Challenges with Diamond Detectors at ITER

Vitaly Krasilnikov

Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization

Birth of ITER Project

ITER - is one of the most ambitious energy projects in the world today.

ITER was set in motion at the **Geneva Superpower Summit in November 1985**, when the idea of a collaborative international project to develop fusion energy for peaceful purposes was proposed by General Secretary M. Gorbachev of the former Soviet Union to US President R. Reagan.

The **ITER Agreement** was officially signed at the Elysée Palace in Paris on **21 November 2006** by Ministers from the seven ITER Members.

Birth of ITER Project

ITER - is one of the most ambitious energy projects in the world today.

- **7** partners representing **>50%** of the world's population work together on the **ITER** project

- **ITER** is designed to produce **500MW** of fusion power (10x power amplification) for extended periods of time (several **100s**)

- **10** years construction
  20 years operation
  5 years de-activation

china eu india japan korea russia usa

The target of ITER Project

ITER is a major international collaboration in fusion energy research involving the **EU, China, India, Japan, Russia, South Korea and the United States**

- **The overall programmatic objective**:
  - to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes

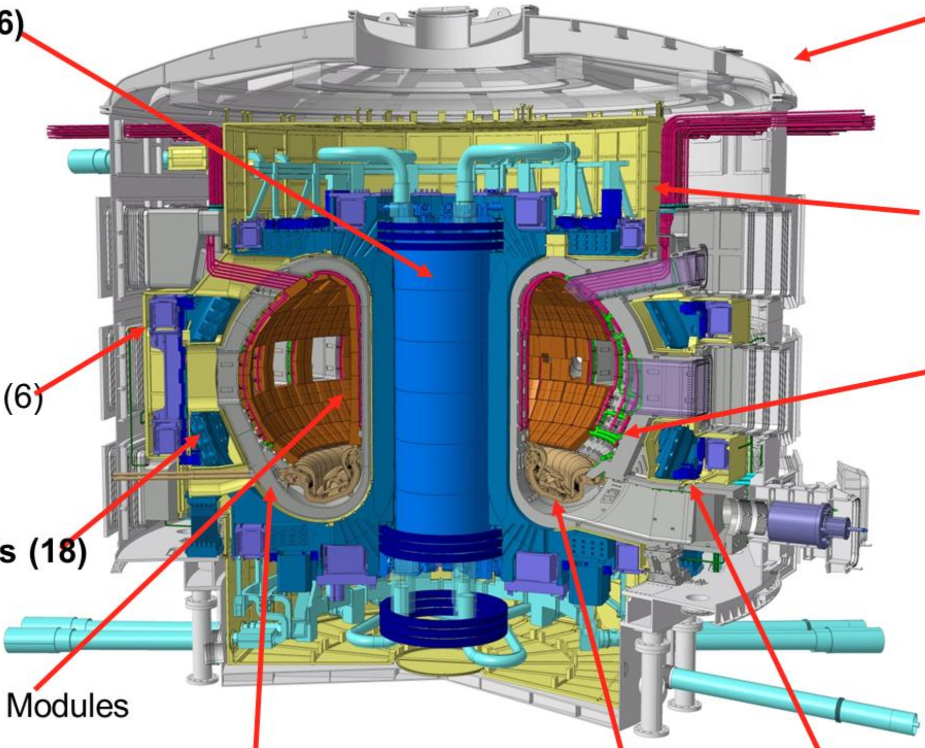
- **The principal goal:**
  - to design, construct and operate a tokamak experiment at a scale which satisfies this objective

- **ITER** is designed to confine a Deuterium-Tritium plasma in which α-particle heating dominates all other forms of plasma heating:

$\Rightarrow$ a burning plasma experiment

ITER Tokamak

Mass: 30.000 tons
Diameter: 28 meters
High: 30 meters



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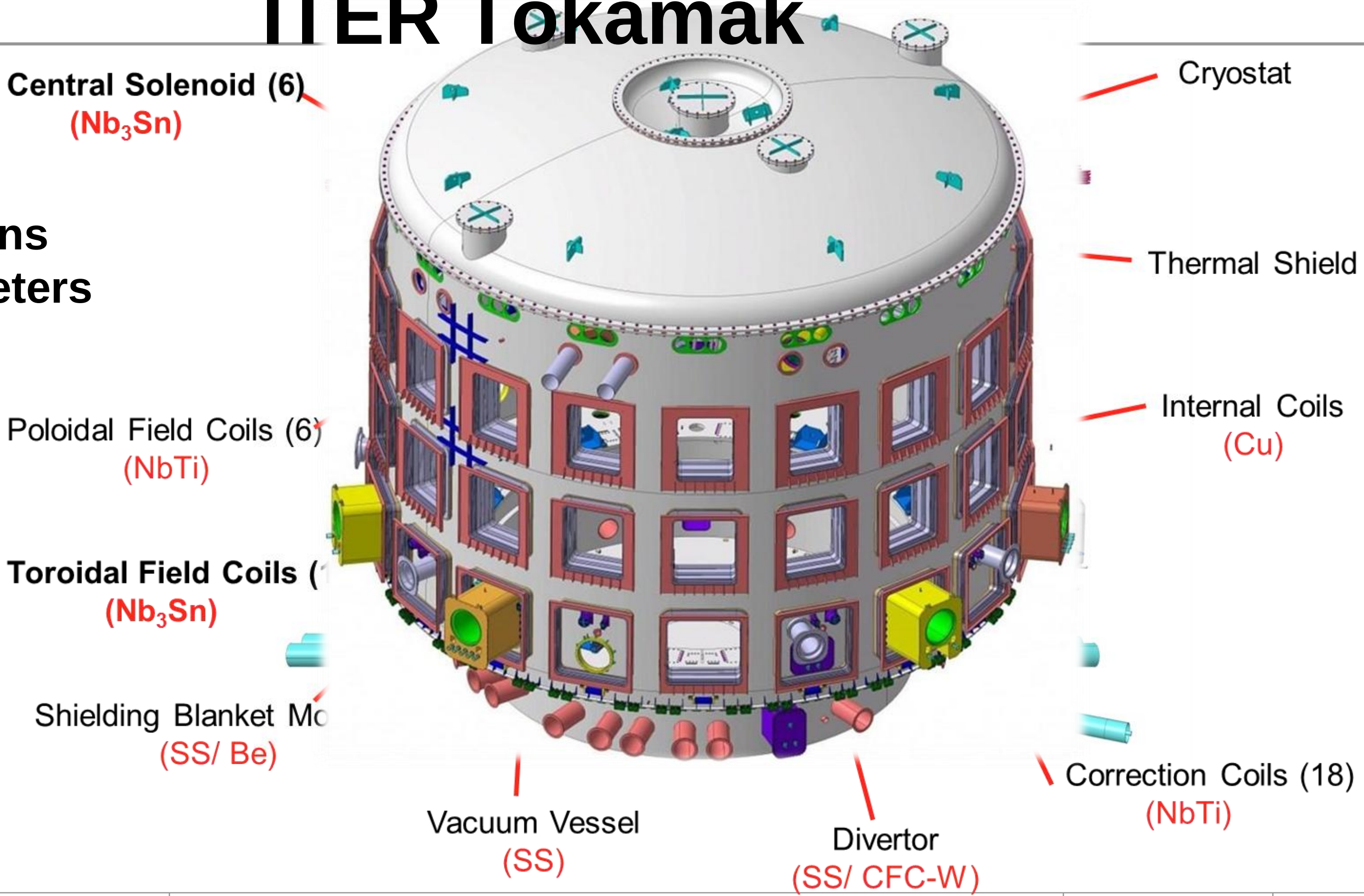
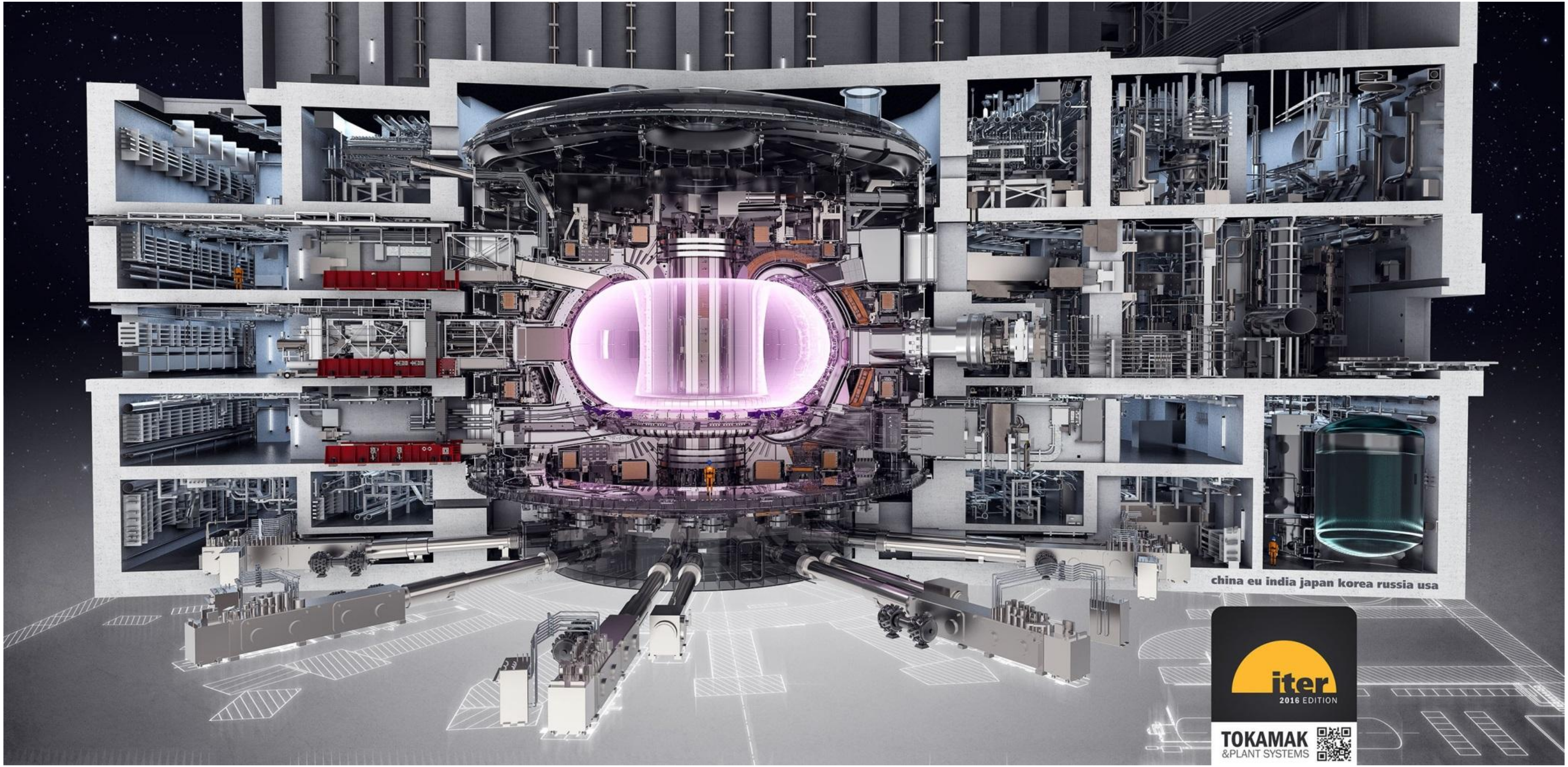


ITER Tokamak



http://www.iter.org/newsline/-/2567

Measurement requirements

Parameter	Range	Time res.	Spatial res.	Accuracy
Fusion power	100 kW – 1.5 GW	1 ms	integral	10%
Total neutron yield	10^{14} – 10^{21} n/s	1 ms	integral	10%
Fusion power density	1 kW•m^{-3} – 15 MW•m^{-3}	1 ms	a/10	10%
Core T_i (r/a < 0.85)	0.5 - 40 keV	1 ms	a/30	10%
Edge T_i (r/a > 0.85)	0.05 – 10 keV	100 ms	1-2 cm	10%
Neutron-and-Alpha-source Profile	10^{14} – 6x10^{18} n•m^{-3}•s^{-1}	1 ms	a/10	10%
nT/nD in Plasma Core	0.01 - 10	100 ms	a/10	10%

…

ITER Neutron Diagnostic Systems

Measurements and Systems

Parameters to be measured	Type	Diagnostics

- Absolute P_{fus}
- Neutron profiles
- n_D/n_T

A) Flux monitors — MFC, NFM, DNFM

B) Activation system — NAS

C) Neutron cameras — RNC, VNC

D) Neutron Spectrometers — HRNS, RNC/VNC, TNS, more…

Primary

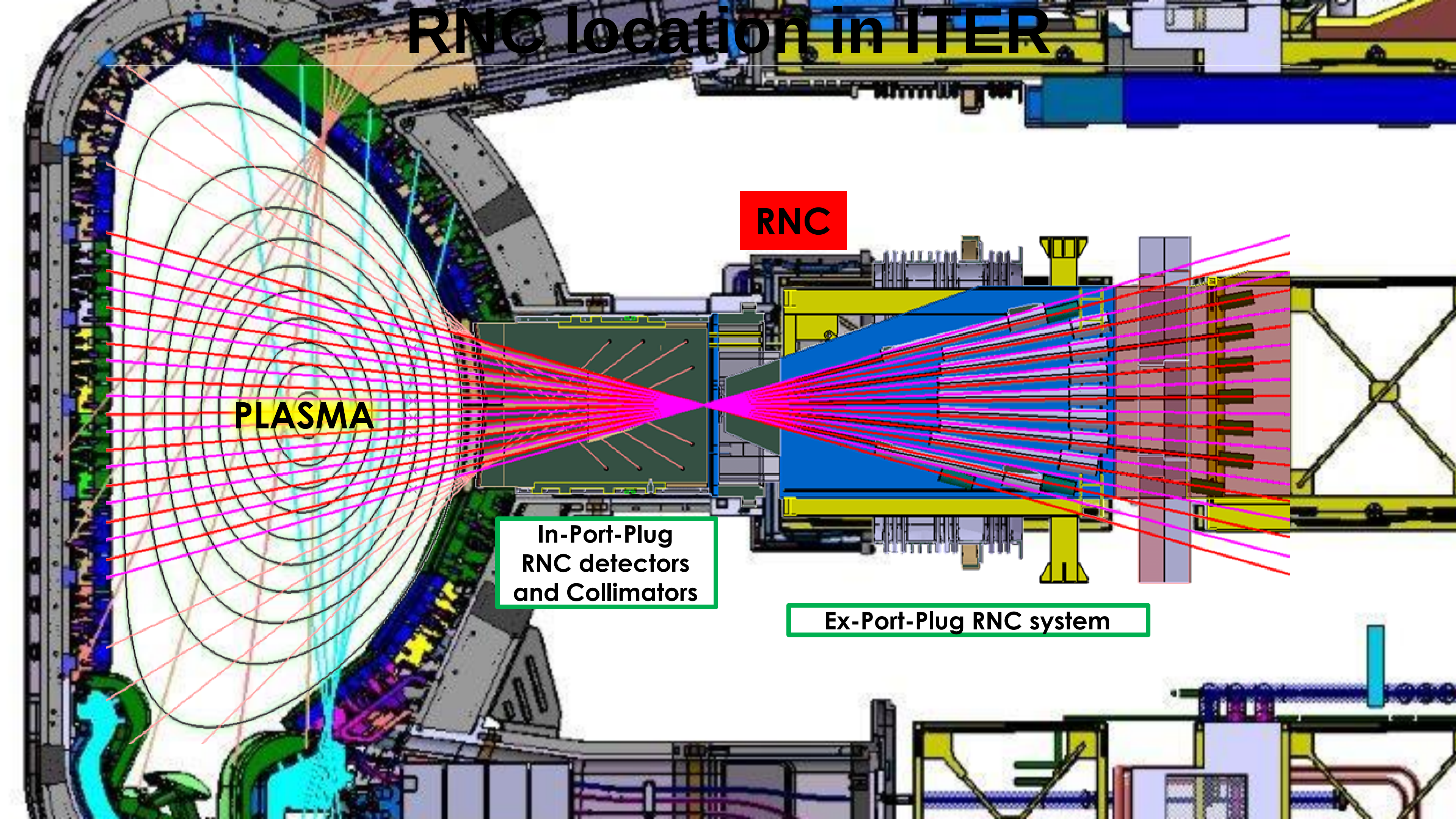
Supplementary

ITER Neutron Diagnostic Systems

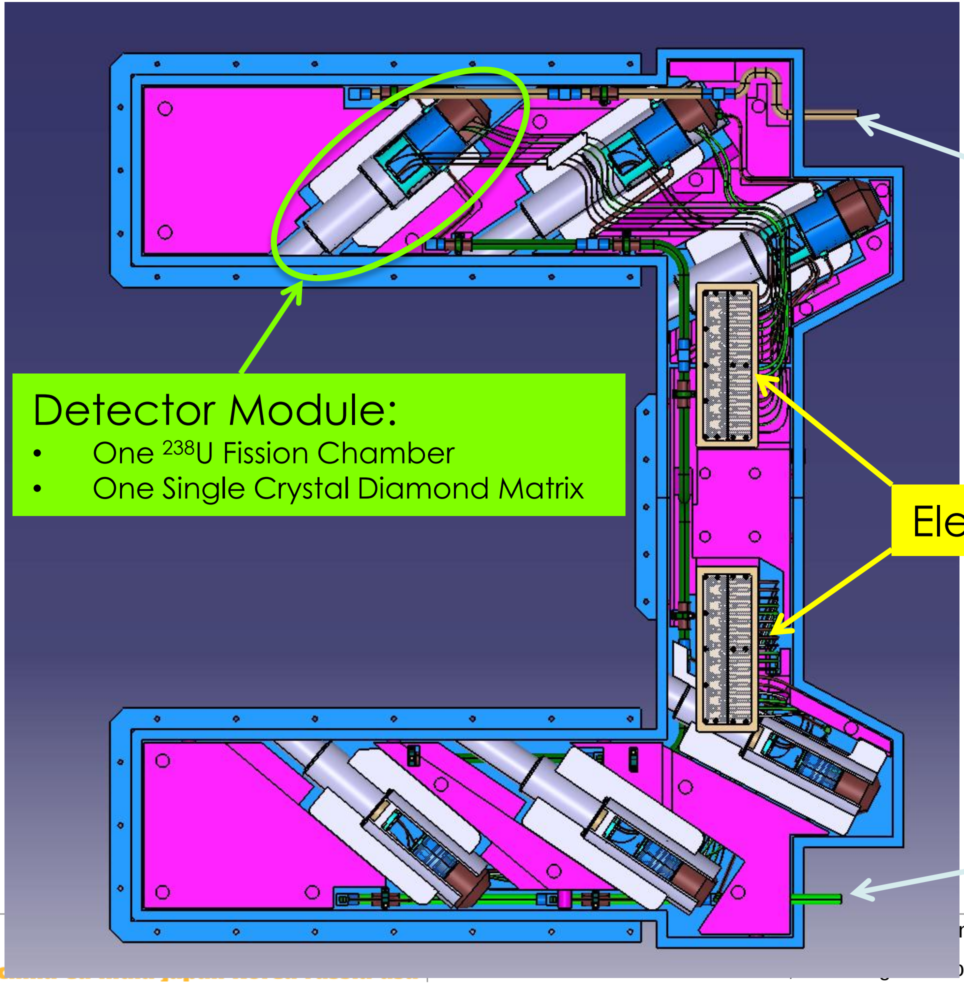
Systems with diamond detectors:

- **Radial Neutron Camera**
- **Vertical Neutron Camera**
- **High Resolution Neutron Spectrometer**
- **Tangential CX atom and Neutron Spectrometer**
- and subsystems of **Neutral Particle Analyzer**

RNC location in ITER



RNC In-Port Detection System



Detector Module:
- One ^{238}U Fission Chamber
- One Single Crystal Diamond Matrix

Diamond Detector Cooling water outlet

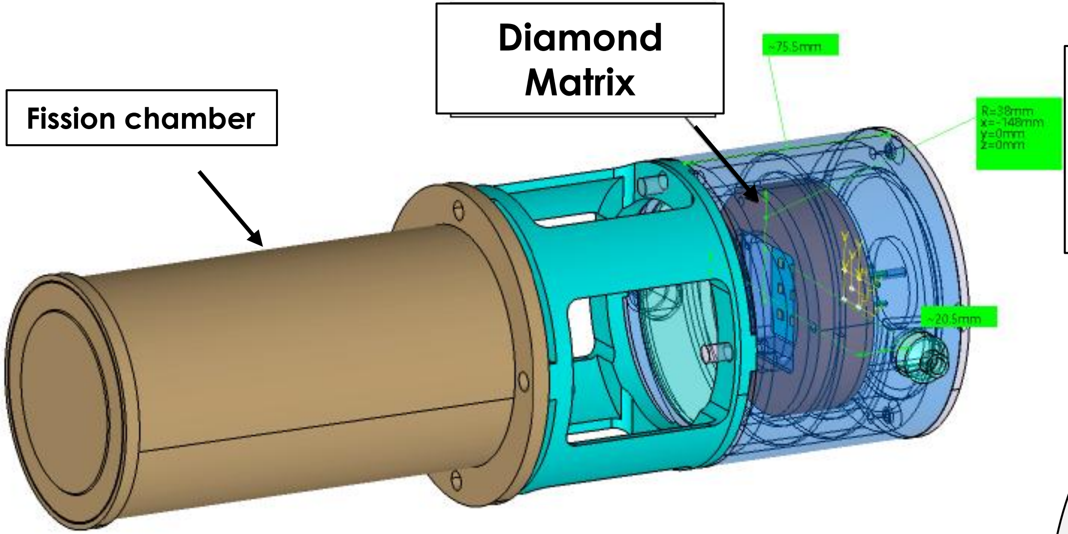
Electrical feedthroughs

⚠ **NO planned maintenance is foreseen for Detector Modules**

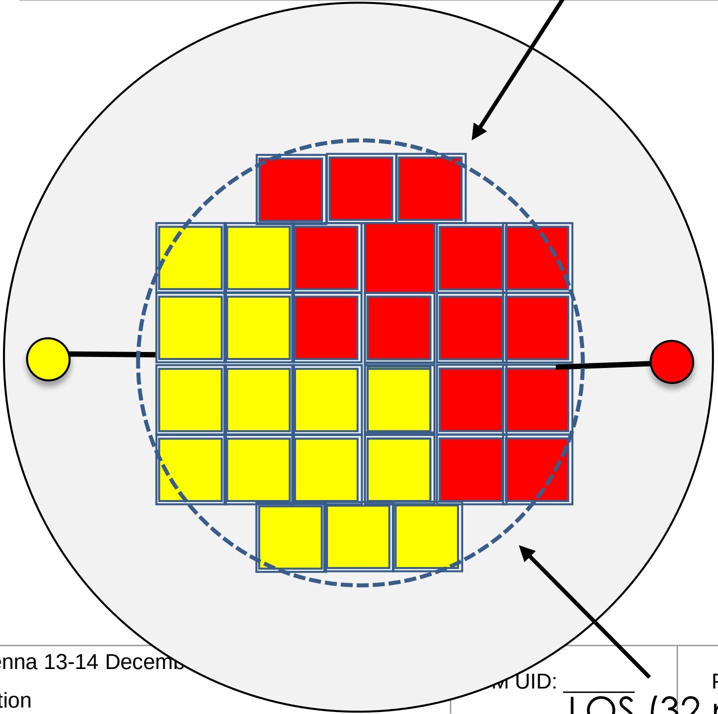
Diamond Detector Cooling water inlet

Detector Module and Diamond Matrix

F.Pompili [XEXUTS]



Diamond matrix:
- **≈30 pixels**, 4.5 x 4.5 mm arranged in two groups
- **Tri-alpha** calibration source (≈**6kBq**) covering the whole sensitive area: deposited on thin film or directly on diamonds.

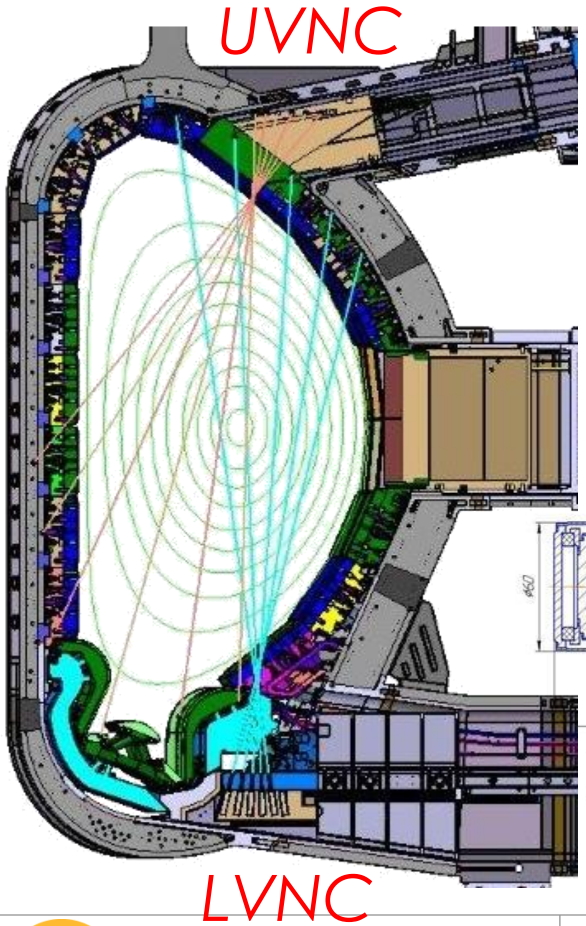


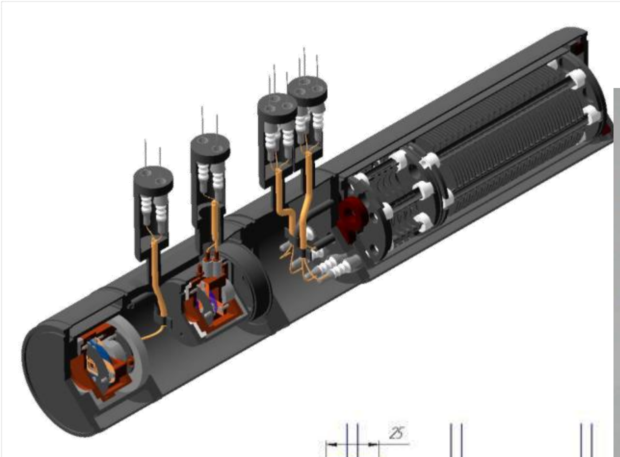
Space constraints due to the interfaces (feed-throughs) and cooling system impose limitations:

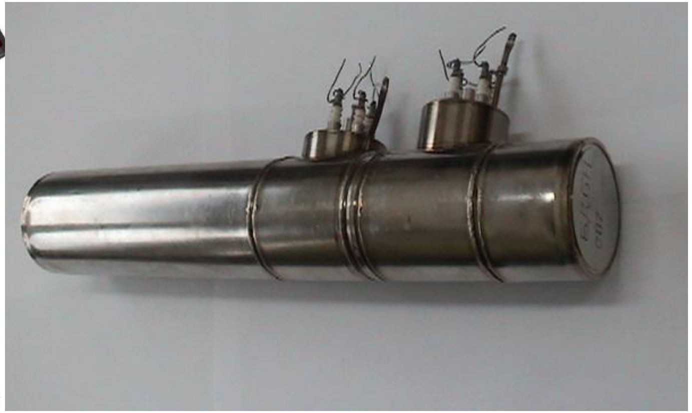
- Max. 2 output signal channels per detector
  - → Diamond Detector pixels divided in two groups of 15 connected in parallel
  - → Potential issue for signal quality
- Diamond Detector behind Fission Chamber

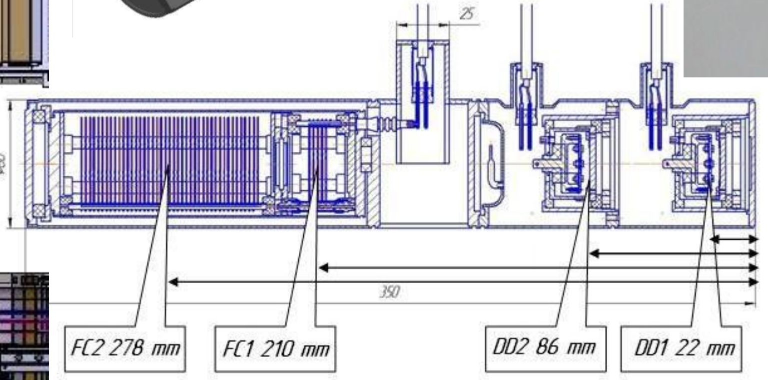
VNC Detectors

G.Nemtsev [XEY528]

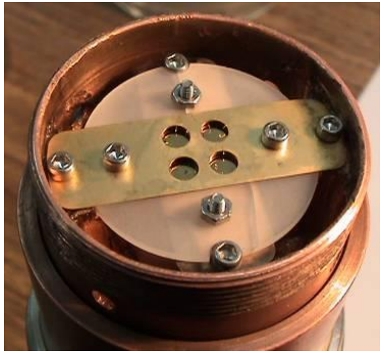








Positions of detectors inside VNC Detector Unit.



4 crystal Diamond Detector with volume of 32 mm^3

Key challenges for diamond detectors' application at ITER

With references to reports given at
Diamond Detectors Development Workshop
held at ITER premises in October 2018

Magnetic field effects

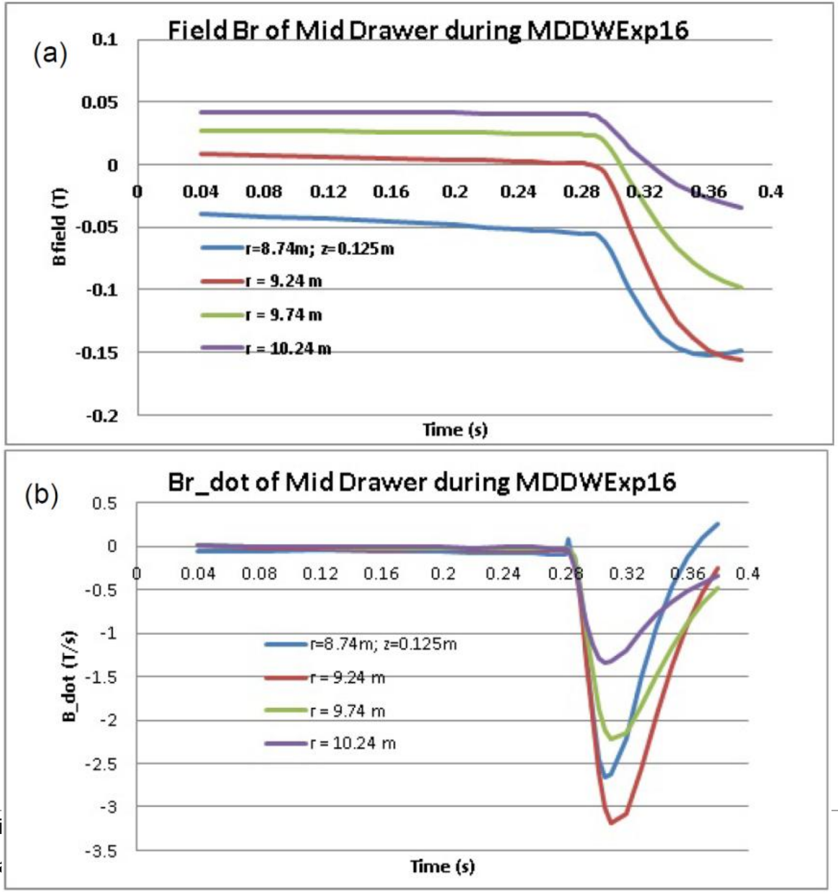
"Diagnostic Equatorial Port Plug; Transient Electromagnetic Analysis during Plasma Disruptions and VDEs EPP_PDR_EM_Report_PPPL (4KXA57 v1.1)"

- ITER Toroidal field at r_{core}, B_T = 5.3 T
  B ~ 50 mT inside port plug.

- Big fields and big field gradients during Major Disruption Events

- Effects in diamond crystal (electron mobility influence)

- Effects in detector housing (spiral components, contacts)



(a) Radial (x direction) magnetic field Br (T) and
(b) dBr/dt (T/s) at r=8.74 m, 9.24 m, 9.74 m and 10.24 m.

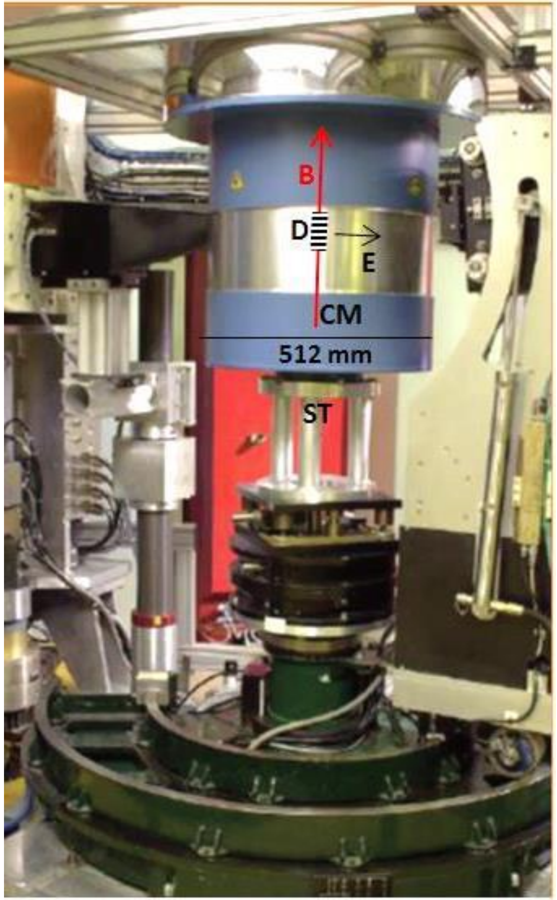
Magnetic field effects

- **No issue**

A.Klix [XEYMLD]

- Epithermal neutrons from D3 facility at ILL Grenoble
  - Room temperature
  - **Magnetic field up to 8 T**
- No significant changes in pulse height spectrum

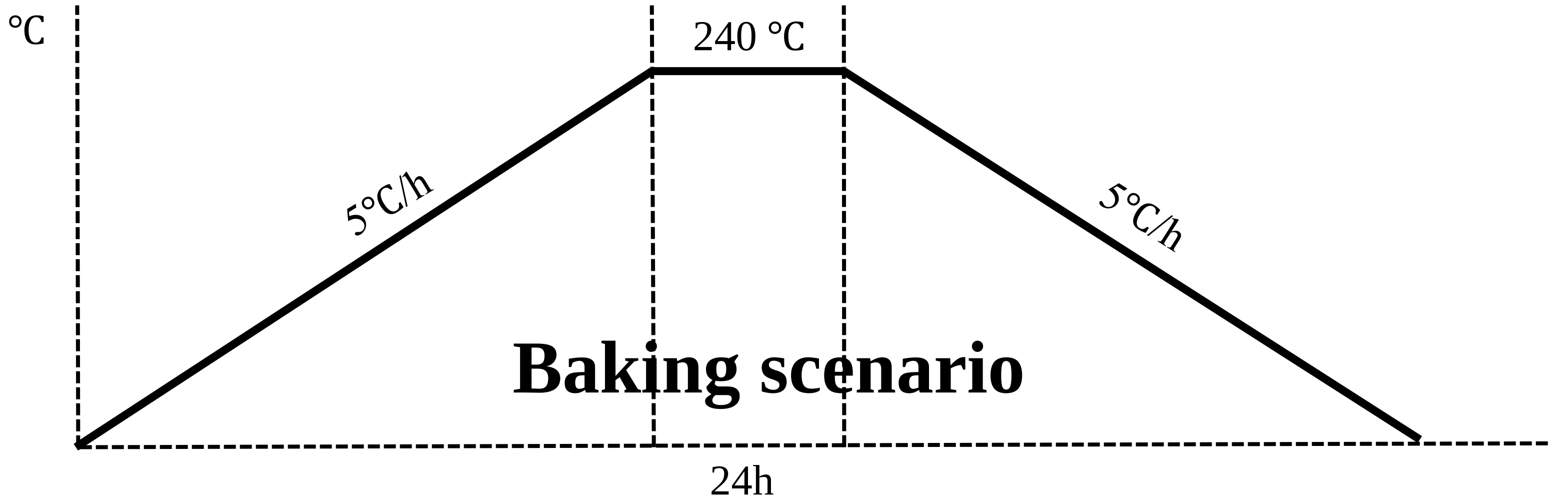
+ other reports of experiments with **B > 4T** with no issues



High temperature

Appendix 15 to VDH - Vacuum Baking (2DU65F v1.3)

- Normal operation – **100 ℃**
- Port Plugs baking – **240 ℃**
- Divertor baking – **350 ℃**
- Baking – before each campaign with a maximum of 500.

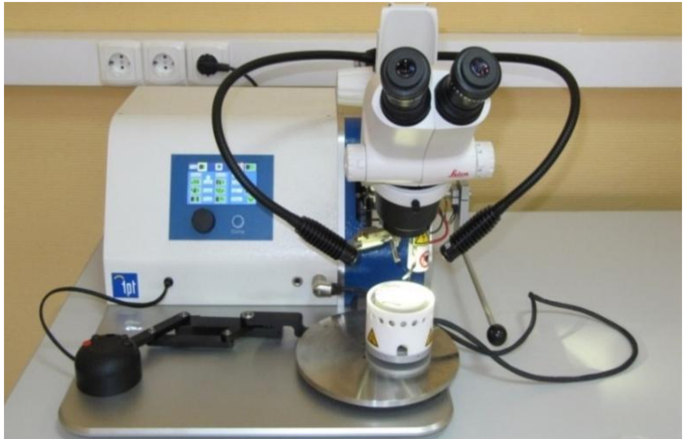


High temperature

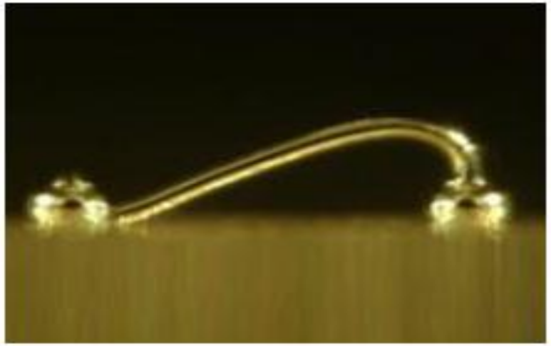
- **No issue for crystal**
  - A.Klix [XEYMLD] – up to 500℃
  - L.Ottaviani [XEXTZ5] – up to 400℃
  - J.Dankowski [XEYFQY] – up to 250℃
  - M.Angelone [XEY7VC] - **stable operation range is up to 230-235°C** (regardless of the type of electrical contacts) → ***Polarization Effects? Contacts? SCD film?***

High temperature

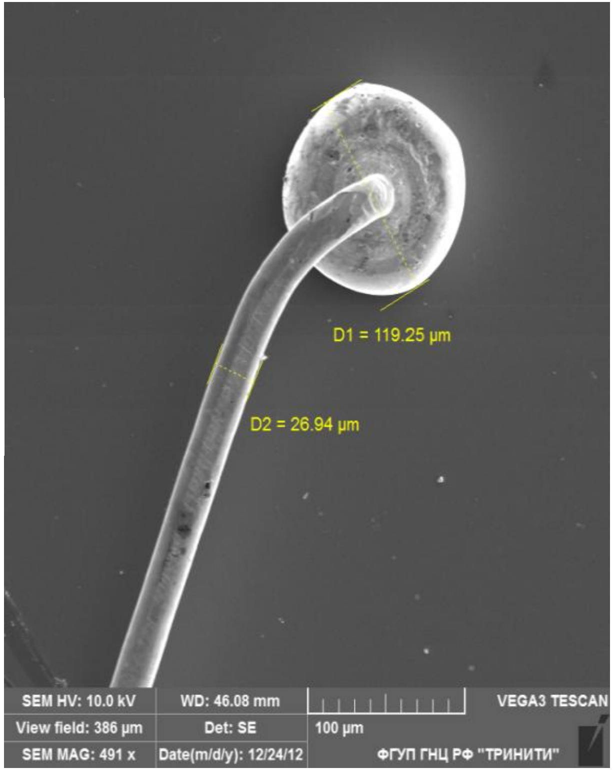
- Special technique of contacts welding is to be applied, then **no issue for detector housing**
  - V.Amosov [XEYQGE]
  - N.Rodionov [XEYQEF]



Gold wire microwelder

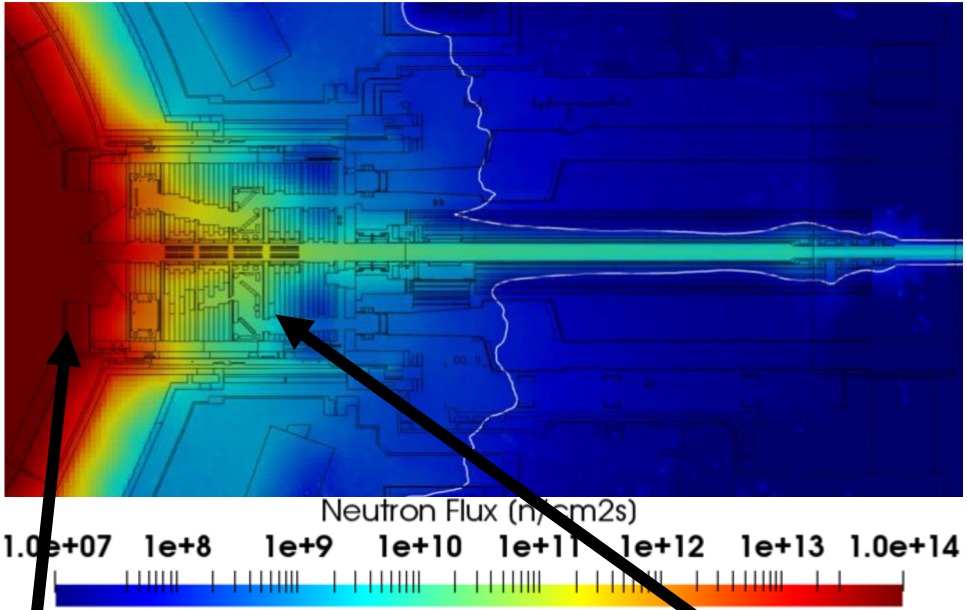


Gold wire is welded to the 35 nm gold contact. Maximum load on gold wire before rupture is 8 g. Wire diameter is 27 μm.



Neutron fluxes and detector lifetime

Example of neutronic calculations in EP11



Contour line
10^8 n/cm^2•s

Neutron fluxes **at the first wall** will reach 10^{14} n/cm^{2}s during full-power discharge

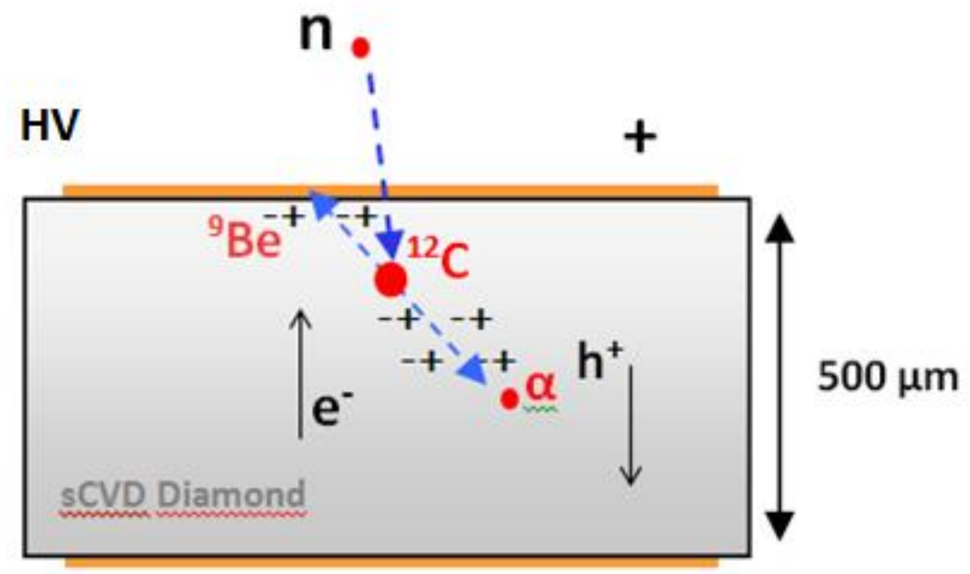
Detectors can be exposed to fluxes of $10^{10}..10^{11}$ n/cm^{2}s **in port plug**

(depends on final design of each particular port plug)

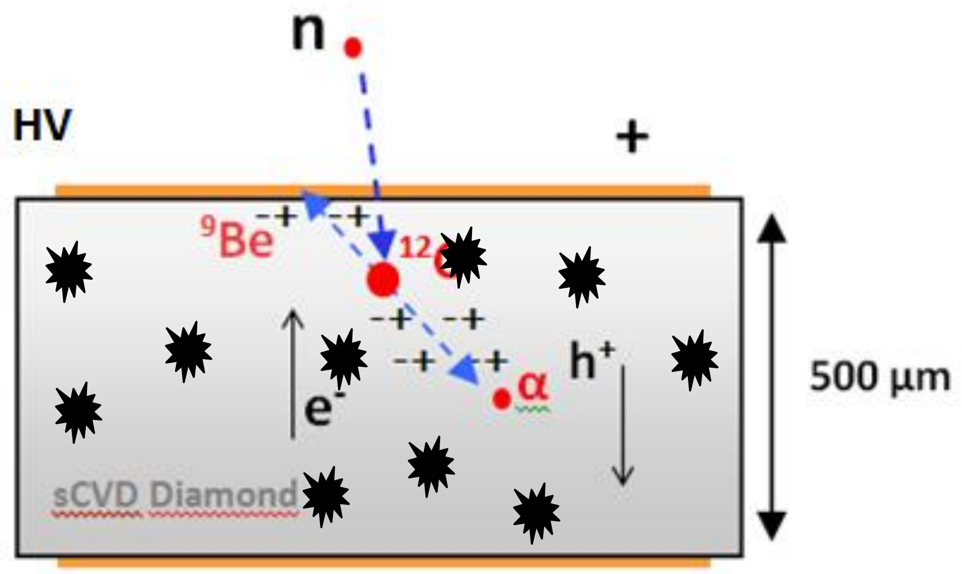
ITER systems have to be designed to be operational after 4800 effective hours of operation.

This results in fluences up to 10^{17} n/cm^2

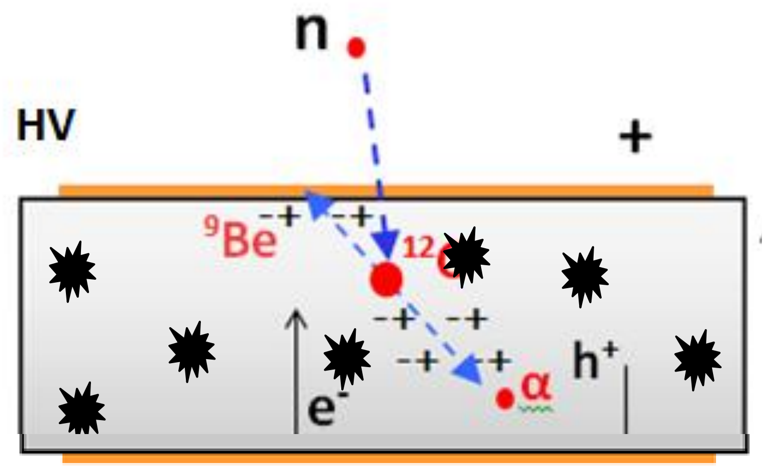
Radiation hardness



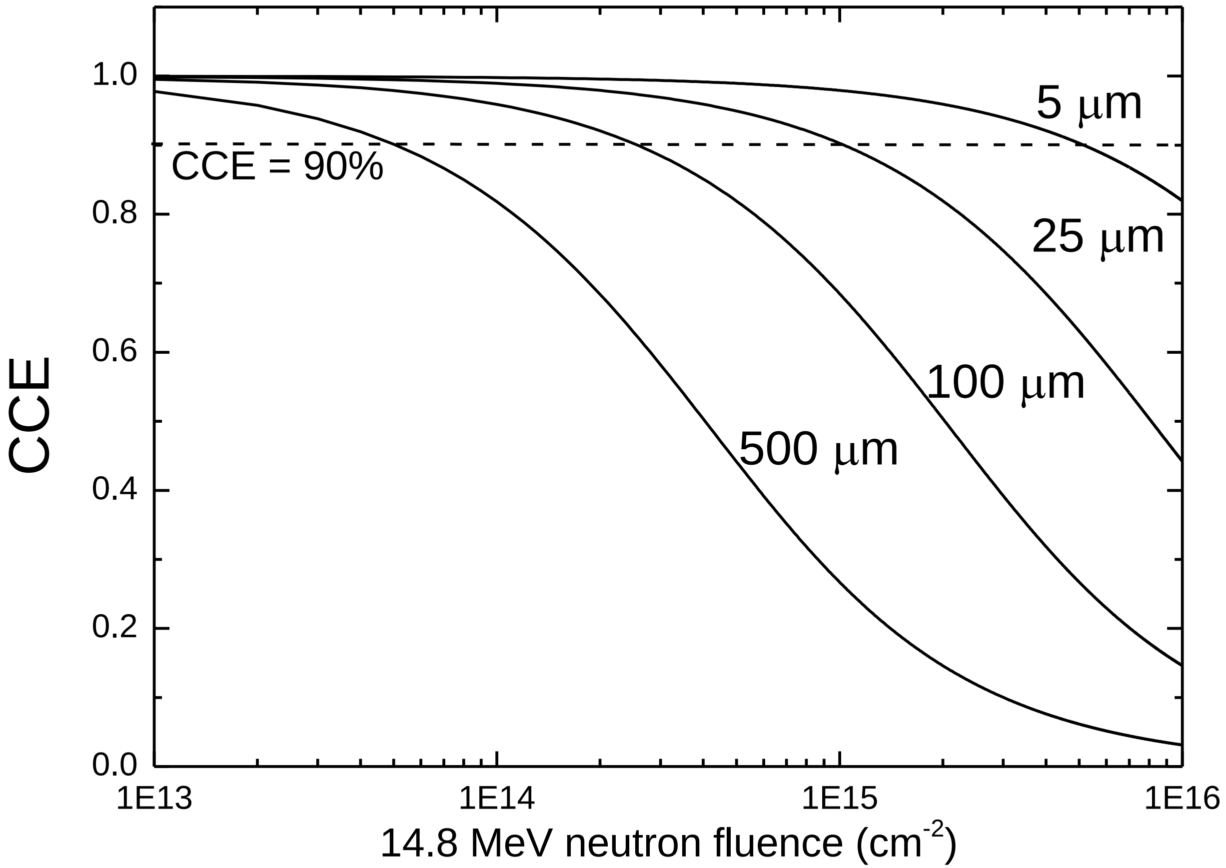
Radiation hardness



Radiation hardness

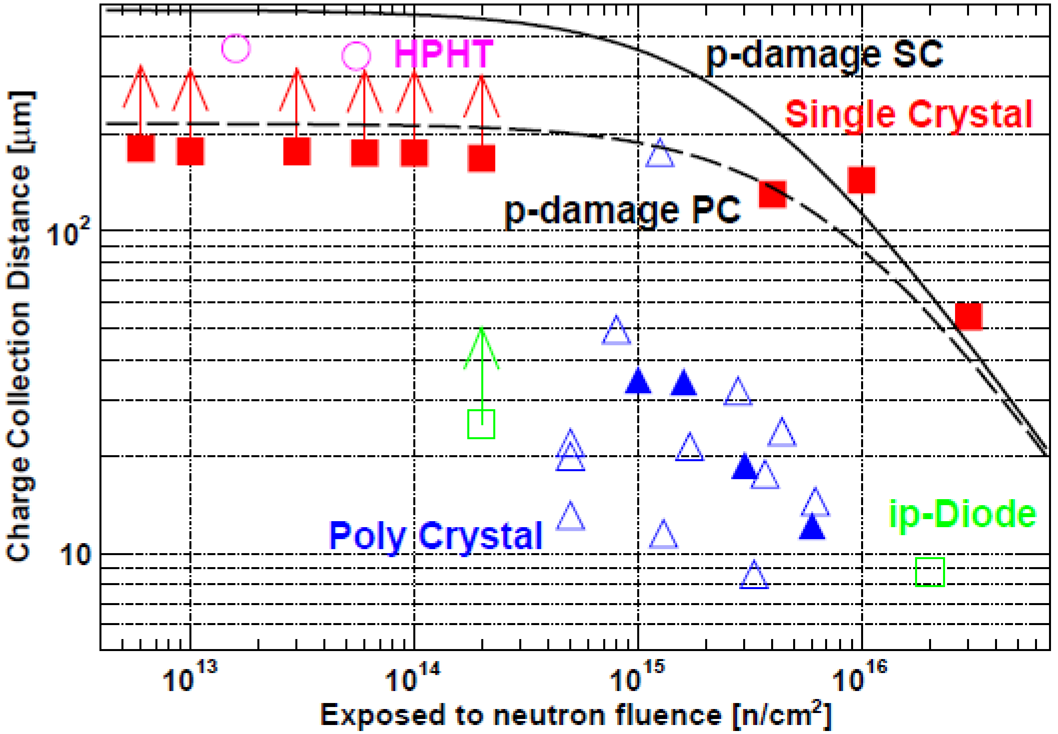


Radiation hardness



G. Verona Rinati [XEYPJV]

Radiation hardness



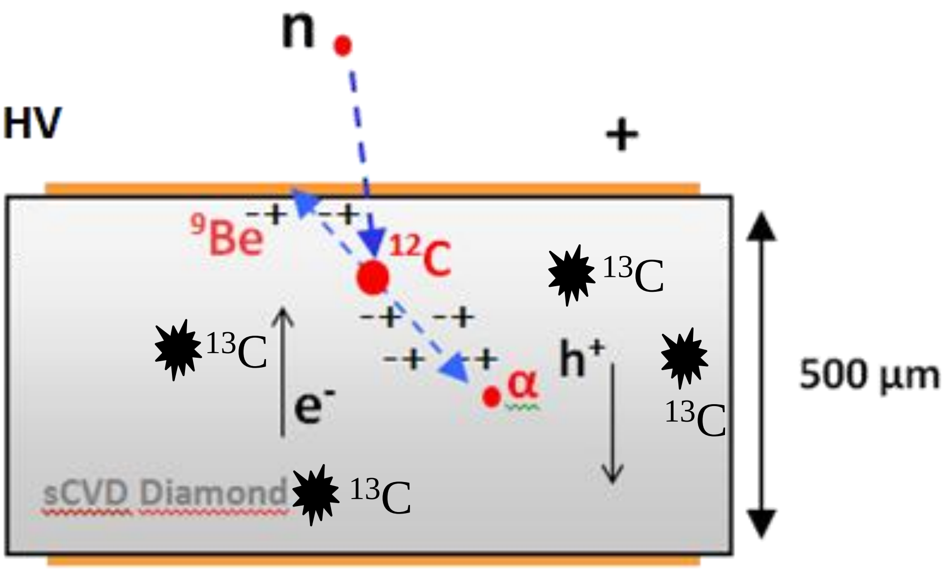
M.Osipenko
[XEYP6K]

Radiation hardness

Making matrices of thin detectors could be a way to increase radiation hardness.

Isotopic purity could be another one!

Radiation hardness



C^{13} concentration is typically 1% in CVD diamonds grown by Element-6 company. Reduction of this value at least to 0.1% can lead to increase of rad-hardness by an order of magnitude.

Front end electronics

From ITER Policy on Electronics Exposed to Nuclear Radiation (RAKTPP) :

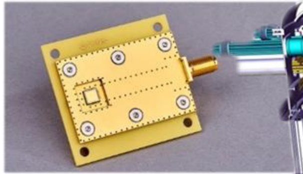
Place	Total Neutron Flux ($n/cm^2 \cdot s$)	Total Ionizing Dose (kGy)
Port Cell L2	$3 \cdot 10^4$	8
Port Cell L1	$3 \cdot 10^4$	12
Port Cell B1	10^5	220

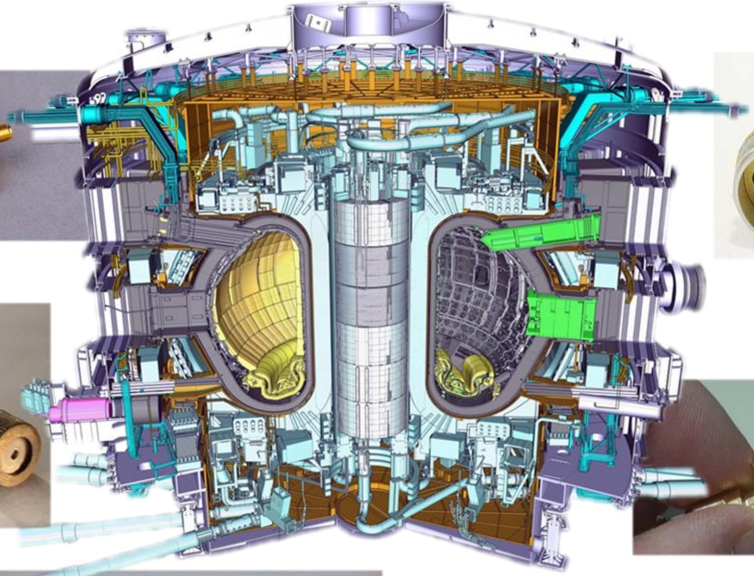
Conclusions

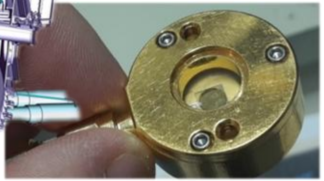
- Diamond Detectors are the best spectrometric neutron detectors to be installed in ITER's Port Plugs and Lower Port's racks. However they are not capable of replacing fission chambers as in-vessel neutron flux monitors.
- The main issue is the lifetime of the efficient diamond detector operation until radiation degradation.

Conclusions

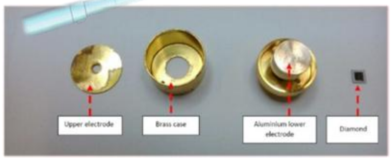
- **Magnetic field** – no issue;
- **Temperatures** up to 250℃ - solvable issue with proper attention paid to detector contacts;
- **Radiation hardness** and detector lifetime can be increased
  - by using thinner crystals,
  - by growing crystals with higher isotopic purity ;
- **^{13}C** diamonds have (theoretical) potential for neutron spectroscopy (V.Amosov [XEYQGE]);
- **Annealing** (>1200℃) shows some recovery effects but is not feasible for ITER.







THANK YOU


Upper electrode
Brass case
Aluminium lower electrode
Diamond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