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Neutronics Experiments and Analyses in Preparation of DT Operations at JET

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In the frame of the WPJET3-DT Technology project within the EUROfusion Consortium program, neutronics experiments are in preparation for the future Deuterium - Tritium campaign on JET (DTE2). The experiments will be conducted with the purpose to validate the neutronics codes and tools used in ITER, thus reducing the related uncertainties and the associated risks in the machine operation. This paper summarizes the status of previous Shutdown Dose Rate benchmarks experiments and analyses performed at JET and focuses on the computational and experimental efforts conducted in preparation of the future DTE2 experiments. In particular, preliminary calculations and studies to select detectors and positions aimed to reduce uncertainties in the Shutdown Dose Rate experiment are presented and discussed.

Keywords: JET, benchmark, neutronics, DTE2, shutdown dose rate, MCNP

1. Introduction

In the frame of the EUROfusion Consortium program, the WPJET3-DT Technology project has been launched in 2014 to exploit the significant 14 MeV neutron production ($1.7x10^{21}$ neutrons) of the future DTE2 experiment at the Joint European Torus (JET), to improve the knowledge and validate current assumptions on ITER relevant issues [1,2]. In particular, within the sub-project NEXP, the *Neutron Streaming* and the *Shutdown Dose Rate* experiments are in preparation to validate the neutronics codes and tools used in ITER, thus reducing the related uncertainties and the associated risks in the machine operation.

In the *Neutron Streaming* experiment, the neutron fluence and dose through the penetrations of JET torus hall will be measured and compared with calculations to assess the capability of numerical tools to correctly predict the radiation streaming in the ITER biological shield penetrations. The results from previous streaming experiments carried-out during 2012-2014 DD campaigns were recently published [3], showing a satisfying agreement over six orders of magnitudes between the calculations with MCNP5 Monte Carlo code [4] and the measurements performed with thermoluminescent detectors (TLDs).

In the frame of the *Shutdown Dose Rate* experiment, the decay gamma dose rate will be measured during non-operational periods inside and outside the JET vessel with active and passive dosimeters, i.e. ionization chambers and TLDs. The experimental data will be used to validate the European state-of-the-art computational tools for Shutdown Dose Rate (SDR) assessment used in ITER. Three different Rigorous-Two Step approaches (R2Smesh [5], MCR2S [6], and R2SUNED [7]) and a Direct-One Step tool (Advanced D1S [8]) based on MCNP Monte Carlo code will be employed in the benchmark analyses. The assessment of shutdown dose rate is a key issue for the design and maintenance operations of ITER components. The dose rate level in ITER maintenance area in the port interspace needs to be less than 100 Sv/h 12 days after shutdown. The fulfillment of this design target must be verified through reliable calculations.

SDR benchmark experiments have been conducted at JET during DD shutdown since 2005 and on overview of the campaigns from 2005 to 2012 has been recently published [9]. The last experiment was carried-out during the 2012-2013 DD shutdown and the analyses were recently completed.

This paper summarizes the results of a recent SDR benchmark experiment and focuses on the computational and experimental efforts conducted in preparation of the future DTE2 experiments. In particular, preliminary calculations and studies to select detectors and positions aimed to reduce uncertainties in the SDR experiment are presented and discussed.

2. 2012-2013 SDR benchmark experiment at JET

2.1 Dose rate measurements

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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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The most recent shutdown dose rate benchmark experiment was conducted at JET at the end of 2012 DD campaign for six months.

Several measurements with different dosimeters and a gamma spectrometer started at the end of July 2012 operations and were performed at times ranging from 1 day to 6 months after JET shutdown. Three Geiger Müller (GM) type detectors (Vacutec GM tube, Automess Teletector 6112D, Mini Rad series 1000R), an ionization chamber monitor (STEP OD-2) and a NaI spectrometer (RT-30 Georadis) were used. The detectors were calibrated in terms of ambient dose equivalent, H*(10), using Cs-137 and Co-60 gamma sources. The measurements were performed along the mid-port of Octant 1 from in-vessel positions to 1 meter outside the port door, and in two ex-vessel positions at the side of the port (figure 1).

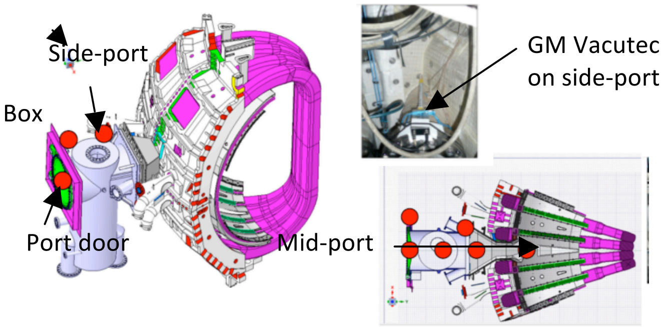

Fig. 1 – Positions of SDR 2012-2013 experiment (red circles) at JET Octant 1.

The GM Vacutec detector was installed before the shutdown (27/07/2012) on a small side port, outside the Octant 1 main horizontal port and measurements were taken from 28/07/2012 to 18/10/2012. The dose rate was measured from 20 hours to ~80 days after shutdown (acquisition time 1000-2000 s). Dose rate measurements along mid-port were performed on 7/11/2012 and on 29/1/2013. Furthermore, several sets of repeated measurements were carried out in two positions at the side of the Octant 1 horizontal port, one close to the GM and the other one close to the box shown in figure 1, from 24/7/2014 to 8/8/2014 with the Georadis RT-30, the MiniRad monitor, and OD-02 monitor. These include isotopes identification with the Georadis RT-30.

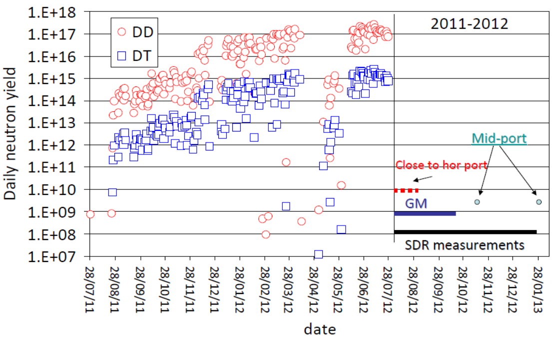

Fig. 2 - JET DD and DT[1] daily neutron yields after installation of ILW and dates of measurements.

Neutron yields of the previous campaign in 2011-2012 (after a long shutdown during the installation of ITER-like Wall) and the date of the measurements are shown in figure 2.

The results of the measurements in ex-vessel positions are shown in figure 3. The experimental uncertainties are as ±30% for the GM (due to energy response), ±20% for the Georadis RT30, MiniRad and OD-2, and ±50% for Teletector due to its angular dependence and results from cross-calibration studies. In both ex-vessel positions (side port and box against port side), the measurements by Georadis RT-30, MiniRad and OD-02 were in good agreement within their combined uncertainties. The dose rate is mainly due to the decay of cobalt isotopes (Co-58 and Co-60) identified by Georadis RT-30.

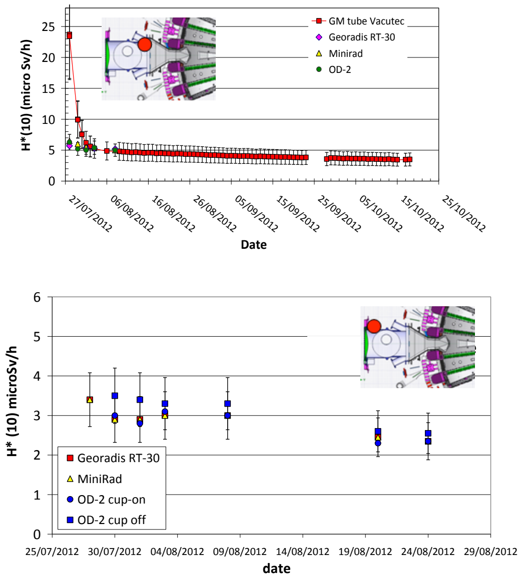

Fig. 3 - Dose rates measured by GM on the side port outside Oct.1 main horizontal port up to 18/10/2012, and by Georadis RT-30, MiniRad and OD-02 (top). Dose rates measured by Georadis RT-30, MiniRad and OD-02 on the box outside Oct.1 main horizontal port (bottom).

At the side-port position, the Vacutec GM showed higher response with respect to the other detectors in the first week. This behavior has been studied. Self-activation of the GM tube wall was investigated through calculations and measurements but the effect would be negligible. The effect could be due to 511 keV gammas produced through electron-positron annihilations and/or by high-energy β interacting with aluminum case of the tube, because its active volume is in contact with steel bolt (see picture in figure 1). Moreover the three detectors were not exactly in the same position: in that area, collimation effects through the port to the machine inner components can cause large gradients in the local dose rates. An additional source of discrepancy could be the anisotropy and non-linearity of GM at high count

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[1] The DT component during operation with pure deuterium is due to triton-burn up and it is of the order a few percent of the total.

rates. This trend was however not clearly understood and further investigations would be needed.

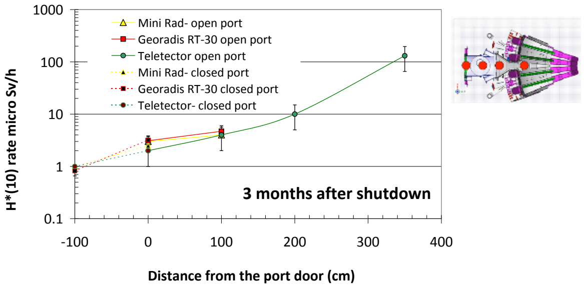


Fig. 4. Dose rates measured by Georadis RT-30, MiniRad and Teletector along the mind-port of Oct-1 on November 7th, 2012.

Dose rate measurements along the mid-port of Octant 1 taken on 07/11/2012 (103 days after shutdown) are shown in figure 4. Measurements in front of the port were taken with port flange open and closed. At 186 days after shutdown (date 29/01/2013) the ratio with the measurements at 103 days varies in the range 0.45-0.9, depending on the detectors and positions. It is important to point out that the measurements were performed with detectors installed on a long pole deployed from the port door, and therefore they are affected by large uncertainties on the actual detectors positions (±10 cm in all directions).

2.1 Shutdown dose rate calculations

The latest versions of R2Smesh [5], MCR2S [6], R2SUNED [7] and Advanced D1S [8] were applied to perform the shutdown dose rate calculations at the experimental positions. Both Advanced D1S and R2Smesh are based on MCNP5 [4] and FISPACT 2007 [10] codes. MCR2S v2 is based on MCNP6 and FISPACT-II whereas R2SUNED uses MCNP5 and ACAB [11] activation code. FENDL-2.1 nuclear data library and EAF 2007/2010 have been selected for transport and activation respectively. All the approaches used the same geometry, nuclear data, irradiation conditions and *tallies* specification.

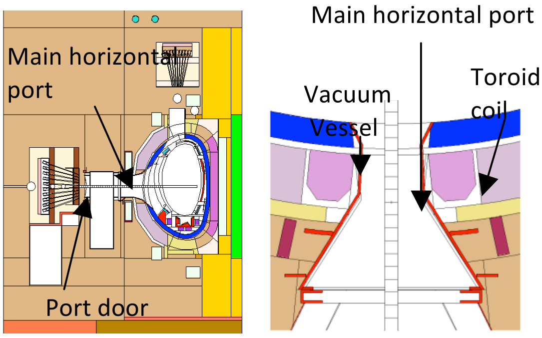


Fig. 5. 3-D JET MCNP model of Octant 1 vertical (left) and equatorial (right) sections.

The JET MCNP 45° geometrical model of Octant 1 used in previous benchmarks [12] has been modified according to CAD files, to implement the ITER-like Wall, TF coil, mechanical structure, port wall and environment around ex-vessel detectors. Materials descriptions include impurities based on available chemical certificates. Reflective boundary conditions on the lateral sides have been used to take into account full 3D transport. 3-D MCNP model sections are shown in figure 5.

The deuterium-tritium (DT) and deuterium-deuterium (DD) neutron sources were described by a parametric representation of a typical JET plasma emissivity already used in previous benchmarks [13]. The DD and DT irradiation scenarios used in FISPACT and ACAB to calculate the decay gamma time correction factors for Advanced D1S and the decay gamma source for R2S approaches accurately describe the real operational scenarios from 1983 to 2012 measured by JET neutron diagnostics (total DD and DT neutron yields 4.11×10^{20} and 2.40×10^{20}, respectively).

Different meshes have been adopted in R2S calculations: R2Smesh used a coarse mesh for neutron spectra (voxel size 15x15x15 cm^3) and fine mesh for flux (voxel size 3x3x3 cm^3), MCR2S a 10x10x10 cm^3 mesh covering the whole geometry in MCR2S and R2S-UNED adopted multiple tailored meshes.

The Advanced D1S calculations were performed for all cooling times using a single MCNP simulation, whereas for R2S methods, where each cooling time requires proper decay gamma generation and separate photon transport simulation, three cooling times and corresponding measurements were selected for benchmarking. These were at cooling times of 19 hours (date 27/07/2012), 1 week (date 03/08/2012) and 103 days (date 07/11/2012) after shutdown in order to provide validation for an extended cooling time range and in all experimental positions.

The calculation error is obtained as the quadratic sum of the statistical errors and ± 10% of uncertainty due to neutron yield from neutron diagnostics (used for normalisation).

2.2 Comparison between calculations and measurements

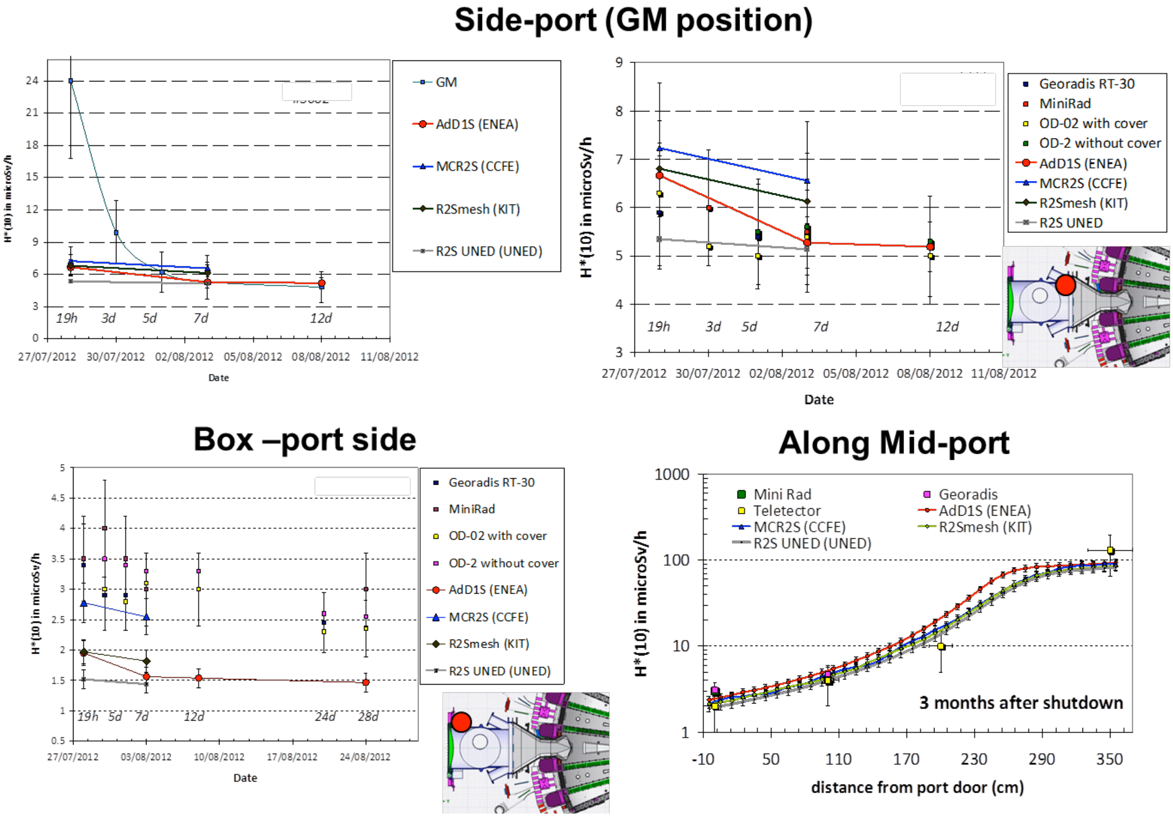
The calculated shutdown dose rates (in terms of H*(10) rate) at the cooling time of interest and the experimental data are shown in figure 6. Concerning the profiles along mid-plane port axis, R2Smesh and MCR2S results agree very well, whereas D1S is always higher (by about +20%) and R2S-UNED lower. This was also observed also in the previous benchmark [12] at cooling times up to ~4 months. This can be due to the different decay gamma emission approach which is point-wise in D1S whereas in R2S methods it is averaged on the mesh element and thus it depends on the mesh size. A good agreement with measurements within experimental uncertainty was obtained but it was not possible to identify which approach agrees better due to large experimental uncertainties. At the box outside Octant 1 main horizontal port a very good agreement between R2Smesh and D1S was obtained, and MCR2S is in general higher and R2S-UNED lower. A significant underestimation of the measurement was found with Advanced D1S, R2Smesh and R2S-UNED (by about a factor 2), while MCR2S agrees better in this position

These differences might be due to the dimensions of the mesh used for neutron flux-spectra calculations and gamma generation and on materials sampling. The discrepancy with measurement can be due modelling uncertainties but further investigations are needed.

At the side port outside Octant 1 an optimal agreement is found between R2Smesh and D1S. MCR2S agrees in this position better with R2Smesh and Advanced D1S than at the box outside, but is always slightly higher than R2Smesh. Optimal agreement with OD2- Mini Rad and Georadis results in the whole temporal range and with GM only from 1 week after shutdown is found for all codes. The behavior of GM at short cooling time is not reproduced by calculations.

All codes predict Co-60 and Co-58 as the dominant nuclides responsible to the dose, confirming Georadis measurements.

In summary, except in some few positions, a good agreement within the overall uncertainties has been found between calculations and measurements and within ±30% among the codes, however the necessity to reduce the uncertainties represents a primary objective for the future experiment. From the experimental point-of-view several requirements for detectors were identified to be carefully addressed for reducing uncertainties: flat energy response, isotropic response, linearity in dose, long term stability, low activation, careful calibration and cross-calibration verification, accurate positioning. Furthermore considering the uncertainties related to the modeling, the environment around experimental positions (geometry and materials composition) should be well known. The lessons learnt in this experiment were fundamental for the preparation of the future DTE-2 experiment.


Side-port (GM position)

Box –port side

Along Mid-port

Fig. 6. Comparison between SDR calculated with R2S and Advanced D1S codes for the SDR 2012-2013 benchmark experiment and comparison with experimental data in ex-vessel positions and along mid-port.

3. Preparation of SDR benchmark during DTE2

Several activities have been performed in 2014-2015 in preparation of the future experiment under DTE-2 on the basis of the previous experience and with the aim to reduce the experimental uncertainties. The detectors and positions have been selected and preliminary tests on active dosimeters have been performed. Preliminary calculations with the four codes have been carried-out to assess the neutron fluence during operations and the shutdown dose rate level for DTE2 in the proposed experimental positions and for computational code benchmarking.

3.1 Experimental activity

3.1.1 Experimental assembly

One in-vessel position (2 Upper Irradiation End) has been identified for passive measurements with TLDs as in 2005-2007 JET benchmark experiment [13]. Two ex-vessel positions will be used for the installation of active gamma dosimeters and activation foils, to measure both decay gamma dose rate during shutdown and neutron fluence during operations. The first ex-vessel position is on the side port of Octant 1 (as in 2012-2013 experiment, see section 2) and it is the reference. The second ex-vessel position is on the top of ITER like

Antenna (ILA) in horizontal port of Octant 2. The positions and experimental lay-out are reported in figure 7.

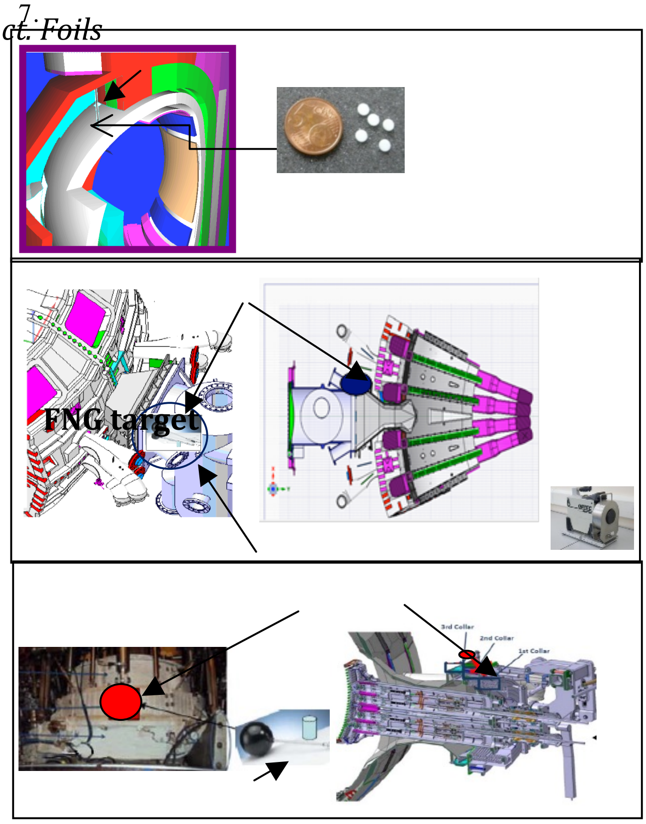


Fig. 7. In-vessel (a) and ex-vessel positions in Octant 1 (b) and in Octant 2 (c) for the future SDR experiments. Detectors are shown as well.

The detectors and the positions on the top of the ILA have been selected on the basis of the calculations described in section 3.2.3.

TLDs for passive decay gamma measurements during off-operational periods will be the same as in the Streaming experiment (MCP-7 type with natural LiF) [3]. Activation foils assembly with Co, Ta and Ag foils during operation will be located close to the active dosimeters to measure cumulated neutron fluence during operations.

The portable High Purity Germanium (HPGe) gamma spectrometer (CCFE) will be also used for identification of radioisotopes contributing to the dose, during DD shutdown and after DT when access for survey will be possible.

Regarding the active dosimeters, three spherical air-vented ionization chambers, electronics and special low-noise cables 100 m long have been procured by ENEA and KIT to perform active measurements outside the vessel.

These detectors will be installed before the start of DTE-2 campaign. The chambers are very light, made of low activation materials, they have excellent reproducibility and long-term stability and the spherical construction ensures a nearly uniform response to radiation from every direction. The energy response is very flat. The detectors have been selected to cover a dose rate range from background to 30 mSv/h (as predicted by calculations in section 3.2.1). The two high sensitive chambers (PTW type 32002, Ø 140 mm) will be used to measure the dose rate after both DD and DT operations in Octant 1 and Octant 2. One smaller chamber (PTW type 32005, Ø 44 mm) will be located in Octant 1 and installed close to the PTW type 32002 during DT shutdown. The electronics will be located out-side the torus hall because the high radiation level (see section 3.2.1) would damage the electrometers. High-voltage and acquisition will be remotely controlled and proper software has been developed by ENEA for this scope. The detectors have been calibrated in terms of Air–kerma and H*(10) at energies ranging from 30 keV to 1.2 MeV.

3.1.2 Preliminary tests on Ionization chamber

Irradiations were performed at the Frascati Neutron Generator on Ionization chamber type 32002, at the end of one-day operations to preliminary test the detector for active measurements of decay gamma dose at the end of DT operations. The detector was located on an aluminum support on the floor below the FNG target. The layout is shown in figure 8. The detector was switched-on at the end of DT irradiation at FNG and the dose rate was remotely collected. The dose at the shutdown was measured for 12 hours inside the bunker hall, after the detector was moved to the control room and the acquisition continued during the whole night. The results are shown in figure 8. These preliminary tests showed that the system correctly measured the background dose of the building, detecting the dose rate behavior of the FNG laboratory after a run of irradiation experiment and also gamma radiation contribution due to the buildup and presence of radon daughters in the control room i.e. when the ventilation was switched off (the dose rate increased during the night).

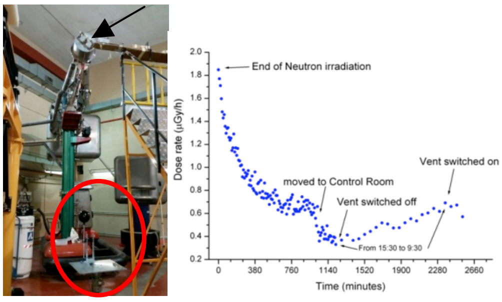
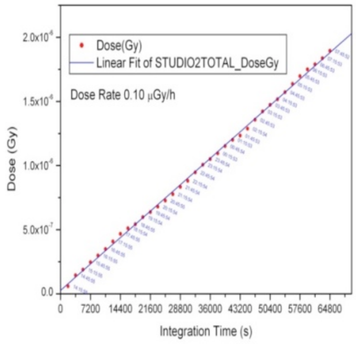


Fig. 8 – Installation of PTW type 32002 ionization chamber in the FNG bunker (left) and dose rate versus time after DT operations (right)



1 hour

Fig. 9– Background dose versus integration time measured by PTW type 32002 ionization chamber in an office located on a second floor.

1 week

In order to verify the stability of the system during long-lasting measurements, further measurements were performed in an office located on a second-floor for one week. The integrated dose versus time is shown in figure 9. The chamber showed high stability to measure background level and the acquisition software managed correctly different events like timeout communication, and power switch off. Further tests will be performed at FNG to verify the low neutron-induced activation of the detector itself and at Frascati Tokamak Upgrade (FTU) to evaluate the effect of electromagnetic field during time-resolved measurements.

After these tests the two PTW type 32002 ionization chambers will be sent to JET and installed in December 2015 in Octant 1 and Octant 2 to perform SDR measurements during off-operational periods and at the shutdown of the next DD campaign.

3.2 Shutdown dose rate calculations with R2S & D1S codes

3.2.1 Neutron fluence and SDR level at the end of DTE-2 in Octant 1

Shutdown dose rates at the end of DTE-2 have been calculated with Advanced D1S (ENEA), R2Smesh (KIT), MCR2S (CCFE) and R2S-UNED (CIEMAT) from 1 hour to 1 year after JET shutdown. The calculations have been done at the same positions of the 2012-2013 benchmark and along the mid-port for comparison with previous experiment. High resolution 3-D shutdown dose rate maps have been produced as well. Neutron flux calculations in relevant positions and 3-D maps have also been provided. The estimated dose rate level and neutron fluence range has been used for the selection of the active ex-vessel detectors. The DTE-2 scenario used in FISPACT or ACAB calculations is in Table 1. It refers to 1.7 x 10^{21} over 17 weeks and assumed high performances in the last period of operations (optimistic performances).

Table 1 DTE-2 irradiation scenario (optimistic performances)

Time	n/s	Total n	Repetition
5 days	$1.09\text{x}10^{14}$	$4.72\ \text{x}10^{19}$	x6
2 days	0		
5 days	$2.62\ \text{x}10^{14}$	$1.13\ \text{x}10^{20}$	x5
2 days	0		
5 days	$3.28\ \text{x}10^{14}$	$1.42\ \text{x}10^{20}$	x5
2 days	0		
4 days	$3.28\ \text{x}10^{14}$	$1.13\ \text{x}10^{20}$	x1
1s	$3.54\ \text{x}10^{18}$	$3.54\ \text{x}10^{18}$	x7
3600s	0		
1s	$3.54\ \text{x}10^{18}$	$3.54\ \text{x}10^{18}$	x1

The cumulated neutron fluence 3-D map calculated with Advanced D1S at the end of DTE-2 operations is shown in figure 10.

The maximum neutron fluence at the detectors positions will be $6\text{x}10^{14}$ n/cm^2 (max flux $2\text{x}10^{12}$ n/cm^2/s for high performance DT shots). Considering the high neutron fluence, low activation detectors have been selected and the electronics will be located outside torus hall.

The 3D shutdown dose rate maps obtained with MCR2S (CCFE) and Advanced D1S (ENEA) are shown in figure 11. At 1 hour after shutdown the dose rate inside the vessel can exceed 400 mSv/h and ~ 20-30 mSv/h at the horizontal port side. At three months after shutdown the dose rate level is of the order of 50 mSv/h inside the vessel and extends to a few hundreds of Sv/h outside, close to the horizontal port.

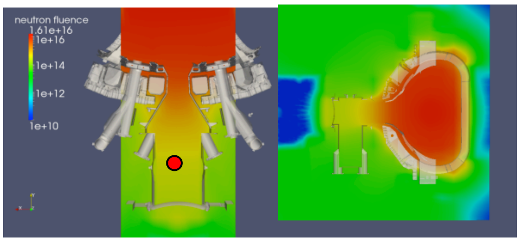


Fig. 10. Cumulated neutron fluence map at the end of DTE2 operations calculated with Advanced D1S. The red circle identifies ex-vessel position.

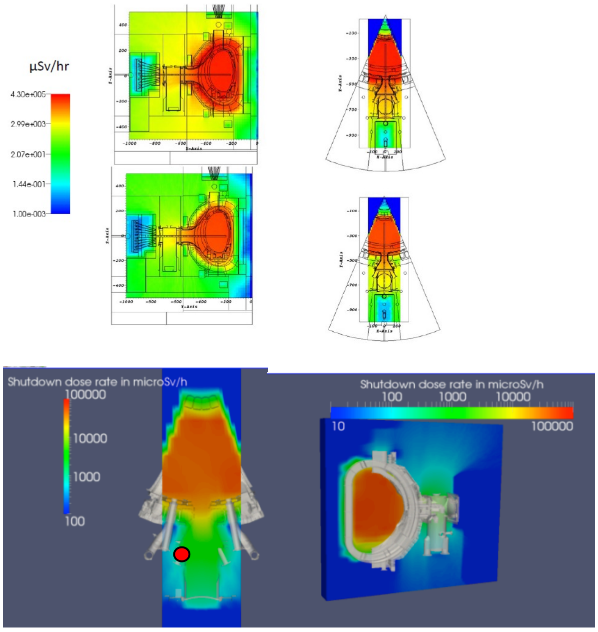


Fig. 11. Shutdown dose rate maps with MCR2S at 1 hour and 1 week and Advanced D1S for 3 months after DTE-2 shutdown.

Outside the vessel, the dose rate level is one or two orders of magnitude lower than inside, depending on the position. In general the dose rate close to the horizontal port is higher in vertical zones. At one year after shutdown the dose rate is expected to still be well above 10 Sv/h. At the same ex-vessel position of the previous experiment the dose rate level is ~ 3 orders of magnitude higher than at the end of DD 2012 campaign. From these calculations the expected range of dose rate with active dosimeter in ex-vessel position close to horizontal port is 1 Sv/h< H*(10)<30mSv/h. The lower limit is set to be able to perform shutdown dose rate measurements even during the next DD shutdown. The maximum decay gamma flux is ~2x10^7 γ/cm^2/s.

3.2.2 Computational benchmarking in Octant 1

For comparing the codes and understand the reasons of the differences observed in previous benchmarking, the calculations with R2S codes have been performed using the same mesh (voxel size 10x10x10 cm covering the whole geometry). The SDR results of the all the codes along the mid-port from 1 hour to 1 year after shutdown are shown in figure 12.

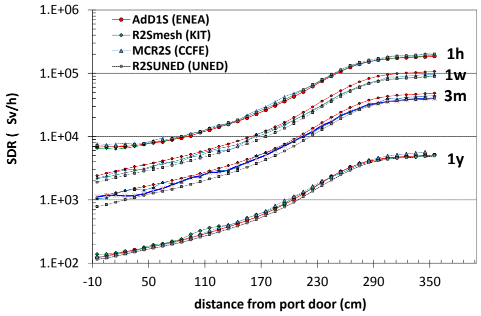


Fig. 12. Shutdown dose rate results versus distance form port door calculated with Advanced D1S, R2Smesh, MCR2S and R2S-UNED at various time after DTE-2 shutdown.

The ratios of the dose rates after 1 week and 1 year after shutdown versus distance from the port door are shown in figure 13.

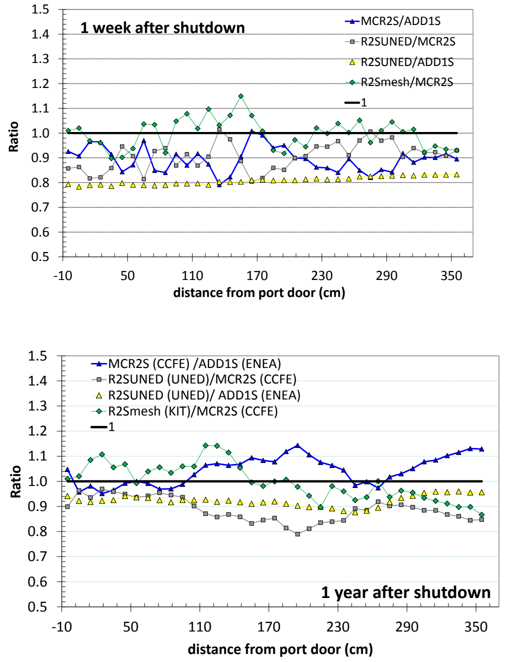


Fig. 13. Comparison among the codes of shutdown dose rate along the mid-port of Oct 1 at 1 week (top) and 1 year (bottom) after shutdown.

In general all codes agree within ±20% over the whole range. At 1 year from shutdown the MCR2S results are generally higher and R2SUNED are generally lower than the other codes. R2SUNED shows the same trend as Advanced D1S. Comparing to other R2S codes, R2SUNED has the capability to separate neutron fluxes inside portion of cells enclosed in the same voxel, similar to point-wise gamma generation of D1S. Advanced D1S, R2Smesh and R2SUNED codes agree also very well in the ex-vessel position (see figure 14), whereas MCR2S results are generally higher. Investigations by comparing decay gamma source results and spectra at various positions are in progress to understand the observed differences. Furthermore simulations will be repeated using the same decay source in common decay format.

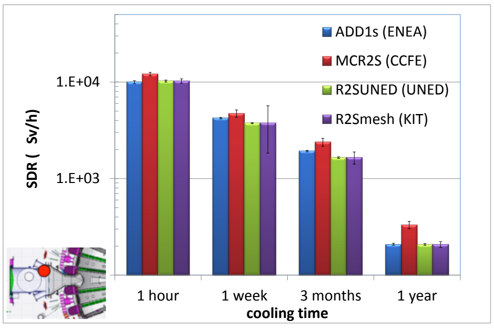


Fig. 14. Shutdown dose rate calculations versus time after shutdown in ex-vessel position in Octant 1.

3.2.3 Shutdown dose rate pre-assessment in Octant-2

A preliminary study to assess the technical relevance of the second ex-vessel position on the top of ITER-Like Antenna (ILA) was carried-out with Advanced D1S. ILA is installed in main horizontal port of Octant 2 and it has an ITER like design. A dose rate benchmarking test close to ILA was considered very attractive because it represents a configuration similar to the ICRH port of ITER. Various surveys of the torus hall and several meetings were held to find a suitable place for installation of active detectors close to the machine without interfering with ILA operations. Taking into account the various constraints, the installation on the collars on top of ILA behind the poloidal field coil (PFC) seemed to be viable (see figure 7c). The pre-analysis was aimed to verify that the expected dose rate level would be affected by ILA. Indeed if the ILA contribution would be trivial, additional measurements in this position are not technically relevant. Furthermore, these analyses are aimed to select the best position over the collars in order to maximize the effect of the component inside the port but with minimum effect of PFC.

A 3D MCNP model of Octant 2 with simplified representation of ILA has been used for this pre-analysis (see top of figure 15). It has been developed by modifying the MCNP model of Octant 1 and the antenna has been simply represented with two boxes filled with a mixture of 50% SS316L and 50% Inconel 625. The density of the mixture has been reduced in order to match the real weight of the main ILA components (~2600 kg). Spherical scoring cells, “detectors”, were located at the top of the main horizontal port at six different positions.

Several shutdown dose rate calculations have been performed using both Octant 2 with ILA and Octant 1 model to assess the differences among the two in-port configurations, at various cooling times using the same DTE2 irradiation history as for the previous assessment.

6 5 4321 PFC

The calculated dose rate in the scoring cells D1-D6 are reported in figure 15. ILA

More accurate analyses will be performed with detailed representation of ILA and environment surrounding the detector.

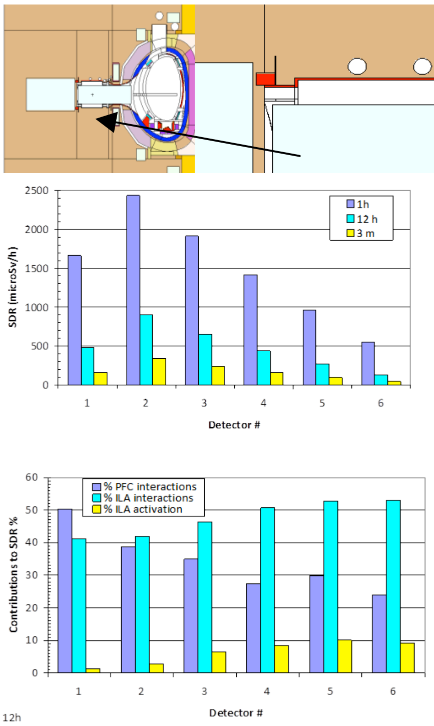


Fig. 15. MCNP Model of Octant 2 with simplified ILA in horizontal port (top). SDR at different times after DTE2 shutdown at the examined detectors positions (middle). Contribution of interactions in PFC, ILA and activation of ILA to the SDR at 12 h after shutdown (bottom).

The maximum value of the dose rate is obtained at position D2. At 1 h after shutdown it is 2.5 mSv/h and at 3 months the maximum is ~ 350 Sv/h. The dose rate level at the top of Octant 2 is lower than in Octant 1 and the ratio (Oct.2/Oct.1) varies between 0.2 and 0.5 depending on the positions. The first position is unlike to be appropriate because it is much affected by shielding from the front PFC. The contributions of the PFC and ILA interactions to the SDR and of ILA activation are shown in figure 15 as well. As expected, the contribution due to PFC decreases as the distance from the vessel increase and the contribution of ILA interactions and activation show the opposite trend. ILA interactions contribute of more than 40 % to the SDR, however only few % is due to decay gamma emitted from ILA itself. The best compromise between the maximization of dose rate level and ILA contribution and minimization of PFC shielding are the positions D2 and D3, i.e. on the second collar. The level of expected dose rate can be well measured with available detectors after DTE-2, whereas at the end of DD operations dose rate could be sufficiently higher than background only at short-medium cooling time depending on future performances.

3. Conclusions

Several calculation and experimental activities are in progress to prepare future SDR benchmark experiments for DTE2 to validate the R2S and D1S tools used in ITER. The results of the recent benchmark experiment at the end of DD operations showed that, except in a few positions, good agreement within the overall uncertainties has been found between calculations and measurements and among the codes, providing confidence in R2Smesh, MCR2S, R2SUNED and Advanced D1S codes for applications to ITER predictions. However, the benchmark accuracy needs to be improved and the current computational and experimental efforts seem a promising route to achieve this challenging goal.

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