MOSAIK® casks – A Comprehensive Solution for Packaging ILW

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1. Abstract

There are a number of waste streams from operation and decommissioning of nuclear power stations and other nuclear installations that require shielding – often called intermediate level waste (ILW). These waste streams have to be treated, packaged and transported in a way to fulfill the acceptance criteria for the respective disposal facility and – as far as applicable – interim storage facilities.

For treatment, transport, interim storage and disposal of ILW waste streams GNS more than three decades ago developed its so-called MOSAIK® casks, first as a family of ductile cast iron casks. Almost 8000 MOSAIK® casks have been loaded to date. MOSAIK® casks are available as containers for Type B or IP-2 packages.

While all the MOSAIK® II casks feature the same outer dimensions, they can be customized to meet the different requirements by e.g. different wall thicknesses, adding lead inserts or by using different lid systems with variable connectors. There are MOSAIK® casks for irradiated core components, for resins, evaporator concentrates and other waste streams. As even the raw material typically requires shielding, MOSAIK® casks have been designed to process the waste inside the casks which provides the required shielding. For this purpose the casks are equipped with connections for drying facilities and other waste treatment equipment.

MOSAIK® casks are available today in several different versions, e. g. with different connections for different types of treatment facilities. The casks can be equipped with additional lead shielding in different thicknesses in order to provide sufficient shielding for high dose rate waste.

After almost 40 years MOSAIK® casks are still state-of-the-art technology proven by current Type B approvals and various test certificates for final repository (e.g. Germany, UK). The MOSAIK® family is subject of a continuous improvement. Therefore, GNS provided state-of-the-art proofs by performing multiple drop tests and fire tests with MOSAIK® casks in the last years.

The paper will give an overview of the different variants of MOSAIK® casks and their designated use. Furthermore, it will focus on the current status of licensing and in particular on the performed drop tests, fire tests and other methods of safety evaluation.

Figure 1 MOSAIK® test program 2018

2. Overview

The name MOSAIK® stands for a cask family for processing, transport and storage of ILW waste streams such as irradiated core components, ion exchange resins, evaporator concentrates, sludges and radiation sources. MOSAIK® casks can be used in many instances, with different wall thicknesses and with additional lead inserts that enhance the shielding level. MOSAIK® casks are available as containers for “Industrial Packages (IP)” and also for “Type B” packages.

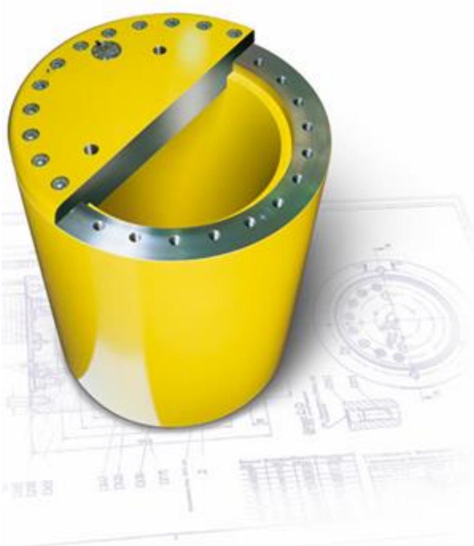

Figure 2 MOSAIK® cask

MOSAIK® stands for a versatile cask family for processing, transport, interim storage and final disposal of all ILW waste streams. The success story of MOSAIK® casks began back in 1980 first with a variant only for irradiated core components, the so-called MOSAIK® I (= Roman one).

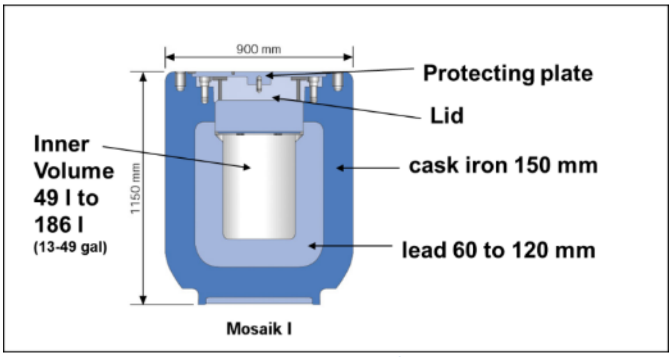

Figure 3 MOSAIK® I cask

This variant was soon followed by the MOSAIK II for a wider spectrum of waste streams. A third variant, MOSAIK® III again for just one single waste stream, dried evaporator concentrates completed the MOSAIK® family.

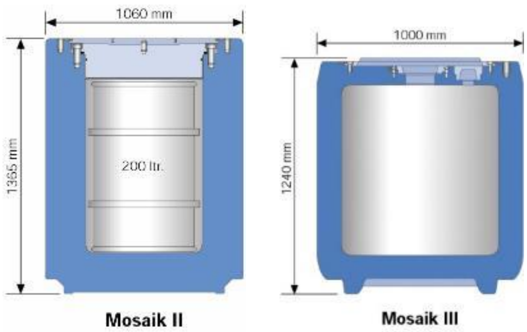

Figure 4 MOSAIK II® and III

The three aforementioned variants were replaced in the late eighties by a further development of the MOSAIK® II, the MOSAIK® II-15 and its siblings MOSAIK® II-10 and MOSAIK® II-12. With currently almost 8.000 MOSAIK® casks delivered it is the best selling shielded nuclear transport and storage cask worldwide. In Germany nuclear operators rely entirely on MOSAIK® casks for challenging ILW waste management problems during operation, decommissioning and dismantling of their nuclear facilities. Nuclear operators in the United Kingdom, Switzerland, the Netherlands and Italy have also chosen MOSAIK® casks as a cost efficient solution to face ILW waste management tasks. Especially in the United Kingdom and Switzerland MOSAIK® casks play an important role evidenced by, amongst other things, applications for granting a “Type B” licence for customer-specific waste streams which are not covered by the already existing “Type B” licence (Switzerland issued 1st September 2018, UK planned 2019) and also by final stage letters of compliance (fLoC) issued by RWM for a number of waste streams in MOSAIK® casks. In the following, the MOSAIK® cask family and its success story are introduced. Moreover, GNS as a German radioactive waste management specialist in the UK, more precisely at Sizewell, Bradwell and Sellafield is presented.

3. THE MOSAIK® CASK FAMILY TODAY

MOSAIK® casks are used for processing, transport, interim storage and final disposal of ILW waste streams arising from operation and decommissioning of nuclear power plants and other nuclear installations such as irradiated core components, ion exchange resins, evaporator concentrates, sludges and radiation sources. MOSAIK® casks are available with different wall thicknesses and, if required, with additional lead inserts to enhance the shielding level (see also **Error! Reference source not found.**). As the casks are equipped with the respective necessary connections, waste can be conditioned directly inside MOSAIK® casks with methods and facilities developed by GNS to make them suitable for final disposal. To accommodate various kinds of waste streams, the cask types have different lid systems and extraction systems. These are the main features of the particular versatility of the MOSAIK® concept (see also **Error! Reference source not found.**5).

MOSAIK® casks are available as containers for “Industrial Packages (IP)” or for “Type B” packages. For public transport as a “Type B” package. The MOSAIK® portfolio contains the MOSAIK® II-12 which is only available as container for “Industrial Packages (IP)”. It has no additional lead insert and with respect to its wall thicknesses the highest volume for loading. The MOSAIK® II-15 casks are available as containers for “Industrial Packages (IP)” and for “Type B” packages. The wall thickness of 160 mm is higher than of the MOSAIK® II-12 (120 mm). Additional lead inserts (20 mm – 120 mm) makes it usable for waste streams with higher activities. The particularity of the MOSAIK® II-15 U EI is that it is used for underwater loading and therefore has a different lid system and extraction system.

The basis design is the same for all MOSAIK® casks. The monolithic cask body and lid are made of ductile cast iron (DCI) with nodular graphite. Closure lids are made of austenitic steel. All seals of the leak-tight containment are designed as double seals made out of Fluorocarbon rubber (FKM), so leak tests are possible at any time. For the handling of the casks, the cask body has a peripheral shoulder on the outside in the bottom area. This shoulder allows the handling of the cask by means, e. g. of a forklift. At the upper side of the lid, four threaded blind holes are located for a crane handling of the casks with load attachment devices. For the transport on public roads MOSAIK® casks as “Type B” package consists of the cask with an additional impact limiter system, which consists of a lid-end, an intermediate and a bottom-end impact limiter (steel construction filled with wood).

Table 1: Overview of MOSAIK® casks

MOSAIK®	**M II-12 T**	**M II-15**	**M II-15 EI**	**M II-15 U EI**
	Typ IP-2	Typ IP-2	Typ B	
Outer height (mm)	1500			
Outer diameter (mm)	1060			

Internal height max. (mm)	1220	1140		
Internal diameter max. (mm)	820	740		
Wall thickness (mm)	120	160		
Lead shielding min. - max. (mm)	-	0 - 120		
Empty weight approx. (kg)	4700	5730 - 9230		
Volume max. (dm³)	620	165 - 490		
Compatible with GNS facilities	FAFNIR MAVAK NEWA FAVORIT TROFA	FAFNIR MAVAK NEWA FAVORIT TROFA		KETRA FAVORIT
Options	Baffle plate Suction device	Baffle plate Suction device	Suction device	

4. 8.000 MOSAIK® casks delivered and no end in sight

Almost 8.000 MOSAIK® casks have been delivered to date. This underlines the success story of the best selling self-shielded nuclear transport and storage casks worldwide. MOSAIK® production began in 1980 with ten casks. And with a continuous annual production of 200-300 casks per year the MOSAIK® family will also maintain its leading position in the future. MOSAIK® casks provide a cost effective solution for challenging waste management tasks and will remain as a central tool to ensure the disposal for the waste from the dismantling of all German nuclear power plants. International customers in Switzerland, the United Kingdom, the Netherlands and Italy also rely on MOSAIK® casks.

Figure 6: Casting and assembly of MOSAIK® casks

5. MOSAIK® a reliable solution also outside of Germany

An important component of the success of MOSAIK® casks is that GNS is not only a reliable manufacturer for MOSAIK® casks, GNS has decades of know-how and expertise in processing, handling, transport and interim storage of MOSAIK® casks. Remarkable examples for GNS as a German radioactive waste management specialist outside from Germany are given by several projects in the Switzerland and United Kingdom.

Switzerland

After a first disposal project at the Nuclear Power Plant Gösgen in 2006, GNS was chosen for a further disposal project at the Nuclear Power Plant Leibstadt in 2010/11. GNS's task was to deliver MOSAIK® casks and to cut contaminated and activated components, such as control rods, water channels and neutron flux measuring lances, as well as loading and drying of the MOSAIK® casks. Due to high dose

rates of single components, disassembly has taken place under water in the nuclear fuel pool. It involved the use of an underwater shear developed by GNS.
In the course of disposal of radioactive waste from Swiss nuclear power plants drum packages have to be transported to the Swiss interim storage in the near future and subsequently to the Swiss final disposal. Therefore, the Swiss nuclear power plant operators rely again on GNS and the proven MOSAIK® concept. The drum packages with their radiological, physical and chemical characteristics are out of the scope of the German “Type B” approval, so in September 2017 GNS applied for a “Type B” approval in Switzerland. The approval will be granted shortly.

United Kingdom

<u>Draining resins at Sizewell</u>
A further remarkable example for GNS as a German radioactive waste management specialist outside from Germany is given by the project to empty the intermediate level waste (ILW) resin tanks at the Sizewell B nuclear power station. At Sizewell, as in other light water reactors, ion exchange resins are used in the primary coolant purification system to eliminate corrosion products from the reactor cooling water. When the resins are exhausted they are replaced, and the spent resins are transferred into a tank. As the radioactivity of the spent resins was low during the first few years of operation of the Sizewell B pressurised water reactor, they could be treated as low-level waste. However, when the activity levels rose, it was found that process applied to treat LLW was no longer suitable. Instead, tanks were built (total capacity 25m³) to store the spent resins.
In 2008/2009 when the first 10 m³ tank was completely filled, and the second 10 m³ tank was nearing capacity, British Energy (today EDF Energy) performed a Best Practicable Environmental Option study of different technologies to treat spent ion exchange resins. Both of the preferred options of the BPEO study have been developed and used in Germany. The first is hot supercompaction as carried out in Philippsburg. The second involves draining the resins, packaging the casks and removing their free water content, as operated by GNS at all other German plants. Five years ago, GNS was carrying out a resin treatment campaign using its FAFNIR and NEWA plants at Biblis in Germany and a group of British Energy employees flew in to see the technology in action. Agreeing to what they saw, British Energy opted for the second solution: draining resins in MOSAIK® casks.

Figure 7: In order to minimise handling times GNS FAFNIR® and NEWA® were placed very close to each other in the Sizewell B Radwaste Building (left). Lifting the closure lid before connecting a MOSAIK® cask to the GNS FAFNIR® facility (right).

The iLoc (interim stage Letter of Compliance) granted by RWM, the authority in charge of the Geological Disposal Facility, in March 2012 marked an important milestone of the project, being the first iLoC in more than 20 years in England and Wales. The iLoC confirms that (except for some minor action points which have to be addressed in the final stage) there are no reasons to assume that a package will not be acceptable for storage in the future GDF. This process included preparation of documents showing that containers used will withstand the assumed accidents and conditions, confirming the stability of the waste product, and documentation that the combination of container and waste product will not lead to undesirable effects. The fLoc (final stage Letter of Compliance) was finally granted by RWM in 2016. GNS delivered 55 empty MOSAIK® casks to Sizewell to take the resins, each with a capacity of 460 l. FAFNIR and NEWA, which had been delivered to Sizewell in five 20-foot ISO containers, were in place and the treatment of the resins from the tanks could begin. As this was the first time that the GNS plants would be operated in the United Kingdom, the Office for Nuclear Regulation and EDF Energy agreed that the whole processing of filling the casks using the FAFNIR kit and subsequently de-watering the resins using the NEWA would be tested on a limited batch of four MOSAIK® casks. This would allow confirmation that all of the processing steps were working reliably before bulk loading of the other 51 casks started. The treatment process works as follows. First, the resin is retrieved from the storage tanks and transferred into FAFNIR's dosing tank through the RTS (old and new pipework) by means of the station's pumps. In the dosing tank of the FAFNIR facility, the excess water is separated from the resins by a screen and recirculated into the station's system. After this initial pre-dewatering step, the water content will be around 50 weight % water (slightly less than in the storage tanks). Next, FAFNIR evacuates the MOSAIK® cask connected to it, and resin is extracted from the dosing tank into the cask. These three steps are repeated until the cask is filled to at least 90%. After this, the casks are disconnected from the FAFNIR and put aside for a week for the remaining free water to settle to the cask bottom. The casks are then connected to the mobile dewatering kit, NEWA. This facility evacuates a buffer cask, and then opens a valve connecting this buffer cask with one of the four resin casks connected to the NEWA. Thus, by means of the vacuum in the buffer cask any water that has settled is removed from the resin cask through a sieve at the bottom. This process is repeated until no significant amount of water can be extracted. Another week after dewatering the "Guarantee Measurement" can be performed, confirming that the objective of less than 1 % of free water in the package has been achieved. In 2014 with all 55 casks filled, FAFNIR and NEWA have been mobilised and removed from the station. Once starting the ILW Spent Ion Exchange Resin Long Term Solution Project to treat the resins at Sizewell B it took approximately two and a half months to complete. Failing to deliver could have caused an unplanned longer term outage at the Sizewell B site, where resin tanks were nearing capacity, only months later.

Vacuum drying at Bradwell

Forty-five miles south of Sizewell at the old Magnox site at Bradwell-on-Sea, GNS used a different technique to treat sludge and ion exchange material from two tanks to bring them into a condition that allows continued storage for decades and final disposal once the GDF opens. Similar to Sizewell, the waste's moisture content was too high and potentially could have lead to undesirable effects, especially gas generation. Vacuum drying technology that has been in use in Germany for more than two decades was used to treat the waste from the two tanks at Bradwell. The waste, which was difficult to characterize, contained a mixture of activation and fission products, including a significant Am-241 content. The GNS FAVORIT plant that was deployed to Bradwell is a vacuum drying/vacuum evaporator facility which is able to convey liquid waste, sludge and slurry into containers and dry them under vacuum at simultaneously elevated temperature. The evaporating water leaves voids in the containers which can be refilled with slurry and then dried again. This fill-dry-fill-dry circuit is continued until the

Figure 8: The GNS FAVORIT® plant ready to process ILW sludge in Bradwell's Circulator Hall 1.

container is filled 90 to 95%. Before the FAVORIT plant could start drying radioactive waste at Bradwell the suitability of the process for treating the waste had to be proved. Bradwell decided to do this by drying simulant material. In autumn 2013, after successful conclusion of the tests, the drying of radioactive material finally began. In total approximately 360m³ of waste was emptied into FAVORIT and dried into six MOSAIK® casks. This represented a volume reduction by a factor of more than ten. In parallel to drying the MOSAIK® casks, drums holding sludge samples were connected to the

FAVORIT plant to ensure that they were always exposed to the same pressure and relative humidity as the bulk sludge being dried in the MOSAIK® casks. As a result Magnox is able to prove that their proposed drying criterion of 5 % water in the package, which has been accepted by RWM Ltd, are not just met but exceeded. The remaining moisture content of the final waste product is proved to be less than 1 %. Encouraged by these results, the drying of ion exchange material from a second tank was started in 2015 and successfully concluded in 2016.

In the course of disposal of radioactive waste from British nuclear power plants Magnox relied upon GNS and the proven MOSAIK® concept. The waste with its radiological, physical and chemical characteristics is out of the scope of the German "Type B" approval, so in summer 2018 GNS has applied for a "Type B" approval in the United Kingdom. The approval is planned to be granted in 2019.

6. Approval Procedure and Testing

A separate set of regulations respectively must be complied with for transport, intermediate storage and final disposal. The analyses required in each case thereby constitute an independent type test. For instance, under transport regulations already, separate type tests are to be performed for Type IP-2 qualification certificate and Type B(U) approval. Since the package configurations in both cases are not as a rule identical (Type B is transported with an impact limiter and Type IP-2 without an impact limiter), successful Type B(U) approval does not automatically cover all the framework conditions required for Type IP-2 packages. If further rules and regulations are now to be observed, such as for example for final disposal of the type, separate type tests are also to be performed for this purpose.

Drop tests for Typ B(U)-certificate

The type tests required for this purpose, including drop tests from 9 m, were already successfully performed in the past. In order to take account of the increased requirements for safety analysis documentation in the course of technological progress, GNS has developed a new impact limiter in 2013 that substantially reduces the deceleration occurring on impact. This results in greater safety margins in design and will make future deployment of the MOSAIK® casks as Type B(U) packages possible in the long term.
The type test for extension of the Type B(U) approval was conducted based on numerical calculations. Since the newly developed impact limiter displays a number of substantially modified design features compared to the previous version, experimental validation of the calculated decelerations was required. This involved three drop tests at different orientations (lid side, horizontal and corner) from a height of 9 m onto an unyielding target according to the specifications of the IAEA. All three tests were performed with the maximum permitted package mass. The horizontal drop and the drop on the corner were performed at ambient temperature. The drop on the lid side was performed at a package temperature of -40°C. Local acceleration values were determined both on the cask body and on the lid and likewise at selected points of the impact limiter system. It was furthermore possible to track the rigid body deceleration of the entire package and the cask body by means of a high-speed video system. Finally, the strains occurring were determined using strain gauges at selected points, particularly at the screws and also the retaining rods of the impact limiter system. The measured decelerations and deformations of the impact limiter indicate a good level of consistency with the previously calculated values. These subsequently also served as initial values for the further numerical calculations of the stresses in the cask body and lid system. These calculations had already been validated by previous tests with MOSAIK® and CASTOR® casks.

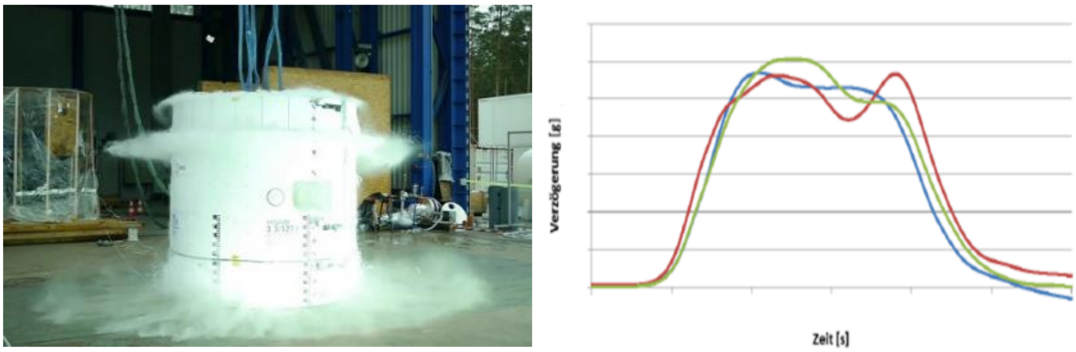

Figure 9: Drop test and resulting decelerations

In summary, it can be stated that the drop test series in summer 2013 was a complete success and it was possible to prove the safety of the package with the current status of technology.

Drop test for Type IP-2 qualification certificate

GNS follows a systematic approach to verify the underlying proofs (Type IP-2 and Type B) according to the current state of the art. This leads to a continuous optimization of the cask and the underlying proofs. For instance the Type IP-2 qualification certificates for the MOSAIK® casks were based on numerous drop tests, conducted in the eighties and nineties. To secure the Type IP-2 qualification certificate for MOSAIK® casks, a drop test (0.8m, -20°C) according to the state of the art requirements was conducted. The horizontal drop test on an unyielding target was carried out with a positive result in January 2018.

Figure 10: Drop test and high speed image

Fire tests (800°C, 1h) for German final repository (Konrad)

In the past, account was taken of the thermal incident of IAEA SSR-6 [1] in developing cask types that were also intended for use as Type B packages. This calls for proof of safe inclusion of the inventory under the influence of a fire scenario of 30 minutes' duration and a temperature of 800°C. This case was successfully demonstrated in particular with the aid of the thermal insulation of the impact limiter. In contrast, the requirement of the Konrad repository with a fire duration of one hour at an identical temperature of 800°C poses major challenges for the packagings. Particularly since no credit can be taken in this case from the insulating effect of the impact limiter only installed during transport. Nevertheless, the tested cask type, in this instance a MOSAIK® II-15, must fulfil the requirements of the Konrad repository conditions in terms of tightness and the maximum possible pressure accumulation.

The thermal incident under the Konrad repository conditions describes a fire lasting one hour at a temperature of 800°C and a subsequent 24-hour cooling phase. Throughout the total 25-hour duration of the test, neither may the maximum pressure of 15 bars be exceeded, nor may a sudden pressure drop occur. Furthermore, the required leakage rate must not be infringed after the cooling phase. In order to fulfil the required framework conditions, a large number of calculations were performed that indicate the maximum temperatures at the crucial points of the cask, such as the sealing system and the inventory. During these calculations, it was apparent that a completely unprotected cask fails to fulfil the requirements imposed for the Konrad repository. Consequently, GNS has developed a protection component that forms an effective insulation against the flames. During the development of these components, calculations have shown that the temperatures in the crucial areas can be reduced such that the aforementioned criteria regarding tightness and pressure accumulation are reliably fulfilled. A fire test with a MOSAIK® II-15, which was equipped with the new protection component, was performed in autumn 2014 in order to verify the calculations. In doing so, the temperature both on the surface and inside the cask and in addition, particularly in the sealing area and inside the simulated waste, was measured. Furthermore, continuous pressure monitoring was performed inside the cask during the fire and cooling phase. The fire test was able to show that the pressure increase with the chosen simulated waste was on an order of magnitude less than the stipulated 15 bars. Moreover, it was even possible to some extent to undershoot the previously already calculated low temperatures. The tightness tests performed following the cooling phase were accordingly successful as anticipated.

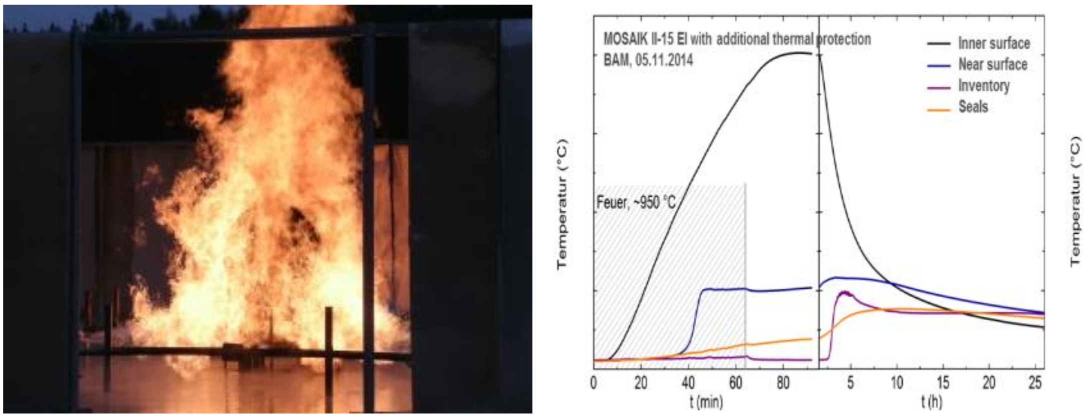

Figure 11: Fire test and resulting temperatures

In 2018 the fire test was repeated within the approval process for the final repository and lead to identical results.

7. CONCLUSIONS

With almost 8.000 MOSAIK® casks delivered to date it is the best selling shielded nuclear transport and storage cask worldwide. MOSAIK® casks provide a cost effective solution for challenging waste management tasks and will remain as a central tool to ensure the disposal for the waste from the dismantling of all German nuclear power plants. The test programmes with regard to transport regulations and the requirements of the Konrad repository demonstrate that the MOSAIK® cask is a state of the art product combined with a long-term experience in practical usage.

International customers in Switzerland, the United Kingdom, the Netherlands and Italy also rely on MOSAIK® casks. Especially in the United Kingdom and Switzerland MOSAIK® casks play an important role evidenced by, amongst other things, applications for granting a "Type B" licence for customer-specific waste streams which are not covered by the already existing German Type B(U) licence (Switzerland granted 2018, UK planned 2019). The success of the MOSAIK® is not only demonstrated in the number of sold casks or Typ B approvals but also in practical usage for example in Gösgen and Leibstadt (both Switzerland) as well as Sizewell, Bradwell and Sellafield (United Kingdom).