

CHARACTERIZATION OF RPV, RPV INTERNALS AND CORE SCRAP AT WÜRGASSEN NUCLEAR POWER PLANT

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ABSTRACT

This paper describes the characterization of the reactor pressure vessel (RPV), the RPV internals and the core scrap of the German Würgassen nuclear power plant (NPP) by means of activation calculations, dose rate measurements, and experimental determination of activity via sampling and activity analyses for crud and matrix samples.

INTRODUCTION

As part of the programme for decommissioning the Würgassen NPP, the reactor pressure vessel, the RPV internals, as well as core scrap that has arisen during the plant's service life, will require disposal. The individual components comprise:

Reactor Pressure Vessel and RPV Internals Core Scrap

Reactor pressure vessel (cylindrical section)	Fuel channels (Zircaloy, steel)
RPV closure head	Control rods (various types)
RPV bottom head	Fuel channel fasteners
Core shroud	Upper tie plates
Core shroud support ring	Poison curtains (first core)
Control rod guide thimbles	Core instrumentation assemblies
Control rod drive nozzles	
Core plate	
Top guide	
Feedwater sparger II	
Couplings for core spray system	
Steam separator assembly II	
Steam dryer assembly III	
Jet pumps	

It was decided to create an extensive database for the above listed components containing information on the radiological characterization of the components at relevant points in time (1999, 2005 and 2025) which could serve as a basis for selecting optimum dismantling strategies as well as appropriate disposal pathways.

Characterization was carried out by performing activation calculations for the individual components and by taking samples from specific locations on various components, this being followed by radiochemical activity analyses and measurement of the dose rate of selected components.

ACTIVATION CALCULATIONS

In addition to the activation and decay times, the neutron flux spectra at the position of irradiation were required to calculate the active inventory.

The neutron flux spectra for the Würgassen NPP were largely known from neutron transport calculations performed during operation, for example, within the framework of the evaluation of RPV irradiation programmes or the updating of RPV flux values using ANISN /1/ and DOT 4.2 /2/. For particular positions the neutron flux spectra had to be re-determined. As a large proportion of the activation results from thermal neutrons, detailed knowledge of the thermal neutron flux at the irradiation point was necessary for an exact determination of activity. This neutron flux is very sensitive to the effects of shielding materials. Hence, the geometric model for the neutron transport calculation to determine the flux distribution had to be very precise.

The neutron flux spectra at the position of irradiation were broken down for calculation purposes into thermal, epithermal and fast energy regions. These spectra were obtained by condensing the 100-energy-group neutron spectra of the individual irradiation positions.

The activation calculations were mainly carried out using the programme KORIGEN /3/. The SIEMENS-KWU own programme NINA /4/ using the activation cross-sections from the "Handbook on Nuclear Activation Data" /5/ was used for the calculation of individual reactions not included in KORIGEN or where the cross-sections in the libraries of the available KORIGEN version were not up to date.

The input data required for the activation calculations, such as material composition, irradiation position, irradiation history and decay time, vary for each component and also vary – sometimes significantly - within each component due to their size and heterogeneous nature. Hence, the large components were divided into parts for determination of active inventory. The size of the parts took into account the material composition, the neutron flux gradients and the degree of activation.

For sub-components which changed their position during irradiation, for example the control rods, this behaviour was taken into account in the irradiation history, simplified as appropriate. Sub-components with similar irradiation histories were considered in groups.

For the calculation of the control rod activity, special account of their effect on the neutron source strength of neighbouring fuel elements was taken into consideration.

Some components contain heavy metal (uranium) impurities e.g. fuel element channels. Actinides and fission products were also taken into account in determining the inventory of these components. As the fission and capture cross-sections of heavy metal nuclides depend significantly on the neutron spectrum, they were recalculated for the particular application.

The activation calculations, numbering much more than 300, resulted in radionuclide-specific activity data for various points in time.

DOSE RATE MEASUREMENTS

Dose rate measurements were performed to check the calculated activation of selected sub-components (control rod, fuel element channels, control rod guide thimbles). These sub-components were modelled in appropriate geometries for comparison with the calculated results. The gamma dose rate at the measurement location was calculated using the estimated radionuclide-specific activity distribution as gamma source.

Point checks of the calculation results with dose rate measurements allowed a relationship to be determined between the activation inventory and the dose rate for certain sub-components. This relationship could then be used to estimate the active inventory from dose rate measurements of other sub-components of the same type but for which no radionuclide composition was known or for which no activation calculation had been carried out.

EXPERIMENTAL DETERMINATION OF ACTIVITY VIA SAMPLING

Samples were taken from representative sub-components and positions using appropriate techniques (grinding, sawing, drilling, mechanical or chemical surface removal) and subjected to radiochemical analysis.

Samples from the RPV, from the relevant internals and from the core scrap were required:

- to determine significant radionuclides from the surface deposits designated as CRUD (CRUD samples)
- to determine significant activation radionuclides in the steel/iron or zircaloy matrix (matrix samples).

The contribution of the CRUD activity to the total activity of a sub-component can only be determined experimentally via appropriate samples and not calculated as for the activation products. The purpose of the analysis of activation radionuclides from the matrix samples – as discussed above for the dose rate measurements – is the point comparison with the results of activation calculations, i.e. support for the calculated activities with values from experimental analysis. In addition, the analysis of matrix samples is also important where insufficient information regarding the material composition was available for calculation purposes.

The sampling and analysis programme covered the following components:

- Steam dryer (1 Matrix and 1 CRUD sample)
- Steam separator (3 Matrix and 3 CRUD samples, different heights)
- Feed water sparger (1 Matrix and 1 CRUD sample)
- 2 Control rod guide thimbles (2 Matrix samples 1 from the control and 1 from the shut-off position, 1 CRUD sample at the control position)
- Jet pumps (1 Matrix sample)
- Top guide (2 Matrix samples)
- RPV bottom head (3 Matrix samples)
- Core shroud (1 Matrix sample)
- RPV external closure head (2 Matrix samples from different depths at each of 2 positions)

- RPV closure head in flange area (1 Matrix sample from each of 2 positions)
- RPV inner closure head (1 Matrix sample from the plating both with and without CRUD as well as 1 CRUD sample)
- Control rods (3 Matrix samples, 2 CRUD samples)
- Fuel channels (2 Matrix samples, 3 CRUD samples).

Sample material was transported from the Würgassen NPP to the Siemens KWU radiochemical laboratories in Erlangen. The testing laboratory there is accredited according to DIN EN 45.001.

ACTIVITY ANALYSES FOR CRUD SAMPLES

The CRUD analyses included Co60, Cs134, Cs137 and other gamma sources such as Sb125, Co58 etc., the alpha sources U233, U234, U235, U238, Pu238, Pu239/240, Am 241, Cm242, Cm243/244, as well as in part Fe55 and Ni63. Total CRUD activity was extrapolated over the surface of the sub-component from the analysis results. CRUD activity for further special radionuclides such as C14 and Sr90 were taken into account in relation to the Co60 or Cs137 activity by using a radionuclide vector valid for the Würgassen NPP.

ACTIVITY ANALYSES FOR MATRIX SAMPLES

Co60 and other gamma sources such as Sb125, Mn54, Co58 etc. as well as in part Fe55 and Ni63 were generally determined from the matrix samples.

Point checks of the calculation results with the analysis results from the matrix samples have also shown the calculation model and associated assumptions have led to good results (see Table 1).

RESULTS

The activation calculations as well as the supporting analyses and dose rate measurements have led to the creation of a data base which allows detailed design of the dismantling and size reduction of reactor pressure vessel internals and core scrap taking due account of radiological implications. In addition, the data base allows the optimisation of disposal path-ways including container loading for the sub-components from the Würgassen NPP.

Detailed knowledge of the neutron flux spectra responsible for the activation allow results with an adequate precision which, following optimisation of container loading, leads to minimisation of the required number of disposal containers.

Table 1: Examples; comparison of calculated and measured values

	Co60 (Bq/g) date of measurement	
	calculated	measured
RPV closure head several positions	2,2 E-01 bis 4,4 E-01	3,6 E-01 bis 7,1 E-01
RPV bottom head several positions	8,9 E-01	7,5 E-01 bis 1,4 E+00
Steam separator assembly several positions	7,4 E+02 bis 4,0 E+04	9,6 E+02 bis 1,5 E+04
Steam dryer	2,2 E+02	2,0 E+02
Jet pump	1,6 E+06	1,6 E+06
Core shroud (head)	1,7 E+07	1,1 E+07
Control rod R067 (head)	5,7 E+08	7,2 E+08
(center)	1,0 E+08	1,5 E+08
	Sb125 (Bq/g) date of measurement	
	calculated	measured
Fuel channel BEK 400	6,9 E+07	5,6 E+07

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