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Technological exploitation of Deuterium-Tritium operations at JET in support of ITER design, operation and safety

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Within the framework of the EUROfusion programme, a work-package of technology projects (WPJET3) is being carried out in conjunction with the planned Deuterium - Tritium experiment on JET (DTE2) with the objective of maximising the scientific and technological return of DT operations at JET in support of ITER. This paper presents the progress since the start of the project in 2014 in the preparatory experiments, analyses and studies in the areas of neutronics, neutron induced activation and damage in ITER materials, nuclear safety, tritium retention, permeation and outgassing, and waste production in preparation of DTE2.

Keywords: *: JET, DT operations, activation, nuclear safety, tritium, waste*

1. Introduction

The DT campaign (DTE2) planned at JET in 2017 will provide considerable added value in many technological areas relevant to ITER and DEMO [1]. In the frame of the EUROfusion Consortium, the Work Package *DT Technology* (WPJET3) was launched to exploit the unique 14-MeV neutron yields produced in DTE2 (up to $1.7 \cdot 10^{21}$ neutrons) and the use of tritium to validate codes, assumptions, models, procedures and data currently used for ITER [2].

Preparatory work started in 2014 to implement the identified activities in time for DTE2. A new calibration of the JET neutron detectors with 14-MeV neutrons is being prepared to be performed before the start of DTE2. Neutronics experiments are also being prepared to validate the numerical tools used in ITER design, including a *Neutron streaming Experiment* through the penetrations of JET building, and a *Shutdown Dose Rate Experiment*. Experiments are designed to test detectors for ITER TBMs in a fusion environment with a high temperature, high magnetic field and radiation level. Activation measurements are prepared to characterize an in-vessel irradiation station where real ITER materials and functional materials will be irradiated for post-irradiation analysis. Data relevant to Occupational Radiation Exposure are collected during shutdown operations, and JET waste management and characterization procedures are reviewed for their applicability to ITER. New facilities are designed to study the tritium permeation, retention and outgassing in JET ITER-like Wall materials. A DEMO relevant, tritium compatible roughing pump is being developed and is planned to be tested in JET during DTE2.

The state and scope of the preparations is reviewed in the following sections, and highlights are given for all the above projects.

2. DTE2 Technology Projects

2.1 The calibration of JET neutron detectors with 14-MeV neutrons

An accurate calibration of JET neutron detectors - ^{235}U fission chambers (KN1) and the in-vessel activation system (KN2) - at 14-MeV neutron energy is needed to allow accurate measurements of the fusion power and of plasma ion parameters during DTE2, and of the neutron yields required for the analyses of the planned neutronics benchmark experiments. It is also needed in order to fully exploit the nominal neutron budget available, and

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*See the Appendix of F. Romanelli et al., Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia

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to obtain a full scientific return for the investment in DTE2. The 14-Mev neutron calibration will take advantage of the experience gained with the recent calibration of JET neutron detectors with 2.5 MeV neutrons [3], and will also benchmark the calibration procedure envisaged in ITER where neutron detectors have to provide, with an accuracy better than 10%, not only the fusion power but also the amount of tritium burnt for tritium accountancy [4].

The 14 MeV calibration will be performed using an accelerator based DT neutron generator (NG) in which 14-MeV neutrons are generated by a D$^+$ beam accelerated on a Ti target containing T. The NG will be deployed inside the vessel at different toroidal and poloidal positions by the JET remote handling (RH) boom and by its Mascot robotic arms (Fig.1a). The main driver in the design of the in-vessel calibration is given by the interfaces with JET RH system, mainly relating to cables for the NG power supply and control, to the Mascot weight handling limit (<10 kg), and by safety requirements. In the adopted solution, the power supply to the NG is delivered through the RH boom which is equipped with integrated 10 A, 600 V cables. In fact, in order to protect the integrity of the machine, it is strongly desirable to have the HV converter unit attached close to the neutron emitting tube, so that only LV cables are to be pulled inside the vessel during the RH boom movements. All JET RH power supplies (connectors, sockets etc.) have to comply with defined safety standards. This solution is illustrated in Fig.1b.

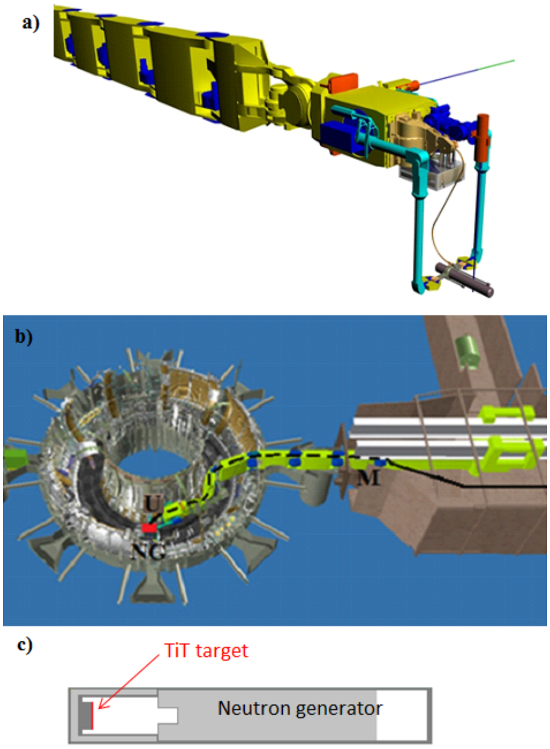

Fig. 1 - Layout of the 14 MeV neutron calibration: a) The neutron generator deployed by the RH Mascot arms; b) The NG deployed in vessel by remote handling: NG - Neutron Generator, U - Power supply and control unit, M - main cable using the cables embedded in the Mascot body; c) Schematic layout of the neutron generator, showing the TiT target position.

As a calibration source, the NG must present adequate characteristics related to sufficient neutron source intensity, lifetime and simplicity of configuration. The selected NG has a neutron emission rate $\leq 2\cdot10^8$ n/s, a total weight of 5 kg, a cylindrical shape with 70 mm diameter and 483 mm length. The NG is not actively cooled during operation, so a limited operation time of 20-30 minutes is expected due to increase of the target temperature, to be followed by adequate cooling time. A total of two weeks (12 days, two shifts per day) is estimated to be necessary to complete the calibration of both KN1 and KN2. The envisaged calibration strategy is such that no particular requirements are put on the NG emission stability. In fact, during the in-vessel calibration, the NG will be equipped with "monitoring detectors" including a CVD diamond and a Si diode, as well as activation foils that will provide the absolute neutron yield at a given angle during a full day of operations. These monitoring detectors are already available and fully characterized in a 14 MeV neutron field. The peak efficiency of the monitoring diamond (referring to the counts due to the ^{12}C(n,α)^{9}Be reaction) has been absolutely calibrated within ±4.5% [5].

The neutron emission from the NG is not isotropic and has an angular – energy distribution due both to the DT reaction kinematics and the NG material configuration (Fig. 1c). Although all neutrons are produced at energies above 13 MeV, the energy spectrum of the neutrons emitted by the NG can extend to thermal energies due to collisions occurring in the NG body. An accurate MCNP model of the DT neutron source and NG has been developed which is needed to analyse the calibration results and to covert the neutron detectors' calibration factors obtained with the NG source to the one pertinent to the plasma neutron source. The NG will be calibrated and characterized at a neutron facility to obtain: i) the total absolute neutron emission in 4π with 5% target accuracy, ii) validation of the MCNP model of NG source, including the energy spectrum at different emission angles, iii) the calibration of the monitoring detectors, in such a way that during the in-vessel calibration their combined signals could be accurately related to an absolute neutron yield. To this purpose, a set of well calibrated "characterization detectors" will be employed at the neutron facility, including Long Counters [6], CVD diamond detectors, a NE213 neutron spectrometer, and Fe, Nb, Al and In activation foils.

2.2 The neutronics experiments

Neutron Streaming and Shutdown Dose Rate experiments will continue in preparation for the future DTE2 campaign at JET. The experiments have the objective to validate the neutronics codes and tools used in ITER, thus reducing the related uncertainties and the associated risks in the machine operation and maintenance. Concerning the Neutron Streaming experiment, in the 2015 DD campaign and in DTE2 additional and different neutron streaming paths in the JET biological shield will be investigated in addition to those already studied in the 2013-2014 DD campaign [7]. The new locations include an X-ray spectroscopy bunker located outside the torus hall, the baking chimney at the basement level, and positions at the inside and the outside of the torus hall main concrete door (Fig.2). The neutron fluence and dose inside the torus hall, along penetrations of its biological shield and outside it will be measured and compared with calculations to assess the capability of the simulation tools to correctly predict the radiation streaming in the ITER biological shield penetrations. Packages of activation foils will now complement the thermos-luminescent detectors (TLDs) used to derive the neutron fluence in the previous experiments [7] for cross calibration of the two methods.

In the Shutdown Dose Rate experiment, the gamma dose rate will be measured during off-operational periods inside and outside the JET vessel with active detectors (calibrated ionization chambers) and TLDs. Two ex-vessel positions have been selected for these experiments, shown in Fig. 3. Three different Rigorous-Two Step approaches, R2Smesh [8], MCR2S [9] and R2SUNED [10], and a Direct-One Step tool (Advanced D1S) [11] based on MCNP Monte Carlo code will be employed in the benchmark analyses and their results will be compared. These codes have been compared and validated using the JET shutdown dose rates measurements from previous DD campaigns [12] showing satisfactory agreement within the experimental uncertainties (Fig.4). The detailed results are given in [13].

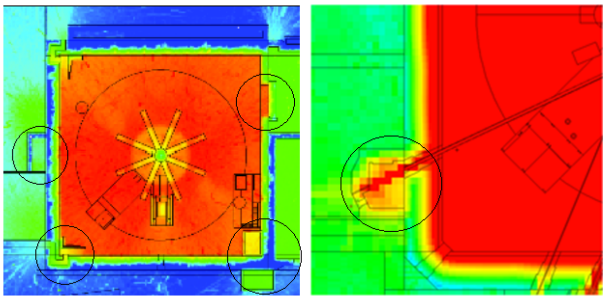

Fig. 2 - Neutron fluence maps in the JET torus hall area with black circles showing the areas where the neutron streaming through the concrete walls will be measured. Left: Torus hall. Right: X-ray spectroscopy bunker on the West wall of the torus hall.

2.3 Testing of neutron and tritium detectors for TBMs

Test Blanket Modules (TBMs) in ITER will provide the first experimental validation of the predictions on tritium production and recovery in tritium breeding blankets. The development and testing of nuclear instrumentation for measurement of neutron/gamma fluxes and tritium production in TBMs represents a major task as such instrumentation will have to work in very hostile conditions. DTE2 will provide a unique occasion to test in a real fusion environment the neutron and tritium detectors under development for TBMs.

Two CVD diamond detectors, one covered with LiF and the other without LiF, will be located inside a JET lower small vertical port (Fig. 5). The testing objectives are to verify the operation and the response of these diamond detectors in harsh environment: in the selected position, the temperature ranges between 250°C and 320°C (during baking of the vacuum vessel), the magnetic field is ≈3 T, the neutron flux $\leq 5\square 10^{12}$ n/(cm^{2}s), the γ-ray flux $\leq\approx 10^{12}$ n/(cm^{2}s) in DT operations.

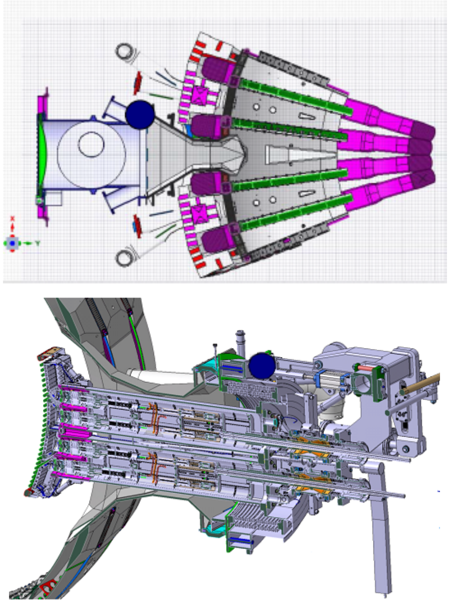

Fig. 3 – Top: horizontal section of Octant 1 of JET showing the first position for shutdown dose rate measurement on the side horizontal port (blue circle). Bottom: The main horizontal port in Octant 2 with installed ITER-like Antenna showing the second position for shutdown dose rate measurement (blue circle).

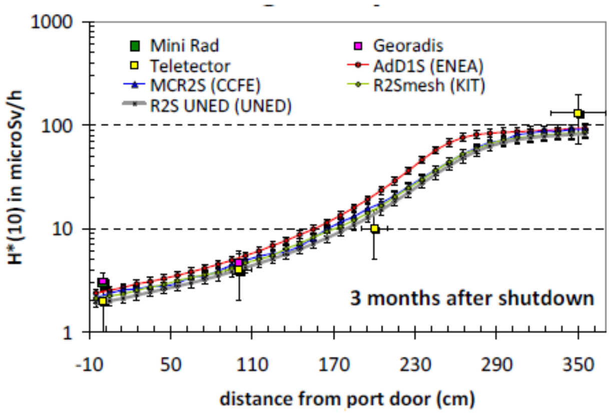

Fig. 4 – Shutdown dose rate measured along the Oct 1 main horizontal port 3 months after shutdown, and calculated for the same cooling time by MCR2S, R2SMESH, R2SUNED and AdD1S [13].

The detector requirements have been defined and most of the working parameters were tested in a diamond detector prototype that worked properly up to 210 °C. Further studies are ongoing to test different metal-diamond contacts to improve the results and further extend the working temperature range. Also, test with LiF covered detectors were performed: up to the investigated temperature the LiF layer performed properly. Test of the prototype were also done, for the first time at high temperature using a fast digitizer. This was possible because of the dramatic reduction of noise achieved with the present prototype.

The neutron activation technique, using stacks of metal foils exploiting a range of reactions with different energy thresholds, combined with a neutron spectrum unfolding technique, is also considered to measure with some time resolution the neutron spectrum in a TBM in ITER. JET is the only facility where this technique can be tested as it has at the same time a high neutron flux and a pneumatic system capable of removing the irradiated foils from KN2 irradiation ends in a short time. The list of the proposed reactions is given in the Table 1 [14]. The pre-analyses of the measurements at JET in KN2 irradiation ends have shown that most of the emitted gamma lines from the selected materials are measurable during DTE2.

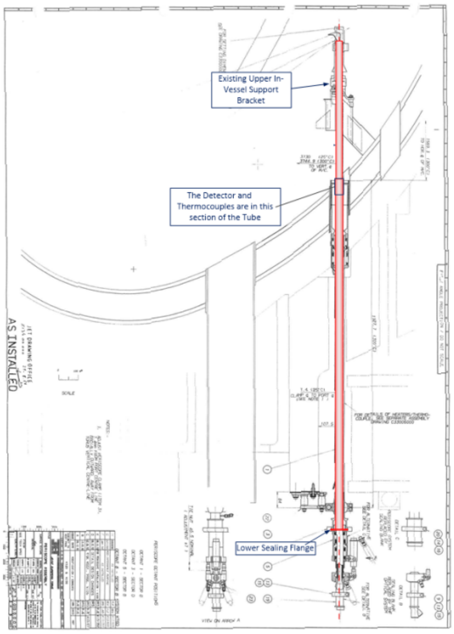

Fig. 5 Detector Tube in JET lower small vertical Port.

The Secondary Charged Particle Activation (SCPA) method is also investigated to measure the tritium production using Li_2CO_3 [15]. The method consists of measuring of the activity induced in oxygen through the reaction $^{16}O(t,n)^{18}F$ by the triton generated in the $^{6}Li(n,t)$ reaction. The method would provide a passive and direct measurement of the tritium production rate in TBMS. Drawbacks of the method are related to the very low probability of the two-step process, and to the uncertainty of triton cross-sections. With the expected neutron flux in JET, measurements to test this method appears feasible using Li_2CO_3 pellets irradiated in KN2 irradiation ends, provided that ^{6}Li highly enriched material is used.

Finally, a benchmark experiment on a mock-up of the Helium Cooled Pebble Bed (HCPB) TBM is being designed using a mock-up already used in a previous experiments carried out at the 14 MeV Frascati Neutron Generator (FNG) [16]. The objective of this experiment is to validate the calculations of the tritium production rate in a real fusion environment. A suitable position for the mock-up has been identified in front of Oct.8 main horizontal port, as shown in Fig.6. For this purpose, a well calibrated CVD diamond detector covered with a LiF layer will be used to measure the tritium production rate during DT discharges, and the results will be compared with calculations. In the selected position, it has been estimated a count rate ≈ 10^3 -10^4 counts/s for a ^{6}Li diamond located inside the mock-up and containing $\approx 10^{16}$ ^{6}Li atoms in the LiF layer.

Table 1 – Radioactive decay properties of the dosimetry reactions for TBMs

Dosimetry Reaction	**Half-life (s)**	**Threshold Energy (MeV)**
$^{140}Ce(n,2n)^{139m}Ce$	56.1	10
$^{140}Ce(n,\alpha)^{137m}Ba$	153.12	12
$^{27}Al(n,\gamma)^{28}Al$	134.46	-
$^{27}Al(n,p)^{27}Mg$	567.48	4.5
$^{52}Cr(n,p)^{52}V$	224.7	5.5
$^{53}Cr(n,p)^{53}V$	97.2	6
$^{54}Cr(n,p)^{54}V$	49.8	11
$^{54}Cr(n,\alpha)^{51}Ti$	348.0	8.2
$^{93}Nb(n,\gamma)^{94m}Nb$	375.6	-
$^{93}Nb(n,\alpha)^{90m}Y$	11.484	6.9
$^{93}Nb(n,n\alpha)^{89m}Y$	15.663	12.5
$^{93}Nb(n,2n)^{92m}Nb$	876.960	9.5

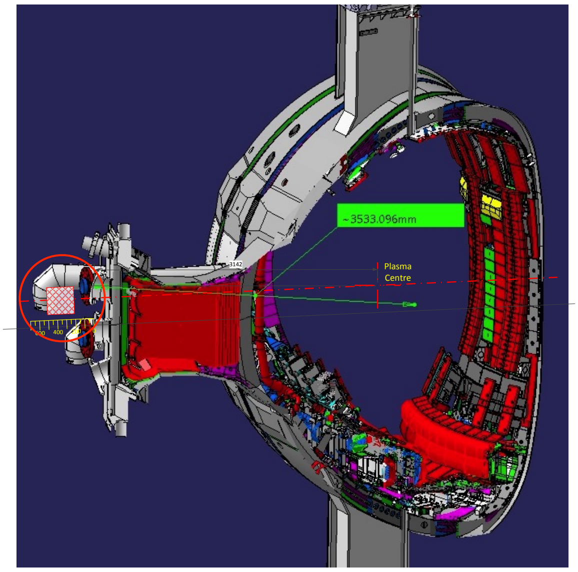

Fig. 6. Sketch of the HCPB TBM mock-up (in the red circle) in front of the Oct.8 main horizontal port.

2.4 Investigation of ITER real materials

Samples of real ITER materials used in the manufacturing of the main in-vessel components will be exposed to the large 14-MeV neutron flux/fluence produced during DTE2. Both the short term (hours) and the medium term (months) activation will be investigated. In the first case, samples will be irradiated on a shot by shot basis using KN2 irradiation ends and the associated pneumatic system. In the second case, samples will be exposed for the whole duration of the campaign; the preferred position is inside the vacuum vessel at the outboard midplane close to the poloidal limiters where the neutron fluence is highest (up to 10^{20} n/m^2 for a total yield of 1.7□10^{21} neutrons). After irradiation, the measured neutron induced activities will be used to validate the calculation predictions for ITER. This will both validate the assumptions used in the activation calculations and also, to a certain extent, show that the materials impurities are within specified limits.

A list of potential ITER real materials to be investigated includes SS316L(N)-IG, SS316L, SS304 (borated), Alloy 660, CuCrZr, W, OF-Cu, XM-19, Al-bronze from in vessel components, Nb3Sn, NbTi from the magnets. The samples of such ITER-grade materials as well as the chemical composition including impurities will be provided by F4E. Priority is being assessed based on available space, the level of neutron induced activation in JET, relevance and importance for activation/rad waste.

For investigating the activation of ITER materials, the JET neutron field must be accurately characterized from 14-MeV down to thermal energy. As a first step, two in-vessel Long Term Irradiation Stations (LTIS) have been realized each one containing 30 18-mm-diameter foils, up to 2mm thick (Fig.7). These LTIS have been installed inside the JET vacuum vessel at the outboard midplane close to the poloidal limiters. They now contain several tens of dosimetry foils that will be exposed for the whole duration of the 2015 DD campaign. After removal, the gamma activity from these foils will be measured to derive the neutron spectrum from 14 MeV energy (from neutron produced from triton burnup) down to thermal energy. The selection of dosimetric foils was performed based on ensuring compatibility with JET environment, sufficiently long half-life and covering the required range of neutron energies.

After DTE2, in order to be able to remove the ITER material samples in a relatively short time, a different approach is being investigated which would allow the LTIS to be located in approximately the same position from outside the vessel through one small horizontal port.

2.5 Radiation damage in functional materials

Concerning radiation hardness of functional materials, data on critical properties exist only for very low radiation levels, and that for some material groups limited data do not exist even at low doses. This last point can be addressed at JET during DTE2, when dose levels in the range of 10^{-5} dpa can be achieved for a total neutron yield of 1.7□10^{21} neutrons [17]. At this damage level, degradation of physical properties in functional materials can already be observed. For almost all selected materials, the JET measurements will provide the first damage data for 14- MeV neutrons. As properties of these materials need to be characterized during ionizing irradiation, but this is not possible in JET, an efficient solution has been proposed: In-beam measurements will be done in a VDG accelerator before and after JET irradiation. Only a couple of optical fibers will be actively measured during JET operation.

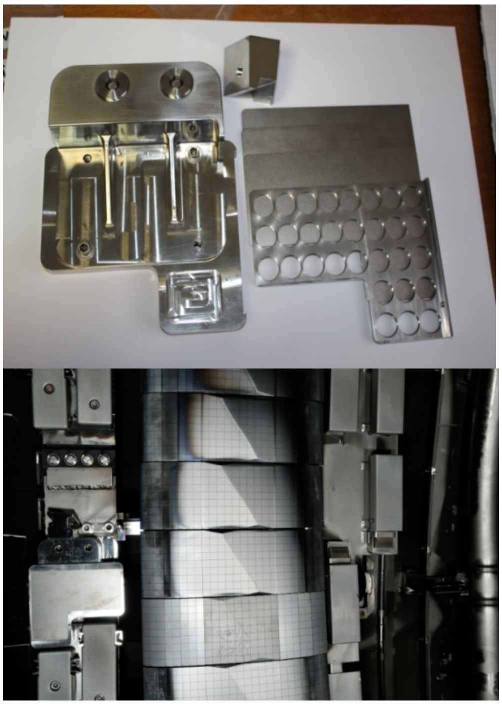

Fig. 7. Top: one of the two the Long Term Irradiation Stations (LTIS) open, showing the box sample holder, the tray sample holder and the shim. Bottom: One of the two LTISs installed at the left hand side of the outer poloidal limiter.

The main properties to be measured before and after irradiation are:

- Electric properties: Electrical Conductivity and radiation induced conductivity (RIC);

- Dielectric properties: Loss tangent and Permittivity in a wide frequency range (from kHz to GHz's);

- Optical properties: Rad. Induced Absorption (RIA) and Radio-Luminescence (RL) in a wide wavelength range (VUV-UV-VIS-IR).

A Fibre Optic Current System (FOCS) has also been successfully installed on JET which uses optical fibres placed around the vacuum vessel to measure the plasma current. Its operation is based on the detection of the Faraday rotation experienced by a polarized light beam in a fibre when a magnetic field is oriented along the fibre axis. FOCS allows a direct measurement of plasma current and therefore its sensitivity is independent of the plasma pulse duration [18]. FOCS will be installed also in ITER as a back-up current measuring system. 2 fibres have been installed in PEEK tubes surrounding one sector of the VV, flushed with nitrogen for cooling. The purpose of the JET experiments is to study the neutron/gamma effects on the FOCS fibre before (DD operation) and during DT operation. In fact, the radiation level behind the JET vacuum vessel is comparable with the one occurring behind the ITER vacuum vessel (although the spectrum is harder).

Table 2 – Selected functional materials for 14 MeV neutron irradiation during DTE2

Material	**Composition**
Sapphire, Coated Sapphire	Al_2O_3 sc, Al_2O_3
Alumina (different types)	Al_2O_3
New KS-4V(*)	SiO2
New KU1(*)	SiO2
Diamond	C
Spinel (different types), Coated Spinel	$MgAl_2O_4$
CaF_2 , Al_2O_3 coated CaF_2	CaF_2
BaF_2, BaF_2 coated	BaF_2
YAG	$Y_3Al_5O_{12}$
Aluminum nitride	AlN
Aluminum nitride	AlN
Silicon nitride	Si_3N_4
Zirconia	ZrO_2

2.6 Tritium retention

The proposed DT campaign will require using 60 g of T_2 in the AGHS plant, while the total amount of tritium inventory allowed outside the storage beds is limited to 11 g on the various cryo-panels and to 4 g on the mobile in-vessel inventory. Tritium retention and outgassing from in-vessel materials, and the airborne tritium (during machine venting) will be measured during the DTE2 campaign. In addition, in order to get a better understanding of tritium behaviour in JET, laboratory studies on tritium short term permeation, outgassing and retention will aim at providing understanding of the relevant mechanisms with tests on samples at different temperatures and loading conditions, for selected materials such as Be and W. The activities will support the investigations of the fuel retention.

Due to the different mechanisms involved in tritium transfer (tritium ions implantations and tritium gas permeation), two facilities have been designed and are being built in the JET Active Gas Handling System area: the Tritium Loading Facility, TLF, aiming to reproduce tritium ion implantation in the in-vessel materials, and the Tritium Permeation Facility, TPF, aiming to simulate tritium gas permeation from the regeneration of JET cryopumps. Studies will be carried out on samples of different size (from 1 cm^2 to a larger fraction of a tile). Based on a reference experiment for both materials, a parameter study is suggested as well as a range of values for each material in each facility. In the TLF, a 1-mA T_2 ion beam with energy in the range 50 – 1000 eV will be directed for up to 4 hours on samples at temperatures between 400°C and 1000°C. In the TPF, samples at temperatures in the range 100°C – 250°C will be exposed to T_2 gas partial pressure up to ~1 mb (40 TBq/m^3). Due to the importance of the material microstructure on the tritium behaviour, both new and used tiles will be studied. Finally, as the samples will be loaded several times with tritium in the JET vessel, the influence of the tritium exposure repetition will also be studied.

The short term outgassing will also be monitored at constant temperature in the facilities where beryllium tiles/tungsten lamellae will be loaded with tritium. Measurements with a Thermal Desorption Spectrometer will be used to determine i) the bonding energy of the tritium implanted in the materials and ii) the total amount of T retained in the samples and so a relation can be established between the outgassing rate and the Tritium content. The experimental results will be analysed with TMAP code to improve understanding of retention/outgassing in/from JET wall during the DT campaign and support the prediction of tritium inventory.

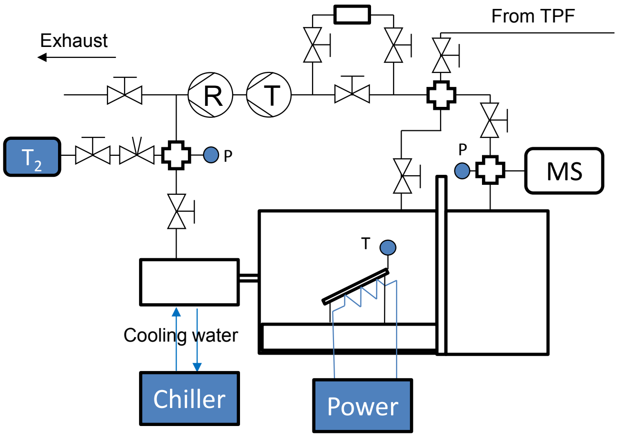

Fig. 8. Schematic view of the Tritium Loading Facility

2.7 Waste production and characterization

As a result of the research program at JET, significant experience on the management of radioactive waste has been gained which will be of benefit to ITER and the nuclear fusion community. The successful management of radioactive waste is ensured by the JET Operator (CCFE) by accurately and efficiently tracking and characterizing the waste streams: all items at JET which are removed from radiological areas are identified and pre-characterized, by recording the radiological history, before being removed from or moved between radiological areas. This system ensures a history of each item is available when it is finally consigned as radioactive waste and also allows accurate forecasting of future arisings [19].

As part of WPJET3, details of lessons learnt from past JET operations are being addressed, and specifically during the upcoming DTE2, which can be provided to ITER to help design and plan activities related to radioactive waste management. As the JET waste has to be managed in accordance with UK legislation and available disposal options, which are different from those applicable in France, the existing procedures may not be relevant to ITER wastes. A number of CCFE's existing waste production and characterization procedures have been reviewed for relevance to ITER, and their applicability to the French Regulations and the French public body responsible for the long term management of radioactive waste (ANDRA) has been assessed. They include the procedures employed for radioactive and beryllium contaminated waste handling procedures for: Management of Waste, Control and Monitoring of Gaseous Discharges, Sample Production Method for tritium activity estimates, Health Physics Pre-characterisation activity estimation, Waste Forecasting Tool, Sorting and sampling of potentially radioactive soft waste, PVC and cardboard, and hard waste. As a result of this assessment, most of the JET procedures have be found to be directly, or with minor adjustments, applicable to ITER, some applicable with major adjustments.

2.8 Nuclear Safety

ITER Occupational Radiation Exposure (ORE) assessment strategy is based on operating experience collected in the existing experimental fusion devices during maintenance activities, mainly in JET. JET ORE data have been gathered in the past years and used in the current ITER ORE analyses. However, data for specific maintenance activities is still missing or largely uncertain. In order to reduce the uncertainties and lack of information, additional data on dose rate, tritium concentration, dust concentration and work effort in maintenance activities, during normal operation and during shutdown, would greatly improve the data base for ITER ORE and provide its validation. JET ORE data corresponding to specific activities and operations are collected and finalized to meet specific ITER safety needs.

The strategy for the data collection focused on tritium concentration, dust concentration and traces, dose rates and work effort. The study will mainly concentrate on data collected during DTE2. However, although currently the radiological contamination levels on JET are very low and may not be relevant to ITER, the collection of data started already during the 2014/2015 shutdown as a useful test for establishing the data collection process for future shutdowns. This includes, logging the work practices, monitoring the dose rate, recording the smear results for Be dust and the tritium-in-air concentrations locally. Three maintenance activities have been selected for study with ambient monitors: the repair of IVIS view tube at Octant 4, 4 KS7 periscope removal at Octant 3, the refurbishment and re-installation, and the installation and commissioning of VUV Spectroscopy (KT7D) feedthrough at Octant 6. The same approach for future shutdowns and/or interventions will be adopted as those used in the 2014/15 shutdown. Suitable personal digital dosimeters for monitoring have been purchased to obtain more accurate information on the single tasks.

2.9 DEMO fuel cycle

A novel and fully tritium compatible Mechanical Tritium Pumping System (MTPS) is being developed in the frame of EUROfusion Work Package *Tritium Matter Injection and Vacuum* (WPTFV) [20] as a key component of the KALPUREX process, currently under development at KIT for integration into the fuel cycle for a fusion power plant [21]. MTPS works continuously and is non-cryogenic and will be tested at JET during the next Deuterium-Tritium experiment (DTE2) in 2017 in the Active Gas Handling System (AGHS) of JET. This provides a unique opportunity to reach a high technical readiness level of this system and is a big step towards a complete validation of the KALPUREX process. The MTPS is based on a modified liquid ring pump which is operated with mercury to make it tritium-compatible. The detailed design of MTPS focuses especcially on the mechanical set-up, the control- and safety system and on the design of a liquid ring pump, that are being developed in cooperation with an industrial partner.

For the MTPS to be installed at JET AGHS, where it will be connected to the JET torus for pumping active gases, it has to fulfil a number of requirements [22]. The pumping speed of the system has to be ≈100 m^3/h and an ultimate pressure of <100 Pa (<0.1 Pa for backing the turbo pumps) has to be reached. For this purpose, a booster pump will also be included to reach lower inlet pressures: a commercially available booster that is normally operated with oil as working fluid has been modified for tritium processing and for mercury as working fluid. This modification includes a new boiler design as well as an inlet- and outlet baffle to avoid mercury propagation towards the outside the pump.

The use of tritium requires a high leak-tightness, the installation in an activity monitored enclosure and the use of compatible materials and a tritium resistant working fluid: mercury. As MTPS has to be integrated into AGHS and accepted by the safety department and the operators, space limitations and infrastructure requirements have been considered and a reliable control- and safety system has to be included. The preparation of the MTPS set-up and integration into the AGHS facility is ongoing and the system should be installed in the pre-DTE2 shutdown.

3. Conclusions

The JET DTE2 will provide considerable added value in many technological areas relevant to ITER and DEMO.

The JET technology programme in conjunction with DTE2 is focused on the preparation of experiments, analyses and collection of data in the areas of neutronics, activation, radiation induced damage in functional materials, tritium retention, nuclear safety and waste production and characterization, aiming to improve our present knowledge on ITER (and DEMO) relevant technological issues, validate design tools and assumptions, and reduce the risks and uncertainties in

ITER plant operation and management. This programme will also provide for the first time a consistent and complete "nuclear case" for a tokamak, from the calibration of the neutron source and the characterization of the resulting radiation field, the induced activity in materials and dose rates, to waste production and occupational dose, relevant to JET and ITER.

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References

[1] Lorne Horton, P. Batistoni, H. Boyer, C. Challis, D. Ćirić, T. Donné, S. Gee, J. Hobirk, E. Joffrin, T. Jones, S. Knipe, X. Litaudon, G.F. Matthews, I. Monakhov, A. Murari, I. Nunes, V. Riccardo, A.C.C. Sips, R. Warren, H. Weisen, K.-D. Zastrnow and JET Contributors, The JET DT Experiment, submitted to Fusion Engineering and Design, this conference

[2] P. Batistoni, J. Likonen, N. Bekris, S. Brezinsek, P. Coad, L. Horton, G. Matthews, M. Rubel, G. Sips, B. Syme, A. Widdowson, Fusion Engineering and Design, Volume 89, Issues 7–8, October 2014, Pages 896-900

[3] D.B Syme, S. Popovichev, S. Conroy, I. Lengar, L. Snoj C. Sowden, L. Giacomelli, G. Hermon, P. Allan, P. Macheta, D. Plummer, J. Stephens, P. Batistoni, R. Prokopowicz, S. Jednorog, M.R. Abhangi, R. Makwana, Fusion Engineering and Design, Vol. 89, Issue 11, 2766-2775

[4] M. Sasao, L. Bertalot, M. Ishikawa, and S. Popovichev, Rev. Sci. Instrum. **81**, 10D329 (2010);

[5] M. Pillon, M. Angelone, P. Batistoni, S. Loreti, A. Milocco, Characterization of a Diamond Detector to be used as Neutron Yield Monitor during the in-vessel Calibration of JET Neutron Detectors in preparation of the DT Experiment, submitted to Fusion Engineering and Design, this conference.

[6] H. Tagziria, D. Thomas, Nuclear Instruments and Methods in Physics Research A 452 (2000) 470}483

[7] P. Batistoni, S. Conroy, S. Lilley, J. Naish, B. Obryk, S. Popovichev, I. Stamatelatos, B. Syme, T. Vasilopoulou, 2015 Nucl. Fusion 55 053028

[8] P. Pereslatvsev, U. Fischer, D. Leichtle, R. Villari, "Novel approach for efficient calculations of mesh based Monte Carlo shutdown dose rates and related V&V analyses on JET", Fus. Eng. Des. 89 , 2083–2087 (2014)

[9] A. Davis and R. Pampin, Benchmarking the MCR2S system for high-resolution activation dose analysis in ITER, Fusion Engineering and Design 85 (2010) p87-92.

[10] JP Catalan, P. Sauvan, J. Sanza, Shutdown dose rate assessment for a DCLL blanket-based reactor: Application of the R2S-UNED approach Fus. End. Des. 88, 2088–2091 (2013)

[11] R. Villari, U. Fischer, P. Prereslatvsev, L. Petrizzi, S. Podda, Shutdown dose rate assessment with the Advanced D1S method: Development, applications and validation, Fus. Eng, Des. 80, 2083–2087 (2014)

[12] R. Villari M. Angelone, P. Batistoni, U. Fischer, L. Petrizzi, Overview of experimental benchmarking of shutdown dose rate calculations in fusion devices, ANS Transactions; 109; 1167-1170. (2013)

[13] R. Villari, P. Batistoni, M. Angelone, B. Colling, D. Croft, U. Fischer, et al., Neutronics Experiments and Analyses in Preparation of DT Operations at JET, submitted to Fusion Enginering and Design, this conference

[14] A. Klix, A. Domula, U. Fischer, D. Gehre, P. Pereslavtsev, I. Rovni, Fusion Engineering and Design, Volume 87, Issues 7–8, August 2012, Pages 1301-1306

[15] I. Rovni, M. Szieberth, and S. Fehér, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 690, pp. 85 – 95, 2012.

[16] P. Batistoni, M. Angelone, L. Bettinali, P. Carconi, U. Fischer, I. Kodeli, D. Leichtle, K. Ochiai, R. Perel, M. Pillon, I. Schäfer, K. Seidel, Y. Verzilov, R. Villari, G. Zappa, Fusion Engineering and Design, Volume 82, Issues 15-24, October 2007, Pages 2095-2104

[17] Igor Lengar, Aljaž Čufar, Sean Conroy, P. Batistoni, S. Popovichev, Luka Snoj, Rafael Vila, Radiation damage and nuclear heating studies in selected structural materials during the JET DT campaign, submitted to Fusion Engineering and design, this conference

[18] Aerssens, M., Gusarov, A. ; Brichard, B. ; Massaut, V. ; Mégret, P. ; Wuilpart, M., Faraday effect based optical fiber current sensor for tokamaks, Proceedings of 2nd International Conference on Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA), 2011, 978-1-4577-0925-8, DOI:10.1109/ANIMMA.2011.6172868.

[19] S. Reynolds, M. Newman, D. Coomb, D. Witts, JET Experience on Managing Radioactive Waste and Implications for ITER, submitted to Fusion Engineering and design, this conference

[20] T. Giegerich et al., Advanced design of the Mechanical Tritium Pumping System for JET DTE2, this conference

[21] T. Giegerich, C. Day, The KALPUREX-process – A new vacuum pumping process for exhaust gases in fusion power plants, Fus. Eng. Des. 89 1476-1481 (2014)

[22] T. Giegerich et al., Conceptual design of the Mechanical Tritium Pumping System (MTPS) for JET DTE2, Fus. Sci. Technol., in press