BRANDNEW FIRE TEST FACILITIES AT “BAM TEST SITE TECHNICAL SAFETY”

Bernhard Droste **Armin Ulrich**

Joerg Borch

BAM Federal Institute for Materials Research and Testing, Berlin, Germany

ABSTRACT

Fire testing is an essential part of the hypothetical, cumulative mechanical and thermal accident test conditions that shall guarantee package safety in severe accidents. Not only for radioactive material transport packages but also for other containments of dangerous goods international standards require specific thermal load specifications. Following the guideline “Safety in technology and chemistry” BAM as a scientific and technical German federal government institute operates a 12 km² large open air test facility for experimental investigations of dangerous goods and their containments. On an area besides the well-known 200-ton drop test facility we put into operation new fire test facilities. This facility area provides two fire test stands that are utilized with liquid Propane as fuel from a central earth-covered 60 m³ LPG storage tank. From that storage the Propane is pumped via pipelines to the test stands where the gas is released from nozzles, and ignited by ignition burners. The fire exposed test facility areas are 12 m x 8 m. Fire test facility B (with gas release nozzles below water-covered ground) is designed for fire testing of containers that may burst during the test. Fire test facility A (with ring burner systems) is designed for heavy test objects up to 200 tons, e.g. for full-scale spent fuel casks.

The paper will present a detailed description of the facility, insight into first test performances, and results of calorimeter fire tests, using containers of various sizes, to verify the absorbed heat fluxes, demonstrating that regulatory fire test conditions are met, and that the Propane fire can be compared with a kerosene or heating oil pool fire.

INTRODUCTION

To demonstrate the integrity of containments for dangerous goods, such as pressure receptacles, gas tanks or transport or storage packages for radioactive material, thermal load tests are required in many cases.

The specifications of these thermal tests are based on test conditions in which a heat flow at least equivalent to that of a hydrocarbon pool fire should be generated. Here, some requirements concerning the arrangement of the test sample and the design of the fire testing facilities must be met in order to ensure that the test specimen is sufficiently engulfed in fire.

In the past, light heating oil, diesel or kerosene was mostly used as the fuel to generate the hydrocarbon pool fire. However, for reasons of environmental protection, it is no longer acceptable to use these fuels, and in many areas, it is even prohibited.

In addition to the production of a great deal of smoke, when test containers burst, unburnt components are scattered near and far over a wide area around the test area, which can lead to considerable quantities of the water polluting substance leaking into the ground and hence into the ground water.

Figure 1. Heating oil pool fire (BAM, Lehre; test 1, nearly complete fire engulfment)

For this reason, BAM set up a fire testing facility as early as 1990-1991 at its old test area in Lehre, near Brunswick (Braunschweig), where the test samples were set on fire with liquid propane [1]. This facility replaced the former heating oil pool fire facility (Fig. 1).
Propane as fuel offers several advantages over the liquid hydrocarbons used previously:

- The intensity of the fire, and hence the heat input into the test sample, can be controlled by configuring the aim of the discharge nozzles and by regulating the delivery rate of the liquid Propane.
- If critical conditions are reached in the test container, the test can be shut down within a very short time.
- Once the test has finished, there are no oil contaminated residues and wastes to be disposed of, as there are when heating oil or diesel is used.
- Considerably less smoke and soot is produced in the test, which also means the course of the test can be observed very clearly. On the other hand, this flame emission coefficient, which is different compared with the heating oil fire, requires precise comparative quantification of the heat flow under each of the test conditions.
- The testing facilities are much easier to manage. Several tests can be carried out within a short period of time.

In a hydrocarbon fire, a mean fire temperature of 800°C and a heat flow of 75 to 110 kW/m² are assumed. According to IAEA guidelines [2], for a fire in an accident, an average heat flow of at least 75 kW/m² must be met [1]. The international and national regulations for so-called portable tanks specify a heat flow of 110 kW/m² for accident fires, for which insulation and the safety devices have to be designed.
In order to ensure exposure to fire under these conditions, it must be ensured for every other heat source that at least this heat flow is reached.

DESCRIPTION OF THE NEW BAM FIRE TEST FACILITIES

The new test facilities built at BAM's TTS (TEST SITE TECHNICAL SAFETY) in Horstwalde, about 50 km south of Berlin are placed on a large open area. On the site plan (Fig. 2) we identify the two separate fire test facilities A and B, each having an operation area of 12 m x 8 m.

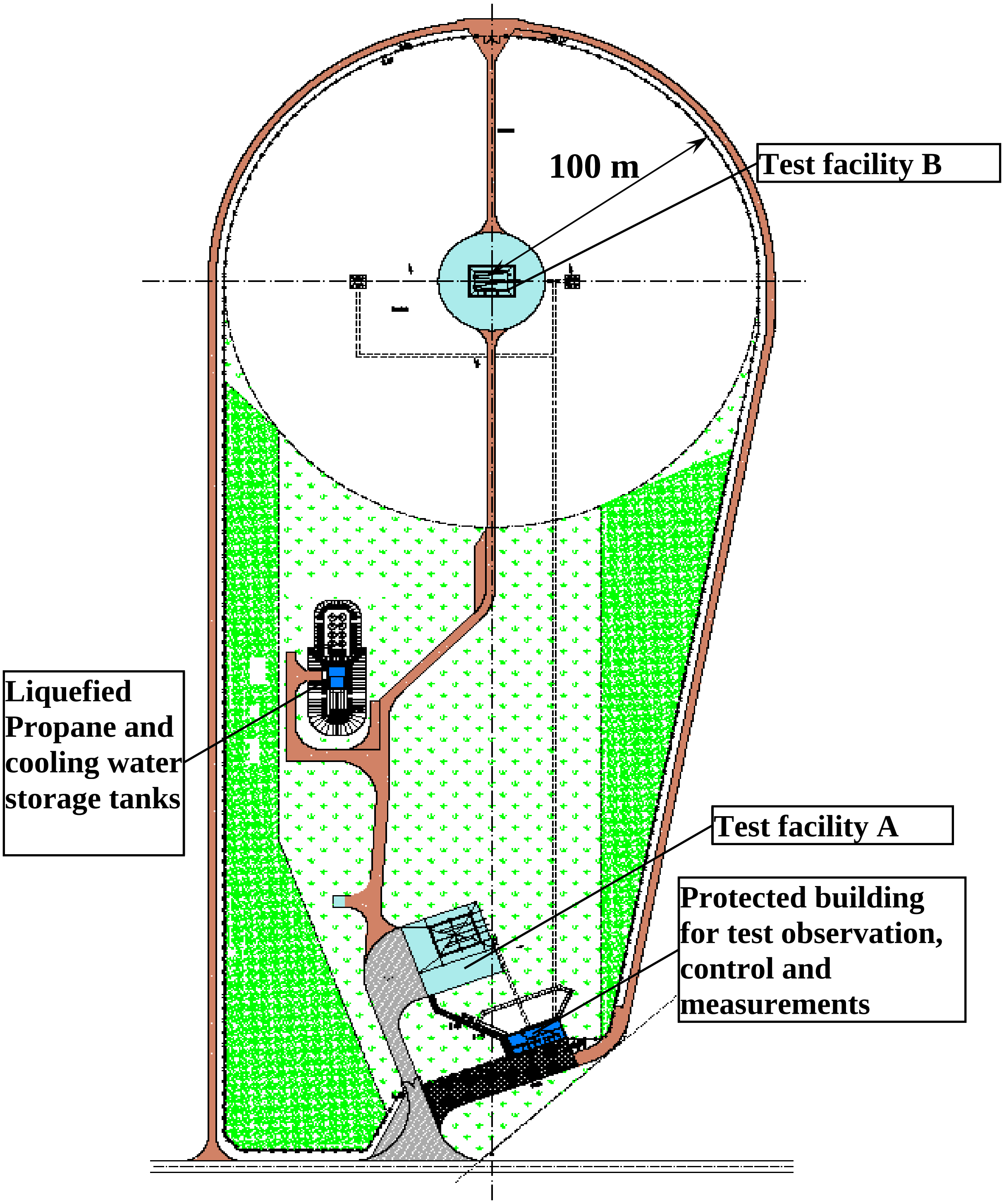

Figure 2. Site plan of the new fire test facilities at BAM Test Site Technical Safety (TTS)

One of the test facilities (test facility A) is based on the principle of a ring burner. The liquid Propane is released through nozzles from a burner ring positioned about 1.5 m away from the test sample (see Fig. 3).

This ring burner is fitted with the burner nozzles and divided into segments, by means of which the burner can be adjusted to the size of the test object. The size of the ring burner in test facility A can be increased to a maximum surface area of 8 m x 12 m and can take correspondingly dimensioned test samples. The test sample may have a mass of up to 200 Mg. The fire test facility A is the one for testing packages for radioactive material.

Figure 3. Test object (cubic tank) in a heat input test in fire test facility A; the Propane is propelled laterally under the test sample from nozzles in the ring burner

The disruptive effect of the wind is minimised by the way the test sample is positioned in the test facility and by hanging up metal sheets. A permanent water circulation system to cool the concrete base and the ring burner guarantees trouble-free operation.
In the second test facility B, the liquid Propane is released through nozzles whose direction of flow is aimed perpendicularly upwards, so the test specimen is surrounded by the fire (see Fig. 4). This test facility B is designed for so-called "destructive tests", i.e. tests in which the test object may burst or leak, but the wind deflector sheets of test facility A were replaced with massive concrete elements. Thus not only the disruptive effect of the wind is minimised here, but pieces of burst containers are caught and the impact spots of pieces of debris are marked. Because of the potential destructive nature of tests, test facility B is located several hundred metres away from the Propane storage tanks (protected additionally by earth covering), fire test facility A and the test control building.

Figure 4. Test object in a heat input test in fire test facility B

Figure 5. Burner area of fire test facility B

The burner area of this test facility B consists of 26 rows of nozzles, each with 16 nozzles (see Figure 5). The burning test area is adjusted to the test sample by shutting off individual rows of nozzles and by plugging the other nozzles. If all the rows and nozzles are used, the resulting burning area is around 10.5 m x 6.5 m.

The liquid Propane arrives at the test facilities through several gas pumps via underground pipes. Before or during the test, the controls enable the operator to select how many and which gas pumps should be used in the test.
In both types of fire test facilities, the heat input into the test piece depends mainly on the output rate of the liquid Propane released. A prerequisite is a nozzle arrangement which ensures that the test sample is fully engulfed in fire.

CALORIMETER FIRE TESTS

Heating Oil Pool Fire

To demonstrate the comparability between a heating oil pool fire and a Propane fire, BAM in former investigations [1] developed a test container with which the absolute heat input (heat flow absorbed) into the tank could be measured in accordance with the calorimetric principle.
It was a LPG storage tank (standard household gas storage tank for Propane) with a nominal capacity of 4850 l, which was filled to 100% with water before the tests.
To make it possible to place instruments inside the container, the test tank was provided with an access opening and a cap. In the test, the cap also served as an expansion tank for the water. In order to avoid temperature stratification of the tank contents in the test, two circulation pumps were built into the tank with a pumping capacity of around 10,000 l/h. The pumps circulated the tank contents during the fire test, thus providing continual mixing of the water to achieve a homogeneous bulk liquid temperature distribution. To measure the water temperatures in the test, several thermocouples were placed inside the tank. The heat flow was determined on the basis of the arithmetic mean value of the measured values of the temperature measuring points to determine the increase in temperature of the water in the tank over the duration of the test.
The absolute heat input into the tank was calculated in accordance with the following formula:

$$q = \frac{m_{water} \cdot cp_{water} + m_{steel} \cdot cp_{steel}}{A_{tank} \cdot t_{test}} \cdot \Delta T$$

q	Heat flow $\left[\frac{kW}{m^2}\right]$
ΔT	Temperature increase of the water filling and the tank material in the test $[K]$
t_{test}	Time of fire exposure $[s]$
A_{tank}	Test sample outer surface $[m^2]$
m_{water}	Mass of water filling $[kg]$
cp_{water}	Specific heat capacity of water $\left[\frac{kJ}{kg \cdot K}\right]$
m_{steel}	Mass of the steel tank $[kg]$
cp_{steel}	Specific heat capacity of the steel tank material $\left[\frac{kJ}{kg \cdot K}\right]$

To obtain a reference measurement, it was necessary to carry out tests with this container in the heating oil pool fire and the Propane gas fire.
The heat inputs in the heating oil pool fire (pool area 6.65 m x 3.35 m) were measured in two tests [3, 5]. In test 1 $q = 90.2$ kW/m² and in test 2 $q = 63.3$ kW/m² was measured.
With one important difference both tests were carried out under almost identical conditions. In test 2, it was observed that as a result of the effect of wind, a part of the bottom of the container was not completely engulfed in flames for the entire duration of the test as can be seen in Fig. 6, what was the reason for a significant smaller absorbed heat flux as in the test 1 (see Fig. 1).

Figure 6. Heating oil pool fire calorimeter fire test 2; as a result of the effect of wind, the test container was not completely engulfed in fire

However, the result of test 1 shows that the heat input of at least 75 kW/m² is certainly reached if the test sample is well engulfed in flames in a heating oil pool fire.

<u>Propane Fire</u>
Determination of the heat input was also carried out at BAM's former Propane fired fire test facility in Lehre/Braunschweig [1, 4].
In those investigations heat inputs of between 47 kW/m² and 109 kW/m² were reached, depending on the weather conditions and the operation parameters of the fire test facility.
Once the new fire test facilities A and B at BAM TTS had been completed, heat input tests had to be carried out again to determine the operation parameters of the test equipment.
Several containers with different geometries were available for these tests:
A 4,850 l LPG tank (standard household gas storage tank), a 1,000 l IBC, a 20,000 l tank, a 5,000 l tank cube and a 2,500 l LPG tank.
As a result of this size and shape differentiation, in future it will be possible to adjust the heat input for almost all types of transport tanks or radioactive material transport or storage packages.
The new fire test facilities provide the opportunity of automatically regulating the gas flow rate. The burners can be operated by pressure control (constant pressure on the burner nozzles during the test) or by controlling the mass flow rate (constant flow of Propane through the burner nozzles). To achieve homogeneous fire engulfment of the containers and tanks, the number of nozzles and their direction were adjusted to the test sample before each test.
By varying the burner pressure setting or the mass flow rate in the test, different heat inputs into the test samples were reached.
In addition, the height of the specimen bottom above the nozzles was varied to some extent. In test facility B, this had some considerable effects on the heat inputs obtained, because the liquid Propane only ignites at a certain distance from the nozzles (e.g. see also Fig. 5).
Depending on the settings, the heat inputs achieved in these tests were:

- for the 4,850 l LPG tank 45 ... 81 kW/m²
- for the 1,000 l IBC 74 …102 kW/m²
- for the 20,000 l tank 48 …100 kW/m²
- for the 5,000 l tank cube 80 …135 kW/m² and
- for the 2,500 l LPG tank 72 …110 kW/m²

Figure 7. 2,500 l LPG tank calorimeter in fire test facility B

As an example one of the investigations with the 2,500 l LPG tank is explained here in more detail. Fig. 7 shows the test set-up, Fig. 8 shows the dimensions and instrumentation plan with thermocouples inside and outside the tank. In Fig. 9 the fire temperatures and in Fig. 10 the water bulk temperatures are shown; this test realized an absorbed hest flux of 77 kW/m^2. The calorimeter tests resulted in measured heat inputs between 50 and 115 kW/m² depending on the amount of gas released through the nozzles.

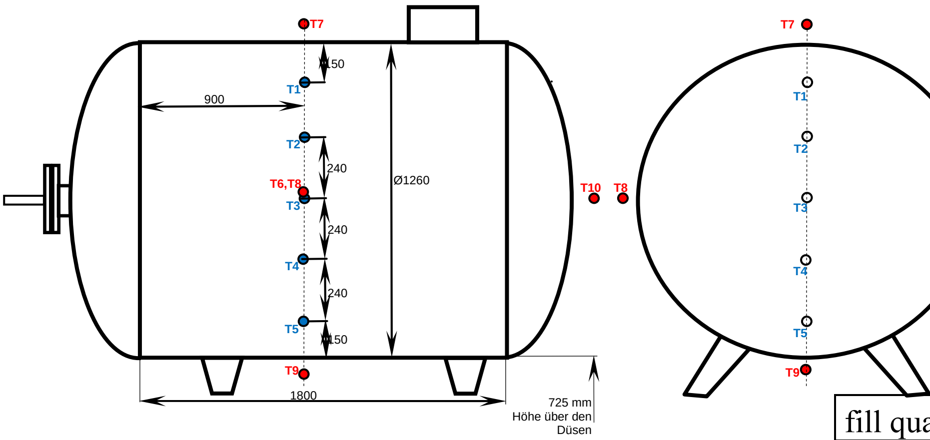

Fig. 8 Plan of the measuring points of the 2.5m³ LPG tank

fill quantity water [l]:	2448
mass steel [kg]:	547
surface A steel [m²]:	10,7

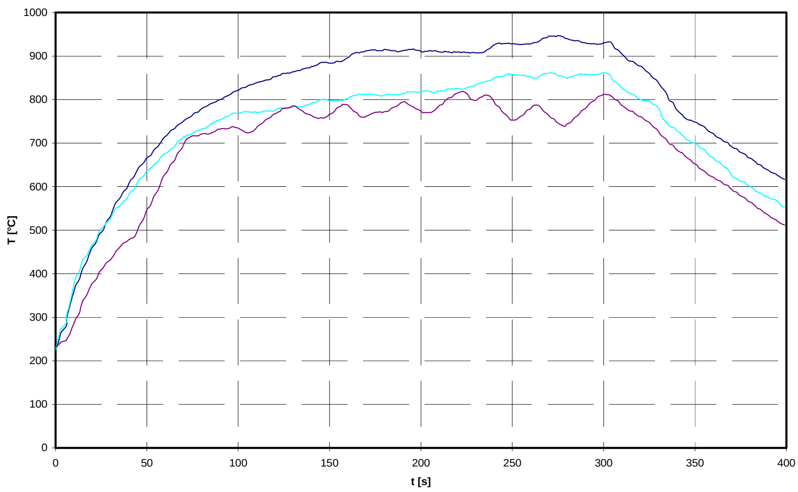

Fig. 9 Progression of fire temperatures of a selected heat input test with a 2,500 l LPG tank calorimeter

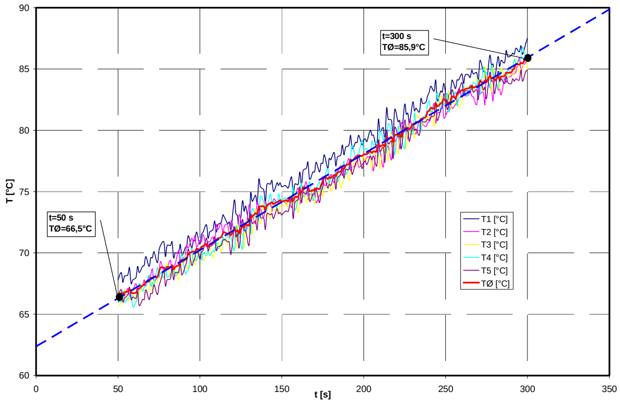

Fig. 10 Progression of the temperatures of the bulk liquid and the mean value TØ of a selected heat input test with a 2,500 l LPG tank calorimeter

CONCLUSIONS

The tests showed that fire tests in accordance with international conventions and regulations, e.g. the UN Recommendations on the Transport of Dangerous Goods or the IAEA Regulations for the safe transport of radioactive material, are possible not only with a heating oil pool fire. The heat inputs required can also be achieved with a Propane fire, if it can be ensured that the test specimen is engulfed in the flames using a suitable arrangement of nozzles and a gas release rate which is adapted to the test sample.

The prerequisite for this is that for each type of test sample geometry, the arrangement of the nozzles and the gas throughput rate at which the required heat input into the test sample is achieved, must be determined with appropriate calorimeter tests before the fire tests are carried out.

These results can be transferred to all test samples whose external shape corresponds largely to those of the calorimeter objects investigated.

REFERENCES

[1] Droste, B., Wieser, G., Probst, U.: “Thermal Test Requirements and Their Verification by Different Test Methods“; Proc. PATRAM 1992, September 13 - 18, 1992, Yokohama City, Japan; Vol. 3, pp. 1263 - 1272

[2] IAEA-International Atomic Energy Agency; Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material; IAEA SAFETY STANDARDS SERIES No. TS-G-1.1 (Rev. 1); VIENNA, 2008

[3] BAM-Bundesanstalt für Materialforschung und -prüfung; Brandversuche an einem wassergefüllten 4850 l - Flüssiggasbehälter zur Ermittlung des Wärmeeintrags mittels Heizölfeuers.; BAM-Versuchsbericht Nr. 9.32/1, Berlin,1993 (non-published test report; results published in /5/)

[4] BAM-Bundesanstalt für Materialforschung und -prüfung; Brandversuche an einem wassergefüllten 4850 l – Flüssiggasbehälter zur Ermittlung des Wärmeeintrags des Flüssiggas- betriebenen Brandprüfstandes der BAM in Lehre; BAM-Versuchsbericht Nr. 9.3-4/92, Berlin, 1992 (non published test report; results published in /5/)

[5] Ludwig, J., Feutlinske, K.; Forschungsvorhaben THEBETA-Thermische Belastbarkeit von Tanks, Schlussbericht, BAM, Berlin, 30. August 1996 (Final report of a research project for the German Ministry of Transport)