CURRENT TYPE B PACKAGE APPROVAL PROCEDURES IN GERMANY: SELECTED TOPICS FROM SAFETY ASSESSMENT

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ABSTRACT
BAM as German competent authority for mechanical and thermal safety assessment, and for the approval of quality assurance measures in manufacturing, in the last three years concentrated not on spectacular approval tests of spent fuel full-scale casks, but on more sophisticated engineering design assessment aspects and on several test series of full –scale packages for fresh fuel. The fresh fuel package investigations are presented in other papers of this PATRAM conference. This paper summarizes the design assessment aspects concerning the mechanical analysis of trunnions and screws for trunnions and lid joints, neutron shielding material design criteria, and time and temperature influences on VITON gasket materials.

INTRODUCTION, THE CURRENT SITUATION IN GERMANY
Concerning the transport and storage of spent fuel and high level waste (HLW) in Germany we find a very complex situation. On the one hand, operating nuclear power plants need a reliable supplywith fresh fuel, and also a reliable transport of spent fuel and waste to reprocessing, intermediate storage and disposal. On the other hand, there is a rising resistance to any kind of transport spent fuel and HLW because each transport is supposed to be extremely dangerous, at least in the verbal explanations of some representatives in public discussions. And it is an obvious fact that such discussions in the public are not very well balanced in any case. Additionally, it is noteworthy that also German representatives who should know better than others the fundamentals of safety (prescribed by international agreed and accepted regulations) use doubtful arguments again and again and insist, e.g. that a package approval certificate is acceptable only when mechanical tests were performed with casks of original size. We have no doubt, that such a test seems to be at the first sight a more appropriate method to demonstrate the ability of a package to withstand accidents, and perhaps it could be impressive for the public. It will also give good support for the transferability of the test results from a full-scale prototype to the original design. These people ignore that the liability of a package design to withstand worst test conditions can be achieved by other (and often) more appropriate measures. This can be demonstrated e.g. not only by drop tests of a prototype cask but also by model testing or by mechanical analyses or by a combination of different methods. But nevertheless such contributions in requiring full-scale testing of 140 ton casks are still helpful in providing the opinion that no transports are necessary in the future and therefore research and development in the field of transport safety is not necessary anymore.

This paper presents Type B package design assessment results directed to cask components which must fulfill their functions during normal transport conditions and accident situations as well. We concentrate on screws, trunnions, shielding components and gaskets. These are examples which illustrate that it is possible to increase the margin of safety of transport casks not only by spectacular drop tests but also by improvements of important details that can have a strong influence on the safety during normal transport conditions and accidents.

MECHANICAL ANALYSES FOR TRUNNIONS, TRUNNION SCREWS AND LID JOINTS

Design requirements and basic instructions for the assessment of strains and stresses in trunnions and trunnion screws are fixed in Germany in the KTA 3905 [1] instruction (Load Attaching Points on Loads in Nuclear Power Plants). This instruction prescribes the loads to be considered for crane transports in nuclear facilities as well as the design criteria for trunnions and trunnion screws with regard to static and dynamic load conditions (prove of stability under static load conditions and evidence of operational stability). Among others, the KTA 3905 instruction refers to the VDI instruction 2230 (Systematic Analysis of High Stressed Bolted Connections) [2] which can also be used for the mechanical analyses of screw joints. This instruction is also recommended for the analyses of screw joints used for closure of cask lids. Though the VDI 2230 instruction was primarily created to estimate the conditions in symmetric screw joints, it is applicable also for eccentric screw joints and screw joint with eccentric loads.

Both the instructions are based on the so called "nominal stress concept". Nominal stresses in this sense are the membrane and bending stresses calculated with methods of the classical mechanics (e.g., the equations for beams and circular plates). If calculations are performed by methods like Finite Element (FE) analyses, especially the KTA instruction gives no detailed information how to interpret the results of such assessments, i.e., of two- or three-dimensional stress fields. Moreover, there are no concrete recommendations how to provide evidence of operational stability on the basis of the results of local stress analyses. Therefore, it is a matter of the user of the instructions to comment his results in an appropriate way in order to fulfil the general requirements of the instructions. In order to overcome this obvious imperfection, BAM (after interaction with applicants, e.g. GNB as designer of the CASTOR casks) has created the requirements for assessments performed with FEM or equivalent methods and the criteria for local stresses that must be fulfilled. Of course, one of the most complicated problems is to define such criteria that are equivalent to the criteria of the "Nominal stress concept" used in the KTA and VDI instructions.

At present time, the discussions with regard to the static proves are finished on principle.
As a matter of a final discussion with other authorities in Germany, the following concept is proposed:

- Calculation of stresses in screws during normal transport conditions (lid screws), under load (trunnion screws) and under IAEA mechanical test conditions (lid screws) require modelling of the systems consisting of lid and screws or trunnion and screws, respectively. Considerations of screws as single components are only allowed in order to estimate pretensions after assembling the lids and the trunnions.

- The pretension (equivalent stress including torsion) in lid screws due to the tightening torque and during normal transport conditions should be limited to percentages of the 0.2 % yield stress in the order of 70 to 90 % depending on the expected load of the lids during IAEA mechanical tests. It means that the pretension in the primary lid bolts should be at the lower limit. The calculations must consider the possible uncertainty of the tightening torque and of the friction coefficients of the lubricants which must be clearly specified in the assembling instructions.

- The maximum local stress (equivalent stress including tension, torsion and bending at bolt periphery) shall be lower than the 0.2 % yield stress during the impact phase of IAEA tests. Remaining plastic deformations of the screws shall be excluded.

- The pretension (membrane stress) of trunnion screws shall be limited to 70 % and the increase of stresses by the loads shall be limited to 10 % of the 0.2 % yield stress. This reflects the requirements of the KTA instruction. Regarding the influences of the uncertainties of mounting torque and lubricants the same requirements as for lid screws must be fulfilled. If loaded by the package mass multiplied by a prescribed load factor the maximum local stress (equivalent stress) shall be lower than the 0.2 % yield stress. Even local plastic deformations of the screws are not allowed. The load factors to be considered are prescribed by the KTA instruction. For example, the factor amounts to 1.8 for packages designed for transport of fuel elements from nuclear power stations to interim storages and minimum 1.35 for other packages.

- The primary design criteria for trunnions is the limitation of the maximum local stress (equivalent stress) to values below a defined percentage of the 0.2 % yield stress (e.g., 70 %). This criterion must be fulfilled if loaded by the package mass multiplied by the prescribed load factors. If this requirement is not met it shall be proved that a failure of trunnions can be excluded if loaded by a force much higher (> 2) than that taken into consideration in the first step of analyses.

For trunnions and trunnion screws the prove of operational stability is necessary taking into account the dynamic load collectives during crane transports and public transports with motor vehicles, railway carriages etc.

ASSESSMENT OF NEUTON SHIELDING MATERIALS

Type B casks used in Germany for transport of spent fuel elements and canisters with vitrified HAW (so-called CASTOR casks) use polyethylene for shielding of neutron radiation. Plates of this so-called "moderator material" are provided for shielding of the lid and bottom side of the casks. Radial shielding consists between one and three rows of drilled longitudinal holes inside the cask wall filled with polyethylene moderator rods.

The objective of investigations in the last two years was the optimization of the radiation protection by polyethylene. The shielding is significantly influenced by the volume of the moderator material situated within the holes inside of the cask wall. For that reason it was necessary we wanted to know the dependency of the polyethylene moderator material on temperature and time. These dependencies were investigated by tests, but in the first step the knowledge of the temperature along the polyethylene rods was necessary. To assess the applicants safety analysis BAM developed a computer code on the basis of the heat flow balance between cask, canopy (if used during transport) and environment, taking into account the heat balance for the cask, equation 1, for the canopy, equation 2 and the ventilation, equation 3.

$$\dot{Q}_I = \dot{Q}_{B_K} + \dot{Q}_{B_S} \quad (1)$$

$$\dot{Q}_{S_S} + \dot{Q}_{B_S} = \dot{Q}_{H,a_S} + \dot{Q}_{H,i_K} + \dot{Q}_{H,a_K} \quad (2)$$

$$\dot{Q}_{H,i_K} + \dot{Q}_{B_K} = \dot{Q}_L \quad (3)$$

with $\dot{Q}_I$ heat flow from the content

$\dot{Q}_{B_K}$ heat flow from the surface by convection

$\dot{Q}_{B_S}$ heat flow from the surface of the cask by radiation

$\dot{Q}_{S_S}$ heat flow to the outer surface of the canopy by sun insulation

$\dot{Q}_{H,a_S}$ heat flow from the outer surface of the canopy by radiation

$\dot{Q}_{H,i_K}$ heat flow from the inner surface of the canopy by convection

$\dot{Q}_{H,a_K}$ heat flow from the outer surface of the canopy by convection

$\dot{Q}_{L}$ heat flow by ventilation inside of the canopy

Solving of these balance equations needs the knowledge of heat input of the sun insulation and the contents of the cask, temperature of the environment, the geometrical and physical properties of the materials used etc. As the result of these calculations the temperature profile along the moderator material was obtained and from this profile the temperature to be considered for the tests of the materials behavior were derived.

For those tests (performed at the manufacturer, witnessed by BAM inspectors) two different materials were used. One polyethylene material was compressed, the other compressed and heat-treated. The knowledge of the heat treatment of the material is important, because compressed, but not heat-treated material will be possibly diminish its volume during the first heat up as the result of the rearrangement of the polyethylene macro molecules. This effect influences the filling of the volume of the bore hole by the moderator material.

With considerations of the results of these investigations tests were carried out with a surface pressure of about 0,2 N/mm^2 at temperatures up to 130 degrees Celsius up to durations of nearly thousand hours. Additional investigations were performed in parallel to the tests in regard to the chemical and physical stability of the matrix of that material. This was necessary because an extrapolation to longer times than covered by the test duration is allowed only if no change of the materials structure appears. These additional investigations were done with polyethylene which was in use in a cask for more than 15 years.

No substantial change of the polyethylene structure was found. That means that also over very long periods of use the optimized radiation protection properties of the materials investigated will not change.

ASSESSMENT OF VITON GASKET MATERIALS

Investigations of the long-term behavior of elastomere sealings (fluorine elastomere, Viton (FKM)), usually used for all types of MOSAIK casks for non-heat generating waste, were another point of interest. It was the objective of these investigations to get more knowledge about the behavior of the material during long storage periods and its dependency on temperature.

For the investigation a cask manufacturere´s program was agreed and witnessed by BAM that included leak-tightness measurements of selected casks in one to two years intervals, gasket investigations of those and additional casks and investigations of gaskets manufactured in recent time. For that examination MOSAIK casks were selected which were stored between 4.3 and 10.6 years. The results of the leak tightness measurement at room temperature are shown in table 1 for two different gasket material mixtures. The significant difference between the two mixtures can be related to the design characteristics of sealing systems. The sealing system of the package consists of a double O – ring. Whereas the gasket with mixture MK 682 was used in combination with a silicon gasket, the gasket mixture MK 634 was combined with a fluorine elastomere gasket. Silicone has a significant higher permeation rate than fluorine elastomere material, and this behavior were also reflected by the test results.

Year	Leakage rate [Pa*m^3/s]	Remark
	Mosaik I, No 251/ MK 682	
1994	1,1*E-6	with kryotrap
1995	4,4*E-5	without kryotrap
1996	2,0*E-5	without kryotrap
1997	6,7*E-6	with kryotrap
	Mosaik II, No 1238/MK 682	
1994	3,4*E-5	with kryotrap
1995	4,3*E-5	without kryotrap
1996	4,5*E-5	with kryotrap
1997	2,5*E-5	with kryotrap
	Mosaik II, No 1675 / MK 634	
1996	7,1*E-7	with kryotrap
1997	9,6*E-7	with kryotrap
	Mosaik II, No 1677 / MK 634	
1996	7,1*E-7	with kryotrap
1997	8,7*E-7	with kryotrap

Table 1: Leakage rates of casks with MK 682 / MK 634 gaskets

Temperature [° C]	Stressing Time [days]	Compression Set [%]		
		MK 682	MK634/1	MK 634/2
- 40	1			100
- 30	1			89
- 20	1	97		49
- 15	1	61		
- 10	1	34		
23	1	5	7	6
23	57	9	11	1
23	216		15	
100	224		22	
125	57		21	21
125	224		37	
150	57		43	
175	28		50	
200	7	37		36

Table 2: Dependency between compression set, temperature and time

In table 2 the values of the compression set measurements in dependency on temperature and time are summarized. The results shows the sensitivity of fluorine elastomere gaskets to low temperatures.

Whereas with mixture MK 682 at - 20 centigrade a compression set value of nearly 100% was found, mixture MK 634 shows 49% at the same temperature. This mixture was optimized for operating conditions at low temperatures, but nevertheless a compression set of 100% was found at - 40 centigrade.
In this condition the gasket has a hardness of 96 Shore A. Because it is doubtful, if the gasket is able to compensate any geometrical deformation of the sealing system during use at these temperatures it was the intention to assess the behavior of such a system in additional investigations.

For that reason sealings were tested with nearly original dimensions. The elastomere seal was mounted in the dovetailed groove of the lid and the lid was screwed to a flange of a vacuum chamber. This test design was positioned within a climatic chamber for the adjustment of the different test temperatures.
The behavior of the VITON mixture MK 634 at decreasing temperatures is shown in fig. 1. During the cooling a slow increase of permeation rate of helium through the VITON seal was recorded. Between – 51 and – 53 centigrade the leakage rate increased significantly as a result of forming a gap. At this temperature (Tg) the elastomere is loosing its ability for elastic deformation. But this process is reversible. After warming up the sealing system the gap was closed again.
In principle irradiated seals show the same behavior, see fig. 2. After an irradiation with appr. 16 Gray the opening of the gap began between –47 and – 50 centigrade.
Based on this test results the conclusion is allowed that special VITON mixtures can be used down to – 40 centigrade without the need for taking into account the special physical and chemical nature of the contents of the package for activity release considerations.

Another field of BAM activities in licensing procedures during the last years was the assessment of different types of casks for the transport of fresh fuel elements. These investigations are subject of other presentations here at PATRAM.

REFERENCES

[1] Kerntechnischer Ausschuß (KTA), Sicherheitstechnische Regel des KTA, KTA 3905 Lastanschlagpunkte an Lasten in kernkraftwerken, Fassung 6/99

[2] Verein Deutscher Ingenieure, VDI 2230 Blatt 1, Systematische Berechnung hochbeanspruchter Schraubenverbindungen; Zylindrische Einschraubenverbindungen, Fassung 7/86

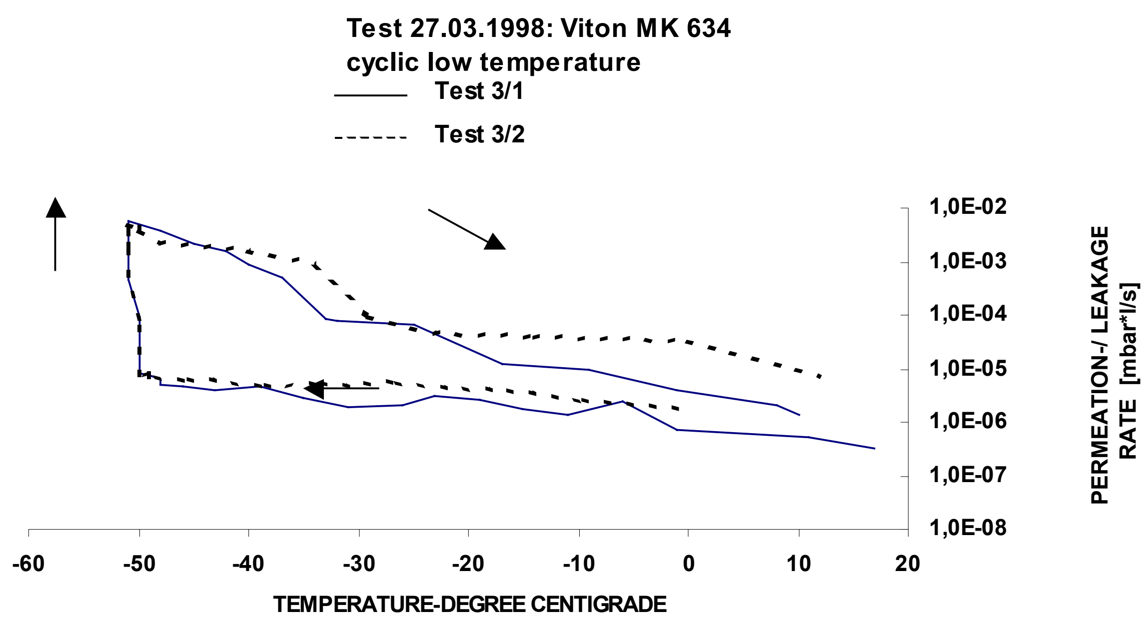

Figure 1: Low temperature behavior of unirradiated MK 634

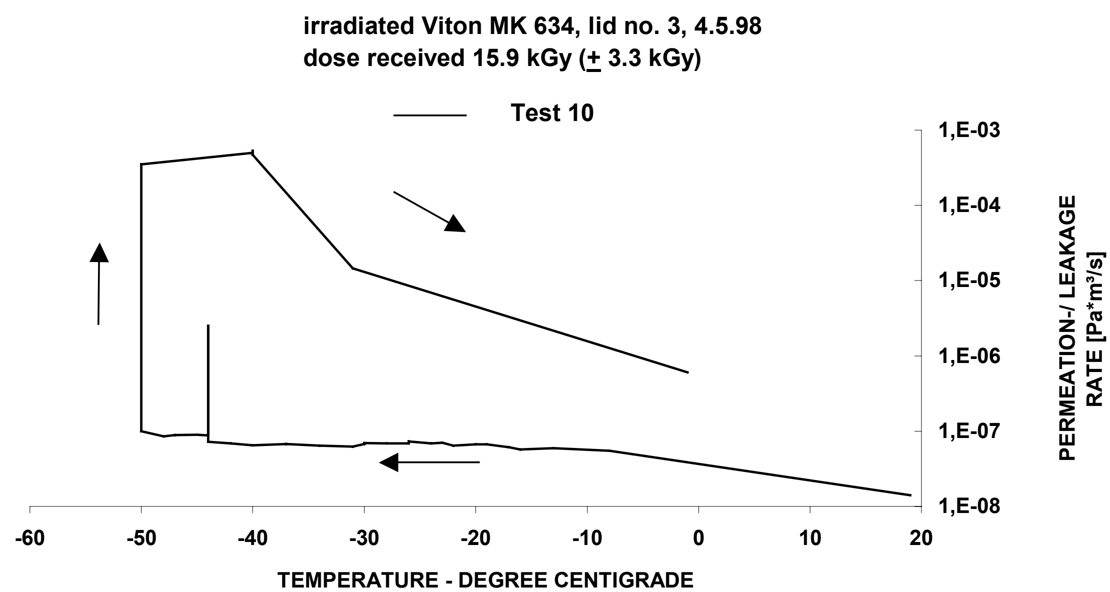

Figure 2: Low temperature behavior of irradiated MK 634