Radiological Characterization and Conditioning of Operational Waste from the Reactor Pressure Vessel

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1. Introduction

During the course of a conditioning campaign of operational waste from the reactor pressure vessel, carried out from mid-September 1997 to mid-May 1998 at the Mühleberg nuclear power plant (KKM), spent fuel channels, detector assemblies, filter cartridges, small activated items and shroud head bolts were decomposed - with the aid of cutting devices where feasible or necessary - and packed into cages which were put into 200-liter-drums and grouted with cement.

As one of the most important steps in the clearance of conditioning procedures, it was necessary to determine the nuclide inventory of the different wastes in advance. This was done using a calculation procedure which was to be validated on the basis of analyses of fuel channel samples collected in an earlier conditioning campaign. Once the calculation code has been successfully validated, it will be possible to use it for characterizing all other activated components from the reactor pressure vessel (with the exception of neutron absorbers). Costly sampling and analysis of such reactor internals will thus be unnecessary in future.

2. Conditioning

Wherever possible, the equipment for conditioning fuel channels, already used in 1991 and 1992 and described in [1], was used for conditioning various raw wastes. Key components of this waste handling equipment are a shielding dome and a grouting container, which are the joint property of the Leibstadt and Mühleberg power plants.

While the procedure for treatment of the raw wastes to be packed into cages is dependent on the waste type, further handling of the filled cages is basically the same for all waste types. The filled cages are removed from the water using a shielding dome and placed in a 200-liter drum, which itself is inside a shielding and transport container. Depending on their contents, the cages may be equipped with a holding-down mesh to prevent components from floating up during grouting. The shielding/transport container is brought to the shielded grouting container and opened remotely. The drum inside is then filled with a cement mixture prepared outside the controlled zone and sealed. Subsequently it is transported to the interim storage facility, where it is taken out of the shielding container and placed in a storage hall.

For technical reasons, inactive cement residues are left behind in the grouting facility; during cleaning these are led off to a settling tank. This is emptied regularly using a silo vehicle. The cement slurry, which constitutes special waste, is transported to a waste management company which disposes of it in an environmentally sound way.

2.1 Treatment of fuel channels

For cutting the fuel channels, the same underwater shear which had already been employed at KKM in 1991 and 1992 was used. This equipment was rented from the Gundremmingen power plant and operated by Noell-KRC, Würzburg. As the procedure for conditioning fuel channels has already been outlined in detail (see [1]), no description will be given here of the process of cutting and packaging the cut material into the cages. As can be seen in Fig. 1, the surface dose rate of the channels is similar to that in previous conditioning campaigns.

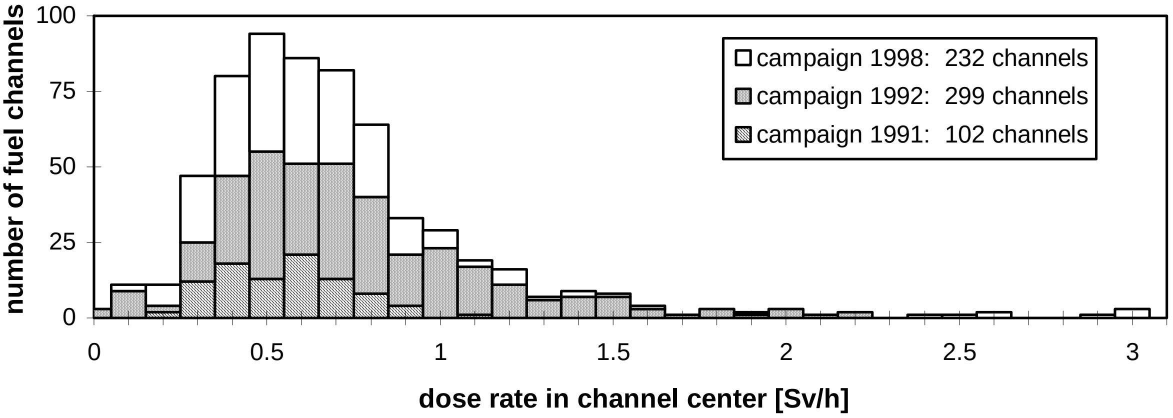

Fig. 1 Surface dose rate for the fuel channels conditioned in the 1991, 1992 and 1998 campaigns

2.2 Packaging of detector assemblies, small items and filter cartridges

A detector assembly is basically an approximately 13 meter long stainless steel tube of varying thickness, the upper part of which houses the detectors for neutron flux measurement and projects into the reactor core during operation. Using a small hydraulic shear, the weakly activated part of the assembly (approx. 8 m) is cut in the fuel element storage pool into pieces around 65 cm long and these are packed underwater into stainless steel cages. The cutting length is controlled by means of a groove-stopper on the shear and the assembly is held between the jaws of the cutting equipment by manual grippers. To make filling easier, the cage can be tilted by 30°. The strongly activated part of the assembly, with the detectors, is kept in special containers in the fuel element storage pool for later conditioning.

Filters consisting of several filter candles and a housing, which together make up a filter cartridge, are dismantled wherever possible and the housing components decontaminated. If dismantling is not possible, the complete cartridge is placed in a stainless steel cage. Individual candles are sorted in an upright position into stainless steel cages. To prevent the candles from floating to the surface in the fuel element storage pool, they are filled with activated stainless steel metal components; small items (generally loaded into separate cages) such as the screws from the fuel channels are ideal for this. Candles with different diameters are placed inside one another wherever possible.

2.3 Sawing the shroud head bolts

For sawing the shroud head bolts, which are kept in the fuel element storage pool, underwater procedures and procedures outside the fuel storage pool were evaluated. Radiological measurements on the bolts indicated that both direct radiation and aerosol-borne contamination of the working area could be kept under control by applying additional handling and shielding measures above water. Since processing outside the storage pool allows costs to be reduced by a factor of 2 to 3, ultimately only dry cutting methods were investigated. Based on the infrastructure available at KKM, a remote-controlled band-saw was selected.

Bolts are 4500 mm in length and weigh 160 kg. They are composed of a stainless steel cylinder and a core of inconel 600. The first step in the sawing procedure is to remove the bolts from the fuel storage pool. After being allowed to drip-dry, they are packed in shielding (lying horizontally) directly next to the pool. This shielding can accommodate two bolts. One side of the shielding projects into a work tent which has a ventilation system equipped with filters. The bolts are pushed using rods over the cutting length of 75 cm up to a groove-stopper and then stopped and sawed.

The bolt pieces are shielded inside the work tent and placed in a 200-liter-container, which contains a perforated inner cage. This is used for fixing, to maintain a 2 to 3 cm thick layer of inactive filling mortar between the bolt pieces and the inside of the container.

A filled container is grouted using the procedure described above and transported to the interim storage facility.

3. Activation calculations - method and results

Activation calculations are generally carried out with the well-known ORIGEN code [2], using cross-section libraries based on neutron flux spectra within the fuel. For activation of structural materials, however, this code shows marked deviations from measurements. In particular, the inventories of fission products and actinides generated by fission and activation of uranium and (to a lesser extent) thorium impurities are severely underestimated.

Nagra runs a PC-compatible code developed in cooperation with GRS [3], which allows reliable characterization of a wide range of reactor internals. The new code basically consists of a version of ORIGEN which runs with three condensed group cross-sections in the thermal, epithermal and fast region of neutron flux. However, these group cross-sections are generated with the neutron flux outside the fuel, which is not subjected to self-shielding or resonance absorption within the fuel.

Extensive analyses performed on fuel channel pieces from normal reactor operation made it possible to validate the new code. Table 1 shows the ratios of measured and calculated activities for some important fission products and the sum of actinides. The results are based on measured impurities of

Tab .1 Comparison of measured and calculated activities

Nuclide	Activity ratio Measurement/Calculation
^{90}Sr	0.82 ± 0.20
^{99}Tc	1.13 ± 0.15
^{137}Cs	0.89 ± 0.13
$\Sigma\alpha$	0.82 ± 0.16

1.5 ppm (0.4 ppm) uranium (thorium) in the structural material. Errors are 1σ deviations, taking into account measurement errors and uncertainties in the calculations.

These results made it possible to validate the new code, even to the extent of determining the nuclide inventories of the structural material of all reactor internals except neutron absorbers. Due to the separation into three groups of neutron fluxes, the calculations can be adapted to meet the prevailing spectral conditions. In the future, costly sampling and measurements on activated reactor internals will thus be unnecessary.

4. Conditioning work and experience gained

Given the possibility of calculating the nuclide inventories of reactor internals, which differ significantly in terms of material composition, positioning in the reactor pressure vessel and irradiation time, the clearance for conditioning was conducted simply and without delay.

During the 1998 campaign, a total of 68 drums containing grouted waste were produced. Table 2 provides an overview of the conditioned wastes, as well as a selection of relevant data on the resulting waste packages.

Table 2 Waste packages produced in the 1998 conditioning campaign

	Fuel channels	Detector assemblies	Small items from RPV	Filter candles	Shroud head bolts
Raw waste - total processed	232	415 m	640 kg	200[1]	52
Raw waste per package (average value)	5.95	138 m	213 kg	20	4
Number of packages	39	3	3	10	13
Total weight per package [kg]	630	662	671	481	907
γ- surface dose rate [mSv/h]					
average	664	39	960	690	5
maximum	1400	230	1900	3300	9

The entire campaign was controlled by KKM. With the exception of cutting the fuel channels and sawing the shroud head bolts, all activities were performed by KKM staff, working a double-shift schedule over a period of four weeks. A total of around 50 persons were involved.

Due to consistent application of the experience gained both at KKM and elsewhere with operating the underwater shear and the grouting container – including assembly, disassembly, maintenance and decontamination – conditioning of the fuel channels was significantly more efficient than in earlier campaigns. This is despite the fact that the number of cuts per channel increased by over 50% (see Fig. 2), due to lower brittleness of the fuel channels as a result of shorter irradiation time in the reactor. Even given the

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[1] additionally around 70 kg of activated small items for weighing down the candles to prevent them from floating up during grouting

increased number of cuts, a further reduction of around 25% (to below € 4500.- per channel) in the total costs of fuel channel conditioning compared to the costs mentioned in [1] was achieved due to the considerably higher shear availability. The specific conditioning costs, taking into account all investments and total expenditure but not disposal and associated transport costs, amount to € 145.- per kg of fuel channel. While these costs are considerably lower for the other metallic wastes (€ 55.- per kg of activated small items, € 40.- per kg of weakly activated detector assemblies and € 20.- per kg of shroud head bolts), conditioning of the filters – with € 280.- per kg – costs around double that for the fuel channels.

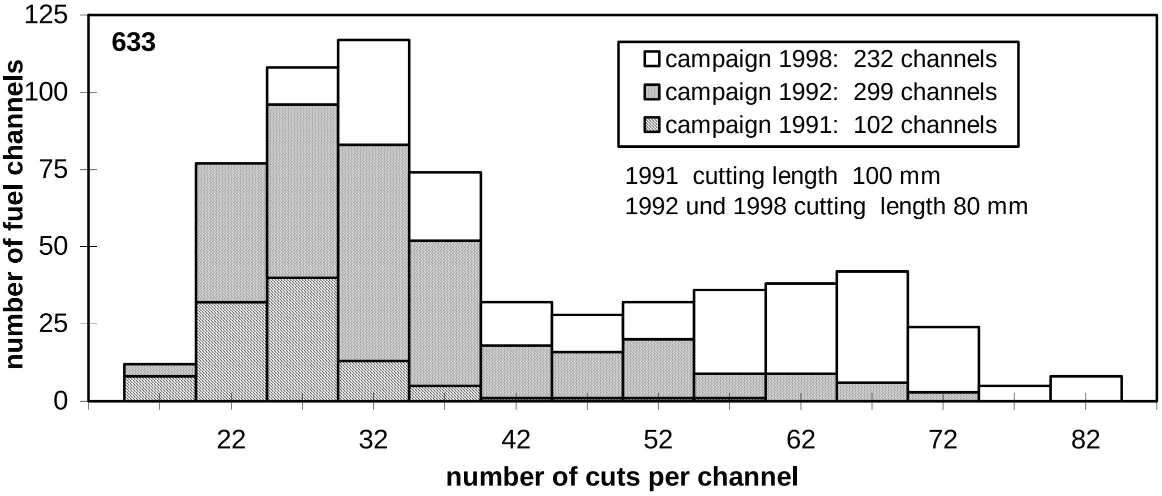

Fig. 2 Number of cuts per fuel channel in the 1991, 1992 and 1998 campaigns; the higher number for 1998 is due to lower brittleness of the channels following shorter irradiation times

With a figure of approximately 70 mSv, the accumulated collective dose was around half the value estimated for the campaign in its optimized form (see Fig. 3). This was mainly due to the optimized use of the underwater shear and the grouting container, the problem-free cutting of the shroud head bolts (resulting in a saving of two working weeks) and, not least, to an efficient radiation protection infrastructure.

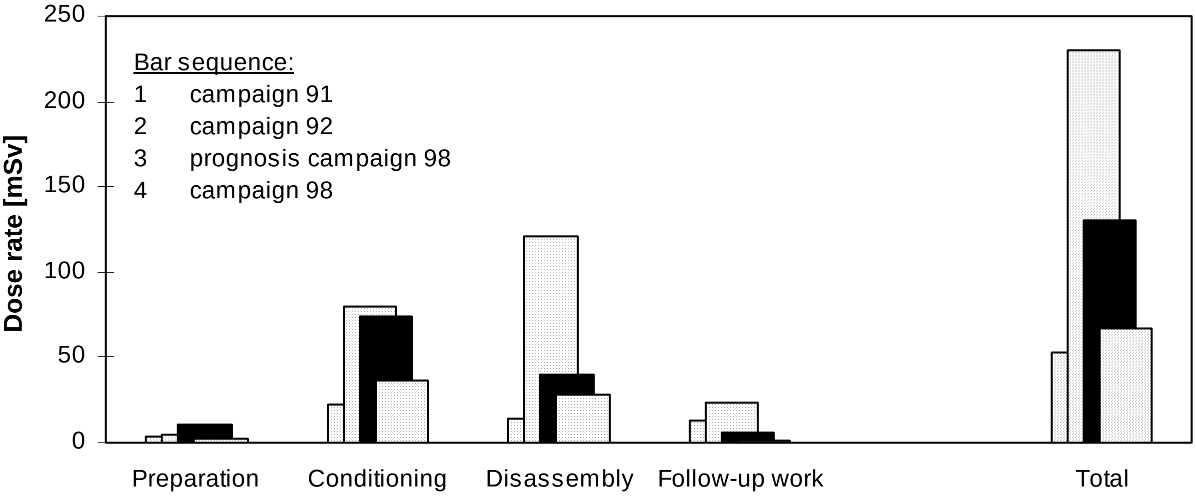

Fig. 3 Accumulated collective dose for conditioning of reactor internals in the 1991, 1992 and 1998 campaigns

Due to dismantling of the filter housings, the high loading grade of the cages with bolts and fuel channel pieces (see also Table 2) and the problem-free sawing of the bolts, around 10 200-liter drums (corresponding to 15% of the waste volume) less than predicted were produced. It should be taken into account that the approximately 2 m^3 waste volume which was saved would involve difficult package handling because of its relatively high activity inventory and associated high dose rate.

The 1998 campaign has shown that the method used for conditioning core components meets KKM's requirements from both a technical and an economic point of view. With regard to shroud head bolt conditioning, the licensing authority has expressed the opinion that an optimized solution has been found using remarkably simple methods and equipment.

5. Prospects

The fuel storage pool still contains control rods and the activated parts of detector assemblies which can, in principle, be conditioned using the same method as for reactor internals. Since the dose rate of these components is 10-100 times higher than that of fuel channels, as an alternative to external conditioning the equipment would have to be retrofitted and the shielding upgraded.

The code described is not suitable for activation calculations for control rods or generally for neutron absorbers with self-generated hard neutron spectra. It also reaches the limits of its application for components such as the reactor pressure vessel or the bioshield. Efforts are therefore being directed towards developing an overall concept which provides a tool for characterizing all activated components arising from operation and decommissioning.

References

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