Association Euratom-IPPLM Council Meeting

Participation to JET activities

Jacek Rzadkiewicz

Outline

- Participation to the JET experimental campaigns C28-C30
- Numerical analyses of impurity seeded plasma discharges in JET with the help of the code COREDIV
- Gas Electron Multiplier detector for X-ray Crystal Spectrometry (KX1 diagnostic)
- VUV spectroscopy with the KT1, KT2, KS6 JET Spectrometers
- Activation measurements in support of the JET neutron calibration
- Measurements and calculations of neutron streaming through JET Torus hall ducts. Dose rate estimation in specific JET locations

Participation to the JET experimental campaigns C28-C30

- The achievements of IPPLM tasks during the last experimental campaigns at JET (2012) were related to the installation of two GEM detectors into the KX1 x-ray diagnostic. The upgraded KX1 system proved capable of providing data with a high spectral and time resolution ($\Delta t \sim 10$ ms).

- Using the VUV spectrometer the influence of the plasma shape, the ICRH antenna phasing, and the minority cyclotron resonance position on the Ni content was investigated and the contribution of Ni to $P_{rad,bulk}$ was evaluated.

- A new set of multi-element samples were prepared for cross-calibration of other neutron diagnostics against KN2. The samples activity after irradiation by 4×10^9-yield Cf-source, located 30 cm below irradiation end) has been predicted.

- A study within JET FT-12-5.45 aiming at validating the calculation of neutron streaming through ducts and of the dose rates outside of the JET torus hall was performed with TLD technology.

KX1 Performance and Preliminary Results

M. Chernyshova, T. Czarski, K. Jakubowska, L. Karpinski, J. Rzadkiewicz, M. Scholz

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Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland

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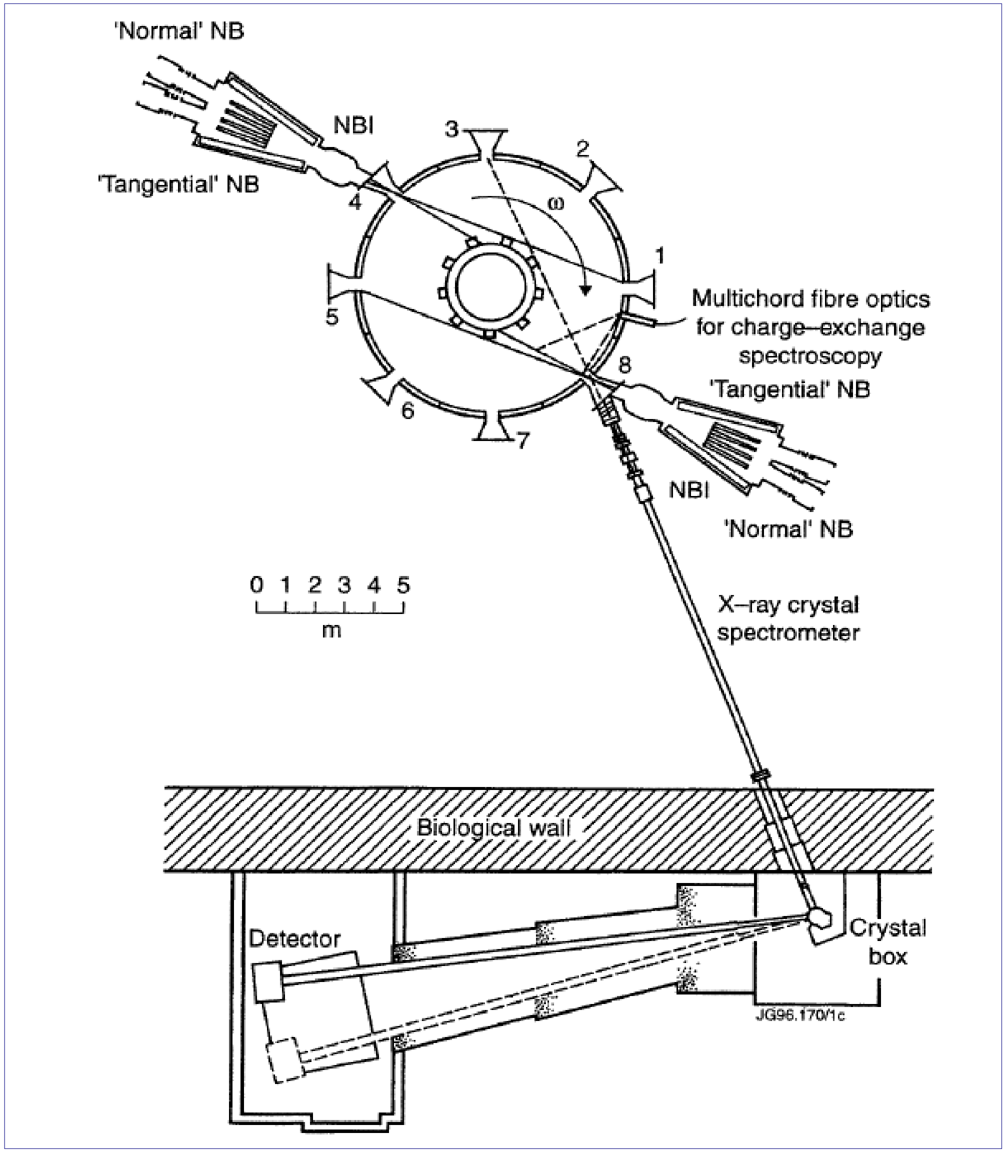
Euratom/CCFE Fusion Association, Culham Science Centre, OX14 3DB, Abingdon, UK

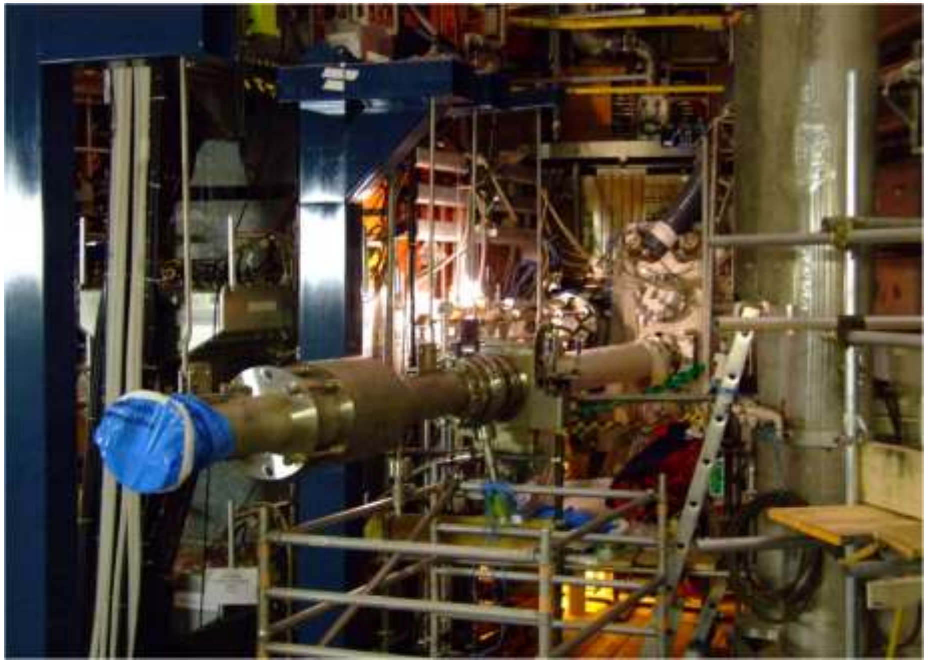
KX1 Geometry

- The KX1 high-resolution x-ray diagnostics is based on a bent-crystal spectrometer operated in Johann geometry with a very large focal length *2R* where *R* is a Rowland circle radius



KX1 Geometry

➢X-rays emitted by plasma reach the crystal vacuum chamber through 25-cm-diam stainless-steel tube



➢ X-rays are diffracted from the crystal according the Bragg diffraction law and are provided to the detector through another tube

KX1 Beam Line Modification

- Two new GEM x-ray detectors were designed, constructed and installed into the ending port window of KX1 diagnostic

- Test measurements were performed in order to determine the working parameters of Ni and W monitor x-ray detectors.

- For calibration measurements t he ^{55}Fe (5.9 keV, 4.5 MBq) x-ray source is used.

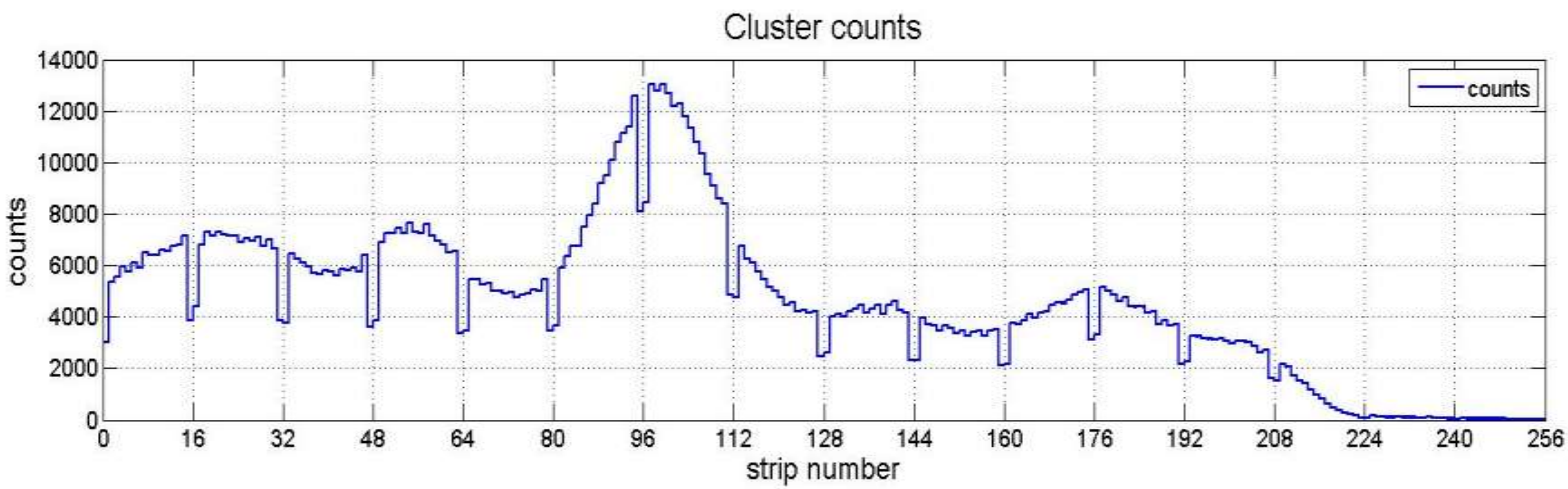
- The detectors are filled with Ar 70% : CO_2 30% gas mixture (±0.1% measured in volumetric percentages at JET) operated in the gas-flow mode at the gas flow rate of 20-30 ml/min.

Preliminary Results

➢ The first JET plasma spectra ware measured in shot # 83268 by means of Ni monitor detector (operated with HV=4700 V) in the Bragg angle range from ~52.1^o to ~52.8^o.

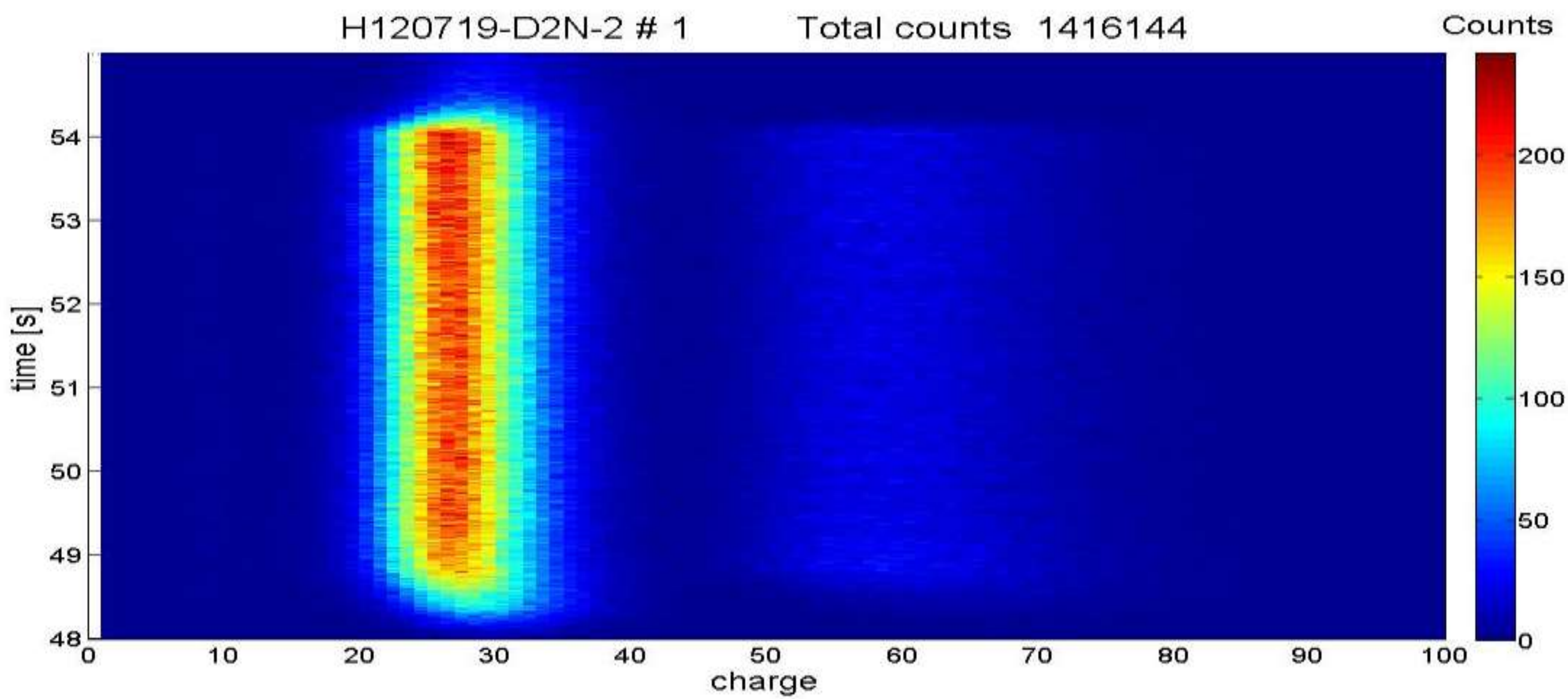
➢The spectrum is a composition of radiation diffracted by the crystal in the first and second reflection order (higher reflection orders can be neglected at this stage of analysis).

➢The dominant x-ray line in the spectrum originates from resonance x-ray transitions (w: $^1P_1 \rightarrow {}^1S_0$) for He-like Ni at wavelength 1.5856 Å (7819.4 eV) registered in the second reflection order.



Preliminary Results

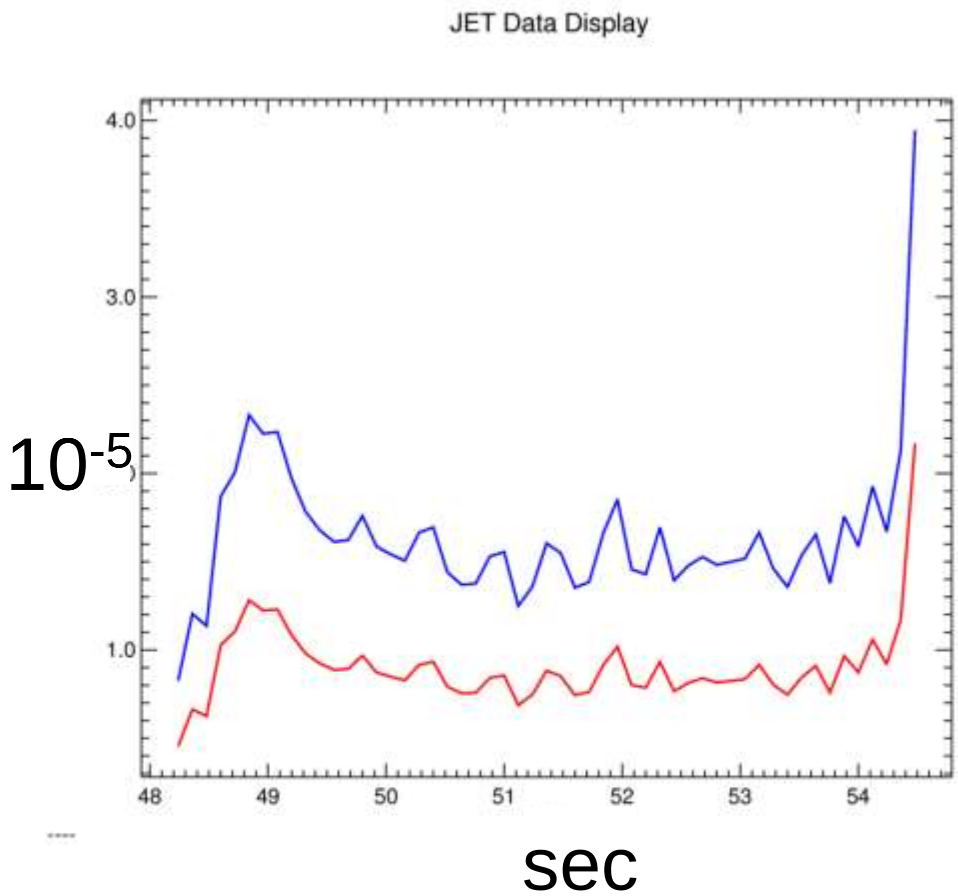
➢The recent development of the detection system allowed to improve the time resolution to 10 ms (the previous KX1 detector registered x-ray spectra with Δt=20 ms).
➢In this way one of the most important aim of the project was reached.



X-ray spectra measured on JET in shot # 83690 with a time resolution Δt=10 ms

Ni concentration

Comparison with charge exchange #83714

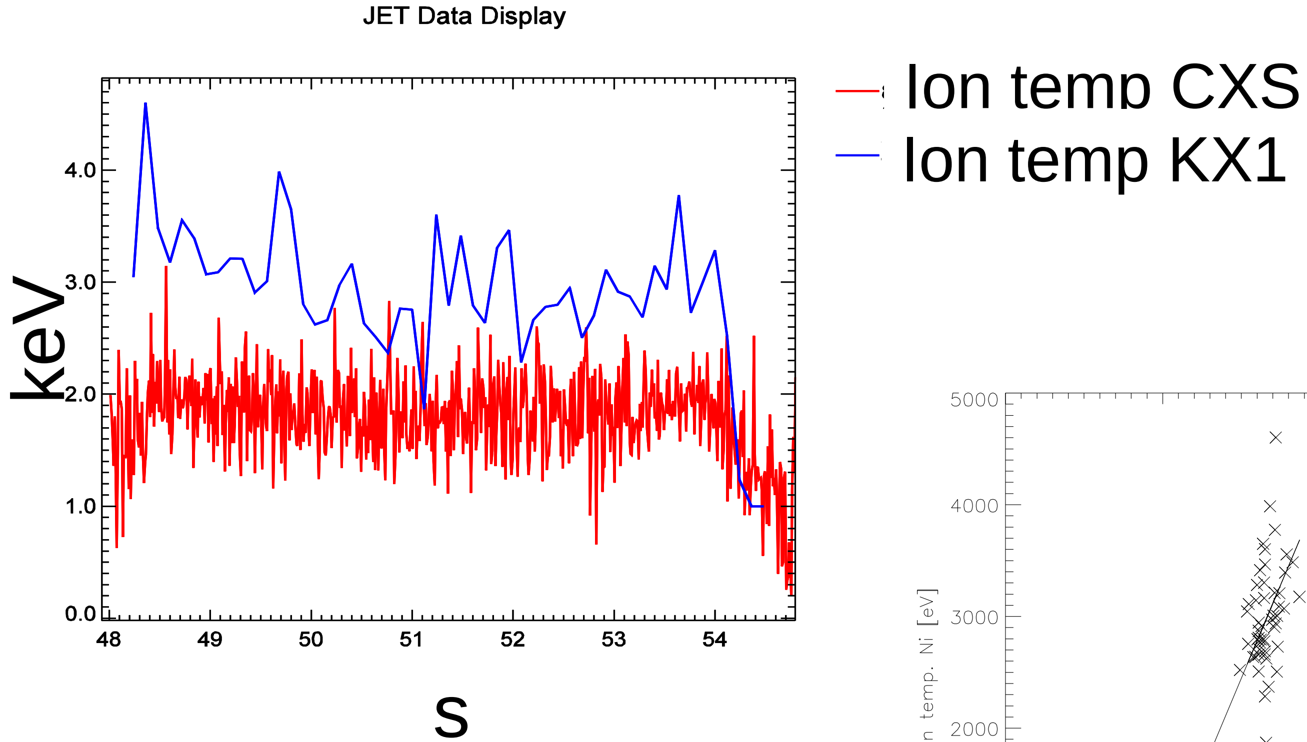


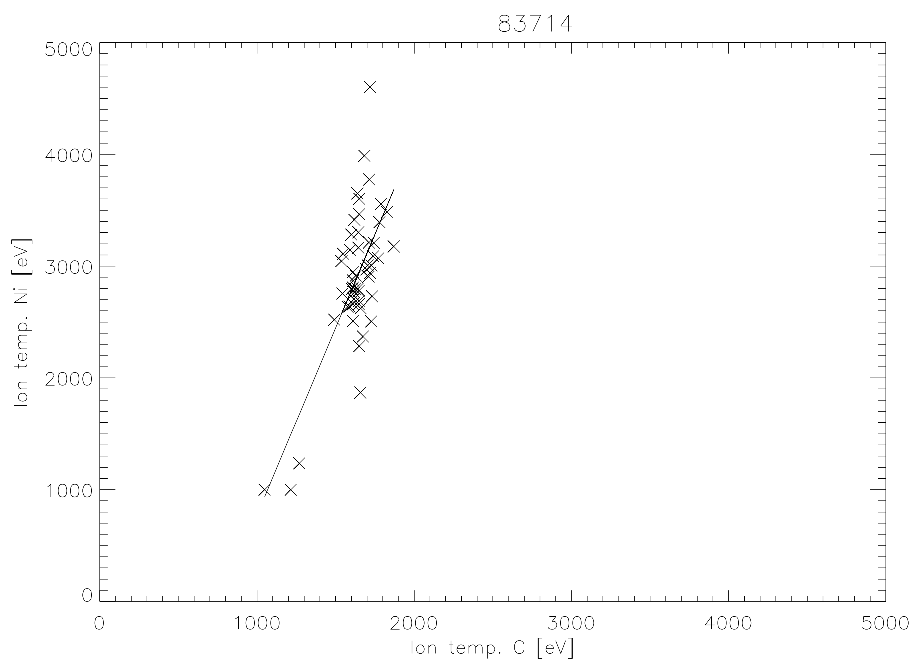
Absolute calibration from part-by-part analysis

Calibrated by comparing continuum from visible spectroscopy (KS3)

Ion temperature

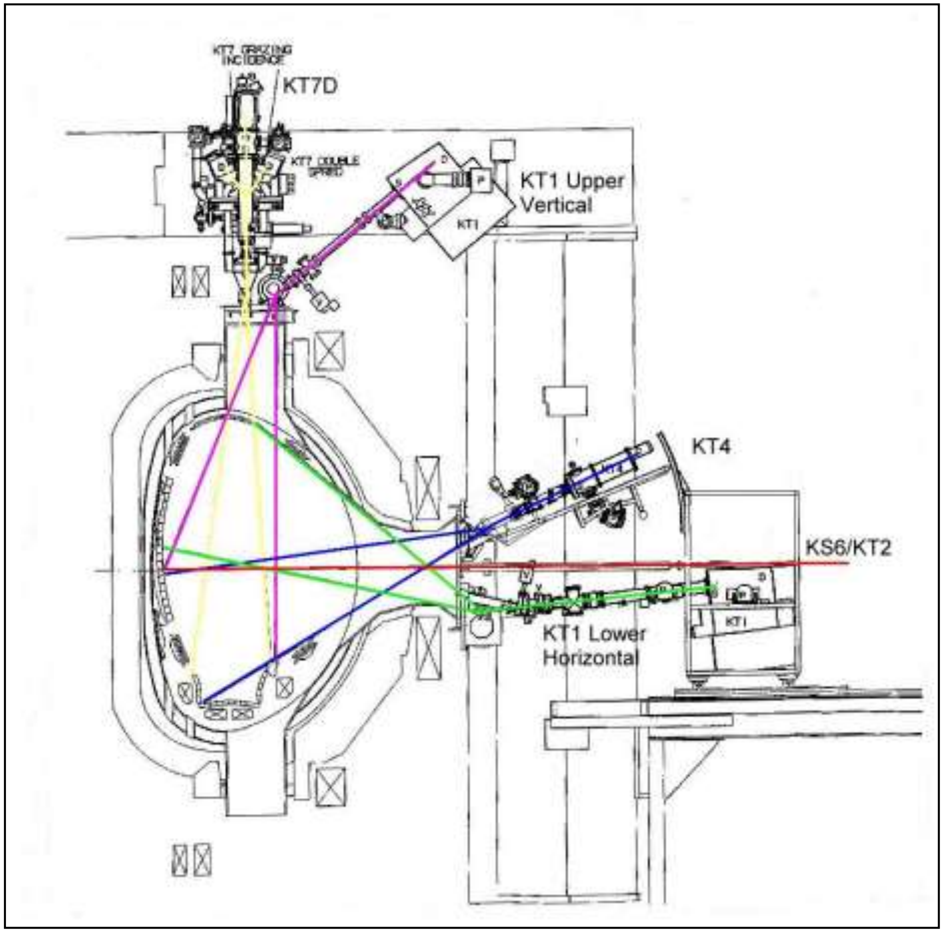
Comparison with charge exchange #83714





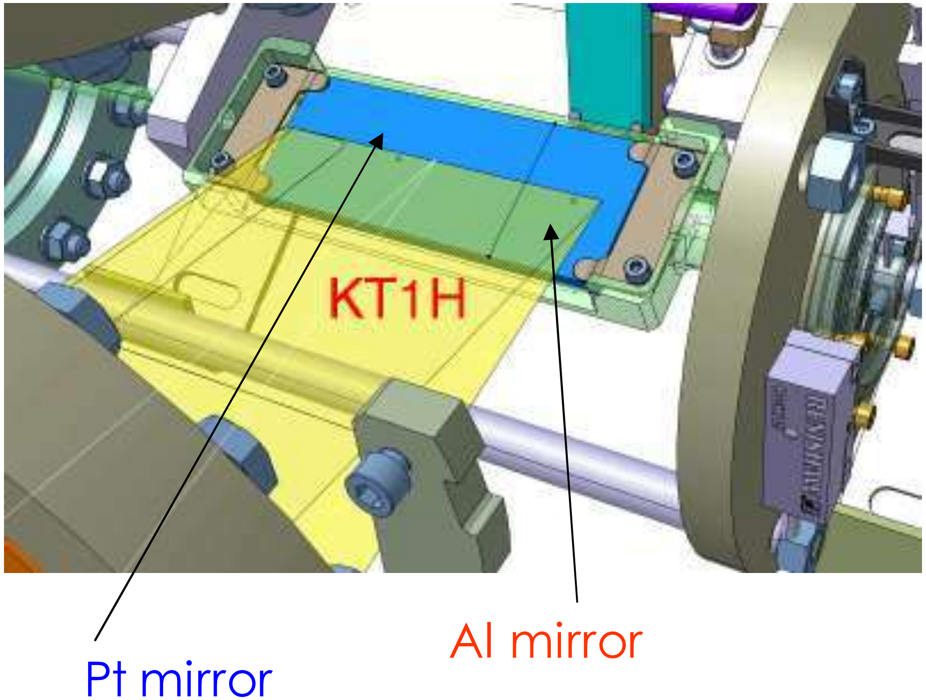
VUV spectroscopy with KT1 Spectrometer

- Upper Vertical KT1 Spectrometer is a VUV diagnostic which is used for observation of the plasma in the area of divertor including the walls of JET.
- The spectrometer is equipped with a grating and can be set to wavelength between 100 and 2000 Å.
- It has two VUV detectors, so that two wavelength can be monitored at a time. The detectors are operating in counting mode.
- The spectrometer is designed to make poloidal scans which are provided by a rotating mirror which has 8 faces.
- A spatial scan duration is typically 24 ms with an integration time of counted pulses of 0.14 ms.



VUV spectroscopy with KT1 Spectrometer

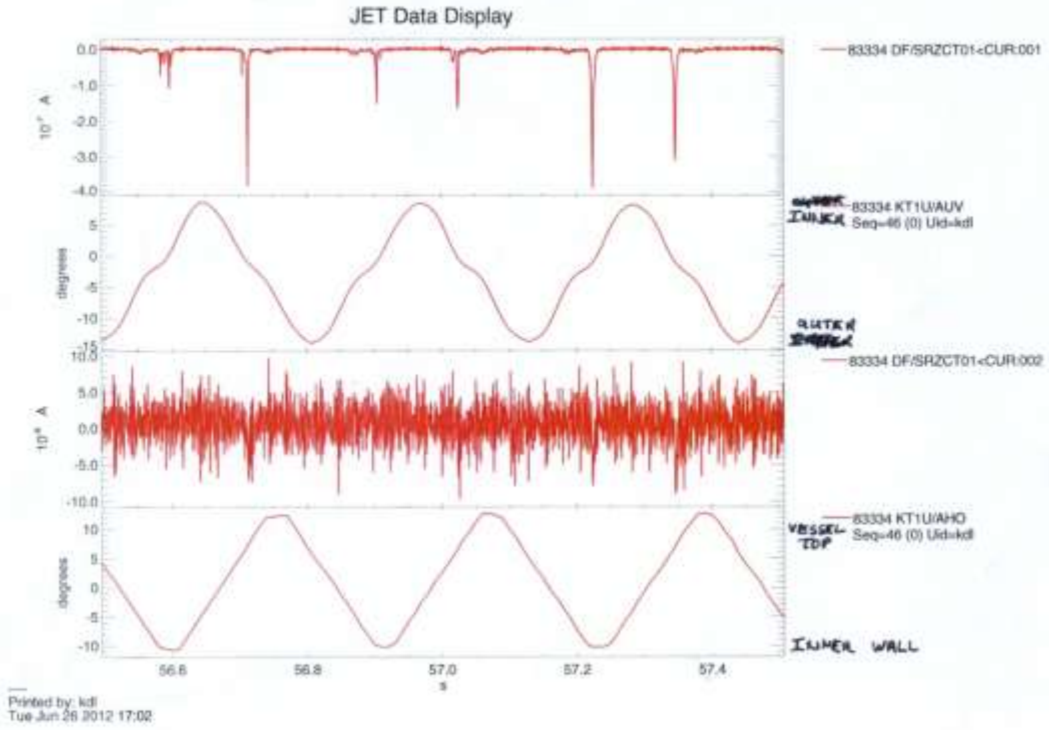
Two optical channels were added to KT1 VUV spectrometer
to have the possibility of scanning plasma emission in the visible range.
Visible lines are separated by a Czerny-Turner spectrometer equipped
with two PMTs.



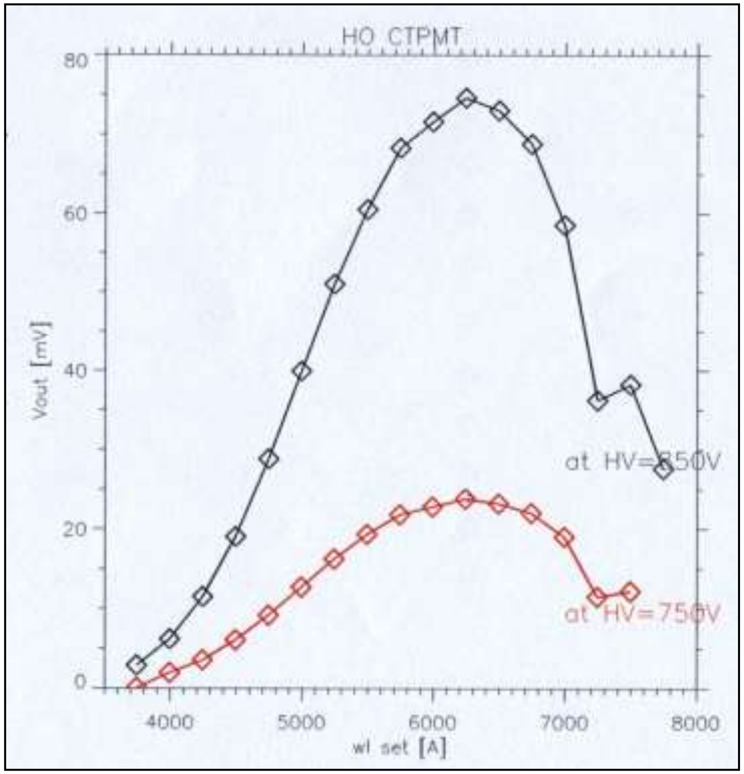
Al mirror was added to existing VUV Pt mirror for scanning plasma
In visible range. The mirrors make oscillating movement.

VUV spectroscopy with KT1 Spectrometer

Tests and calibration



Example of signals from the visible KT1 spectrometer shown together with signals indicating the position of oscillating mirror.



Sensitivity of both channels vs. wavelength.

Calibration experiments: K.D. Lawson, S. Menmuir, **L. Ryć**, C.F. Maggi

The activation measurements in support of the JET neutron calibration JW11-FT-4.21

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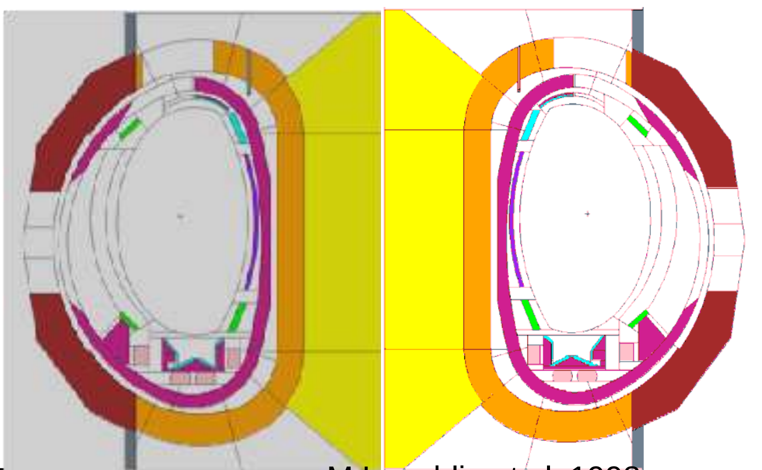
Neutron calibration by means of Cf-252 source as an opportunity to check correctness of the JET MCNP model

- Implementation of the point/plasma neutron sources into numerical model of tokamak (see FT Tasks JW11-FT-5.34, 5.35, 5.36)
- Simulation of the detector responses to point/plasma neutron sources (foil cross-sections into MCNP)



M.Loughlin et al. 1998

Benchmark

Neutron activation measurements as a benchmark against numerical calculations

- Measured activity of reactions induced by neutrons from well known calibration source inside tokamak allow to obtain nuclear reaction rate

$$\alpha_m = \frac{A}{N_a \cdot \left(1 - e^{-\lambda \cdot t_r}\right)}$$

- Calculation of the same reaction rate by means of neutron transport code (MCNP) by implementation of the calibration source inside tested model

$$\alpha_c = \int_0^\infty \sigma(E) \ \ \varphi(E) \ \ dE$$

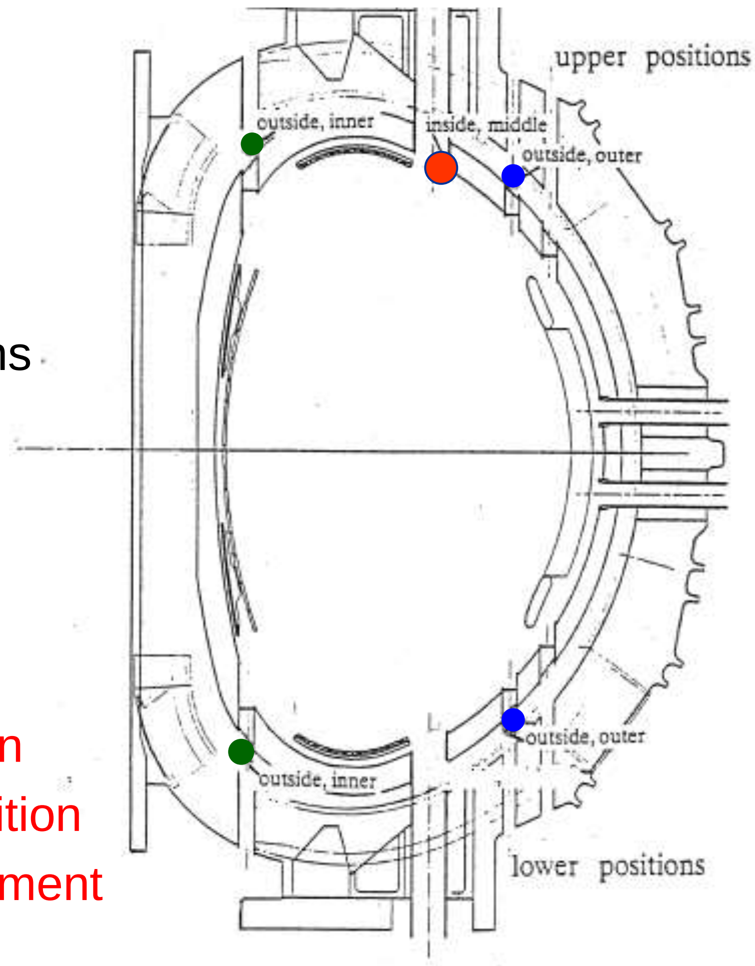
- If both results correspond to each other then we trust the numerical model

Activation system at JET

- **KN2** - conventional gamma-radiation measurements
  - most widely used reactions at JET:
    DD neutrons – $^{115}In(n,n')^{115m}In$,
    DT neutrons – $^{28}Si\ (n,p)^{28}Al$, $^{56}Fe(n,p)^{56}Mn$
  - detectors: 3 NaI, HPGe
- **KN4** - delayed neutron, counting of beta-delayed neutrons from fission events (^{232}Th, ^{238}U, ^{235}U)
  - usually used to measure DD neutron yield on conditions that Y_{DD}>> Y_{DT}
  - detector system: 2 stations with 6 ^{3}He counters
- At JET – **8** irradiation ends located:

- in 4 octants → test of *toroidal symmetry* of neutron emission with **inboard and outboard** positions → *radial* plasma position and **upper and lower** positions → *vertical* plasma displacement

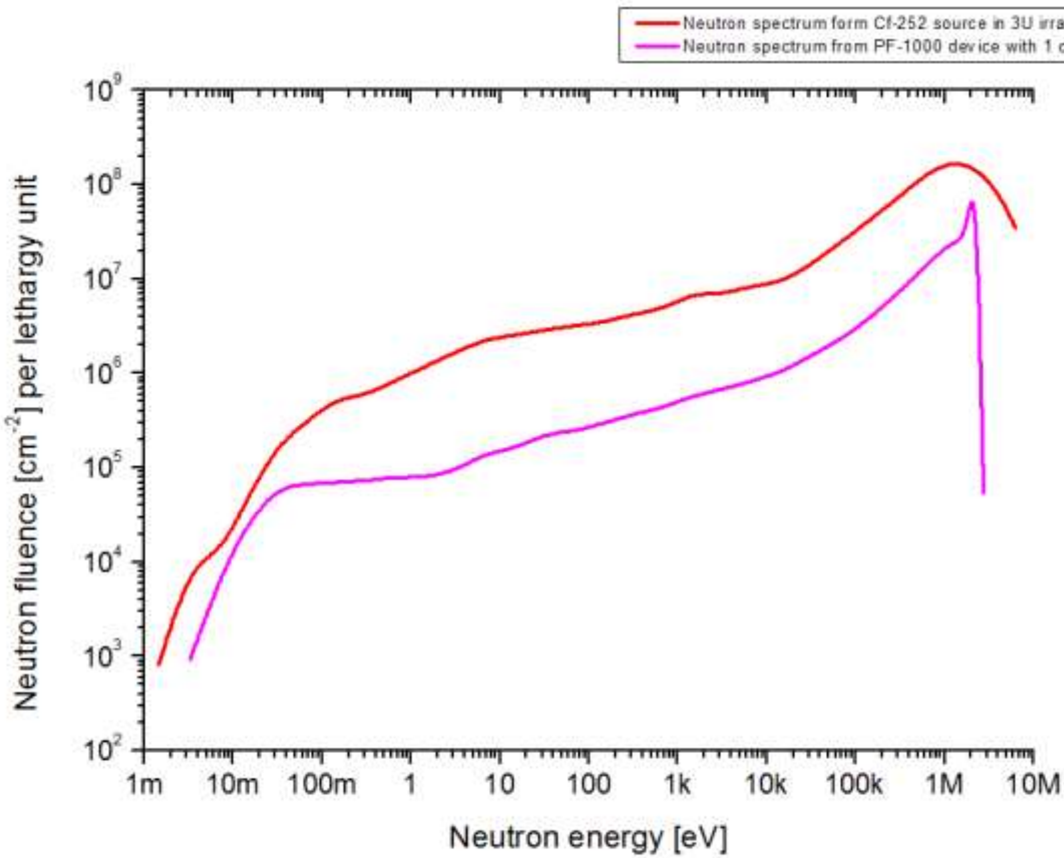
- **1 inside** (in vessel) irradiation end (octant Nº 3)

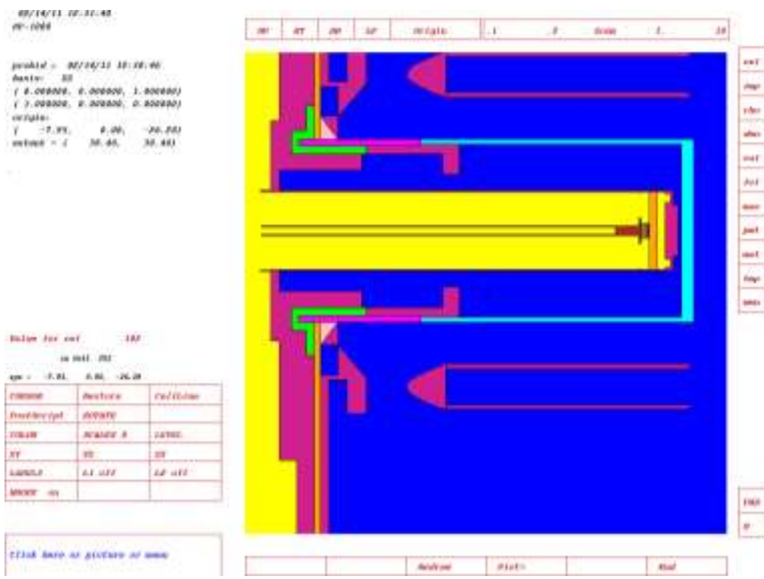


Use of activation techniques for the measurement of neutron yield from deuterium plamas at JET
Jarvis, Clipsham, Hone, Laundy, Pilon, Rapisarda, Sadler, van Belle, Verschuur
Fusion Technology, Vol.20, Nov.1991

Spectrum shaping (MCNP)

- Simulation of the neutron spectrum in 3U irradiation end from Cf-252 source located 30 cm below
- Simulation of the neutron spectrum from PF-1000 device behind the poliethylene moderator



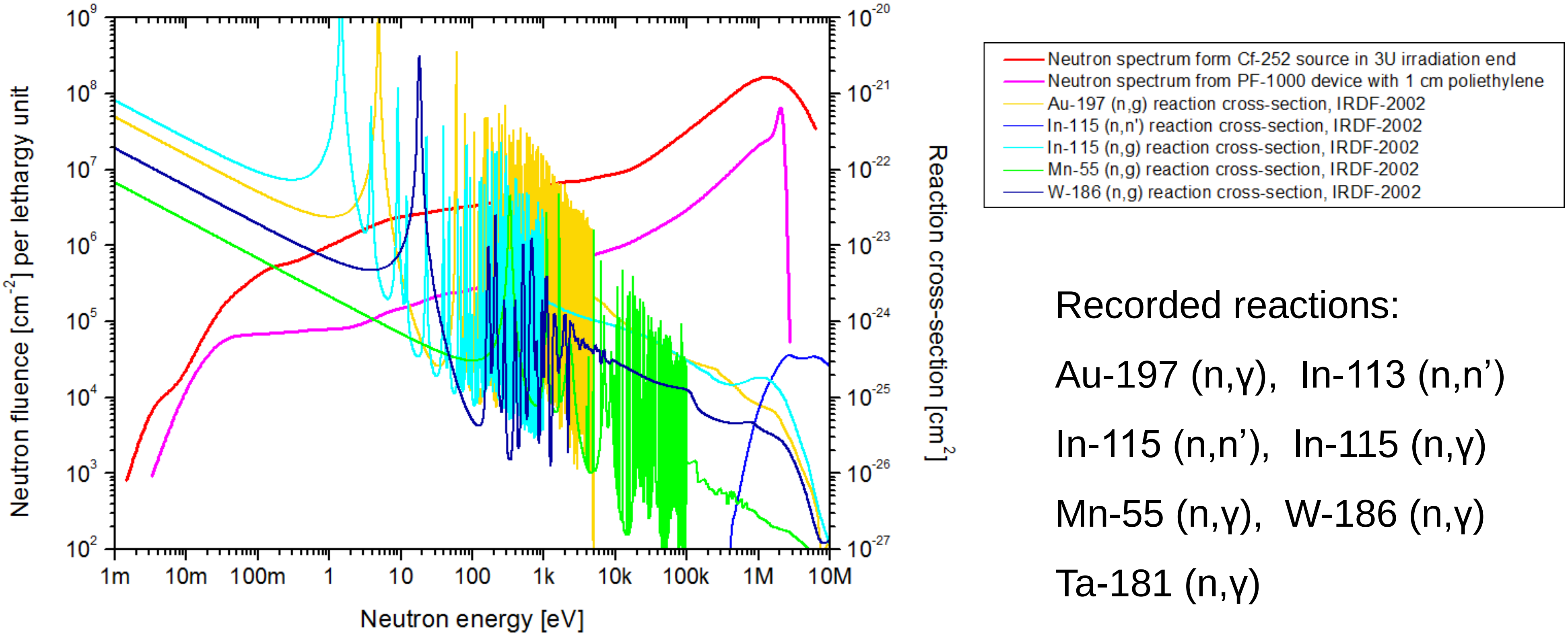


The MCNP simulations

Test irradiation on PF-1000

Irradiation on PF-1000 of the following samples: Sc, Ta, Mn, W, Au, In

The series of 7 shots within 2 hours, total neutron yield 1.33E+11 (Ag count.)



Recorded reactions:

Au-197 (n,γ), In-113 (n,n')

In-115 (n,n'), In-115 (n,γ)

Mn-55 (n,γ), W-186 (n,γ)

Ta-181 (n,γ)

To be done (based on the above experiments):

Performing the activation measurements during JET neutron calibration

Task title: Measurements and calculations of neutron streaming through JET Torus hall ducts

JW12-FT-5.45

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Production of TL detectors and preparation of the dosemeters

500 LiF TLDs were manufactured at the IFJ Kraków: 2 types (both with three LiF isotopes' abundancies: natural, Li-6 enriched and Li-7 enriched

	LiF:Mg,Ti	LiF:Mg,Cu,P
Relative senstivity	1	30
Detection treshold	20-50 μGy	<1 μGy
Linearity range	~ 2 Gy	~ 2 Gy
Saturation dose	~ 1 kGy	~ 1 kGy

Newly discovered high-temperature emission extends the measuring range of LiF:Mg,Cu,P detector up to ~ 1 MGy

Neutron measurements:

- **high cross-section of Li-6 for low energy neutrons (940 b for thermal neutrons)**
- **for higher energies – use of moderators**
- **pairs $^{6}LiF/^{7}LiF$ allows distinquishing between neutron/non-neutron components of radiation field**

Detectors in holders

Detector types

LiF:Mg,Ti	MTS-N	equivalent to TLD-100
^{7}LiF:Mg,Ti	MTS-7	equivalent to TLD-700
^{6}LiF:Mg,Ti	MTS-6	equivalent to TLD-600

high-sensitive:

LiF:Mg,Cu,P	MCP-N	equivalent to TLD-100H
^{7}LiF:Mg,Cu,P	MCP-7	equivalent to TLD-700H
^{6}LiF:Mg,Cu,P	MCP-6	equivalent to TLD-600H

MTS-6	MCP-6	95,58% Li-6	Ø 4.5mm d=0.6mm
MTS-N	MCP-N	7,59% Li-6	Ø 4.5mm d=0.9mm
MTS-7	MCP-7	0,03% Li-6	Ø 4.5mm d=0.9mm

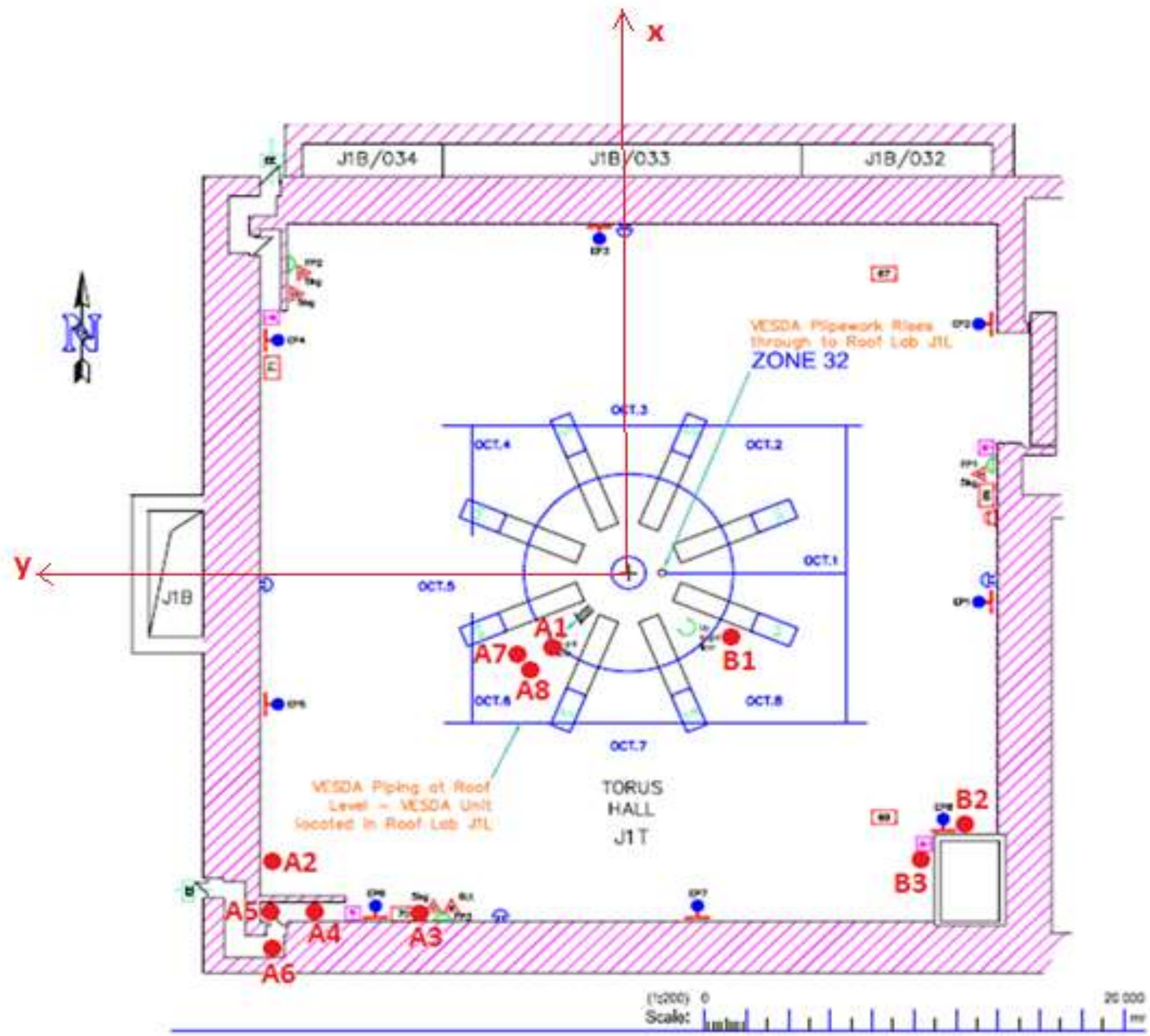
Installation of the dosimeters

Installation of the dosemeters at JET was done by JET team in July and a two week exposure took place in Summer 2012.

All TLDs were located in the centre of cylindrical polyethylene (PE-300) moderators.

The dosemeters were located in 11 positions in the Torus hall, the rest of them were stored in J1D lab storage in CH2 Plugs (5 holders) and at Office drawer (3 holders) for Lab background and Office background.

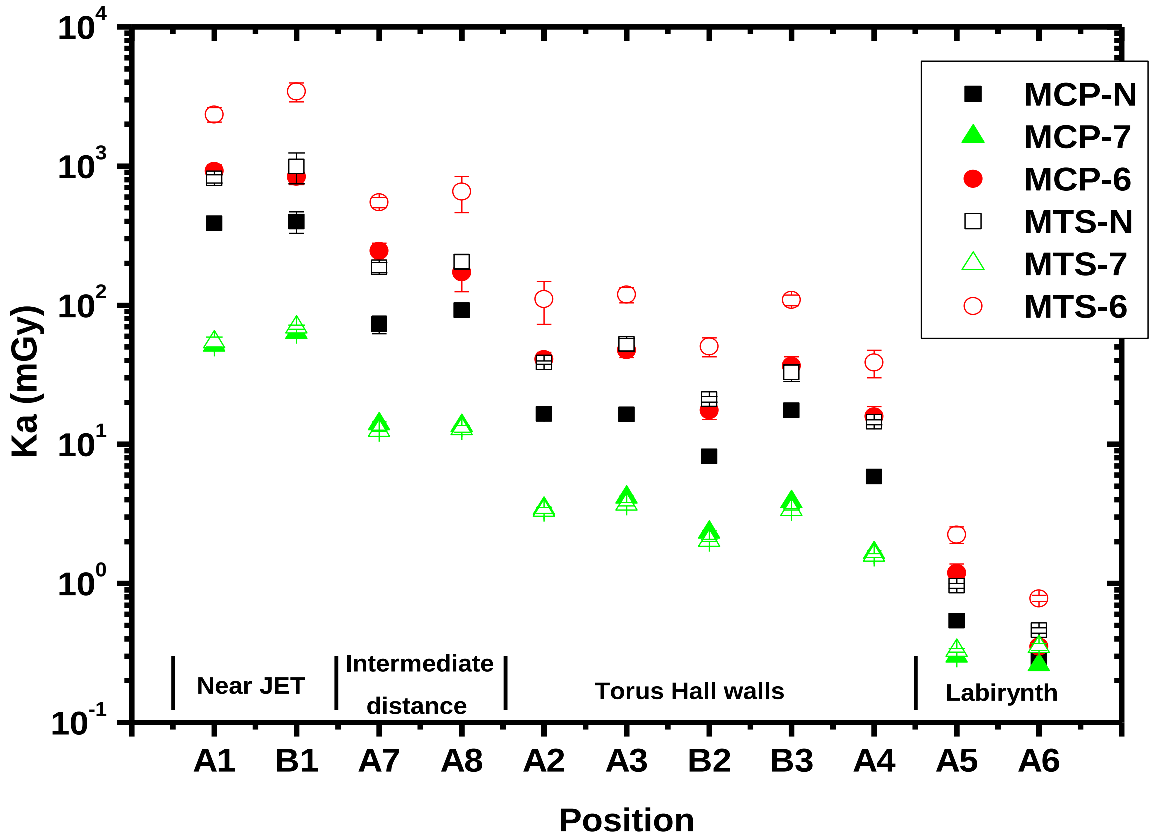
Positions of TLDs exposed in the JET Torus Hall during C30



Results

Air Kerma [mGy]

MCP (filled symbols) and MTS (empty symbols) detectors' results calculated as mean value of the same type detectors response calibrated in kerma in air with Cs-137 gamma rays.



Shadowing effect visible for Li-6

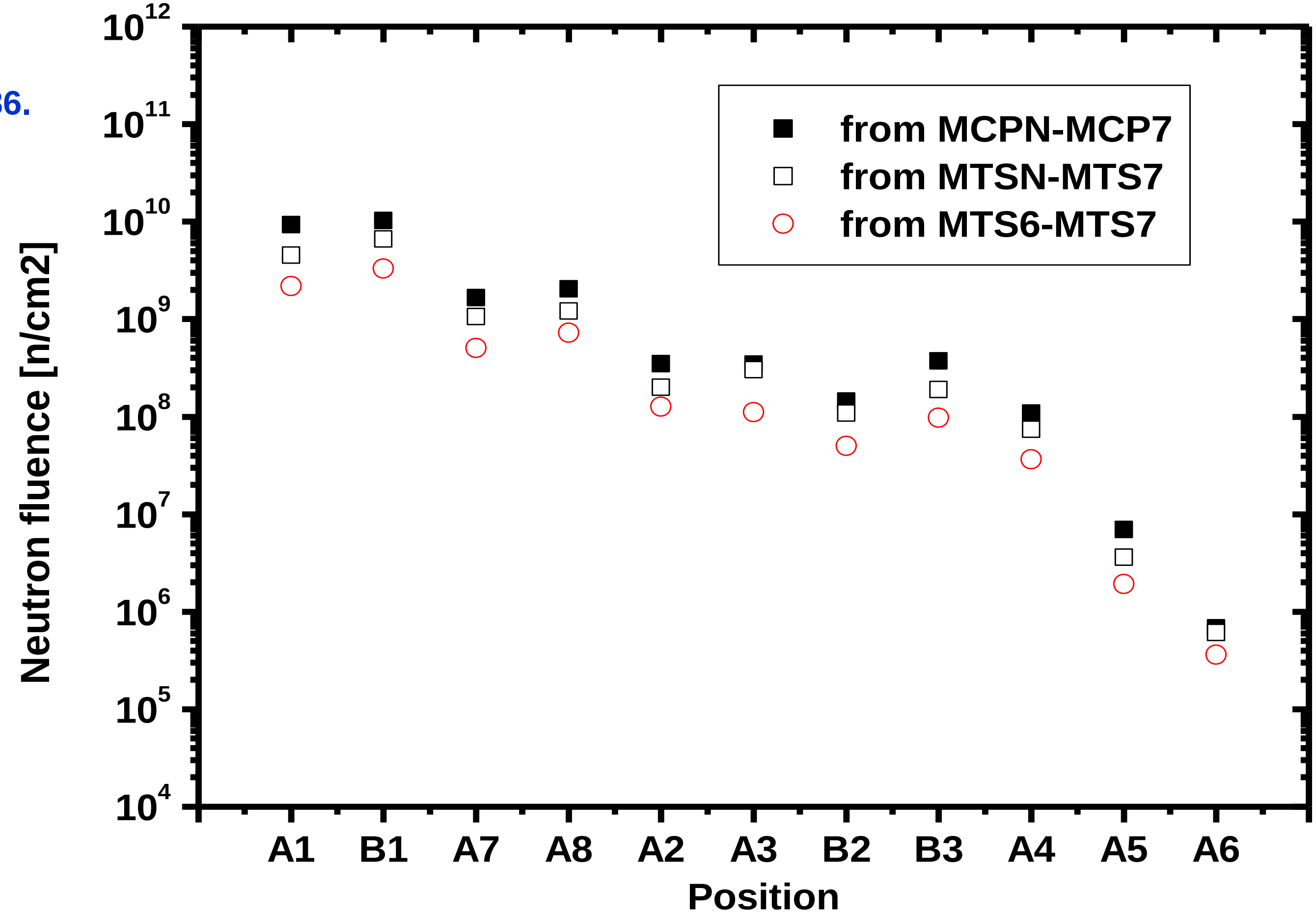
Results obtained from response of detectors which contain higher amount of Li-6, i.e. Li-6 enriched detectors, but also those produced from Li with natural abundance of isotopes, are showing very high dispersion, in a few cases even close to 30%. It can be explained with a help of observation of shadowing effect for detectors containing Li-6 which is illustrated at the photo of detectors' after unpacking them at the IFJ. Due to this as a next step of results' evaluation calculation of doses from maximum signal of each detector type was made.

Results

Composition and dimensions of the different TLD used in this study and their related experimentally determined thermal neutron responses by Burgkhardt et al., 2006, RPD 120, 83-86.

Burgkhardt et al.	**fluence/dose 1n/cm2->mGy**
MTS-6 (0.6)mm	1,19E-06
MTS-N (0.9mm)	1,81E-07
MTS-7 (0.9mm)	2,81E-09
MCP-N (0.9mm)	4,1E-08
MCP-7 (0.9mm)	1,3E-09

Neutron fluence [n/cm^2]



Neutron fluence at different positions evaluated from response of MCP and MTS detector types with different Li-6 content using Burgkhardt et al. calibration factors