14th Pisa Meeting on Advanced Detectors
PM2018

Radiation and Thermal Stress Tests on Diamond Detectors for the Radial Neutron Camera of ITER

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The ITER Radial Neutron Camera (RNC) is a multichannel detection system designed to measure the uncollided neutron flux from fusion plasma, providing information on the neutron source strength and emissivity profiles. Fission chambers, diamonds and scintillators will be employed in different parts of RNC, with different environmental conditions.

Single-Crystal Diamonds (sCD) detectors will be located in the port plug (*In-port RNC*), shall operate in a high radiation environment (up to ~5.3 MGy gamma dose and ~2*10^{16} n/cm^2 neutron fluence) and resist to about 500 baking cycles up to 240 °C during the whole ITER lifetime (~ 10 years). In order to assess the feasibility of a diamond detector in such harsh conditions and to study the best technological solutions, we are currently performing a set of tests to understand the behaviour of commercial SCD (4.5x4.5x0.5 mm^3), from 3 different manufacturers, under radiation and thermal stresses.

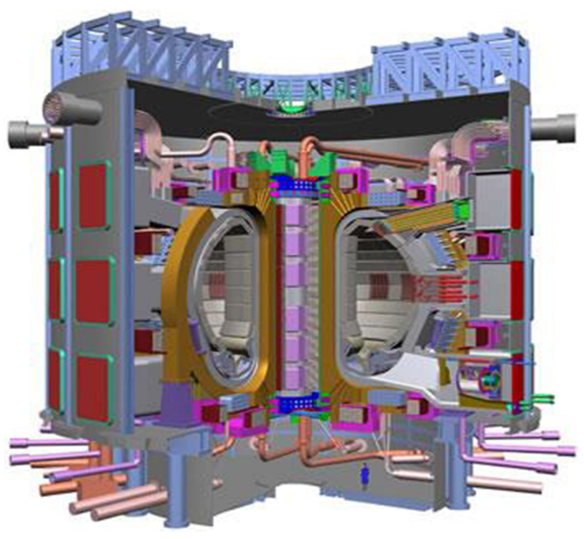

Fig. 1. *ITER global view*

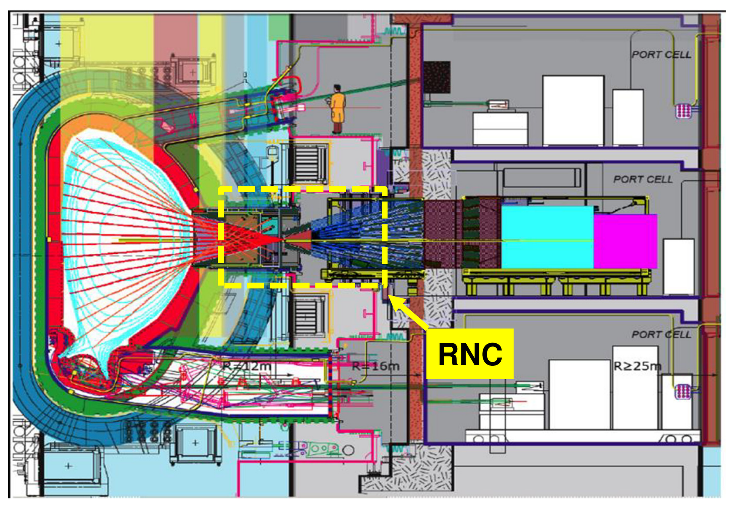

Fig. 2. *ITER poloidal section*

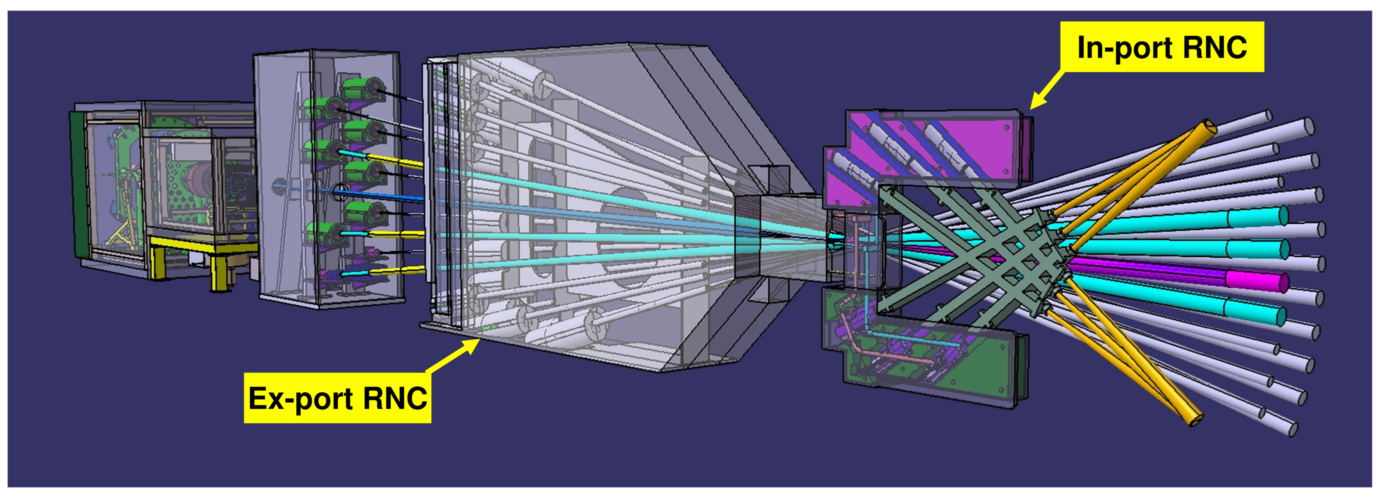

Fig. 3. *RNC CAD model*

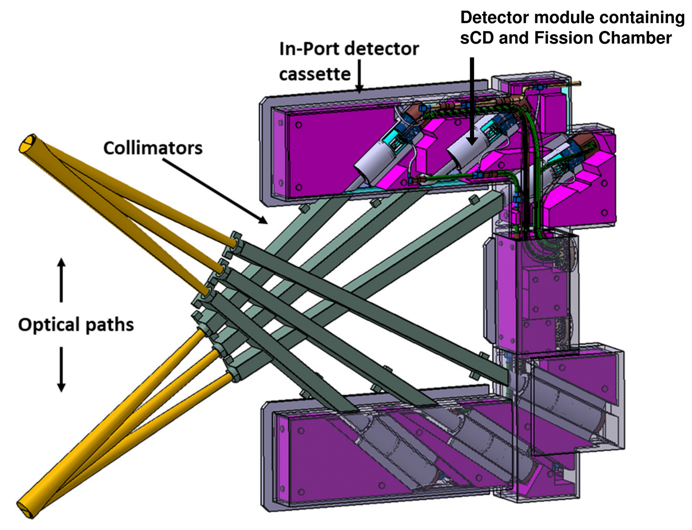

Fig. 4. *Detail of RNC In-port*

THERMAL FATIGUE TEST

Motivation: sCD will be located in the port plug (**In-port RNC**), where the operating temperature is 100 °C, and 500 baking cycles up to 240 °C are foreseen during ITER lifetime. The test is aimed to prove that sCD can survive the baking cycles and operate reliably at 100 °C during the whole ITER lifetime.

Test method: The sCD performance evaluation under thermal stress over a period of ten years requires an *Accelerated Testing* strategy [1] to extrapolate information from a short-time test. Due to the lack of physical or statistical models of the damage mechanisms, a *Usage Rate Acceleration* approach has been chosen.

Two separate tests have been developed to separate the effect of high temperature and thermal cycling:

- ***Steady Temperature Test (STT):*** an accelerated test at steady maximum baking temperature, (~240 °C) to study the effects of the high temperature on a long time scale.
- ***Temperature Cycling Test (TCT)***: a continuous cycling between the maximum baking temperature and the operating temperature in the In-port cassette (~100 °C).

The time evolution of detector performance during the tests are evaluated by periodical measurements of the spectrum of a Tri-alpha source (Pu, Am, Cu). The foreseen duration of the test is 5 months.

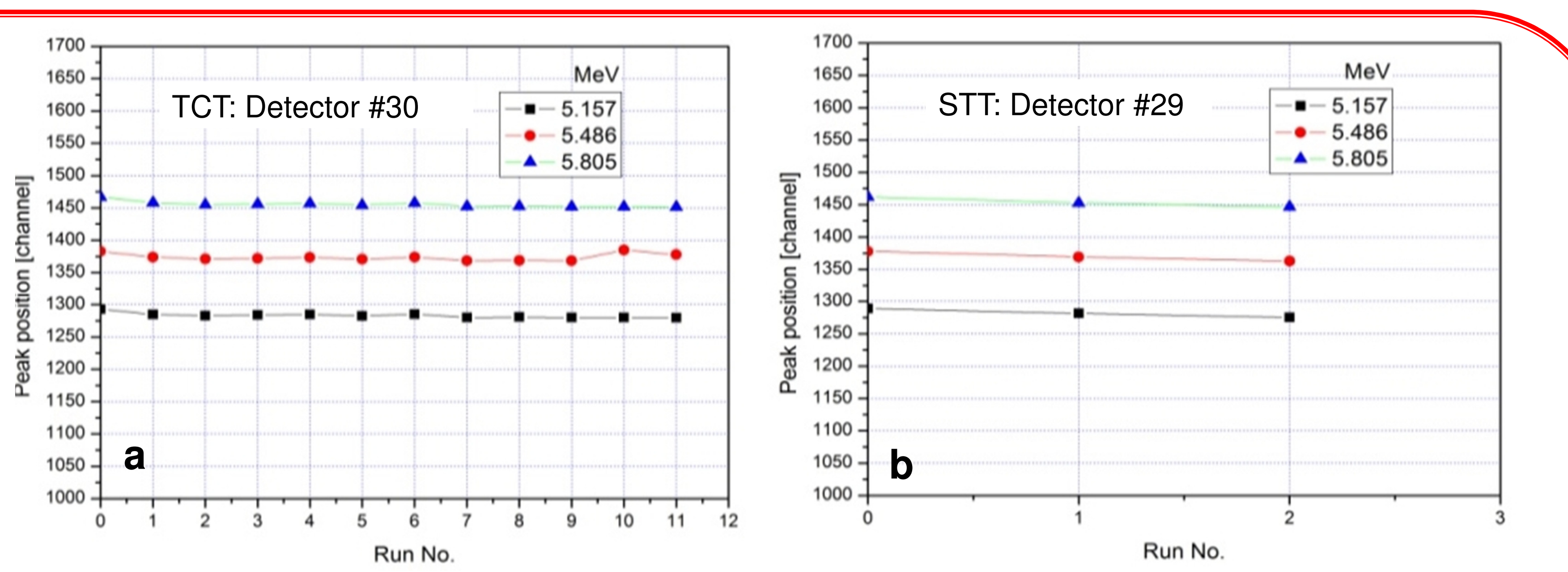

Fig. 5. *Tri-alpha peak positions as function of run n.(time) in two weeks. (a) TCT; (b) STT*

Implementation: Two identical vacuum chambers, one for STT, and one for TCT, have been designed and constructed at IFJPAN. Each chamber hosts two sCD from different producers: one with Ti-Ag contacts and one with Pt-Au. The test operating pressure is 1 mBar. The heating elements, as well as a robotic arm to move the alpha source near the detectors during measurements, are controlled by a Siemens PLC.

First results: The tests are still running, at present. After two weeks (10% of total test time), no significant alterations of sCD spectral response have been observed: the peak positions of the tri-alpha spectra are almost unchanged, as shown in Fig. 5 for TCT (a) and STT (b).

GAMMA IRRADIATION TEST

Motivation: sCD will be installed on the Line Of Sight (LOS) of the In-Port system. According to [2], the gamma dose at the detector position in the whole ITER lifetime is ~5 MGy, or ~3 MGy with a 0.25 cm thick lead shield around the detector box. The test is intended to check the Gamma Radiation Hardness of sCD at such high doses.

Test method: Three identical sCD (Ti-Ag contacts) provided with special removable SMA connectors developed by ENEA (to avoid radiation damage to the connectors) were irradiated at CALLIOPE facility [3]: two up to 4.7 MGy (high dose rate: 1.4 kGy/h) and one up to 1.0 MGy (low dose rate: 0.3 kGy/h). The alpha-spectrum of one sCD has been measured at four different doses (Fig. 7).

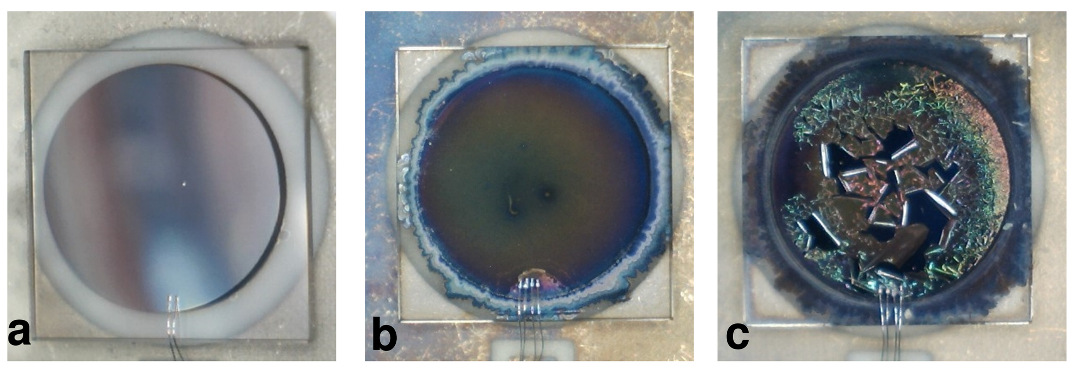

Fig. 6. *sCD: (a) non irradiated; (b) 1.0 MGy: (c) 4.7 MGy.*

Results:

- Operation up to 3.1 MGy has been observed, with only a 3% reduction of Charge Collection Efficiency (CCE), and a slightly reduced counting efficiency (Fig. 7)
- Compete failure at 4.7 MGy has been observed due to gamma-induced contact degradation, already evident at 1 MGy (Fig. 6).
- No dose-rate effects were observed.

Discussion: SEM and microanalysis inspection reveals that contact damage is likely due to a gamma-accelerated chemical reaction between silver and the sulphur contained in air (2 Ag +H_2S → Ag_2S+ H_2) that can be overcome operating sCD in inert atmosphere and/or not using silver contacts.

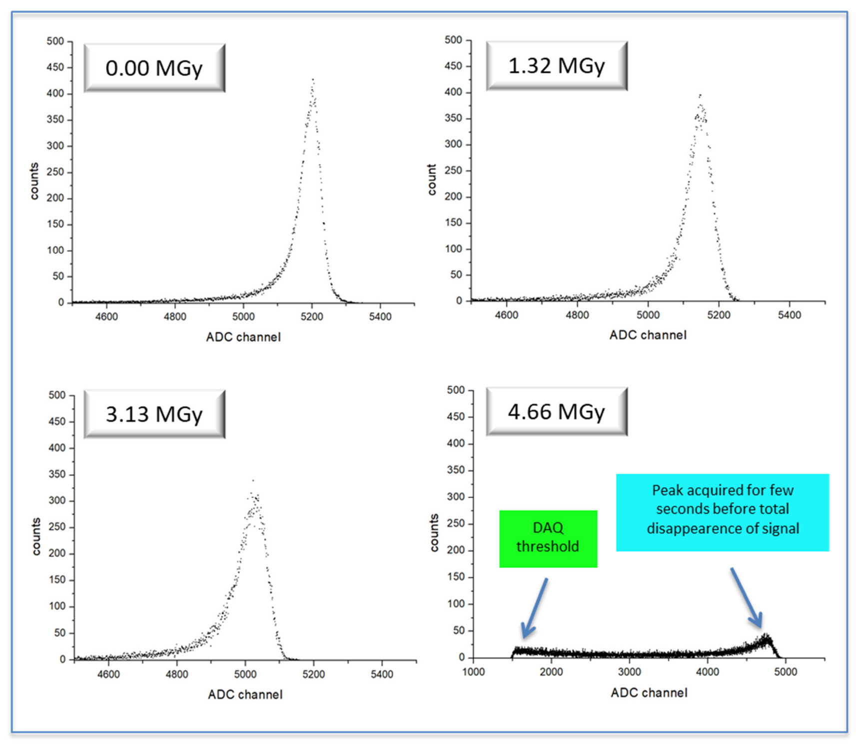

Fig. 7. *alpha spectra of one sCD at different doses*

NEUTRON IRRADIATION TEST

Motivation: sCD will be installed on the Line Of Sight (LOS) of the In-Port system. According to [2], the 14 MeV neutron fluence, calculated over ITER lifetime, is ~2x10^{16} n/cm^2. The test purpose is to measure how the sCD performance degrades with neutron fluence.

Test method: Irradiation of three sCD from different manufacturers employing different contact technologies (Ti-Ag, Pt-Au, and DLC-Ti-Au). The plan was to perform irradiation in the fission reactor BR1 (SCK-CEN, Belgium) in three **14 MeV equivalent (ASTM E722-14 for Si)** fluence steps: 2x10^{14} , 2x10^{15}, and 2x10^{16} n/cm^2. Detectors performance is evaluated by measuring the alpha spectra before irradiation (reference), and after each irradiation step.

Results after first irradiation step (~1% of total ITER fluence):

- All sCD were strongly activated. Two weeks after irradiation, the alpha peaks were still not distinguishable from background activation products. Clean alpha peaks were obtained six weeks after irradiation, except for one detector, whose alpha peak was still not distinguishable from background.
- All sCD show a **CCE reduction of about 90%.** See the peak shift in Fig 8 (a,b). **Priming with ^{90}Sr for 15 hours was unsuccessful.**
- Pulse shape analysis showed a strong reduction of drift time for both electrons and holes (see Fig. 9 for holes). This is a typical sign of charge trapping due to crystal damage.

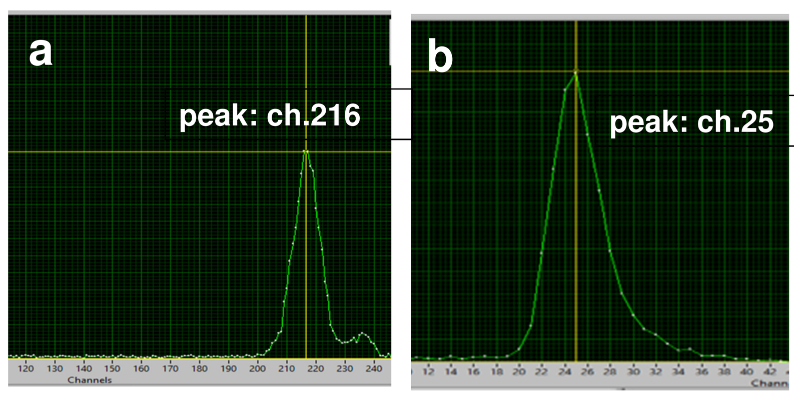

Fig. 8. *alpha spectra (a) Before irradiation; (b) after 2x10^{14} n/cm^2 (vertical scale not normalized)*

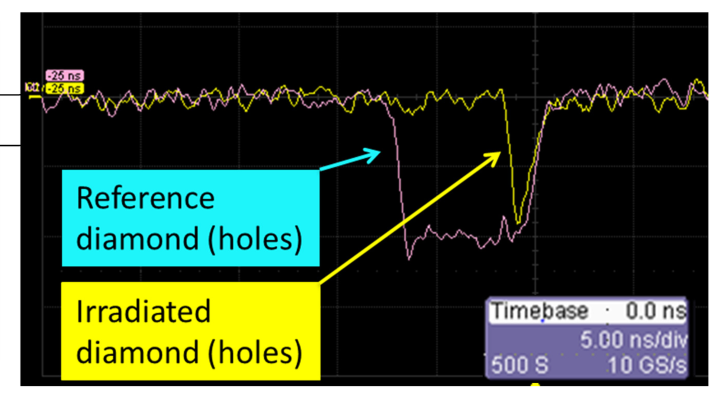

Fig. 9. *alpha pulse waveforms before and after the first irradiation step*

CONCLUSIONS

- **Thermal fatigue**: tests are still ongoing but first results are promising: after two weeks of tests (10% of total test time), no significant alterations of sCD spectral response have been observed.
- **Gamma irradiation**: sCD reliable operation found up to 3.1 MGy (expected gamma dose on the detector when shielded with thin lead layer). The contact radiation damage might be avoided by operation in inert gas atmosphere and/or avoiding use of silver in contacts.
- **Neutron irradiation**: 90% Charge Collection Efficiency reduction already at 2x10^{14} n/cm^2 (14 MeV equivalent). Use of thinner diamonds (≤ 140 µm) to improve radiation hardness is under evaluation.

References

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Acknowledgments

The work leading to this publication has been funded partially by Fusion for Energy under the Contract F4E-FPA-327 and the Specific Contract F4E-OFC-358-01-01-0.This publication reflects the views only of the author, and Fusion for Energy cannot be held responsible for any use which may be made of the information contained therein. The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.