Bundesanstalt für Materialforschung und -prüfung

Sicherheit in Technik und Chemie

NUMERICAL SIMULATION OF TRANSPORT AND STORAGE CASKS FOR RADIOACTIVE MATERIAL

FOCUS AREA ENERGY

Portfolio

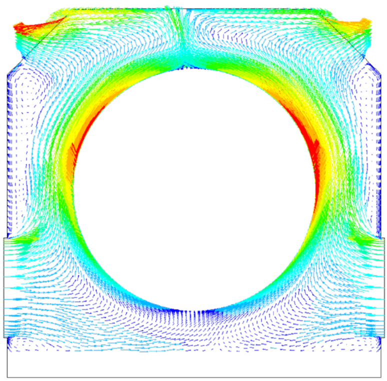
The task portfolio of BAM includes the safety assessment of containers and enclosures for dangerous goods. The safety-related assessment of transport and storage casks for radioactive material considers national and international regulations. For this purpose numerical methods such as the Finite Element Method (FEM) and the Computational Fluid Dynamics (CFD) are of great importance. The use of simulation tools for testing and analysis tasks is performed in combination with a continuous expansion of competence. The processing of scientific problems enables the specific further development of safety-related assessment methods.

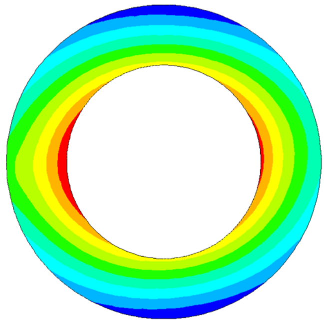
BAM uses established software for FEM and CFD such as Abaqus, Ansys/Mechanical, Ansys/CFX, LS-Dyna, ANSA, MSC Patran including C- and Fortran-compiler for the enhancement of functionality, e.g. by own material routines. SMP workstations individually configured to the numerical solution method are available for the simulations. If required, a computer cluster can be used.

In addition, BAM has a longtime experience in the field of experimental container and component testing. This enables the experimental validation of numerical results for mechanical and thermal problems.

The following pages provide an insight into the simulation competencies of BAM based on selected examples.

Temperature distribution and flow around a transport cask under a canopy





Transport casks for high-level waste are usually transported underneath a canopy. The thermal energy has to be transfered out of the package passively without active cooling. Analytical approaches for free, buoyance driven convection around a horizontal cylinder, e.g. according to VDI or McAdams, only result in uniform tem-peratures around the entire circumference.

The cylindrical cask shown above is placed under a typical canopy with inlets on each side. In addition, a slight unbalance is induced due to a lower inlet temperature of 1 K from the left (assumed shading). A CFD-Analysis of the flow field was performed to gain a more precise picture of the realistic temperature distribution. This simulation contains e.g.:

- determination of pressure loss coefficient at the in- and outlets,
- appropriate parameters for the streaming media (hereby air),
- choice of an appropriate turbulence model,
- mesh refinement according to the chosen turbulence model,
- and several relaxation and stabilization parameters to gain a converging flow field.

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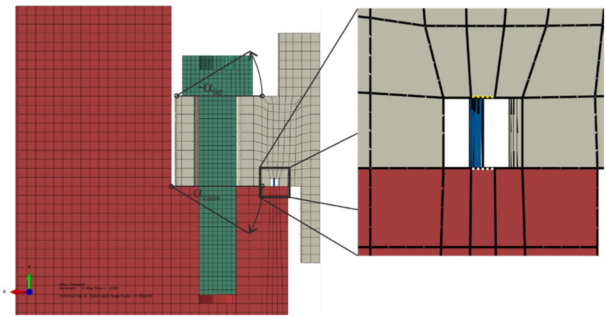
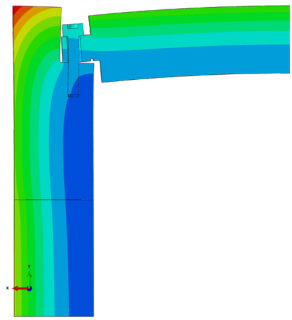
Tightness of containers due to thermal exposure





The regulations for transport packages for spent nuclear fuel and high-level waste require the safety assessment against an engulfing fire of 800 °C lasting 30 minutes. The deformations of the lid system and the cask walls due to the thermal exposure can impair the leak-tightness function of the enclosure. The tightness can be determined by implicit, thermo-mechanically coupled simulations of the closure system during the fire and cooling phases. The following partial steps arise from the results of the tests:

- experimental determination of the behavior of the metal gasket used (consisting of the compression force, expansion and leakage rate) and data processing,
- calculation of the assembly configuration with pretensioned bolts and compressed gasket (partial view of the geometry in the left figure),
- thermal simulation of the thermal radiation and conduction (right figure), and step-by-step mapping of the determined temperatures to the implicitly calculated mechanical model (Abaqus/Standard),
- and evaluation of the simulated gasket expansion against the experimentally determined acceptable value.

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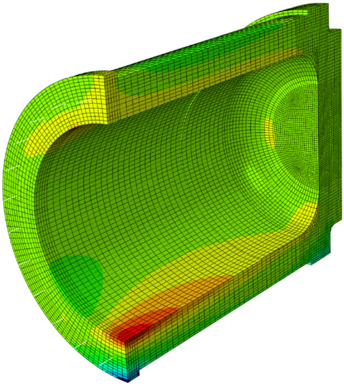
Numerical analyses of drop tests with storage containers without impact limiters onto hard targets



Storage containers for radioactive waste with negligible heat generation for the Konrad repository have to withstand drop tests without impact limiters onto a concrete plate of a specified strength class. The left figure shows the stress distribution in a cylindrical cast iron cask at the time of maximum load during a 0.8 m drop, calculated by using FEM. The lid is blanked for a better visualization. Numerical analyses have the following functions in such scenarios:

- parameter studies in preparation for drop test programs to identify the covering drop test positions and boundary conditions,
- test-related analyses to assess loads at positions inaccessible to apply with strain gauges for direct measurement,
- detailed analysis to determine undisturbed local stress states necessary to specify size and position of artificial crack-like defects for the experimental fracture mechanical safety assessment,
- and numerical analysis as an alternative to drop tests if sufficiently validated finite element models are available.

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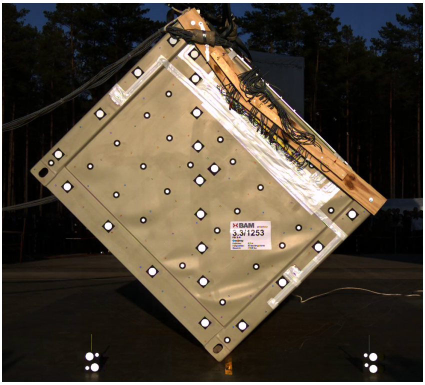
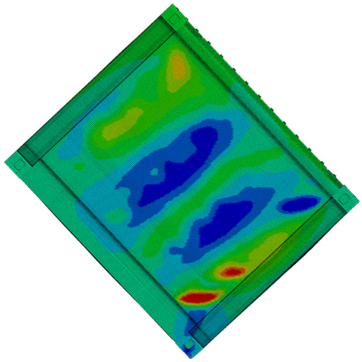
Finite element analyses of drop tests with steel sheet containers for the Konrad repository





Steel sheet containers for the use in the German Konrad repository must meet general basic requirements and have to withstand mechanical loads due to normal operation as well as potential accident scenarios. In this regard, experimental drop tests are essential for the safety assessment and hence central to any container design testing procedure. Numerical simulations based on the FEM provide an efficient and flexible alternative, if the applied numerical models are suitable and sufficiently verified. In particular, this includes the following considerations:

- determination of strain-rate dependent material properties by means of representative dynamic tensile tests with various loading rates,
- development of a FE model for realistic simulations of the kinematic behavior and the reliable determination of mechanical stresses of thin-walled steel sheet containers in dynamic load scenarios,
- determination of crucial drop orientations resulting in deformation and damage,
- and verification of the numerical model based on the data from drop tests with instrumented steel sheet containers.

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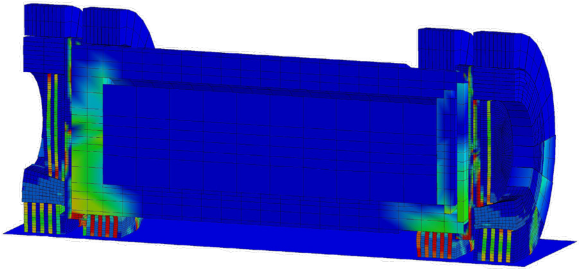
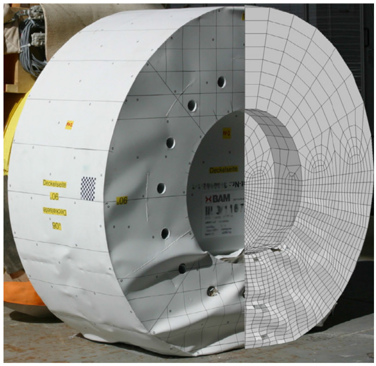
Simulation of the mechanical behavior of wood filled impact limiters under accident conditions





Wood-filled impact limiters as part of transport casks for radioactive materials protect the components of the containment during severe impact conditions by transforming kinetic into deformation energy. Maximum forces acting onto the cask body, lids and inventory are thereby significantly reduced. For the simulation of this impact process BAM developed a phenomenological material model for the explicit FE-solver LS-Dyna. It is based on a continuum mechanical surrogate, where the evolution of the yield surface is governed by the multiaxiality of the stress state. The simulation process encompasses:

– experimental identification of strain-rate dependent surrogate stress-strain-curves for wood under large deformations and different states of multiaxiality,
– assignment of the surrogate stress-strain-curves to the material model,
– flexible model setup using scripted procedures,
– calculation and evaluation of deceleration-time-curves and loading of containment components,
– and comparison of the drop test results with full scale mock-up casks.

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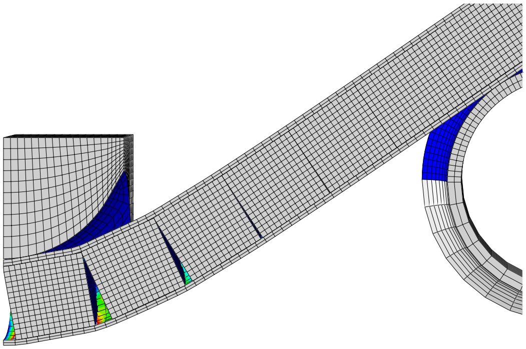
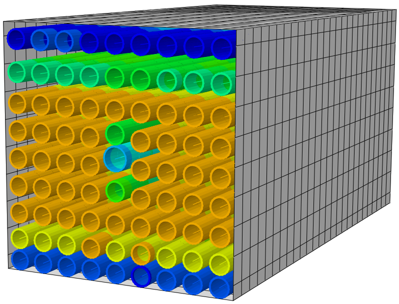
Assessment of the mechanical behavior of spent fuel assemblies under transport conditions





The mechanical behavior of spent nuclear fuel assemblies is an important input for the assessment of criticality safety of transport packages under hypothetical accident conditions of transport. The regulatory test conditions can lead to severe loads onto the fuel assembly. The numerical analysis considers the following aspects:

- estimation of the material properties of spent fuel rods by using an optimization method on the basis of an experimental bending test in the hot cell (left figure),
- dynamic calculation of a fuel assembly segment under transport loads by using Abaqus/Explicit (right figure),
- adaptable scripted model generation,
- application of an experimental deceleration load which was obtained by a drop test,
- and assessment of the loads on the individual fuel rods and identification of decisive load cases.

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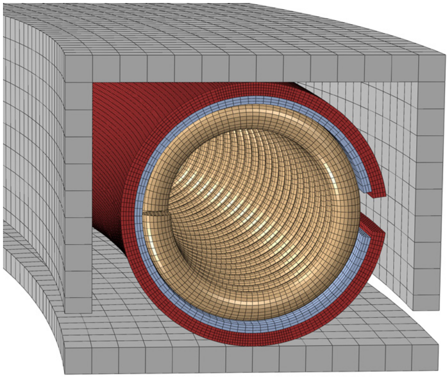
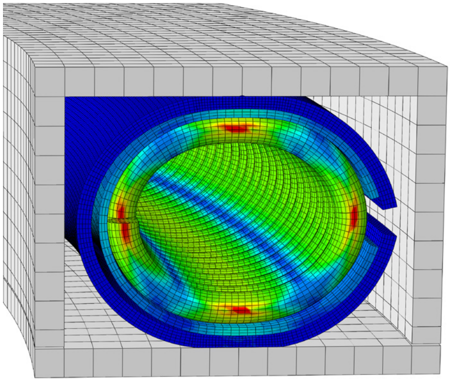
3D-modeling of metal gaskets

Metal gaskets are typically applied in the lid system of transport and storage casks for radioactive materials to guarantee a permissible leak-tightness and the safe enclosure of the radioactive inventory. In order to ensure safety, metal gaskets must resist even extreme loads such as impact and fire in the event of accidents, as well as long-term operating periods of several decades. A suitable modeling of metal gaskets with FEM is therefore a necessary prerequisite for reliable numerically guided safety assessment. For this purpose, the following steps are taken into account:

- modeling of a detailed metal gasket configuration with volume elements in Abaqus,
- verification of the model by experimental testing,
- embedding of the validated gasket model in the closure lid system of the cask in the pretension state,
- numerical analysis under several conditions, such as impact, fire or aging during long-term storage and the subsequent transport,
- and a better understanding of the time-dependent behavior by detailed modeling of the metal gasket.

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