REPORT ON THE JOINT USA-GERMANY DROP TEST PROGRAM FOR A VITRIFIED HIGH LEVEL WASTE CASK*

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INTRODUCTION

Designing systems for transporting radioactive material (RAM) has gained increasing importance as the need for transporting and storage of RAM has increased. As a result, significant applied research efforts are under way to develop new generation transportation casks which are more efficient than past designs and maintain the same or higher levels of safety. Many of these efforts focus on qualifying Ductile Iron (DI) as a suitable material for use as the containment boundary in transportation and storage casks.

In Western Europe, the acceptance and licensing of DI has been attained and DI transport casks are in use throughout Europe. The basis of the acceptance rests on numerous proof tests by BAM which have demonstrated the material integrity. Drop tests with DI-prototypes up to 90t were performed according to International Atomic Energy Agency (IAEA) test conditions. The ability to transfer results obtained from the drop tests of prototypes to the serial casks is ensured by combining a number of quality and compliance assurance measures.

The transportation community outside of Western Europe has been slower to adopt DI. The principle issue is the establishment of a general adopted fracture mechanics approach. This issue is being investigated extensively in the Federal Republic of Germany, Japan, and the United States of America.

This data report is a U.S. Department of Energy (DOE) extension of the efforts previously performed in Germany. The U.S. effort has had oversight from France, Germany, Japan, and the U.S. foundry industry. A contract was let by the DOE to General Nuclear Systems, Inc. (GNSI) to design and develop a DI cask to transport RAM; specifically to transport DOE's vitrified high level waste. This program resulted in testing of a full-scale truck cask that became a joint effort between the USA and Germany.

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A series of full-scale drop tests were performed on a DI transport cask in a cooperative program between the DOE and Bundesanstalt für Materialforschung und -prüfung (BAM) in Germany. The tests, which were performed at BAM's test facility near Lehre, Germany, were preformed on a prototype cask designed for transport of Vitrified High Level Waste (VHLW) canisters. The VHLW cask is a right circular cylinder with a diameter of 11.56 mm and a height of 3454 cm, and which weighs approximately 24,600 kg, including its payload of a single VHLW canister. The drop tests were performed with a non-radioactive, prototype VHLW canister in the cavity.

OBJECTIVES OF THE TEST PROGRAM

Objectives of the test program were to confirm and quantify brittle fracture criteria and the integrity of the DI cask against mechanical impacts. This required a series of drop tests which were performed by GNSI (Germany). Data collection was taken by both GNSI and Sandia National Laboratories (SNL) of Albuquerque, New Mexico.

The objectives of the testing were as follows:

(1) To benchmark the finite element analyses performed for the cask subjected to Hypothetical Accident Conditions.

(2) To demonstrate that the VHLW ductile iron cask can safely withstand the drop tests specified for Hypothetical Accident conditions in 10 CFR 71.

(3) To demonstrate that the VHLW cask ductile iron containment material will not fail by means of brittle fracture under Hypothetical Accident Conditions.

(4) To measure fracture toughness properties of the ductile iron.

PACKAGE DESCRIPTION

The package consists of a ductile cast iron shipping cask with a toroidal-shaped impact limiter located at each end. The cavity is covered by the primary lid, which is bolted to the cask and sealed by a pair of elastomeric o-rings. Penetrations in the primary lid are provided for venting the cavity and for testing the o-ring seals. The package configuration is shown in Figure 1. A glass-filled, non-radioactive VHLW canister obtained from Savannah River Site was installed in the cavity for all tests. Canister dimensions are nominally 24 in. (610 mm) in diameter and 118 in. (3000 mm) in length.

CASK BODY

The CASTOR VHLW cask body is made from ductile cast iron which conforms to ASTM A 874-89, "Ferritic Ductile Iron Castings Suitable for Low-Temperature Service." The cask overall height is nominally 136 in. (3455 mm) and the overall diameter approximately 45.5 in. (1166 mm). The internal cavity is nominally 25 in. (635 mm) in diameter and 118.7 in. (3015 mm) high with the primary lid in place. The ductile cast iron body has 10.25-in. (260.35-mm) thick walls, and a 9.5-in. (241-mm) thick base. The intended use is to transport a single VHLW canister inside the internal cavity.

DESCRIPTION OF TEST FACILITY

All prototype drop tests were performed at the test facility belonging to Bundesanstalt für Materialforschung und -prüfung (Federal Institute for Materials Testing) (BAM) near Lehre, Germany. A drawing of the test stand used to perform the testing is shown in Figure 2. The drop

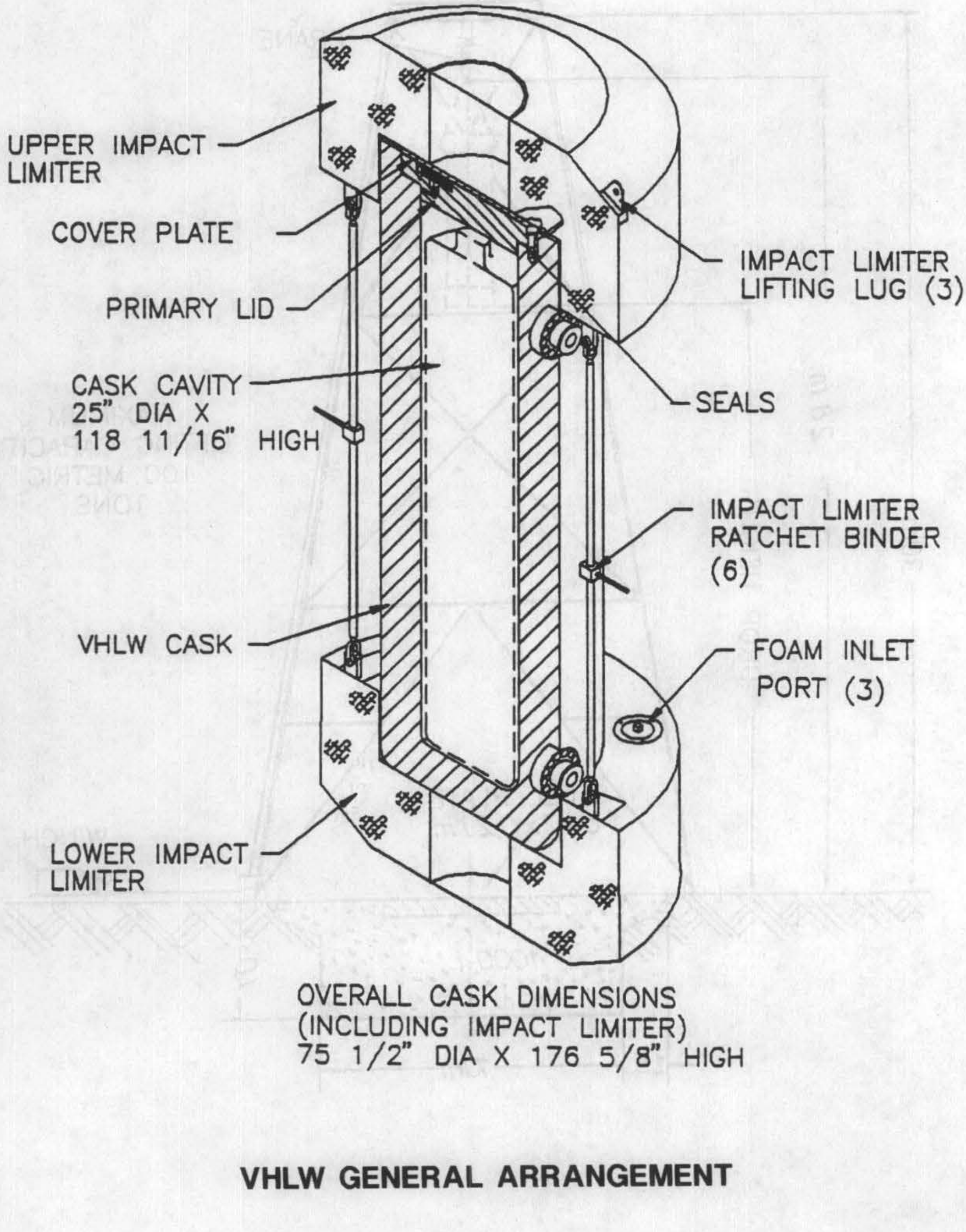

Figure 1. Cask Configuration

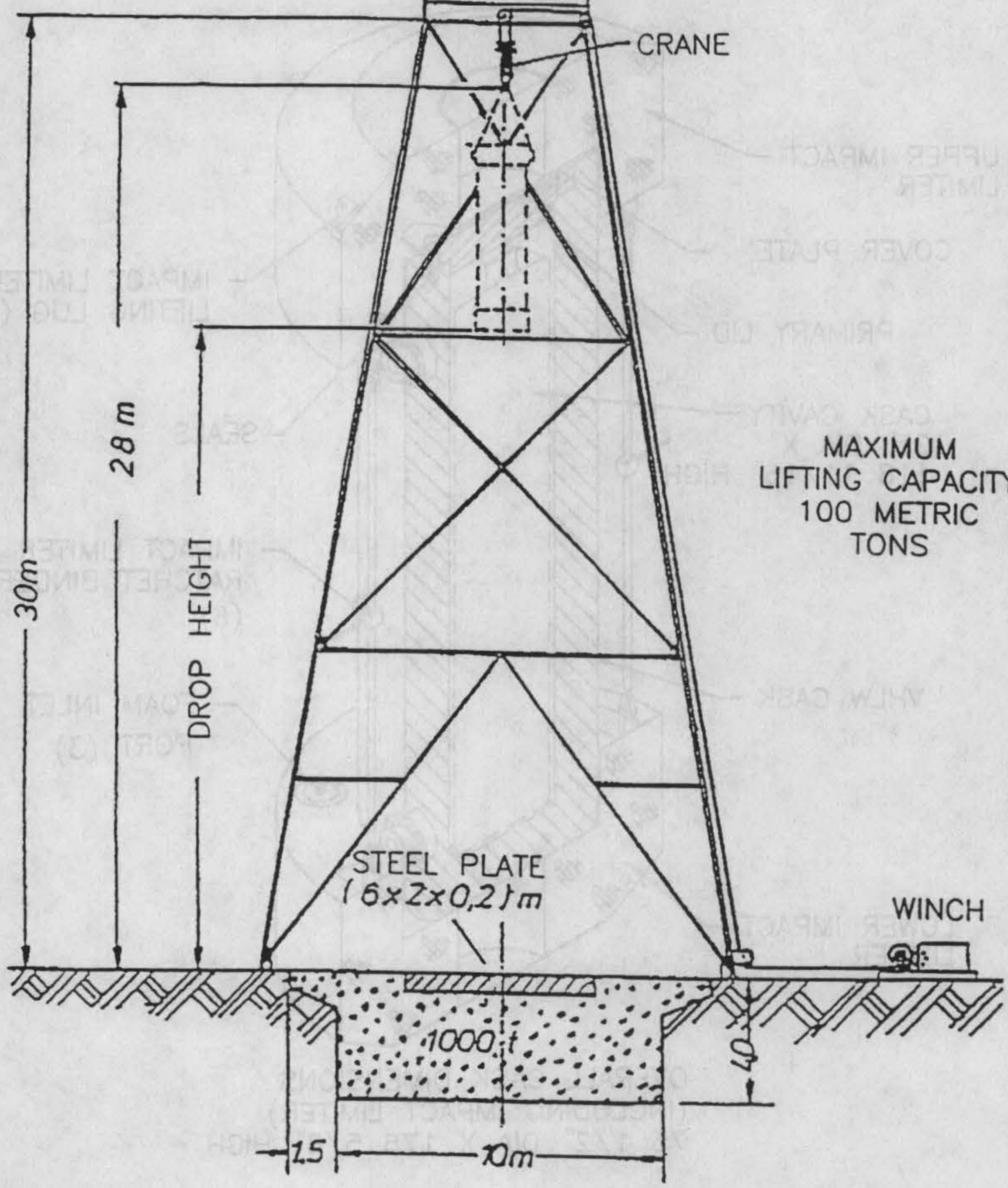

Figure 2. Drop Test Stand at Lehre, Germany

test stand has a weight capacity of 100 metric tons. It consists of a steel-frame grid construction with hoist and hydraulic release mechanism.

The impact surface for the cask is a reinforced concrete foundation with dimensions of 394 in. x 394 in. x 157 in. (10 m x 10 m x 4 m). The concrete impact pad is covered by a steel plate with dimensions of 236 in. x 78 in. x 8 in. (6 m x 2 x 0.2 m) and is shown in Figure 2. The total weight of the concrete and steel impact pad is approximately 1000 metric tons. Therefore, the impact pad is essentially an unyielding surface.

TESTING

The program sequence began with the design and fabrication of the prototype cask. The testing was performed in accordance with written procedures and under quality assurance controls. Each test was monitored by BAM personnel and instrumentation. In addition, (see Table 1) two of the first form series of tests, as well as fourth drop (60-mm flaw and -29°C) were monitored by a mobile instrumentation laboratory developed for the DOE by SNL. Specific details from all the drop tests will be published in a pending safety analysis report prepared by GNSI.

For each of the drop tests, the cask was instrumented with accelerometers and strain gages. Prior to the first side drop test and after the last test, a leak tightness test of the seal was performed and found satisfactory.

The drop testing was performed in three series. The first was performed by DOE and BAM for benchmarking the finite element analyses. These tests were instrumented and monitored by BAM personnel, and a number of tests were also monitored by SNL. This series of testing consisted of side, top-end, and slapdown drop tests from a height of 9 m, with the impact limiters installed, and also a puncture test from 1 m onto a pin. BAM also conducted a single side-drop test by dropping the cask without impact limiters onto rails from a height of 1 m. A peak deceleration of 158-g's was recorded.

The second series of tests consisted of a single side drop from a height of 9 m with the impact limiters installed. However, in order to demonstrate the brittle fracture resistance of the DI, the test was performed with a sharpened artificial flaw 60-mm deep machined into the side wall. In addition, the cask was cooled to -29°C for the test. No crack initiation from the tip of the artificial flaw was observed.

The third series of drop tests on the VHLW cask was performed by BAM. This testing consisted of subjecting the DI cask to progressively more severe challenges by dropping it from increasing heights, in an effort to cause crack initiation. Drop tests from 2.4, 3.5, and 14 m were performed by dropping in onto its side, onto rails, and without the impact limiters being installed. In addition, before this final series of tests was conducted, the section of the cask containing the 60-mm flaw was removed for examination and a deeper, 120-mm artificial flaw was machined into the same location. After each drop test, the applied stress intensity (K-applied) induced at the flaw during the impact was compared to the fracture toughness material property of the ductile iron (K_{IC}). On the last drop from 14 m, partial crack initiation was achieved. This testing verified the resistance of ductile iron to brittle fracture even at relatively large values of applied stress intensity.

Table 1 summarizes the three series of testing. Note that tests numbered 710 through 754 exceed NRC 10 CFR requirements.

Table 1. Performance Testing for the VHLW Cask

Test No.	Drop Orientation	Drop Height (m)	Deceler-ations (g)	Strain & Stress Max. um/m & MPa	Remarks
700	side on	9	80	175/28	with shock absorber
709	side on 15° inclination	9	70	135/22	with shock absorber
710*	drop on rail side on	1	158	371/59	without shock absorber
713*	side on	9	75	165/76	60-mm flaw in max. stress area; with shock absorber; cask @ -29°C; no crack extension
714*	lid, vertical	9	-	170/27	same as above but @ ambient temperature
715*	vertical on punch-bottom center	1	85	640/102	same as above
716*	drop on rail side on	2	239	518/83	60-mm flaw in deep compression area; without shock absorbers
717*	see above	3	254	444/71	same as above
752*	see above	2.4	300	706/113	120-mm deep flaw in strain area; without shock absorber
753*	see above	3.5	344	1185/190	same as above
754*	see above	14	600	1880/300	same as above**
				(Young's Modulus = 160 K MPa)	

*These tests exceed the Nuclear Regulatory Commission 10 CFR Requirements.

**The success of this final and most severe drop test is that the predicted crack extensions of 0 to 0.0008 inches were observed, followed by crack arrest.

CONCLUSION

The objectives of the drop test program were accomplished, demonstrating that the VHLW ductile iron cask can safely withstand the Nuclear Regulatory Commission (NRC) requirements for hypothetical accident conditions. The cooperative international relationship between the DOE and BAM has provided a large amount of data for any technical program that would propose the use of ductile iron casks used for storing, transporting and disposing of RAM.

The ANYS finite element analysis performed has been benchmarked. This has ensured the accurate production of stresses in the cask as if it had been subjected to the drop tests specified in the hypothetical accident condition requirements of NRC 10 CFR 71.

These test results demonstrate that a prototype cask of the tested cask can safely withstand brittle fracture when subjected to the drop tests specified in NRC 10 CFR 71. This is the case even with a flaw in the cask wall that is much larger than the largest permissible flaw size.

The prototype cask, with the two machined-in flaws, has been subjected to the worst combination of circumstances possible from the drop tests. These test circumstances are even more severe than the hypothetical accident conditions prescribed in NRC 10 CFR 71 and include the worst combination of flaw sizes, applied stress to the flaws, and low temperature. Since these tests envelop potential accident scenarios that might possibly be encountered by future production casks, the successful completion of these tests with a full-scale prototype has demonstrated that the design is safe from brittle fracture.