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NUCLEAR POWER PLANT WASTE MANAGEMENT STRATEGY IN GERMANY

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ABSTRACT

The shut-down of eight nuclear power plants and the phase out of the nuclear energy generation in Germany, due to a decision of the German government after the Fukushima accident, has rapidly forced the need for transportation and storage of spent nuclear fuel (SNF) from shut-down reactors in this country. In accordance with the present strategy in Germany, which is characterized by searching for appropriate final repository areas, only the dry interim storage facilities are available for storage nuclear waste of the decommissioned plants as well as the operating plants. Therefore, the transportation and the storage casks must be available for both types of light water reactors. But for the time being this is the bottleneck. Unfortunately the prognoses are neglecting the fact, that such a high number of casks are needed in a very short space of time. This requires the acceleration of formal activeness in relation to the licenses but also an increase of the production. In the meanwhile to get this process started, the only possibility is the storage in the pools at the plant site. Anyway, for the time being, this is one of the problems for dismantling the eight plants which have been shut down due to the decision of the Government, which is now fixed in the last amended German Atomic Energy Act dated 24th of February 2012. Starting to dismantle in the radioactive regions of the plants requires empty pools. For emptying the pools of damaged SNF special procedures regarding the transportation and storage are necessary. The transportation of damaged SNF requires special casks or at least special procedures and therefore also a special licenses.

This paper describes the challenge for the management in transportation and storage of SNF in Germany after the shut-down of the nuclear power plants by reason of the Fukushima accident.

INTRODUCTION

The Fukushima Daiichi accident on 11th of March 2011 was the date for rapid changes in the German politics regarding electric power generation. Two independent expert commissions, the Reactor Safety and the Ethic Commission, were established carrying out the robustness of the German nuclear power plants /1/ and Germany’s energy transitions /2/. The reactor safety commission (RSK) has conducted their statements about the robustness of the German plants in comparison to the knowledge of the Fukushima accident available at that time. A total mirroring of the Fukushima events to the German NPP is not reasonable.

For the decision of the classification of the robustness levels, the RSK has defined safety relevant events which may be possible in Germany as shown in table 1 in comparison to the Fukushima events. The basic level zero for the different events was the state of the art at the date of licensing of the individual plant. A higher grade of event means a higher level of robustness. In addition to the Fukushima events the RSK has evaluated man-made hazards like aircraft crash, blast waves and toxic gases.

Table 1: Fukushima events versus robustness check-up

Fukushima Events		**Robustness examination of the German NPP (Questionnaire)**
Natural hazards		
Earthquake	➡	Earthquake
Tsunami	➡	Flooding
		Man-made hazards
		Aircraft crash
		Blast waves, toxic gases
Robustness of precautionary measures Independent of specific event sequences		
Station Black Out	➡	Station Black Out
		Long-lasting loss of offsite power
		Loss of service water supply

Regarding these events the following examination of general safety objectives of German NPP about:

- reactivity control,
- cooling of fuel assemblies in the reactor pressure vessel **as well as in the spent nuclear fuel pool** and
- limitation of the release of radioactive substances (keeping up barrier integrity)

should be fulfilled in the event of impacts beyond the design requirements.

The level of robustness of a NPP as high or low depends on the management of aging effects during service life as well as the maintenance for decreasing the failure rate during that time. The well-known bathtub diagram describes this situation during the life of a technical component in general (Fig 1). As shown in the diagram the initial region of failures begins at time zero when a customer uses the product firstly. This beginning is characterized by a high but rapidly decreasing failure rate. This region is known as the early failure period (also referred to as Infant Mortality Period). This decreasing failure rate typically lasts several weeks to a few months.

In the subsequent region, the failure rate levels off and remain roughly constant for (hopefully) the majority of the useful life of the product. This long period of a level failure rate is known as the intrinsic failure period (also called the stable failure period or a constant random failure rate). Fortunately most systems have their operating timers in this flat portion of the bathtub curve. In this lifetime of a component also periodically in-service inspection procedures are carried out like the application of non-destructive testing methods. That is part of the life time management.

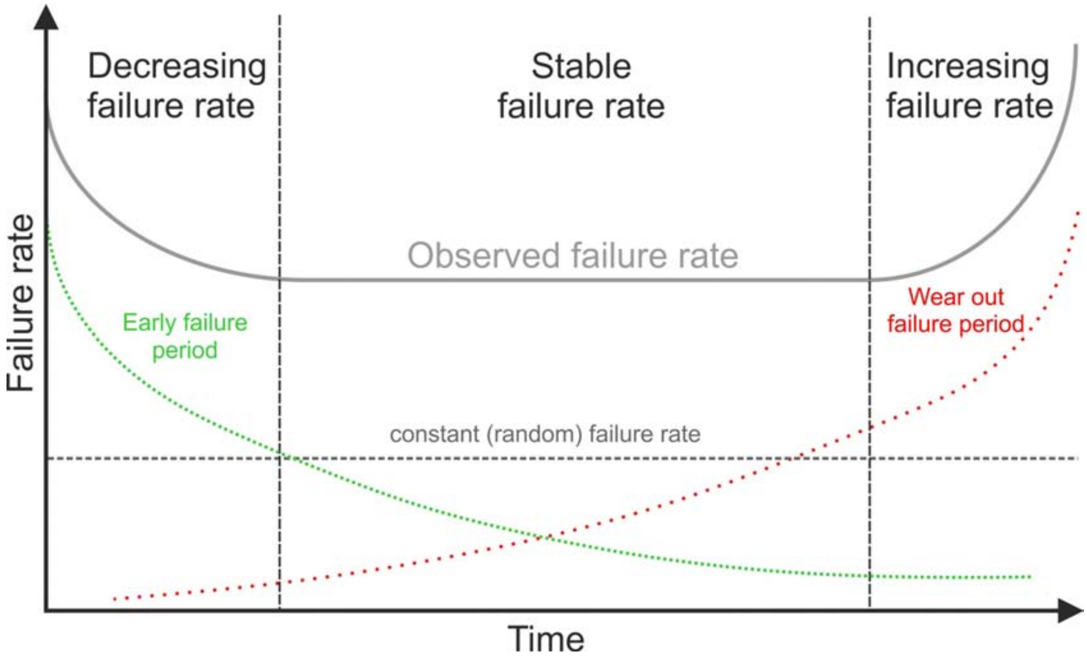

Fig. 1: Failure rate versus the life time of a component

Finally, if units from the population remain in use long enough and aging mechanisms occur, the failure rate begins to increase as materials wear out and degradation failures come into existence at an ever increasing rate. This is the Wear out Failure Period. In this lifetime some repairs or the exchange of parts of the components are required; this is the period of extensive maintenance.

The NPP which have been shut down in August 2011 were in accordance with Fig. 1 in the region between phase II and phase III. In some of these plants huge maintenance activities were carried out in the past. Nevertheless all this management decisions in the past do not help to solve the present problem to emptying the SNF pools soon by shipment of the SNF to an interim storage facility which is ideally placed on plant site. One of the reasons is the lack of shortly available containers.

WASTE MANAGEMENT ON PLANT SITE

The shutdown of eight nuclear power plants in Germany with the deadline of the 6th of August 2011 was not only a challenge for the utilities in the energy supply but also a challenge for the nuclear waste management especially for the SNF present at that time on site /3/. By the way, the German government calls the time after the shutdown of these eight plants and the general nuclear power phase-out an energy turnaround. This is the realization of a sustainable energy supply in the future which includes the renewable energy generation by wind, solar and biomass. The political future of the Renewable Energy Sources Act – EEG is as follows /4/:

- a sustainable development of energy supply
- to reduce the costs of energy supply to the national economy
- to conserve fossil fuels and

- to promote the further development of technologies for the generation of electricity from renewable.

Nevertheless, the phase-out is one part; the other part is the management of the existing nuclear waste. Initially Germany has established centralized dry interim storage facilities but after a transport ban this has been changed to the establishment of on-site storage facilities at each NPP site. At the same time investigations at the Gorleben salt dome with regard to its suitability as a final repository was stopped by a memorandum on 1st of October 2000. The operation of the first dry interim storage facility started in November 2002 (see table 2)followed by another eleven on-site storage facilities. Generally storage licenses are limited to 40 years /5/. in Germany and the choice of the cask materials, the dewatering and the drying of the casks, the leak tightness procedures and other handling activities during the storage are designed and manufactured for the required 40 years /6/. After that time it is foreseen that the content of these interim storage casks is reloaded into casks developed for the repository or the present interim storage casks are used after toughening and qualification for this purpose. Based on table 2, the first on-site interim storage license expires is in 2042 (Lingen) whereas licenses of the centralized storage facilities expire already in the 2030's. Policy so far assumed to have a high level waste repository available until that time.

Table 2: Interim storage facilities in Germany /BMU/

Location	Status		Capacity # of places	Occupied # of places	Capacity Mg of HM	Date of license	Date of implementing
	Plan.	Appr.					
Biblis		X	135	46	1400	22.09.2003	18.05.2006
Brokdorf		X	100	13	1000	28.11.2003	05.03.2007
Brunsbüttel		X	80	6	450	28.11.2003	05.02.2006
Grafenrheinfeld		X	88	13	800	12.02.2003	27.02.2006
Grohnde		X	100	13	1000	20.12.2003	27.04.2006
Gundremmingen		X	192	25	1850	19.12.2003	25.08.2006
Isar		X	152	22	1500	22.09.2003	12.03.2007
Krümmel		X	80	19	775	19.12.2003	14.11.2006
Lingen		X	125	32	1250	07.11.2002	10.12.2002
Neckarwestheim		X	151	36	1600	22.09.2003	06.12.2006
Obrigheim	X		15	15			
Philippsburg		X	152	36	1600	19.12.2003	19.03.2007
Unterweser		X	80	7	800	22.09.2003	18.06.2007

SPENT NUCLEAR FUEL POOLS

Nevertheless, for the transportation between nuclear power plants and storage facilities the waste must be loaded into approved casks - in Germany dry storage is required. In the past the utilities have managed this part in the frame of the plant life management (PLiM) which comes up in structured manner with the beginning of a long-term operation of the NPP. /7, 8/. So far it is common practice that SNF is stored inside the NPP pools before transportation until its decay heat declines to a decay heat level lower or equal to 39 kW (valid for Castor®[1] V/19 (19 SNF) and TN 24 (21 SNF)) whereas the maximum of a single fuel rod is given by 3.5 kW. Depending on these decay heat values, SNF removed from the reactor pressure vessel core is usually stored in the SNF pools for some years. After that time dry storage in a cask

[1] **Ca**sk for **S**torage and **T**ransport of **R**adioactive material (CASTOR)

and transportation to the interim storage facility is destined. In the present situation in Germany, after the decommissioning of the eight nuclear power plants, the management must solve the storage problem in the pools which are more or less full of SNF. This cannot be carried out successively anymore as done by operating plants, but rather immediately. The pools are full due to the circumstances that only free capacity for a complete core is required /5/. This space is now used for the removed core at most of the eight shut down plants and is a challenge in the nuclear waste management, because the waste management strategy has not foreseen emptying the pools at the same time for such a high number of plants. During dismantling, the NPP must be free of nuclear inventory including the SNF, i.e. starting dismantling is only possible with an empty pool. This requires the availability of casks for the transportation to the interim storage facilites. Due to the high number of plants which have been shut down in August 2011 casks with valid licenses for transportation of Boiling Water Rector (BWR) fuel are strongly needed. The total numbers of required casks for the eight NPP are listed in table 3 /9/.

Table 3: Number of needed casks for the eight NPP shut down in August 2011

Nuclear Power Plant	**# of Casks** (Type of CASTOR ®)
Brunsbüttel (BWR)	13 CASTOR®V/52[1)]
Krümmel (BWR)	22 CASTOR®V/52[1)]
Unterweser (PWR)	31 CASTOR®V/19[2)]
Biblis A (PWR)	24 CASTOR®V/19[2)]
Biblis B (PWR)	27 CASTOR®V/19[2)]
PhilippsburgBlock 1 (BWR)	18 CASTOR®V/52[1)]
Neckarwestheim Block 1 (PWR)	18 CASTOR®V/19[2)]
Isar Block 1 34 (BWR)	34 CASTOR®V/52[1)]

[1)] License not available for transportation and storage
[2)] License at the present only available for transportation

Further the pools of BWR come into focus, because those reactors have the pools outside the containment and have therefore a higher risk potential in case of aircraft crashes. It is noted that - for the time being - neither for the cask transportation nor for the cask storage, a valid licenses are available. Therefore a longer wet storage period as expected has to be assumed. Anyway, the necessary cooling capacity for the storage pool must be available as required and approved. That is also valid under the aspects of the events used for the robustness check of the NPP in Germany, i.e. the cooling of the pool must be guaranteed also after nature events like earthquakes or flood but also after man-made hazards. Risk of pool storage are described for the United States in /10/ where 75% of the SNF are stored inside pools. The scenario discussed is the loss of cooling water and the consequence of high radioactive material release due to potential overheating, fire and hydrogen explosion as it destroyed the reactor building of Unit 4 of Fukushima.

All cask licenses of for the transportation and storage of SNF are limited to a certain decay heat level and to minimum burn-up. But nowadays SNF with only 11 to 300 days of burn-up (see Table 4), thus SNF with a very low burn-up have to be managed together with those elements that have a high burn-up. The burn-up of SNF inserted during the last refueling is in the range of a few hundred to a few thousand MWd/tHM. This means that, compared to the target burn-ups of 40.000 to about 65.000 MWd/tHM, the burn-ups achieved are significantly lower /5/. As a basic principle, a mixed loading of low burn-up fuel assemblies and those with a high burn-up might be possible regarding the decay heat, the radioation and other safety relevant parameters but licenses have to be adapted to such mixed loadings.

Another well-known problem which has forced the discussion after the shutdown of the plants is the handling of damaged spent fuel rods and assembles. Is it necessary to handle those rods separately or is there a possibility to store them into a cask together with regular fuel assemblies? So far, this discussion is still going on and options have their specific advantages and disadvantages. The separate handling of a damaged SNF rod, using a special containment, is described in /11/. Packaging the damaged fuel rods into a regular cask designed for SNF demands special receptacles with the geometry of a SNF, but such a solution has to be developed and applied for.

Table 4: Overview; new SNF at the plants shut down August 2011 /5/

Reactor type	Plant	Location	max. enrichment	# of new SNF	Out of operation
BWR	KKB	Brunsbüttel	4,02%	76	18.07.2007
BWR	KKK	Krümmel	4,00%	104	04.07.2009
PWR	KKU	Unterweser	4,40%	40	19.03.2011
PWR	KWB-A	Biblis	4,00%	44	19.03.2011
PWR	KWB-B	Biblis	4,00%	92	26.02.2011
BWR	KKP-1	Philippsburg	4,40%	112	16.03.2011
PWR	GKN-1	Neckarwestheim	4,40%	40	16.03.2011
BWR	KKI-1	Isar	4,70%[1]	136	18.03.2011

[1]max. value, the mean of all fuel rods into a SNF

The first method, transportation of a fuel rod, has the advantage that the license for this special container still exists. For the second possibility, fuel rods in a special designed receptacle, the license does not exist but the advantage is that the storage in the interim storage facility can be managed as usual and carried out as ever. Due to the currently not existing solution to remove all SNF from the shut-down NPPs, wet storage will take longer than probably expected from the phase out decision makers in May 2011. The nuclear inventory is still in the plants and decommissioning of the plants becomes farer. The only positive aspect might be the limited total amount of the SNF in Germany. On the other hand problems arise due to the fact that this technical field is not attractive anymore for young engineers and scientist. In addition, the motivation of remaining and older staff members in operating plants decreases continuously. The Reactor Safety Commission has picked up this problem in a memorandum titled: Treat endangerment of the nuclear safety due to loss of knowledge and motivation, dated 12th July 2012 /12/. This memorandum is addressed to the German utilities, the politics and the media scene. Anyhow, it is very difficult to get a feedback from those stakeholders. An objective evaluation of the motivation loss of the plant staff is very difficult. Therefore only subjective data are available based on personal contacts. Nevertheless, the discussion about further safe operation of the SNF pools, the criticality issues in the pools regarding SNF with sometimes very different burn-up, damaged spent fuel rods and the discussion of lost water-levels in the pools are still going on. The safety of the SNF pools is also part of the discussion of the Reactor Safety Commission about the robustness of the German NPP /1, 13/.

EXTENDED INTERIM STORAGE IN GERMANY

Transportation of SNF in Germany was always accompanied by very active protesters along the whole transportation route and security had to be guaranteed by thousands of policemen resulting in high costs for the German taxpayer. Such effort is avoided in case of in-house transportation only to an adjacent on-site interim storage facility (Fig. 2).

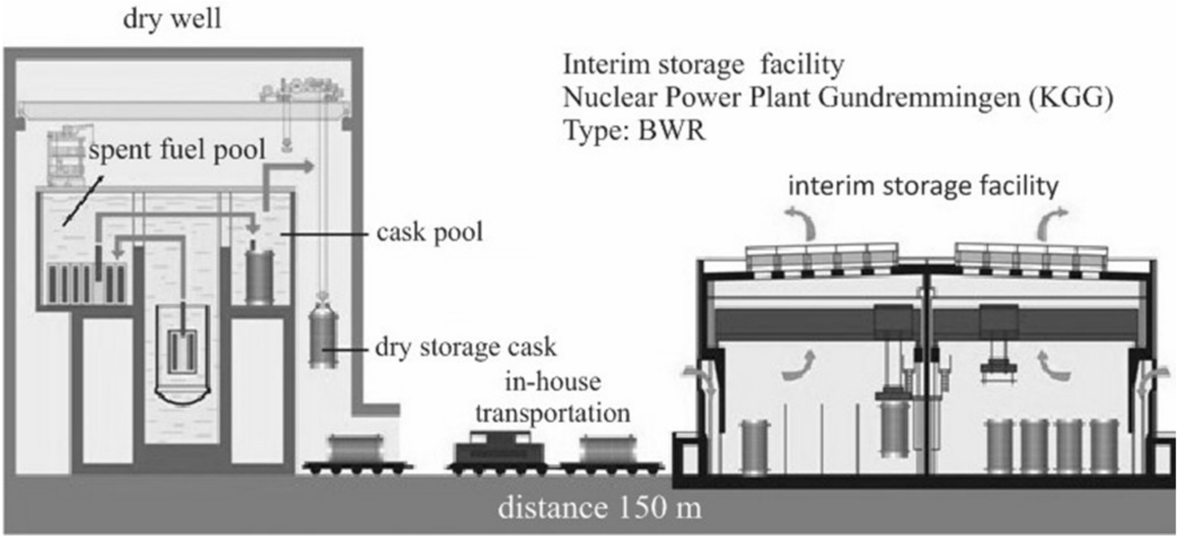

Fig. 2: Interim storage facility on plant site

Interim storage facilities for SNF and other heat-generating radioactive waste are licensed and operated on the basis of a license of the German Atomic Energy Act (AtG) /3/. The storage license is currently limited to 40 yearsWith the German decisions about a restart of the siting procedure by a new law to find the best place for a repository for high active waste major delays have to be considered until a repository will be ready to operate. Therefore life time extensions of the interim storage facilities are an upcoming challenge. This forces a modification of the interim storage ageing management in relation to the established plant life management (PLiM) /7/. PLiM means the overall management starting from the components and their ageing management until economic aspects and asset management (Fig 3). Ageing management is a big tool and embraces a lot of activities to overcome the ageing mechanisms /14, 15/. These are as follows:

- physical and chemical aging through loads and environment conditions
- technological aging through change of knowledge
- conceptual aging through change of requirements or specifications.

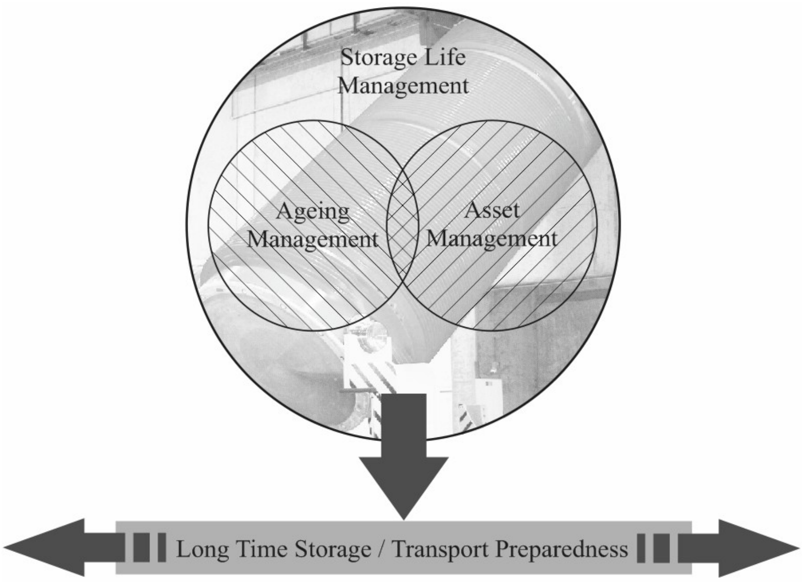

Fig. 3: Storage Life Management

The physical loading is related to mechanical damage of parts of the cask e.g. due to the handling and/or thermal effects. The focus on environmental or chemical loadings will be on corrosion phenomena. The life time extension of interim storage requires a system analog to the PLiM, i.e. a storage life time management (SLiM). Also for SLiM the ageing management is a big part of the management task. The definition of ageing is the time dependent change of functional related properties of technology (mechanical components, safety functions, constructional installations, instrumentation and control components), i.e. the relevant systems for storage management, specifications and documentation data, as well as the facility operating staff /16/. In the present contribution the ageing management will concentrate on the containment systems loaded with SNF or other heat-generating radioactive waste which must guarantee sufficient resistance against mechanical and chemical loadings during storage. Furthermore the transportability must also be ensured at any time for later removal e.g. to a final repository /6, 17/. Nevertheless, the ageing management is not only prevention to physical influences like damage mechanism as embrittlement due to irradiation, corrosion or fatigue but also on the evaluation of codes and the development on safety confirmations. If based on new evaluation and calculation methods a replacement e.g. of trunnion or new shock absorbers are required. This should be possible without certain changes of the loaded cask.

The requirement of the all-time shipment preparedness demands in-service inspections of the safety relevant components for shipment. The examination of the resistance of the casks against mechanical and thermal loading is only possible by knowledge of the mechanical properties of the materials existing at the time of the design and the surveillance of temperature and damage during operation and their documentation during storage. These aims can only be fulfilled by the application of monitoring systems and in-service inspection methods. Such an in-service inspection method is the periodically visual inspection of the casks in a direct or indirect achievement /18/. Fig. 4 shows the sketch of these two types of visual inspection possibilities. Visual examination means, in principle, inspection with eyesight. In the case of non-destructive testing (NDT), visual inspection has a much broader meaning. There are differences in the aim of the visual inspection if:

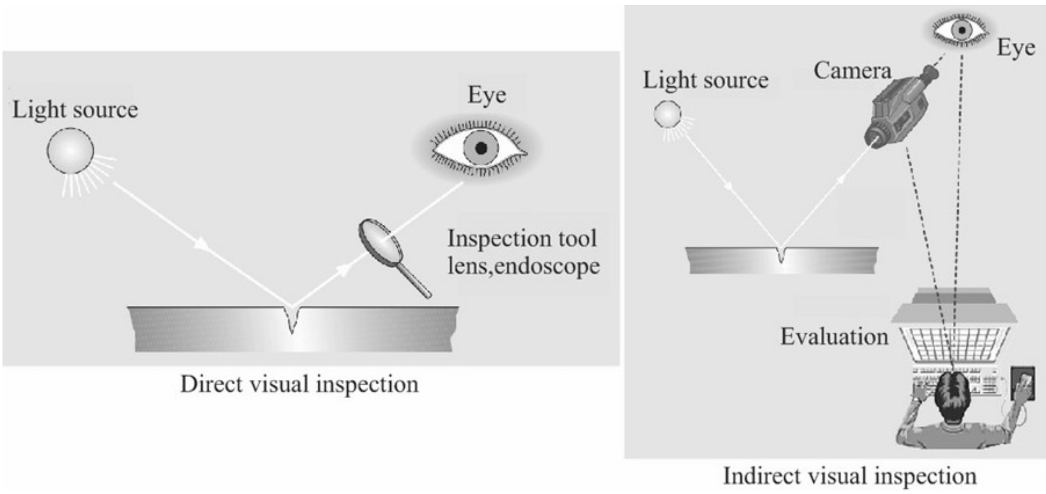

Fig. 4: Principles of visual inspection methods

- only surface characteristics, such as scratches, wear or corrosion phenomena are of interest, or
- detection of cracks or deformation is included.

For the storage casks the first bullet is important, considering that some of the mentioned damageing mechanisms might occur. The second bullet might be of interest after cask handling procedures. In most of the cases the direct visual inspection is easily applicable and can be performed periodically, e. g. every ten years at a representative number of casks during storage. Indirect visual inspection methods, as widely used for inspection of NPP, are applicable if needed, e. g. to demonstrate proper cask conditions in case of extending storage licenses beyond 40 years. Bases of those kinds of techniques are manipulator supported camera movements to the area of interest. An example of a typical direct inspection is presented in fig. 5 left.

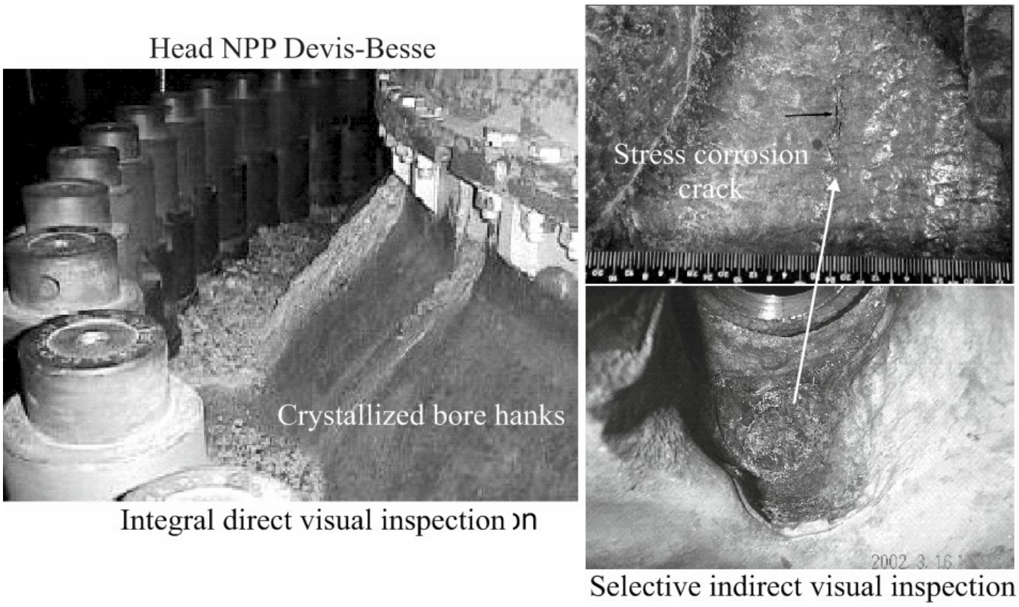

Fig. 5: Detection of damaged area and a crack employing visual inspection methods

Clearly recognizable are the bore acid hanks starting at the upper parts of the dome of the reactor pressure vessel (RPV). An example of an indirect method is demonstrated at the right side in fig. 5. This picture shows the source of the bore acid, a stress corrosion crack into the stainless steel cladding of the dome of the RPV. Very clear recognizable is the missing carbon steel in this damaged area. The pictures demonstrate the possibility of a visual inspection procedure in a nuclear environment. Sometimes manipulator devices are needed for the inspection but such tools are widely spread in the technical field, e.g. for the inspection of the pipes in NPP. Such manipulator devices are adaptable to the interim storage facility conditions.. The advantage of such a system is that the inspection data can be stored and furthermore used to compare these data with those received by the next inspection (maybe 5 years later). By that way, differences between these two inspections can be found

CONCLUSIONS

The German phase out decision about the nuclear energy generation in Germany after the Fukushima accident has rapidly forced the need for transportation and storage of SNF from shut-down reactors to interim storage facilities. Especially the SNF pools of BWR come into the focus and clearing of those pools is one of the major nuclear waste management challenges for the time being. Therefore a significant number of additional casks is required but neither licenses for transportation as well as storage nor enough fabricated casks are available in the short-term. Major issues in this context are storage of SNF with very different burn-up as well as the storage of damaged SNF rods. To enable loading with SNF not having reached at least the minimum burn-up yet, modifications of the certifications and storage licenses are required or the possibility of individual proofs must be provided. This mixed loading of a cask was not intended in the licenses for transportation and storage so far.

Other management tasks are due to the fact that a repository for HLW is far away. The discussion about possible and suitable sites and to agree a widely accepted procedure is still going on. Therefore the need for extending interim SNF storage beyond 40 years is obvious. Analog to the NPP, where the Plant Life Management (PLiM) for safe long-term operation was established also the life time extension of the interim storage should be managed. Hence a Storage Life Management (SLiM) must be developed and established in due time.

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