

# Status of TBM Neutronics Experiment

(Task TTMN-002)

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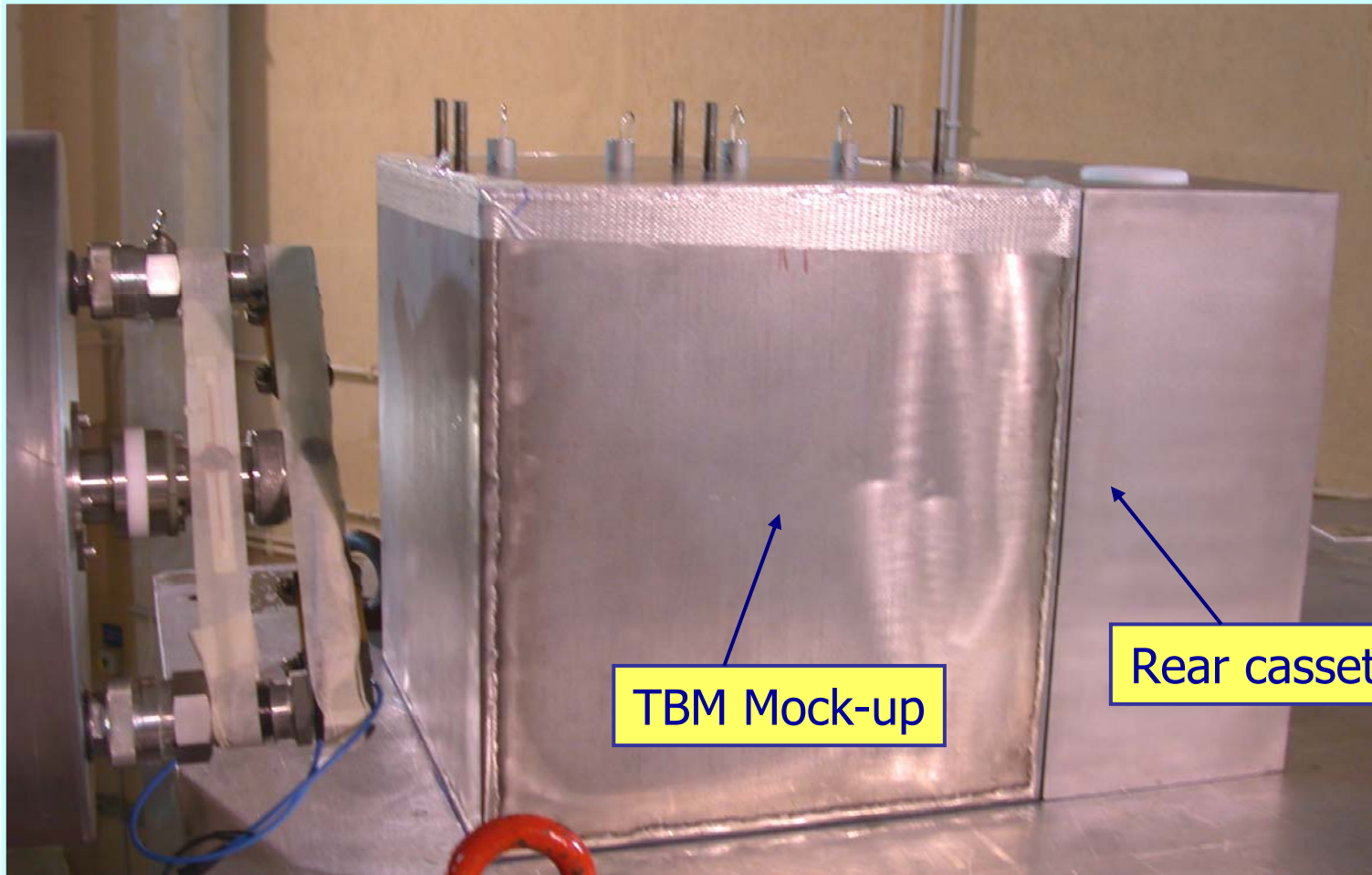
EFF/EAF Meeting

NEA Data Bank, Paris, 28 December 2005

# OUTLINE

- Experiment configuration (dimension, materials etc)
- Irradiation conditions
- Neutron source
- Measurement set up
- Measurements results
- Calculation results
- C/E comparison

## The TBM – HCPB breeder unit mock-up in front of FNG target



## TBM Mock-up

- External box

Dimension 310 x 310 x 290 mm<sup>3</sup>

Thickness = 5 mm

- Box cover

Dimension 310 x 290 mm<sup>2</sup>

Thickness = 5 mm

Provided with 4 holes

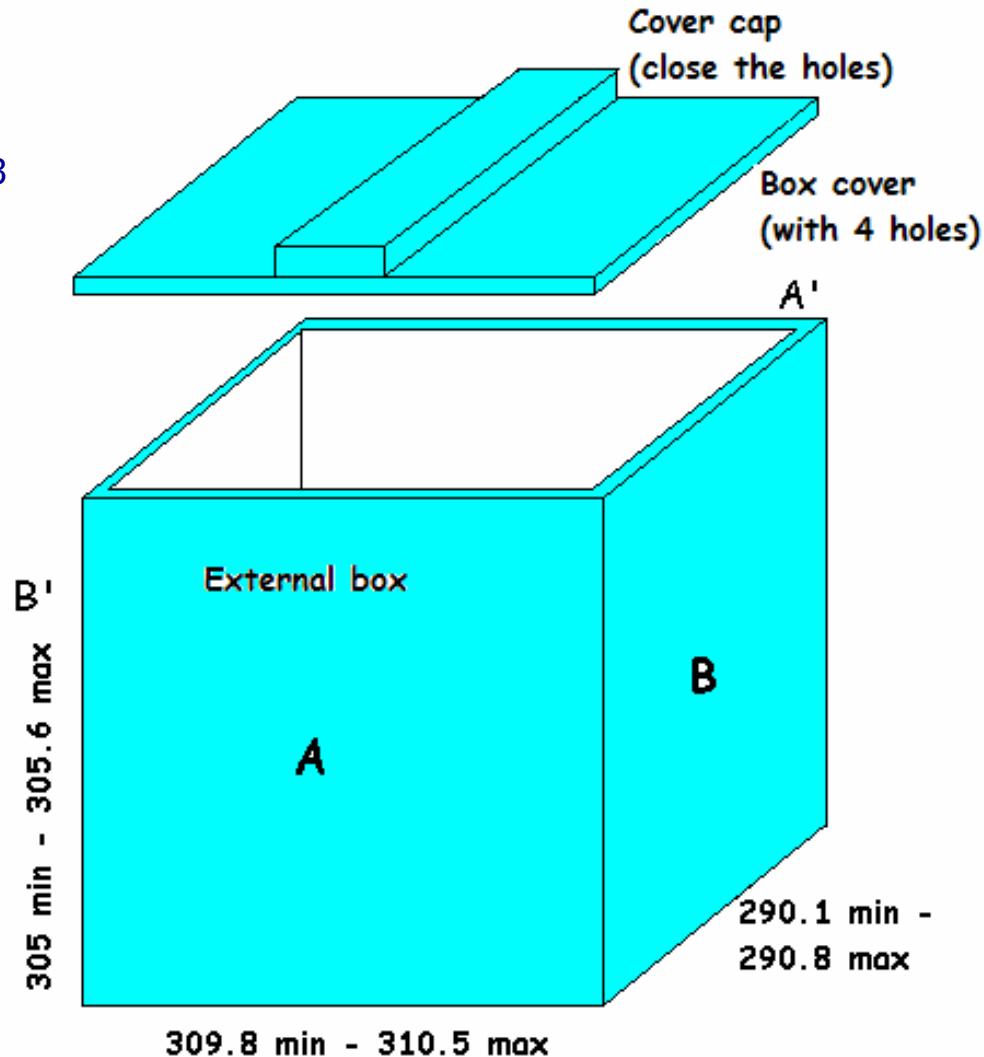
- Cover cap

Provided with a sealing gasket to close the cover holes

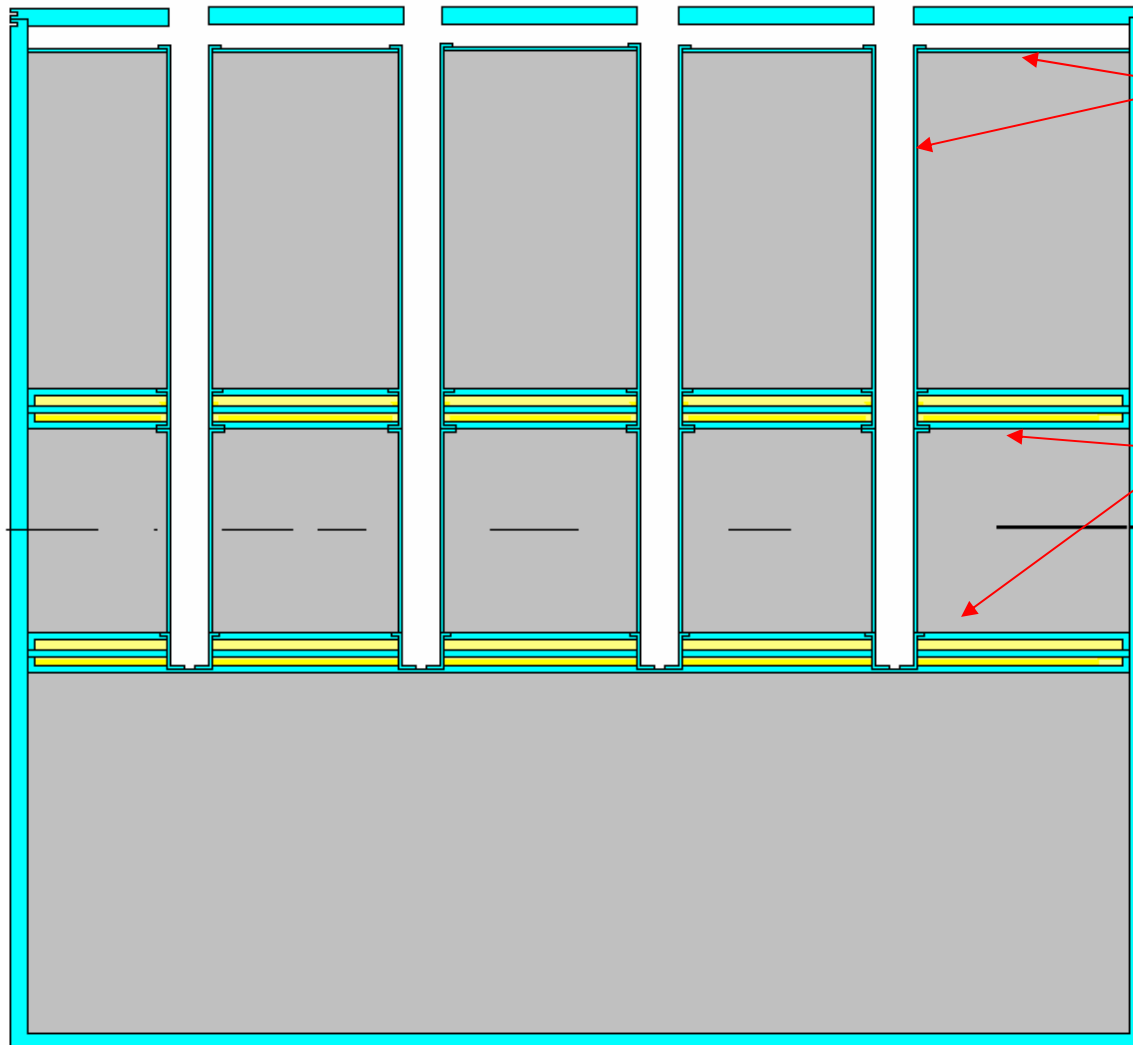
Not used during the experiment

- Material AISI-303

Density 7.954 g/cm<sup>3</sup>



## TBM Mock-up – Internal configuration



- A very thin steel layer on top and 4 steel tubes to avoid Be leak

- Two steel cassettes filled with  $\text{Li}_2\text{CO}_3$

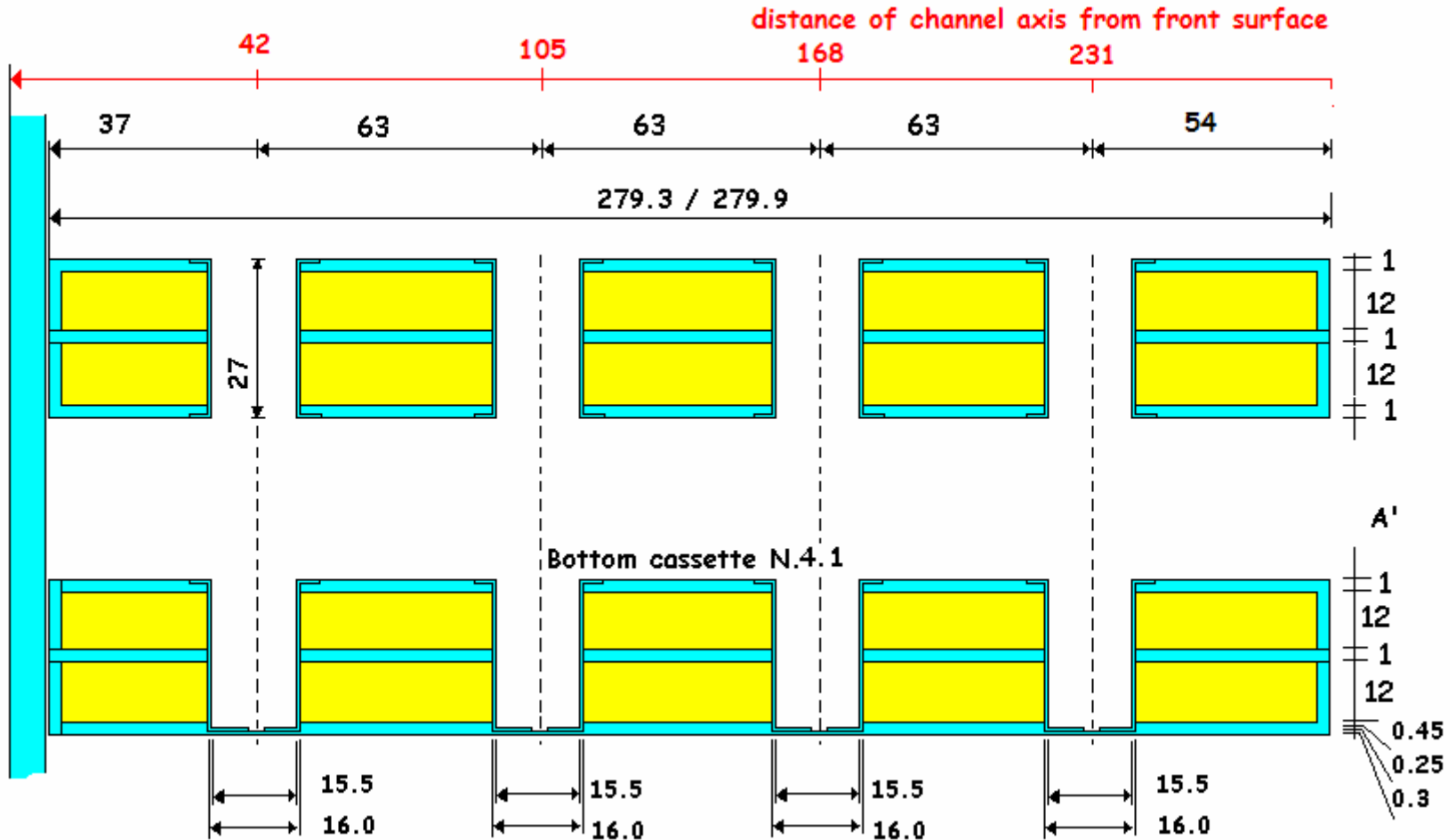
- Three Beryllium blocks

Stainless steel  
Metallic beryllium  
 $\text{Li}_2\text{CO}_3$  powder

## TBM Mock-up – Cassette configuration

$\text{Li}_2\text{CO}_3$  powder : 7.5%  $^6\text{Li}$  + 92.5%  $^7\text{Li}$

Total amount : 4423.7 g / Density : 1.13 g/cm<sup>3</sup>



**TBM Mock-up – Beryllium**

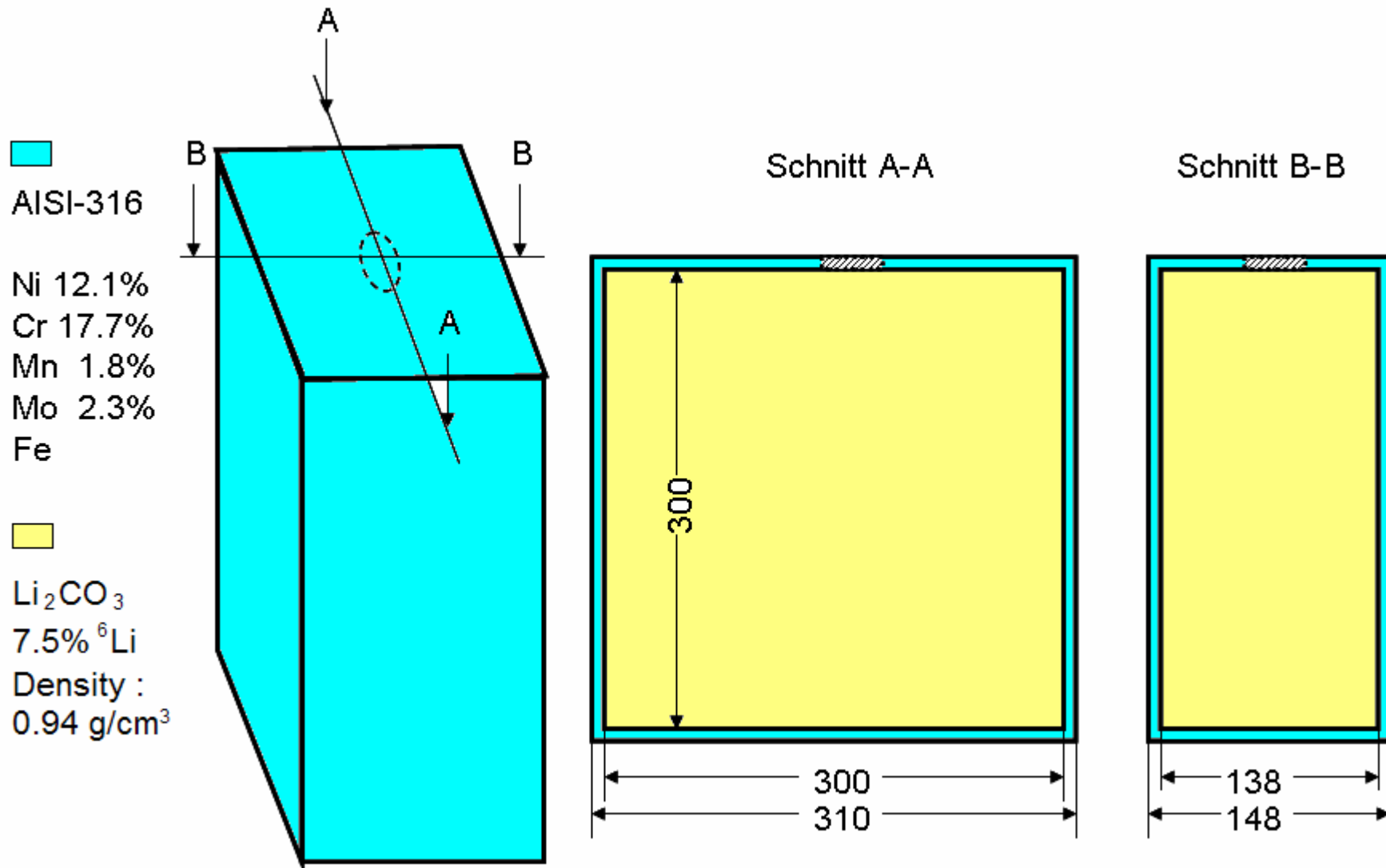
Number of pieces : 11 (3 blocks + 8 capsules)

Total amount : 37162.38 g / Density : 1.86 g/cm<sup>3</sup>

Composition (% weight):

Be	98.76	Si	0.013
O <sub>2</sub>	0.88	Al	0.012
C	0.075	Ti	0.028
F	0.0009	Cr	0.025
Fe	0.16	Mg+Mn+Cu+Ni	0.05

## Rear cassette





- The irradiation at FNG was carried out on  
**4,5,6,7 and 12 April 2005**

(We had planned to conclude the irradiation on April 8 but the Pope died in the period and the funeral took place just on April 8. That day Rome was completely stopped, including ENEA).

- Irradiation hours where from about 10.00 to 17.00 every day
- The total amount of neutrons was **5.834 e15 ± 3%**

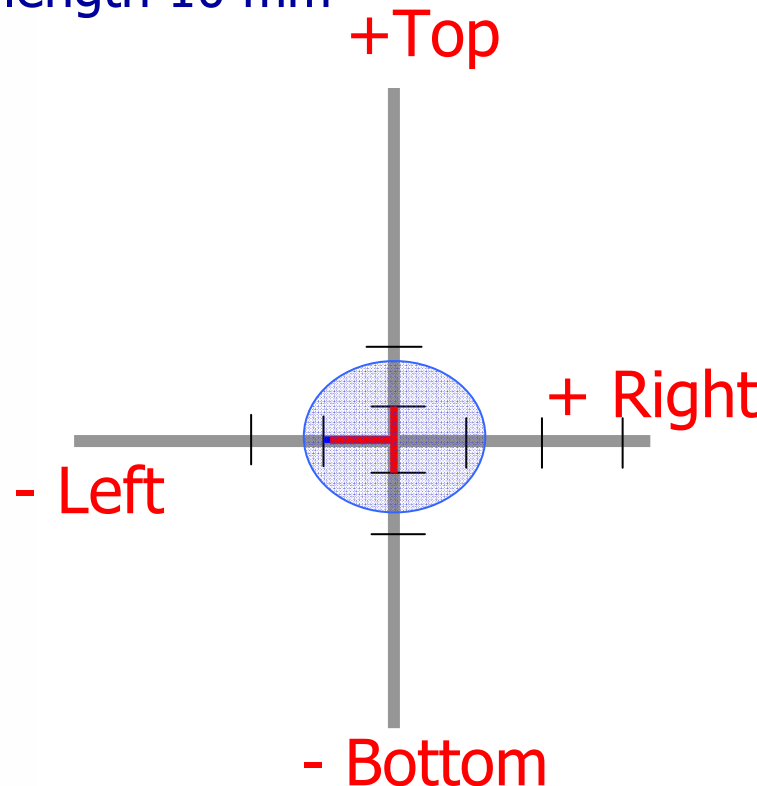
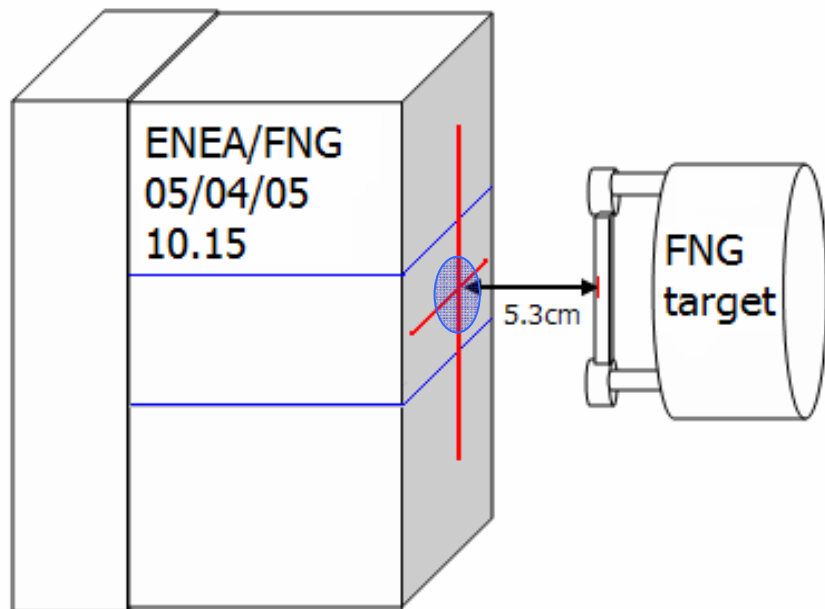
of which:

**5.3252 e15 on 4-7 April**  
**5.0875 e14 on 12 April** (~ 9% of total)

- The T measurements have been referred to  
**April 7, 2005 at 16.00 hour**

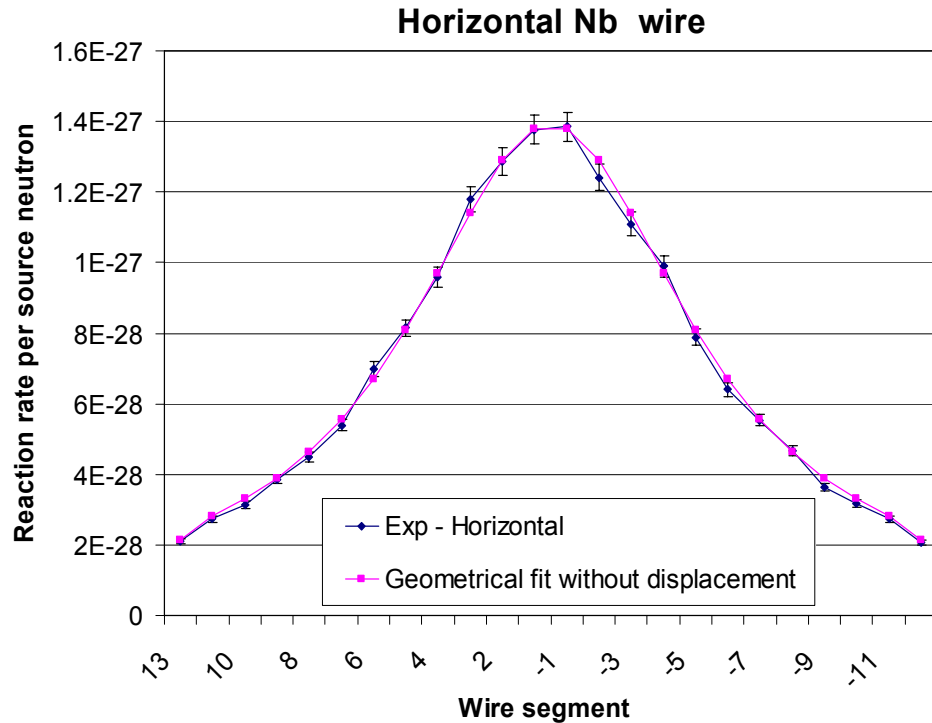
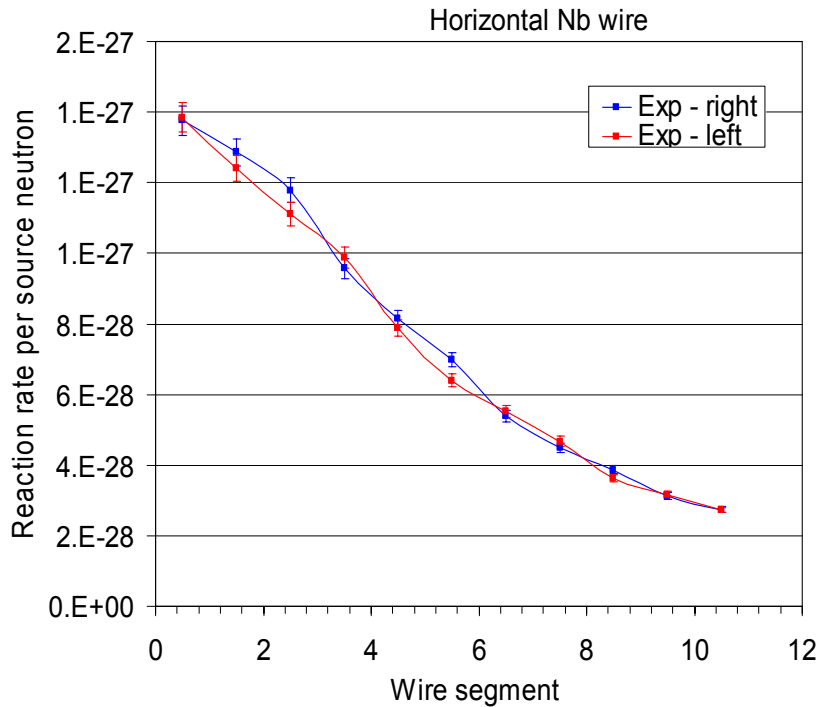
- JAEA meas. on April 5,  $\pm 2.5\%$

Neutron source intensity / position by activation of Nb wire  
 (cut in segments,  $\phi = 0.508$  mm, segment length 10 mm



- ENEА meas. on April 5-12,  $\pm 2.5\%$

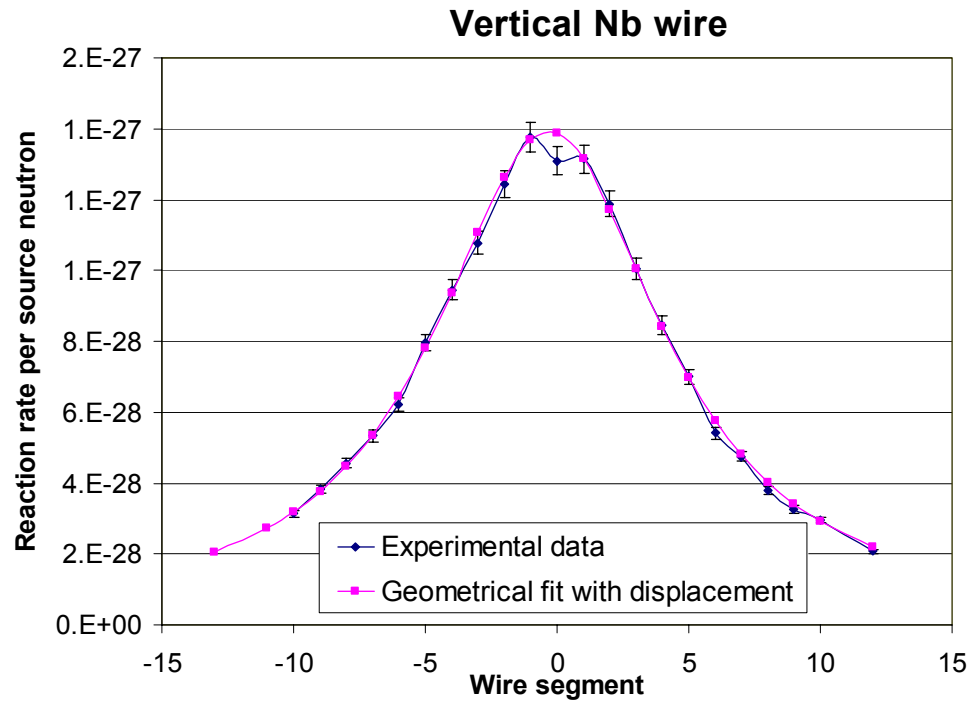
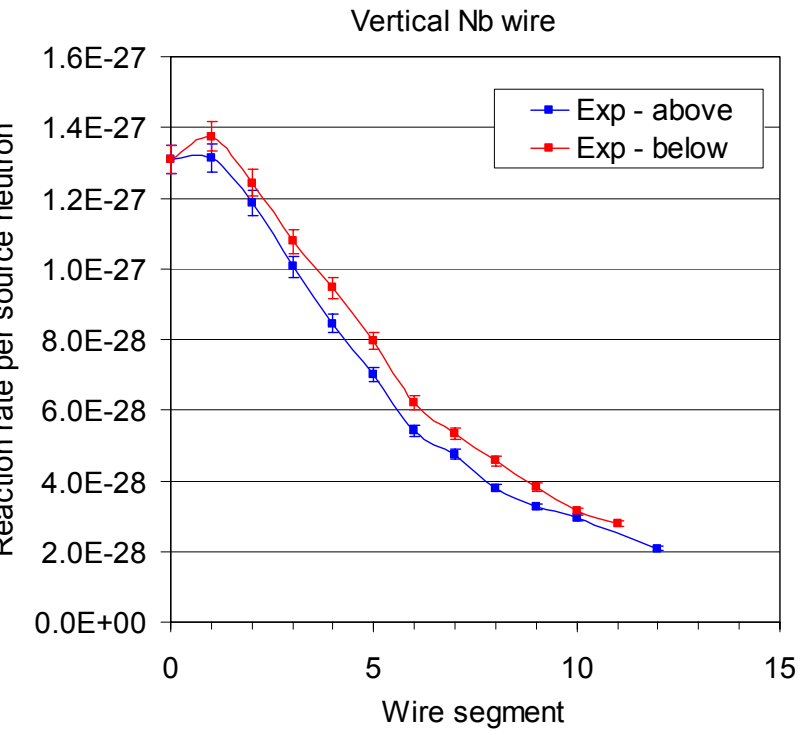
Neutron source intensity by activation of Nb foil  $\phi = 25.4$  mm



**Geometrical fit**  

$$g = K / \{5.3^2 + d^2\}^{1/2}$$

Horizontally, the block is perfectly symmetrical with respect to the neutron source

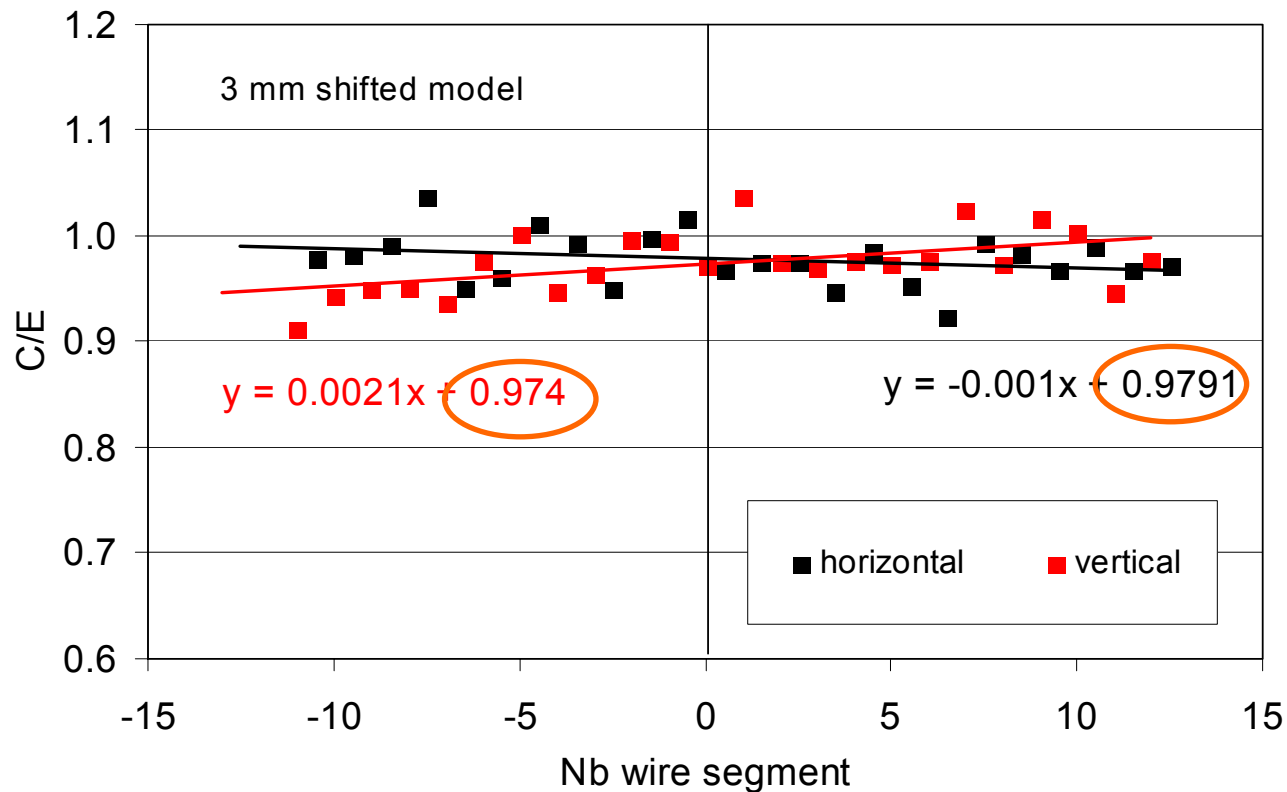


**Geometrical fit**  

$$g = K / \{5.3^2 + (d+0.3)^2\}^{1/2}$$

Vertically, the block is shifted upward by 3 mm with respect to the neutron source

## MCNP analysis of Nb wire measurements (by Sara)

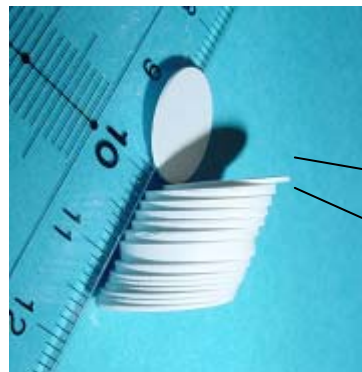


$N_b$  (ENEA) /  $\alpha$ -det = **1.00** (MCNP simulation of foil with 3mm)

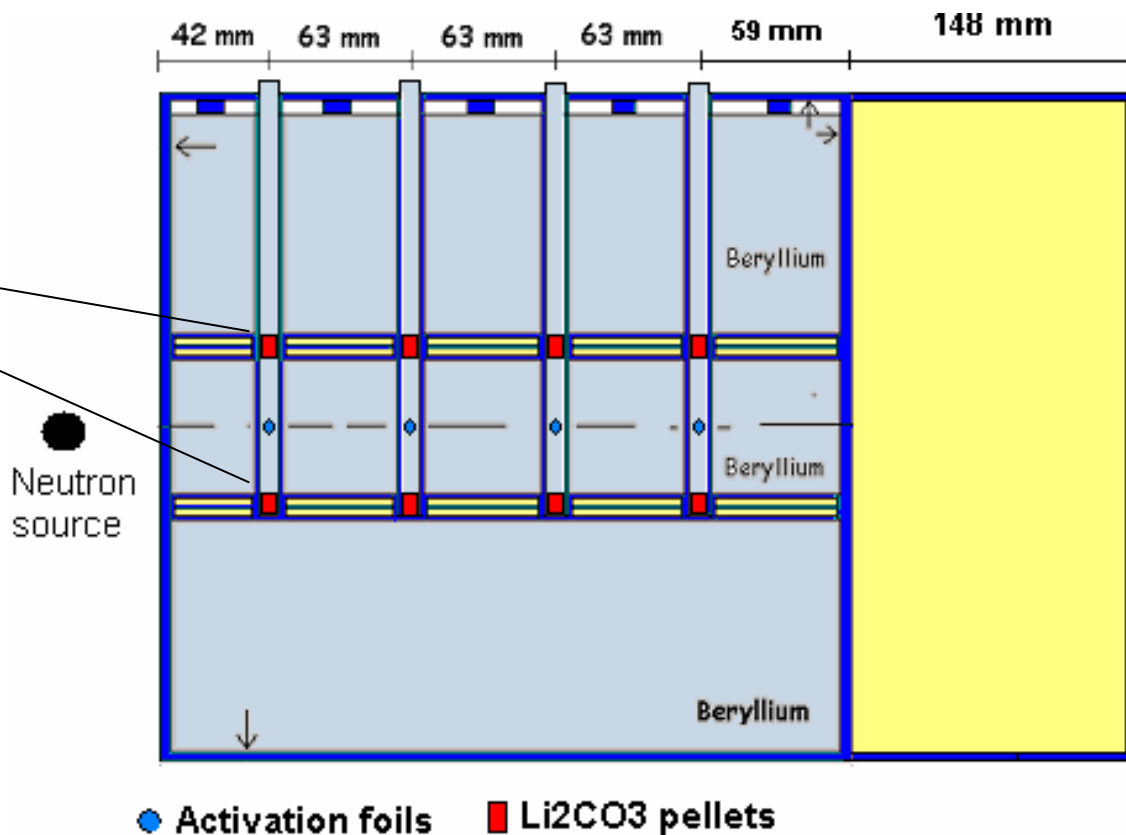
$N_b$  (JAEA) /  $\alpha$ -det = **0.98** (MCNP simulation of wire w/o 3mm)

→ Source calibration confirmed well within  $\pm 3\%$

- TPR measurements by  $\text{Li}_2\text{CO}_3$  pellets (nat. Li) → ENEA, TUD, (JAEA)
- Neutron flux in the central Be layer (ENEA)
- Neutron &  $\gamma$ -ray spectra behind the breeder unit (TUD/Rosendorf)

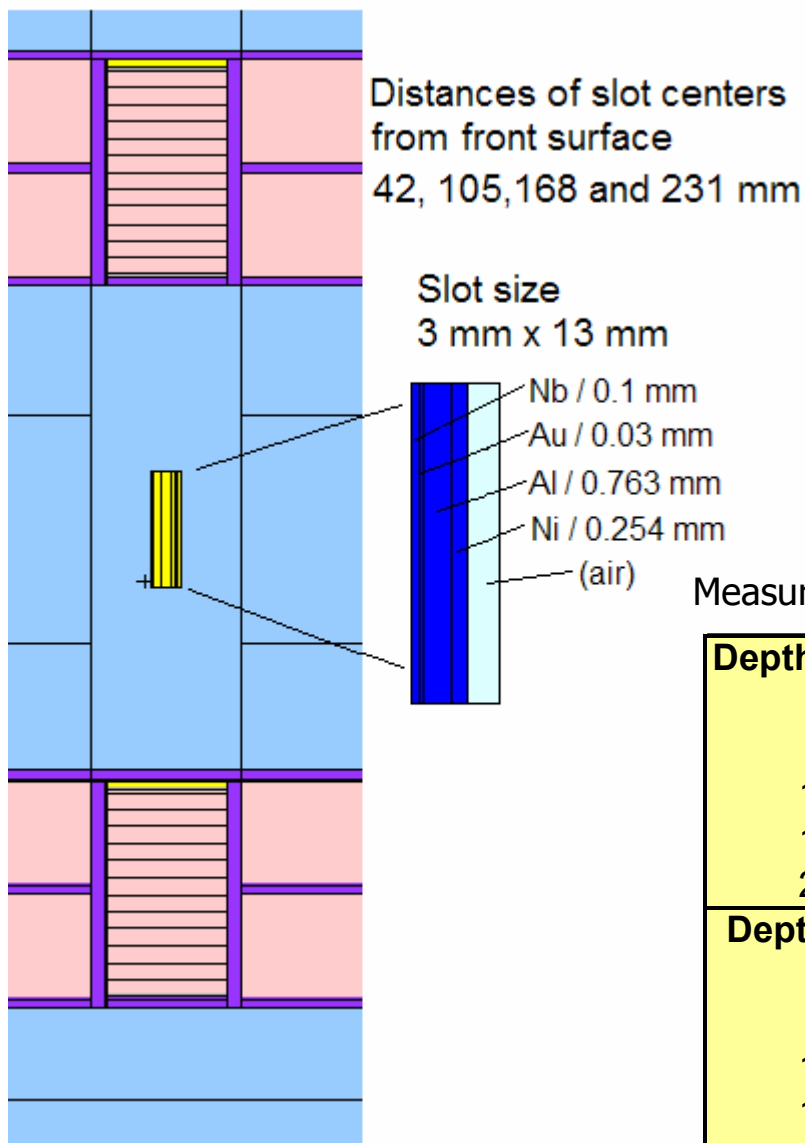


12 pellets (2mm thick)  
in each position to  
measure the TPR  
gradient across the  
ceramic breeder layer



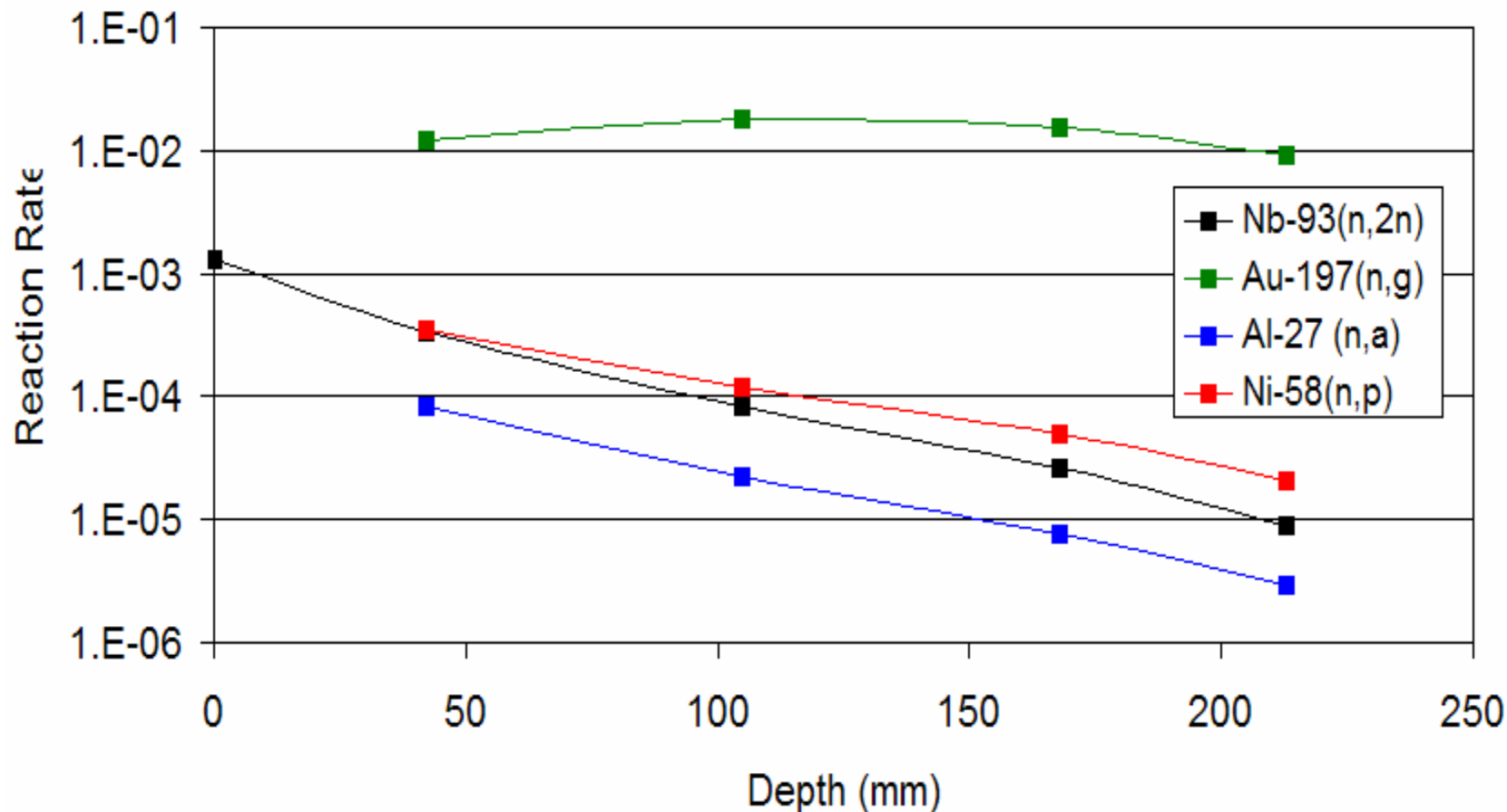
## Activation measurements

- 4 foils where located simultaneously in each position as shown in the figure
- The reaction rates are given in the table (Maurizio Angelone)
- Errors include counting statistics, detector and FNG source calibration ( $\pm 3\%$ )



Measured reaction rates ( $10^{-24}$  activated nuclei/(nuclei • neutron).

Depth (mm)	Nb-93(n,2n)	±	Au-197(n,g)	±
0	1.29E-03	4.1%		
42	3.37E-04	4.3%	1.23E-02	4.2%
105	8.30E-05	4.3%	1.82E-02	4.2%
168	2.60E-05	4.3%	1.52E-02	4.2%
213	9.04E-06	4.5%	9.02E-03	4.2%
Depth (mm)	Al-27 (n,a)	±	Ni-58(n,p)	±
0				
42	8.42E-05	4.2%	3.50E-04	4.2%
105	2.20E-05	4.2%	1.18E-04	4.5%
168	7.48E-06	4.3%	4.98E-05	4.5%
213	2.88E-06	4.3%	2.05E-05	4.7%

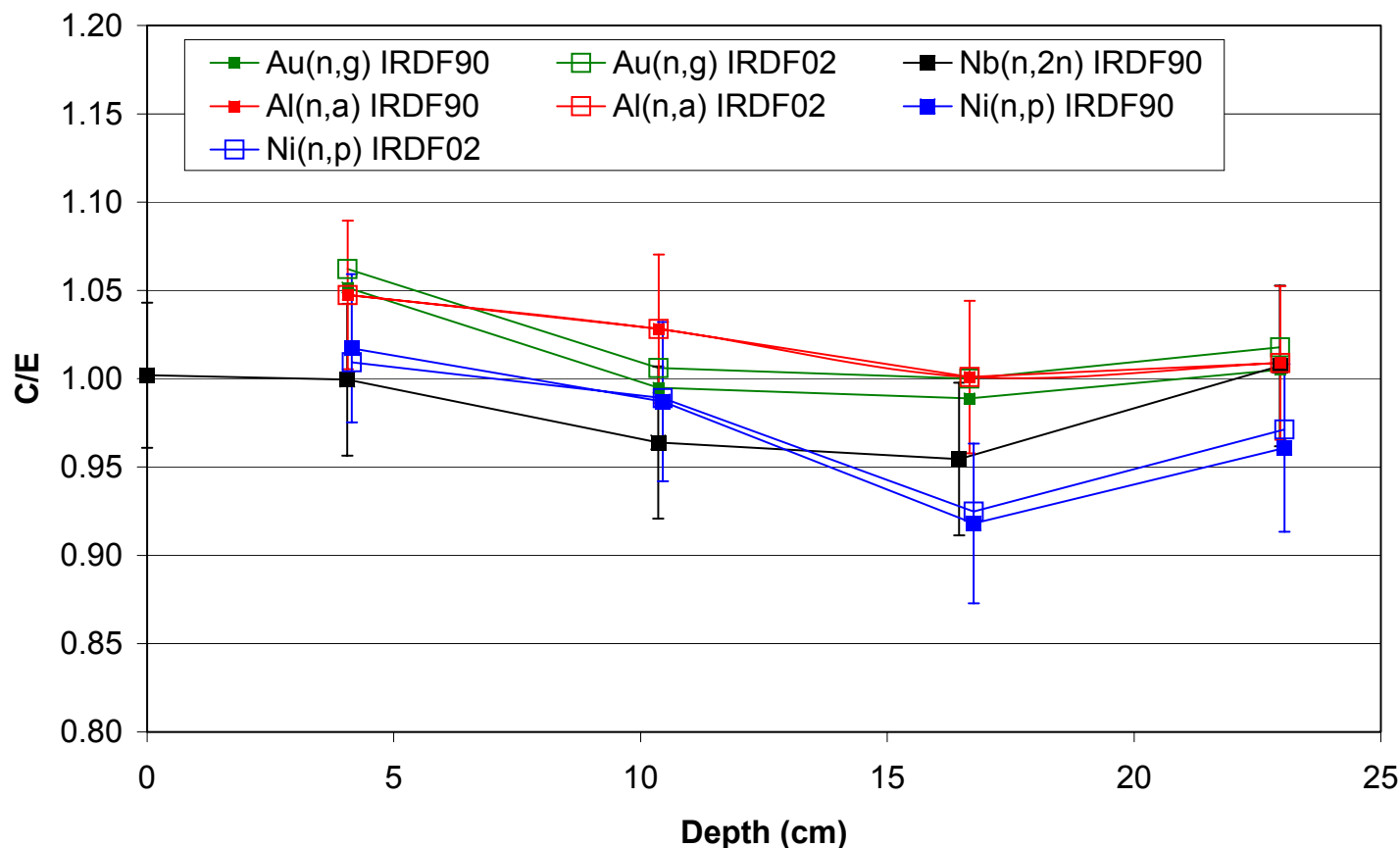
**Activation measurements : measured reaction rates**



## Preliminary analysis of activation measurements

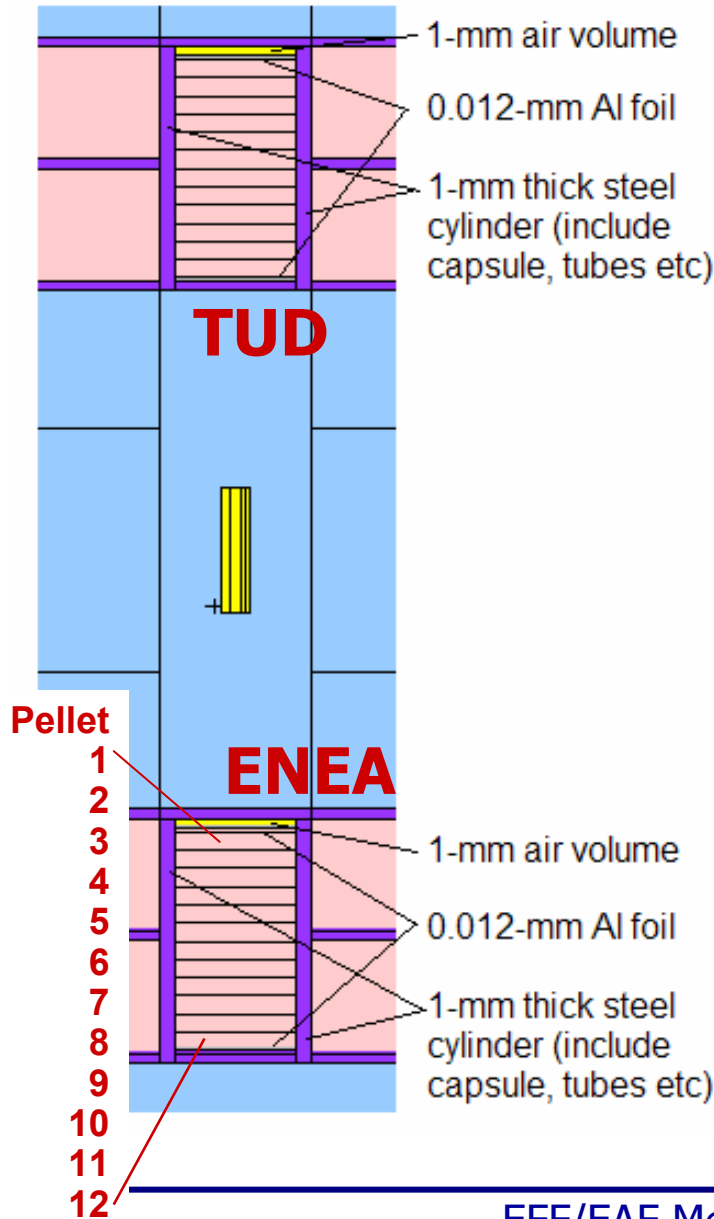
- MCNP4c with EFF - 2.4 (Sara Villari)
- Both IRDF-90 and IRDF-02 dosimetric cross sections

→ very good agreement



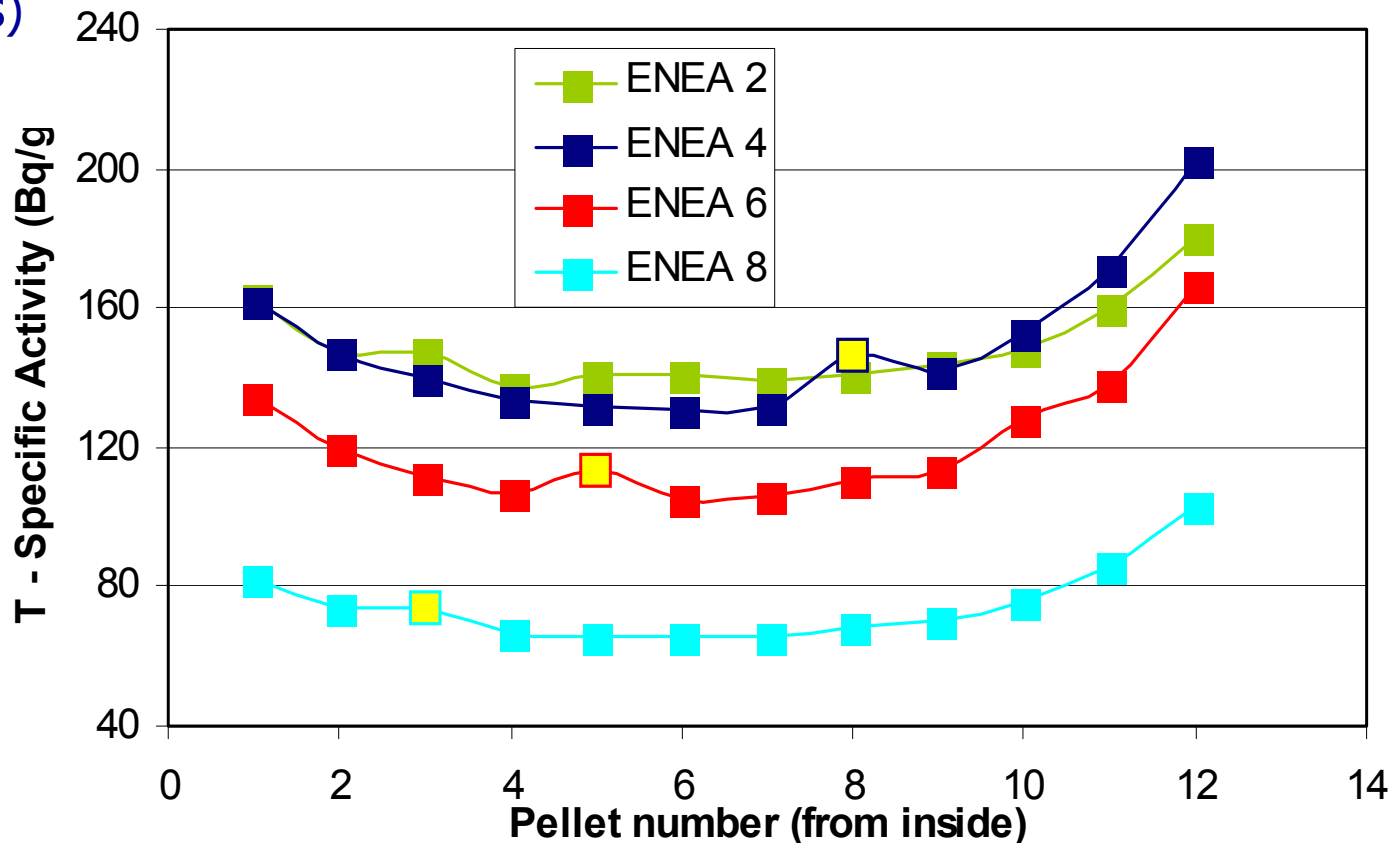
## Tritium measurements

- Stack of 12 pellets
  - ✓ diameter = 13 mm
  - ✓ thickness = 1.93 mm
  - ✓ average mass = 405 mg
  - ✓ density = 1.58 g / cm<sup>3</sup>
  - ✓ material = Li<sub>2</sub>CO<sub>3</sub> powder
  - ✓ (7.5% <sup>6</sup>Li + 92.5% <sup>7</sup>Li)
  - ✓ dry preparation (no material added)
  
- The stack is enveloped in an aluminum foil with thickness 12.5 μm
  
- Errors include counting statistics, detector and FNG source calibration (±3%)



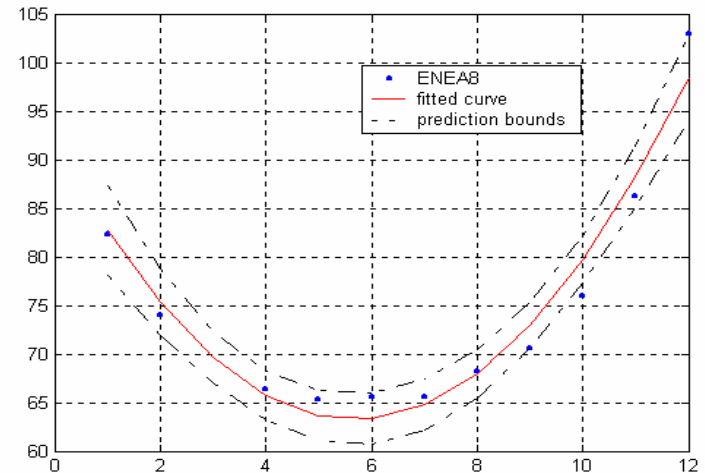
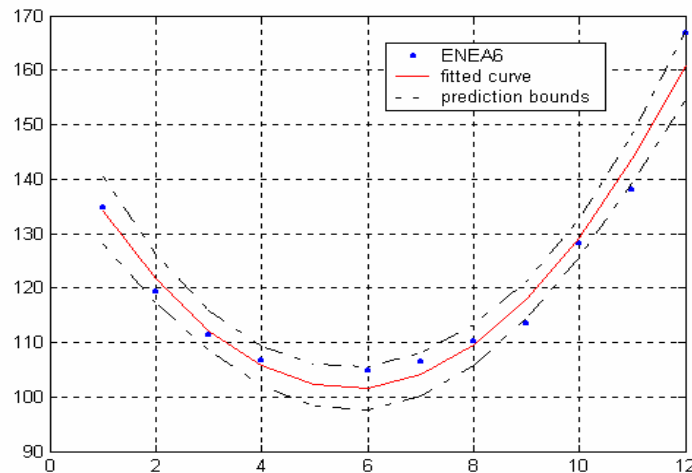
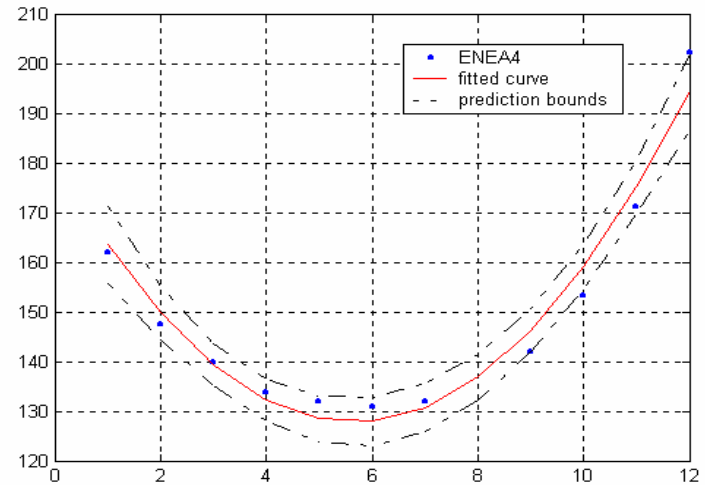
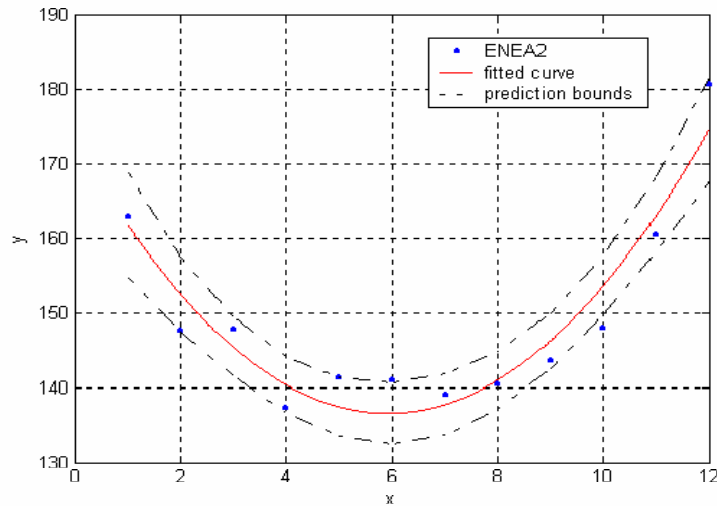
## Measurements of Tritium production rate (TPR)

- Experimental errors  $\approx \pm 6-7\%$
- The T – specific activities measured in ENEA compare rather well with those measured at JAERI (JAERI / ENEA  $\approx 1.08$ , well within combined errors)



## Statistical analysis of measurements

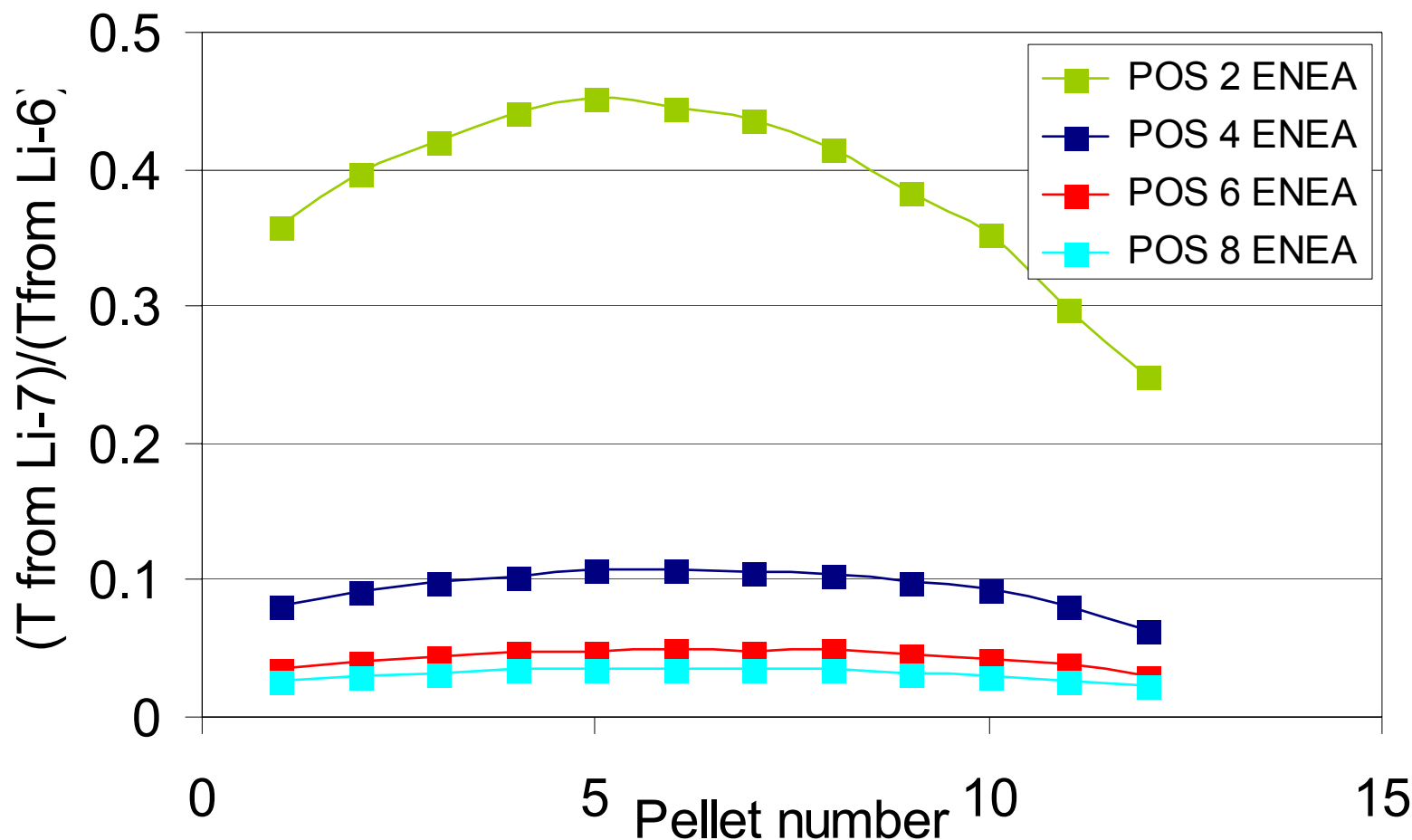
Best fits and prediction bounds (95% confidence) for measured specific activities in each experimental position  $\rightarrow A_i, \Delta A_i \approx \pm 3 - 5 \%$



## Preliminary analysis of TPR

## ENEA Positions (lower)

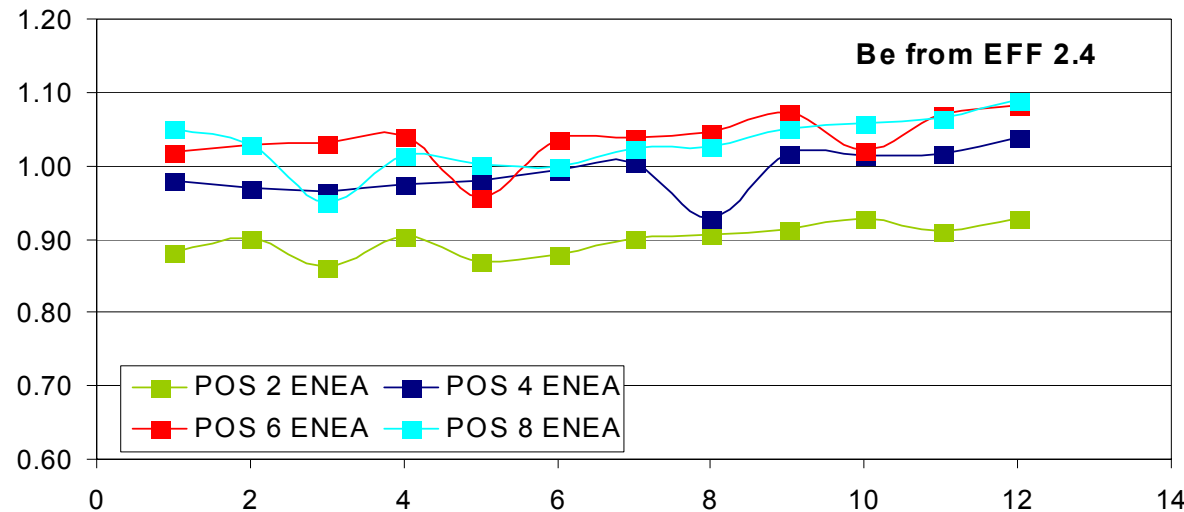
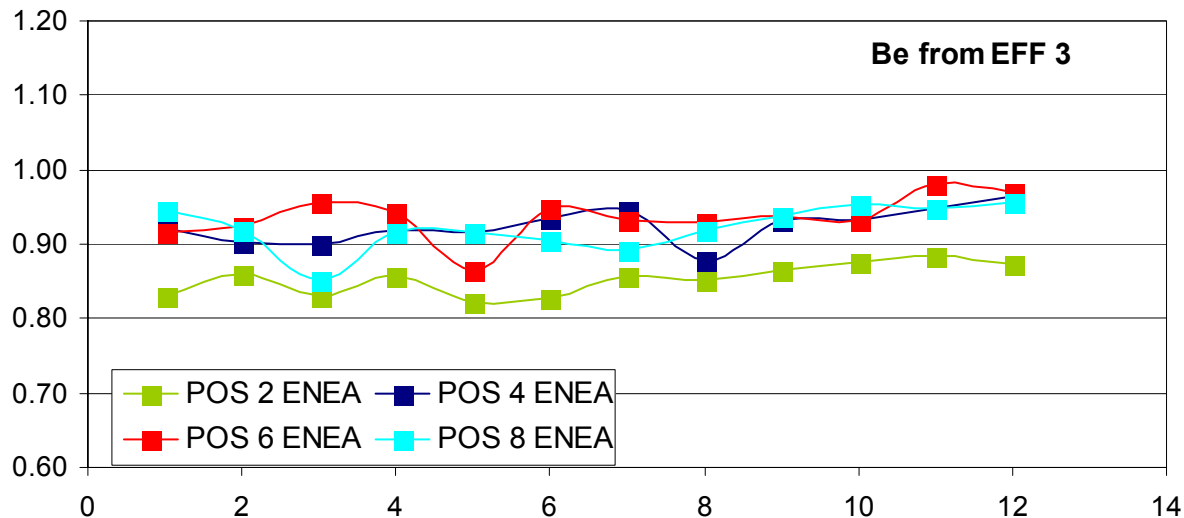
- Tritium production from  $\text{Li-7}(n,Tn)\alpha$  and from  $\text{Li-6}(n,T)\alpha$  in the four experimental positions



# Preliminary analysis of TPR

## ENEA Positions (lower)

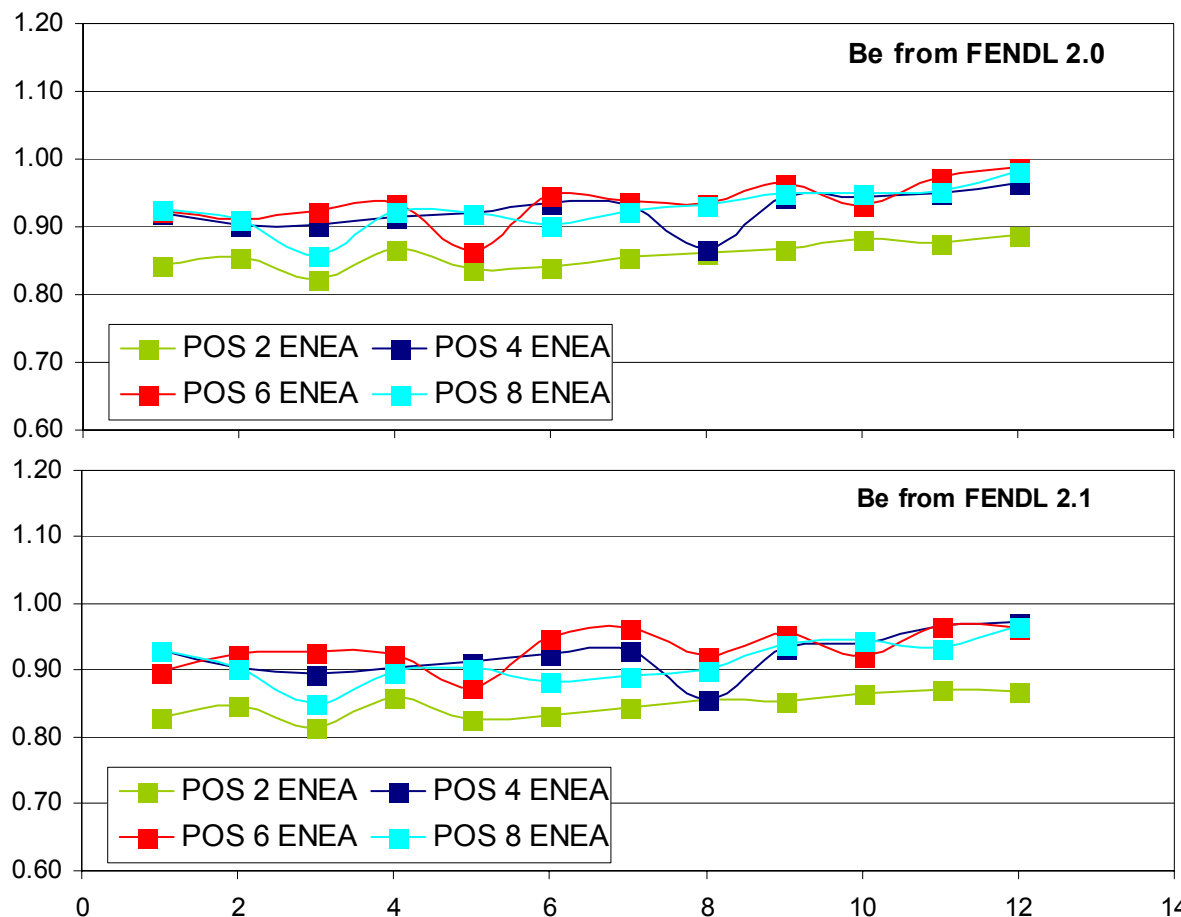
- MCNP-4C / **Be-9** from **EFF 2.4** / **EFF 3** (Fe-56 from EFF 3, all others from 2.4)



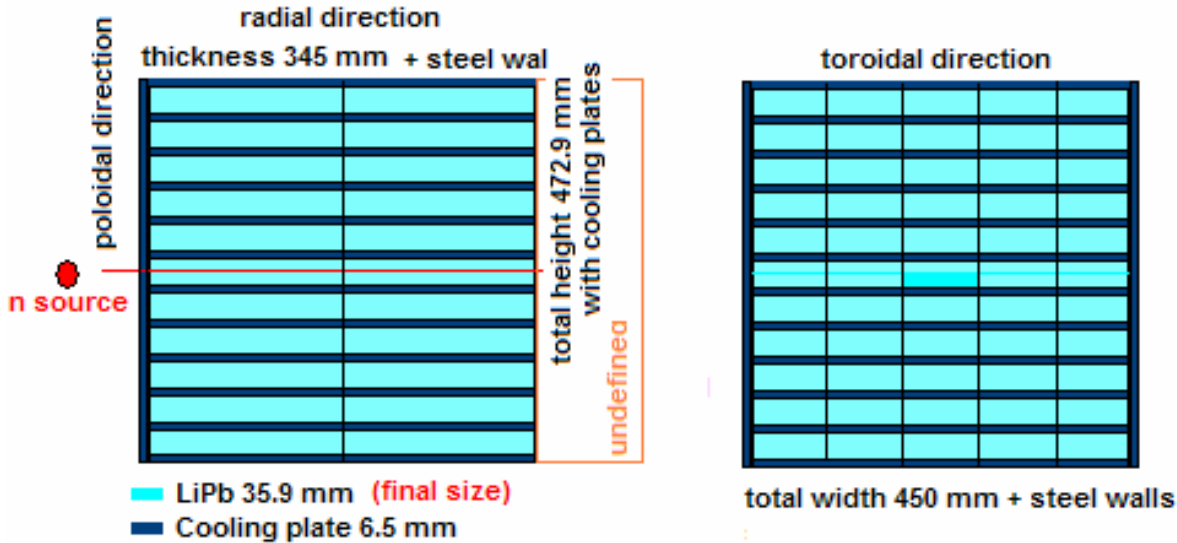
# Preliminary analysis of TPR

## ENEA Positions (lower)

- The T – specific activities measured in ENEA compare rather well with those measured at JAERI (JAERI / ENEA  $\approx 1.08$ , well within combined errors)



# TBM HCLL Mock-up (Pb-Li)



N. bricks: 2 (radial) x 11 (poloidal) x 5 (toroidal) = 110  
 Size of bricks: 172.5 (radial) x 35.9 (poloidal) x 90 mm<sup>3</sup>  
 Weight of one brick: 5.7 kg  
 Total weight: 630 kg

mock-up + margin → at least 130 bricks / 750 kg

In comparison with the HCPB experiment the T specific activity in the same experimental positions will be lower by a factor

6, 17, 38, 67

respectively, with the same neutron budget

- reduce the measured activity (from about 140 to 45 Bq/g)
- increasing the size of pellets ( from 400 to 700 mg max)
- increase FNG neutron budget