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ANITA-2000 activation code package - updating of the decay data libraries and validation on the experimental data of the 14 MeV Frascati Neutron Generator

Manuela Frisoni[a]

ENEA,CR "E.Clementel", Via Martiri di Monte Sole4, 40129 Bologna, Italy

Abstract. ANITA-2000 is a code package for the activation characterization of materials exposed to neutron irradiation released by ENEA to OECD-NEADB and ORNL-RSICC. The main component of the package is the activation code ANITA-4M that computes the radioactive inventory of a material exposed to neutron irradiation. The code requires the decay data library (file fl1) containing the quantities describing the decay properties of the unstable nuclides and the library (file fl2) containing the gamma ray spectra emitted by the radioactive nuclei. The fl1 and fl2 files of the ANITA-2000 code package, originally based on the evaluated nuclear data library FENDL/D-2.0, were recently updated on the basis of the JEFF-3.1.1 Radioactive Decay Data Library. This paper presents the results of the validation of the new fl1 decay data library through the comparison of the ANITA-4M calculated values with the measured electron and photon decay heats and activities of fusion material samples irradiated at the 14 MeV Frascati Neutron Generator (FNG) of the ENEA-Frascati Research Centre. Twelve material samples were considered, namely: Mo, Cu, Hf, Mg, Ni, Cd, Sn, Re, Ti, W, Ag and Al. The ratios between calculated and experimental values (C/E) are shown and discussed in this paper.

1 Introduction

The evaluation of the neutron induced material activation plays an important role for the development of future fusion power plants for issues related to safety, engineering design and radioactive waste management. The availability of reliable nuclear data and activation codes is required. ANITA-2000 [1,2] is a code package for the activation characterization of materials exposed to neutron irradiation released by ENEA to OECD-NEADB [3] and ORNL-RSICC [4]. It has been widely validated and used in the past in ENEA-Bologna for radioactive inventories and source terms calculations for fusion plants safety analysis [5,6,7].The original package contains: a) the activation code ANITA-4M that traces back to the ANITA code (Analysis of Neutron Induced Transmutation and Activation [8]), b) two activation cross section libraries based respectively on EAF-99 [9] and on FENDL/A-2.0 [10], c) the decay data library (file fl1) containing the quantities describing the decay properties of the unstable nuclides and d) the library (file fl2) containing the gamma ray spectra emitted by the radioactive nuclei. The fl1 and fl2 files of the ANITA-2000 code package, originally based on the

[a] Corresponding author: manuela.frisoni@enea.it

evaluated nuclear data library FENDL/D-2.0 [11], were recently updated on the basis of the JEFF-3.1.1 Radioactive Decay Data Library [12]. The ANITA-4M code actually uses a neutron cross section library based on the data of the European Activation File EAF-2010 [13] provided in the package EASY-2010 [14]. This work presents the results of the validation of the new fl1 decay data library through the comparison of the ANITA-4M calculated values with the measured electron and photon decay heats and activities of fusion material samples irradiated at the 14 MeV Frascati Neutron Generator (FNG) of the ENEA-Frascati Research Centre. Twelve material samples were considered, namely: Mo, Cu, Hf, Mg, Ni, Cd, Sn, Re, Ti, W, Ag and Al. The ratios between calculated and experimental values (C/E) are shown and discussed.

2 Updated decay data libraries

The Decay, Hazard and Clearance data library (file fl1) provides the information describing the decay properties of the unstable nuclides. It contains, for each nuclide, the decay mode, the branching ratios, the decay constant (s^{-1}), the total energy (MeV) released in the decay and the energy (MeV) released in the form of gamma or X-rays. The decay data of the new fl1 file were taken from the JEFF-3.1.1 Radioactive Decay Data library (MF=8, MT=457 section in the ENDF-6 [15] standard format notation).

The fl1 file provides also for each radionuclide the clearance level C_L (Bq/g). This quantity allows to establish if a radioactive material can be potentially moved out of the originating facility and recycled. The safe handling of radioactive waste is recognized as crucial to ensure protection of human health and the environment. IAEA publish regulations on these issues and Ref.[16] provides information on suggested clearance level values for a set of important radionuclides. The clearance level data contained in the new fl1 file have been updated by including the information contained in Ref.[16] and Ref.[17]. The updated fl1 file actually contains data for 3433 nuclides.

The gamma library (file fl2) contains the gamma ray spectra emitted by the radioactive nuclei in the ORNL-SCALE 18-γ energy group structure. It was updated on the basis of the gamma radiation spectra contained in the JEFF-3.1.1 Radioactive Decay Data library. The data given in the fl2 gamma library are used in ANITA-4M to compute the intensity and the energy distribution of the gamma-rays emitted by the irradiated material. The production of the new fl1 and fl2 files required the development of a series of proper interface codes in order to process the ENDF6 format JEFF-3.1.1 evaluated decay data, to calculate the clearance level quantities and to convert these data into the specific format required by the ANITA-4M code.

3 The FNG experiment

The availability of reliable nuclear data to be used in the neutron transport and activation calculations is highly recommended. To this end, suitable experimental activities (benchmark experiments) are necessary. One of those experiments was carried out at the ENEA Research Centre of Frascati at the 14 MeV Frascati Neutron Generator (FNG) based on the T(d,n)α fusion reaction [18]. The FNG group used a neutron reflector that forms an irradiation cavity where the neutron spectrum simulates that existing in the first wall of a typical fusion device. More details on the experimental set-up are given in Ref. [19]. Twelve high purity samples of different materials (i.e. Mo, Cu, Hf, Mg, Ni, Cd, Sn, Re, Ti, W, Ag, Al) were irradiated at a fixed position close to the FNG neutron target. The irradiation time ranged between 160 s and 1600 s . For each sample the experimental results were provided for various cooling times ranging from about 130 s to 1440 s. The experiment allowed to measure simultaneously the total activity and the electron and photon decay heats for each irradiated sample. The FNG experimental results enable to validate both the cross section and the decay databases used by the activation codes.

4 Calculation-experiment comparison

The validation of the updated decay data library (file fl1) has been performed through the comparison of the ANITA-4M results with the FNG experimental data. The physical quantities involved in the comparison are, for each one of the material samples, the electron and photon decay heats (kW) and the activity (Bq). The ANITA-4M calculations were performed by using the neutron activation cross sections based on EAF-2010. The assessment refers to Mo, Cu, Hf, Mg, Ni, Cd, Sn, Re, Ti, W, Ag, and Al samples. The details of the experimental set-up (material composition, sample mass, irradiation time, neutron flux, etc.) provided by FNG team were used in the ANITA-4M input files in order to model each experiment. The ratios between calculated (C) and experimental (E) values (with the error bars obtained by using the error propagation theory and considering the errors of both the C and E values at 1σ) for material samples electron and photon decay heat and activity are shown in Figs.1,2,3.

For each material the C/E values have been calculated as a mean over the cooling times. The overall set of detailed experimental data and calculation results is given in Ref. [20].

For sake of comparison, decay heat and activity calculations were also performed by using the EASY-2010 code package (FISPACT-2010 code + EAF-2010 libraries). The comparison between the ANITA-4M and FISPACT-2010 results is shown in Figs.4,5,6.

5 Results discussion

5.1 Comparison between experimental results and ANITA-4M calculations (new fl1 file and EAF-2010 neutron cross section activation library)

1. Electron decay heat:
- The discrepancies between the calculated mean electron decay heat C and the experimental E values are inside 20% for Cu, Mg, Cd, Sn, Ti, Al and up to 30% for Mo, W and Ag. Materials with discrepancies greater than 30% are: Hf (42%), Ni (70%) and Re (31%).
- The mean electron decay heat C/E values show agreement within error bars for Mo, Cu, Mg, Sn, Ti, W and Al.

2. Photon decay heat:
- The calculated photon decay heat values are lower than the corresponding experimental values for all the material samples.
- The discrepancies between the calculated mean photon decay heat C and the experimental E values are inside 20% for Mo, Mg , Al and up to 30% for Cu, Cd and Sn. The materials with discrepancies greater than 30% are: Hf (60%), Ni (40%) , Re (55%); Ti (40%), W (40%) and Ag (35%).
- The photon decay heat C/E values show agreement within the error bars only for Mo, Mg and Al.

3. Activity:
- The calculated activity values show in general an underestimation of the experimental values except for Mo and Ni.
- The mean activity values for Mo, Mg and Al show a good agreement between the experimental and calculated results (discrepancies ≤ 10%). The discrepancies are inside 20% for Cu, Sn, Ti, W and Ag. The largest discrepancies are for Hf (55%) , Ni (79%) , Cd (35%) and Re (30%).

5.2 Comparison between ANITA-4M and FISPACT-2010 calculations

For the electron decay heats, the ANITA-4M and FISPACT-2010 calculated results differ by less than 5% for all the materials except for Hf (13%), Ni(30%), Cd (12%) and Sn (26%). For Sn, ANITA-4M overestimates the experimental values whereas, on the contrary, FISPACT-2010 gives an underestimation.

For the photon decay heats, the ANITA-4M and FISPACT-2010 calculated results differ by less than 5% for all the materials, except for Hf (10%) and Ni (16%).

For the activity, the ANITA-4M and FISPACT-2010 calculated results differ by less than 2% for all the materials, except for Hf (7%).

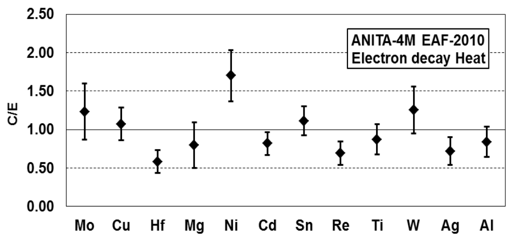

Figure 1. Material electron decay heat: calculated (C) and experimental (E) comparison.

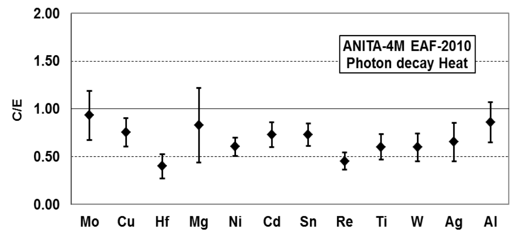

Figure 2. Material photon decay heat: calculated (C) and experimental (E) comparison.

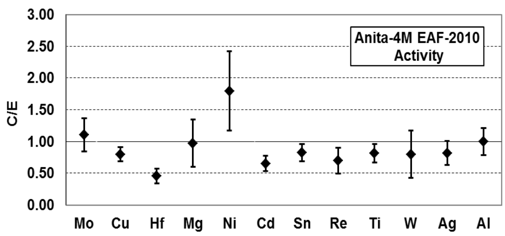

Figure 3. Material activity: calculated (C) and experimental (E) comparison.

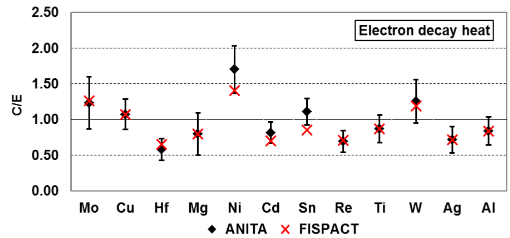

Figure 4. Material electron decay heat: ANITA-4M and FISPACT-2010 comparison.

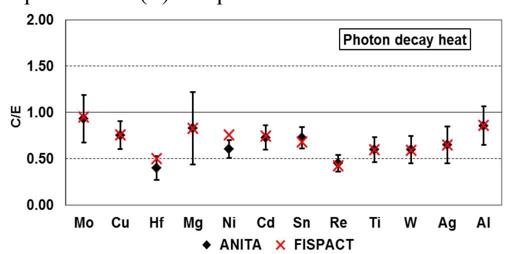

Figure 5. Material photon decay heat: ANITA-4M and FISPACT-2010 comparison.

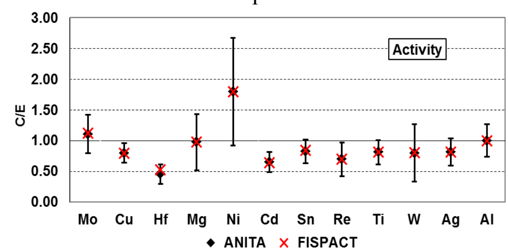

Figure 6. Material activity: ANITA-4M and FISPACT-2010 comparison.

6 Conclusion

The validation of the updated decay data library (file fl1) based on JEFF-3.1.1 evaluated data was performed through the comparison between ANITA-4M calculated values and the measured electron and photon decay heats and activities of twelve fusion material samples irradiated at the 14 MeV Frascati Neutron Generator (FNG) of the ENEA-Frascati Research Centre.

For sake of comparison the FISPACT-2010 code has been also used for decay heat and activity calculations.

The ANITA-4M and FISPACT-2010 results are quite comparable confirming once again that both are reliable tools for the activation calculations in the frame of the fusion field.

The ANITA-4M and FISPACT-2010 calculations were performed by using the same neutron activation cross sections based on EAF-2010 data. The differences between the ANITA-4M and FISPACT-2010 results can be explained as due to differences in the decay data (e.g. life-times, beta and gamma decay energies, etc.) and/or a different numerical treatment of the nuclear chains.

The calculation/experiment comparison presented in this paper shows that the decay data and the neutron activation cross sections also of the most recent evaluations need a further assessment and improvement.

References

1. D.G. Cepraga, G. Cambi, M. Frisoni, ANITA-2000 Activation Code Package. Part I - Manual, ENEA Report ERG-FUS/TN-SIC TR 16/2000 (2000)
2. D.G. Cepraga, G. Cambi, M. Frisoni, ANITA-2000 Activation Code Package. Part II : Code validation, ENEA Report FUS-TN-SA-SE-R-020 (2001)
3. D.G. Cepraga, G. Cambi, M. Frisoni, G.C. Panini, ANITA-2000, OECD NEA Data Bank NEA-1638, (2000)
4. D.G. Cepraga, G. Cambi, M. Frisoni, G.C. Panini, ANITA-2000, RSICC CCC-693 (2002)
5. G. Cambi, D.G. Cepraga, M. Frisoni, Experimental fusion material photon and electron decay heat measurements: Its use for activation codes validation, Fus. Eng. and Des. **75–79**, pp. 1253–1256 (2005)
6. D.G. Cepraga ,G. Cambi, F. Carloni, M. Frisoni, D. Ene, Neutronics and activation calculation for ITER generic site safety report, Fus. Eng. and Des. **63-64** pp. 193–197 (2002)
7. G. Cambi, D.G. Cepraga, M. Frisoni, Material activation assessment for waste analysis of the EU design of RC/RTO ITER, Fus. Eng. and Des. **58–59**, pp. 949–954 (2001)
8. C. Ponti and S. Stramaccia, ANITA: Analysis of Neutron Induced Transmutation and Activation, EUR 12622 EN report (1989)
9. J.-Ch. Sublet, J. Kopecky and R.A.Forrest, The European Activation File: EAF-99 cross section library, UKAEA FUS 408 (1998)
10. A.B. Pashchenko, H.Wienke, J. Kopecky, J.-Ch. Sublet and R.A. Forrest, FENDL/A-2.0 Neutron Activation Cross Section Data Library for Fusion Applications, report IAEA-NDS-173, Rev. 1(1998).
11. R.A. Forrest and F.M. Mann, FENDL/D-2.0, Decay Data Library for Fusion Applications, summary documentation by A. B. Pashchenko and H. Wienke, report IAEA-NDS-178 (1997)
12. M.A. Kellet, The JEFF-3.1.1 Decay Data Library, JEFDOC-1188 (2007)
13. J.-Ch. Sublet, L.W. Packer, J. Kopecky, R.A. Forrest, A.J. Koning and D.A. Rochman, The European Activation File: EAF-2010 neutron-induced cross section library, CCFE-R (10) 05
14. EASY-2010 OECD NEA Data Bank NEA-1564/13 (2011)
15. ENDF-6 Formats Manual Data Formats and Procedures for the Evaluated Nuclear Data Files ENDF/B-VI and ENDF/B-VII Written by the Members of the Cross Sections Evaluation Working Group, Edited by M. Herman and A. Trkov (2010)
16. Application of the Concepts of Exclusion, Exemption and Clearance, IAEA Safety Standard Series No. RS-G-1.7, IAEA Vienna (2004)
17. IAEA, Clearance levels for radionuclides in solid materials - Application of exemption principles, IAEA-TECDOC-855, IAEA, Vienna, (1996)
18. M. Martone, M. Angelone, M .Pillon, The 14 MeV Frascati neutron generator, J.of Nucl.Mat. **212-215,** pp. 1661-1664 (1994)
19. M. Pillon, M. Angelone, R.A. Forrest, Development of a Spectrometer to Measure Photon and Electron Decay Heat from Radionuclides, J. of Nucl. Sci. and Techn., Supplement 2, pp. 649-652 (2002)
20. M. Frisoni, Updating of the Libraries Included in the ANITA-2000 Code Package on the Basis of the JEFF-3.1.1 Radioactive Decay Data Library, ENEA Report ADPFISS-LP1-025 (2014)