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VERIFICATION OF DESIGN LEAKAGE RATES FOR ACTIVITY RELEASE CALCULATION

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ABSTRACT

The mechanical and thermal loadings associated with the routine, normal and accident conditions of transport can have a significant effect on the leak tightness of the sealing system of transport casks for spent fuel and high radioactive waste.

Applicants are requested by BAM to provide test programmes for verification of design leakage rates of the sealing system under the possible loads.

Two test series initiated to clarify the dependency of the standard leakage rate on dynamic lid displacement as well as the dependency of the useful elastic recovery r_u of a metallic seal on temperature and time, are outlined in this paper as examples of present investigations:

Sliding tests simulating a lid displacement possible by a horizontal drop of the cask are carried out at the controlled drop test facility of BAM with test flange pairs equipped with metallic Helicoflex seals.

For specification of covering values for the useful elastic recovery r_u GNS has started a very comprehensive test programme with overall 70 metallic seals installed in test flanges which are stored for a period of one year at three different temperatures up to 150°C.

This paper gives an overview about the current approach of BAM in the assessment of cask tightness and informs about the status of the running test series.

INTRODUCTION

Type B casks for transport of radioactive materials have to meet the International Atomic Energy Agency requirements for routine, normal and accident conditions of transport (RCT, NCT, and ACT). In regard to containment capability a transport cask has to be designed to restrict the release of radioactive content to the required limits of 10^{-6} A_2 per hour under NCT and A_2 per week for ACT /1/.

The mechanical and thermal loadings under corresponding conditions of transport could lead to deformations or displacements of cask components involving an unloading or a movement of the lids or the seals, which could have a significant effect on the leak tightness of the cask sealing system. These effects have to be properly considered in the safety analysis carried out by the applicant. The assumptions and results of the activity release calculations are verified by BAM Federal Institute for Materials Research and Testing. BAM is the German competent authority responsible, in particular, for containment safety assessment within the licensing procedure of transport casks for radioactive materials.

For verification of conservative design leakage rates of the sealing system under possible loads two test series have been started on application by GNS (Gesellschaft für Nuklear Service mbH) under supervision of BAM:

a) Test program to clarify the dependency of the standard leakage rate on a dynamic lid displacement (Testing by BAM on specimen provided by GNS under a program approved by BAM)
b) Test program for specification of bounding values for the useful elastic recovery r_u of metallic seals of Helicoflex type (Testing by Technetics/CEA, France, contracted by GNS under a program approved and witnessed by BAM)

This paper informs about the status of the running test series and summarizes the current approach of BAM in the assessment of cask tightness.

DESIGN LEAKAGE RATES

For activity release calculation it is necessary to specify reasonably conservative design leakage rates, which identify the efficiency of the cask sealing system under the relevant transport loadings. Using these specified design leakage rates applicants have to demonstrate that the containment design of the cask maintains the permissible limits of activity release in every stage of transport.

These conservative design leakage rates are deduced from tests with real casks, cask models and cask components, for example test flange systems. Component tests can be necessary for adjusting of worst case conditions and for a statistical validation of measured leakage rates. Details about an example for a component test program, which is required for qualification of each new seal type and is also used for specification of design leakage rates, are described in /2/.

In case of scaled model or scaled component testing involving seals it might be difficult to extrapolate the leakage rate results to the response expected in a full sized package (IAEA Advisory TS-G1.1, § 701.25) /3/, or e.g. /4/. Possible effects of surface roughness, seal behavior as a function of material thickness, etc. should be considered for this issue. If necessary the design leakage rates determined on this basis must be verified by a real cask test.

DYNAMIC LATERAL LID DISPLACEMENT

The lateral lid movement as a reason for a shifting of the seal is a typical effect associated with the horizontal drop test. The maximum displacement of a lid is limited by cask design and can be calculated from geometrical configuration of cask components in the flange area considering permitted manufacturing tolerances. For specification of conservative design leakage rates for NCT and ACT, BAM requires tests to investigate the sealing behavior after a dynamic lateral lid displacement in a range of **possible** displacement distances /5/.

Previous test results and conceptual formulation of further investigations

Component tests at scaled flange systems with metallic seals of the Helicoflex type simulating a quasi- static lateral seal displacement did not indicate a significant increase of standard leakage rates after sliding /2/.

Sliding tests with a maximal dynamic displacement of the lid flange of 1.25 mm (one blow) and 3 mm (step by step) did not show considerable influence on the leakage rate. The design of the metallic seals tested was similar to the Helicoflex type except the outer layer which was a coated one /6.

In a series of leakage tests conducted using an 1/10 scale model of a cask lid structure the relationship of maximum sliding displacement and leakage rate did not show a significant dependency on the loading rate. Aged aluminum - seals were used in these tests and sliding distances up to about 3 mm were realized /7/.

For specification of conservative design leakage rates for NCT and ACT, BAM required additional tests to investigate the sealing behavior after a **dynamic** lateral lid displacement in a range of **possible** displacement distances /6/. Depending on the cask design the maximum possible sliding distance of the lid can however be **greater than 3 mm**. Conservative design leakage rates have to be identified for this range of seal displacement as well.

Test assembly and implementation

A component test program with bolted flanges for investigation of the influence of dynamic loading on the closure lid system with metal seals, planned and prepared by GNS and assessed by BAM, has been started in 2011. This program comprehends four test series, each with Helicoflex seals of HN 200 type with silver as well as with aluminum outer jackets (further referred to as Ag- or Al-seals), at ambient and lower temperature as well as with aged and non- aged seals:

Series 1: RT, non- aged seals

Series 2: RT, aged seals

Series 3: -40°C, non- aged seals

Series 4: -40°C, aged seals

Regarding material, torus diameter of 9.9 mm (Al-seals) respectively 9.7 mm (Ag-seals), the design of the helical spring and the thickness of inner and outer layer, the test seals are identical to the original ones used in the real cask designs. For optimization of the handling during the test procedure the circumference chosen is 1 m. The materials of the test flanges (Ni coated ductile cast iron and martensitic stainless steel no. 1.4313), as well as the groove depth and the surface roughness are also identical to the real cask design.

The flange pairs used for testing are designed as a lid flange (1.4313, impacted part) with inserted seal and a body flange (Ni coated ductile cast iron) mounted to each other by bolts with defined tightening torque. The specified displacement distance is adjusted by a shifted flange assembling, an eccentric fitting.

Tests are carried out at a drop test facility at BAM Test Site Technical Safety (TTS). The full instrumented test stand for a maximum input energy of 118 kJ can be configured for different applications /8/. The main design consists of a steel frame structure of a height of 14 m with a maximum load capacity of 1000 kg and a maximum drop height of 12 m (Fig. 1).

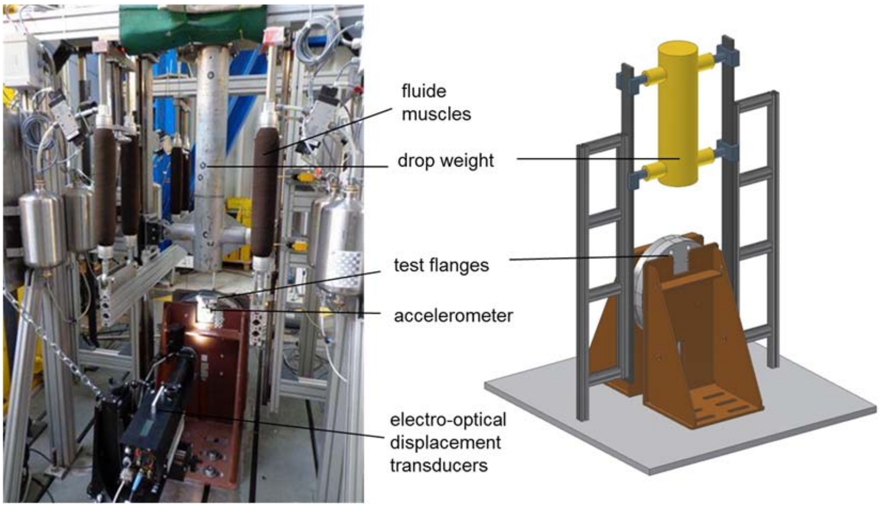

Fig.1: Test assembly

Flanges and drop weight are equipped with accelerometers to compare the dynamic characteristics of loading with those under real cask drop test conditions. “Fluid muscles” are installed to avoid a second impact of the drop weight. The Helium-leakage rate as well as the realized displacement is measured simultaneously during the impact. A laser method used for distance measurement in the first pilot test is replaced by an electro-optical measurement system, which is more precise. The advantage of the simultaneous distance measurement is the determination of the sliding maximum which can be, depending on the test conditions, up to 25% higher than the value determined after the impact by a simply linear measurement. A lot of preliminary tests were necessary to qualify the test assembly for a reproducible achievement of the designated displacement distance in every test. A drop mass of 212 kg and a drop height of 2.80 m were specified for a suitable load.

First results:

First test results show a significant influence of the dynamic lateral lid displacement on the He-standard leakage rate. In test series with Al- seals at ambient temperature with realized sliding distances relevant for typical cask designs the maximum He –leakage rates measured were in the range of up to 10^{-5} Pa m^3 s^{-1}. That implies a significant reduction of the tightness, which has to be considered in the activity release calculation. A clear dependency of the standard leakage rate on the sliding distance can be observed.

TEMPERATURE AND TIME DEPENDING BEHAVIOR OF THE USEFUL ELASTIC RECOVERY OF A METALLIC SEAL

When assessing the mechanical and thermal safety analysis BAM evaluates the maximum widening between the lid and body flange surfaces, which can result from deformation of the bolts, bending of the lid or the cask body. The different thermal expansion of lid and cask body material due to different coefficients of thermal expansion or inhomogeneous heating under thermal impact can be the reasons for this widening as well. Such relative displacements lead to decompression of the seal with potential inadmissible impairment of the sealing system`s efficiency. So it is important to assess the calculated widening in the seal area against the useful elastic recovery of the seal (r_u, Fig.2). Above this range the efficiency of the seal is exhausted and the standard leakage rate exceeds the value of 10^{-8} Pa m^3 s^{-1}, specified for an optimal tightening function of a Hexicoflex type seal (manufacturer information, www.techneticsgroup.com). Maintaining the efficiency of the seal regarding the limiting value of r_u in principle is a precondition for the applicability of any specified design leakage rate.

Previous test results

Results of BAM investigations show a significant influence of temperature and time on the remaining seal force and r_u /9, 10/. Therefore applicants were requested to justify conservative values for r_u under the relevant temperatures for transport and storage.

Test assembly and implementation

GNS has started a very comprehensive test program at the Technetics/CEA Test Laboratory in Pierrelatte for testing the influence of higher temperatures and time on the behavior of compressed metallic seals of the Helicoflex type.

In each case 10 test flanges equipped with Al-seals and 10 test flanges with Ag-seals are stored at three different temperatures of 100°C, 130°C and 150°C. These temperatures cover in any case the typical maximum seal temperatures of German spent fuel transport casks under NCT, which are normally between 80°C and 110°C. The wider temperature range was chosen to determine material data for the prediction of the long- term behavior of the seals by using the Larson Miller Parameters approach. For comparison, 5 flanges with Al-seals and 5 with Ag-seals are stored at ambient temperature. Despite of the circumference (in each case only 1m), for all tests original seals are used. For every seal the characteristic curve is determined (Fig. 2).

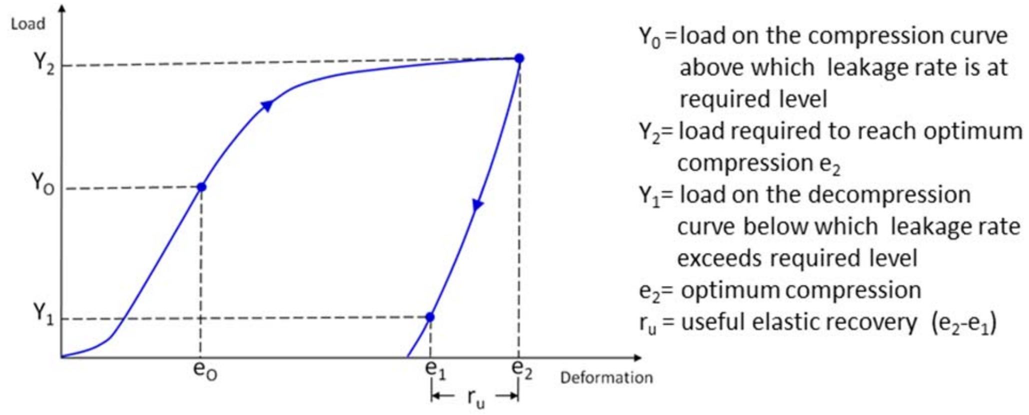

Fig.2: Characteristic curve of a Helicoflex seal for illustration of useful elastic recovery (according to www.Techneticsgroup.com)

Overall 70 test flange systems are stored in 3 ovens. After 10, 40, 100, 200 and 365 days the test flanges are taken out of the ovens to determine the alteration of the parameters Y_2 and r_u. One seal of each test temperature is removed from the test flange system after each storage period, to be investigated for its deformation and possible changes in the structure of the different seal components. For that purpose metallographic specimen are to be prepared. In addition the surface profile of the outer seal jacket is measured.

First results

Up to now, measurement results for time and temperature depending behaviour of r_u are available until the 100 day storage period. At a temperature of 100°C a significant reduction of r_u is observable for both Al- and Ag-seals already after 10 days storage time. After that r_u decreases more slowly. As expected, measurements at Al-seals show a considerable higher influence of temperatures between 130°C and 150°C on r_u than those at Ag–seals. The values measured in this program up to the present confirm the tendencies ascertained in BAM investigations.

CURRENT APPROACH OF BAM IN ASSESSMENT OF CASK TIGHTNESS

Whenever deformations of the bolted lid connection induced under transport conditions cannot be compensated by the seal, the leak tightness of the cask containment is no longer guaranteed. The compliance of the maximum of seal decompression (widening in seal area) with the allowable limit is a crucial condition for the specification of any tightness. The leakage rate of a cask with metallic seals can also increase after a rotation or a lateral sliding of the seal due to movements of the lid.

Therefore, the specification of a He- standard leakage rate of $1x10^{-8}$ Pa m^3 s^{-1} as the design leakage rate for release calculation is acceptable only under the following limiting conditions:

- only short term elastic deformation in bolted connection with a maximum widening of flange surfaces < r_u (or < $r_{u,allowable}$,see below),
- no lateral sliding of the lid.

The compliance with these requirements have to be verified by calculations or by experiments.

For RCT this compliance is binding. Transport and handling accelerations (e.g., 2 g vertical and horizontal) as well as operational temperature and pressure must not induce any reaction in the sealing system resulting in a reduction of leak tightness.

If a lateral lid movement under NBB and UBB drop test loads (e.g., horizontal drops from heights of 0.3 m and 9 m) cannot be excluded, reasonable conservative values of design leakage rates have to be specified for release calculation. In default of suitable test results covering dynamic lid sliding up to the relevant distances, the values for the design leakage rates are currently derived from tests with original or scaled models of casks. The test program described above is intended to gain a more complete understanding of the phenomena leading to changes in sealing capability due to such lateral displacements of the lid and should support the corresponding assumptions used by GNS in activity release calculations. An allowable maximum of flange surfaces widening in the seal area $r_{u,allowable}$ without increasing of the design leakage rate has to be deduced from a representative number of characteristic curve tests done by the manufacturer for every batch of seals with additional consideration of the time and temperature depending seal behaviour. The specification of a sufficient conservative value is currently made by use of a safety factor in accordance with $r_{u,allowable} = 0.5 \times r_u$ This safety factor considers the possible systematic deviation in the test performance as well as the current uncertainty about the potential reduction of r_u under operational conditions. The safety factor can be revised after justification by the final test results of the investigations about the temperature and time depending seal behaviour.

It must be emphasized that the transferability of component test results to real casks behaviour has to be ensured in all cases of application of these measurements for specification of design leakage rates.

CONCLUSIONS

The mechanical and thermal loadings associated with the normal and accident conditions of transport can have significant effects on the leak tightness of the sealing system and consequently on cask containment efficiency.

For verification of the activity release compliance with the regulatory limits, two important test programs are still running:

- Investigations into the influence of a dynamic lateral lid displacement on the leak tightness
- Investigations into the influence of time and temperature on the useful elastic recovery of a metallic seal.

Final results of these test programs are expected in the near future, but first findings seem to confirm the stringent setting of limiting values in safety analysis currently assessed by BAM.

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