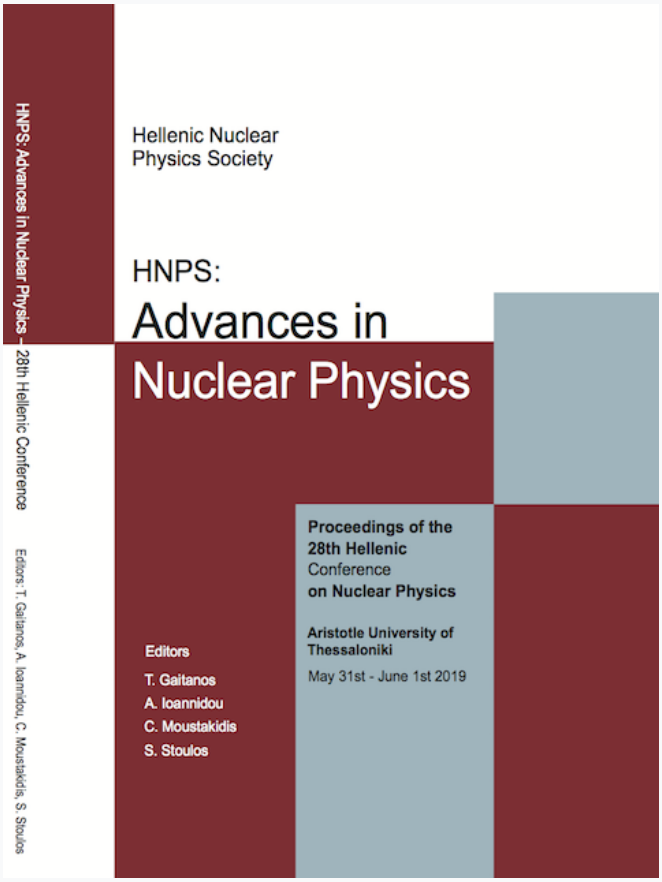
HNPS Advances in Nuclear Physics

Vol 27 (2019)

HNPS2019



Neutron induced transmutations in tungsten for fusion energy applications: Preliminary results

Vasileios Chatzikos, Marilia I. Savva, Theodora Vasilopoulou, Konstantina Mergia, Ion E. Stamatelatos, Dmitry Terentyev, Alexey Stankovskiy, Spyros Messoloras

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V. Chatzikos[1,2], M.I. Savva[1], T. Vasilopoulou[1], K. Mergia[1], I.E. Stamatelatos[1], D. Terentyev[3], A. Stankovskiy[3] and S. Messoloras[1]

[1] *Institute of Nuclear & Radiological Sciences and Technology, Energy & Safety, NCSR Demokritos, Aghia Paraskevi, 15341, Greece*
[2] *Department of Physics, School of Sciences, University of Ioannina, Ioannina, 45110, Greece*
[3] *SCK·CEN, Institute for Nuclear Material Sciences, B-2400 Mol, Belgium*

Abstract *Scope of the work is the validation of the methodology applied for the prediction of induced activity and transmutation products in Tungsten due to neutron irradiation. Three types of tungsten products were irradiated at the BR2 material test reactor, SCK-CEN, Belgium, at doses of 0.12 and 0.18 displacements per atom (dpa) at the irradiation temperatures of 600, 800, 900 and 1200 ℃. Gamma spectroscopy enabled the determination of the concentration of activities of the isotopes ^{185}W, ^{181}W, ^{188}W, ^{188}Re and ^{182}Ta in the irradiated samples. The results were compared with FISPACT-II calculations and in the case of ^{185}W a satisfactory agreement between the calculated and experimental data was observed.*

Keywords *fusion materials, gamma spectroscopy, tungsten, MCNP, FISPACT-II*

Corresponding author: V. Chatzikos (v.chatzikos@ipta.demokritos.gr) | *Published online:* **PROOF COPY**

INTRODUCTION

Tungsten is a candidate Plasma Facing Material in future fusion power plants presenting high melting point, high thermal conductivity, low coefficient of thermal expansion, high sputtering threshold energy, low tritium retention and low neutron activation properties. However, the properties of tungsten can be detrimentally altered under the high neutron fluence irradiation encountered in a fusion plant due to the accumulation of neutron induced transmutation products [1, 2].

Scope of the present work is the validation of the methodology applied for the advanced prediction of transmutation products and their activity in Tungsten due to neutron irradiation.

EXPERIMENTAL DETAILS

Three types of tungsten products were irradiated at the BR2 research reactor, SCK-CEN, Belgium, at doses of 0.12 and 0.18 displacements per atom (dpa) at the irradiation temperatures of 600, 800, 900 and 1200 ºC. The samples were fabricated from: (a) high purity (99.999%) single crystal tungsten (SC) supplied in a form of rod, (b) swaged tungsten bar (BAR) of 36×36 mm^2 cross section, forged/hammered from the two orthogonal directions (>99.97% purity), and (c) rolled tungsten sheet (PL) of 1 mm thickness (>99.97% purity). The activation products were determined using a calibrated spectrometry system based on a Germanium detector of 40% relative efficiency. Since sample activities were quite high, samples were positioned at a distance of 100 cm from the detector. At this distance the detector's dead time during the measurements was less than 5-6% and, moreover, the samples could be considered to be point sources.

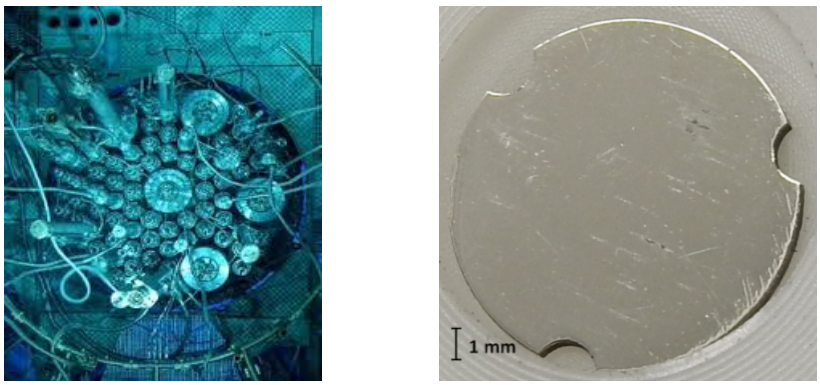

Figure 1. *(a) BR2 Reactor Core, (b) Tungsten Sample.*

The radioactive isotopes to be detected were produced by (n, γ) reactions on the isotopes of tungsten. The activity was determined by eqs. (1) and (2) [3]:

$$R = \frac{\sum_i (R_i / s_i^2)}{\sum_i (1/s_i^2)} \tag{1}$$

$$R_i = \frac{N_i}{eff(E_i) \cdot I_i \cdot t_{live}} \cdot f_{self-att} \tag{2}$$

where $f_{self-att} = \frac{\mu(E) \cdot L}{1 - e^{-\mu(E) \cdot L}}$ is the self-attenuation correction factor, $\mu(E)$ is the energy dependent attenuation coefficient, L is the thickness of the sample, N_i are the counts of the peak at energy E_i, I_i is the emission probability of the photon with energy E_i, t_{live} is the measurement time of the detector in s, $eff(E_i)$ is the full energy peak efficiency for the energy E_i and s_i is the uncertainty of R_i.

SIMULATIONS

Theoretical calculation of the transmutation product activities, as well as their evolution in time, was performed using the nuclide inventory code FISPACT-II [4] with cross section data from both TENDL-2017 and EAF–2010 library [5,6]. The neutron spectrum and fluence were evaluated by SCK·CEN using a detailed MCNP model of the BR-2 reactor core and irradiation elements. The neutron energy spectrum used by the FISPACT-II code is given in Fig. 2.

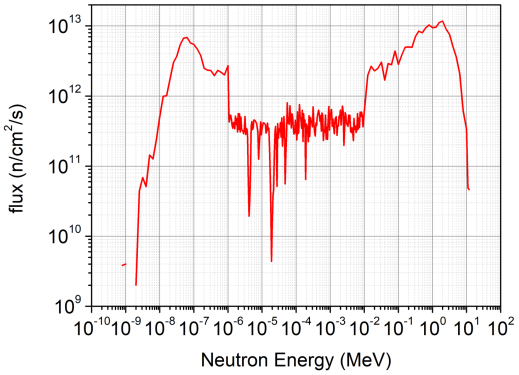

Figure 2. *Neutron spectrum at position G180 channel of BR2 (where the samples were irradiated), used for FISPACT-II calculations.*

RESULTS AND DISCUSSION

The gamma spectrum of a rolled sheet tungsten sample irradiated at T=600°C, up to 0.12 dpa, is shown in Fig. 3. In agreement with the theoretical calculations, the dominant spectrum peaks were attributed to ^{185}W, ^{181}W, ^{188}W, ^{188}Re and ^{182}Ta.

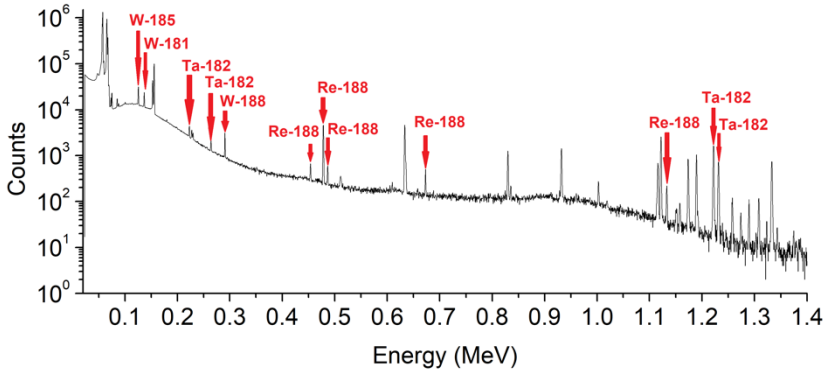

Figure 3. *Gamma spectrum of rolled sheet tungsten sample irradiated at T=600°, up to 0.12 dpa.*

A comparison of the FISPACT-II specific activity calculations for ^{185}W and ^{181}W against experimental data from measurements for the three types of W and four irradiation temperatures tested is given in Fig. 4. For both isotopes, the measured specific activities are almost the same, within error bar, for all W material types and irradiation conditions, as expected. The nuclear data libraries used for the calculations are TENDL-2017 and EAF-2010. A satisfactory agreement between calculated and experimental specific activities is observed in the case of ^{185}W, especially in the case of TENDL-2017 nuclear data base. However, in the case of ^{181}W, only the calculated data using EAF-2010 agree with the experimental ones while the use of TENDL-2017 data base results in an overestimation of the specific activities by a factor of about three. This difference is due to the difference between the two libraries in the neutron absorption cross-section of ^{180}W in the thermal part of the energy spectrum. TENDL-2017 presents three times higher absorption cross section for ^{180}W than EAF-2010 in the energy range 10^{-5}-10 eV.

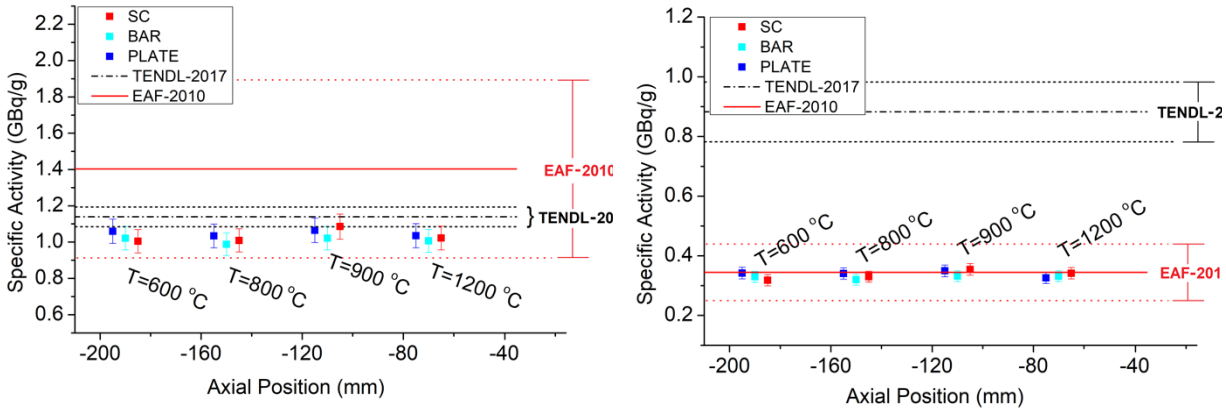

Figure 4. *Specific activity of ^{185}W (left) and ^{181}W (right) for 0.18 dpa samples normalized to 0.2 dpa, at 475 days after the end of irradiation, versus axial position in the irradiation channel.*

A future work will be expanded to include gamma spectroscopy measurements on tungsten samples irradiated at 0.5 and 0.75 dpa and detailed calculation of the transmutation products.

Acknowledgments

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under Grant Agreements No. 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission. V. Chatzikos acknowledges support of this work by the project "NCSRD – INRASTES research activities in the framework of the national RIS3" (MIS 5002559) which is implemented under the "Action for the Strategic Development on the Research and Technological Sector", funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014-2020) and co-financed by Greece and the European Union (European Regional Development Fund).

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