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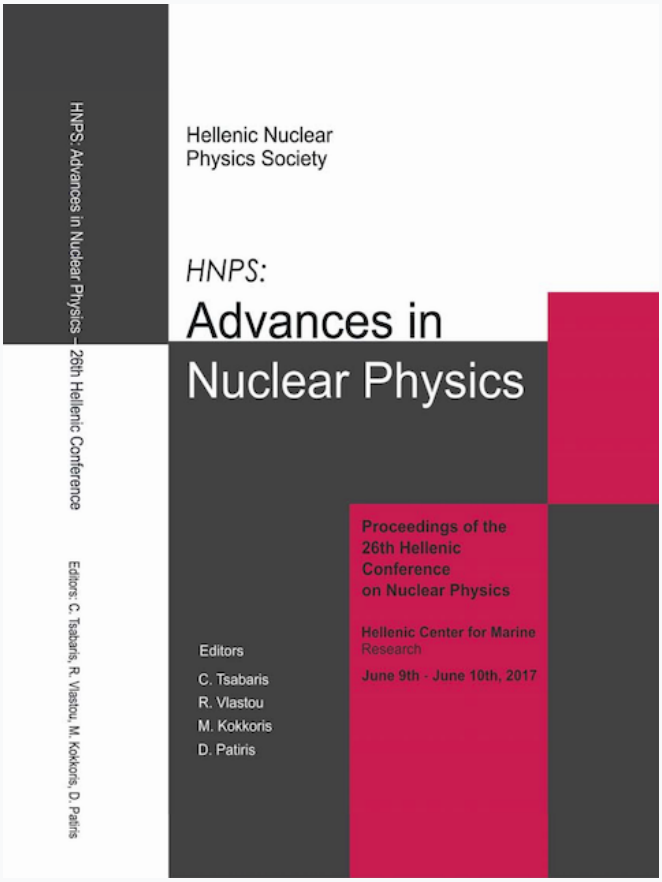

Development of a novel neutron detector for fusion - Preliminary results

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Development of a Novel Neutron Detector for Fusion – Preliminary results

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Abstract For future fusion reactors such as ITER and DEMO there is a great need for detectors capable to accurately monitor neutrons under the harsh conditions imposed by the fusion environment. In particular, it is required to utilize detectors that are capable to accurately measure neutron fluence under high and variable neutron count rates, high gamma background, high temperature and high and variable magnetic fields encountered during the measurement. A novel neutron activation detector providing a robust approach for accurate neutron fluence measurements under the harsh environment conditions encountered in a fusion plant has been proposed. The detector comprises of a composite low activation matrix compound capsule containing a defined concentration of added metallic elements (targets). The neutron fluence and energy spectrum will be inferred by analysis of the multiple gamma lines produced by the activation of the metallic elements in the matrix. In the present work, the candidate metallic elements (targets) for the new detector were defined. FISPACT-II radionuclide inventory code and EAF-2010 data were used to calculate induced activities and gamma ray detector responses for different conditions simulating irradiations at the Joint European Tokamak (JET) Short Term and Long Term Irradiation Stations. Moreover, the activation properties of different matrix materials were examined. The results of the study provided preliminary data for a detailed material trade-off investigation carried out in order to optimize detector target and matrix elements as well as the method of inclusion of the target elements in the matrix.

Keywords fusion; neutron detection; JET; ITER; FISPACT-II

INTRODUCTION

The neutron diagnostics in large tokamaks are the essential and primary means in estimating fusion power. The power output of fusion experiments and fusion reactor-like devices is measured in terms of the neutron emission rates which relate directly to the fusion yield rate. Different approaches have been developed in order to measure neutrons in fusion. Most fusion experiments employ both active detectors located around the machine such as fission chambers, proportional counters, scintillation detectors etc. enabling to monitor the time evolution of the neutron emission rate as well as complementary systems which allow determining local neutron fluence levels off-line (1).

Neutron activation methods are well suited to perform accurate measurements of the neutron fluence in environments with a high background of gamma-rays or other forms of

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radiation and magnetic fields. Their response is linear over a wide range of fluence rates. Moreover, since activation detectors are passive detectors, they address the problem of measuring neutrons in the presence of electromagnetic fields, high temperature and high radiation loads, i.e. in environments where active detectors may lose their reliability. At JET, for example, neutron activation systems are used to measure neutron yield and provide complementary information to highly sophisticated instruments such as advanced neutron spectroscopy systems and neutron cameras (2). They have been shown capable to provide neutron measurements with accuracy better than 10% (3), as required for example for ITER, where precise neutron yield measurement is important for tritium accountancy.

A novel neutron activation detector providing a robust approach for accurate neutron fluence measurements under the harsh environment conditions encountered in a fusion plant has been proposed. The detector comprises of a composite low activation matrix compound capsule containing a defined concentration of added metallic elements (targets). The neutron detector should be capable in a single measurement to perform characterization of the neutron energy spectrum from the thermal up to the fast neutron region, therefore allowing discrimination of the detected neutrons as primary from the source (D-D and/or D-T) and scattered from walls and other structural materials and components.

In the present work, the candidate metallic elements (targets) for the new detector were defined using state-of-the-art activity inventory codes and data for specified relevant fusion neutron spectra. The choice of elements is based on their neutron cross-sections, neutron interactions covering the whole range of fusion neutron energies (thermal up to 20 MeV), the half-lives of the product nuclides, as well as potential interferences between the emitted γ-rays and other related measurability factors.

METHOD

A set of 19 candidate active metallic elements (targets) was studied in terms of material and activation characteristics. Induced activity calculations were performed using FISPACT-II inventory code for different neutron irradiation and gamma ray detection schemes. The FISPACT-II code is part of the EASY package developed by the Culham Centre for Fusion Energy – CCFE (4) and predicts how materials evolve under irradiation and through radioactive decay processes. The input data required are the neutron spectrum, the target material and the mass to be irradiated, as well as the irradiation scheme and the cooling time. The results are in terms of specific activity (Bq/g) for each isotope. In this study the EAF-2010 nuclear data library was used with VITAMIN-J 175 group energy bin structure (5). The criterion for the estimation of the mass required for each of the examined elements is to get sufficient counting statistics at the photo-peaks at a given measurement time. Sufficient count rate at the time of the measurement was specified as 1 cps for short-time irradiations and as 0.1 cps for long-time irradiations. The calculated mass is the minimum required mass to achieve the set count rate. Larger mass will lead to a higher count rate, which is not prohibitive.

Irradiation schemes

Different irradiation time regimes were examined, representing measurement of a single neutron pulse or a long series of pulses. Two different positions in the JET reactor were considered: a) the inner position of the KN2 pneumatic rabbit for short term irradiations (Fig. 1.), and b) the position B of the Long Term Irradiation Station (Fig. 2). Moreover, the methodology will be validated by a set of experiments performed in quasi mono-energetic reference neutron fields. The experiments will be performed at the ENEA Fast Neutron Generator (FNG) facility (6). Thus, the irradiation scheme at FNG was also considered and the respective neutron spectrum is presented in Fig. 3.

All irradiation conditions considered in each position are summarized in Table 1. The neutron fluence rate was taken from the 2015-2016 DD campaign data. All evaluated neutron energy spectra are calculated using the MCNP code (7).

Position	Neutron plasma source	Neutron flux (n/cm^2/sec)	Irradiation
JET KN2 inner	D-D, T-T, D-T	1.82×10^{10}	1 pulse of 1sec
JET LTIS B	D-D, T-T, D-T	3.69×10^{10}	3682 pulses of 1 sec
FNG 5.5 cm	D-T	1.78×10^{8}	5 hours

Table 1. Examined irradiation/detection schemes

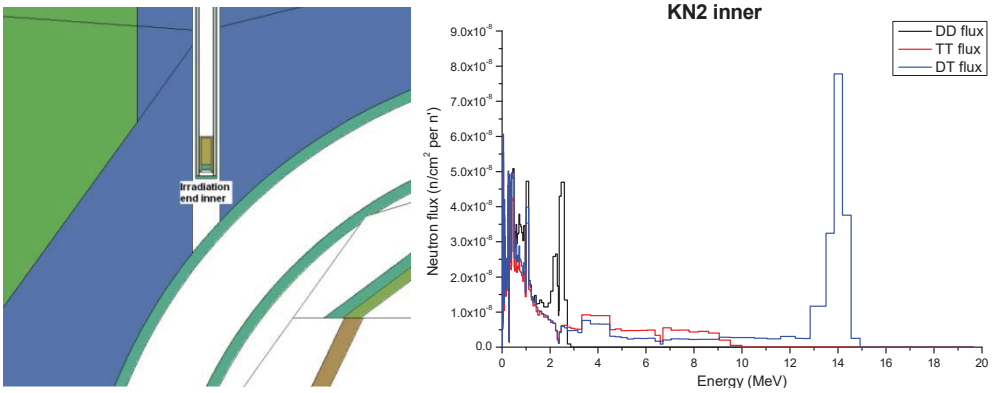

Fig. 1. KN2 inner position in JET (left) and the respective MCNP evaluated neutron energy spectrum (right).

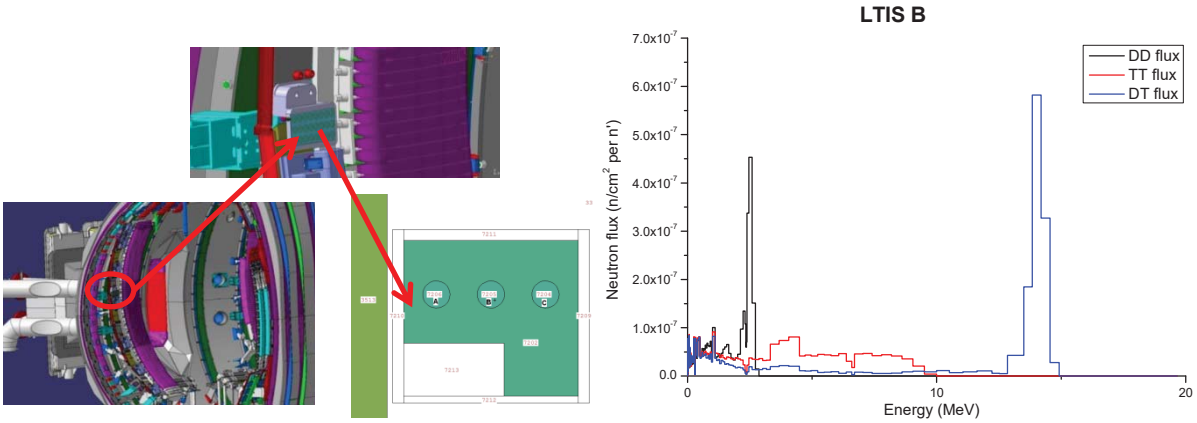

Fig. 2. LTIS B position in JET (left) and the respective MCNP evaluated neutron energy spectrum (right).

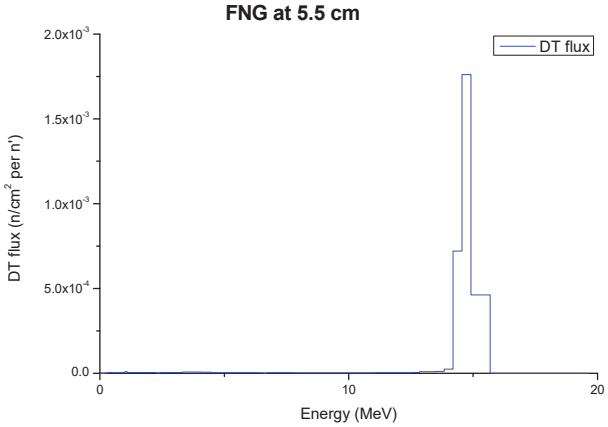

Fig. 3. MCNP evaluated neutron energy spectrum at FNG.

RESULTS AND DISCUSSION

The results in terms of induced activity as a function of time post-irradiation for DT plasma source, as calculated by the FISPACT-II code are presented in Fig. 4 for the JET KN2 inner irradiation position, Fig. 5 for the JET LTIS and Fig. 6 for the FNG facility.

From the results of the study of the candidate elements for all irradiation/detection scenarios, in general the same metallic elements are chosen. Some elements were excluded for the short irradiations at JET KN2 inner position due to the comparatively large half-life of the product isotopes, which indicates that a comparatively longer irradiation is needed for their formation. For example, ^{92m}Nb produced by the reaction ^{93}Nb(n,2n)^{92m}Nb has a half-life of 10.15 d, which is much larger than the neutron pulse duration at KN2 position. Moreover, some elements were excluded from the longer irradiation schemes at JET LTIS B and FNG, due to the short half-life of the products compared to the time post-irradiation.

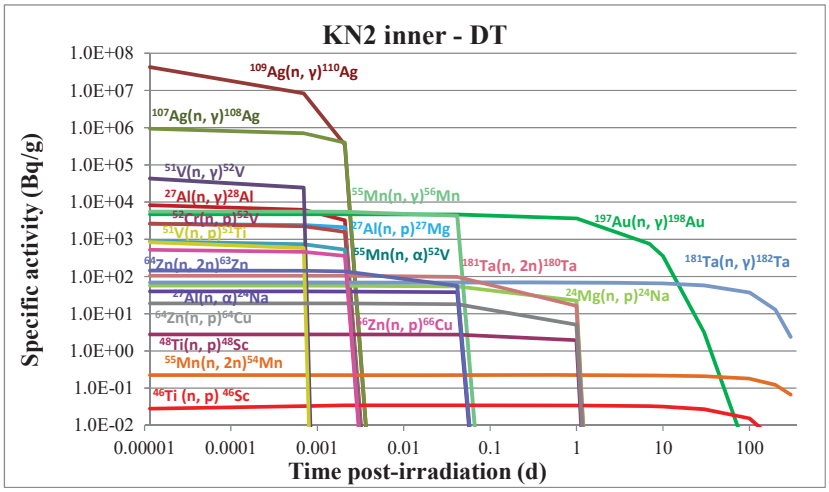

Fig. 4. Induced activity as a function of time post-irradiation for KN2 inner

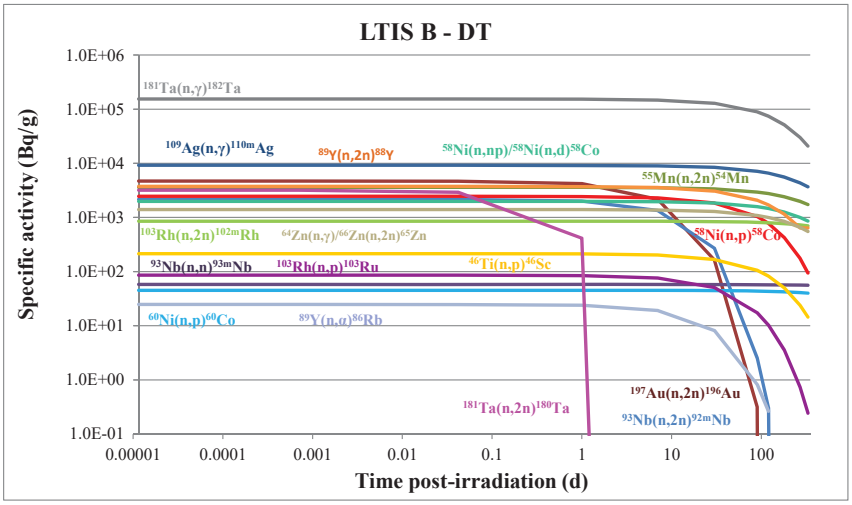

Fig. 5. Induced activity as a function of time post-irradiation for LTIS B

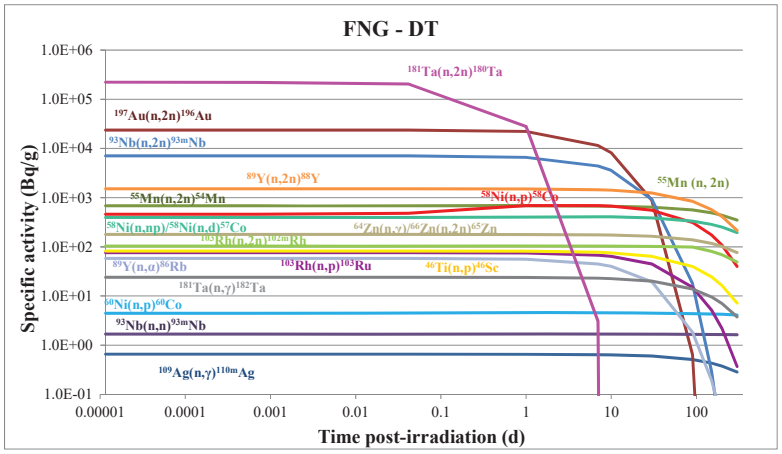

Fig. 6. Induced activity as a function of time post-irradiation for FNG

For the test experiments at ENEA Frascati Neutron Generator facility the proposed

detector composition is presented in Table 2. Advanced gamma spectrum prognosis using NAAPRO (8) is presented in Fig. 7.

Material	Threshold energy (MeV)	Reaction	Proposed mass (mg)
Ag	--	^{109}Ag (n, γ) ^{110m}Ag	3
Au	-- 8.13	^{197}Au (n, γ) ^{198}Au ^{197}Au (n, 2n) ^{196}Au	5
Mn	-- 0.64 10.50	^{55}Mn (n, γ) ^{56}Mn ^{55}Mn (n, α) ^{52}V ^{55}Mn (n, 2n) ^{54}Mn	2
Nb	9.00	^{93}Nb (n, 2n) ^{92m}Nb	0.3
Ni	0.40 2.20 9.24 6.08	^{58}Ni (n, p) ^{58}Co ^{60}Ni (n, p) ^{60}Co ^{58}Ni (n, np) ^{57}Co (67.8%) ^{58}Ni (n, d) ^{57}Co (32.2%)	2
Rh	9.50 0.20	^{103}Rh (n, 2n) ^{102}Rh ^{103}Rh (n, p) ^{103}Ru	13
Ti	1.62 3.29 -- 6.40	^{46}Ti (n, p) ^{46m}Sc ^{48}Ti (n, p) ^{48}Sc ^{50}Ti (n, γ) ^{51}Ti ^{50}Ti (n, p) ^{50}Sc	200
Y	3.03	^{89}Y (n, α) ^{86}Rb	40
Zn	-- 11.32 12.50	^{64}Zn (n, γ) ^{65}Zn ^{66}Zn (n, 2n) ^{65}Zn ^{64}Zn (n, 2n) ^{63}Zn	80

Table 2. Proposed elements and masses for the FNG experiments

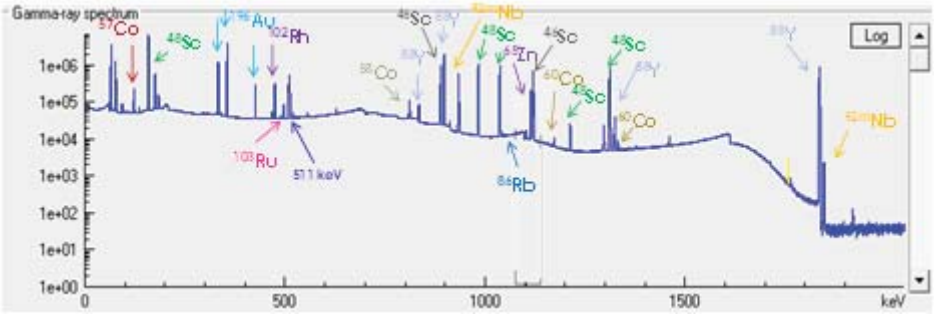

Fig. 7. Gamma spectrum prognosis for the proposed detector composition after FNG irradiation

CONCLUDING REMARKS

Several metallic elements have been studied using the FISPACT-II code in terms of activation characteristics (cross-sections, product half-life, interferences between activation products and γ-lines) and a preliminary active elements composition for the new activation detector was proposed. Taking into account the requirements for the target elements, the fabrication of the proposed detector will follow. Processes will be developed, tested out-of-field, optimized and the most promising route for fabrication will be defined in parallel with the matrix composition. A material trade-off investigation will be carried out in order to optimize the inclusion of the target elements in the matrix. Following these, a number of

prototype detectors will be fabricated and tested at ENEA Fast Neutron Generator facility. Depending on their performance, fabrication parameters will be improved and better tuned to the requirements and specifications.

Acknowledgements

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References

[1] Batistoni, P. Fusion Engineering and Design (105), p. 58 (2016)
[2] Prokopowicz, R., et al., Nuclear Instruments and Methods (637), p. 119 (2011)
[3] Syme, D.B., et al., Fusion Engineering and Design (89), p. 2766 (2014)
[4] Sublet, J.-C., et al., CCFE-R (11). s.l. : UK Atomic Energy Authority (2013)
[5] Sublet, J.-C., et al., CCFE-R (10) 05 (2010)
[6] Martone, M., et al., Journal of Nuclear Materials (212-215), p. 1661 (1994)
[7] Goorley, T., et al. Nuclear Technology (180), p. 298 (2012)
[8] Basenko, V.K., et al., Journal of Radioanalytical and Nuclear Chemistry (263), p. 675 (2005)