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EXPERIENCES AND PERSPECTIVES OF PACKAGE TESTING UNDER HYPOTHETICAL ACCIDENT CONDITIONS

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ABSTRACT

The presentation, introducing into the PATRAM 2007 technical sessions, concentrates in one part on the complex considerations for the correct application of the relevant package test methods: experimental testing of full-scale or small-scale packages; calculation, or reasoned argument, or reference to previous satisfactory demonstrations. The focus concentrates on drop testing issues of Type B packages for spent fuel and HLW. The BAM 9 m drop tests with large full-scale spent fuel casks CONSTOR V/TC (181 tons) and MHI-MSF 69 BG (127 tons) performed during technical tours of PATRAM 2004 will be briefly presented. Experiences from full-scale as well as from small-scale model testing, and considerations for the correct incorporation of test results in the safety analysis report, where variations of temperature, package properties and design changes, most damaging drop sequences and attitudes have to be covered, will be highlighted. It will be concluded that a complete safety case usually has to be assembled by a complex combination of nearly all test methods; even in the case of full-scale drop testing, the structural analysis may require pre- and post-test calculations, and additional coverage e.g. by material or component testing. Small-scale model testing needs more complicated measures for correct transfer of test results to the original design to be approved. Calculation needs verification based on experimental tests.

From history of package testing in Germany numerous spectacular tests with Type B packages under non-regulatory test environments will be presented in a second part. The aims of these projects were the identification of package safety margins beyond regulatory standards, and the consideration of accident scenarios that are not covered by the IAEA transport regulations. The presentation will address the experiments and computations performed by BAM briefly.

INTRODUCTION

Testing in the sense of the IAEA Regulations means: “Assessment of package safety performance under all relevant regulatory requirements, using experimental testing (of small-scale or full-scale) package specimens, reference to satisfactory previous tests of similar nature, and conservative calculations, or a combination of all methods”. The paper will concentrate mainly on aspects of regulatory mechanical testing under hypothetical accident conditions with brief excursion to non-regulatory testing of different nature.

BAM DROP TEST FACILITY AND MEASUREMENT METHODS

During Technical Tour 1 of the PATRAM 2004 conference the largest full-scale spent fuel transport and storage cask worldwide ever tested, the CONSTOR V/TC (GNS), was investigated in a 9 m horizontal drop at the new BAM drop test facility Horstwalde. Figure 1 shows the cask before and after the drop test. A more comprehensive description of the test, the specimen, the instrumentation and test results are presented in /1/.

Figure 1.9 m Horizontal Drop of CONSTOR V/TC full-scale Cask

Technical Tour 2 of PATRAM 2004 presented the second drop test with a large full-scale spent fuel cask in the same week, a 9 m slap-down drop with the full-scale MSF 69 BG cask (MHI). Figure 2 shows the cask before and after this test. More details of the test program are presented in /2/.

The new BAM drop test facility is capable in handling and testing of objects up to 200 tons /3/. The unyielding target has a mass of more than 2600 tons; investigations on the target are presented in /4/. Considering the value and uniqueness of test results and the purpose of quantitative stress and deformation analysis in the safety case and for calculation bench-marking, an extensive coverage with strain gauges, accelerometers according to a sophisticated instrumentation plan is necessary for those tests /5/. Before and after the test designated measurement techniques, e.g. to quantify leakage rates by Helium leakage test, and to document position or deformations changes by bolt torque forces measurement, 3 D geometry testing, close range photogrammetry or optical surface digitalization /6/ are used by BAM.

Figure 2.9 m slap-down Drop of MSF-69 BG full-scale Cask before (left) and after (right) Impact

DROP TESTING AS PART OF "STATE-OF-THE-ART ASSESSMENT"

The safety case has to consider all combinations and technical variations /interdependencies of

- the requirements (test positions and sequences to meet the most-damaging-criteria for all safety relevant package components, maximum and minimum temperatures, etc.)
- the actual test package specimen properties (its existent geometry, material, properties, component characteristics, scaling factor etc.),
- the design to be approved (tolerances in geometry, material properties, characteristics; real contents influence, etc.).

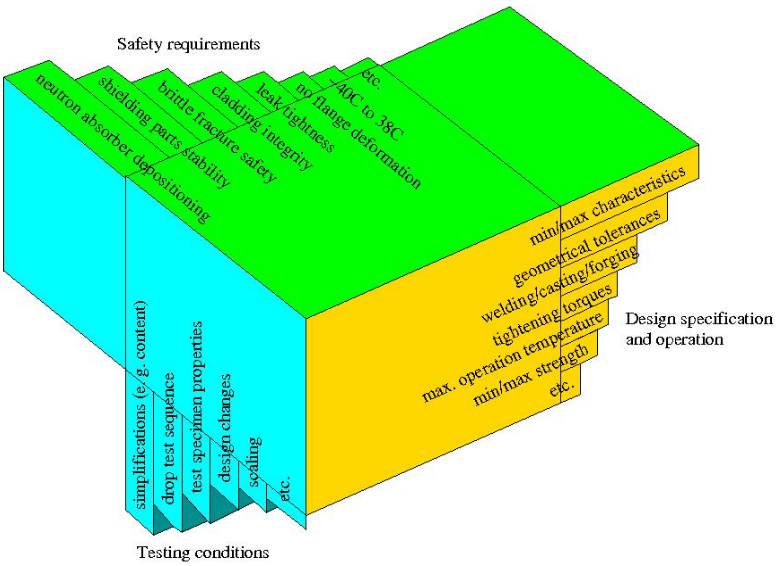

Figure 3. „Assessment Cube“

The fact that any experimental test represents only a “spot” in that multi-dimensional assessment matrix (see “Assessment Cube” in Figure 3, /8/), requires an assessment strategy including the application of sophisticated measurement and calculation methods. Sometimes it is very much recommendable that the transfer process or the calculation verification has to be supported by additional material and/or component testing.

Figure 4 gives an outline of those aspects and logical interactions that should be considered for a successful implementation of drop tests in the safety case. Papers /7, 8/ give more details.

Strategy for Safety Assessment of Mechanical Accident Conditions

1. **Pre-Test Finite –Element Calculations with the Package Design**
   - for Justification of most damaging Drop Positions and Drop Test Sequences
   - for Identification of maximum Stresses and Deformations, to justify the Instrumentation Plan
2. **Performance of the Test Program with an extensively instrumented Package Specimen under Coverage with appropriate Measurement Techniques.**
3. **Verification of the Package Specimen (small- or full-scale Cask) Finite-Element Model**
   - Comparison with Test Results, considering real Test Specimen Properties
   - Determination of most critical Stress Levels, Stress Intensities/J-Integral, Deformations
   - Justify Model Simplifications
   - FE Model Verification needs to be supported by Sensitivity Studies, Material/Component Testing to reach better Model Accuracy
4. **Final Safety Analysis of the Package Design to be approved, using the verified FE Model**
   - Determine max. Stresses, Stress Intensities/J-Integral, Deformations and compare them with relevant Material Properties, using appropriate Evaluation Concepts
   - Consider max./min. Temperatures, conservative Material and Geometry Specifications, max./min. critical Relations of other relevant Package Component Characteristics, Interactions, Reactions, Functions
   - Justify Package Design Safety > 1 regarding Safety against Failure due to Desintegration or undue Deformation

Figure 4:Strategy for Safety Assessment of mechanical Accident Conditions

PROBLEMATIC DROP TESTING ISSUES

Specifically the use of small-scale models in drop testing with respect to the transferability of the performance of impact limiters, of gaskets and of bolts onto the original design need careful consideration.

Scaling Problems

For quantification of stresses and deformations, for verification of calculation models and methods, and for identification of construction weak points, tests with small-scale models are quite valuable. For design and manufacturing verification small-scale tests are much more problematic because of given incompatibility of geometric, dynamic and material similarities with respect to impact time and strain rate effects. For safety demonstrations to improve public acceptance only full-scale testing seems to be appropriate.
As drawn up in Figure 3 both methods need to be accompanied with pre- and post-test calculations; small-scale models even need one step in calculation model verification more than full-scale models. In case of packages with large soft deformable structures (e.g. impact limiters) similarity and scaling law considerations require in small-scale testing a correction of the drop height to reach a similar energy input onto the package containment boundary. This correction is usually nearly negligible for the 9 m drop, but could be remarkable for the 1 m puncture drop. In this case, as detailed described in /9/, even the difference in punch bar deformation has to be considered for drop height correction.

Gaskets, Bolting of Closure Systems

Gaskets with usually non-linear force-deflection characteristics are problematic to scale. For metal gaskets an equivalent elastic decompression (where specified leaktightness is lost) should be adjusted; for elastomere gaskets an equivalent, as optimal recommended 0-Ring compression should be the similarity criterion. For more details in gaskets assessment see /10, 11/. For closure systems performance similarity it is always essential to adjust the lid bolting in a way that guarantees an equivalency of the closure system flanges reaction, i.e. the flange interfaces of the scale model and the original package shall relief under forces in a relation defined by scale laws. The difficulties with these requirements all discussed in detail in /12/.

Impact Limiters

The problems with “soft” impact limiters accumulate in the problem that a direct transfer of test results from a small-scale model to original design is very limited. For appropriate calculations there is a significant lack of appropriate proven (e.g. wood) material laws as input data. Papers /13, 14/ reflect the current BAM suggestions concerning the rather complicated, inhomogeneous impact limiter material wood. For an impact limiter with the more homogenous material Polyurethan paper /15/ presents a well suitable calculation solution.

TESTING OF TYPE B PACKAGES IN GERMANY TO ENVIRONMENTS BEYOND REGULATORY TEST CONDITIONS

For more than 30 years at BAM Type B Packages have been tested to non-regulatory test environments in different research and regulatory assessment projects. The aims of these projects were the identification of package safety margins beyond regulatory standards, and the consideration of accident scenarios that are not covered by the IAEA transport regulations. The following BAM experiments and computations have to be mentioned:

- Drop tests of Type B packages from a height of 200 m, including a 1:2 scale model of a TN 8/9 spent fuel cask;
- 19.5 m drop test of a full-scale spent fuel cask (CASTOR Ic) onto a highway target;
- 13 m drop test of the CASTOR Ic cask onto a HEXCEL shock absorber;
- 14 m test of a CASTOR VHLW cask with artificial flaw, onto steel rails;
- BLEVE impact involving a CASTOR THTR/AVR cask;
- Aircraft crash tests and FE calculations;
- Prolonged fire tests (3h, 10 min) with a Pu-Nitrate package after 200 m drop test;
- FE calculations of external pressure from TNT explosions at a distance of 25 m.

Other remarkable tests in Germany were:

- GNS drop tests with different ductile iron waste packages (MOSAIK) from 800 to 900 m height;
- a 25.5 m drop of a 1:3.4 scale model of a GDR spent fuel cask C-30 onto a concrete building structure.

All of the above mentioned tests and investigations have been described in more detail in /16/.

The tests and calculations of test scenarios that are reported underline significant margins of safety of massive Type B packages. The investigated Type B package designs, representing those packages that have been widely used in the past in Germany for fissile radioactive materials transportation, show high safety margins, as it was confirmed also in similar accident testing in other countries (US, UK, Japan). A general transfer of positive test results to other package designs should not be assumed because every scenario and every cask design needs specific consideration. From real target drop calculations e.g. it could be concluded that new generation casks with large soft impact limiting structures need specific studies concerning their effectively existing margins of safety beyond regulatory test conditions. It is a matter of fact, that casks with “hard” integrated impact limiting structures (as they were built at the beginning of spent fuel cask design development) have higher margins of safety in real accident drops. Packages with large “soft” impact limiters do not have these high safety margins because in there drop onto a real target the cask deceleration is also dominated by the impact limiter compression, similar to its behavior in the 9 m regulatory drop. For new cask designs the handling accident drop, e.g. inside a nuclear installation, where the impact limiters have been removed before from the transport package configuration, has to be assessed by appropriate additional measures as e.g. described in /17/. In the case of other severe accident impacts, which could be quite different from regulatory tests, it could be demonstrated that massive Type B package designs represent a safe confinement category, even in explosion and aircraft crash incidents.

CONCLUSIONS

The IAEA package test requirements are of very basic character. The way to fulfill them seems to be simple, but this not the case. It needs a combination of all relevant experimental and analytical methods for structural analysis completion. Within the different methodologis careful planning for accuracy is required: sophisticated measurement techniques in experiments, and exact verification in calculations. Every testing has to be based on a safety assessment strategy which links the required actions to integrate them into the safety case.

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