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AUDITORIO ALFREDO KRAUS LAS PALMAS DE GRAN CANARIA, SPAIN

EUROfusion

Measurement of tritium production in the HCPB TBM mock-up at JET during DTE2

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*See the author list of "Overview of T and D-T results in JET with ITER-like wall" by CF Maggi et al. to be published in Nuclear Fusion Special Issue: Overview and Summary Papers from the 29th Fusion Energy Conference (London, UK, 16-21 October 2023)

ENEA
Italian National Agency for New Technologies, Energy and Sustainable Economic Development

JET

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Outline

Introduction

- DTE2 campaign at JET
- TBM mock-up

TBM Diamond Detector

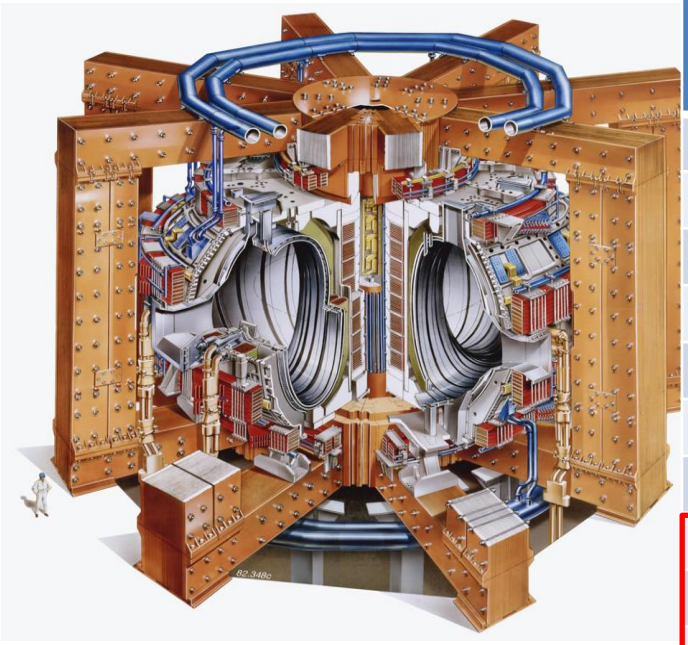
- Neutron detection
- Calibration
- Experimental Setup

Measurements and Simulations

- DTE2
- MCNP predictions and C/E during DTE2
- Hardware upgrade
- Preliminary results from DTE3

Concluding remarks

DT campaigns at JET



JET campaign	start date	end date	Total N yield	Max N yield per pulse
C36a (DD)	04/01/2016	27/06/2016	7.6E+18	5.0E+16
C36b (DD)	10/10/2016	15/11/2016	1.1E+19	1.3E+17
C38a (DD)	03/06/2019	20/12/2020	3. 7E+19	1.5E+17
C38b (DD)	17/02/2020	23/03/2020	1.5E+19	2.1E+17
C38c (DD)	06/07/2020	26/09/2020	1.7E+19	1.9E+17
C39T (TT)	07/12/2020	18/12/2020	6. 1E+15	1.6E+15
C40 (TT)	04/01/2021	31/07/ 2021	8.5E+18	1.5E+17
DTE2	**08/08/2021**	**21/12/ 2021**	**8.5E+20**	**2.1E+19**
….				
DTE3	**30/08/2023**	**ongoing**	**9.7E19**	**8.4E18**

Successful JET DT campaign in 2021 (DTE2)

- Record sustained fusion power of 10.3 MW averaged over 5 seconds
- 8.5 x 10^{20} DT neutrons
- Max daily yield rate 1.04 10^{20} DT on 21 December

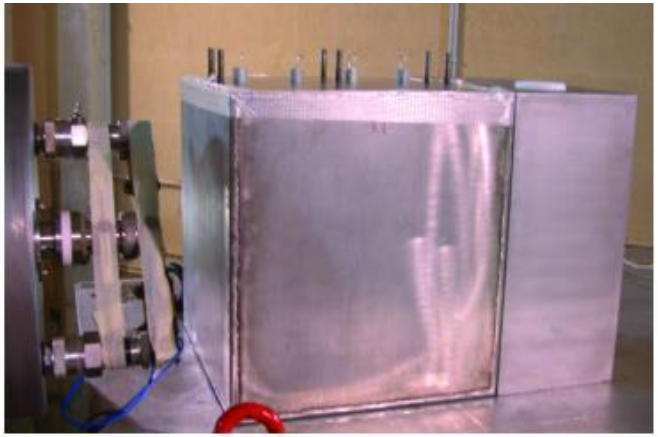
Several activities under WP PrIO SP5 (Neutronics, Nuclear waste and Safety)

DTE3 ongoing, ~ 9.7E19 DT neutrons up to now (08/09/2023)

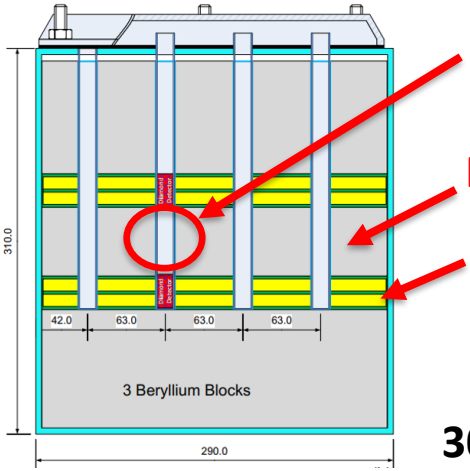
→ *R. Villari PL1*

TBM mock-up

- **Tritium breeding blanket** is a key component in a fusion reactor (**DEMO**);
- **Test Blanket Modules** (TBMs) in **ITER** will provide the first experimental data to validate the predictions on tritium production and recovery;
- **Mock-up of HCPB TBM** (Helium Cooled Pebble Bed) featuring all the relevant nuclear details to reproduce as close as possible the neutron energy spectra occurring in the TBM in ITER.



Same mock-up used at FNG for HCPB TBM experiment



Detector (online measurement of T production rate)

Filled with Be

Li_2CO_3 powder simulating the Li_4SiO_4 breeder ceramics of the TBM

300 D x 290 L x 310 H mm^3

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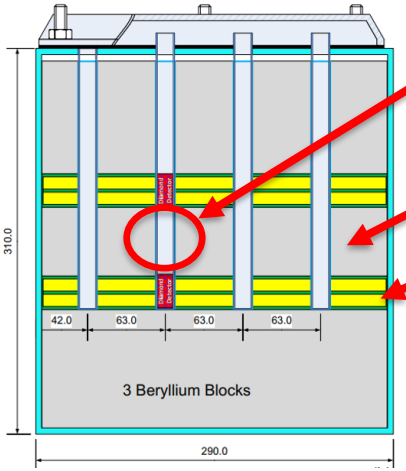

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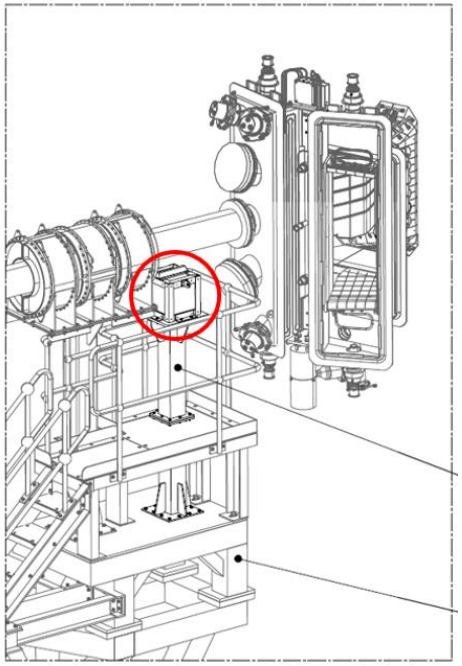


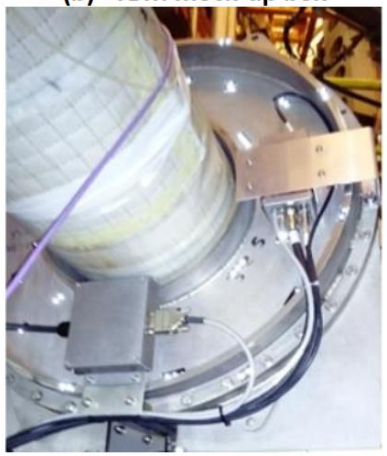
TBM mock-up installed at JET to take advantage of the high neutron emission during DTE2 campaign.

TBM mock-up at JET

(a) Octant 8

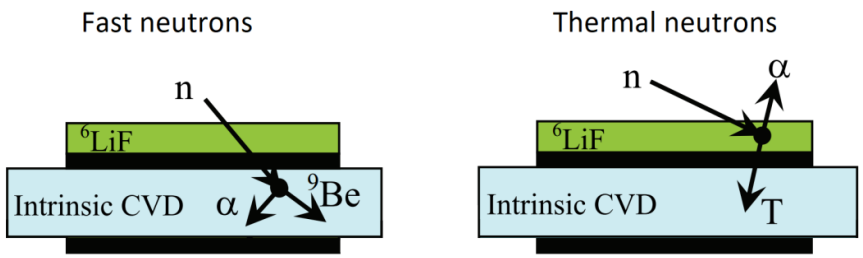
(b) TBM mock-up box

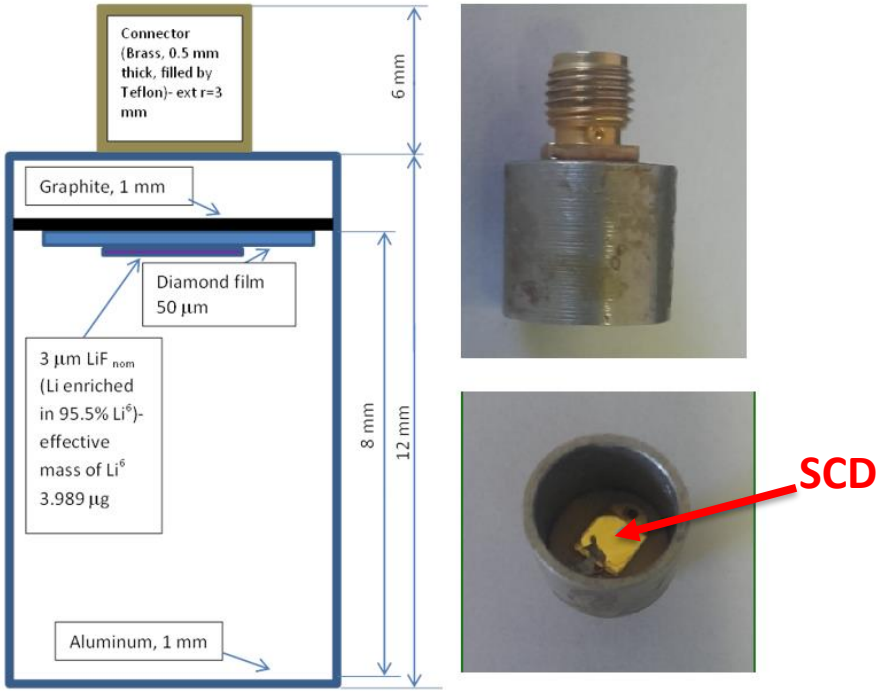
(c) The cable which connects the detector



(d) The preamplifier and the junction box

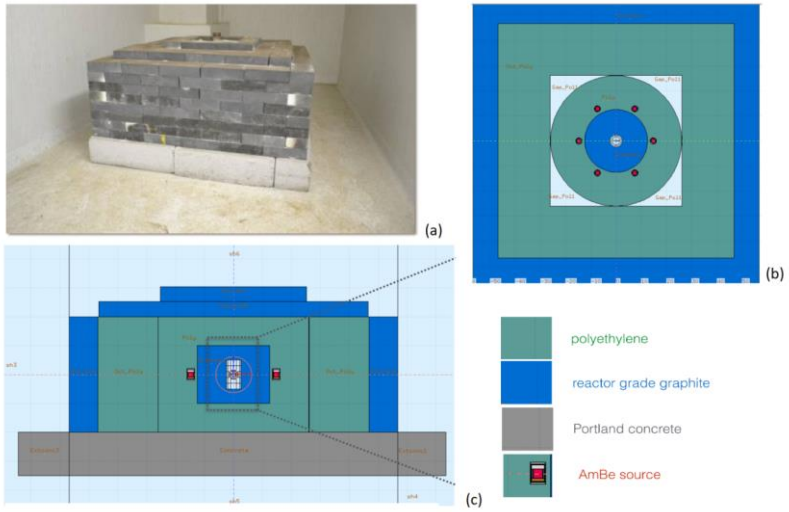
TBM Mock-up Diamond Detector (TBMD)





- Single Crystal Diamond (SCD)
- 50 µm thick, surface of 4.3x4.3 mm^2
- 3 µm LiF converting layer (95 % enriched ^{6}Li) on top of the upper electrode
- 14-MeV neutrons detected through **^{12}C(n,α)^{9}Be**, E_n > 6.1 MeV
- Thermal neutrons detected through **^{6}Li(n,α)T** (T@2.73 MeV, α@2.07MeV)
- Calibrated to assess TBM performance (T production inside TBM mock-up)

TBMD Calibration at ENEA-INMRI



ENEA-INMRI thermal neutron flux density standard: picture (a), horizontal (b) and vertical (c) cross sections.

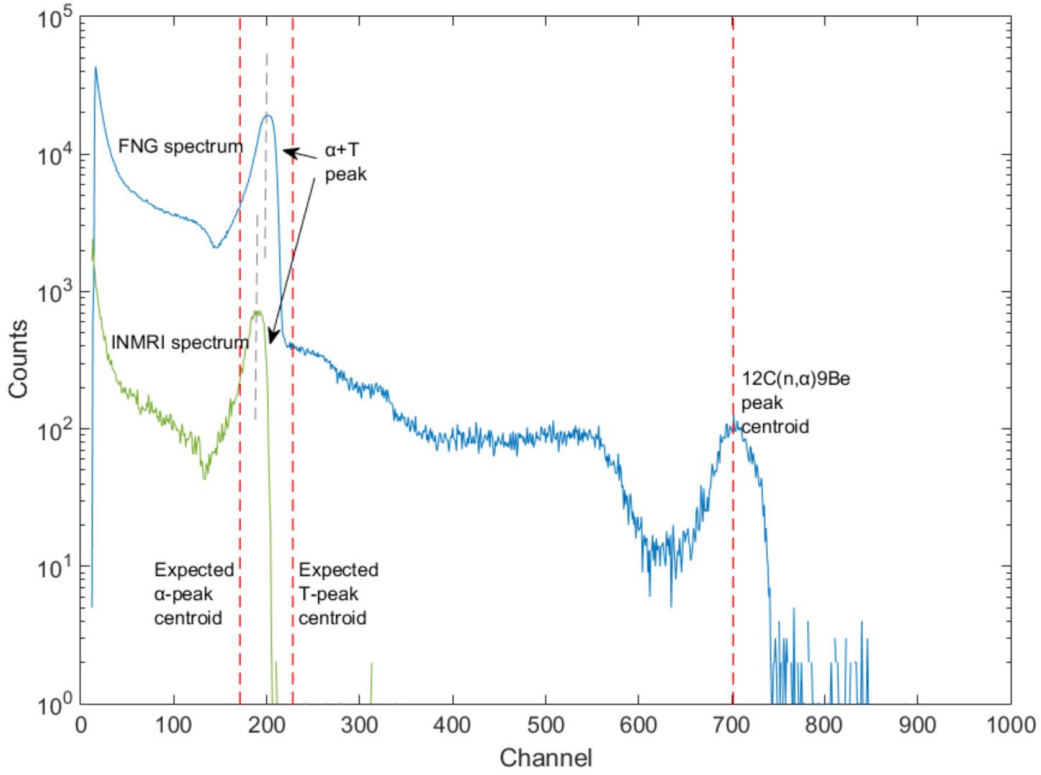


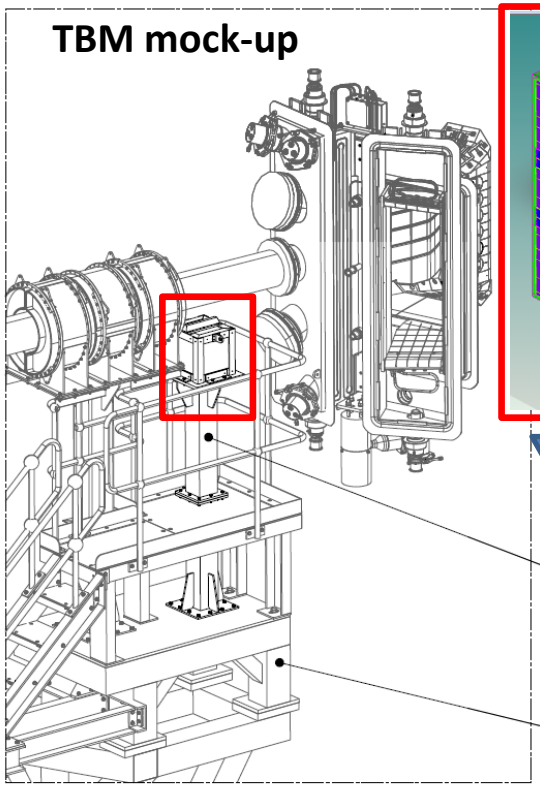
Table 4.2 Characteristic limits of the measurement

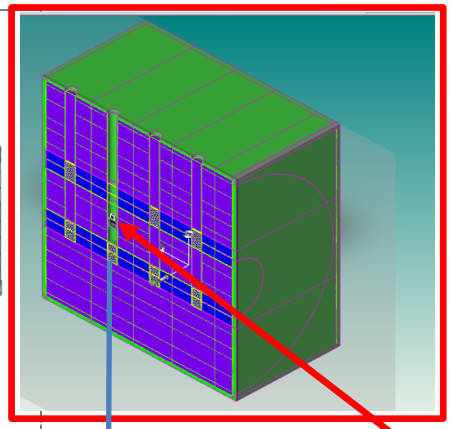
Quantity	Symbol	Value
Primary measurement result (i.e., ROI net counts)	y	17670
Standard Uncertainty associated with y	u(y)	188
Decision threshold	y^*	219
Detection limit	$y^\#$	440
Lower limit of the confidence level (95%)	$y^<$	17302
Upper limit of the confidence level (95%)	$y^>$	18038
Best estimate of the measurand	$\hat{y}$	17670
Standard uncertainty associated with $\hat{y}$	$u(\hat{y})$	188

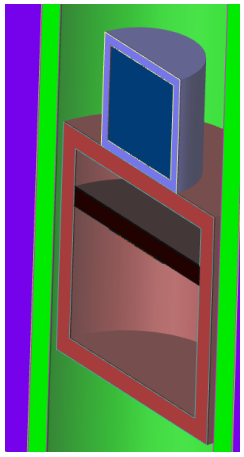
$$R_{Li6} = <\sigma\varphi> = \frac{cps\ M_{Li6}}{N_{Av}\ m_{Li6}\ \varepsilon\ k} = K_{cal}\ cps$$

Kcal=(2.504±0.039)x10^{-18}, i.e., 1 count per second (cps) corresponds to Kcal reactions ^{6}Li(n,T)α per atom of Li^{6} in the converting layer

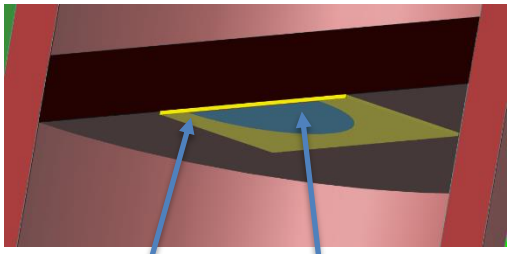
Experimental Setup







Detector in the middle of the HCPB block



Ortec 142PC

RG214 cable, 100 m long

J1T (Torus Hall)

J1D (Cubicle Hall)

HV PS CAEN R1419ET

HV

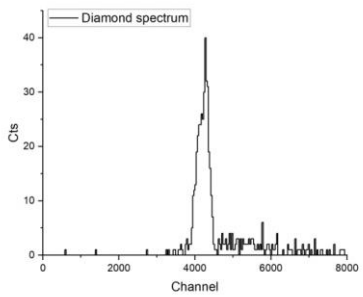
MCA CAEN DT5780

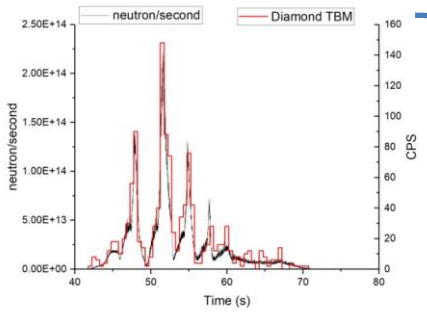
CODAS

Office PC

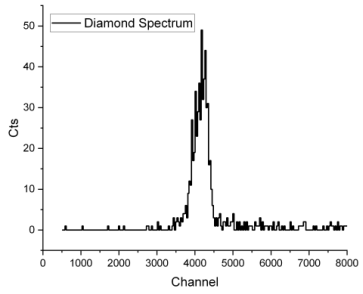
Measurements at JET during DTE2

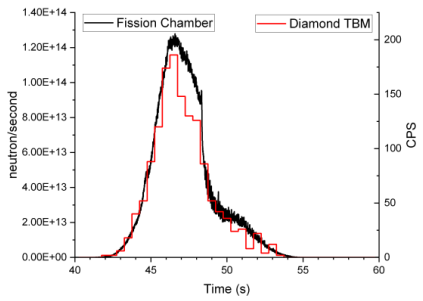
Pulse 99447



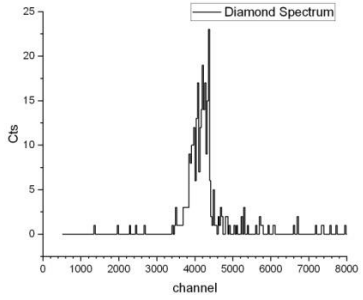


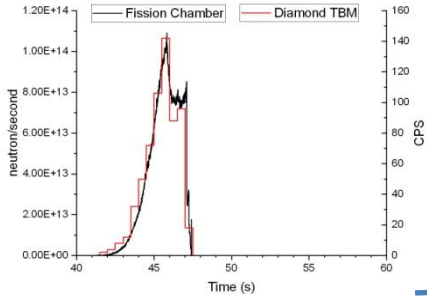
Pulse 99451





Pulse 99453





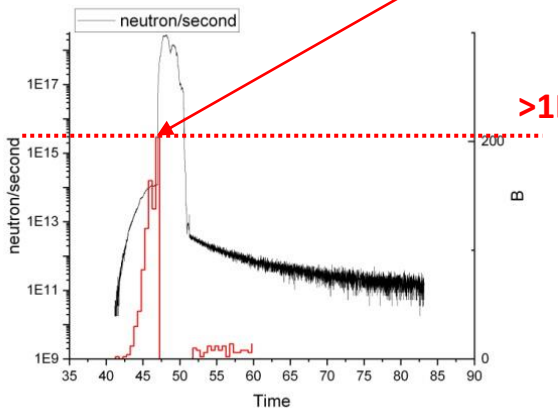
JET yield rate

<1E15 n/s

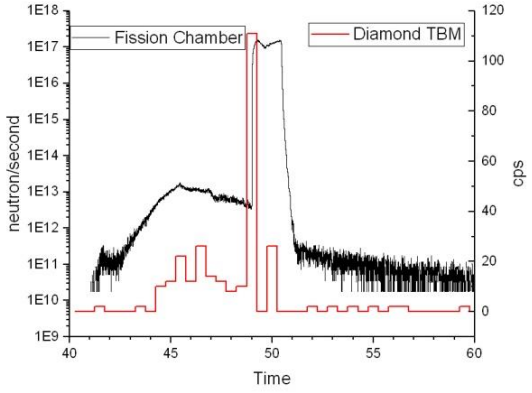
>1E15 n/s

Pulse 99452

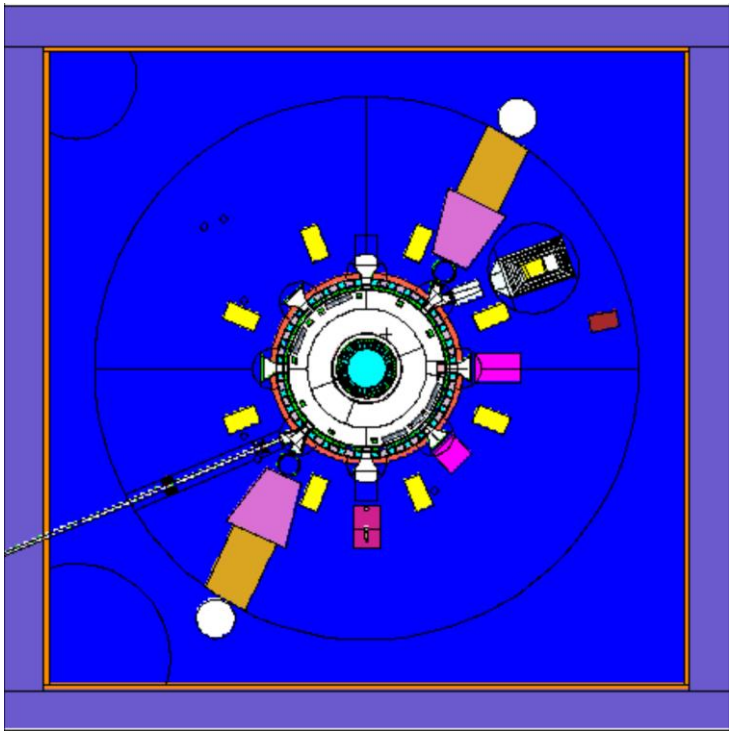
Pile-up/saturation

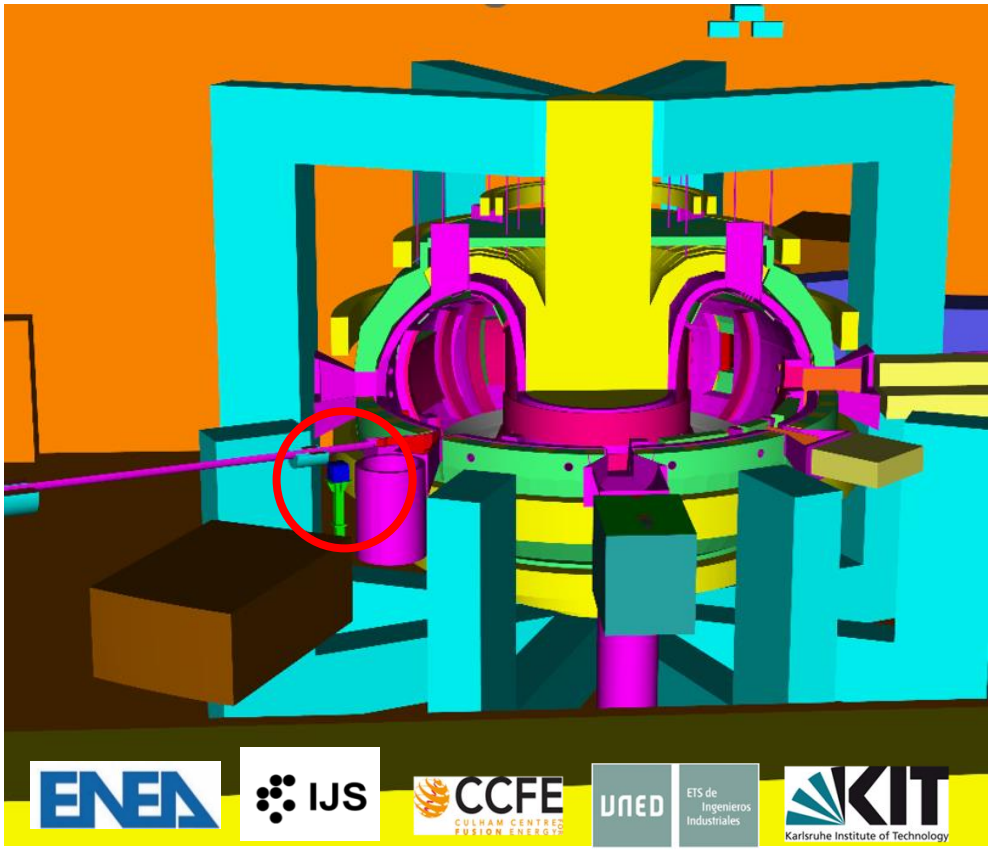


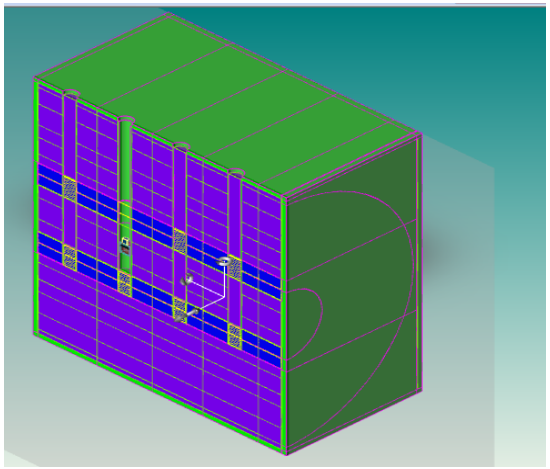
Pulse 99454

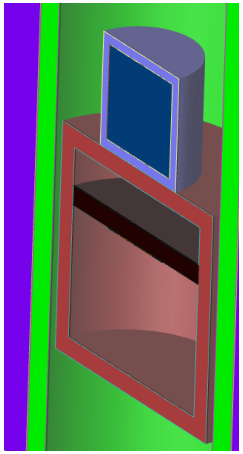


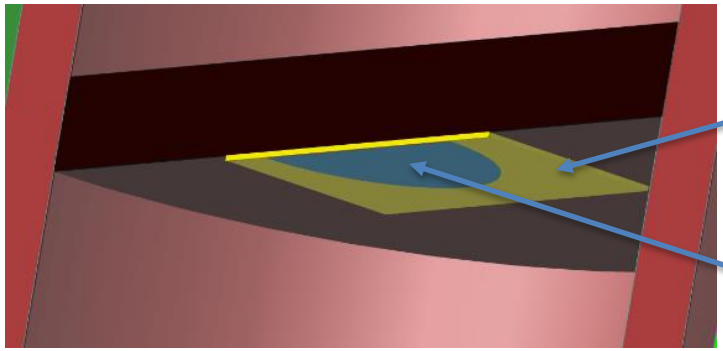
MCNP model



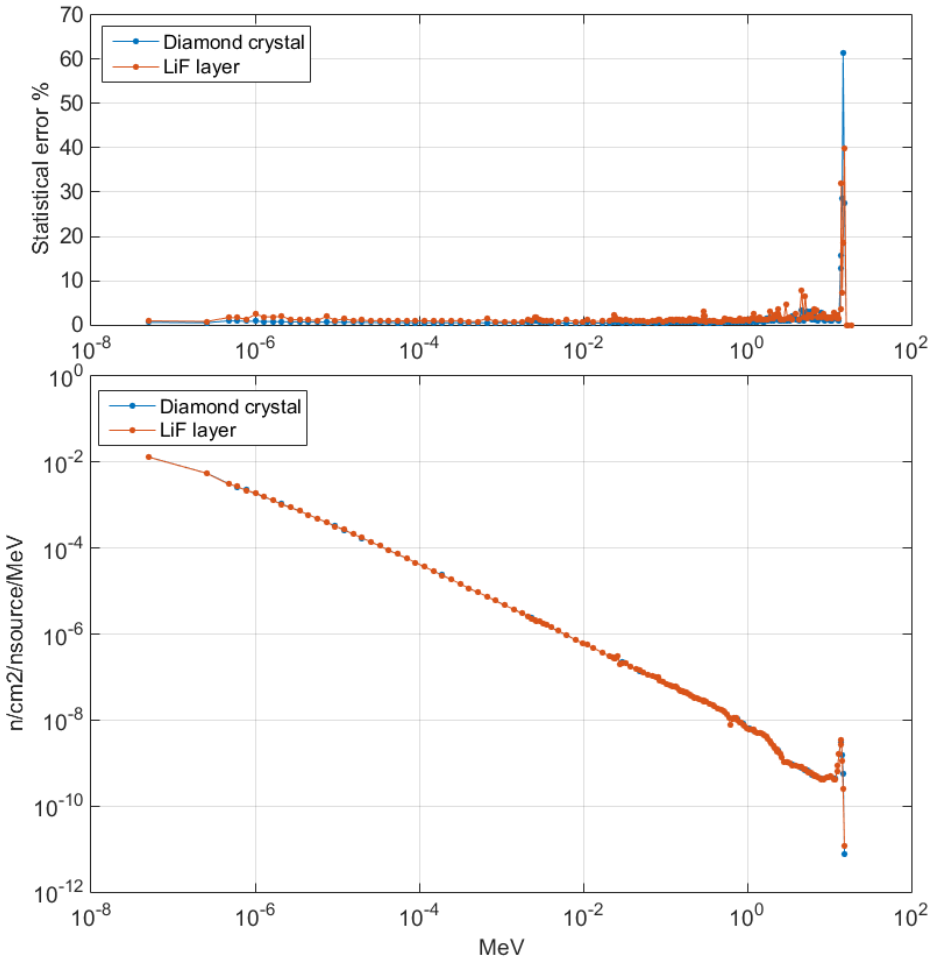

ENEA
IJS
CCFE
CULHAM CENTRE FOR FUSION ENERGY
UNED
ETS de Ingenieros Industriales
KIT
Karlsruhe Institute of Technology



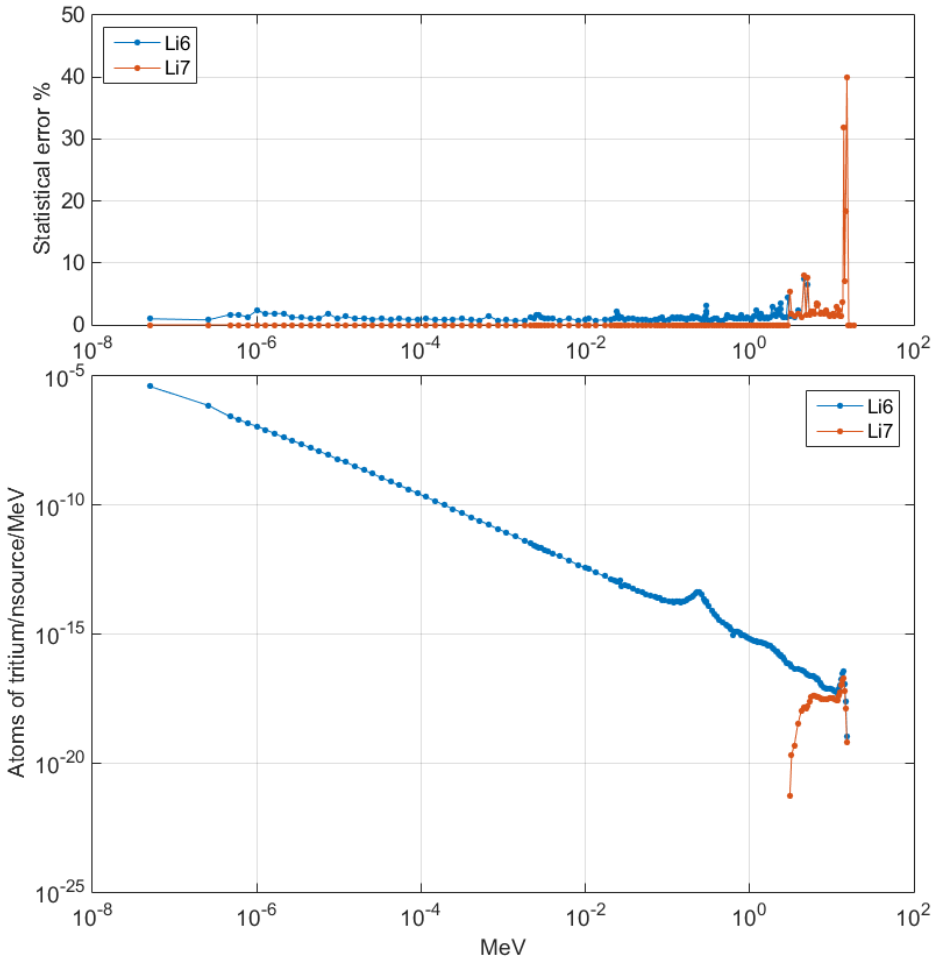



Diamond crystal
LiF

MCNP Calculation of TBMD response

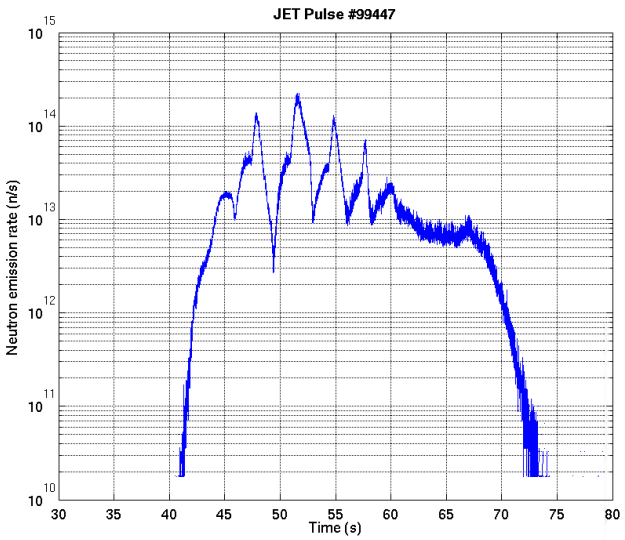


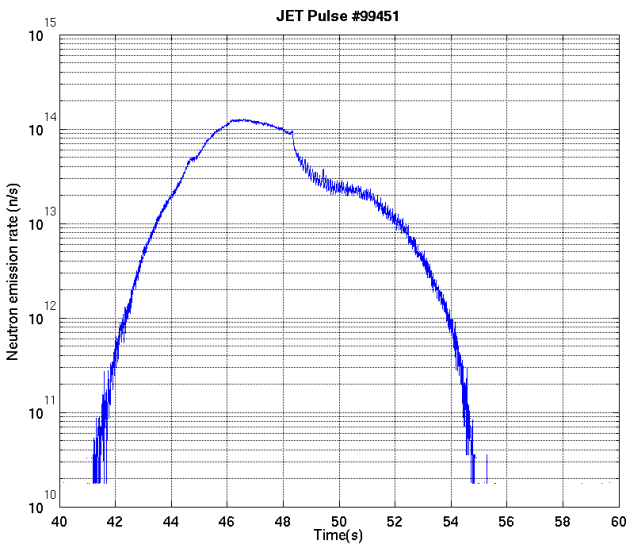
Neutron Flux

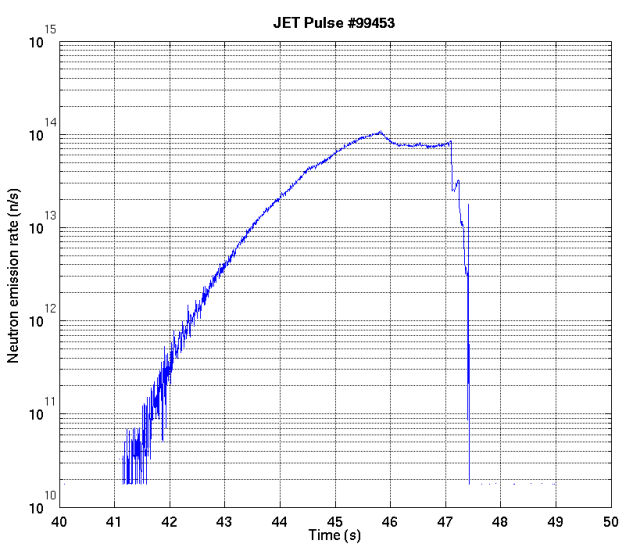


T production

Calculation/Measurement (C/E)

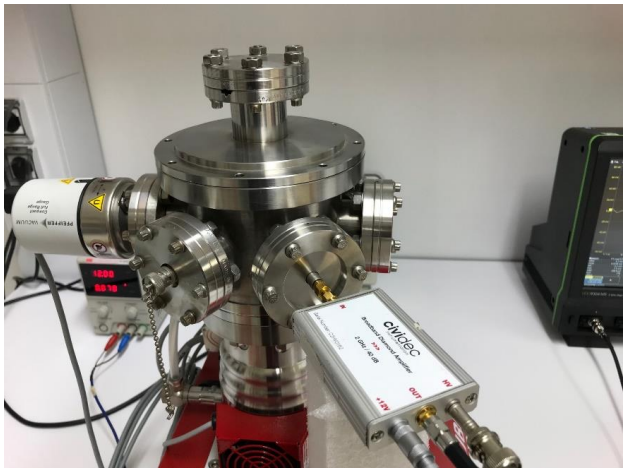




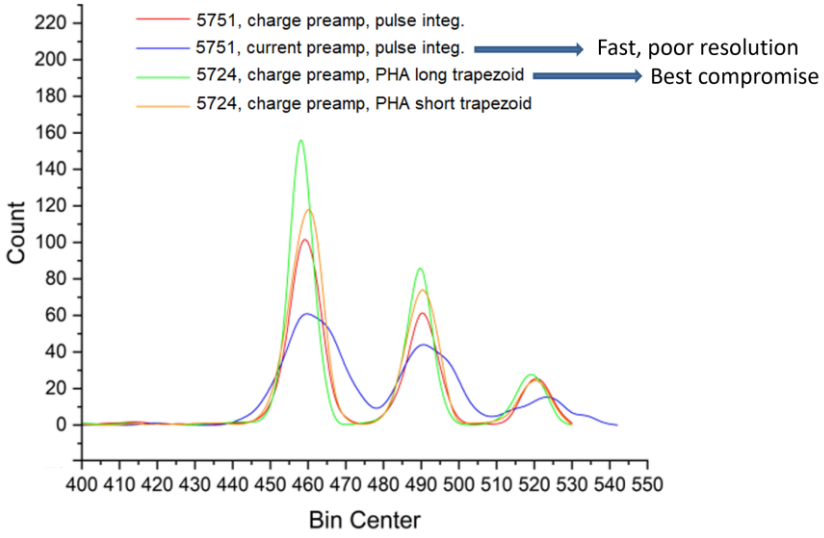


		MCNP calculation		TBMD measurements		
Pulse number	**Neutron yield**	**T/neutron source in Li6**	**in Li7**	**T/neutron source in Li6**	**C/E for Li6**	**Note**
99447	7.23E+14	**1.08E-12**	4.81E-17	**1.40E-12**	**0.77 (±0.03)**	
99451	5.03E+14	**1.08E-12**	4.81E-17	**1.40E-12**	**0.77 (±0.03)**	
99453	2.31E+14	**1.08E-12**	4.81E-17	**1.36E-12**	**0.79 (±0.05)**	below detection limit

Upgrade of measuring chain with a faster preamp.

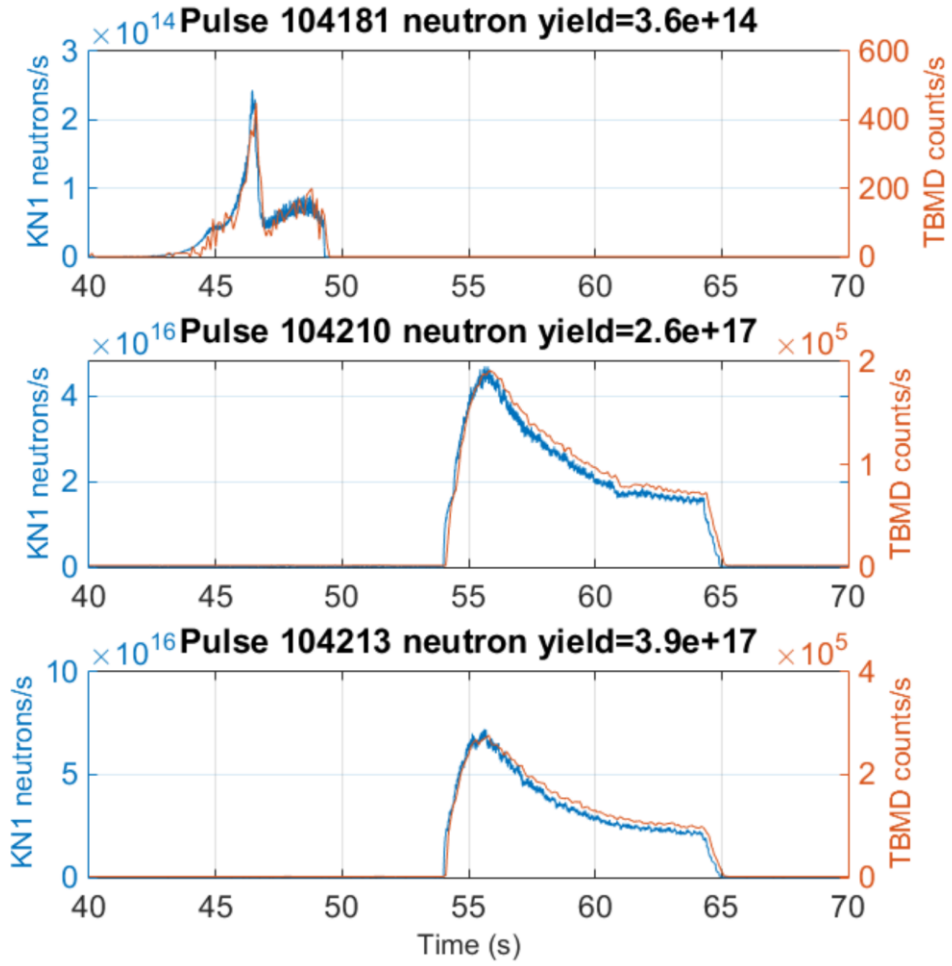


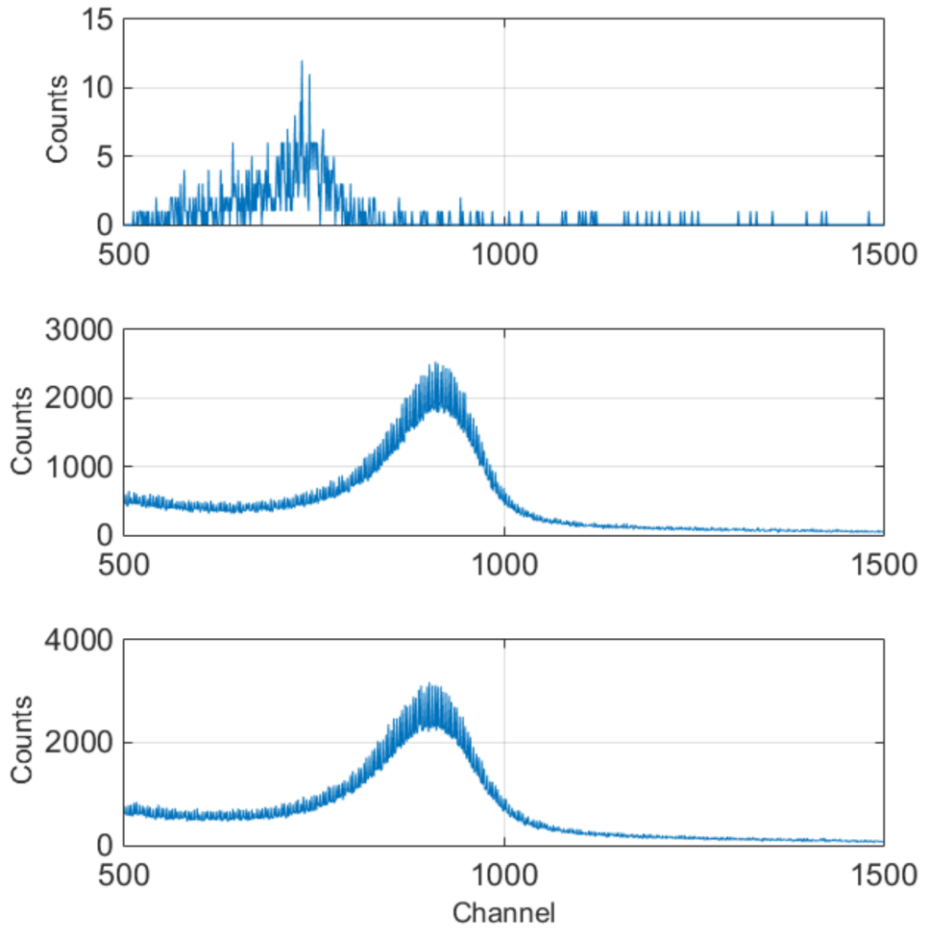
- **Commercial CVD in vacuum chamber;**
- **Alpha source(^{239}Pu-^{241}Am-^{244}Cm).**



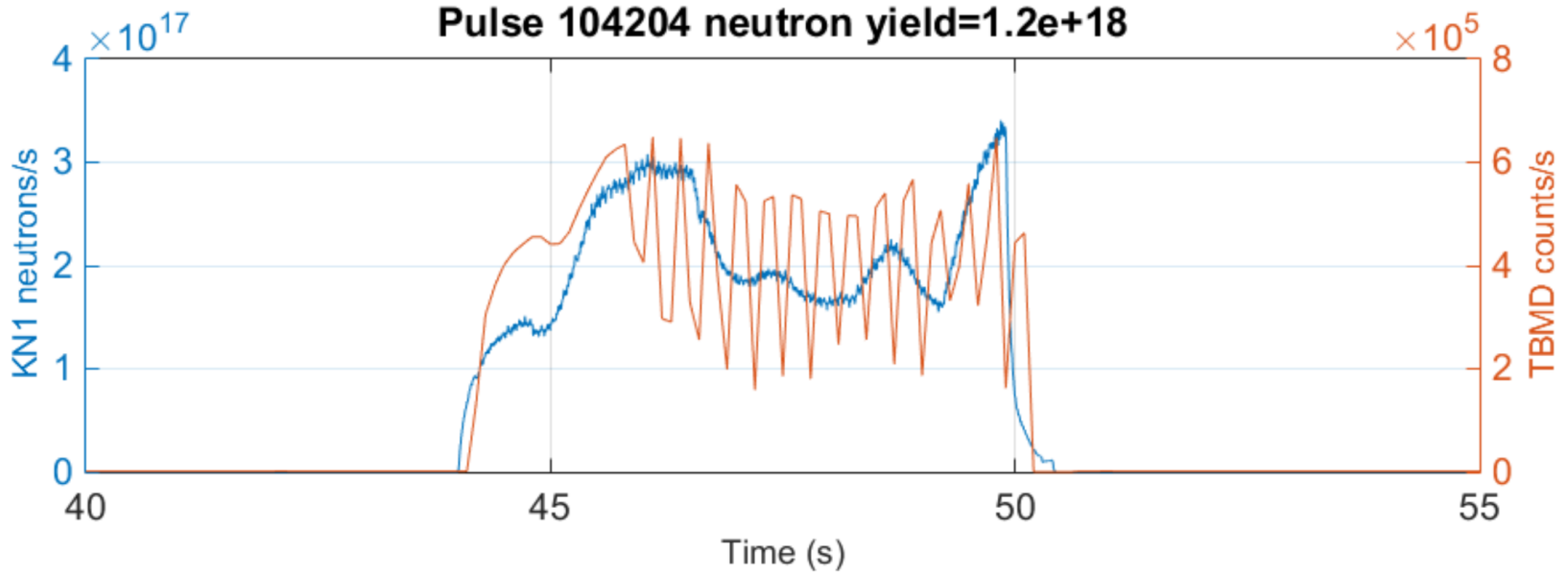
PreAmp Type	Digitizer Type	Pulse Analysis Type	Pulse Width (ns)	Max Count rate (x10^3)
Cividec Charge Preamp	DT5751	Pulse integration	500	400
Cividec Current Preamp	DT5751	Pulse integration	30	6500
Cividec Charge Preamp	**DT5724**	**Pulse height (long trapezoid)**	**800**	**250**
Cividec Charge Preamp	DT5724	Pulse height (short trapezoid)	500	400

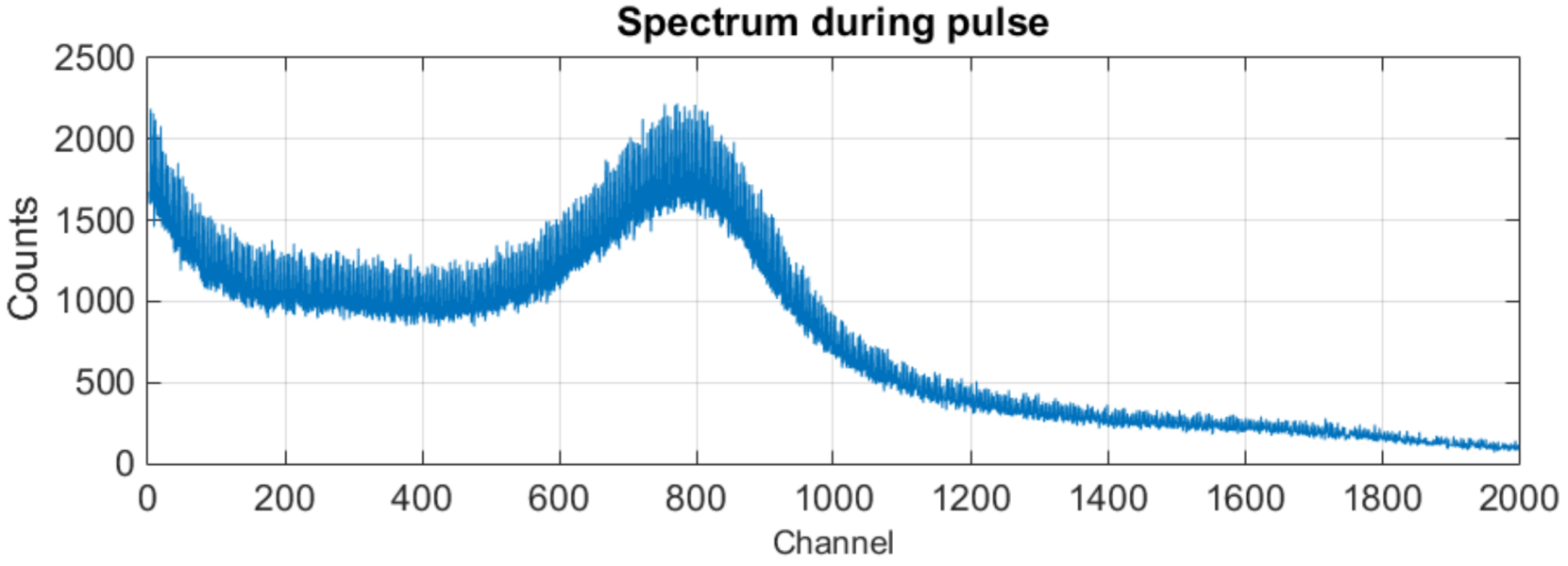
Measurements during DTE3



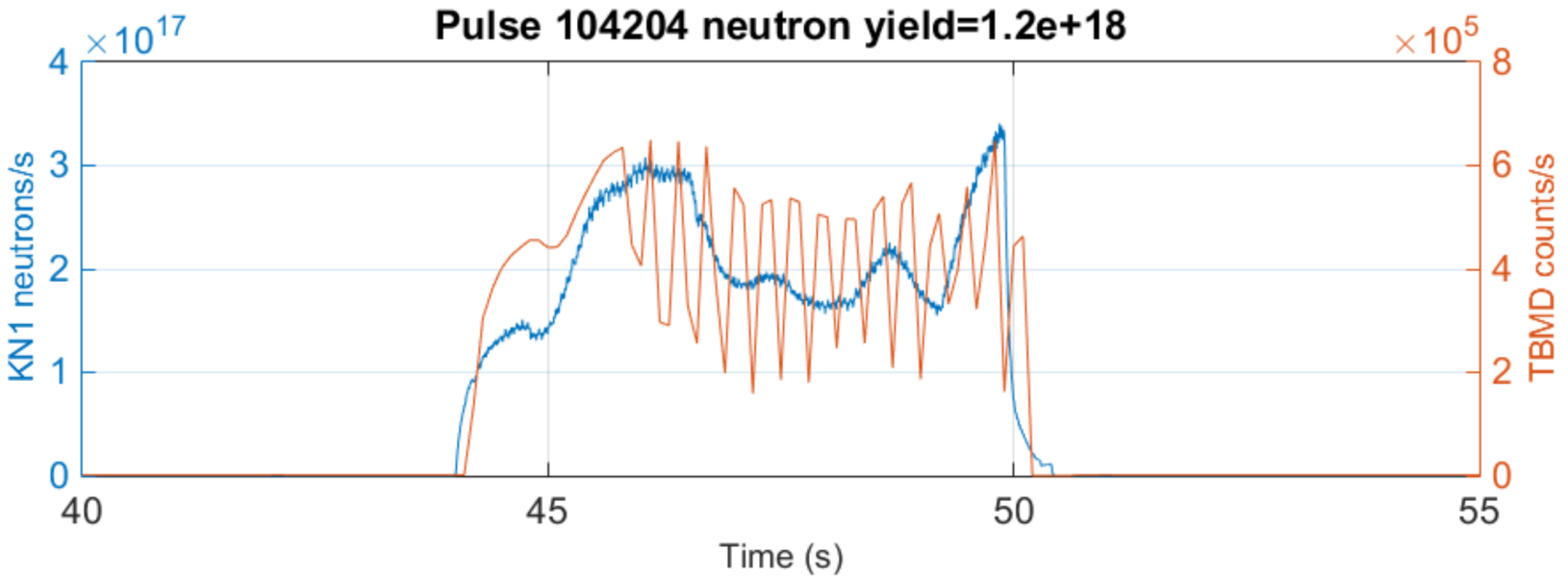


Measurements during DTE3





Measurements during DTE3



- n flux ~$3x10^{10}$ n/cm^{2}s
- Dead time < 20%
- T production measured up to $3x10^{17}$ n/s (so far)
- Max data transfer rate reached?
- C/E to be assessed

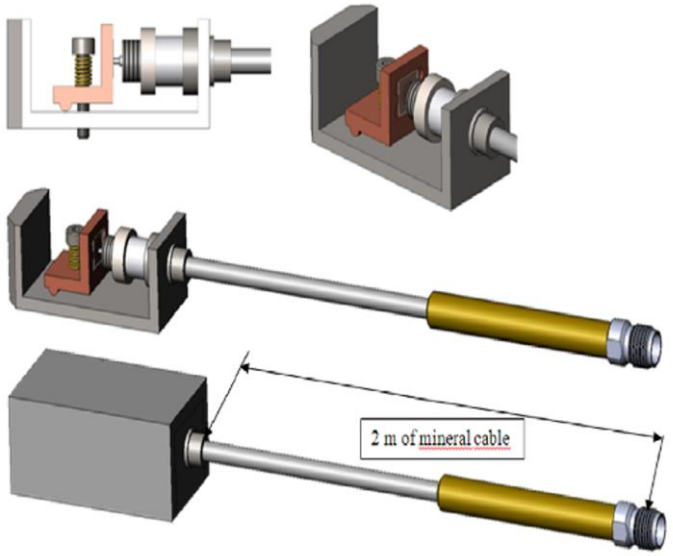
Extrapolation to ITER TBM

In ITER TBM neutron flux ~ 500-1000 times higher

- Reduction of detection efficiency to work at higher n flux
  - thickness of LiF layer
  - isotopic abundance of ^{6}Li
- Improve data transfer rate of measuring chain (optical link)

High temperature environment

- More robust configuration
- Mineral-insulated cable



Concluding remarks

- Diamond detector installed at JET inside TBM mock-up for **online measurement of tritium production**
- Aim is testing detector for ITER TBMs under fusion relevant operating conditions
- **C/E=0.77** determined during **DTE2** campaign at JET
- Max neutron emission rate of TBMD operation during DTE2 **~$1x10^{15}$ n/s**
- System upgraded, during DTE3 (up to now) **~$3x10^{17}$ n/s** JET pulses are properly measured
- C/E during DTE3 to be assessed

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Thank you for your attention !

nicola.fonnesu@enea.it

Italian National Agency for New Technologies, Energy and Sustainable Economic Development

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