10 Radiation protection research

Radiation Protection Research at KIT-INE is focusing on assessing radiation exposures both by estimation of doses from external radiation fields and estimation of doses from intakes of radionuclides. The techniques applied for assessing radiation exposures are direct measurements and numerical simulation of radiation fields. During 2016, research activities have been focused on experimental and numerical simulations of the radiation field around a spent nuclear fuel cask as well as on assessment of uncertainties in biokinetic and dosimetric models by means of Monte Carlo simulations. Close collaborations are established with national and international partners in networks such as "Strahlung und Umwelt" in Competence Alliance Radiation Research KVSF and the European Radiation Dosimetry Group (EURADOS).

10.1 First-time operation of the neutron generator of the TU Dresden in the range of high-level nuclear waste neutrons at 2.5 MeV and neutron spectra determination after "POLLUX-type" materials

H. Saurí Suárez and F. Becker

in co-operation with:

A. Klix[a], T. Döring[b]

[a] KIT-INR; [b] IKTP/TU Dresden

Introduction

A proper and safe management of spent nuclear fuel (SNF) discharged from commercial nuclear power plants is a subject of societal concern. Certain working scenarios in the storage / disposal facilities might lead to an *enhanced* level of radiation exposure for workers. Hence, a realistic estimation of the personal dose during individual working scenarios is desired.

In previous work [1,2] the Monte-Carlo code MCNP6 [3] was employed to simulate the radiation fields and exposure in a final disposal in a rock salt and a clay stone repository. In both cases POLLUX® casks containing a mixture of spent PWR UOX and MOX fuel assemblies were investigated.

For the numerical simulations, the POLLUX® cask structure was simplified and composed of three layers: an internal stainless steel shielding layer, a neutron moderator layer (consisting mainly of polyethylene), and a modular cast iron external shielding layer.

However, to benchmark the MCNP6 simulations there is no POLLUX® cask with spent nuclear fuel available, so that measurements of the radiation field around a real POLLUX® are not feasible so far. Hence, to assess the modelling and simulation approaches applied in MCNP6, experiments with a setup consisting of materials similar to the POLLUX® were performed. Our simulations predict that for the POLLUX® containing UOX and MOX fuel assemblies the radiation field and dosimetry is dominated by neutrons.

For this reason, we have chosen a well-defined neutron source, which produce neutrons in the energy range close to neutrons emitted from spent nuclear fuel. The neutron generator of the TU Dresden (TUD-NG), located at Helmholtz Zentrum Dresden Rossendorf (HZDR), was selected for this purpose.

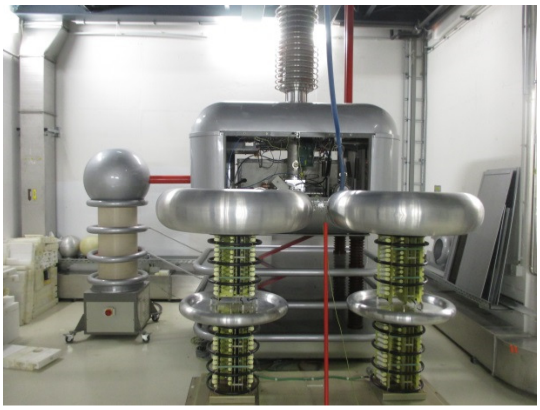

Fig. 1: *Deuterium accelerator at HZDR.*

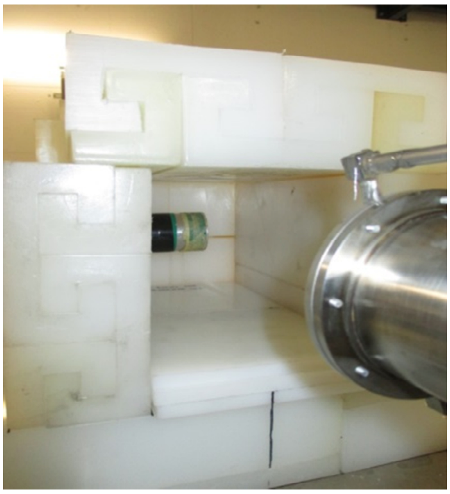

Fig. 2: *Experimental setup at the end of the beam line. The target was located in the beam line visible on the right; behind the beam line a polyethylene housing was mounted (white bricks) in which the NE213 detector (the scintillator position is indicated by the yellow/green tape) was placed.*

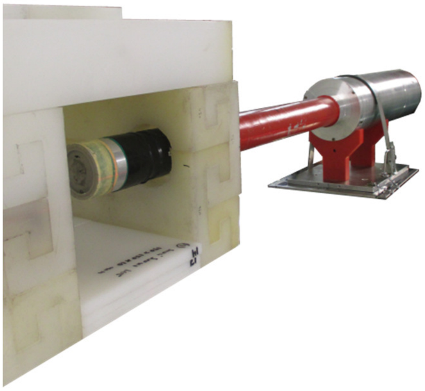

Fig. 3: Experimental setup showing the NE213 detector. The picture was taken before the rear side of the PE house was closed. The scintillator position indicated by the yellow/green tape is inside the house while the light guide inside of the red tube and the adjacent photomultiplier in the metallic cylinder is located outside of the housing.

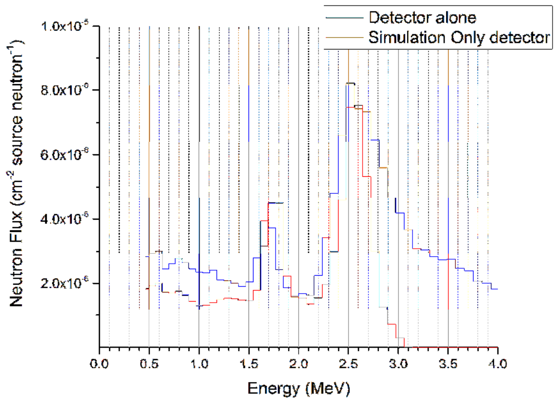

Fig. 4: Measured and simulated spectra free-in-air.

Experiment

As described by Klix et al. [4], the neutron generator is a Cockroft-Walton type deuterium accelerator (Fig. 1) with a terminal deuteron energy of 320 keV and a maximum current of 10 mA. Depending on the target, the generator can produce neutrons with different energies. So far the deuteron reaction of impinging on a tritiated titanium target, generating neutrons with energies of 14.1 MeV, was employed.

For the present investigation for the first time the TUD-NG was operated with a deuterated titanium target, so that neutrons of 2.5 MeV stemming from the reaction d + D → n + ^{3}He were produced.

The basic setup is displayed in Fig. 2. At the end of the beam line behind the target a polyethylene housing (PE house) was mounted. The scintillator of a NE213 detector [5], with the ability to measure both fast neutrons and gamma rays, was placed inside the housing (see Figures 2 and 3). This ensures a shielding of background radiation. The distance from the target to the detector amounted to 35.5 cm. The opening in the housing, empty in Fig. 2, was filled with different materials.

Four configurations were investigated:

- Detector free-in air (without polyethylene housing)
- polyethylene housing without material in the opening (“polyethylene house” configuration)
- polyethylene housing with a 10 cm polyethylene closure
- polyethylene housing with closure layers of 4 cm steel, 10 cm polyethylene, and 4 cm steel (“POLLUX-type” configuration)

The acquired raw pulse height spectra for the different configuration were unfolded according to the procedure given in [5].

Results and discussion

The Figures 4 to 7 show the resulting measured neutron spectra for the four configurations as well as the first simulation results of respective MCNP6 simulations. In all spectra two prominent peaks are observed. The one at a neutron energy of 2.5 MeV is in agreement with the expected neutron energy of the reaction d + D. The other one at 1.7 MeV is attributed to the inelastic scattering of 2.5 MeV neutrons on iron, one of the materials employed around the target position. According to the scattering reaction (n,n′γ) on ^{56}Fe, the gamma energy of the first excited state of ^{56}Fe would reduce the energy of the scattered neutrons to 1.7 MeV in agreement with the peak position in the spectra. Moreover, the enhancement of this peak in the “POLLUX-type” configuration (Fig. 7), with additional 4 cm steel in the entrance window, supports this explanation.

The effect of the shielding concept of the polyethylene housing can be recognized when comparing the configuration free-in-air (Fig. 4) with the configuration “PE house” (Fig. 5). A suppression of high energy neutrons above 3 MeV, stemming from background radiation, is observed. Hence the preliminary reflections of the experimental design concerning background shielding are confirmed to be successful.

When the opening on the target side of the PE house is closed, the shielding/moderation effect is visible in

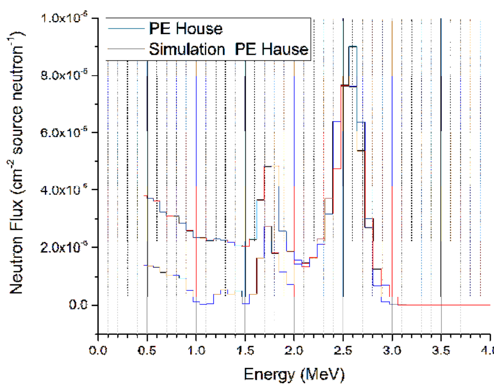

Fig. 5: Measured and simulated spectra for the detector placed in the housing without material in the opening.

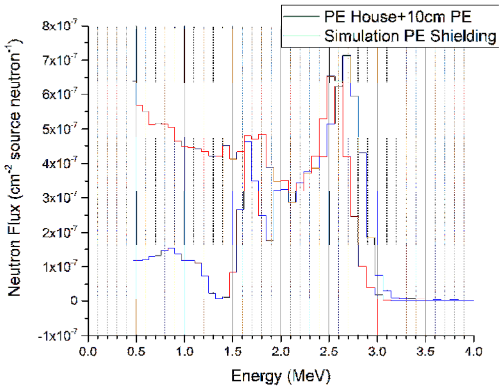

Fig. 6: *Measured and simulated spectra for the configuration polyethylene housing with a 10-cm polyethylene closure.*

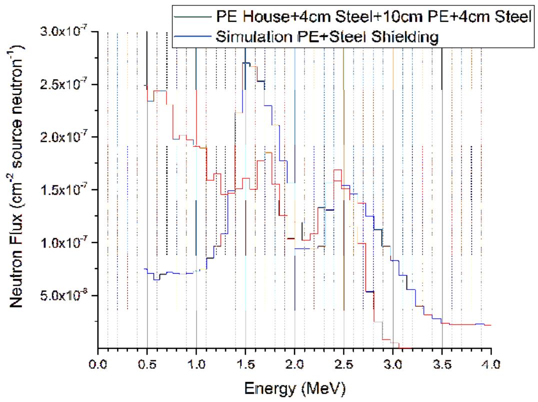

Fig. 7: *Measured and simulated spectra for the polyethylene-steel configuration ("POLLUX-type").*

the spectra, as the neutron flux is reduced (Fig. 6). When looking at the "POLLUX-type" configuration, the intensity of the 2.5 MeV peak is further reduced due to the larger amount of shielding material, but as stated before the iron in the neutron beam raises the respective inelastic scattering peak at 1.7 MeV.

Summary and conclusions

In the current study experiments at TUD-NG were performed, where for the first time, the reaction d + D was used to obtain 2.5 MeV neutrons. This complies with the energy range of neutrons in POLLUX® shielding casks loaded with UOX and MOX. As the radiation field is dominated by neutrons, we focused in this study on the neutron flux measurements and the corresponding MCNP6 simulations. The experiment for the first time realized at TUD-NG yielded straightaway comprehensive data. In general, the experimental and simulated results agree quite well, keeping in mind that the detector response and unfolding procedure is attributed with some uncertainties. Moreover, the simulations do not account for background neutrons e.g. stemming from cosmic radiation. The on-going data analysis and corresponding simulations will consider gamma-ray spectra too. In particular gamma rays from the scattering reaction (n,n′γ) on ^{56}Fe and other materials could be revealed more detailed in future.

Summarizing the first results of experiments at TUD-NG together with our modelling and simulation approaches applied in MCNP6 show that this methodology in promising to assess simulation scenarios with POLLUX® type casks containing a mixture of spent PWR UOX and MOX fuel.

Acknowledgements

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