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Introduction of BAM safety assessment experience feedback list

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Abstract

BAM as competent authority regarding assessment of mechanical and thermal design, activity release and quality assurance aspects of SNF and HLW transport packages developed a thesaurus of experience feedback topics from recent approval procedures. The list is structured according to the European PDSR guide. It involves issues, which from BAM point of view, needed clarification during last package design assessment procedures. The list contains issues from operation (e.g. deactivation of handling lugs not intended for package handling), maintenance (e.g. leak tightness of impact limiting devices) to technical assessment (e.g. formation of hydrogen by radiolysis and its impact on pressure and ignitability, consideration of ageing mechanisms, thermo-mechanical assessment, impact of gaps between content and flask, spent fuel behaviour) as well as to general and specific safety analysis report requirements (e.g. report structure and required data).

Introduction

In Germany, decommissioning of nuclear power plants is based on the use of dual purpose casks for the transport and storage of spent fuel or vitrified high-level waste. Currently about 1200 casks (from 12 package designs) are in interim storage. Several thousands of packages for non-heat generating radioactive waste are also in operation. During the assessment of these and many other package designs, which in many cases contain drop testing of small or full scale casks by BAM, during intensive evaluation of the applicants package design safety analysis reports (PDSR), or by official BAM control of package manufacturing, a lot of experience is accumulated.

During package approval procedures applicants have to answer different questions by the competent authorities regarding their safety analysis approach. Consequences in many cases are rounds of meetings, questions and the time consuming work for e.g. revision of documents and modification of analyses.

BAM has collected frequently encountered issues, concerning their responsibility in assessment of mechanical and thermal design and activity release. The evolution of the state-of-the-art technology with improved techniques, methods and standards is considered. The experience feedback is used by BAM as a guide for their package approval applicants to provide complete and sufficient design safety

reports. The full list of the experience feedback list is intended to be published on the BAM website. In a future edition of the PDSR guide (PDSR) the feedback list will be considered as well.
In addition BAM developed and published several guidelines for specific guidance on typical technical issues of package design [BAM-GGR 007, BAM-GGR 008, BAM-GGR 011, BAM-GGR 012]. These documents provide additional information on accepted assessment approaches applied by BAM. BAM experts develop also experimental and numerical assessment methods, as well as safety margins of packages in research projects. Research results and some of the assessment experiences are published; a collection of publications can be found on BAM Technical Safety website (BAM TES).
A similar experience feedback for applicants was introduced by IRSN in France [LeMao, 2007].
The following points are derived from assessment procedures of high level waste (HLW) and spent nuclear fuel (SNF) heavy weight Type B(U) packages. If applicable, for other types of packages the points are of same relevance.

Specification of contents and packaging

From a transport point of view, transport and interim storage casks for spent fuel may be loaded with contents with very high **heat load**. Occurring temperatures may be higher than allowed according the transport regulations. A consecutive (immediate) transport after loading doesn't fulfil the regulations and is not possible in a regular way. The duration until the earliest possible transport date or relevant criteria for determination have to be defined. Additionally it has to be shown that all safety functions of the cask remain unimpaired, taking into account the additional heat load. This may comprise effects of elevated temperature to temperature dependent properties of materials, such as seals, neutron absorber materials and thermal ageing aluminium alloys.
According to (Droste et al, 2015, BAM-GGR011) aging mechanisms, the **compatibility and long term stability of materials** resp. material combinations for all safety class 1 and safety class 2 components should be proven in order to guarantee transportability of transport and storage casks after the interim storage period. Boundary conditions such as ionizing radiation, mechanical and thermal loads and possible corrosive environments should be taken into account. Up to now, in Germany the time period for spent fuel and HLW dual purpose casks to be considered is 40 years, resulting from license durations of interim storage facilities.

Operation and Maintenance

Dedicated equipment such as attachment point guards should be used to disable **lifting lugs** not intended to be used for lifting the package (such as lifting lugs for impact liming devices). This requirement results from (IAEA SSR-6) paragraph 609 "Attachments and any other features on the outer surface of the package that could be used to lift it ... shall be removable or otherwise rendered incapable of being used during transport."
During package design approval assessment, **transport frames and canopies** should be detailed in construction. Effects on the package (e.g. thermal evaluation of the canopy) should be taken into

account. If constructions, different from the ones licensed shall be used, these constructions should be detailed and are then to be approved by BAM. An assessment period of minimum three month at BAM should be taken into account.
Restraints of the package resulting from the **transport frame**, e.g. due to different thermal expansion, should be ruled out by constructive measures.
Load cycles for all relevant modes of transport to be included in the package design approval certificate should be defined and justified for all relevant package parts for fatigue analysis. Measures to ensure compliance have to be incorporated in the operating instructions.
Some components such as impact limiters are welded and then painted. Before a repair of the painted surface, **welds under painted surfaces** should be checked for damage.
Leak tightness of impact limiting devices should be checked (if applicable) every three years. This ensures stability of the impact limiting device filling properties by ruling out influences such as humidity loss to the outside, or influence of different outside conditions onto the impact limiting device filling.

General Provisions for all technical Analyses

BAM advises to provide a **material data report** containing all required material data, including justification in a PDSR. Other PDSR documents requiring material data may then relate to this material data report.
All relevant documents for the PDSR should be **provided automatically** to the competent authority. This may encompass documents such as technical notes, reports and regulations not easily accessible in public domain.
Upon revision of documents, any **changes have to be highlighted** in the document with recognizable markings. A revision summary shall be added to the beginning of the document.
Parts of PDSR should be cited without **revision index** within one PDSR. One central document should ensure the index of applicable revision. Upon revision of one PDSR part should checked that all relevant data for other PDSR parts (information, argumentation, source etc.) remain valid.
PDSR parts have to be handed in legally binding as paper copies. In parallel electronic versions should be provided to the authorities. It has been deemed beneficial in the past to send automatically the documents **in parallel as pdf-files** (preferably scanned title page, rest of document as pdf printout, searchable).

Analysis Methods

Regarding the **quality assurance requirements for mechanical test campaigns** of package specimens (Mueller et al., 2013) may be consulted.
Experimental safety cases with reduced scale models may require **detailed similarity analysis**. Examples are the possible requirement to increase the drop height above 1m in the 1-m puncture drop test, according to (Wille et al., 2007), the considerations regarding small scale closure systems in

(Ballheimer et al., 2010) and the comparison of full and reduced scale models in (Quercetti et al., 2008). **Values and equations** should be referenced to standards, codes, PDSR parts etc., unless their source is clearly unambiguous.

The guideline (BAM-GGR 008) for **numerical analysis** should be cohered to. All finite element data required for assessment but also for independent calculation with e.g. modified boundary conditions, meshing etc. should be sent to BAM automatically. This encompasses all files and macros required for pre- and post-processing. Any macro or command objects (snippets) shall be self-explaining or correspondingly documented.

All analyses and calculations should be **documented in a verifiable and comprehensible manner**, e.g. for an analytical calculation: "general formula + formula with values and units + result". Values taken should be referenced (e.g. construction details of drawings). A tabular summary of analysis results and comparison with relevant deduced criteria is often very helpful.

Structural Analysis

The possibility to **detach from the transport frame** should be proven if the safety of the package may be impaired under accident conditions of transport. Loads leading to detachment should be significantly below loads under accident conditions of transport. A sufficient fastening should be ensured in all three directions under routine conditions of transport. The German approach to consider and assess the interaction between package and transport frame is briefly described in (Reiche et al. 2004).

In safety analyses for **closure systems and attachment points** the guideline (BAM-GGR 012) should be followed. BAM gives guidance on design analysis for assembly state of screws and the approach for strength and fatigue analysis of the components in (BAM-GGR 012). The requirements account for attachment point loads for both handling and routine conditions of transport. Handling by crane is distinguished into handling within and out of scope of national standards (in Germany the relevant standards are the KTA standards). The relevant KTA standard (KTA 3905) refers for bolted load attachment points of transport casks to be used in nuclear power plants to the BAM guideline (BAM-GGR 012). The requirements of (KTA 3905) section 5.1.2 (4) have to be respected for bolted trunnion systems according to (BAM-GGR 012) section 2.2.3 footnote 7. Stress cycles resulting from mounting and dismounting operations should be taken into account in a fatigue analysis. Is a fatigue analysis not required, a maximum number of ten mounting/dismounting operations must be adhered to.

Any **internal collision** such as possible interaction between content and lid system based on construction related gaps should be addressed in the safety case (Wille et al., 2015). Potential additional loading of the lid system by means of a possible delayed impact of the content should be assessed. Excessive loading of the lid system is possible according the results of BAM drop tests (Quercetti et al., 2013). The maximum possible gap should be taken into account in principle.

The material of the components of a package should be suited for a temperature range of -40°C up to maximum operational temperature under normal conditions of transport according to IAEA SSR-

6/SSG-26. Specifically for ductile cast iron (DCI) BAM issued a guideline (BAM-GGR 007). (Komann et al., 2013) explain an approach for **fracture mechanical evaluation** for a specific package design. The temperature range requirement includes a fracture mechanical evaluation of trunnions provided that they are to be used for handling or public transport. One of the methods shown in (IAEA SSG-26) Appendix V.3. may be selected therefore. In BAM experience the application of method (i) or (ii) proofed to be beneficial with passable expenditure of time in the past.

Thermal Analysis

The **most unfavourable conditions** according to analysis objective should be taken into account for thermal analysis, e.g. radially and axially centred or not centred position of basket/inventory. This encompasses e.g. contact between lid and basket/inventory.

Any cavity pressure increase driven by **evaporation of liquids** due to temperature increase, especially during heat test under accident conditions of transport, should be taken into account taken that free or chemically/physically bounded liquids are present in the content. This applies especially for water, but is also valid for all other liquids.

Due to the temperature gradient and different thermal dilatation the stresses and the flange opening displacement at the seat of the metal seal should be investigated by means of **thermo-mechanical assessment**. The flange opening displacement should be evaluated against the acceptable useful elastic recovery of the (especially metal) seal. An example can be seen in (Sterthaus et al., 2014).

Any surface treatments such as **paint** may change the thermal properties of the surface. This includes properties such as absorption and emission coefficients. Common paints or varnishes have normally much lower heat conducting properties than the base materials used. Therefore even thin layers of paint may significantly affect the package temperatures. The issue should be considered in the thermal analysis.

Containment Design Analysis

The existing or forming (e.g. hydrogen formation by radiolysis) **gas mixture** within the cavity should not be ignitable. Any resulting pressure increase has to be assessed.

Regarding the actual **release of volatile fission** products of fuel rods, the release rates of H3 and Kr85 for the release from pellets into the fuel rod plenum should be according to (Rolle et al., 2012) at least 15% unless additional evidence is given. Additionally, unless additional evidence is given, a fuel rod failure rate of 100% according to (Ballheimer et al., 2012) has to be taken into account.

External Dose Rate and Criticality Safety Analysis

The fuel assembly behaviour regarding **fuel rod breakage**, especially taking into account high burn-up, should be addressed sufficiently regarding assumptions for activity release and criticality safety analysis. The amount of fuel loss, especially for high burn-up fuel, due to cladding rupture should be quantified experimentally. For the time being, a transport of spent fuel with a maximum average burn-up of more than 65 GWd/t_U is only acceptable in a canned form.

The evaluation of external dose rate and criticality safety analysis is in Germany under the responsibility of the Federal Office for Radiation Protection (BfS). Nevertheless the BAM has to confirm **assumptions resulting from mechanical and thermal analyses required** for external dose rate and criticality safety analysis. They should therefore be summarised in dedicated technical interface reports. This encompasses among others possible damage due to tests under normal or accident transport conditions, like reduced moderator thickness, plastic deformations of components such as e.g. basket or loss of parts such as e.g. impact limiting devices.

Conclusions

The examples from the thesaurus of experiences from the last assessment procedures summarises main issues resulting from recent approval assessment procedures. The full list is intended to be placed at the relevant BAM website, and will be added to the next issue of the PDSR guide. The experience feedback list should be a help for applicants to provide complete and sufficient package design safety reports and reduce the rounds of questions

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