EUROFUSION WPJET3-CP(16) 15300

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Status and planning of ITER material activation experiments at JET

Preprint of Paper to be submitted for publication in Proceedings of 29th Symposium on Fusion Technology (SOFT 2016)

Status of ITER material activation experiments at JET

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Activities under the EUROfusion work package JET3 programme have been established to enable the technological exploitation of the planned JET experiments over the next few years, which culminates in a D-T experimental campaign, DTE-2. In the areas of nuclear technology and nuclear safety the programme offers a unique opportunity to provide experimental data that is relevant to ITER. The key purpose of the collected data will be to support benchmarking and validation activities relating to neutronics and activation codes, and associated nuclear data, that are used to predict the nuclear behavior of ITER component and materials, during and after operations.

This paper details the status and key issues of the ongoing ACT sub-project under work package JET3, which aims to take advantage of the large 14 MeV neutron fluence expected during JET DTE-2 to irradiate samples of real ITER materials used in the manufacturing of the main in-vessel tokamak components. The materials considered, with specified minor elemental impurity levels, include: Nb_3Sn, SS316L steels from a range of manufacturers, SS304B, Alloy 660, Be, W, CuCrZr, OF-Cu, XM-19, Al bronze, NbTi and EUROFER. The activities include provision for measurement of nuclide activities for each material and comparison against the predicted quantities through calculation with the FISPACT-II inventory code. Included here are key pre-analysis results for the selected ITER irradiation samples, and corresponding optimization of dosimetry foils (Ti, Mn, Co, Ni, Y, Fe, Co, Sc, Ta) that will be irradiated at selected positions inside JET irradiation stations in order to determine the neutron spectrum. Preliminary experimental activation results through recent JET D-D operations are discussed.

Keywords: JET, ITER, activation, neutronics

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1. Introduction

Activities under the EUROfusion work package (WP) JET3 programme have been established to enable the technological exploitation of the planned JET experiments over the next few years, which culminates in a D-T experimental campaign, DTE-2 [1]. In the areas of nuclear technology and nuclear safety the programme offers a unique opportunity to provide experimental data that is relevant to ITER.

The aim of the WPJET3 ACT subproject is to perform benchmark irradiation experiments at JET, taking advantage of the large 14 MeV neutron fluence expected during the JET DTE-2 campaign, to irradiate samples of real ITER materials used in the manufacturing of the main in-vessel tokamak components, with a neutron flux comparable to the ITER flux near cryostat locations. In order to meet the aims the project requires detailed characterization of irradiation positions in JET are required. Figure 1 shows an example of the sample holder that contains a number of dosimetry foils. Two positions to place assemblies were considered inner long-term irradiation station (ILTIS), shown in figure1, and outer long-term irradiation station (OLTIS). These positions have been subjected to pre-analysis via neutronics and activation calculations to determine predictions of activity levels and measurement criteria for dosimetry foils and the selected material samples. Measurement of nuclide activities for each material and comparison against predicted quantities through calculation with the FISPACT-II inventory code will be performed.

The materials considered to date, with specified minor elemental impurity levels, include: SS316L steels from a range of manufacturers, SS304B, Alloy 660, Be, W, CuCrZr, OF-Cu, XM-19, Al bronze, Nb_3Sn, NbTi and EUROFER. Example images of some of the bulk materials already acquired by F4E are shown in Figure 2.

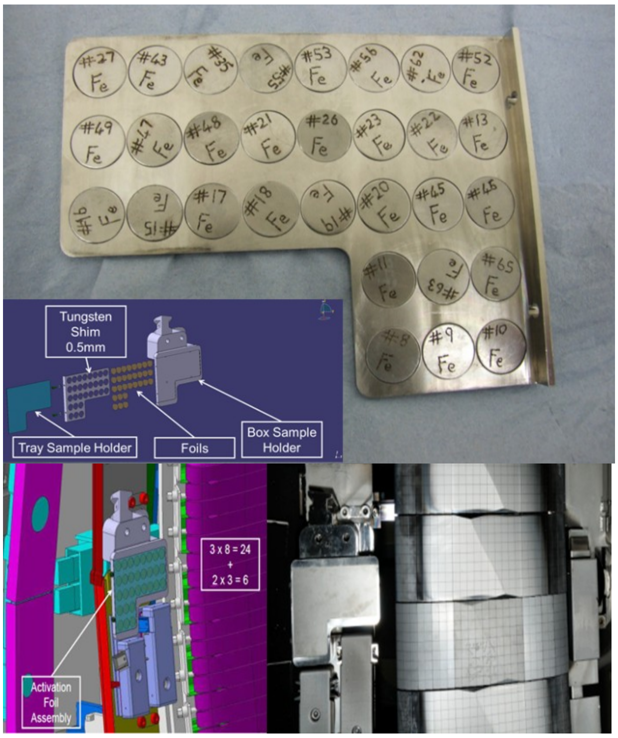

Figure 1: (top) Activation foil assembly prior to installation in JET. (bottom) Activation foil assembly at the ILTIS position in JET.

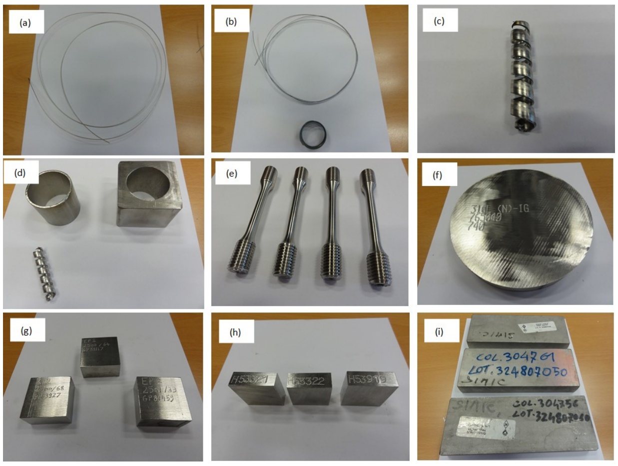

Figure 2: Images of some of the ITER materials that have been selected. (a,b) PF and TF Nb_3Sn strands; (c) TF cooling spiral (316L steel); (d) : TF jacket (316L(N), top left, PF jacket (316L), top right, TF cooling spiral (316L), bottom; (e-f) various 316L(N) steel specimens from TF and PF components and 316L(N)-IG VV forged block.

2. Pre-analysis activation studies

Pre-analysis has been performed for the selected ITER irradiation samples, and corresponding optimization of dosimetry foils (Ti, Mn, Co, Ni, Y, Fe, Co, Sc, Ta) that will be irradiated at selected positions inside JET irradiation stations in order to determine the neutron spectrum.

Figure 3 shows the total specific activity predictions for the ILTIS for selected ITER materials. A comparison was made at the OLTIS position though the levels of the activities of ITER materials are determined to be similar for these positions.

Among the considered ITER materials, Nb_3Sn (as used for the poloidal and toroidal field coils) and W (as used for the divertor) show the highest total specific activities (see Figure 3). Concurrently, OF-Cu (divertor), Be (Be armour) and CuCrZr (first wall, divertor) are predicted to have the lowest total specific activities.

The accurate knowledge of the contents of impurities present in ITER materials is of a great importance since some of them (e.g. Ta in SS316L, CuCrZr, EUROFER) contribute significantly to the total activity following irradiation. This is illustrated in Figure 4; the highest contribution to the total activity of Nb_3Sn comes from the presence of Ta ($^{181}Ta(n,\gamma)^{182}Ta$, T1/2=114.43 d), which is used as a diffusion barrier.

The activities induced in dosimetry foils (Sc, Ti, Mn, Fe, Co, Ni, Y, Ta) irradiated in the LTIS position remain at a high level (even up to 1×10^7 Bq for 2 mm thick foils, φ=18 mm) for a significant period of time. To enable measurement, activities are ideally in the 10s kBq range, thus, the use of thinner foils (with smaller masses) in the D-T campaign will be considered.

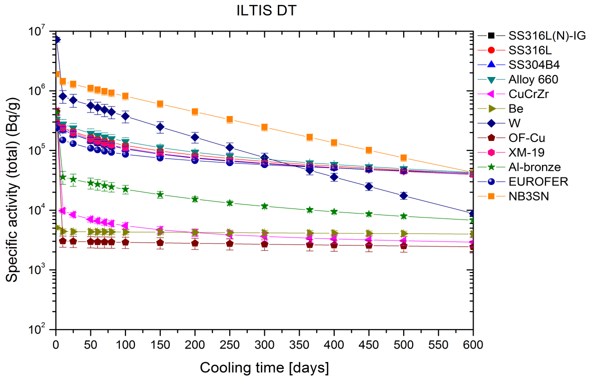

Figure 3: Total specific activity [Bq/g] of ITER materials irradiated in ILTIS position at JET.

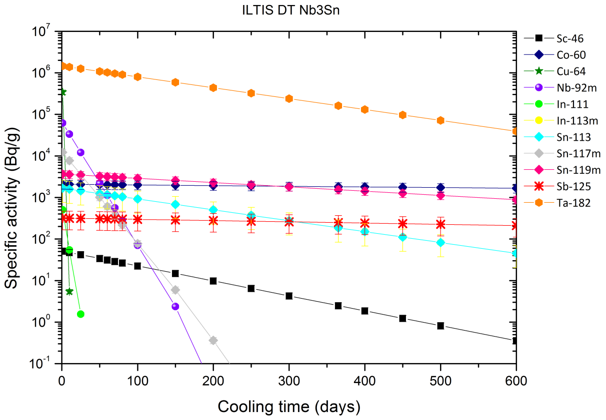

Figure 4: Time evolution of activity of the dominant radionuclides in Nb_3Sn irradiated in ILTIS.

3. Activation foil measurement feasibility analysis for JET DD campaigns

A scoping study was performed using IFJ, NCSRD and CCFE HPGe measured detector response to determine the expected activation foil measurement requirements following the irradiation of foils through 2016 JET DD operations, also including a prediction for neutron irradiation for JET campaigns that are expected up until the early part of 2017.

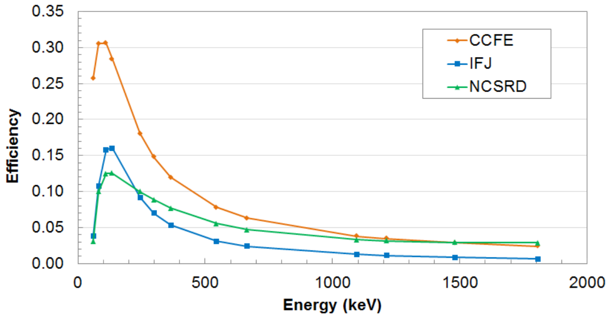

Figure 5: CCFE, IFJ and NCSRD detector absolute full energy peak efficiency functions.

Figure 5 shows the full energy peak efficiency functions for the CCFE, IFJ and NCSRD detection systems and Figure 6 shows a number of images of the various detection systems that are considered for low activity measurements at these laboratories.

The JET irradiation scenario for the LTIS dosimetry foils, including the predicated end of 2016 and early 2017 shots, is shown in Figure 7. A month of 1 second pulses with a neutron yield/shot of 1 x 10^{16} has been assumed. The specific activity for the nuclides from each analyzed reaction was calculated using FISPACT-II with EAF-2010 nuclear data. The specific activity is shown over 500 days in Figure 7. The neutron flux spectrum in the LTIS location is shown in the figure insert.

Figure 6: (a) IFPiLM HPGe detector and lead shielding; (b) IFJ PAN HPGe detector and lead shielding; (c) CCFE BEGe detector with NaI Compton suppression ring; (d) CCFE SAGe well detector.

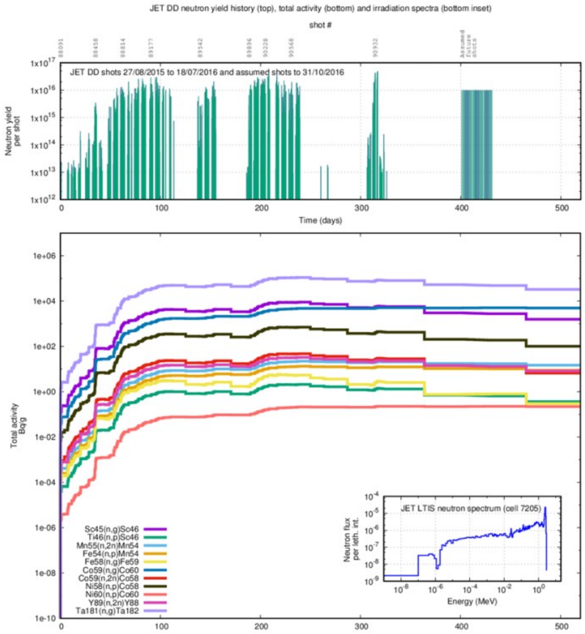

Figure 7: JET irradiation scenario and predicted foil specific activities at the ILTIS position.

Using the calculated specific activities at 70 days after the end of JET irradiation (to account for required cooling time and the processing of samples through the beryllium handling facility) the predicted nuclide peak counts during a 3 hour count period are shown in Table 1. The count time required to achieve 10k counts is also estimated and shown in the table.

The predicted peak counts were calculated using detector efficiency functions for the CCFE, IFJ and NCSRD detector setups. The majority of the nuclides should be measurable with either detector, though longer count times and lower count peaks will likely be required for ^{58}Fe(n,γ)^{59}Fe, ^{60}Ni(n,p)^{60}Co and ^{46}Ti(n,p)^{46}Sc. Longer count times are required for the IFJ setup.

Table 1: Predicted peak counts and required measurement times for dosimetry reactions using various detection systems following irradiation at the ILTIS position.

			Detected peak counts			Time required for 10,000 peak counts (hours)		
Foil	Reaction	Nuclide for detection	CCFE	IFJ	NCSRD	CCFE	IFJ	NCSRD
Fe	^{54}Fe(n,p)^{54}Mn	Mn54	4.72E+03	1.68E+03	3.70E+03	6.36	17.87	8.10
Fe	^{58}Fe(n,g)^{59}Fe	Fe59	6.89E+01	2.25E+01	5.95E+01	435.29	1332.79	503.80
Ni	^{58}Ni(n,p)^{58}Co	Co58	6.22E+04	2.23E+04	4.84E+04	0.48	1.34	0.62
Ni	^{60}Ni(n,p)^{60}Co	Co60	9.55E+01	3.04E+01	8.51E+01	314.23	985.77	352.60
Co	^{59}Co(n,g)^{60}Co	Co60	2.14E+06	6.82E+05	1.91E+06	0.01	0.04	0.02
Co	^{59}Co(n,2n)^{58}Co	Co58	4.10E+03	1.47E+03	3.19E+03	7.32	20.39	9.39
Ta	^{181}Ta(n,g)^{182}Ta	Ta182	9.68E+06	3.14E+06	8.44E+06	0.003	0.010	0.004
Ti	^{46}Ti(n,p)^{46}Sc	Sc46	1.05E+02	3.67E+01	8.39E+01	285.61	816.53	357.51
Y	^{89}Y(n,2n)^{88}Y	Y88	2.19E+03	7.65E+02	1.76E+03	13.67	39.20	17.06
Mn	^{55}Mn(n,2n)^{54}Mn	Mn54	7.30E+03	2.60E+03	5.73E+03	4.11	11.55	5.24
Sc	^{45}Sc(n,g)^{46}Sc	Sc46	2.52E+05	8.81E+04	2.01E+05	0.12	0.34	0.15

4. Measurements of short-lived activation products in JET DD campaign

In addition to the irradiation of ITER materials in the LTIS position for measurement of long-lived products, the irradiation of materials using the KN2 3U position will be utilised to focus on measurement of short-lived reaction product that will be present. To test and characterise the irradiation position and methodologies, measurements of radioactivity induced in dosimetry foils were performed during the C-33 DD experimental campaign at JET were performed. A capsule containing dosimetry foils is irradiated in the KN2 3U position then pneumatically transported to a measurement station where the sample is retrieved and subsequently measured via gamma spectrometry methods using a HPGe detector. The reactions ^{27}Al(n,p)^{27}Mg, ^{27}Al(n,α)^{24}Na, ^{56}Fe(n,p)^{56}Mn and ^{93}Nb(n,2n)^{92m}Nb were utilised as neutron monitor reaction in these experiments. The results of measured activities for short lived products were recorded for six JET pulses and these were compared with simulations using FISPACT-II and MCNP6 calculations to predict activities. For brevity in this paper only shot 87214 activity measurement results and associated uncertainties are presented here in Table 2. Measured and simulated activities are within experimental error, with the exception of the ^{90}Zr(n,2n)^{89}Zr and ^{56}Fe(n,p)^{56}Mn reaction which require further study and analysis. Full results and analysis are presented in WPJET3 project documentation.

Table 2: Comparison of IFPiLM experimental results @KN2-3U activation end during the C-33 experimental campaign for 87214 JET pulse with FISPACT-II simulation.

JET pulse: 87214, Y_n=2.77·10^{16} n/s, t_{irr}=6 s				
Reaction	**C-33**		**FISPACT-II**	
	A_{spec} [Bq/g]	**unc. [Bq/g]**	**A_{spec} [Bq/g]**	**unc. [Bq/g]**
^{27}Al(n,p)^{27}Mg	472	20	471	47
^{27}Al(n,α)^{24}Na	6.0	0.3	6.1	2.8
^{56}Fe(n,p)^{56}Mn	62.5	2.2	14.70	0.44
^{24}Mg(n,p)^{24}Na	7.52	1.03	8.7	4.1
^{58}Ni(n,2n)^{57}Ni	0.127	0.019	0.1391	0.0070
^{90}Zr(n,2n)^{89}Zr	1.02	0.06	0.63	0.19
^{93}Nb(n,2n)^{92m}Nb	0.425	0.027	0.420	0.042

3. Discussion and summary

The WPJET3 ACT subproject will take advantage of the large 14 MeV neutron fluence expected during JET DTE-2 to irradiate samples of real ITER materials used in the manufacturing of the main in-vessel tokamak components. To date a number of pre-analysis and preparatory activities have been performed to support the project. The next key step will be to retrieve activation foils from the JET ILTIS position prior to distribution and analysis. In addition the ITER material selection, acquisition and specification process conducted by F4E is progressing with expectation that concrete samples will be included in irradiation experiments. Further improvements of the gamma spectrometry measurement capability are being planned at JET which are expected to support measurement aspects of this subproject, as well as other WPJET3 subprojects, notably TBMD and NC14.

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 under grant agreement No 633053 and from the RCUK Energy Programme [grant number EP/I501045]. To obtain further information on the data and models underlying this paper please contact PublicationsManager@ccfe.ac.uk. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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