Legacy Waste Containers for Low and Intermediate Level Radioactive Waste in Germany - Actual Situation and Challenges –17070

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ABSTRACT

Low and intermediate level radioactive waste has been produced in Germany for several decades. While a part of the waste had been deposited in the Morleben repository and the Asse mine which have been operated for just a limited period of time, the major amount is conditioned and packaged in temporarily stored waste containers. Those containers are designated for final disposal in the KONRAD repository being currently under construction and expected to start operation in 2022. As a consequence, an assessment of the waste container documentation and safety is strongly needed to receive an approval for the Konrad repository. This requalification is challenging because those old containers have to meet the same safety requirements as new containers.

INTRODUCTION

The first supply of electricity generated by nuclear power in Germany occurs in 1961. Over the time, the number of nuclear power plants increased to its maximum in 1986-1990 (see Fig. 1). Since then, some of the plants stopped their operation, while no new commercial reactors have been built. On June 30, 2011 the German government decided the nuclear power phase-out [1]. As major consequence of this decision the last nuclear power plants are scheduled to be shut down by the end of 2022.
During the operation of the power plants as well as of research reactors and other nuclear facilities (e.g. facilities for medicinal applications) low and intermediate level radioactive waste (LILW) has been produced. Also dismantling of nuclear facilities and reactors contribute to the amount of nuclear waste. Most of the waste is handled at the regional collection points in every federal state of Germany.

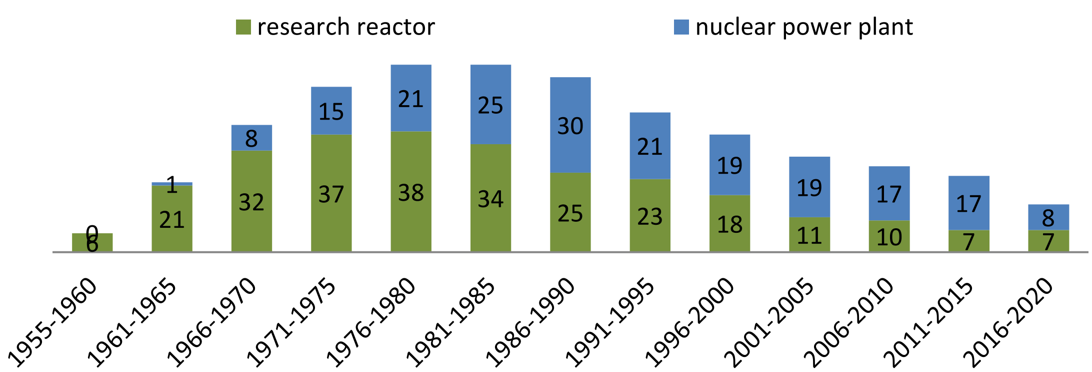

Fig. 1: Overview of operating nuclear research reactors and power plants in Germany [2]-[4].

The first approach to solve the challenge of final disposal of radioactive waste was a research repository in the region of Lower Saxony (formerly West Germany), where LILW had been emplaced between 1967 and 1978. In 1971 a final repository for LILW started its operation in Saxony-Anhalt (formerly East Germany). Different waste deposition methods have been tested there, but after 27 years the last deposition took place. Currently the final repository KONRAD, which is designed for hosting approximately 300,000 m³ of LILW, is under construction and its operation is planned to start in 2022 according to the Federal Office for Radiation Protection (BfS).
Till now, there has been no final repository where all the waste from the last decades could have been stored. That means that a large part of LILW in Germany is conditioned and packaged in temporarily stored waste containers which have been produced since the 1970´s and are eventually designated for final disposal in KONRAD repository. These containers, denoted as “Legacy Waste Containers”, have to demonstrate their compliance with the KONRAD acceptance criteria to be approved by the BfS.
Since the beginning of LILW container manufacturing, production guidelines and technical standards have significantly changed. For example, the quality management guideline ISO 9000 was internationally accepted in 1987 and a few years later national guidelines were released. Furthermore, guidelines for welding, casting, design of concrete structures and other fabrication aspects have been modified affecting LILIW containers which are typically made out of steel sheets, concrete or cast iron. Thus, assessment of legacy waste container documentation, which is a central part of the container requalification process, is compounded by the fact that legacy waste containers have to comply in principal to the same safety and quality requirements as new containers.
Up to now, a few hundreds of these containers are already certified, whereas a much larger number of containers are still in the approval process to meet the schedule till the opening of KONRAD. Hereby, the challenge is not alone the assessment of their manufacturing documentation, but also the inspection of the current container condition and the proposed aging management during interim storage until delivery to the final repository.

FINAL REPOSITORY KONRAD

The concept of the KONRAD final repository is based on the safe enclosure of radioactive content around 800 m to 1,300 m below ground level in a deep geological formation [5]. According to [6] it was assumed that containers are usually not able to delay the leach of the waste if they are directly in contact with water. Thick-walled cast iron containers are an exception by delaying the leaching process for 4 years. Therefore, the main barrier for leach and diffusion of radioactive substances to the surface is the geological formation, in particular an overlying clay layer with 400 m thickness. Due to the geological barriers, water from the final repository will need more than 300,000 years to reach the surface ground water; see Fig. 2.

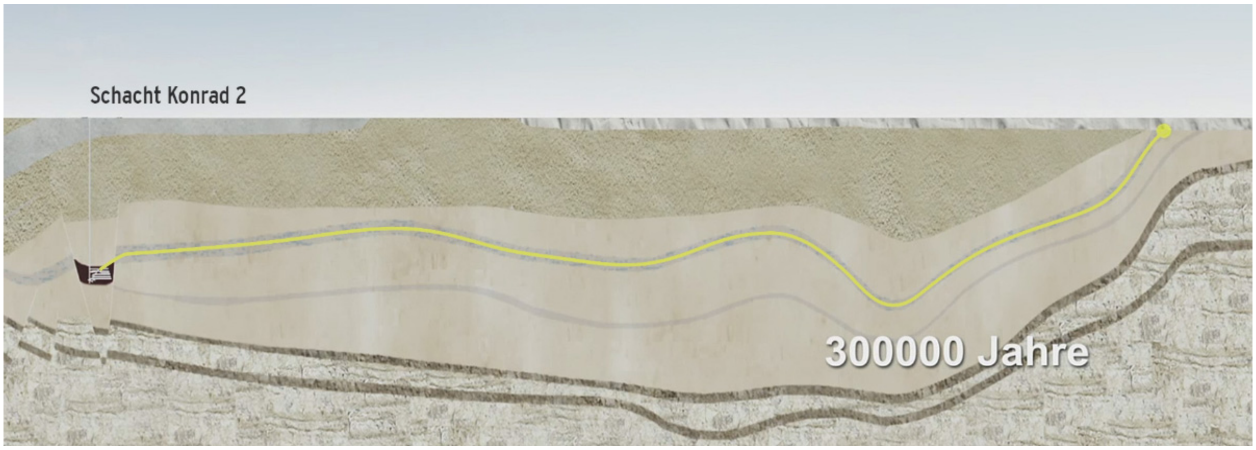

Fig. 2: Deep geological KONRAD repository for LILW. The yellow line highlights the fastest diffusion way of water from the repository to the surface [7].

As a consequence, containers are not required to provide any long term barrier function. Furthermore, neither container recovery during the operational phase nor retrieval after sealing of the repository is planned. Thus, maintenance of container safety functions is not required after container emplacement.

Delivery of all LILW packages from the interim storage facilities to the final repository will be performed by rail cars or trucks. After their arrival at the repository reception area they will be reloaded to different transport vehicles (see Fig. 3), stacked in a buffer hall or directly transported to the emplacement chambers. The container requirements are mainly derived from safety evaluation of the handling chain within the repository considering normal as well as accidental conditions. The containers have to be designed for handling with top and side spreaders and stacking. Additionally, they have to limit radioactive release during a one hour fully engulfing fire with an overall temperature of 800 °C near the container surface after an impact with a velocity of 4 m/s. This corresponds to a collision of the transport vehicle which catches fire. Accident safe waste containers have to comply with additional requirements like a 5 m drop test [8], [9].

Fig. 3: Waste packages arriving in the repository's surface facilities will be reloaded from the train or truck to local transport vehicles [7].

DISPOSAL CONTAINERS FOR THE KONRAD REPOSITORY

Containers designated for the KONRAD repository are generally made from steel sheets, cast iron, forged steel or concrete. Steel sheet containers are usually produced with 3-5 mm thick sheets and are quite similar to (ISO) fright containers but having smaller dimensions. Concrete containers originally are cylindrically or cubically shaped and reinforced with steel bars or mats. While this type was rather produced in the past, nowadays modified constructions, e.g. robust steel-hulled casks, have become common. The highest barrier function, which is especially required for packaging intermediate level radioactive waste, is provided by thick walled cast iron and forged steel containers. The shape and dimensions of containers for the KONRAD repository have to comply with the guideline SE-IB-29/08-Rev-2 [8], as shown in Table 1. It should be noted, that the dimensions in case of cubic container types are independent of the vessel materials, while the dimensions of cubical casks differ for concrete or cast-iron due to historical reasons.

Table 1: Overview of admissible container dimensions of LILW containers for the KONRAD final repository

Cubic Container	Type I	Type II	Type III	Type IV	Type V	Type VI
Length	1.60 m	1.60 m	3.00 m	3.00 m	3.20 m	1.60 m
Width	1.70 m	1.70 m	1.70 m	1.70 m	2.00 m	2.00 m
Height	1.45 m	1.70 m	1.70 m	1.45 m[a]	1.70 m	1.70 m

Cylindrical Cask	Concrete		Cast-Iron		
	Type I	Type II	Type I	Type II	Type III
Diameter	1.06 m	1.06 m	0.90 m	1.06 m	1.00 m
Height	1.37 m	1.51 m	1.15 m	1.50 m	1.24 m

Three examples of waste containers from Table 1 are shown in Fig. 4.

Fig. 4: Sheet steel cubic container (left), concrete cubic container (middle), concrete cask (right)

CONTAINERS CLASSIFICATION AND REQUIREMENTS

Based on the designated or already contained radioactive inventory, KONRAD-containers have to fulfill specific barrier functions, which can be distinguished between the four following classifications according to the guidelines [8] and [9]:

Table 2: Basic waste container classifications.

Container with normal barrier properties (ABK I)		Container with increased barrier properties (ABK II)	
without accident safe waste packaging (nsf) I	with accident safe waste packaging (sf) II	without accident safe waste packaging (nsf) III	with accident safe waste packaging (sf) IV

From left (I) to right (IV) of Table 2, the permissible radioactive inventory as well as the barrier and safety requirements of the container increase. To get an overview, the requirements can be separated in three parts - basic requirements, quality management requirements and type specific design testing requirements –, whereas a non-comprehensive, more detailed list is given below:

Basic requirements:

- External dimension and shape
- Suitability of materials
- Corrosion resistance

Quality management requirements:

- Quality manual
- Quality assurance program
- Fabrication and examination sequence plan

Type testing requirements:

- Leakage test
- Stacking test
- Drop test
- Thermal test (engulfing fire, see Fig. 5)

Fig. 5: Thermal test of a waste container at the BAM test facility

In addition to the upper classification, waste containers can be classified with respect to their certification status. Container types being approved before their serial production starts, are here denoted as “New Containers”. In contrast, “Legacy Waste Container” might be defined as:

Legacy Waste Container

Any kind of container which is designated for emplacement in the KONRAD repository and produced before container type approval.

Any “New Container” approval procedure must provide a straight forward compliance with the guidelines and clean evidences.

Everything from the container documents and drawings to quality management and assurance must be in order for fabrication and warrantee that fabricated containers will be identical to the approved container type.
The specific requirements for legacy waste containers (listed in Chapter 7.2 in SE-IB-30/08-Rev-1 [9]) state, that the safety level of legacy containers has to be equivalent to the one of new containers. Anyhow, the demonstration strategy is allowed to draw on compensation measures in case that some individual proofs can not be provided. Hereby it has to be ensured, that these provisions enable reliable evaluations of all containers which should be approved. The more flexible evidence of the safety of legacy waste containers is needed to qualify a specific number of already produced containers. It is not allowed to produce new containers with a legacy waste container qualification.

APPROVAL PROCESS OF LEGACY WASTE CONTAINERS

First, an explanation is needed about which kind of container approval is focused on in this paper. In Germany, there is the need of demonstrate compliance with the regulations for the transportation of dangerous goods on public roads and rail net-works, for example, for moving packages from one interim storage to another or to the final repository. Another approval is needed for their storage in an interim storage facility. And at least, an approval is needed to emplace containers in the final KONRAD repository. So, this paper is focused only on the approval procedure of legacy waste containers for the final KONRAD repository.

In Germany, the radioactive waste producers are responsible for the safe management of the waste up to its final disposal. If they have loaded materials in containers without a valid Konrad certificate based on an interim storage license issued by the local state authority, they have normally to carry out the package application procedure prior to the shipment to the KONRAD repository timely. Thus, a safety report for a series of similar or identical legacy waste containers has to be submitted to BfS evidencing that all containers are in line with the KONRAD guidelines [8] und [9]. BfS reviews the application and transfers the documents to the Bundesanstalt für Materialforschung und -prüfung (BAM), the Federal Institute for Materials Research and Testing, which is in charge to evaluate the container compliance with the Konrad acceptance criteria. After a positive evaluation, BAM sends an comprehensive expert report to BfS which forms the basis of the Kontrad approval certificate issued by BfS.

Current State of Approval of Legacy Waste Containers

Currently, seven approval processes especially for legacy waste containers are underway BAM and five have quite recently been completed. Actually, more than 5,000 legacy waste containers are in approval procedures and more than 500 are successfully qualified. An overview about the applied containers including their volume, age and classification, is given by table 3. Similar container types have been merged. Because the KONRAD guideline SE-IB-29/08 was released 1995 the approval processes are split in two categories with beginning of production before and after 1995.

Table 3: Overview of legacy waste container types which are approved or currently in approval processes.

Container Type in respect of SE-IB-29/08-Rev-2	Category	Amount			Fabrication has begun	
		< 99	100 – 999	> 1000	before 1995	after 1995
Cubic Steel Sheet Container Type III	ABK I nsf	X			X	
Cubic Steel Sheet Container Type IV	ABK I nsf		X			X
Cubic Steel Sheet Container Type IV	ABK I nsf	X			X	
Cubic Steel Sheet Container Type V	ABK I nsf			X	X	
Concrete Cask Type I	ABK I nsf			X	X	
Concrete Cask Type II	ABK I nsf	X				X
Cast-Iron Cask Type II	ABK I nsf		X			X
Cubic Cast-Iron Container Type VI	ABK I sf	X				X
Cubic Cast-Iron Container Type VI	ABK I + II nsf + sf	X				X

On October 19, 2016 a law for the reorganisazion of responsibillities in the radioactive waste disposal process has passed the (German) federal cabinet [10]. To warantee the final disposal of radioactive waste in Germany, radioactive waste producers have to pay into a federal fund to finance building and operation of interim storages and the final repository KONRAD. In return it is planned that the ownership of interim storages and already packaged radioactive waste will be transmitted to the Federal Republic of Germany given that the waste is packaged technically correct and certified [11], [12]. It is predicted that the law becomes applicable by the end of 2016. In this context the operators of interim storage facilities are called to qualify all remaining legacy waste containers as soon as possible, which very likely leads to a significant increase of approval procedures in the near future.

BASIC CHALLENGES OF APPROVAL OF LEGACY WASTE CONTAINERS

Legacy waste containers have been produced since the 70´s. They have been stored and handled up to 50 years till now, though they are originally not designed for this lifetime. In 1984 it was predicted that disposal of waste containers in the KONRAD repository starts in 1990 [14]. It is now planned that disposal starts in 2022 with a transition to full operation, where 10,000 m² of waste will be disposed per year [5]. This is in line with the latest national waste management programme report [15] (2015) stating that the emplacement operation should not be longer than 40 years.

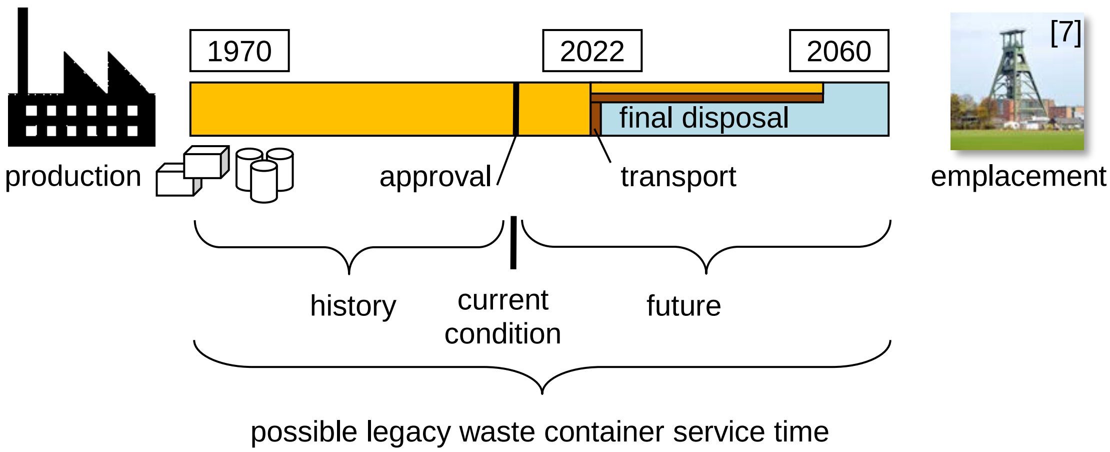

Fig. 6: Maximum timeline from manufacturing of a legacy waste container to the final disposal in the KONRAD repository.

Moreover, it has to be taken into account that containers might be delivered towards the end of the emplacement phase, resulting in some more decades of interim storage and handling. Taking the worst case scenario into account, legacy waste containers may need to be stored and handled over 90 years, as depicted in Fig. 6. If they are approved today, they have been operated already up to 40 years before approval and they may need to be operated up to 50 years after receiving the approval until their final disposal. The safety assessment has to consider the whole service time from the fabrication (documentation) to the future until the containers will be delivered to the repository. To address the challenges within the approval process, the legacy waste container service time is split into three parts according to Fig. 6. This parts are the "history" of the container till now, the "current condition" when the approval process occurs and at least the outlook in the "future" up to the point when the container is disposed in the emplacement chamber as described in the following subchapters.

Waste Container History

Any waste container history begins with its manufacturing process. According to the KONRAD [8] guideline, it should be organized at follows: First a technical design and fabrication concept has to be finalized and documented, which forms the basis of the waste containers production. During each production step a quality management and assurance system is applied to ensure the conformity with the fabrication documentation and production guidelines. Any deviation from the target design has to be assessed with regard to its tolerability and the need of repair measures or rejection. After the container is finished, the manufacturer or - dependent on the container

classification – an independent expert should check the conformity and issue an inspection certificate. Finally, the waste container can be shipped to the customer who should perform a receiving inspection. Then it can be loaded with conditioned radioactive waste.
The loading procedure as well as the waste conditioning process should have been approved by BfS and needs to be well documented. Finally, the package is stored in an interim storage facility where it is handled in accordance to the approved manufacturer's handling instructions and maintenance plan.

Practically, the above described ideal scenario is realized only for "young" legacy containers. Indeed, fabrication concepts and documentation are often incomplete or inconsistent, especially if the fabrication took place before the ISO 9001 was established (or implemented by the company). Containers that have been produced over a long period of time typically undergo several design changes due to technical development and optimization. For example, typical modifications of a steel sheet container involve different steel sheet thicknesses, steel sheet materials, welding seams or weld seam positions, screws and further constructive details of the lid. Also, the traceability of containers to the production batch and documentation could be difficult. It is possible that one manufacturer sold containers without unique identification numbers to different customers or consumers ordered similar waste containers from different manufacturers. According to the waste report of 2013 [16], containers are currently stored at 31 different facilities. For example, the cast iron cask type II is stored in 22 facilities, container type IV in 18 facilities and the concrete cask type II in 12 facilities. If the container has already been loaded, there are often uncertainties about the inventory including its mechanical and thermal properties which might affect the package behavior under operational or accidental conditions. Also the loading process itself has to be considered as it could reduce the container durability. For example, the inner corrosion protection of steel sheet containers could have been damaged. At last, there are not always appropriate handling instructions or maintenance concepts that prevent damages during interim storage and transportations.

For approval of legacy waste containers, a complete documentation or similar evidences are needed. As just pointed out, there can be lots of challenges that have to be overcome. The submitter of the approval request is responsible for choosing its evaluation strategy, which should be agreed with BfS and BAM at an early stage. There are the following three basic strategies applicable:

<u>Requalification Strategy</u>
If documentation of the containers history (manufacturing, handling, etc.) are incomplete, inconsistent or lost, requalification of each kind of uncertain property or lost documentation has to be done.

For example, if there are no individual labels, containers have to be inventoried. Thereby their construction types, properties and conditions have to be documented. For requalification of a container design all technical drawings and construction material documentation and qualifications must be evaluated and the results have to be reported with respect to the container safety. To cover uncertainties along with the production process, the manufacturing and quality assurance documentation must be evaluated and reconstructed results have to be documented in a technical report. Representative spot checks can be also used to verify the documentation and properties. If there are uncertainties in the container strength, an investigation concept is needed to verify and study specific container properties for all production batches. Such gaps can also be overcome with additional parameter studies, material or component tests or equivalent measures.

Delta Consideration Strategy

This Strategy can be used when containers have been produced over a long period of time undergoing several design changes due to technical development and optimization.

If a series of legacy waste containers out of the total number is in line with the guidelines (potentially a very "young" series of legacy containers), the approval of these containers can first be requested. Alternatively, the approval of similar new containers can be requested, especially if further production is planned in the future. Subsequently, definite series of similar legacy containers which have certain deficiencies can be approved as codicil to the first certificate.

For the first approval of a young legacy or a new container, a safety report has to be created and consistent and complete documentation for the production have to be prepared. Testing procedures have to be done to prove the compliance with the requirements. Furthermore, it is recommended that testing is accompanied by numerical analyses to obtain additional information about structural properties and safety margins.

After the first approval of the first container series is confirmed, differences to a series of similar legacy containers can be studied, evaluated and documented in a delta consideration report. Determined safety margins can be used to verify that minor design changes or uncertainties have no influence on the safety level of containers. This procedure can be done with each series of similar legacy containers, beginning with the youngest series having only minor deviations to the initially approved container design and ending with the oldest series with probably larger modifications and uncertainties.

Restricted Approval Strategy

This strategy can be used for legacy waste containers which are generally in line with the requirements except for some aspects which cannot be overcome with other strategies. For example, if the construction materials may not be reliably certified for the handling temperature range down to -20°C.

In agreement with BfS, an approval of these containers is possible with defined restrictions provided that the repository safety level is not compromised. For example, when materials are not certified for the lower range of handling temperatures, delivery of these containers can be restricted to periods where the temperature is determinately well above a certain level, e.g. 0°C.

The Current Container Condition

Each applicant has to evaluate whether the containers are in a condition that corresponds to the documentation. While this should be not a problem for "younger" legacy waste containers, older types have to be evaluated with regard to aging/corrosion sensitive materials, tightness if necessary and exceeding material certifications (e. g. corrosion protection duration according to DIN EN ISO 12944). During the approval process, BAM might perform spot checks of the containers in the interim storages to evaluate the current condition.

During the approval process, BAM checks whether the manufacturing documentation is in line with current standards (DIN, EN, ISO). It might be possible that some fabrication steps were in line with the standards in the past but not today anymore. This has to be evaluated regarding the safety concerns. On the other hand, also the design requirements and dimensioning have to be in line with the common standards [9]. For example, concrete containers dimensioning should consider the "ultimate limit states" and "serviceability limit states" according to the DIN EN 1992-2 or similar standards. Thereby the dimensioning standards in the past could be incomplete in comparison to current standards. Also the maintenance and handling concept could have changed since the legacy container production and the applicant has to address these changes and aspects along with the evaluation.

The final part is the maintenance and repair concept. The applicant has to evaluate the current condition of the containers and take care that handling and potential repairs avoid impact on the corrosion protection properties. Especially for spalling of concrete containers on surfaces and edges a damage tolerant container concept with a definition of a critical spalling size is a possible way to overcome uncertainties in the current condition.
In summary, the older the legacy waste containers are and the poorer the manufacturing and operations history is documented, the more evaluations and checks are necessary to determine the current container condition and safety level. Outer damages can be checked rather easily (e. g. by visual inspection) while inner damages are difficult to check and identify especially when containers are already loaded and closed.

The Container Condition Before Delivery to KONRAD

The guidelines define that only containers which are free of obvious damages or corrosion are accepted. According to [9] (Ch. 3.5.1) "obvious damage or corrosion" is defined as corrosion or damage that is visible on the outer surface and have no impact on the container structural integrity. In order to meet this requirement, applicants usually provide an appropriate container maintenance (or handling) concept stating that a visible inspection has to be done shortly before delivery to the KONRAD repository and that only containers which pass the test are allowed for shipping. Also the readability of container labeling will be checked.
Besides assuring no outer damage of the containers, the safety assessment during the approval process has to ensure that there will be no inner damage when the delivery to the repository starts, see [9] Ch. 3.5.1. Inner damages can be prevented

by quality assurance measures during the production and handling and by an appropriate design. More investigations are needed to overcome uncertainties in the assessment of the long term behavior with respect to the enhanced container service time of up to 90 years in total.

CONCLUSIONS AND OUTLOOK

The approval of legacy LILW containers for the German final repository KONRAD is a continuing challenge. Based on the different history of legacy waste containers each approval procedure is rather unique and requires an individually adopted safety concept. Younger series of legacy waste containers are usually in line with common standards and can usually be approved easier in comparison to older ones. The latter often need compensation for uncertainties in the documentation and constructional details. In addition, aging and corrosion sensitive aspects have to be evaluated. For older legacy waste containers, a maximum service time of around 90 years needs to be considered. The design approval has to consider the entire service time which ends with the emplacement in the repository chamber. More generic investigations have to be done to evaluate safety relevant aspects of the extended service time to warrantee the safety level.
Three basic approval strategies have been explained and also more strategies for a successful approval process could be found if all involved parties work closely together. Thereby, rework of documents and requalification can be a promising approach.
The current work along with legacy waste container approval procedures and their long term performance can serve as a basis for upcoming legacy waste container qualification procedures to reduce risks and uncertainties and to figure out the most effective and efficient strategies.

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