Impact Testing of High Level Waste Canisters

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Management of High Level Waste (HLW) generated during recycle of spent fuel consists of process of immobilization of HLW, storage in retrievable interim storage facility and disposal in deep geological repository. The HLW canisters made of SS 304L are used to store vitrified High Level Waste. The borosilicate glass is poured inside this canister along with HLW to 80% of its volume. The canisters containing vitrified HLW are stored in an engineered facility called Vitrified Waste Storage Facility (VWSF) in stacks of four canisters. During handling and storage of these canisters, there is a remote possibility of accidental drop of canister. In order to assess the integrity of canisters during and after the drop, impact testing by physical testing was carried out in four representative orientations.

Physical drop tests of simulated canisters were carried out at a National Shipping Cask Drop Testing Facility at Pune. It was found that plastic strains in the canisters were within failure limit. Helium leak test of dropped canisters revealed that leak rate was lesser than acceptable value. In order to reduce the reaction forces on thimble tube during accidental drop, shock absorbers are being envisaged.

This paper describes the impact testing of HLW canisters.

Introduction

The vitrification technology using Joule Heated Ceramic Melter (JHCM) has been mastered by India and a large quantity of HLW has been processed and converted into vitrified waste filled canisters. The glass filled canisters are sealed by remote welding using an Autogeneous Orbital Welding Machine inside a hot cell. After decontamination of outer surface, the vitrified waste filled canisters are to be stored in an interim storage facility named as Vitrified Waste Storage Facility (VWSF) in stacks of 4 canisters in one location.

Description of HLW canister:

A canister has dimensions of 355 mm outside diameter, 6.35 mm thickness and 1.95 m height. The material of construction selected is austenitic stainless steel SS 304L from corrosion point of view. Canister body is divided into three parts: a) Shell, b) bottom dish & c) top portion. Shell is made of 350 NB Sch 10 seamless pipe and has length 1.7 m. Bottom dish has 50 mm corner radius and welded to shell by full penetration butt welding. Top portion is made of frustum of a cone with flange head for lid welding. This is joined to shell by full penetration butt welding. Canister lid has 203 mm diameter and 10 mm thickness. Canister is subjected to stringent quality assurance (QA) during manufacturing like 100% radiography of full penetration welds. Empty weight of canister is 120 kg and glass filled weight is 450 kg. Typical HLW canister is shown in Fig. 1.

Objective

The objective of impact testing is to determine structural response and to ascertain structural integrity of HLW canisters subjected to postulated drop conditions during the handling and storage operation. Following postulated drop conditions were selected such that the canister suffers maximum damage.
Drop 1: Canister falling from a height of 12 m onto an unyielding target surface

Drop 2: Canister falling from 6 m height on its corner with its center of gravity (CG) in line with point of impact onto an unyielding target surface

Drop 3: Canister falling from 6 m height onto its lid with its CG in line with point of impact on an unyielding target surface

Drop 4: Canister falling from a height of 9 m in guided vertical orientation onto another canister kept on an unyielding target surface.

The basis for selecting above representative orientations are described below,

Drop 1: At VWSF, maximum handling height for canister is 12 m and during accidental drop, canister will get guided by thimble tube in vertical orientation. Hence 12 m vertical drop has been selected.

Drop 2 & Drop 3: In the hot cell, maximum handling height of HLW canister is 6 m. The canister may fall in different possible orientations; however the maximum damage will occur in corner orientation where centerline joining canister CG and point of impact is vertical. Hence 6 m corner and inverted corner orientation has been selected.

Drop 4: For this drop, the accidental scenario considered was fall of canister in thimble tube at VWSF on another canister already present at bottom location. Here drop height will be 9 m.

In all above drops it was required to demonstrate integrity of canisters after impact testing. This means canister body which is containment boundary of vitrified HLW shall not breach.

Method

A two-step process was carried out to assess the integrity of canisters under the postulated drop testing. In first step, impact testing was carried out by FE simulation. In second step, Physical drop testing of simulated canisters was carried out at a National Shipping Cask Drop Testing Facility at Pune. FE simulation was carried out to know the deformations beforehand. FE simulation is not described in this paper due to space limitations. The results of FE simulation were also used to plan for physical drop test in order to validate the methodology and results.

Physical Drop Testing

Test Description:

The physical drop testing was performed to check the structural integrity of HLW canisters during postulated drop tests. The drop tests were carried out at the National Shipping Cask Drop Testing Facility at Pune. The drop test facility consists of 10 Te goliath crane, quick release mechanism and unyielding drop surface. The target surface provided for drop was unyielding as defined by IAEA in Reference 4.

For drop testing purpose, five nos. of SS canisters were fabricated as per its technical specification and ASME Sec. III,
NC. Canisters were filled with inactive borosilicate glass during commissioning trials of JHCM such that actual weight of vitrified HLW is simulated. After filling with glass, the lid was welded remotely to the canister using Autogeneous Orbital Welding Machine inside a hot cell.

For Drop 4, a fabricated MS guide pipe of 12 m height was used which simulates thimble tube of VWSF. A glass filled canister was positioned inside guide pipe at bottom and another canister was dropped onto it from a height of 9 m. Refer fig. 3 shows test setup.

**Instrumentation:**
The instrumentation provided for drop test included accelerometer for measuring ‘g’ values, strain gauges with data acquisition system & low pass filter for measuring strain levels during drop tests at designated locations and high speed photography (HSP) system for recording and measurement of deformations. The instrumentation used had valid calibration. The locations of strain gauges was decided based on FE simulation results.

**Post drop investigations:**
After completion of drop tests, following investigations were carried out on the drop tested canisters:

a) Visual inspection
b) Dimensional measurement
c) Dye Penetrant (DP) Test
d) Helium leak test:

**Results**
The strain results are given in fig. 4 to 7.
In order to ensure leak tightness of canisters after drop testing, Helium leak test was carried out on dropped canisters. The acceptable leak rate of Helium from dropped canister was required to be less than $1 \times 10^{-5}$ atm-cc/sec. The test method used was detector probe technique (snifer probe). Test was carried out at 1.2 kg/cm² pressure for 15 minutes duration. Fig. 8 shows test setup of Helium leak test.

**Table 1: Strain gauge results**

<table>
<thead>
<tr>
<th>Orientation</th>
<th>12 m Vertical (microstrain)</th>
<th>6 m Vertical Corner (microstrain)</th>
<th>6 m Inverted Corner (microstrain)</th>
<th>9 m Canister on Canister (microstrain)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.G. No.</td>
<td>DAS</td>
<td>DAS</td>
<td>DAS</td>
<td>DAS</td>
</tr>
<tr>
<td>SG 1</td>
<td>20500</td>
<td>200</td>
<td>-1225</td>
<td>-175</td>
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<tr>
<td></td>
<td>7500</td>
<td>300</td>
<td>475</td>
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<td>SG 2</td>
<td>-8000</td>
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<td></td>
<td>13000</td>
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</tr>
<tr>
<td></td>
<td>14000</td>
<td>4500</td>
<td>625</td>
<td>-475</td>
</tr>
<tr>
<td>SG 4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-350</td>
</tr>
<tr>
<td></td>
<td>10000</td>
<td>600</td>
<td>225</td>
<td>175</td>
</tr>
</tbody>
</table>

**Table 2 gives comparison of accelerometer & HSP results.**

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Parameter</th>
<th>Accelerometer</th>
<th>HSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 m Vertical</td>
<td>Acceleration, g</td>
<td>424</td>
<td>545</td>
</tr>
<tr>
<td></td>
<td>Time of Contact, ms</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>6 m corner</td>
<td>Acceleration g</td>
<td>252</td>
<td>359</td>
</tr>
<tr>
<td></td>
<td>Time of Contact, ms</td>
<td>-</td>
<td>3.5</td>
</tr>
<tr>
<td>6 m inverted corner</td>
<td>Acceleration g</td>
<td>35</td>
<td>247</td>
</tr>
<tr>
<td></td>
<td>Time of Contact, ms</td>
<td>-</td>
<td>7.5</td>
</tr>
<tr>
<td>9m Canister on canister</td>
<td>Acceleration g</td>
<td>NA</td>
<td>166</td>
</tr>
<tr>
<td></td>
<td>Time of Contact, ms</td>
<td>-</td>
<td>19</td>
</tr>
</tbody>
</table>

**Helium Leak Testing**

Following are the results of Helium leak testing:

- Leak rate observed for Drop 1 tested canister = $2.9 \times 10^{-5}$ atm-cc/sec.
- Leak rate observed for Drop 2 tested canister = $4.2 \times 10^{-5}$ atm-cc/sec.
- Leak rate observed for Drop 3 tested canister = $2.2 \times 10^{-5}$ atm-cc/sec.
- Leak rate observed for Drop 4 tested canister = $2.1 \times 10^{-5}$ atm-cc/sec.

**Fig 8: Test set up for Helium leak test**
Observations & discussions
The plastic strains are observed to be in ±3%max and that too in localised regions (near drop surface). These are well within typical failure limits of 10-13% for SS 304L.
For all drops, visually no cracks were observed and the canister integrity was maintained (lid & body). No glass fragments were observed near impacting surface. DP test of impact region revealed no cracks.
In drop 4, the gap between neck and lid was reduced but still sufficient for remote handling. The bottom deformed canister was also tested for remote retrievability with its handling grapple and it was observed that remote handling of deformed canister was possible from the storage grids.
Leak rate observed in Helium leak testing for all cases was less than acceptable value of $1 \times 10^{-4}$ atm-cc/sec.
The physical testing was carried out at room temperature. However, in actual case, the canister surface temperature may reach max. 250°C due to heat generating nature of its contents. From engineering judgement, the plastic strains at this temperature may not exceed ±5-6% which are well within limiting values (assumed conservatively).

Shock Absorbers for Thimble Tube
Very high impact forces are exerted on thimble tube which is used to store the canisters during postulated accident. In order to reduce the impact forces, two types of shock absorbers are envisaged. The high reaction forced during 12 m drop will be reduced by use of shock absorber. The evaluation of proposed shock absorbers is being carried out by NRB.

Conclusion
Physical drop test was carried out to evaluate canister response. No significant plastic strains were observed in physical drop tests which does not amount to failure. Visually all drop tested canisters maintained structural integrity. This fact was also confirmed by DP test and Helium leak test. Based on the results it is concluded that canister maintains structural integrity in postulated accidental scenario.

References