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NUMERICAL APPROACH FOR CONTAINMENT ASSESSMENT OF TRANSPORT PACKAGES UNDER REGULATORY THERMAL TEST CONDITIONS

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ABSTRACT

The requirements of the IAEA safety standards for Type B(U) packages include the thermal test as part of test sequences that represent accident conditions of transport. In comparison to mechanical tests, e.g., 9 m drop onto an unyielding target with short impact durations in a range of approximately 10 ms to 30 ms, the extended period of 30 min is defined in regulations for exposure of a package to a fire environment. Obviously, the required containment capability of the package has to be ensured not only after completing the test sequence but also over the course of the fire test scenario.

Especially, deformations in the sealing area induced by the non-uniform thermal dilation of the package can affect the capability of the containment system. Consequently, thermo-mechanical analyses are required for the assessment.

In this paper some aspects of finite element analysis (FEA) of transport packages with bolted closure systems under thermal loading are discussed. A generic FE model of a cask is applied to investigate the stress histories in the bolts, lid, and cask body as well as the deformations in the sealing area and the compression conditions of the gasket. Based on the parameter variations carried out, some recommendations in regard to modeling technique and results interpretation for such kind of analyses are finally given.

INTRODUCTION

Type B(U) packages have to be evaluated regarding their responses to the different conditions of transport defined in International Atomic Energy Agency (IAEA) regulations No.SSR-6 [1]. Among other criteria the containment system of the package has to be in compliance with regulations when subjected to drop and fire tests that covers the load of severe accidents. These criteria are expressed in terms of activity release in a period of one week as a result of the combined effect of mechanical and thermal loads onto the containment boundary. The prime interest here is in the total leakage during the week after the test sequence and not in any peak values of leakage rate. Specific to the thermal test, however, is its long duration in comparison to the drop tests. Therefore it is important to have the possibility of observing the containment boundary during the heating and cool-down phases of the fire test to detect any excess of the design leakage rate, which are used in activity release analysis of package design, over an extended time.

Since it is rather unrealizable to measure the leakage rate immediately over the course of the fire test, the numerical investigation of phenomena resulting in impairment of containment capability has assumed a great significance. What follows is a discussion regarding some conceptual questions of finite element analysis (FEA) in relation to this issue.

As an example the paper focuses on the containment system of Type B(U) packages for transport of spent nuclear fuel (SNF) and high level waste (HLW). These packages mostly consist of thick-walled cylindrical shells with flat bottoms. The containment of Type B(U) packages used in Germany for transport and interim storage is closed by two bolted lids (primary and secondary lid). Each lid system (or a barrier) consists of the lid, covers for openings in the lid, bolts, the corresponding cask area (flange), and metallic or elastomeric gaskets.[1] Typically, two gaskets are placed in special grooves on every lid and cover: the inner metallic gasket with aluminum or silver outer jackets to ensure long-term leak tightness, and the outer elastomeric gasket primarily designed for testing purposes. The packages are equipped with shock absorbers to reduce the accidental loads on their components. The top-end shock absorber performs additionally the thermal insulation of the package lid area which is of interest in the context of this paper.

Some design parameters influencing the thermal behavior of thick wall cask under the transport fire tests conditions were investigated in [2] with analytical and simplified FE models. The FE model consisted of cask body only, the lid and the bolts were not included. Various thermal boundary conditions were considered while exploring the influence of shock absorbers on the deformation of the cask body. The temperature fields due to and after the transport fire test were defined in a transient FE calculation over a time of 2 hours. These temperatures were used in the subsequent transient mechanical analysis to estimate the deformations in seal area of the cask flange and their possible impact on leak tightness.

Another example of thermo-mechanical FE investigations of cask behavior is given in [3] for interim storage fire scenarios. For that study a two-dimensional, axisymmetric FE model with different simplifications for the lid bolts were created. The temperature of containment components and respective thermal expansion and displacements in the seal area were also calculated in two separate steps.

THERMO-MECHANICAL EFFECTS AND CONTAINMENT ASSESSMENT

As noted, thermo-mechanical loads on a package may produce effects that could impair its containment capability. The main driving forces for potential leaks under accident fire conditions are the pressure build-up inside the containment, the stress in components due to thermal gradients as well as the relative displacement of key elements of the containment system induced by the non-uniform thermal dilation. Therefore the FE model has to provide the reliable data regarding:

[1] Double barrier system is implemented in Germany due to interim storage requirements. For the transport condition only one barrier is necessary.

– temperature of components, especially of metallic gaskets;
– stress in components;
– temporary or permanent deformation or displacement of components leading to changes in position and compression of metallic gaskets.

The criteria for the temperature and stress assessment are normally defined as allowable maximums on the basis of the material specifications for the components. The corresponding numerical results may not exceed these allowable values.

To estimate the potential changes in the working conditions of the gasket, the geometrical configuration of the lid system in the seal area in relation to its assembly state should be analyzed. The main parameters to monitor are:

– the change of the gasket position in the flange due to lid sliding,
– gasket decompression due to lid/cask contact opening and
– loss of pretension in the lid bolts as a result of their plastic deformation or complete failure.

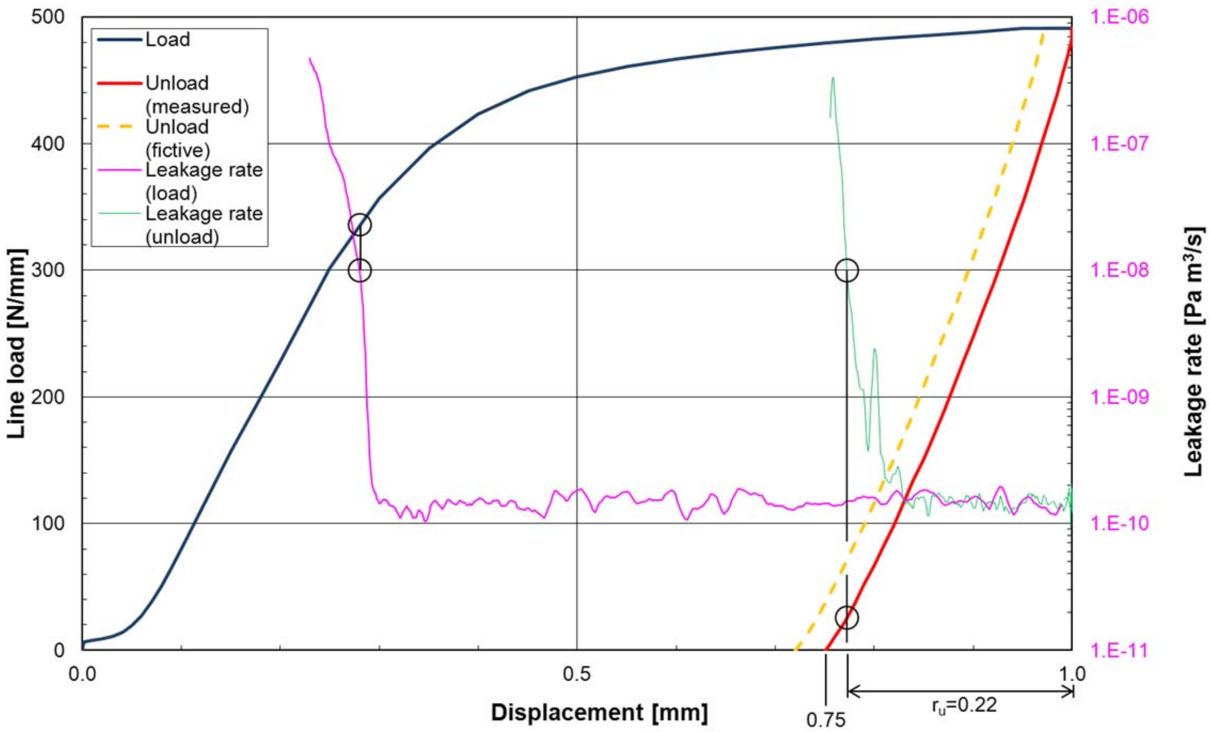

Figure 1: Displacement versus leakage rate and line load

The verification of the sealing function with the results from numerical analysis is usually based on the load-displacement curve of the metallic gasket shown in Figure 1 for an example of BAM tests with a special Helicoflex design [4]. A change of the sealing function is always expected if decompression of the gasket beyond the useful elastic recovery r_u (Figure 1) takes place under loading. The sliding of the lid also affects the gasket and can lead to an increase of the leakage rate if limited value is exceeded. In general, gasket dislocations of such dimensions have to be prevented by defining appropriate gaps in the lid flange region.

In safety analysis of a specific package design the maximum of gasket recovery or decompression r_u without increase of design leakage rate has to be deduced from a representative number of characteristic curve tests done by the manufacturer for any batch of gaskets. To ensure a sufficient conservative value BAM requested currently a reduction factor of 0.5, i.e. the allowable decompression is limited by $r_{\mathrm{u,\,d}} = 0.5\, r_{\mathrm{u}}$ where r_{u} is the characteristic value and $r_{\mathrm{u,\,d}}$ is the design value. The reduction factor considers the possible systematic deviation in the test performance as well as the current uncertainty about the potential decrease of r_{u} under operational conditions [5].

MAIN ASSUMPTIONS AND GENERELISED FINITE ELEMENT MODEL

For the numerical investigation of the thermo-mechanical phenomena in the containment system a generalized FE model was created. The dimensions and materials of the model are referred to the typical Type B(U) package used in Germany for transport of SNF and HAW but only one lid system was considered. This simplification was reasonable here since the purpose of the numerical analysis was the general estimation of some governing parameters and their influence on the working conditions of the metallic gasket and not an assessment of any specific package design. Therefore the model consists of the cask body, the lid with lid bolts and metallic gasket, two shock absorbers and the cask content.

The pretension in the lid bolts has an essential influence on the sealing function. There is a considerable scatter in the bolt pretension by an appointed torque because of the dispersion of friction conditions at the threads and under the bolt heads as well as an imprecise bolt tightening technique. A model with primary lid (PL) geometry with bolts of strength class 8.8 having the minimum pretension in accordance with BAM criteria [6] was considered as the basis configuration for calculation in this paper.

The radioactive content generates heat and interacts with the cask’s inner surface by conduction and radiation. The uncovered outer surfaces of cask, lid and bolts interact with the environment by convection[2] and radiation.

A sequence of thermal loads and environmental conditions has to be considered for the package. First, the package (incl. shock absorbers) is transported in a horizontal orientation at an ambient temperature of 38 °C and a prescribed (additional) heat flux due to the sun according to [1], §728. The transport is assessed under stationary conditions. Therefore heat flux and temperature are independent on time. Second, there is the fire phase with an ambient temperature of 800 °C which lasts for 30 minutes as defined in [1], §728(a). After fire cool-down of the package at an ambient temperature of 38 °C is considered for a time of 24 hours. Then a stationary state is practically reached.

Purpose and general description of the model

To examine the integrity and tightness of the containment, a thermal simulation is sequentially coupled with a mechanical one. The term ”sequentially coupled” means that the temperature data as a result of the first simulation is stored and used as input for the driving load in the second one instead of solving the thermo-mechanical problem simultaneously which would also be possible. Using the sequentially coupled process presumes that the thermal results are not considerably dependent on displacements calculated in the mechanical

[2] Convection is considered in this model as surface film coefficient as part of conduction.

part (e.g. possible changes of the prescribed temperature fields as an effect of the calculated displacements can be neglected). As a benefit an independent meshed model aligned to each specific purpose can be used. In general the CPU consumption is lower than in the direct coupled approach. As a disadvantage the dependency of the conductivity on contact gap and pressure cannot be examined because all contacts of the mechanical model are considered as ideally closed in the thermal calculations.[3] This implies that the spread of temperature in the continuum is intrinsically driven by the ambient temperature. On the other hand it would be questionable to gather the input data like conductivity as a function of contact gap and pressure.

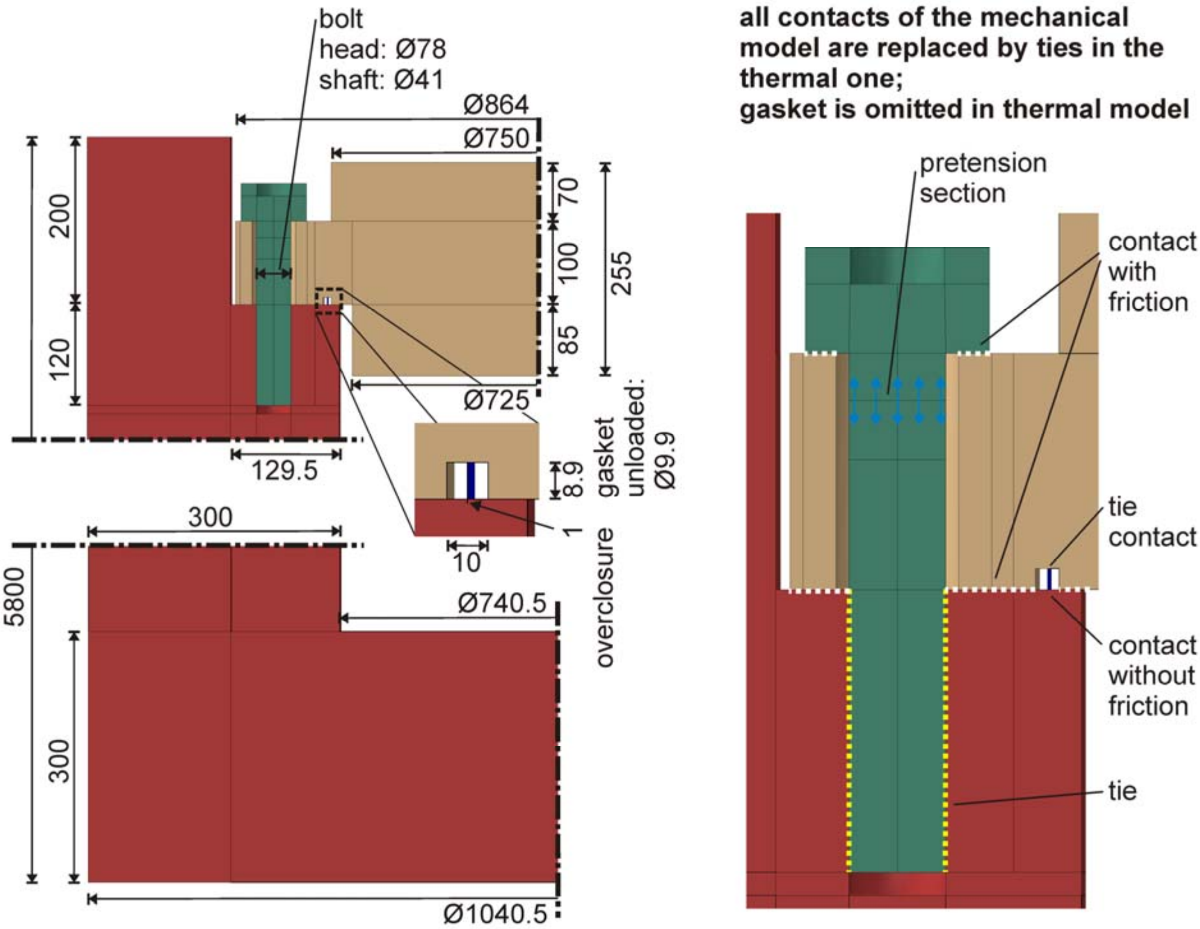

Figure 2: Measures and contact conditions

The buildup of the model is programmed in *PYTHON*[4]. All parameters mentioned in this paper are used as variables. The angle of the modeled sector is prescribed by the number of the lid bolts. The thermal model represents an entire sector and the mechanical model a half sector. Due to a more general modeling of radiation including calculated viewfactors in a preliminary simulation, it was necessary to represent the entire sector. Later on, a special modeling technique for gaps was used, which would have allowed using a half sector as well. Both techniques are described below.

[3] Additional it is implied that no heat is generated due to mechanical straining which also may be seen as a consequence of performing a geometric linear computation.

[4] *PYTHON* is an object oriented programming language. The capabilities of *ABAQUS* CAE are accessible from *PYTHON* if the program runs in the *ABAQUS* environment.

The thermal and mechanical models have the same geometrical shape as shown in Figure 2 and use elements with a quadratic approach for geometry and physical behavior. Due to the nature of the problem the mesh of the mechanical model is significantly finer. Gasket elements are additionally implemented in the mechanical analysis.

The thermal model

All connected components are modeled with tie contacts in the thermal simulation. The thermal simulation is carried out in steps for transport, accident fire and cool-down phases. During transport the lid and the top and bottom parts of the cask are covered by the shock absorbers. Their availability influences such parameters as ambient temperature, emissivity and film conditions. If a surface is covered by shock absorbers none of the mentioned parameters is effective and thermal conditions can be assumed as adiabatic in corresponding areas. Whether the shock absorbers remain attached in the fire and cool-down phases depends, however, on the drop test results. Therefore for some cases the fire conditions without absorbers are also examined. The physical effects included in the model are illustrated in Figure 3.

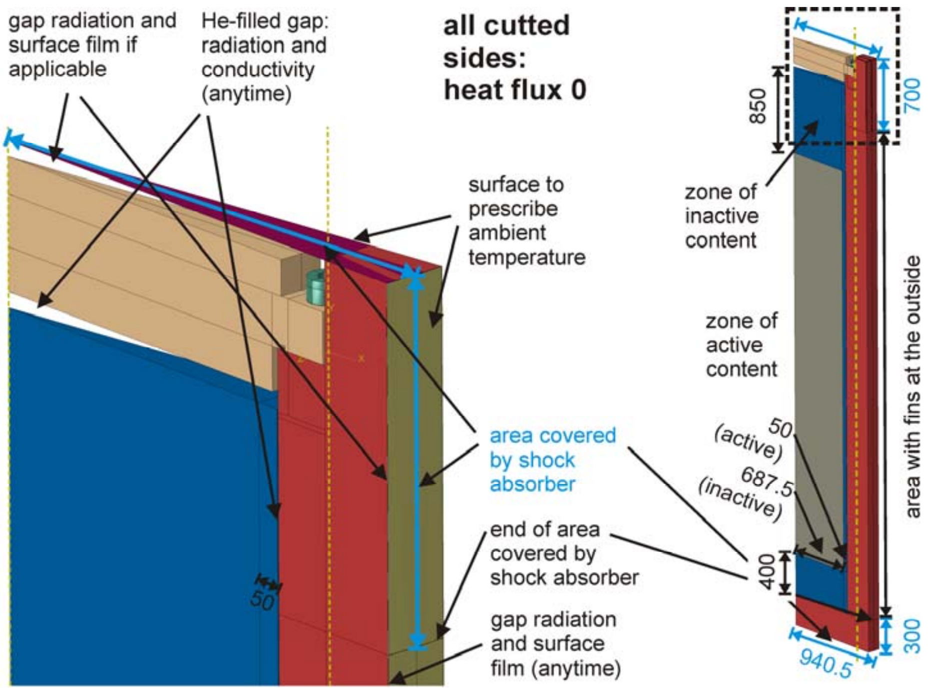

Figure 3: Physical effects included in the thermal model

In general, the solution of the radiation problem requires the calculation of the viewfactors. The dimensionless viewfactor is a geometrical quantity which describes the area ratio of the facets. For complex areas, the calculation of the factors is very CPU-consumptive. For a trivial case like parallel surfaces with approximately equal size such an approach is not necessary. A viewfactor equal 1 represents a direct coupling of the emitting and the receiving surface. Furthermore, there is a special approach for this case: gap radiation. Gap radiation as a direct coupling of two surfaces is used in this model in two different ways, firstly in the cask cavity to couple the outside of content to the inside of the cask and lid, secondly for coupling of a virtual surface on the containment’s outside to set an ambient temperature.

Additionally, the conductivity of the helium -the best gaseous conductor- in the inside gap is considered and modeled meshless by gap conductivity. The low conductivity of the surrounding air is omitted. On the other hand the convective behavior at the interface of cask and surrounding air is covered by film coefficients, whose properties were changed in the different thermal steps. The virtual surfaces remain for the entire time of the simulation but interaction is activated and deactivated for each step as necessary. Some properties are not constant, e.g. uncovered parts are changing from bright finish to a sooted state during the fire. Therefore the effective emissivity gets changed from 0.93 to 0.735 at the beginning of the fire (due to the flame emissivity of 0.9 [7], §728(28)) and 0.8 in the cool-down phase.

At the outside surfaces of the lid and the cask a film coefficient is considered if the area is not covered by the shock absorber. Under transport und cooling conditions the film coefficient h is derived from the Nusselt-numbers $Nu = c\,(Gr\,Pr)^{1/3}$ with $c = 0.13$ for horizontal cylinders [8] in each required temperature range and calculated as $h = f\,\frac{Nu\,\lambda}{D}$ where f is a geometrical factor for the surface enlarging effect of the fins and D is the outer diameter of the cask. Under fire conditions there is $h = 10f$ [7], §728(30). In the case of a plane surface like lid and bottom there is $f = 1$ for both formulas.

The parameters and material properties for the heat transfer problem are given in Table 1.

Table 1: Parameters and material properties for the heat transfer problem

	Conductivity	**Specific heat**	**Film coefficient**	**Emissivity bright/sooted**	**Emissivity (inside)**	**density**
	W/mK	kJ/kgK	W/m^{2}K	1	1	kg/m^3
Cask	36	0.50	see text	0.93 / 0.8	0.4	7100
Lid	40	0.41	see text	0.93 / 0.8	0.4	7700
Bolt	20	0.43	see text	0.93 / 0.8	-	7700
Content	radial: 7.5, circumferential: 7.5, axial: 10.0	0.40	-	-	0.6 to wall / 0.45 to lid and bottom	*total mass:* 20000 kg
Virtual surface	0.1	0.001	-	1	-	10
Helium gap	see below	-	-	-	-	-
Helium gap: -50, 0.124; 0.0, 0.143; 25, 0.150; 50, 0.174; 200, 0.205; 300, 0.237; 400, 0.270, 500, 0.302; 1000, 0.425 given as tuples of temperature [° C] and conductivity [W/mK] for 1 bar [10], table DC 27						

As shown (below) in Table 3 the package has no initial temperature prescribed. The initial temperature does not matter in the thermal simulation because the transport step is stationary.

The mechanical model

The mechanical model has the geometric properties as shown in Figure 2 and mechanical properties as listed in Table 2. The modulus of elasticity and the yield parameters are modeled as temperature-dependent. The temperature dependency of expansion coefficient and friction is not considered. Contact conditions are implemented as shown in Figure 2 (right). The bolt shaft is connected with a tie[5]. The contacts under the bolt head and between cask and lid are directly enforced in normal direction and use the penalty method in tangential direction. The friction beneath bolt head is 0.12 and 0.18 between lid and cask (unless otherwise stated). All these contacts are established in the initial step. For the gasket there are different kinds of interface conditions: connection to the lid by a tied contact[6] and a separable contact with the cask flange. The gasket's torus diameter is 1 mm larger than the depth of the groove. Therefore the unstressed gasket is overclosed by 1 mm in the reference configuration.

The mechanical analysis has an additional step over a fictive time of 1 s for the simulation of the assembly state. All following steps (transport, fire and cool-down) are the same as in the thermal simulation, see Table 4 for details. The initial temperature is set to 20° C. In the assembly step the bolt is preloaded by a force applied to the preload section and after that the length of the section is kept fixed. The gasket gets compressed while the contact to the cask is established and remains for the following steps. Mapping of the temperature data starts with the transport step. Additionally the internal pressure is ramped to the maximum value and remains to the end.

Table 2: Mechanical properties

	Thermal expansion	**E, ν, (temp.-dependent)**	**σ_y, (temp.-dependent)**	**Friction**
	1/K	N/mm², 1, °C	N/mm², 1, °C	1
Cask	1.2E-5	164000, 0.27, 20 161000, 0.27, 150	-	lid - cask: 0.18
Lid	1.1E-5	210000, 0.3, 20; 191800, 0.3, 120	-	
Bolt 8.8	1.3E-5	212000, 0.3, 20; 206000, 0.3, 110	660, 20; 565, 150	bolt - lid: 0.12
Bolt 10.9			940, 20; 832, 150	

[5] Tie is a constraint which is valid through all steps of a simulation and cannot be deactivated in single steps. The degrees of freedom (DOF) of the slave surface are substituted the ones of the master. Consequently the number of DOFs is reduced.
[6] Tied contact is a contact formulation with surfaces which cannot separate (except if contact is deactivated). Tied contacts can get (de)activated in a step. For the enforcement of the contact additional DOFs are introduced.

Table 3: Loads and boundary conditions in different phases of the analysis

Thermal analysis			Transport	Fire	Cool-down
Process			stationary	transient	transient
Time	s		1 (fictive)	1800	86400 (=24 h)
ambient temp. (uncovered)	°C		38	800	38
Heat flux (covered)	W/m^2		Total heat flux 0 prescribed for all currently covered surfaces (adiabatic)		
Body heat (content)	kW/m^3		6.85 (in sum 40 kW in the active zone of the content)		
Heat flux (sun)	W/m^2		400 (cask) 200 (lid, if applicable)	0	400 (cask) 200 (lid, if applicable)

Table 4: Loads, boundary conditions and contacts if not applied initially

Mechanical analysis			Assembly	Transport	Fire	Cool-down
Time		s	1 (fictive)	1 (fictive)	1800	86400 (=24 h)
Temperature (continuum)		°C	20 (initial)	mapped from thermal analysis		
Bolt preload	**8.8**	kN	min: 260; max: 440 (ramped)	keep length of preloaded bolt fixed		
	10.9	kN	min: 383; max: 651 (ramped)			
Pressure (inside)		bar	0	6.4 (ramped)	propagated	
Gasket			compress and establish contact	propagate contact		

The behavior of the gasket and its tightness characteristic under loading are shown in Figure 1. The line load and the leakage rate over displacement are given. The points where the leakage rate falls below the value of 10^{-8} Pa m^3/s while compression and exceeds this limit while decompression (unload) are marked by vertical lines and circles at each intersection. The useful elastic recovery of the gasket is $r_u = 0.22$ mm in this example. According to the diagram and in combination with the separable contact to the cask flange, a gap at the seal position occurs for a relative displacement larger than 0.25 mm. The measured gasket data is slightly modified to create a monotonic load characteristic needed for the FE simulations. An additional 0.03 mm shifted decompression curve (“unload (fictive)”, Figure 1) is added as well to take into account the possibility of uncompleted compression of the gasket due to local deformations of the lid and cask flange.[7]

To model the gasket, an element type of the special purpose family has been used. This chosen 6 node line like type with quadratic approach and normal direction behavior only (GK3D6LN) looks like a shell element but has only one degree of freedom (DOF) per node. The DOF is in plane direction. This direction is vertical according to the Figure 4.

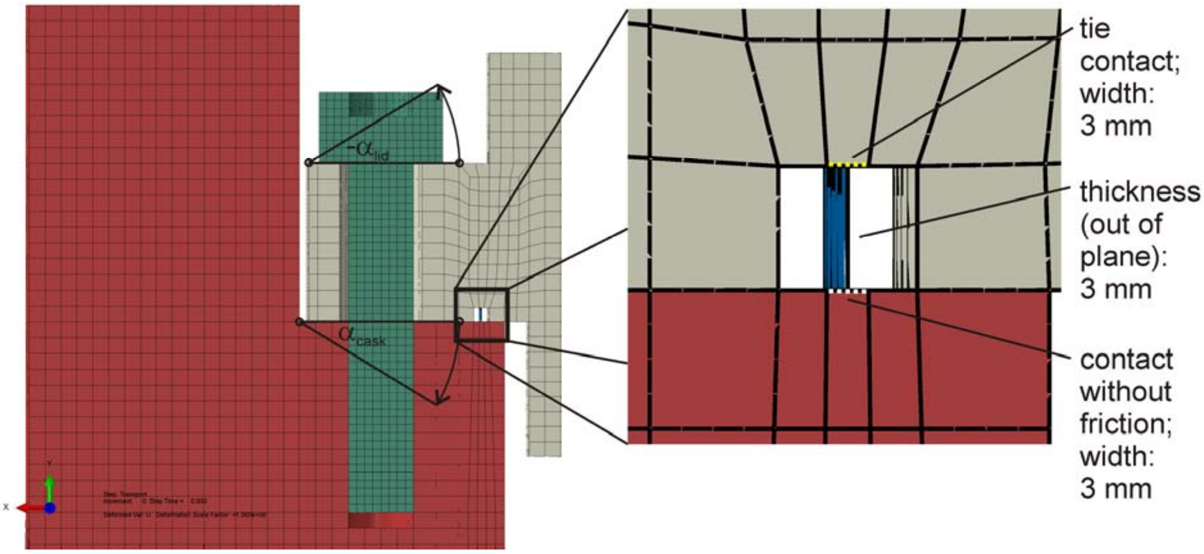

Figure 4: Discretization of gasket (compressed state) and definition of angles

If needed, the gasket elements allow using a phenomenological description of its behavior instead of material properties. In this special case and for this type of gasket element this would be (compressive) displacement versus force per length (line load). The description of loading may be enriched by multiple unloading curves. There is only one unload curve measured referring to the nominal optimal point of compression but the option of multiple curves was used as described above (Figure 1). The gasket's minimum area of contact interpreted as the width of the flattened area after total decompression is approximated to 3 mm. Consequently it is used to describe the maximum contact pressure of the gasket element. This is achieved by using a contact option for this element.

Additionally, the counterparts (lid and cask) have a dedicated contact zone modeled with the same width as considered for the gasket. The lid's and cask's seeding of the mesh in this area is enforced to have at least one element in the thickness direction as shown in Figure 4.

The chosen modeling strategy better reflects the mechanical behavior of the gasket and its surroundings as previous techniques, e.g. using one line of nonlinear springs with a pair of normal forces to introduce pretension [9]. Aside from the fact that traction in the contact pair may occur instead of creating a gap, the stresses and local deformations in the area of contact are wrong because the distribution of forces over the area is arbitrary.

[7] This is not a shortcoming of the model but because the gasket curve is defined on basis of test flange displacements and therefore reflects rather the joint behavior of the gasket and the flange and is not the characteristic of gasket alone.

DISCUSSION OF CALCULATION RESULTS

By analogy with safety analysis, the allowable decompression limit is defined in this paper by applying the reduction factor of 0.5 to r_{u} derived from the characteristic curve for gasket element used in the numerical model (Figure 1) so that $r_{\mathrm{u,\,d}} = 0.11\ \mathrm{mm}$. The containment capability of the lid system during the mechanical step of the FE calculations is assessed in the following by the monitoring of the gasket element decompression or flange opening in the seal area and comparing of these values with the allowable recovery of the gasket $r_{\mathrm{u,\,d}}$.

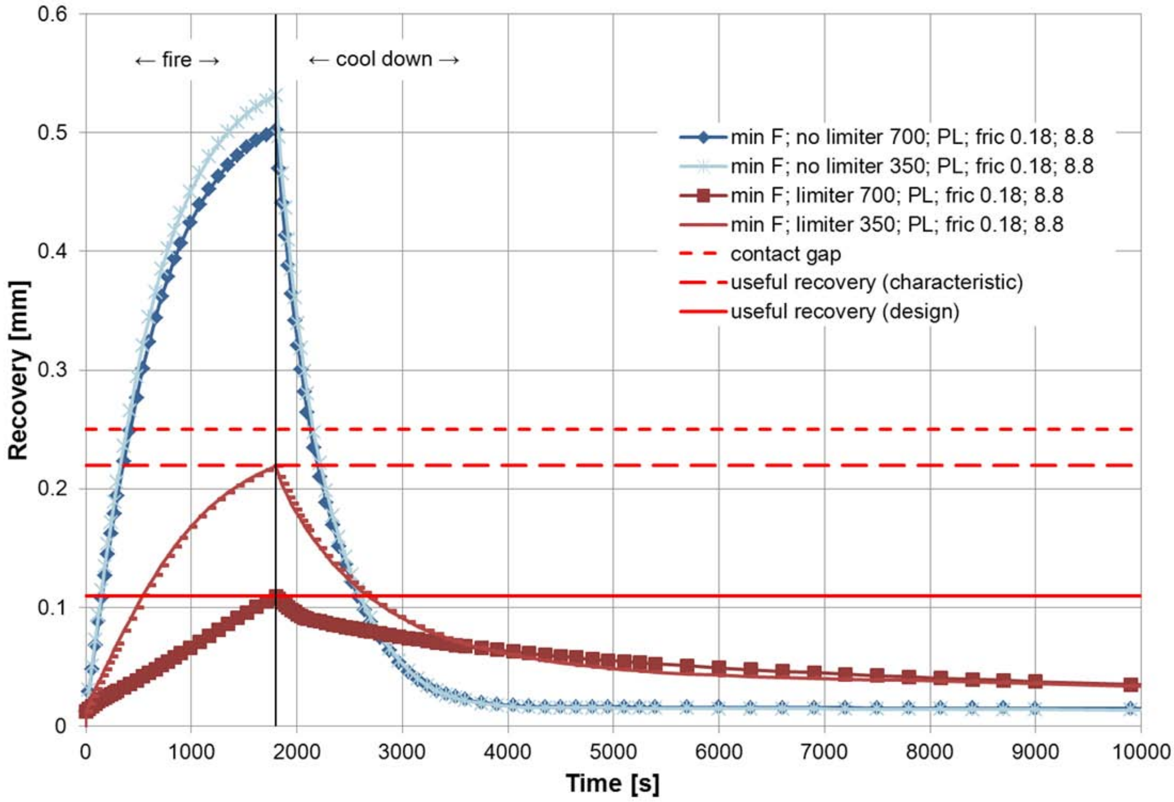

Figure 5: Decompression of gasket as a function of the shock absorber size (l=0, 350mm, 700 mm)

The influence of the shock absorber on the deformations of the cask flange in the seal area was already discussed in [2]. Additionally, the more detailed FE model used here allows one to estimate the effect of the lid system on these deformations. Figure 5 shows the decompression of the gasket depending on the availability and lateral sizes of shock absorbers. The zones protected by shock absorbers are simulated by applying adiabatic boundary conditions in the thermal calculation steps. The results for the case without shock absorber are clearly negative: the thermal deformations lead to complete decompression of the gasket and furthermore to a gap formation in the seal area over a long period. For the shock absorber covering 350 mm of the cask wall the decompression of gasket is under r_{u} but exceeds the allowable limit of $r_{\mathrm{u,\,d}}$ at ca. 540 s after the beginning of the fire test. For a time period of approx. 36 min (2700 s - 540 s = 2160 s), in which the gasket decompression remains above this limit, the containment function has to be assumed as inadmissibly impaired as well. Only from the shock absorber's lateral length of more than 700 mm, sufficient protection against the thermal deformations is given.

Figure 6 shows the distribution of the temperature at the end of the fire phase. Without a shock absorber there is a significant temperature gradient in the lid's thickness. In the configuration with a shock absorber the gradient in the lid can be neglected.

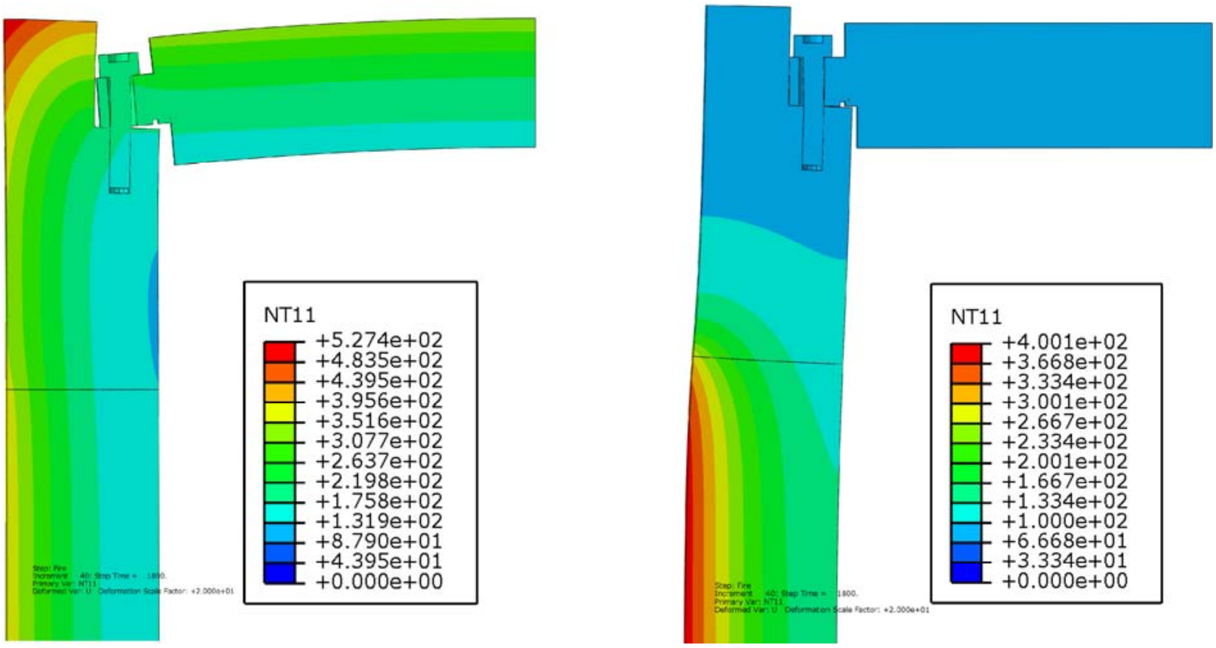

Figure 6: Temperature and deformations at the end of fire phase: left without, right with shock absorber (l=700 mm) during fire

The partial deformations of the lid and the cask flange (angle to the initial orientation) over time are demonstrated in Figure 7. The points where the deformations are readout and the definition of the angles and their signs are illustrated in Figure 4. It can be seen that in the absence of the shock absorber the inclinations of the lid and the cask flange reach the absolute maxima. In addition, they rotate in opposite directions forming a significant gap at the gasket position. For the analysis with the shock absorber both components rotate in the same direction but the inclination of the cask flange cannot be fully compensated by the lid. As consequence the gasket is decompressed as well, but as shown in Figure 5 the decompression lies in an allowable range.

It should be noted that the temperatures of the gasket are in the allowable range[8] for all configurations without and with the shock absorbers calculated here (Figure 8). That means the temperature cannot be the only criteria for the estimation of working conditions for the gasket. The availability of the shock absorber after the drop test sequence before fire is not necessary for the temperature criteria but only with shock absorber the gasket recovery can be maintained at an acceptable value. In the case under consideration the lateral protection zone for the cask wall at the lid end should be at least of 700 mm length.

[8] In Figure 8 the allowable temperature for the gasket refers to an entire sealing system including elastomeric gaskets which is conservative for the metallic gasket. Metallic gaskets are able to resist higher temperatures.

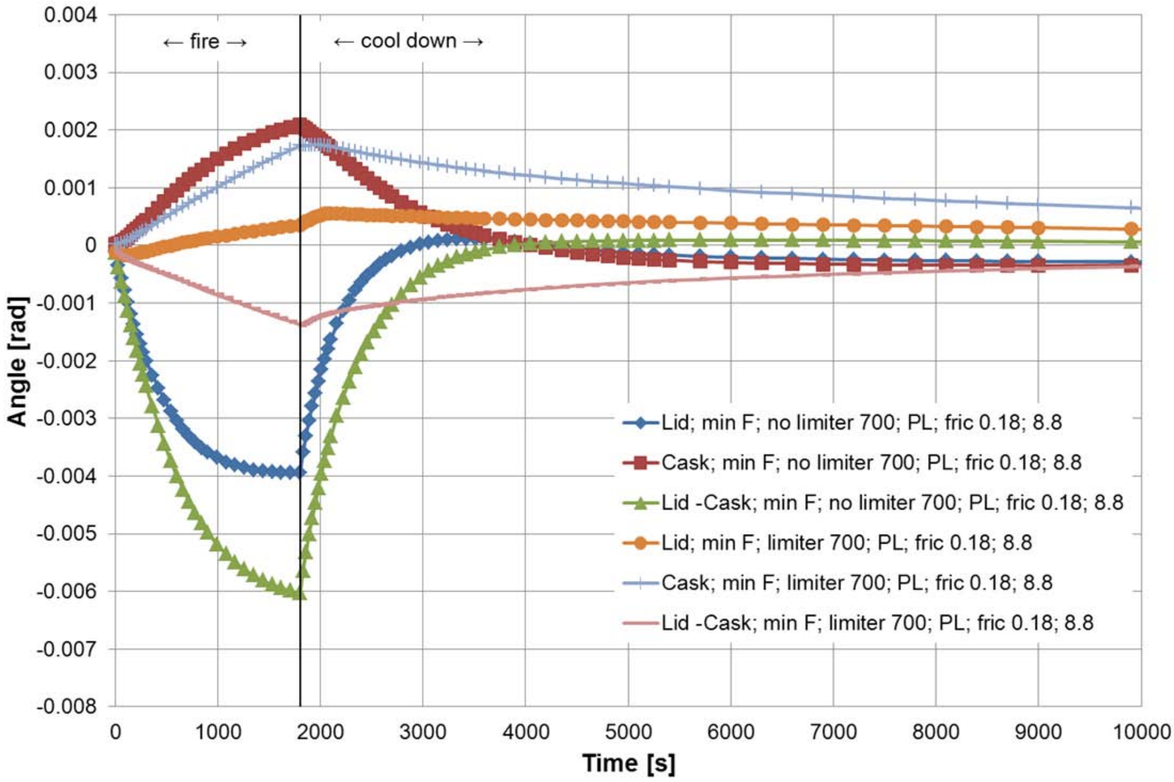

Figure 7: Partial rotations of lid and cask with regard to the shock absorber size (l=0, 700 mm)

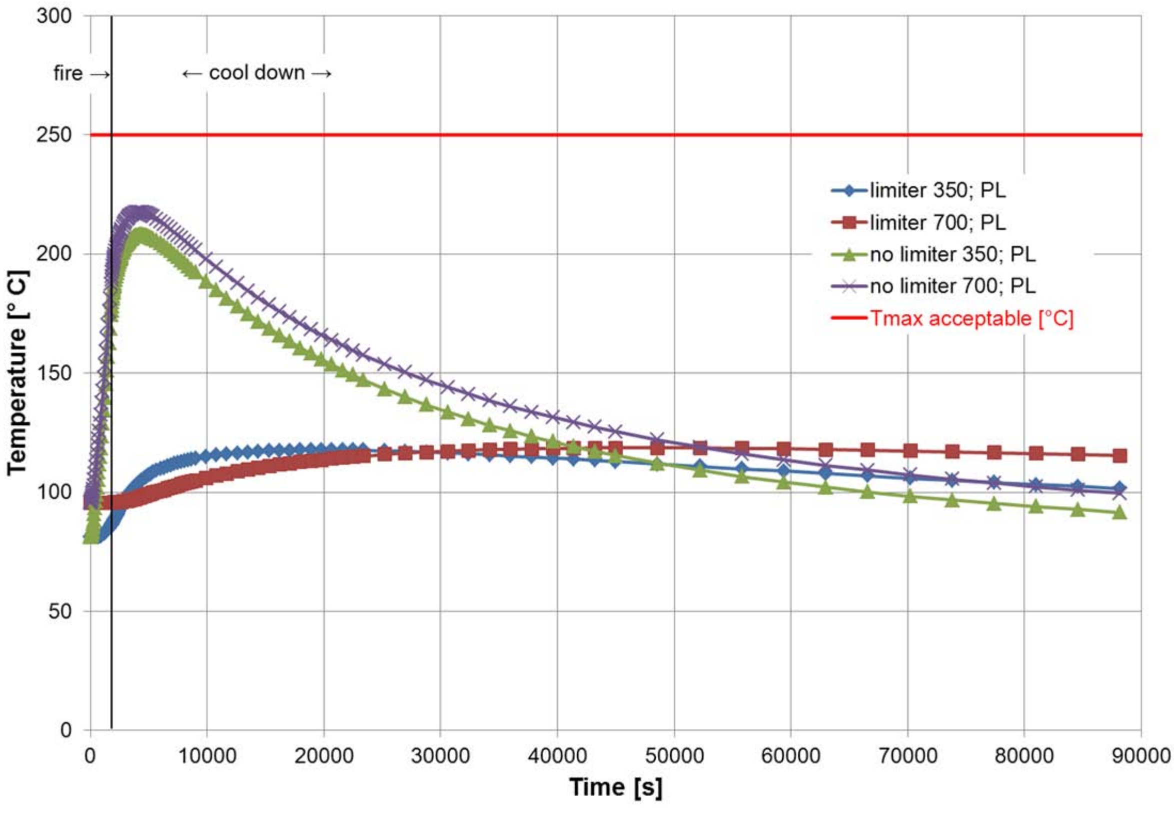

Figure 8: Temperature of gasket for different sizes of the shock absorber (l=0, 350mm, 700 mm)

The design of the lid system has obviously an important influence on the deformations in the seal area. Due to the nonlinear nature of the thermo-mechanical phenomena this influence can vary for other combinations of parameters, such as, thickness and diameter of the lid, its position in the adiabatic zone protected by the shock absorber, number and pretension of the lid bolts, etc. These structural characteristics have to be accurately considered in the safety calculations of each specific design. The physical parameters, which cannot be exactly determined, should be estimated by suitable variations. This is necessary for an understanding of safety margins or design optimization. As an example for such estimation the gasket recovery in dependence of friction conditions in the cask flange are shown in Figure 9.

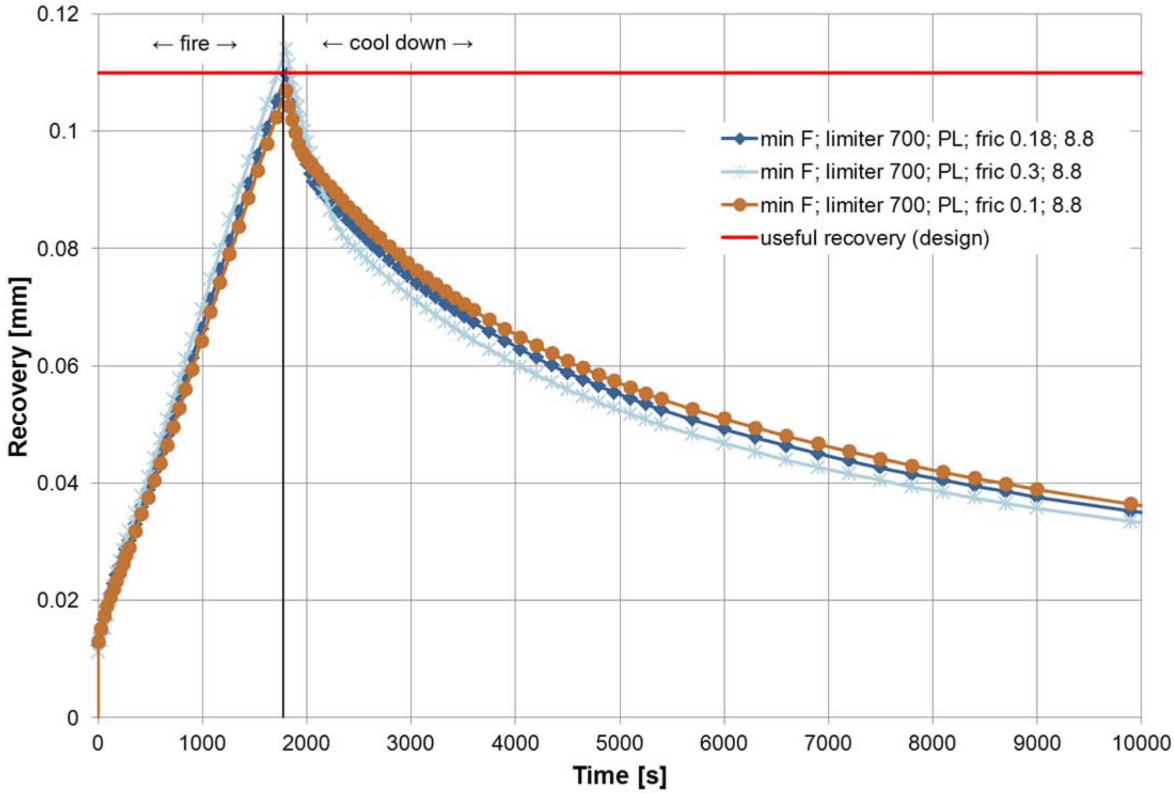

Figure 9: Influence of friction conditions at cask flange
(l=700 mm, 8.8-Fmin, μ=0.1, 0.18, 0.3)

It can be seen that the gasket decompression will be higher with increasing friction and the assessment criteria will be slightly exceeded if the friction coefficient is 0.3.

To improve safety margin the strength class of the lid bolts can be change from 8.8 to 10.9. This allows an increase in the bolt pretension by factor 1.5. As a consequence the gasket recovery will be reduced by 20.9 percent (from 0.110 mm to 0.087 mm, Figure 10) and all friction uncertainties will be covered.

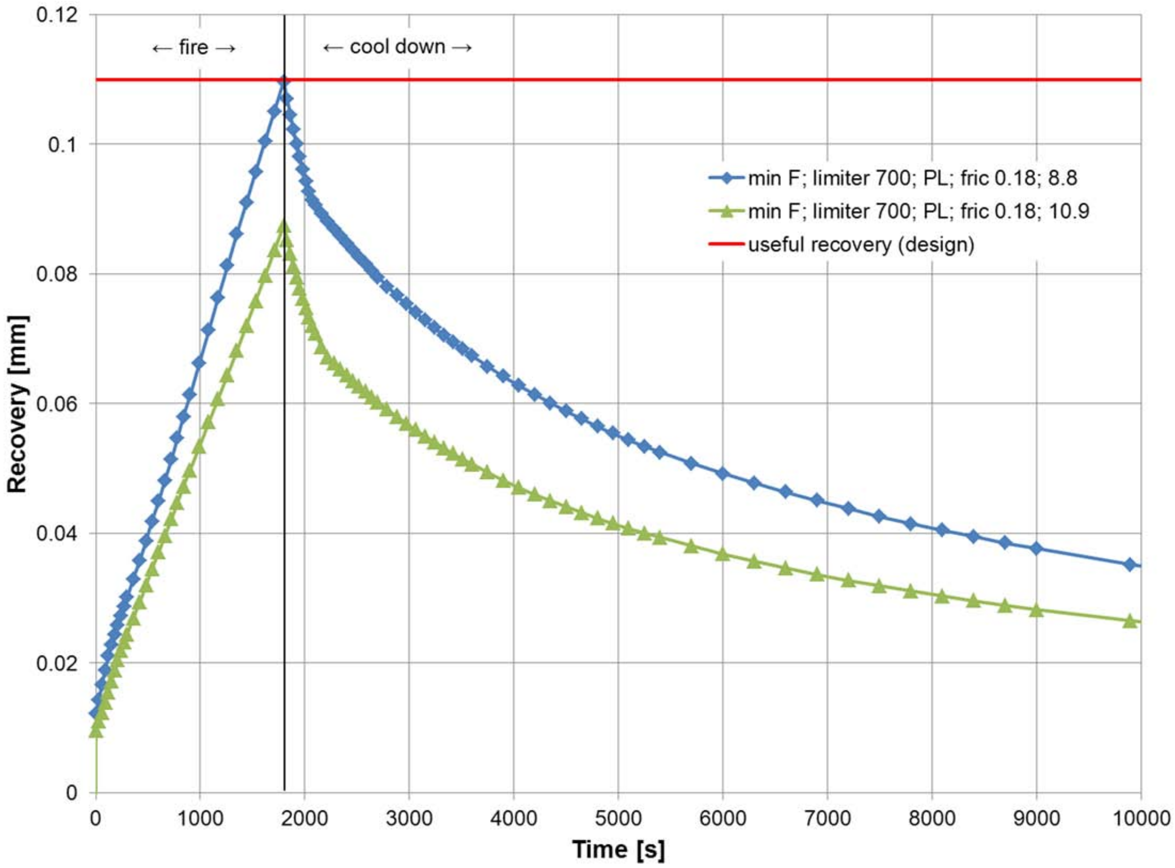

Figure 10: Influence of the bolt material and pretension (l=700 mm, 8.8-Fmin, 10.9-Fmin μ=0.18)

CONCLUSIONS

The containment capability during and after the fire test representing the thermal loading under ACT is an important aspect in the assessment of the package design. In addition to the temperature of the gasket the deformations in the seal area determine the response of the closure system to these loads. Due to the highly nonlinear nature of the thermo-mechanical phenomena numerical investigations are generally recommended for the safety analysis of each specific package design. Some methodical aspects of FE modeling and a sequential thermo-mechanical approach were discussed in this paper. The influence of such design characteristics as availability of shock absorbers, lid thickness, pretension of the lid bolts, friction conditions on the flange between the lid and the cask were presented for the FE model of a generalized design.

ACKNOWLEDGEMENT

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