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ASSESSMENT FEEDBACK ON MATERIAL COMPATIBILITY AND DETERMINATION OF MATERIAL PARAMETERS FOR TRANSPORT PACKAGES USED AS DUAL PURPOSE SNF AND HLW CASKS

Sven Schubert **Frank Wille** **Viktor Ballheimer**

Bernhard Droste

BAM Federal Institute for Materials Research and Testing
Berlin, Germany

ABSTRACT

In Germany dual purpose casks have to be assessed concerning material corrosion and aging, i.e. that a transport has to be considered within or after several decades of interim storage. The knowledge of reliable mechanical, physical, and chemical material properties of the cask components is necessary for safety analysis. Furthermore it is important for appropriate inspections which are necessary, e. g. during preparation for a transport after the interim storage period. In recent years BAM developed recommendations for an appropriate documentation applied in Safety Analysis Reports.

We describe approaches and experience on assessment of material compatibility of cask components of SNF and HLW transport packages. The IAEA regulations [1] -SSR6, § 614 require that materials of the packaging and any components or structures shall be physically and chemically compatible with each other and with the radioactive contents. Account shall be taken of their behavior under irradiation.
Also the loading and unloading operation and the specific situation of dual purpose casks during storage at an interim storage facility before a final transport have to be considered. These operational phases are the basis to derive boundary conditions for the analysis of the chemical and physical compatibility of each material used and of materials/components among each other. Different types of degradation mechanisms such as surface corrosion, galvanic corrosion, pitting, stress corrosion cracking, and crevice corrosion, hydrogen embrittlement as well as aging processes resulting from radiation and/or high temperatures have to be examined depending on the operational phase and the design of the package.

Furthermore the competent authority assessment requirements by BAM regarding the documentation and verification of material properties and data will be shown. Numerical analyses have an increasing significance for the safety case methods of package designs. The accuracy of the material behavior description and their verification depends among others on the amount and quality of the available material properties data. The material data have to be verified for materials used in a traceable and plausible documentation. The behavior of materials and components under high temperature and under long term interim storage has to be assessed in an appropriate way as well.

INTRODUCTION AND BOUNDARY CONDITIONS

The IAEA regulations [1] -SSR-6, § 614 requires that the materials of the packaging and any components or structures shall be physically and chemically compatible with each other and with the radioactive contents. Account shall be taken of their behavior under irradiation. Additional § 653 b) and c) points out to consider for normal conditions of transport that heat can effect an alteration of radioactive content and an acceleration of corrosion when combined with moisture. First of all the different kinds of operational phases have to be analyzed for the assessment. According to IAEA [1] -SSR-6, § 106 transport comprises all operations and conditions associated with, and involved in, the movement of radioactive material. That means the scope of the transport regulations comprises both the design, manufacture, maintenance and repair of the packaging and the preparation, consigning, loading, carriage including in-transit storage, unloading and receipt at the final destination of loads of radioactive material and packages. The interim storage represent in this context an "extraordinary" part of transport preparation respectively an interim stay of transport (to repository respectively other nuclear technical facility. From BAM point of view the loading and unloading operations and longer stays, like in an interim storage, have to be additionally considered in the context of transport approval procedure for an appropriate assessment of the material applicability in design of dual purpose SNF and HLW casks. From these operational phases one can derive the boundary conditions for the analysis of the chemical, physic-chemical and physical compatibility of a single material and of materials/components among each other. Probable forms of metal corrosion as well as degradation phenomena of materials/components, connecting elements and radioactive content occurring due to radiation and/or heat have to be analyzed for cask design depending on operational phases. Furthermore possible changes of operational conditions such as internal pressure or pre-stress of screws have to be evaluated. This assessment is done within the storage licensing procedure [4], but there it is concentrated on storage conditions, not related to behavior under transport conditions.

In Germany dual purpose SNF and HLW casks are designed in addition to the transport also for an intended dry interim storage (up to 40 years), which could follow after the first loading and ending with an expected transport after the storage period. For the post-storage transport it has to be ensured that also under the effects of corrosion and/or aging the properties of the cask components will not inadmissibly deviate from the specification of the approved package design. This statement is especially essential for the components which normally could not be checked by inspections, such as cask cavity, basket, seals, etc. Therefore the behavior of materials and components has to be reliable predicted for the complete period of storage.

Besides the necessary verification of the material compatibility, the knowledge of the variation of material properties with time is important as well for an appropriate implementation in numerical analyses. The reference of the material data has to be traceable and plausible and applicable to the material used.

The paper shows BAM experience regarding these issues, which are gained at various license procedures over recent years and explains requirements to be fulfilled by the applicant for the reference of material data.

EFFECT OF OPERATIONAL FACTORS ON MATERIAL COMPATIBILITY AND MATERIAL DATA

The environmental atmosphere, the existence of fluid and gaseous media, and the actual temperature of the components have to be known generally for the assessment of an expected corrosion of materials/components. Additional effects for the structural and chemical properties of materials could arise from radiation and high temperature of cask content and from environmental UV radiation. From operational phases mentioned above (loading, transport and dry interim storage) the following loads, which significantly affect material compatibility, can be derived for dual purpose casks:

- Radioactive content: radioactive radiation (gamma, neutron), heat, fission products, crud,
- Wet loading: pool water, products of radiolysis,
- Environment: water coming from precipitation (rain, snow, condensation), salt water in marine environment, humidity, atmospheric pollution, UV radiation, temperature.

From the impacts named above both visual changes of the outer structure of a material/component and also a change of the inner structure (microstructure, molecular chain, cross-linking) can be generated. These are for instance:

- corrosion of metals in liquid environment as surface, galvanic, crevice, pitting or stress corrosion,
- enclosure of hydrogen in carbon steel, low alloyed steel, martensitic and austenitic stainless steel with potential for hydron environment,
- changes in the lattice structure of metals because of gamma and neutron radiation,
- cross-linking and degradation of polymers because of gamma and neutron radiation,
- aging effects of shock absorbing materials like wood or polyurethane foam.

Changes on the material/component due to corrosion and transformation of microstructure affect the mechanical, thermal and operational parameter, and specific values, for instance:

- strength values of metals and polymers (e.g. tensile strength, yield stress, fracture toughness),
- compression characteristics of shock absorbing materials,
- specific values for thermal design (e.g. coefficient of thermal expansion and heat conductivity),
- adhesion strength and resistance of organic and inorganic coatings,
- development of pressures in closed internal cavities (e. g. cask cavity, cavity between primary and secondary lid, cavity for the enclosure of shielding material)
- strength parameters of mechanical permanently loaded components like springs or bolts,
- resilience of metal seals,
- pre-stressing of screws,
- surface pressure of connections,
- coefficient of friction of contacting metals with lubricants.

OPERATIONAL PHASES AND THEIR SPECIFIC FEATURES FOR THE COMPATIBILITY OF MATERIALS

Loading

The loading of casks with SNF and HLW is carried out as so-called dry or wet loading. The dry loading is carried out in dry atmosphere and no relevant exposure to corrosion will be given if there are no operating liquids or high humidity. Casks for spent fuel assemblies are usually loaded in pools so that a direct and full surface contact of pool water on the materials/components occurs. In this case the single materials and the contacted materials have to be analyzed accurately regarding their corrosion behavior in view of the boron acid containing pool water and the presence of crud. The drying and filling of cavity with an inert gas follows drainage of the cask. Thus oxidation processes can be widely limited.

By wet loading attention should be paid when the basket design contains aluminum especially for the contact with noble stainless steel. Anodization of aluminum components could considerably reduce the possible contact corrosion in this case.

Corrodible surfaces of the cask cavity are normally coated. This coating has to be tested regarding porosity as well as for resistance against surface and galvanic corrosion with the contacted materials of the basket.

The tightening of the trunnions to the cask body should be in such a way that an entry of water into gaps could be excluded. If it is not possible to ensure the tightness, the trunnions have to be disassembled by visual inspection after loading.

Seals of underwater attached lids have to be investigated in detail. Besides the galvanic and surface corrosion of the seal and the sealing surface a remaining enclosure of pool water due to the seal compression has to be examined as well if the design of the seal makes it applicable [4], [5].

Transport

For the definition of a maximum transport period BAM accepts explanation in §229 of IAEA SSR-6 [1] and corresponding in TS-G-1.1 [2] for a transport period of one year. For the transport the residual amount of water after drying has to be assessed regarding the corrosive and radiochemical effects to the components of the containment. In this case also a full contact of the whole residual water on the seal of the lid has to be assumed. Under normal transport conditions the behavior of chemical bonded water on surfaces of components has to be evaluated additionally, for instance in oxide layers. For organic materials often used for neutron shielding the change of its structure has to be considered because of ionizing radiation. Release of volatile gas has to be taken into account for material compatibility issues and in design assessment. Relevant ambient effects for the package during transport are rainwater, water condensation and UV radiation. All areas of the package have to be evaluated if an access of rainwater is possible. A special importance has the area between lid side shock absorber and lid.

Dry Interim storage and following transport

For the application within the storage licensing procedure the assessment of containment components concerning corrosion and aging phenomena has to be performed for the period of a specific interim storage [6]. But load cases and assessment criteria for the interim storage are different to the requirements of transport regulations. The main point for transport is the compliance of design parameters and safety cases with package characteristics during and after interim storage. The applicant has to show that the package will be not unacceptable affected under storage conditions and fulfills the safety functions like leak tightness, shielding, subcriticality, heat removal under routine, normal and accident transport conditions. Besides the corrosive effects during loading operations and transport the changes of material and component properties due to aging arisen from radiation [7], thermal and mechanical effects are of great concern.

To know the external state of package inspections (e. g. visual inspection, surface crack and load attachment test) could take place on components which are well accessible like cask body, outer lid, trunnions and shock absorbers. An inspection of cask cavity is normally not intended during and after storage. Therefore it is mandatory to know the state of the not accessible components of the containment (lids, screws, seals, cask cavity), the basket, the shielding and radioactive content in relation to service history (loading, transport, dry interim storage).

For dual purpose SNF and HLW casks aging effects are expected mainly at metal and elastomeric seals, polymer shielding components, at screws, springs, wood as damping material and spent fuel assemblies.

ADVICE FOR VERIFICATION CONCEPT FOR MATERIAL COMPATIBILITY

The applicant has to demonstrate that under operating loads and exposures discussed above the package remain in compliance with transport package design approval certificate. This demonstration has to be part of the SAR. The applicant should provide a joint report or separate reports about material compatibility and aging effects. The load assumptions are derived from radioactive content, wet loading and environmental effects and have to be applied to the assessment of components both separate and in combination. Additional tests, inspections and measures in view of a final transport after dry interim storage period, e. g. to verify the leak tightness, are expected especially regarding the assessment of aging effects. These measures have to be implemented in procedures of periodic inspections.

The corrosion rate has to be determined for the chemical and electrochemical corrosion of metals. If there are any uncertainties in the assessment of corrosion, experimental investigations have to be performed to obtain information about corrosion behavior and the expected kind and rate. Thereby the maximum temperatures under normal transport conditions are to be considered. In all cases experimental investigations of material compatibility and aging behavior has to be performed for metal seals used for the containment and for materials of their bearing surfaces.

Components from interim stored dual purpose casks which are accessible, inspectable and removable have to be analyzed by inspections too. Components which are not accessible or removable have to be assessed regarding corrosion and aging effects for the postulated service life. The foregoing operational activities like loading and transport has to be considered for that purpose. The verification about long term behavior should be substantiated by experimental investigations. BAM accepts in this context the use of the Larsen-Miller parameter approach for reduction of time for thermal aging processes of metals.

ADVICE FOR THE VERIFICATION CONCEPT FOR MATERIAL DESIGN DATA

Reference of material data

BAM requires for all components of a package design directly and indirectly ensuring the safety objectives like subcriticality, leak tightness and shielding a traceable and plausible documentation of material data for mechanical and thermal assessment. According to the

German guideline BAM-GGR 011 [3] these components have to be classified in the classification grades 1 or 2.
Material data like e. g. tensile strength, yield stress, Young's modulus of elasticity, Poisson's ratio, yield curves, density, coefficient of thermal expansion, heat conductivity, specific heat capacity, emission coefficient have to be specified by the applicant for material qualification and for use in design calculations. As reference of these data sources are acceptable like technical standards, guidelines, specification by manufacturers, technical literature or own investigations.

Besides the manufacturing process of the component or semimanufactured product (e. g. rolled or forged sheets) also the intended heat or surface treatment and dimensions of the semimanufactured product (wall thickness, diameter) have to be attended if data from technical standards literature are applied. If a component can be manufactured from different types of material grades or semimanufactured products, the material data for design assessment has to be determined in a conservative way. For components which are exposed with high thermal loads it should be considered that emission coefficient changed during operation because of change of surface condition.

Data from manufacturers have to be referenced by documents as testing reports or certificates.

Material data from technical literature need the exact description of source. These data should be chosen with caution because information about the material and its manufacturing history are often incomplete. Another aspect to be considered is that the determined specific values are normally not the lower boundary values needed for the safety-related design. In this case BAM needs additional validation of data.

Specific values like e. g. strength at high temperature or thermal expansion or emission coefficient are often not available. In some cases there are data related to different temperatures. Then it could be acceptable to use linear interpolation to estimate the unknown quantity for the design temperature. This approach will be only reasonable if the curve characteristic is as far as possible known and a conservative approximation could be expected. Generally these approximated values can be accepted if the range between the reverence points is not too wide spreaded. In the absence of information the necessary parameters have to be measured in an appropriate laboratory under supervision by BAM.

Specific values for standard materials like e. g. tensile strength and yield stress at high or low temperature which are referenced but statistically not sufficient assured could be verified also in line with tests during manufacturing. In this case an extensive additional testing program is not necessary.

Furthermore the behavior of materials and components at high temperatures during the assumed dry interim storage of dual purpose casks should be examined closely. Here high temperature strength and creep rupture strength are important. Main materials of containment and basket components as well as shielding components made from polymeric materials are sensitive in this regard.

It is important that the specific values determined in the manufacturing documents are associated with the values used for design calculation. Deviations can be acceptable only if they do not have any negative effects on design safety.

Qualification of materials and components

For materials and components with no data available from literature investigation programs have to be carried out. Following categories of materials and components are mainly concerned:

- Materials referenced in technical standards, guidelines but not sufficiently referenced with specific values for the application, like e. g. wood, metals at high and low temperature

- Materials referenced in technical standards, guidelines but not sufficiently referenced with specific values in consideration of long term thermal and/or radiation loads like e. g. polymers, precipitation hardening aluminum alloys

- Materials or components manufactured by new and/or very sophisticated processes, which have to be supervised, like, e. g. ductile cast iron, stainless steels alloyed with boron, composite materials, polymers, gaskets.

Generally BAM requires for these materials or components a qualification program. The qualification program has to be agreed with BAM. The realization of the program needs supervision of BAM. The essential parts of the program should be the definition of necessary tests, description of the manufacturing process in accordance to BAM-GGR 011 [3] including all manufacture and testing instructions, definition of number and position of samples, sampling and choice of the testing laboratories. The applicant summarizes the results of investigations in a report which will be assessed in a statement by BAM. Applicants report is the basis for the definition of specific values for manufacturing and design.

Safety analysis report documentation of material data

Due to the number of components, materials and necessary material data for dual purpose casks BAM requires a separate summary material report as part of SAR. Such report improves the documentation and simplifies the assessment effort as well. Besides the material names, a link to the corresponding component is important in the report. This has to be done by listing of components data from the part list including name and position number as well as indication of material specification for manufacturing. In this way a prompt overview can be provided about such significant details as additional surface treatments or whether the manufacturing is really possible with the referenced semimanufactured product or not. The listing of material data is from BAM point of view the best way for examination because of its transparency. Besides the necessary material data and its references, the material report must contain at least the following information:

- Exact material name
- Component and position number from the part list
- Information about semimanufactured product and/or manufacturing process and heat treatment
- Dimensions of semimanufactured product, blank
- Information about heat treatment
- Information about corresponding material specification for manufacturing

For applicants with multiple package designs made from similar or identical materials it is reasonable to arrange a material data base. The advantage is the minimization of possible mistakes owing to consistent, verified basis for the work of users in the company (like designers, test engineers) and for the experts from authorities.

CONCLUSIONS

The transport package design safety case has to consider the operational scenarios. For dual purpose casks which are used for storage of SNF or HLW this implies the consideration of all relevant degradation mechanism, like corrosion, aging etc. by the assessment under transport conditions.

For the safety assessment, a documentation of all relevant material properties considering the applicable operational conditions has to be created and approved by BAM.

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