DE LA RECHERCHE À L'INDUSTRIE

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MEGAPIE: Feedback for neutronics

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FINAL MEGAPIE TECHNICAL REVIEW MEETING
OCTOBER 23RD - 24TH 2014, BREGENZ, AUSTRIA

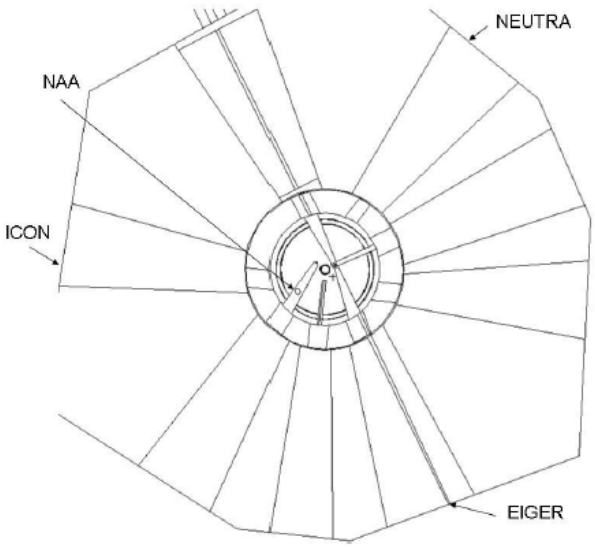
GOALS OF THE NEUTRONICS STUDIES

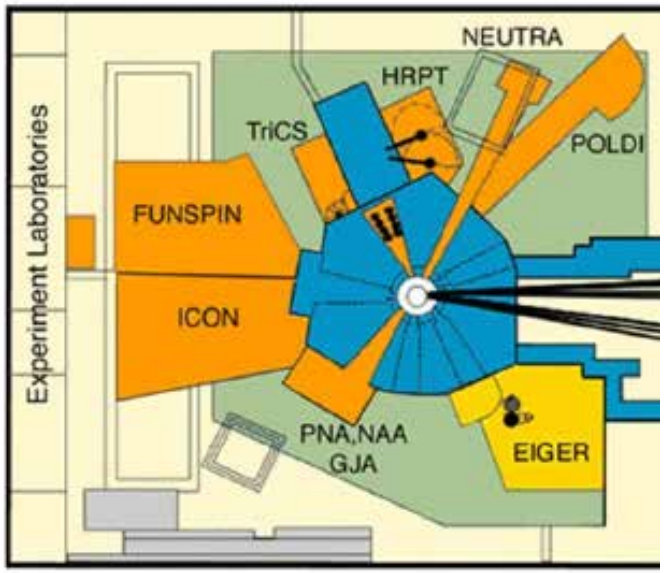
- Measurement of the neutron fluxes at various points of the facility;
- Measurement of the flux inside the spallation target;
- Comparison in term of neutronic performance of MEGAPIE with solid targets used routinely at SINQ;
- Measurement of the delayed neutrons;
- Measurement of gas release and comparison with calculations;
- Target activation calculations of interest to the target disposal and the post-irradiation experiment;
- Spallation code validation, and if necessary improvement of the codes

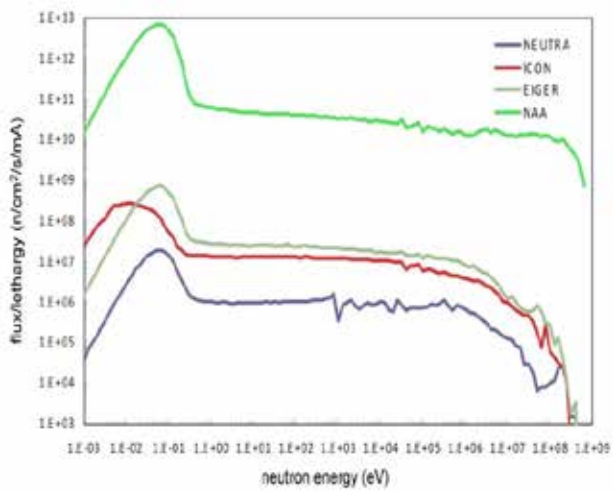
NEUTRONIC PEFORMANCE

OUTER NEUTRON FLUX MEASUREMENTS

Measurements of absolute fluxes with activation foils



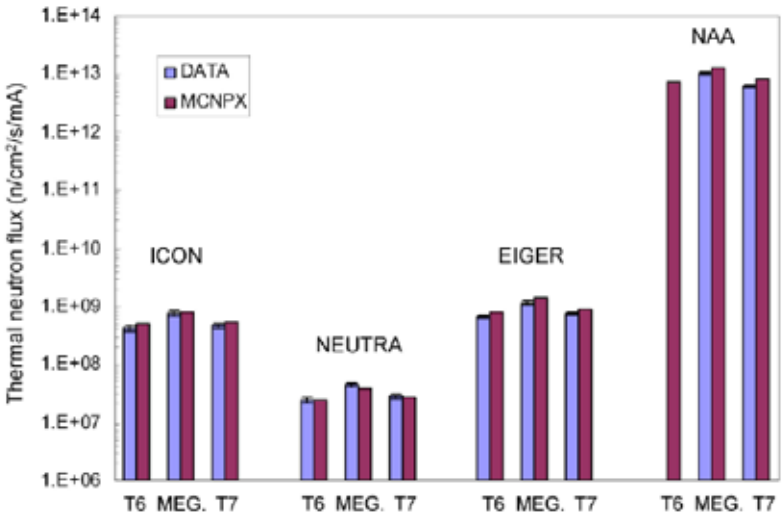




- at different distances from the target
- Thermal and epithermal components of the flux

OUTER NEUTRON FLUX MEASUREMENTS

	Thermal		Epithermal	
	Experim.	C/E	Experim.	C/E
Target 6				
ICON	4.19 × 108 (10)	1.17	5.70 × 106	1.18
EIGER	6.73 × 108 (7)	1.19	1.22 × 106	0.98
NEUTRA	2.47 × 107 (10)	0.97	–	–
MEGAPIE				
ICON	7.45 × 108 (10)	1.08	1.62 × 107	0.80
EIGER	1.14 × 109 (7)	1.23	2.61 × 107	9.5
NEUTRA	4.48 × 107 (10)	0.84	–	–
NAA	1.04 × 1013 (5)	1.25	4.43 × 1010	1.07
Target 7				
ICON	4.61 × 108 (10)	1.18	4.53 × 106	1.45
EIGER	7.45 × 108 (7)	1.16	–	–
NEUTRA	2.83 × 107 (10)	0.95	–	–
NAA	6.20 × 1012 (5)	1.29	1.97 × 1010	1.32



	Φepi / (Φepi+ Φth) exp	Φepi / (Φepi+ Φth) calc
ICON		
T6	0.13	0.13
MEGAPIE	0.19	0.15
T7	0.10	0.12
NAA		
MEGAPIE	0.045	0.038
T7	0.034	0.034

- **Increase of thermal flux by 1.74 compared to Target 6, 1.67 to target 7**
- **Epithermal component higher in MEGAPIE**
- **Fast flux (E>1 MeV) measured at NAA almost identical with MEGAPIE**

OUTER NEUTRON FLUX MEASUREMENTS

Comparisons Calculations / Experiment

	Thermal		Epithermal	
	Experim.	C/E	Experim.	C/E
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	Φepi / (Φepi+ Φth) exp	Φepi / (Φepi+ Φth) calc
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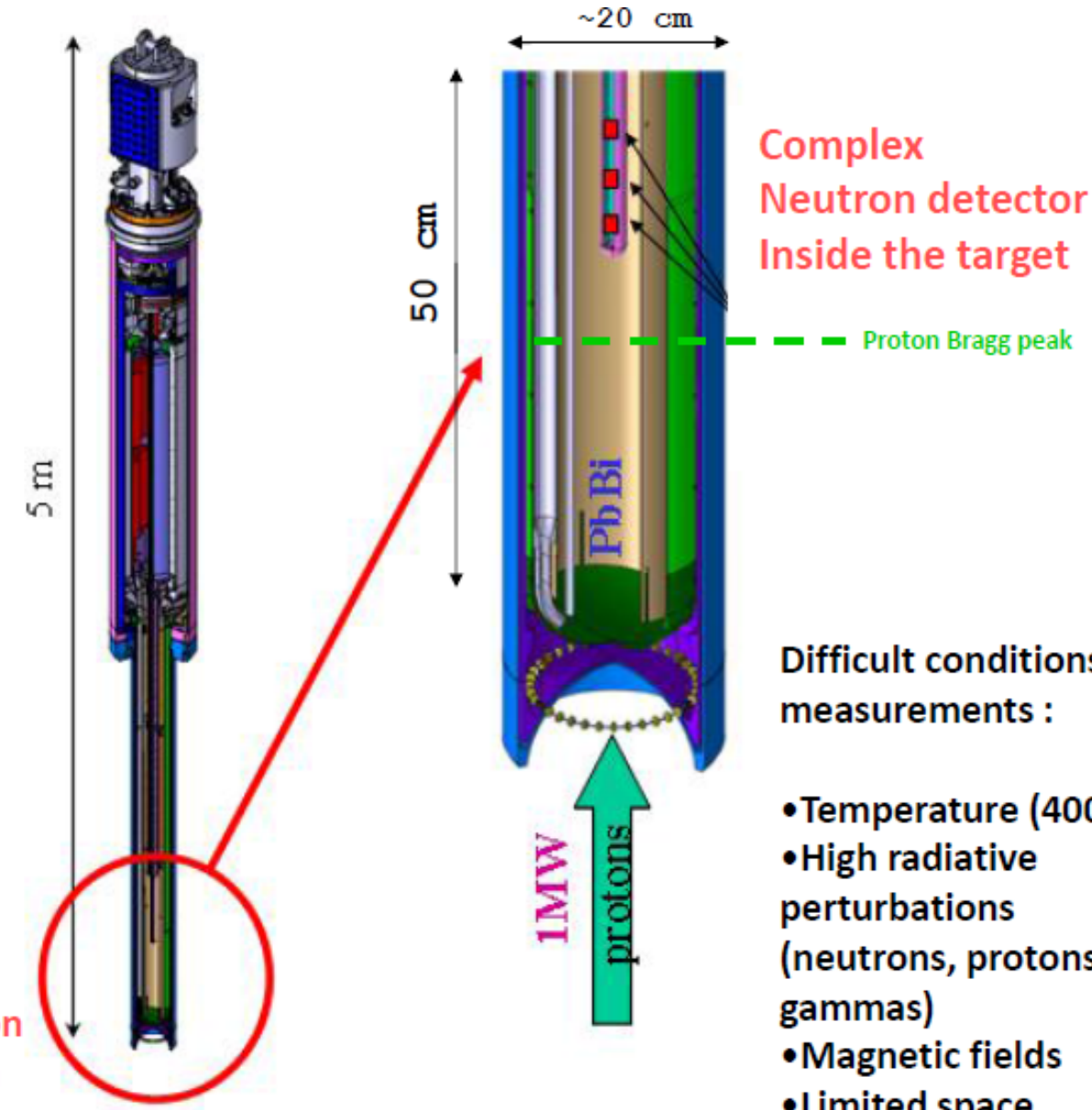
NAA		
MEGAPIE	0.045	0.038
T7	0.034	0.034

- Agreement generally within 20% for thermal flux
- Larger discrepancies closer to the target (NAA)
- Larger discrepancies for the epithermal component
- Large sensitivity to geometrical and composition details

INNER NEUTRON FLUX MEASUREMENTS



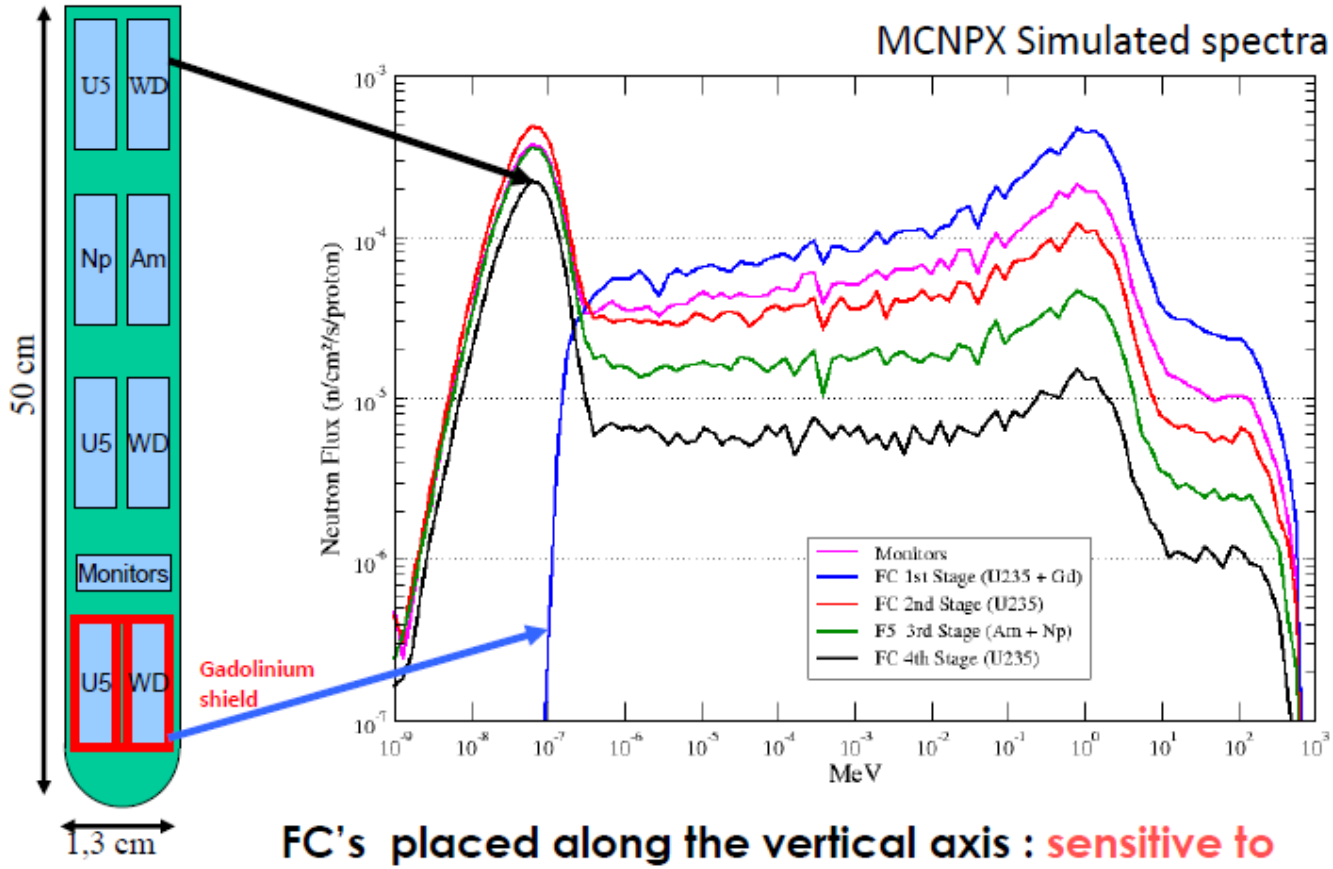
Panebianco et al.,
ANE 36 (2009) 350

Difficult conditions for measurements :

- Temperature (400°C)
- High radiative perturbations (neutrons, protons, gammas)
- Magnetic fields
- Limited space

INNER NEUTRON FLUX MEASUREMENTS

NEUTRON DETECTOR :
8 Fission Chambers (FC) …



FC's placed along the vertical axis : sensitive to different neutron spectra

Gd shielding on 1st pair of FC : epithermal and fast part of the spectrum.

Panebianco et al., ANE 36 (2009) 350

INNER NEUTRON FLUX MEASUREMENTS

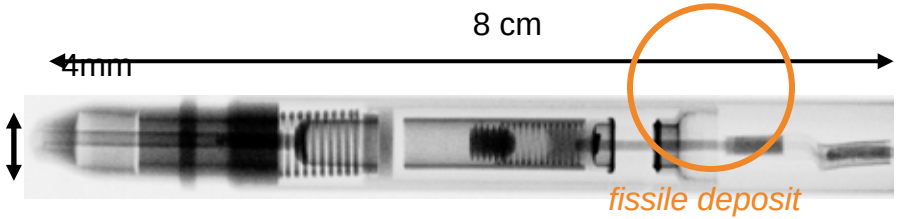
Online evolution of neutron flux deduced from FC currents

$$I(t) \mu\, t_f = \langle s_f \rangle f(t)$$

measured calculated

FC *sensitivity* measured with 3% precision at the ILL High Flux Reactor (France)

Panebianco et al., ANE 36 (2009) 350

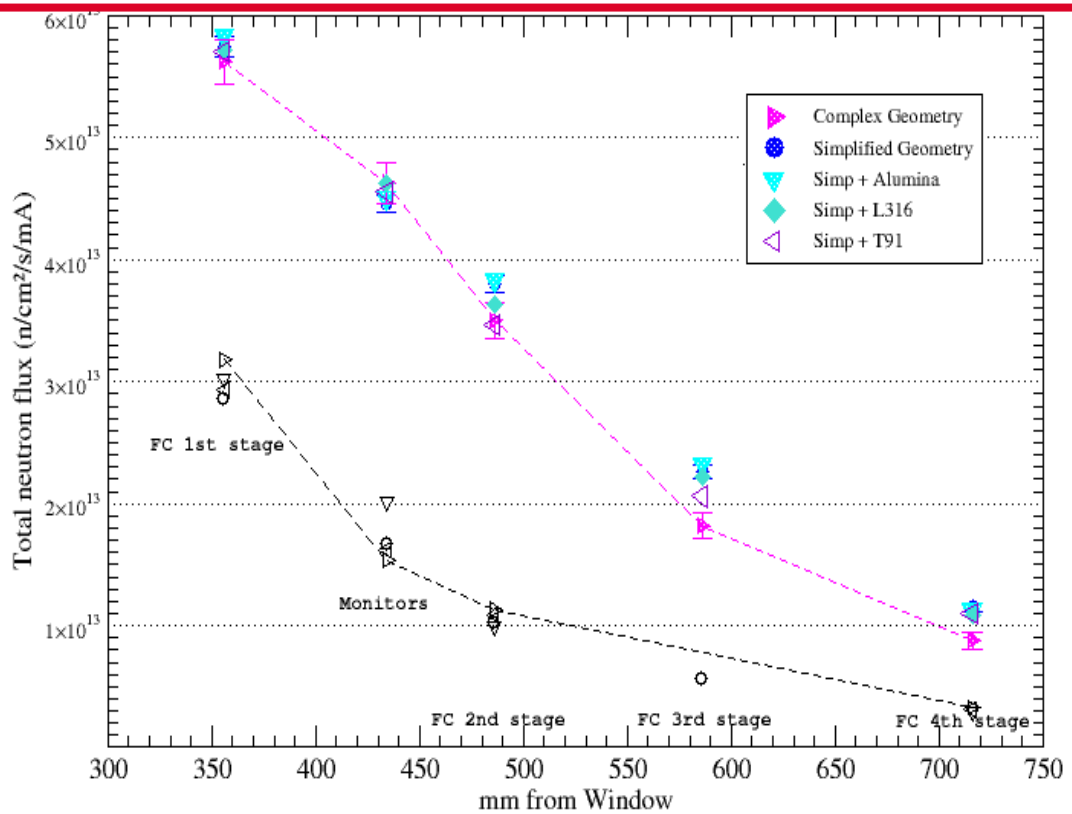


Fission rates t_f (per proton)	1st Stage	2nd Stage	4th Stage
FC measured	3.70E-10	2.85E-09	1.19E-09
MCNPX	6.67E-10	8.48E-09	3.31E-09

DISCREPANCIES OF A FACTOR 2 to 3 !

INNER NEUTRON FLUX MEASUREMENTS

Discrepancy also with activation measurements
Factor ~2 for all measurements compared to MCNPX calculations



Michel-Sendis et al., NIMB 268(2010) 2257

- No clear explanation: Beam divergence?
- Larger discrepancies closer to the target

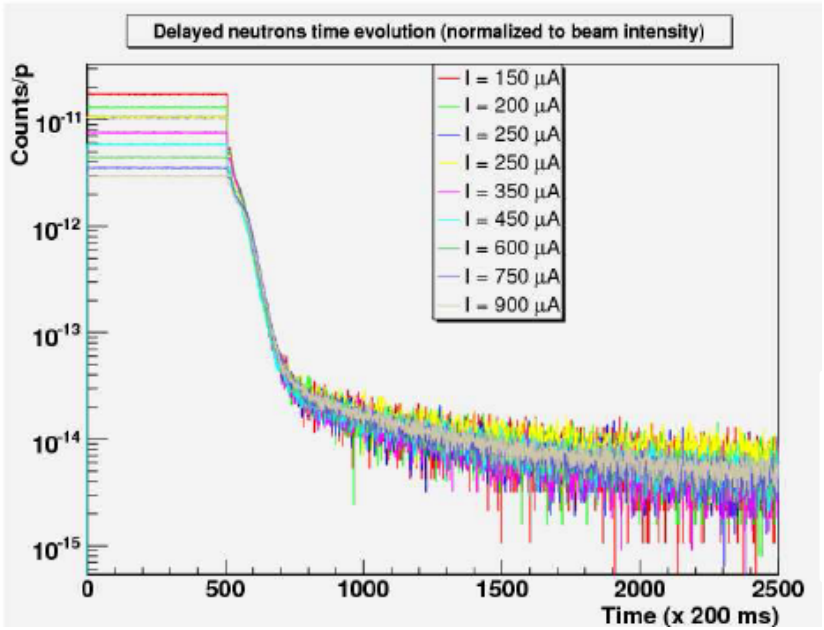
LESSONS LEARNED FROM MEGAPIE

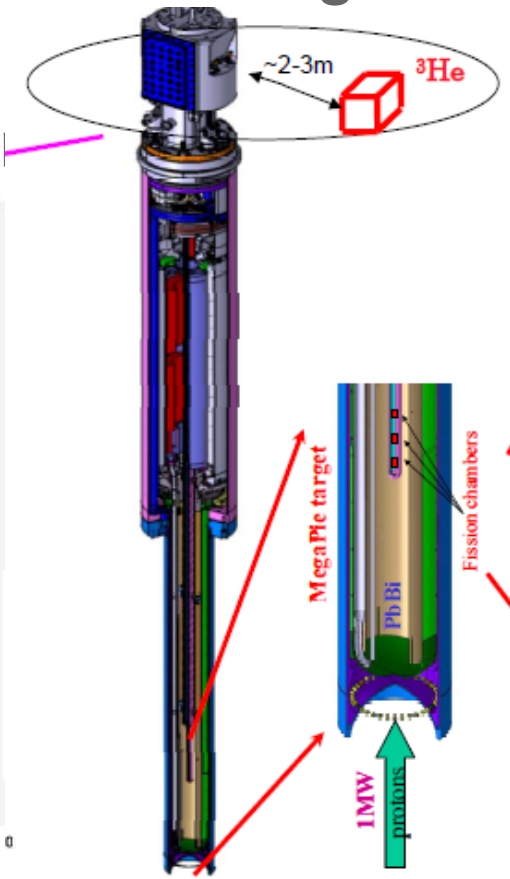
- Determination of neutron fluxes with Monte Carlo codes can be achieved within 20% but needs a very careful description of the geometric details
- Difficulty to predict flux close to or inside the target probably due to the importance of boundary conditions i.e. the beam profile
- More measurement points and more precise spectral measurements could have helped.

DELAYED NEUTRONS

DELAYED NEUTRON MEASUREMENTS

- Delayed neutrons could be a radioprotection issue due to the circulation of the activated LBE outside of the target
- Measurements using a ^{3}He counter in the TKE during the 1st week of target irradiatio





Panebianco et al., ND2007 Nice

- Complementary measurement at Gatchina on a solid Pb target to identify main contributors: ^{9}Li, ^{17}N, ^{88}Br, ^{87}Br

DELAYED NEUTRON MEASUREMENTS

Use of parameters extracted from PNPI/Gatchina experiments

Ridikas et al., EPJA 32 (2007) 1

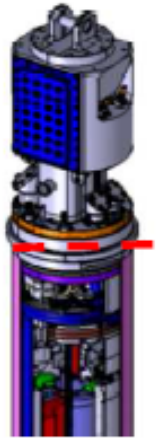
$$a(x) = \sum_{i=1}^{n} a_i(x) = \sum_{i=1}^{n} a_i^a \frac{1-\exp(-\lambda_i \tau_a)}{1-\exp(-\lambda_i T)} \exp(-\lambda_i \tau_d(x))$$

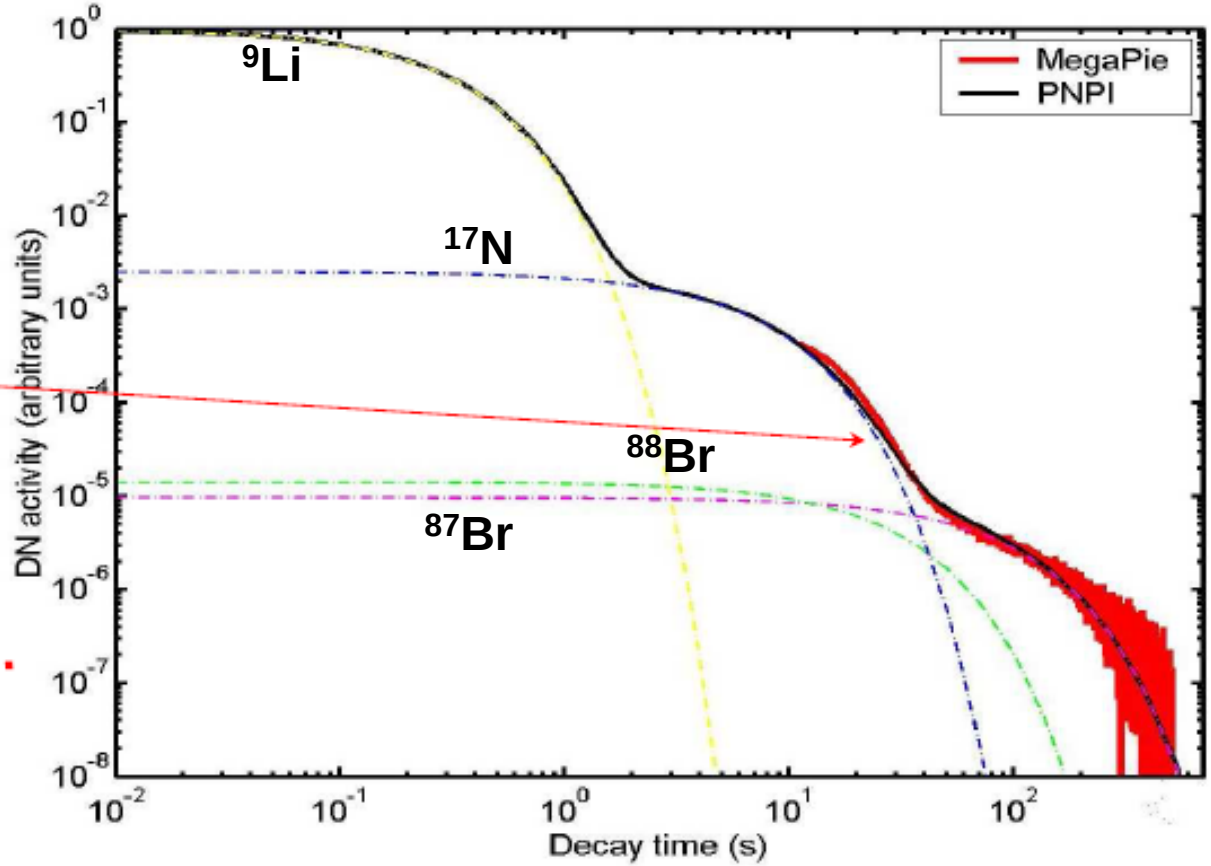
Estimates:

τ_a ~0.5 s irradiation

T ~20 s relaxation

τ_d ~10 s heat exchanger

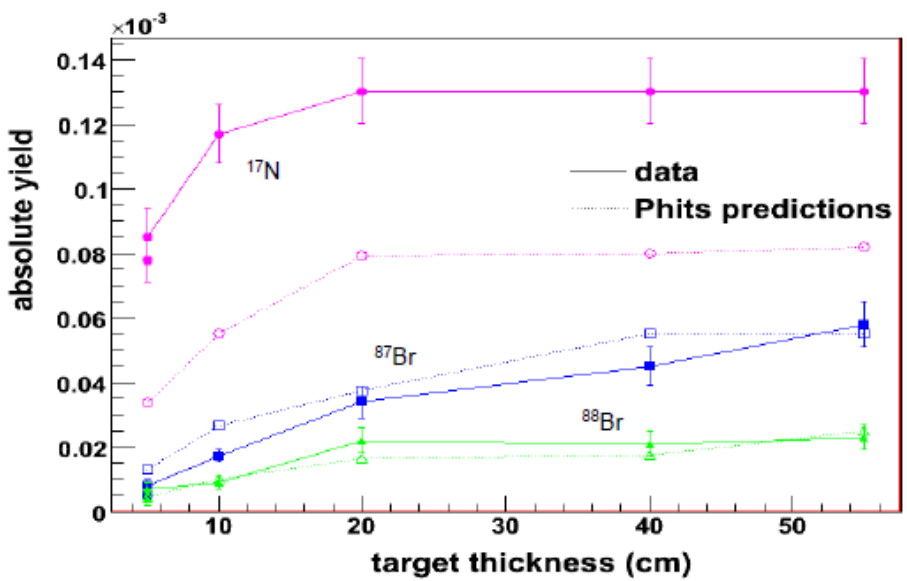


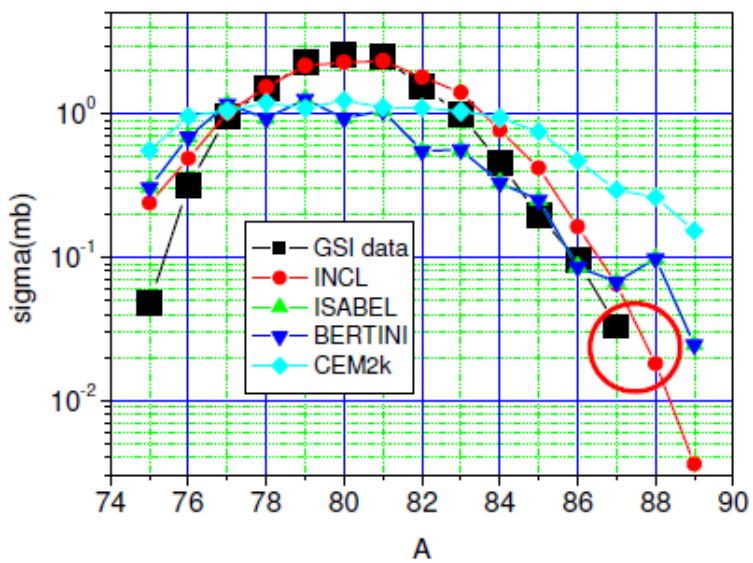


Contact: ridikas@cea.fr

DELAYED NEUTRON ESTIMATION

- Using a geometrical model involving three averaged liquid metal transit times and the DN precursor parameters it was possible to estimate the fast DN fluxes at the level of **10^6 n/cm^2/s/mA ~same order of magnitude as the flux of prompt neutrons**
- Code validation:
  - data from Gatchina experiments in fair agreement (within a factor of 2) with calculations with PHITS
  - Large discrepancies between models for Br isotopes





GAS PRODUCTION AND RELEASE

GAS PRODUCTION AND RELEASE

- Since release fraction not known absolute comparison of data with calculations is difficult
- Normalized isotopic distributions : discrepancies with calculations and between codes larger on the tails of the isotopic distributions
- Global agreement acceptable

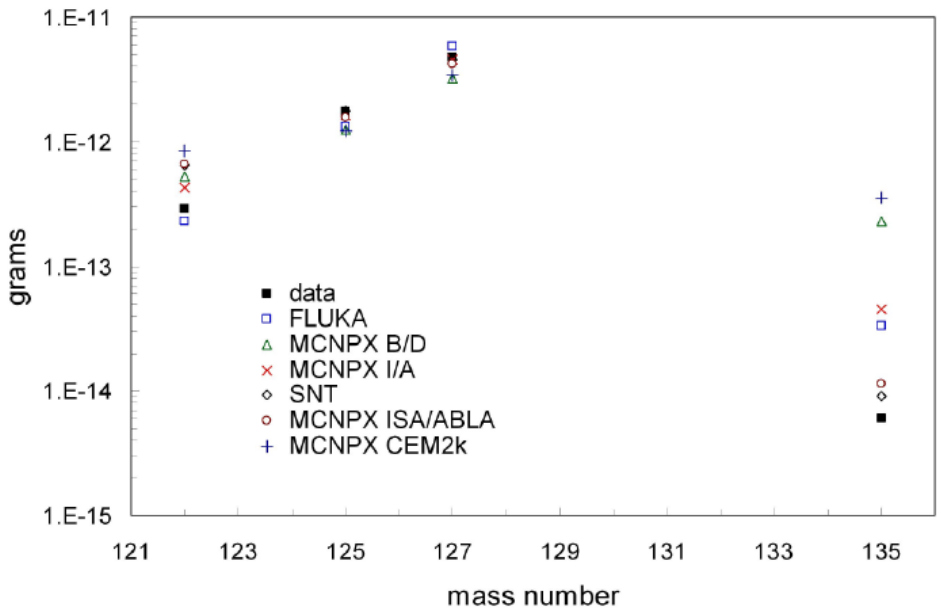


Figure 6.15. Measured and calculated amounts (in grams) of Xe isotopes. Calculations are normalized to the data (see text).

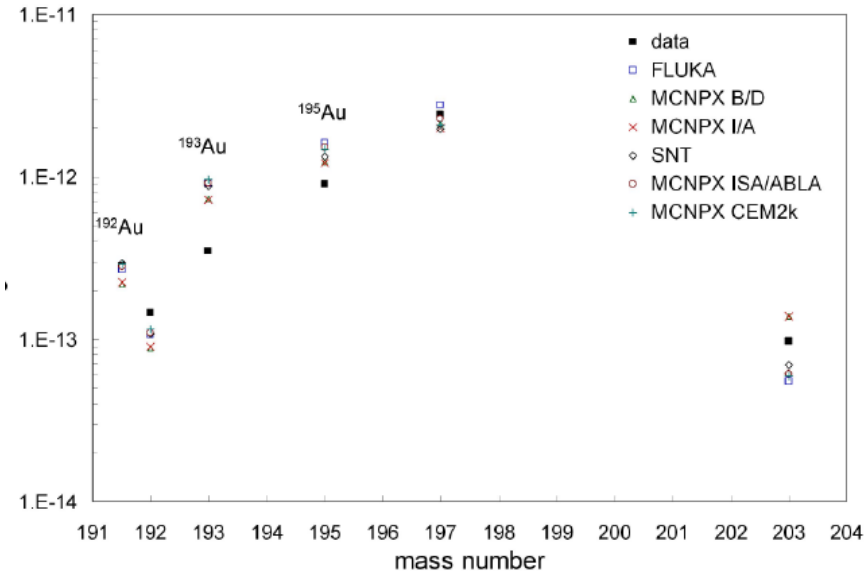
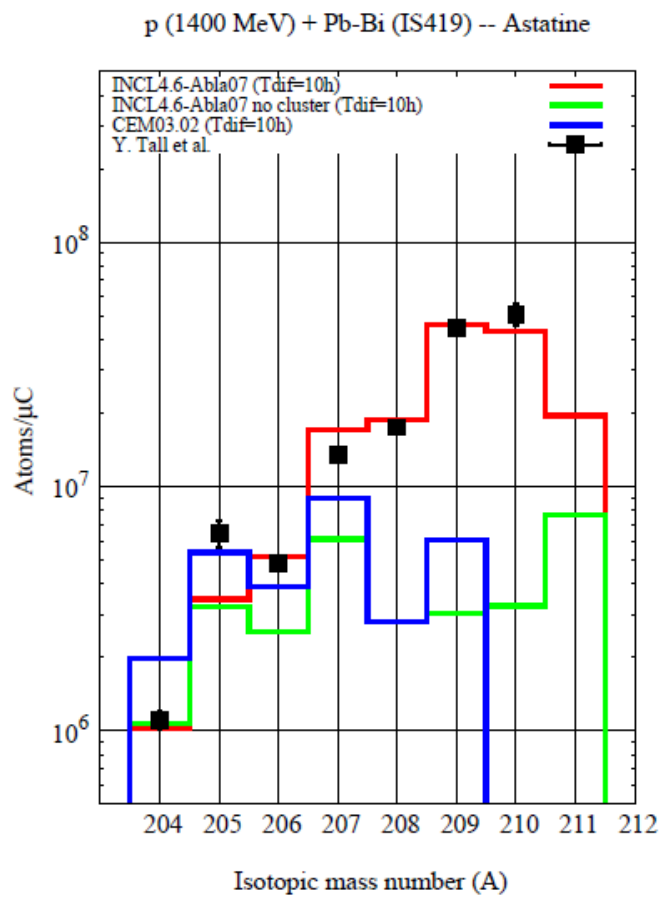


Figure 6.16. Measured and calculated amounts (in grams) of Hg and Au isotopes. Gold isotopes are indicated in the figure. Calculations are normalized to the data.

GAS PRODUCTION AND RELEASE

- Traces of Po isotopes were detected from the gas samples. The quantity of Po observed is compatible with production from the decay of parent astatine isotopes, which have higher volatility than polonium

- Improvement of the physics models which were unable to predict Z_{target}+2 isotopes
- Comparison to ISOLDE data
- Calculations: INCL4.6-ABLA07 in MCNPX2.7.b
  - Ê **Importance of the coalescence mechanism**
  - Ê Much better than CEM03



J.C. David et al., EPJA 49, 29 (2013)

Data from Y. Tall et al., ND2007

GAS PRODUCTION AND RELEASE

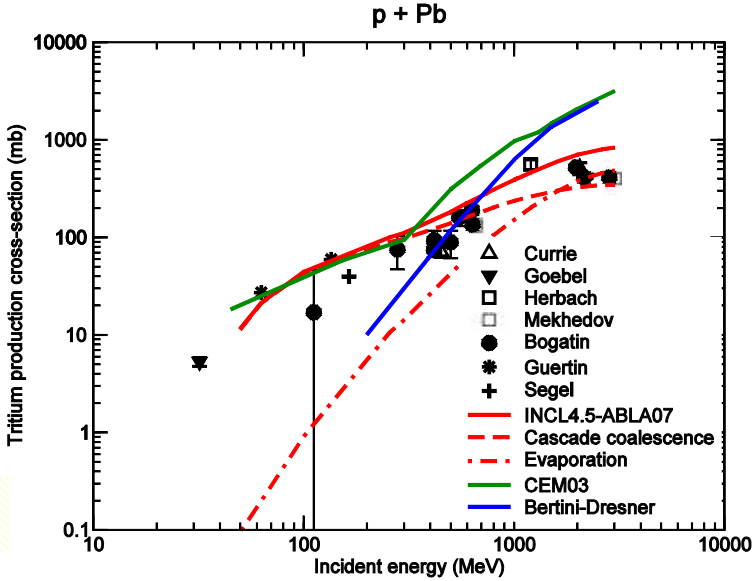
- Hydrogen and helium not measured but estimated from codes

Table 6.11. Calculated production rates (atoms/source proton) in LBE of hydrogen and helium isotopes.

Particle	MCNPX 2.5.0				SNT	FLUKA 2006.3b
	INCL4/ ABLA	Bertini/ Dresner	ISABEL/ ABLA	CEM2k		
proton	1.57	1.83	1.43	1.28	1.27	1.15
deuteron	-	0.089	-	0.36	0.210	0.22
triton	-	0.048	-	0.12	0.057	0.073
helium isotopes	0.173	0.203	0.300	0.192 (^{4}He) 0.031 (^{3}He)	0.133	0.108 (^{4}He) 0.0063 (^{3}He)

- Significant differences between the different models

Ê Improvement of the models

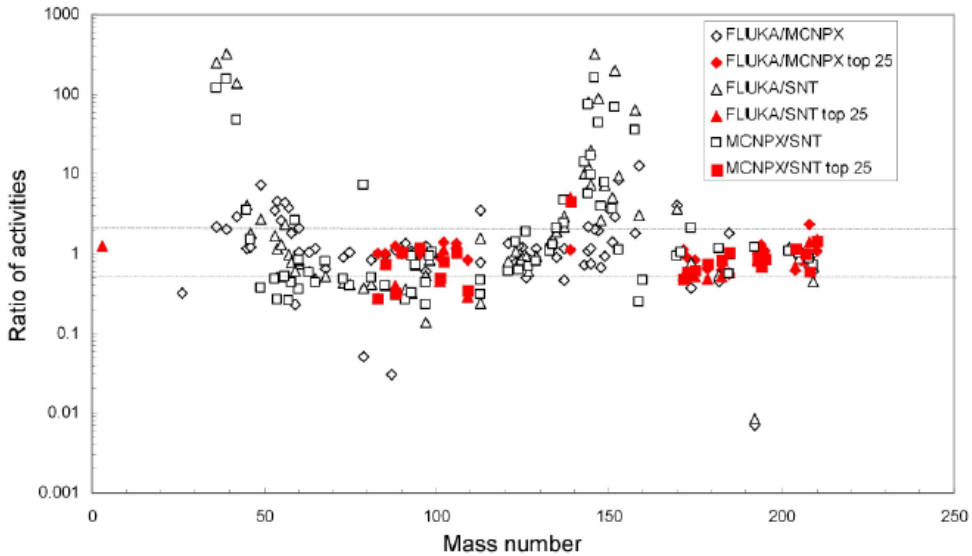


From NIM B 268 (2010) 581

TARGET ACTIVATION

TARGET ACTIVATION CALCULATIONS

- FLUKA 2006.3b, MCNPX 2.5.0 and SNT were used
- For the LBE the results compare well, with some larger discrepancies mostly on isotopes with low activity.



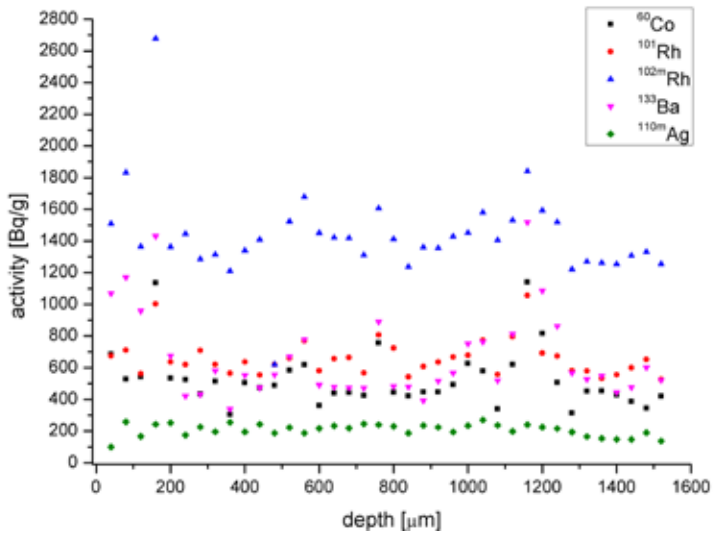
- Discrepancies for the structural materials are bigger.
- The effect of the impurities in the radionuclide inventory of the LBE, using the actual chemical composition of the LBE used in MEGAPIE, is negligible.

ANDES WP4 - HIGH ENERGY MODEL VALIDATION IN THE 150-600 MEV

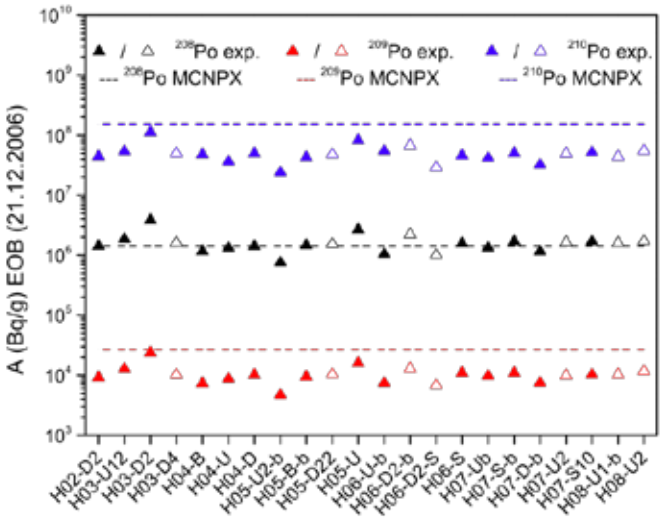
Accurate Nuclear Data for nuclear Energy Sustainability

Ø Task 4.5: Validation on the results from the post irradiation analysis of MEGAPIE samples (PSI, CEA/DSM)

Ê new radiochemistry methodology developed and analysis of MEGAPIE (and ISOLDE) samples achieved



ISOLDE



MEGAPIE

More results in Dorothea Schumann's presentation

CONCLUSIONS

- Measurement of the neutron fluxes showed an increase by 75% of the thermal neutron flux and an epithermal component larger than with the solid targets
- Calculations are in good agreement with outer flux measurements but not with inner flux: the discrepancies increase when coming closer to the target;
- The delayed neutron flux in the TKE has been estimated;
- Measurements of gas release and comparison with calculations have led to improvements of the codes;
- Results from sample analysis still to come;
- As regards the prediction capabilities of the codes: still things to understand/improve