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Non-Heat Generating Legacy Waste: New Strategies for Older Vessels

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Abstract

The German repository "Konrad" is approved for the final storage of approximately 300.000 m³ of non-heat generating radioactive waste considering also the expected residues from operation and decommissioning of current power plants. According to the latest survey as constituted end of 2014, a large proportion of this volume already exists, of which 100.288 m³ are fully loaded packages. As prerequisite for their "Konrad" acceptance, the vessels have to be designed against operational and accidental conditions of the site and be manufactured according to adequate quality assurance programs. The respective safety assessment performed by BAM on behalf of the Federal Office for Radiation Protection is a major challenge especially for those casks that had been produced and loaded already some decades ago. Typically, they were manufactured in big numbers over a longer period of time involving a lot of constructional and management changes. This fact in combination with the previously rather low documentation standards often causes relevant uncertainties about the specific physical and geometrical characteristics of the cask materials and components as well as about details concerning their whole assemblage.

This paper highlights current assessment strategies for such older vessels including cubic steel sheet containers as well as cylindrical thick-walled casks. As compliance with each "Konrad"-requirement can hardly be shown independently, only integrated approaches promises success: First, a broader concept of data collection has to be implemented that allows closing documentation gaps by linking dispersed and diverse data, e.g. delivery slips and handwritten fabrication records, by including plausibility considerations as well as random inspection programs. Thereby, the relevant properties of all applied casks have to be identified and their potential range should be quantified as accurately as possible. This knowledge is necessary to define one or more representative configurations of the cask as the base for design testing. The actual investigation program must enable to track the influence of deviations and determine safety margins especially in the likely case that not the most conservative setting of all cask features can be tested. The paper evaluates the respective ongoing efforts of industrial applicants and summarizes BAM experiences and associated research projects.

Introduction

The use of nuclear power in Germany has already a history of around 60 years, whereas repositories for the resulting low and intermediate level radioactive waste (LILW) had only been in operation for certain periods of this timeline. After closure of the Morsleben repository, which was established in the former German Democratic Republic in 1971 and continued its operation after German reunification until 1998, all waste has to be stored temporarily. In addition, from the earlier period mentioned above considerable residues are still stored in central and on-site interim facilities. Thus, according to the latest survey as constituted end of 2014 the total LILW volume amounts to 117.00 m³, whereof more than 100.000 m³ are already packaged. Typical vessels are cylindrical concrete or cast iron casks and especially steel sheet containers having a gross volume between around 1 m³ to 10 m³. According to the German waste management policy, these packages as well as future LILW with an expected total volume of about 300.000 m³ are finally to be stored in the Konrad repository, a former iron ore mine in the northern part of Germany. It´s examination for suitability to host such a facility started in 1975, but it was not before 2007 that the plan-decision approval was finally confirmed and conversion could start. Currently, start of operation is expected in 2022 while the emplacement phase is planned to run for about 40 years.

Along with the repository approval procedure, acceptance criteria for the waste packages had been specified. In principal, all waste has to be conditioned and then packaged in type-approved containers. Requirements for the containers focus mainly on the operational phase of the repository because long term safety, especially confinement of radioactive substances after sealing of the emplacement chambers, is provided by the host rock – a covering layer of clay rock being up to 400 meters thick. However, admissible containers have to undergo a sophisticated design assessment in which they have to demonstrate their functionality under operational and accidental loadings as well as their quality controlled production. This type approval is particularly challenging for those vessels that have been manufactured and often loaded some decades ago as the required safety level must be the same compared to new containers. With regard to the big amount of containers concerned, their qualification is currently a major issue to be solved prior to the operation of the Konrad repository.

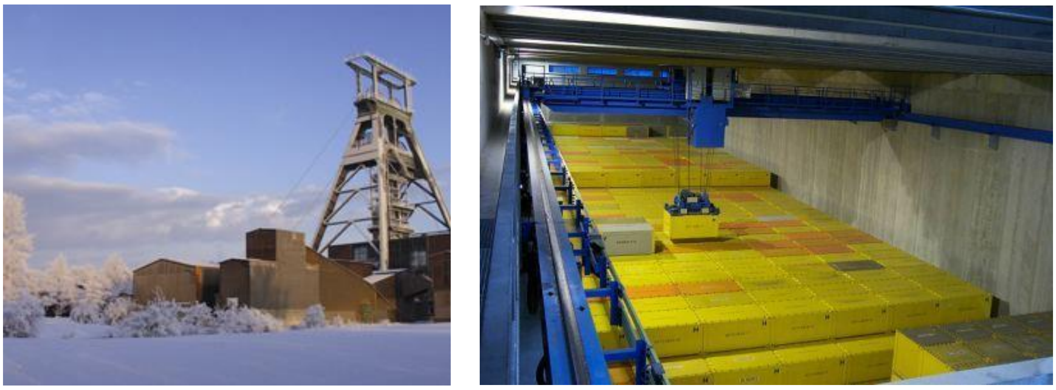

Figure 1: Konrad repository and interim storage of LWC at WAK [4]

Requirements and approval procedure for Konrad containers

Waste and container classification

Radioactive waste that will be disposed in the Konrad final repository has to be conditioned and packaged in type approved Konrad containers. The radioactive inventory is classified within 6 product classes depending on the waste properties and especially their tendency to disperse radioactive substances under thermal or mechanical loading. The admissible radioactive inventory of each package accordingly increases with the waste product class, but also with the so called barrier function of the package. Altogether, there are four different barrier function types based, on the one hand, on a container-related distinction and, on the other hand, on the packaging configuration. Containers themselves belong either to class I or II, where class II requires higher barrier properties. If the package configuration is classifiable as “accident-safe” (AS) because, for example, the inventory is fixed into inner barrels and/or the inner barrels are fixed within the container, the container class is enhanced by the “AS” characteristic. The classification as “AS” package allows the loading of higher radioactive inventory but also reducing some of the container requirements.

Container and waste package approval procedures

Due to a reorganization of responsible organizations within the nuclear waste management sector in Germany, parts of BfS (Federal Office for Radiation Protection have been transferred to BGE (Federal company for final disposal) being now responsible for the operation of final repositories and in charge of licensing Konrad waste packages. In order to obtain a Konrad certificate for a specific container type, the application has to be submitted to the BGE who subcontracts BAM for the container design assessment. As a result of the type approval procedure, BAM issues an expertise which evaluates in detail the conformity of the container with the regulations. It specifies all allowable waste forms with regard to the waste product class, but also considers their thermal and mechanical properties as far as they affect the package behavior under operational or accidental conditions or the ”AS”-classification discussed above. Furthermore, the expertise may include additional requirements for the qualified production and operation of the containers (e.g. regular manufacturer audits). The Konrad certificate is issued by BGE (BfS) on the base of this BAM expertise, what typically marks the starting point for the series production.

Container requirements

Containers have to fulfill different kind of criteria that had been deduced from the fundamental safety analyses performed for the Konrad repository and are specified in the BfS documents [1] and [2]. Firstly, basic requirements have to ensure the operational safety of the repository. In order to be able to plan the emplacement procedures, the containers dimensions and weights are limited and, concerning the shape, they should preferably be classifiable as one of the eleven predefined Konrad types including specifications of handling devices as well as their allowable tolerances. Furthermore, the containers have to be designed to perform the expected handling operations such as transport, lifting and staking within the surface and underground facilities of the repository without damages or loss of leak tightness, if applicable. Thus, specific handling scenarios have to be assessed as part of the type approval what can be done experimentally or analytically by numerical calculations or by comparison with prior assessments concerning similar container design. Practically, full-scale experimental container type testing is the preferred method in this area so far.

Based on the operational processes, accidental scenarios were identified by the Konrad repository safety evaluation and assessed in order to determine the most damaging configurations for the packages. It turned out that drops from 5 m and impacts with a velocity of 4 m/s with subsequent fire of 800 °C over one hour have to be considered as most critical events. Generally, containers have to resist resulting thermally or mechanically induced stresses, while the specific criteria depends on their barrier classification: containers with the lowest barrier function solely have to minimize oxygen entering to avoid open flames, while high barrier containers have to retain a leakage rate less than 10^{-4} Pa m³/s under both fire and drop test conditions. Such proof can either be provided by analogy consideration of similar previous type approvals or by numerical or experimental investigations. In praxis, especially in the case of high barrier function containers, type testing is based on both numerical as well as experimental studies. Hereby, simulations are used to determine critical drop orientations or critical loadings with regard to their mechanical properties, while final evidence is supplied experimentally under the numerically pre-selected boundary conditions.

Figure 2: Type testing of a concrete cask (left) and steel sheet container (right) at the BAM drop test facility

In order to ensure properties of the samples or prototypes used in the type approval are representative or covering for products of the later serial production, various provisions have to be made already as part of the licensing procedure. On the one hand, a detailed description of the container has to be submitted including parts list and material specifications for all components, where especially non-standardized materials and components have to be qualified in accordance with BAM requirements. Furthermore, series production assuring sufficient quality has to be defined by means of manufacturing and testing sequence plans (FPP), which in turn have to be integrated in the overall quality assurance system of both applicant and the manufacturer. The implementation of the entire production process as well as the quality assurance measures are in general audited when production starts and periodically thereafter. During series production, FPPs are stamped where necessary in order to confirm compliance with specifications and prescribed fabrication and testing processes, and test results are compiled. Any deviation from the original plan requires evaluation and approval. Consequently, a deviation report has to be prepared and assessed by the manufacturer and, in case of casks with higher barrier function it also has to be accepted by BAM. After assembly of the cask, a final inspection has to be performed whose results are added to the container documentation. Subsequently, reports about the use and examination of the cask as well as information about special incidents need to be collected and added to the container documentation.

Challenges in qualifying legacy waste containers

Specification

While usually containers for Konrad repository are manufactured based on a valid Konrad design approval certificate, the regulation [1] also provide for qualification of legacy waste containers (LWC). This applies to all containers whose production had been completed before a Konrad license for the specific type had been issued or which had been produced or operated not in complete conformity with a Konrad design approval certificate. The latter might, for example, occur when the prescribed quality assurances measures have not had been sufficiently implemented – a fact that is at latest revealed in the final acceptance test at the end of the container production process. In all these cases, a requalification of the containers can be applied for. In principal, the requirements are the same as for new container qualifications. Nevertheless, there are some differences with regard to the quality assurances measures due to the fact that manufacturing is already completed. Furthermore, the regulations allow LWC for deviating agreements within the type approval procedure also with regard to required documents as soon as the safety level is not affected. As the criteria are formulated to some extent in a quite general manner leaving room for interpretation, there are several options to settle the problems of LWC described below.

Incomplete container documentation

In contrary to new container qualification, the whole production documentation of LWC has to be submitted for type approval in order to assess the already completed manufacturing. As an equal safety level is required, the document should include the stamped FPPs, material and components certificates, deviation reports and documents about audits or similar records. Hereby, the necessary control level increases with the barrier function of the containers. Especially the production of those class II container components that are relevant for tightness, have to be supervised by external experts. While only such gapless documents guarantee the conformity of an actual container with the type applied for, in reality only a portion of it is available. Depending especially on the age of the containers, the material specifications and FPPs are far behind the current state of the art and lack relevant information. Furthermore, specifications had often been continuously modified, normally to optimize the container design, while these changes are not sufficiently documented. Subsequently, even the cask type specification opens a large field of interpretation and design variations. The resulting uncertainties about material and constructional details are further amplified by a lack of control during cask manufacturing and lost or defective container documentation. In summary, at the beginning of LWC type examination procedures, the documentation level ranges from reliable and validated records for each container up to relatively rough assumptions about the container design and its manufacturing process for larger quantities of not separately identifiable containers.

Damages due to longer interim storage

Casks for low and medium level radioactive waste in Germany have never been subjected to specific demands of long term interim storage. Though, due to the delays in the commissioning of the final repository Konrad together with the 40 years emplacement phase, many casks are expected to be in operation for 50 years and more. While corrosion resistance is prescribed by the Konrad guidelines, there are no details about the period of time to be considered or the applicable conditions. Anyhow, the casks are required to be free from any corrosion damages that could affect container integrity with regard to operational as well as accidental loadings at the moment of Konrad delivery. Accordingly, LWC type approval, which is conducted sometime within the lifespan of the casks, has to consider both potential damages and those which have already occurred. The particular challenge is on the one hand, to identify points susceptible to corrosion or other damages as not all containers can be checked due to their large numbers and limited accessibility, or the damages may enter into effect only in the future. Moreover, the nature and scope of damages which affect the container safety functions have to be distinguished from those which can be neglected. Unfortunately, up to now there is very little experience on how far the container integrity might be impacted by specific container impairments during cask handling or the prescribed accidental drop scenarios.

Limited disposability of adequate test samples

An essential part of the container type approval procedures often is prototype testing and investigation to prove the design against operational and accidental condition. According to the regulations [1], the properties of the respective samples should cover all possible variations of the serial containers. In case of new container qualifications, this requirement can be met by manufacturing special test samples having, for example, lower material characteristics, bigger gaps or a combination of all possible lid openings within one lid. In contrary, the production of LWC typically has already ceased and prototypes must be taken from the existing charge. Their properties are very often not completely known due to limited manufacturing documentation and, even worse, penalization can hardly be realized. Their available number is furthermore limited due to the high effort connected with unloading and decontamination and also the identification of representative individuals is a challenge.

Status and concepts for legacy waste container approval

Current status of approval procedures

Until now, only a very small portion of the existing low and medium level radioactive LWC has already been qualified. Their successful procedures are almost limited to steel sheet containers with low barrier functions and comparable good documentation level. Anyhow, there are big numbers of cylindrical concrete and cast iron casks as well as cubical concrete and further steel sheet containers, whose ages range from just a few years to several decades. Especially the thick-walled casks are often loaded with inventory requiring a higher barrier level, but even today there are no considerable applications for LWC as class II containers. In contrary, the efforts concerning some particularly problematic class I containers have substantially increased. They play an important role in the federal government's waste management policy because their numbers are in the higher four-digit spectrum representing a large proportion of the total legacy waste packages stored in interim facilities. Though they had been applied for qualification already some time ago, only now sustainable strategies had drawn up due to an increase of resources and close collaboration between industry and authorities.

Concept – Reduction of complexity

A major reason for the unduly length of LWC assessment procedures and their almost failures, is the complexity of the subject. So far, one-size-fits-all approaches had been pursued in order to qualify all containers of a generic type at once. Thus, different inventories, barrier functions, constructional arrangements and container ages had to be considered within one single type approval due only to the fact that the containers have a similar design. It turned out, that (nearly) no strategy could be found that accounts for all the particularities stated above and lack of clarity about the specific needs hampered efficient solutions. The discussions between applicants and authorities often continued endlessly because of the multitude of options and influencing factors. Experience has shown that complex container approvals better should be dissected, in a way that has to be adapted very carefully to the actual circumstances. It is recommended to firstly isolate a separate application procedure for a clearly defined case with rather low anticipated difficulties, e.g. a comparatively young container series or containers loaded with an inventory that offers rather low potential radioactive release under mechanical or thermal test scenarios. The already qualified containers then might serve as a reference for the remaining ones, whereas most parts of their approval can be tackled by rather simple delta-considerations. This allows concentrating on those subjects, where analogies to the reference do not suffices. Here, either a completely different strategy for the safety proof can be adopted as the regulations allow for a variety of approaches, or the delta-consideration has to be put on a more sophisticated foundation. Provisions should already be made in the reference qualification to gain as much data and information as possible to support such argumentations.

Concept - Reduction of uncertainties

LWC are typically characterized by several uncertainties concerning material properties and constructional details due to defective documentations and possible damages caused by long storage. However, as type approval stipulates a nominal container design with clearly defined admissible deviations, the reliability and the detail level of container specification and condition must often be improved. In-depth investigation of the manufacturing process in combination with random reexaminations can, within certain limits, substitute for missing records and also reveal weak points of the design, if any. Thus, it is required to describe each manufacturing step and provide all available documents to verify the anticipated characteristics and quality of the hereby manufactured components. If data cannot directly be assigned to individual containers, plausibility consideration may be added. The findings from the whole production chain should be summarized and be eventually merged in a nominal design including a reliable approximation of possible deviations. In the rare cases that the assembly of the containers cannot be traced and the design is only described by means of part lists, it might be necessary to reinvent all possible manufacturing sequences and, based on this, identify especially the potential defects. All such assumptions are normally be verified by non-destructive testing of a reasonable control sample.

Concept - Compensation of uncertainties

While in new container qualifications, type testing should be performed with test samples covering the series product, LWC approvals have to handle the restrictions of already existing samples as well as remaining uncertainties about constructional or material details. In order to compensate for the only restricted representativeness of LWC test specimens, safety reserves can be exploited. At the same time the robustness of the design has to be ensured, without weak points leading to failure under slight modifications of loading or other boundary conditions. Such an evidence or quantifications of safety margins can hardly be supplied by experimental testing only. Even though conservative configurations can easily be implemented, for example by applying larger drop heights or fire temperatures, the hereby generated load increase is extremely difficult to be credited against potential impairments of the containers. It is therefore necessary to rather perform numerical simulations aiming to identify the most critical areas of the container design as well as the sensitivity of material and constructional properties. In the first step, the input data should be taken from real container samples allowing for model validation by means of experimental testing, while comparative studies then consider the expected deviations. If the sensitivity analysis indicates the risk of container failure or increase of leakage rate due to such assumed values, further investigations are required. On the one hand, reexamination of these properties with a bigger volume of containers should be performed. If they confirm a reasonable likelihood of the critical values, it might be necessary to select a test sample having just these properties under consideration and use it for the type approval.

Integration of the concepts

In general, the successful approval of LWC requires the integration of all concepts stated above. A current example for this procedure is the qualification of steel sheet containers loaded with bulk waste or drums and having been manufactured by several producers over a long period of time. Especially the older charges suffer from incomplete and defective documentation and probably an inferior lid construction. In coordination with BAM and BfS, the applicant applied for a strategy to firstly implement a reference container qualification to which older containers are stepwise mirrored. The special feature hereby was the definition of reference type based on completely new documents being quite similar in content to the existing ones – but free from defects and in accordance with the state of art. Type testing had been performed with one of the existing LWC under penalizing boundary conditions and aimed to gain as much information as possible. Thus, multiple drop configurations had been experimentally realized and also numerically simulated in order to fully understand the container's mechanical behavior [3]. Based on this, the actual LWC have been started to qualify, beginning with the youngest charges moving backwards on the timeline. Although the tallest hurdle still looms ahead in this process, essential prerequisites for success are laid out.

Conclusions

The qualification of containers with legacy low and medium level radioactive waste (LWC) for emplacement in the Konrad repository is an increasingly important topic in Germany with regard to their large numbers and foreseeable delivery from the interim storage. Big efforts are currently devoted to solve possible discrepancies between the formal Konrad acceptance criteria and the actual LWC conditions and restrictions (incomplete documentation, limited availability of samples). It turned out that application procedures are considerably accelerated if they are divided in minor fractions not targeting a one-size-fits-all approach. Furthermore, it is required to reduce, as far as possible, uncertainties mostly resulting from insufficient container documentation by tracing all manufacturing steps and integrating diverse types of records. The remaining possible deviations of the containers under consideration and especially of the applicable test specimens from any nominal design specification can be compensated by exploiting safety margins and ensuring robustness of the construction. Thus, a combination of experimental testing under preferably conservative conditions together with validated numerical simulations allow assessing the sensitivity of material and constructional properties as well as the identification of most critical points. Within an integrated approach, this knowledge forms the basis for random reexamination programs or further sample testing under clearly defined conditions. The explained measures and strategies aim to achieve Konrad LWC design approvals in order to avoid cost-consuming reloading campaigns with inevitable radiation exposure for a large volume of LILW.

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