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Numerical Analysis of Neutron Activation Processes in Cladding Material of Spent Fuel Rod

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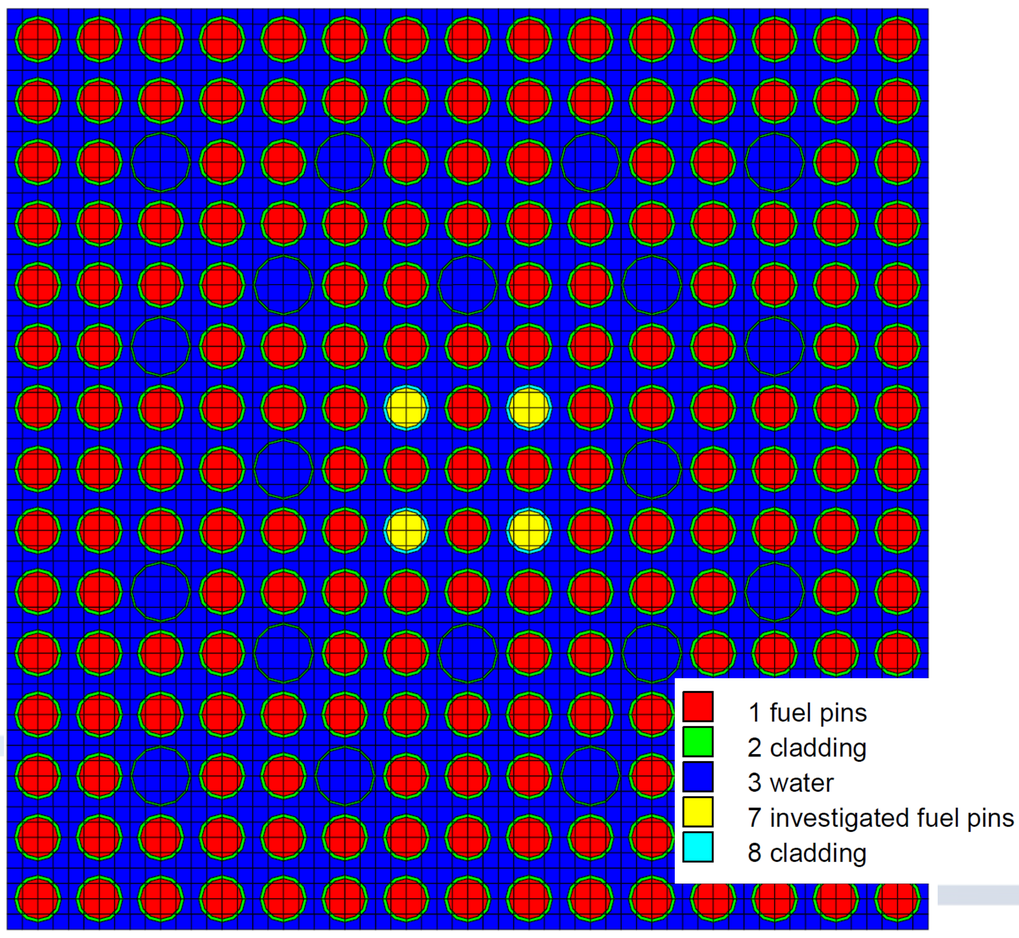
1. Introduction

European Joint Programme on Radioactive Waste Management (EURAD-1, 2019-2024) was established to support the participating countries in implementing EU Directive 2011/70/Euratom that defines a Community framework for the responsible and safe management of spent nuclear fuel and radioactive waste in their national Research, Development & Demonstration (RD&D) programmes. One of the EURAD-1 work packages was dedicated to spent nuclear fuel characterisation. The main objective of this work package was to perform experimental and numerical studies to determine reliable source terms for spent nuclear fuel and associated uncertainties from the irradiation of the fuel assembly in the reactor core to the time of its disposal into a deep geological repository (DGR).

2. Description of the Research Problem

In radiological impact assessments of the DGR, the analysis is performed per released radionuclides rather than as a bulk of released elements. Fuel rod cladding material contains impurities that due to irradiation and neutron activation produce safety relevant long-lived radionuclides such as C-14, Cl-36. It also produces fission products since the cladding material contains uranium impurities. The ability to determine the nuclide inventory is essential for safety and other licensing issues of the back-end of the fuel cycle and final disposal.

The objective of this research was to analyse inventories of activation and fission products in the Zircaloy cladding of the PWR fuel assembly with known fuel data and irradiation history. KIT-INE (Germany) has performed experimental measurements of irradiated Zircaloy-4 cladding samples at their Hot Cell facility, while the numerical modelling using stochastic and deterministic computer codes with different depletion solvers have been performed by KIT-INE (Germany), LEI (Lithuania), CIEMAT (Spain), NAGRA (Switzerland), and VTT (Finland).



3. Methodology

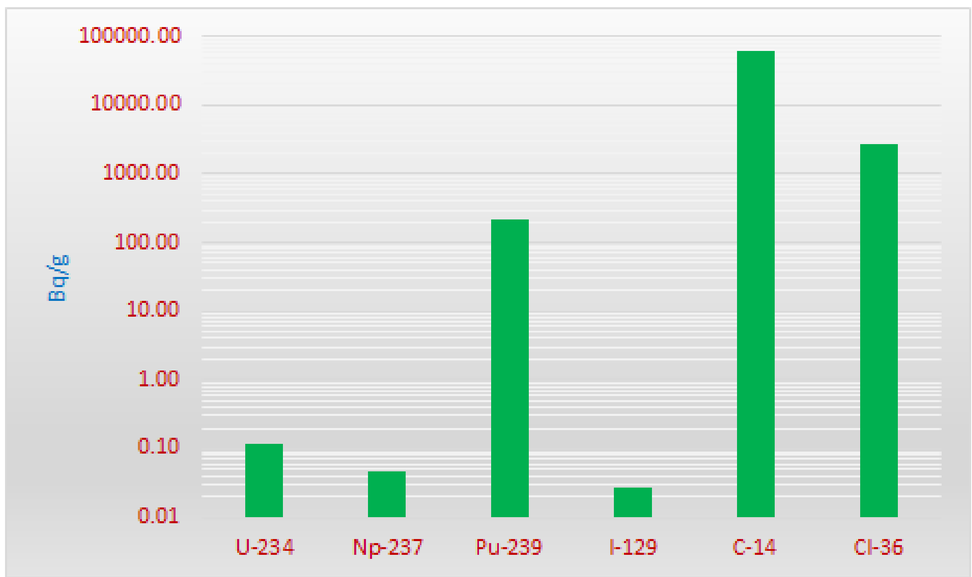
A numerical analysis of radionuclide inventories in the Zircaloy-4 cladding of the PWR spent fuel assembly irradiated in the Gösgen Nuclear Power Plant (Switzerland) has been performed using a SCALE 6.1 control module TRITON that is used for transport, depletion, sensitivity and uncertainty analysis for reactor physics applications.

The main assumptions that were accepted as input to TRITON code:

- PWR 15x15 fuel assembly containing 205 fuel rods (FR) and 20 guide tubes (filled with water) was described in 2D geometry, neutron activation analysis of the cladding of four fuel rods (indicated in yellow colour) was performed.
- U-235 initial enrichment 3.8%, cladding Zircaloy-4 composition, including impurities: Zr, Sn, Fe, Cr, O, C, Cl, Co, Mn, Ni, N, U.
- Effective full power 1226 days in 4 even cycles, average burn-up of 50.4 MWd/kgU.
- Constant boron concentration in water 1500 ppm for all cycles.
- 238-group ENDF/B-VII library for cross-sections and depletion data.

4. Results

The performed modelling has revealed that the activated impurities in the fuel rod cladding are important for long-term impact assessments. The obtained modelling results have also been used in the work package to perform the code-to-code comparison and compare them with experimental investigations of fuel rod cladding.



5. Conclusions

The calculations have shown that the presence of impurities in the Zircaloy cladding greatly affect accurate determination of the long-lived activation products, fission products and actinides (generated due to the presence of uranium impurity in the cladding material) when assessing the radiological consequences of geological disposal facilities. Under deep geological disposal conditions the release of radionuclides from the Zircaloy cladding due to corrosion processes is faster than due to spent fuel dissolution.

Acknowledgments

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