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New evaluation of photon production for JEFF-3

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Abstract. In this work, new gamma production evaluations are proposed for JEFF-3 for crucial nuclei for power reactors and Jules Horowitz Reactor: Fe, Ag, In, Cd and Gd. We specifically work on two nuclear reactions: the inelastic scattering and the radiative capture. We performed gamma production multiplicities, angular distributions and energy spectrum for incident neutron energies between 10^{-11} and 20 MeV by simulating the whole intranuclear gamma cascade. For this simulation, the discrete part of the nuclei level schemes came from the RIPL2.0 library and the latest EGAF measurements carried out at Budapest facility. The EGAF measurements are available in the adopted IAEA library. The continuum level scheme part has been estimated with a level density model: the Gilbert-Cameron model and a strength function model: the Generalized Lorentzian model. Then, the gamma cascade has been simulated using TALYS which is a nuclear reaction modeling code.

1. Introduction

The local energy photon deposit must be accurately accounted for advanced light-water nuclear reactor and the new experimental Jules Horowitz Reactor [1] (JHR). The nuclear data library JEFF-3.1.1 [2] contains most of the photon production data. However, we found some nuclei with missing or erroneous data which need to be completed or modified. In this work, we propose new gamma production evaluation for JEFF-3.

Most of the gamma production in a nuclear reactor comes from neutron interactions with matter: inelastic scattering, fission, radiative capture and all other neutron-induced-nuclear reactions except for elastic scattering. We focus on the radiative capture (MT102 in the ENDF format [3]) which is energetically predominant on the inelastic scattering for the emission. 6 crucial nuclei have been identified for the JHR and power reactor with missing or wrong data: Fe, Ni, Ag, In, Cd and Gd. Each natural isotope of these elements has been studied.

2. Processing of new gamma production spectra

2.1. Experimental measurements: the EGAF library

EGAF [4] is an online library validated by the AIEA. It contains gamma production spectra due to a neutron capture. All these spectra are evaluated with well known data from the ENSDF [5] library and new measurements partly performed with a thermal neutron beam at Budapest facility. They only contain discrete gamma production peak without accounting for a continuous part. This is pointed out by Figure 1 that compares the integrated discrete photon energy using AIEA or ENSDF data sets to the actual energy emission (B_n) for thermal-neutron-radiative capture. For heavy nuclei (A>70) neither EGAF nor ENSDF dissipate the entire available gamma energy. In other terms, the continuum part must be taken into account by simulation.

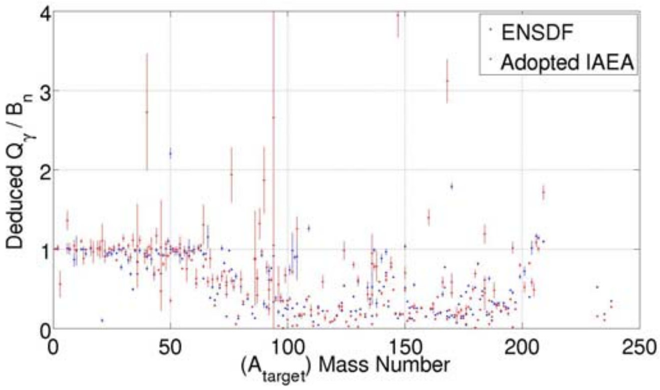

Fig. 1. Comparison between the integrated discrete gamma energy from radiative capture evaluations and B_n

2.2. A modeling code: TALYS

TALYS [6] is a nuclear reaction modeling code developed by NRG and the CEA/DAM. It can model the gamma cascade after a radiation capture for many incident neutron energies by a Hauser-Feshbach decay with a strength function and a level density model. The chosen models are the Generalized Lorentzian and the Gilbert-Cameron composite model as advised by Kopecky and Uhl [7]. TALYS can account for the first well known discrete levels, which are available in the RIPL2.0 [8] database. So the resulting spectra, after a TALYS calculation, contain both a discrete and a continuous part.

2.3. Processing of new ENDF evaluation for JEFF3.2

The new spectra, which are proposed for JEFF3.2, are divided in two parts. For incident neutron energies fewer than 1 keV, it means around 90% of the neutron capture in steel, the spectra contains the EGAF-discrete peaks and a continuous part calculated by TALYS if needed. Above 1keV, the spectra are fully calculated with TALYS [9].

3. Effect of the new evaluations

3.1. Shape of the new spectra

TRIPOLI [10] calculations of a given thermal neutron source in an infinite medium give the following photon production spectra. The energy mesh contains 94 groups from 10^{-11} to 20 MeV. The results are shown in figure 2 for 4 nuclei: ^{54}Fe, ^{56}Fe, ^{177}Hf, ^{180}Hf.

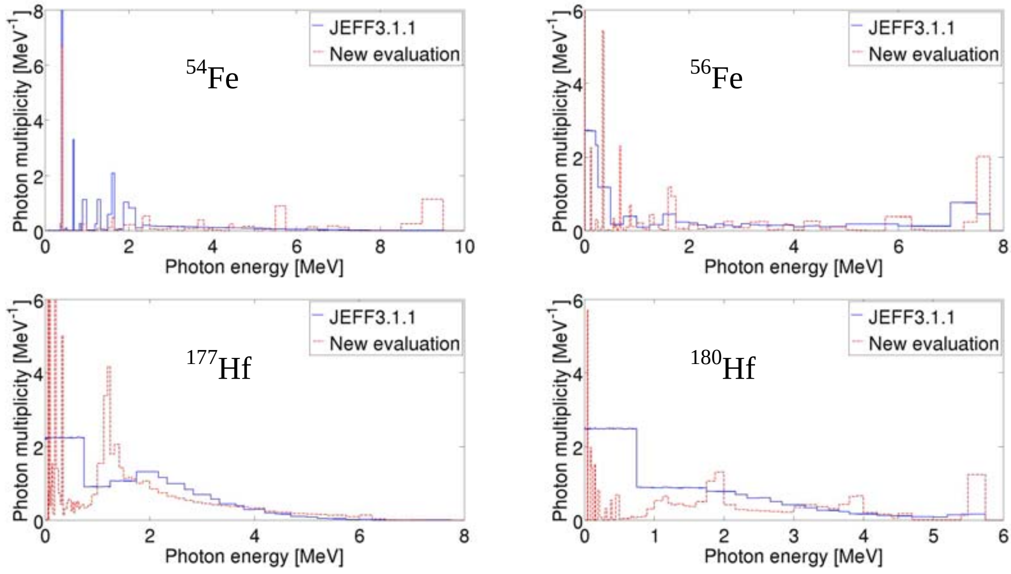

Fig. 2. Photon production spectra after a thermal neutron capture

The new gamma production spectra are more accurate and account for more discrete peaks. In the case of the ^{54}Fe, ^{177}Hf and ^{180}Hf, no high-energy-primary-gamma peak was present in JEFF-3.1.1.

3.2. Effect of the new spectra on the local energy deposition

The new gamma production spectra must affect the photon transport and consequently the local energy deposition. A 10cm-sphere, divided in 10 1cm-long shells with a thermal capture on ^{54}Fe or ^{56}Fe at its center, has been simulated using TRIPOLI4.7 with both evaluations to highlight this effect. The results are given on figure 3 for a sphere of Fe with $8.3.10^{-2}$ $atom.cm^{-1}.barn^{-1}$ density. This density is quite similar to that of the stainless steel.

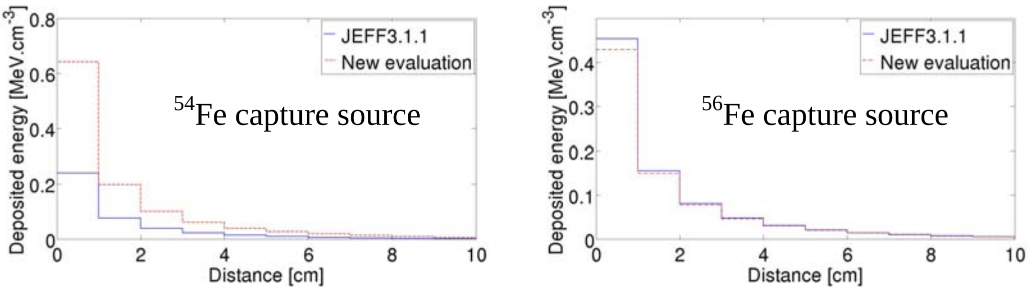

Fig. 3. Local energy deposition of photon in a sphere after a thermal capture at its center

The local energy deposition has strongly increased in the case of ^{54}Fe. The total energy deposited in the whole sphere is 150% greater with the new evaluations. In the case of ^{56}Fe, the new spectrum is harder, so the mean free path of the emitted photons is longer. Thus, energy is deposited further with the new evaluation.

The same calculation has been performed with a sphere of stainless steel. The differences from the central to the external shell between the new evaluation and JEFF-3.1.1 range from -0.5% to 3%.

3.3. Application on the PERLE experiment interpretation

PERLE [11] is an integral experiment performed in the zero-power reactor EOLE at CEA Cadarache. One of the PERLE purpose is to estimate the local gamma heating in a heavy reflector for the 3rd generation reactors. It is a regular PWR-type core, with 3.7% enriched UO_2 pins in a 1.32cm square pitch, surrounded by a 22cm-thick stainless steel reflector. A variety of TLDs have been inserted across the reflector to measure the gamma KERMA.

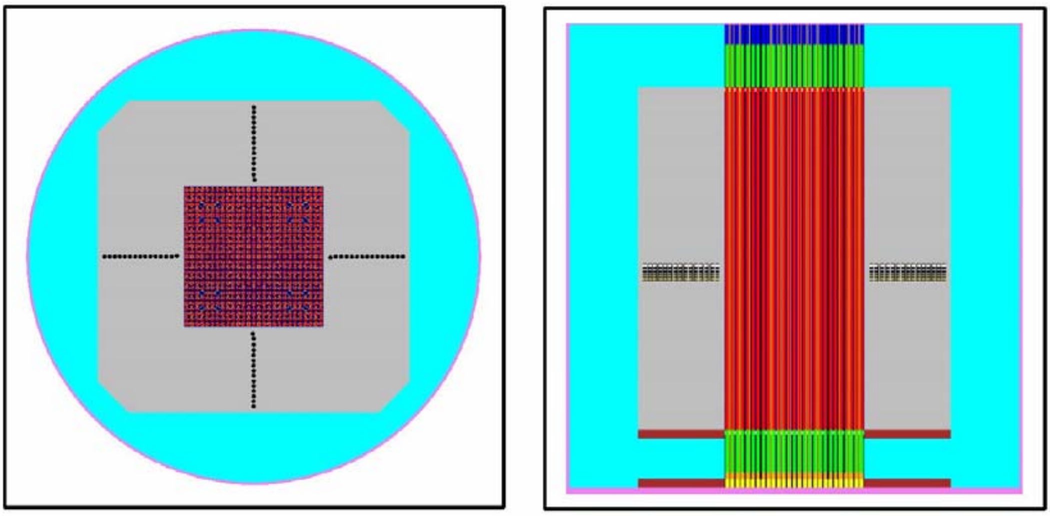

Fig. 4. The PERLE core simulated by TRIPOLI4.7

Previous interpretations of the measurements have shown that the calculated gamma dose in the reflector is slightly underestimated by -7±6% (1σ) when performed with the JEFF-3.1.1. library. The new evaluations allow us to improve this result by 1 to 2%. The difference between the two evaluations is given on table 1.

Table 1. Difference between JEFF3.1.1 and the new evaluations on the calculated local-deposited dose in the reflector of the PERLE experiment

Penetration in the SS reflector [cm]	Differences with JEFF3.1.1 [%]
3.08	0.9
5.94	1.3
8.58	1.5
11.19	1.5
13.84	2.3
16.38	2.3

4. Conclusion and perspectives

The photon production knowledge is becoming a very important issue. The JEFF3.1.1 library which is very efficient for the neutron transport calculation [12] [13], needs improvements for this new problematic. Thus, new gamma production spectra have been produced mixing discrete gamma peak available in the latest EGAF measurements and a theoretical calculation using the modeling code TALYS. 16 new evaluations are proposed for the next JEFF-3.2 library.

These new evaluations are energetically coherent. They account for more discrete gamma peaks, especially the high-energy-primary-gamma rays, and describe them more accurately than before.

Few tests made with the TRIPOLI code on the iron isotopes have shown that the impact of the new evaluation on the local energy deposition is not negligible. On a stainless steel sphere, this difference can locally be higher than 3%.

An application has been performed on the PERLE experiment, showing an improvement of the new evaluations on the dose calculation in a stainless steel reflector.

Acknowledgments

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