpose of the tests which is to evaluate the performance of the LRD, the device worked very well. Figure 3 shows that the steel skirt of the top cap of the LRD suffered no visible external damage from the movement of the concrete lid inside the cap. The eight retaining cables and ratchet binders that connect the top and bottom caps together remained tight following the impact.

ORNL PHOTO 5888-2001

Fig. 3. The top steel cap of the lid-retaining device undamaged after the test.

A number of hairline cracks appeared in the external surface of the MVST vault body. Many appeared to run at approximately a 45-degree angle to the base of the vault body, but none appeared that they would, or even could, contribute to a significant increase in surface dose rate.

The MVST vault was uprighted and the top steel cap and concrete lid were removed. The monolith was removed and inspected, and the top surface of the shielding wall of the MVST vault was then examined for cracks. The monolith was completely undamaged; however, a small number of cracks appeared in the top of the wall, one of which was considered significant and was located immediately adjacent to the buttress on which the impact occurred. The significance of this crack and its potential to contribute to a dose rate increase was considered in an additional evaluation.

ORNL PHOTO 5909-2001

Fig. 4. Crack in top surface of shielding wall adjacent to impacted buttress.

SHIELDING
As in the outer surface of the MVST vault, several cracks in the top surface of the vault shielding wall appeared to be very fine and hairlike at the surface. Several of these cracks started at the outer surface and ended at the inner surface, but most typically followed a curved, circuitous, path and did not pass through the wall in a straight, radial, direction. These were insignificant with regard to damage to the shielding properties of the vault shielding wall. None of the cracks were straight, probably because of the large quantity of aggregate rocks that were used in forming the concrete

walls, and only one appeared to be radial oriented and wider than could be considered hairline (see Fig. 4). This crack was created by the buttress on which the impact occurred, which tried to thrust and shear into the concrete shield body, producing high stress risers at the junction of the buttress and shield wall and create a tendency for the shielding wall to assume an oval shape. This tendency put a large tensile stress on the inner surface of the wall creating something greater than a hairline crack.

In order to evaluate the likelihood that any of the cracks produced in the wall of the MVST vault body could contribute a significant increase in the surface dose rate, the shielding problem was examined from a geometric point-of-view. The analysis consisted of evaluating the diameter of a hypothetical [straight right-circular cylindrical hole, radially oriented,] which would produce a 20% increase in the surface dose rate. A second set of calculations modeled the reduction in dose due to various bends in these cylindrical-shaped holes.

These scenarios were calculated using the SCALE SAS4 (ref. 5) code system. The SAS4 module of SCALE uses the MORSE three-dimensional Monte Carlo shielding code as a tool for quantifying the doses due to particle streaming through holes or cracks in the shield materials.

The results of these calculations are shown in Figs. 5 and 6 for the straight penetrations and bent penetrations, respectively. The results in Fig. 5 can be used to establish that any straight penetration with a radius of less than 0.36 in. should meet the criterion of less than a 20% increase in the dose rate due to the crack. However, as noted from the series of photos after the test, the cracks are quite jagged, very thin, and not radial-oriented as assumed in the calculations. The results in Fig. 6 can be used to establish the shielding value of a bend or a jagged change in direction in the penetration.

The increases in dose due to the various penetration sizes shown in Fig. 5 are useful even if the penetrations are not cylindrical in nature. The literature has shown that the results of studies with cylindrical penetrations can be used for non-cylindrical penetrations if the *areas* of the penetrations are approximately equal.

Using these data, the following generalizations can be made with respect to the dose increases for more crack-like breaks in concrete. Consider the area of a cylindrical hole having a radius of 9.14 mm (0.36 in.) is 2.62 cm^2 (0.407 square in.). This is approximately the same area as a crack that is 15.25 cm (6 in.) long and has a width of 1.6 mm (1/16 in.) [2.42 cm^2 (0.375 square in.)]. Thus, a crack that is straight through the 30.5-cm (1-ft) thick concrete shield wall, having a length of 15.25 cm and a width of 1.6 mm, would result in approximately a 20% increase in the dose rate at the surface. If the size of the hole were doubled (e.g., a 15.25-cm-long crack with a width of 3.2 mm (1/8 in.), there would need to be one 20-degree bend in the 1-ft thick concrete wall to reduce the dose to only a 20% increase in the surface dose rate. Similarly, if the size of the hole were doubled again (e.g., a 15.25-cm-long hole having a width of 6.4 mm (1/4 in.), the hole would need three 20-degree bends to reduce the surface dose rate to only a 20% increase. This information is given in Table 1.

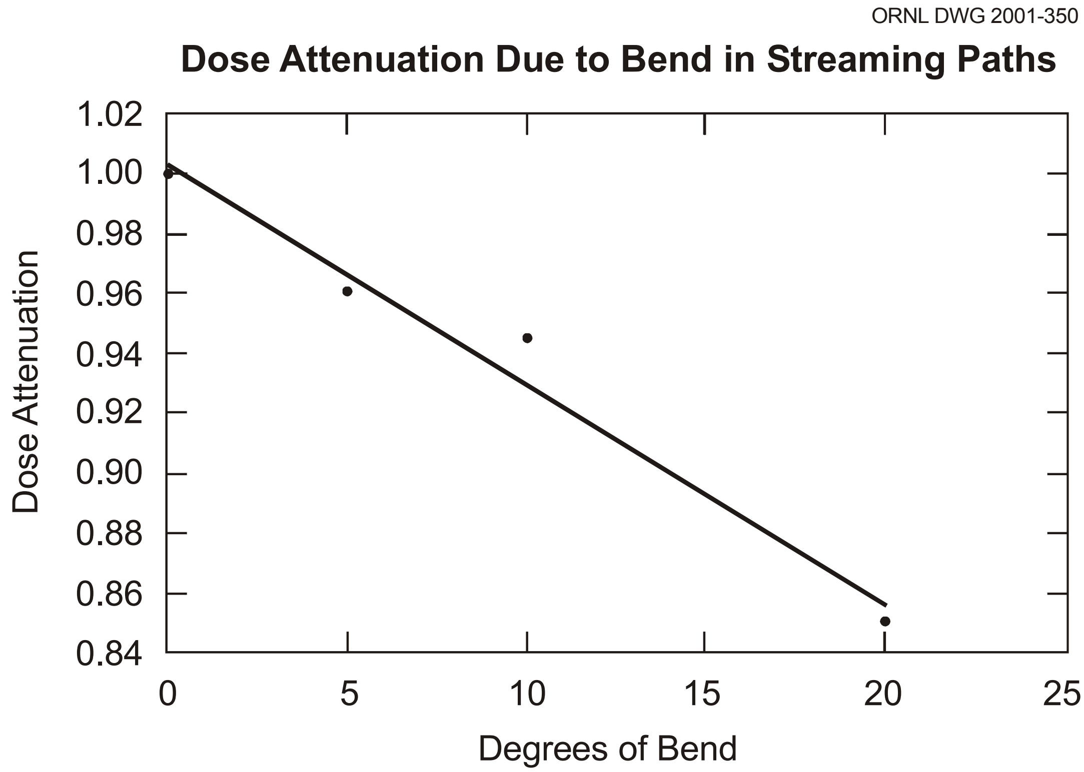

Fig. 5. **Dose increase as a function of the radius of a cylindrical void penetration.**

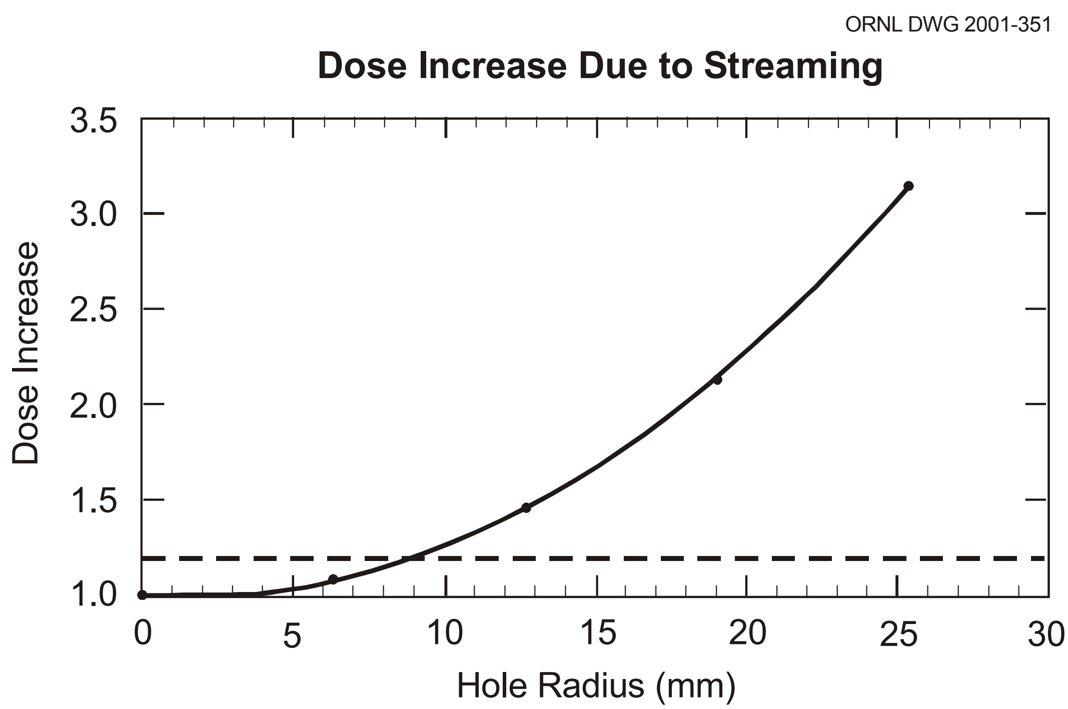

Fig. 6. Dose attenuation as a function of bend in streaming paths.

Table 1. Scenarios to meet 20% dose increase criterion

Crack width, [mm (in.)]	Crack length, [cm (in.)]	Equiv. R [mm (in.)]	Dose increase from Fig. 5	Attenuation needed for 20% net dose increase	No. of 20-degree bends *N* needed, $(0.85)^N$
1.6 (1/16)	15.25 (6)	8.9 (0.35)	1.19	1.00	0
3.2 (1/8)	15.25 (6)	12.4 (0.49)	1.45	0.83	1
6.4 (1/4)	15.25 (6)	17.5 (0.69)	2.00	0.60	3

Examining the cracking in the test piece showed that there are no cracks that pass straight through the concrete shield wall. The maximum crack width, shown in Fig. 4, maintained that maximum width only for a distance of several inches, finally decreasing to a hairline crack at the outer wall of the shield. Most observed cracks in the concrete shield were less than 0.8 mm (1/32 in.) in width and could be penetrated with a knife blade to only a depth of about 3.2 mm. In addition, many of the cracks exhibit numerous direction changes, often varying by 20 degrees or more. Thus, none of the cracks that were produced in the test were of sufficient size to result in a significant increase in the dose rate at the package surface.

CONCLUSIONS

The results and detailed discussion of the test and analysis of the package have been submitted to the Department of Energy–Oak Ridge Operations for evaluation and confirmation that the package meets the IP-2 requirements.

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