Package Analysis: Structural Analysis and Verification

Numerical Analysis of Cask Accident Scenarios in Storage Facilities

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NUMERICAL ANALYSIS OF CASK ACCIDENT SCENARIOS IN STORAGE FACILITIES

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Introduction

- Mechanical drop test scenarios for Type B (U) packages according to the IAEA regulations have to be carried out onto the so-called “unyielding target” (usually with cask impact limiters) and onto the puncture bar respectively. They are predefined and do not require any further investigation of scenarios that really could happen on transportation routes.

- Cask accident scenarios in the framework of approval procedures for interim storage sites in Germany are derived from a detailed analysis of the handling procedures necessary from arrival of cask at the site to its storing position.

- Temperatures that have to be considered for the cask and the target are not defined in any regulation as fixed values but derived from the thermal analyses of the cask and the site specific interim storage conditions.

- Casks are usually handled without impact limiters in the interim storages. Dependent on possible drop heights, drop positions and underground, conservative cask accident scenarios are derived for further safety proofs.
Introduction

- Storage of spent fuel from power reactors in Germany is currently managed in dual purpose metal casks designed for both transport and storage.
- For the storage of casks in storage buildings licenses are granted by the competent authority, the Federal Office for Radiation Protection (BfS).
- Amongst others, the Federal Institute for Materials Research and Testing (BAM) can be contracted in order to evaluate all cask related safety issues concerning safe enclosure, decay heat removal, subcriticality and shielding.
- Concept for dry interim storage of spent fuel and heat-generating waste is defined by the German Nuclear Waste Management Commission (ESK) in specific guidelines.
- Using the example of one possible accident scenario the development and investigation of an independent finite element model of a generic storage cask is described.
1. The cask, loaded in the reactor area, arrives the unloading area of the interim storage by a special transport vehicle.

2. It has to be attached to the crane and erected.

Source: W. Botsch, S. Smalian, P. Hinterding, H. Völzke, D. Wolff, E. Kasparek
3. Now, the cask is moved out of the vehicle area and has to be lowered.

4. If one element of the load chain fails now, the vertically suspended cask drops from a maximum height of 3 m onto the floor.

5. A damping concrete in the floor construction, covered by screed, has to minimize the loads in the cask.
Reference Model

- half model with a mass of about $\frac{1}{2} \times 126$ Mg = 63 Mg
- loaded with gravity and initialized with a velocity of 7.67 m/s caused from 3 m drop height
- cask body made from ductile cast iron, described with strain rate dependent true stress versus logarithmic strain curves
- bottom closure plate was modeled purely elastic, the screws were prestressed
- the neutron shielding plate, made from polyethylene was not considered in the reference model
- foundation slab was modeled as a rigid body, the screed by the ABAQUS™ material model CONCRETE DAMAGE PLASTICITY and the damping concrete by the CRUSHABLE FOAM* model
Animation of the impact (vertical displacement)
Fringe plots at time of first contact of closure plate with the center of cask bottom

Deformation of closure plate, DSF*: 4

* DSF-deformation scale factor
Modifications and Parametric Studies

**Investigated modifications**

M 1/2: Modification of mesh density of screed layer

M 3: Modeling the reinforcement by shell elements

M 4: Increase of screed strength

M 5: Reduction of closure plate screws pre-tension

M 6: Material model change of closure plate from purely elastic to elastic/ideal-plastic

M 7: Consideration of neutron shielding plate

**Assessed cask areas**

Area 1

Area 2

Area 3
Modifications and Parametric Studies

R1 - reinforcement by beam elements
M3 - reinforcement by shell elements
M2 - 8el.
M1 - 2el.

R1 - prestressed closure plate screws
M5 - pretension of screws reduced to zero
R1 - neutron shielding plate not considered
M7 - neutron shielding plate considered
Modifications and Parametric Studies

M6 - Material model change of closure plate

- Effective stress ($\sigma_{\text{eff.}}$)
- First principal stress ($\sigma_1$)
Modifications and Parametric Studies

M7 - Consideration of neutron shielding plate

![Graphs showing max. principal stress and effective von-Mises stress over time](image)

- $\sigma_{\text{eff.}}$
- $\sigma_1$
Conclusions

- By using the finite element code ABAQUS/Explicit™ an independent dynamical finite element model of an exemplary accident scenario with a generic storage cask was developed.
- The influence of selected parameter studies and model modifications on the decisive loads during an assumed accident scenario were discussed.
- The finite element model can help to understand the complex mechanisms of the interaction between the cask components and the floor construction and to answer questions in the context of comparable accident scenarios.
- Both the elastic modeled closure plate and the not considered neutron shielding plate (R1) on the one hand side and the elastic/ideal plastic modeled closure plate (M6) and the considered elastic shielding plate (M7) on the other side represent extreme cases and do not exactly represent the reality.
- But, it is still obviously that the loads in the impact area, generated by the reference model, are conservative.
The material model for the screed should be improved and verified by sample tests. A „real“ damage behavior should be implemented. Afterward, the available damage criteria for the damping concrete can be integrated.

The nonlinear elastic and inelastic material behavior of the neutron shielding plate made from polyethylene should be investigated and considered in the modeling.

Finally, the complete finite element model should be validated by a large scale drop test onto a representative target construction.
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Thank you for your attention!