INVESTIGATION OF A SPENT FUEL CASK BESIDE AN EXPLODING PROPANE TANK

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ABSTRACT

In 1999 a fire test was performed with a 45 m³ rail tank car partially filled with 10 m³ pressurised liquid propane. An original CASTOR THTR/AVR spent fuel transport cask was positioned beside the propane tank as to suffer maximum damage from any explosion. About 17 minutes after fire ignition the propane tank ruptured. This resulted in a BLEVE with an expanding fireball, heat radiation, explosion overpressure, and tank fragments projected towards the cask. This imposed severe mechanical and thermal impacts directly onto the CASTOR cask , moving it 7 m from its original position. This involved rotation of the cask with the lid end travelling 10 m before it crashed into the ground. Post-test investigations of the CASTOR cask demonstrated that no loss of leaktightness or containment and shielding integrity occurred.

INTRODUCTION

BAM was contracted by a federal state authority to investigate the behaviour of a LPG rail tank car in an engulfing fire. This led to the preparation of a fire test with a 45 m³ propane vessel, a size one order of magnitude bigger than those tested by BAM in the past (1). A fire engulfment of a LPG tank not equipped with a safety relief valve, and without any other thermal protection, can rupture within a reasonable short fire duration (2). LPG tank ruptures in a fire produce very severe consequences due to the release of pressurised inflammable gas resulting in a "BLEVE"(Boiling Liquid Expanding Vapour Explosion). Such a BLEVE causes intensive heat radiation and explosion overpressure due to an expanding fireball, and fragments of the ruptured tank are propelled away with high energy. LPG tank ruptures by fire caused many of the most catastrophic losses in industry, e.g. the Mexico City disaster 1984 (3), or the Waverly/Tennesee LPG tank car BLEVE (4). The simulation of such an extreme accident in a controlled environment led BAM, as the German competent authority for Type B package assessment, to the idea of investigating the behaviour of a spent fuel transport cask under these severe accident conditions. The manufacturer of the CASTOR casks, the "Gesellschaft für Nuklear-Behälter mbH (GNB)" provided an unused clean CASTOR THTR/AVR for such an investigation. A combined fire test was performed on 27 April 1999 with a propane rail tank car, and a spent fuel transport cask positioned directly beside it, at the BAM test side in Horstwalde/Brandenburg (south of Berlin). This paper reports on the results concerning the spent fuel cask investigation.

TEST OBJECTS AND TEST FACILITY

The fire test facility was located in the centre of a circular sandy area, with a diameter of 400 m. In the centre of this area a U-shaped sand wall was constructed by army engineers. Two steel troughs for the fuel oil pools were positioned inside this wall. The LPG rail tank car, with a tank volume of 45 m³, a tank length of 7.6 m, a diameter of 2.9 m (test overpressure 28 bar (2.8 MPa), cylinder steel wall thickness 14.9 mm) was positioned above a pool 10 m by 5 m. The test site is shown in Figure 1. For the test, the LPG tank was partially filled with 10 m³ liquified propane (22 % of tank capacity), and extensively instrumented with thermocouples and pressure gauges. The propane content was limited to control the consequences to the test site.

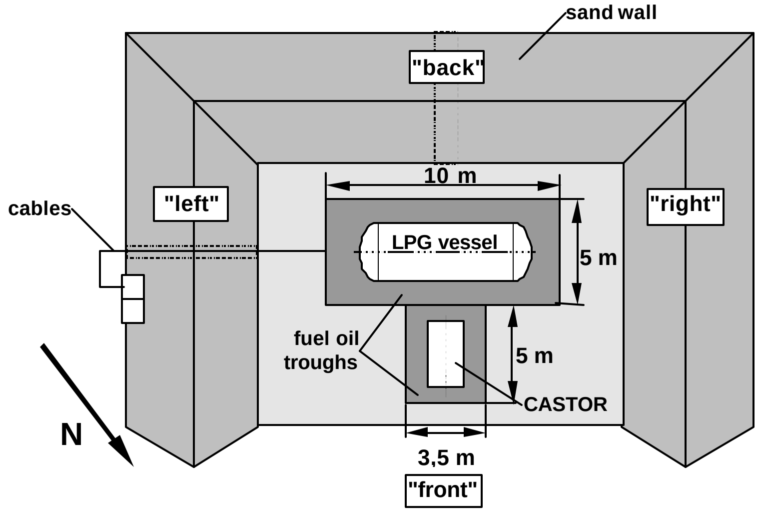

Figure 1. BAM Fire Test Site in Horstwalde

The spent fuel cask used in the test was a CASTOR THTR/AVR cask designed for the transport and dry interim storage of pebble-bed reactor spent fuel. The main dimensions of a CASTOR THTR/AVR cask are: length: 2.785 m, diameter: 1.38 m, wall thickness: 0.37 m. The monolithic ductile iron cask body is closed by a double-barrier lid system as used in all German transport casks intended for long-term interim storage of spent fuel and high level radioactive waste (5). The primary lid (250 mm thick, ferritic steel) and the secondary lid (70 mm thick, ferritic steel, bolt hole circle diameter 1000 mm) are each screwed with 28 screws (M36) to the cask body. These main lids and small lids closing orifices inside the main lids, are sealed with HELICOFLEX metal gaskets as used in all CASTOR transport and storage cask designs.
The CASTOR cask was subjected to the test without the impact limiters used during transport, and without the additional protection lid used inside the storage facility.

The empty cask with a weight of 22,450 kg was positioned horizontally on a massive steel frame that was thermally insulated and supported by two concrete slabs. The cask axis was perpendicular to the propane tank axis, with the cask lid side facing to the propane tank as shown in Figures 1, 2a and 6. The cask was instrumented with two thermocouples (penetrating the lids through leak-test ports and bore holes) for temperature measurements close to the large metallic seals of the primary and of the secondary lid. Flame temperatures were measured by two thermocouples 100 mm from the lid horizontal diameter. The CASTOR cask was positioned above a separate fuel oil pool with the dimensions of 3.5 m x 5 m directly beside the LPG rail tank car pool.

COURSE OF THE TEST

The fuel oil was ignited electrically by small pyrotechnic detonators inside gasoline dishes that were destroyed after about 100 seconds, and ignited the two fuel oil pools. The pressure inside the propane tank began to increase continuously 130 seconds after primary ignition, indicating that full fire engulfment of the test objects had been reached. Due to a slight wind from northern direction (2 m/s), the test objects were only engulfed partially by the flames. As a result the right and the front side fire temperatures were lower than at the left and back. After a continous pressure increase over 15 minutes (approx. 17 minutes after primary ignition) the propane tank ruptured at an internal overpressure of 25

Figure 2. View of the Test Facility

a) Before the Test (above): Propane Tank (left) and CASTOR Cask (right) above Fuel Oil Pools

b) After the Propane Rail Tank Explosion (below) bar. The tank wall split at the weakest point, starting from 8.5° above the horizontal centre-line (and well above the liquid level), at the middle of the side furthest from the cask, when the wall temperature there reached about 550°C. The tank ruptured at first in axial direction, along the cylindrical tank part. After that, the tank ruptured around the circumference, disconnecting the two tank heads. The tank content was released instantenously, igniting and creating an expanding fireball. The approximate largest fireball had a diameter of about 100 m with the top about 150 m above ground level. The fire-ball burning time was about 7 seconds. The maximum secondary lid seal temperature at that moment was measured with 160°C. Figure 2b shows the test facility shortly after the tank explosion. Fragments of the propane tank have been ejected from the walled area. The main part of the cylindrical tank shell, with a mass of 6700 kg was thrown 150 m. A small part of the cylindrical tank shell went 200 m, and the tank heads 130 m and 155 m away. All the propane rail tank car fragments were thrown out of the open side of the U-shaped sand wall, in the direction of the CASTOR cask.

IMPACT ANALYSIS AND TEST RESULTS

As a consequence of the propane tank initial rupture at the back furthest from the cask, the rupturing tank was accelerated rocket-like onto the CASTOR cask. The rail tank car hit the CASTOR cask at the upper half of the lid. The tank impact area could clearly be identified as the part where the tank shell was rivetted to the rail carriage. The imprint of this tank car area was found on the surface of the CASTOR cask secondary lid (Figure 3).

Figure 3. Excavated Lid Side of the CASTOR Cask with Imprints of the LPG Tank Support Saddle on the Outer Lid of the Cask

The deformed parts of the rail carriage were found at the steel support where the CASTOR cask was positioned originally (Figure 4). The combined impulse of the rail car fragments and the explosion moved the support frame 0.5 m away, and threw the CASTOR cask out of the test facility. The excen-tric impact onto the cask lid caused the cask to rotate. The cask bottom corner touched the concrete slabs in front of the fuel oil pool, and, after rotation the CASTOR cask lid side crashed into the soil (Figure 5). The CASTOR cask motion is shown in Figure 6.

Figure 4. Fragments of the Rail Tank Carriage after the LPG Tank Explosion

Figure 5. CASTOR Cask Thrown out of the Test Facility, with its Lid Side Crashed Into the Soil

The total rotation angle was estimated to be 201°. The flight distance of the cask's point of gravity was 7 m and the flight distance of the lid end was about 10 m. After excavation of the lid area, the cask was inspected, and the lids were measured for leaktightness (as before the fire test) under the control of BAM inspectors. Deep scratches and imprints from the impacting tank car fragments can be seen on the cask body beside the lids. The integrity and geometry of the secondary lid was unchanged, no permanent distortion had occurred. The results of the helium leakage measurements of the lids metal seals gave the following results:

- secondary lid, main seal: 2.2×10^{-11} Pa·m³·s^{-1}
- closure lid in secondary lid: 3.5×10^{-11} Pa·m³·s^{-1}
- primary lid, main seal: $< 4.5 \times 10^{-10}$ Pa·m³·s^{-1}

closure lid seal in primary lid: 4.3×10^{-11} Pa·m³·s^{-1}

The leakage rates after the test are unchanged compared to the measurements before the test, and well below the specified maximum leakage rate of 10^{-8} Pa.m³.s^{-1}. The torquing forces required to loosen the screws were virtually unchanged from the original torquing forces.

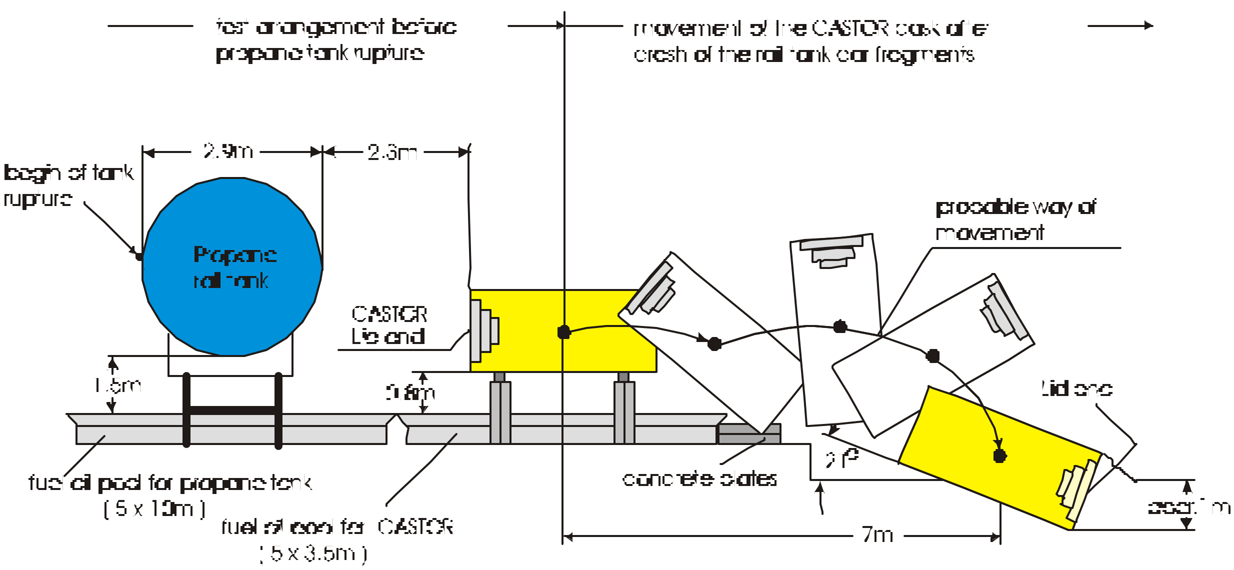

Figure 6. Test arrangement before LPG tank rupture (left) and movement of the CASTOR Cask After the Impact of the Propane Rail Tank Explosion (right)

CONCLUSIONS

The fire test caused a propane tank failure that resulted in a severe impact of rail tank car fragments onto the CASTOR cask. An exact estimation of the mechanical impact energy, resulting in cask rotation, translation, and penetration into ground, is impossible, because there are no velocity data available. Considering the crash of the tank fragments on the unprotected lid, the cask flight distance, and the crash of the unprotected lid end into the ground, it can be qualitatively concluded that this impact was slightly below, or of the same order of magnitude, as an impact from the regulatory mechanical test conditions (cask with impact limiter protection, 1 m drop onto steel punch, 9 m drop on to unyielding target). The thermal impact was below the regulatory thermal test condition (30 Minutes full fire engulfment), because of lower fire duration, and intensive, but only short fireball heat radiation. The test scenario on the other hand resulted in a sequence different from the regulations: the cask was mechanically impacted after being previously heated. Nevertheless the safety relevant functions and properties of the spent fuel transport and storage cask remained unchanged, and it can be concluded generally that Type B packages have remarkable margins of safety, even in severe and highly improbable accident situations. As demonstrated, the regulatory test conditions can cover even extreme accident impacts, such as an LPG tank BLEVE.

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