

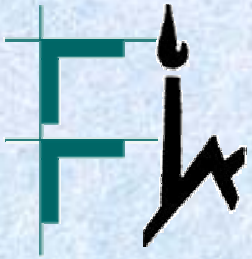


Monte Carlo based transport and sensitivity/uncertainty analyses of the Tritium production in the HCPB breeder mock-up experiment

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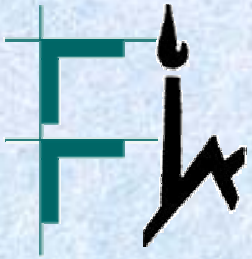
Outline

- **Objectives**
- **TBM experiment and MCNP model**
- **Nuclear Data**
- **Results**
- **Conclusions**



Objectives

- **TBM Objectives for nuclear testing in ITER:**
 - *Demonstration of Tritium breeding performance*
 - *Validation of codes and data to predict nuclear responses (TPR, flux spectra, heating) with sufficiently high accuracy*
- **TBM Experiment objectives**
 - *Benchmark of codes and data, including breeding performance and uncertainties*
 - *Development of tools and data including uncertainty assessment*
 - *Preparation of neutron diagnostics*



TBM Experiment and MCNP Model

- **Mock-up**

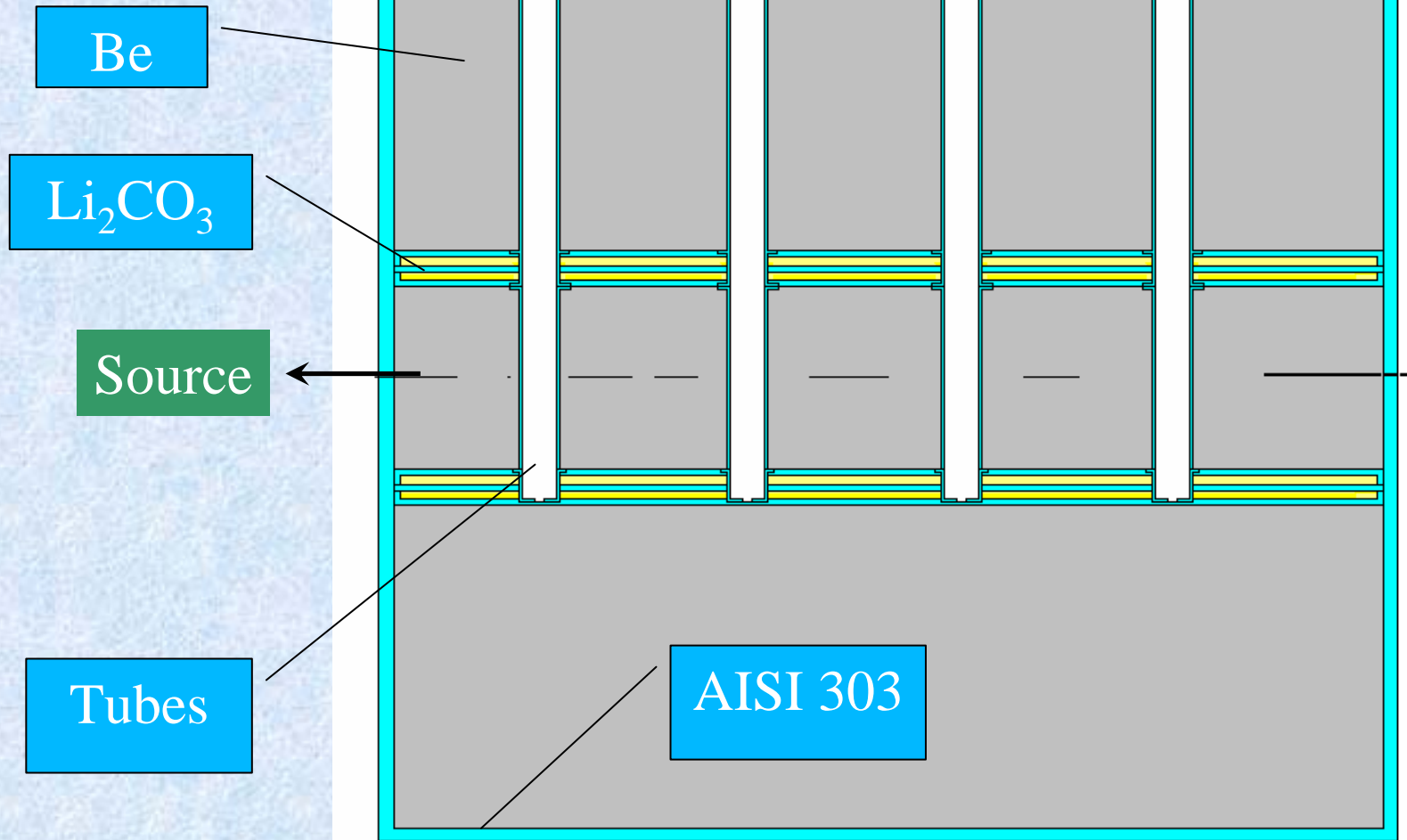
- *Stainless steel box (AISI-303)*
- *Beryllium blocks*
- *Li₂CO₃ powder (7,5% ⁶Li) in double cassettes*
- *Rear shield block of AISI-316 container and Li₂CO₃ pebbles*
- *Detectors: Ceramic pellets (0.193mm thickness, 13mm diameter)*

- **MCNP Model**

- *Shifted 3mm upward (relative to source)*
- *Modified aluminium support*
- *Updated FNG source routine*

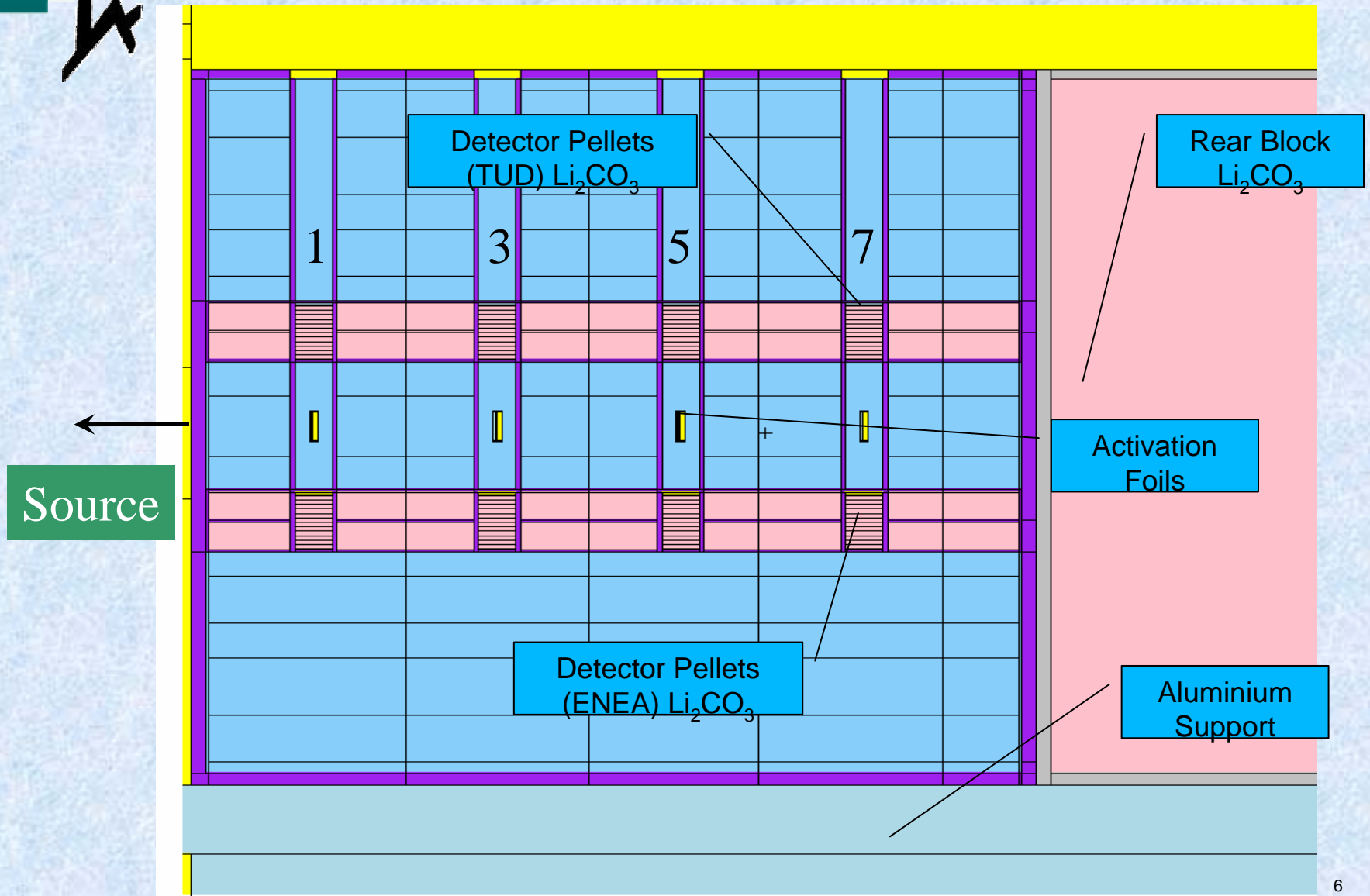


TBM Experiment and MCNP Model

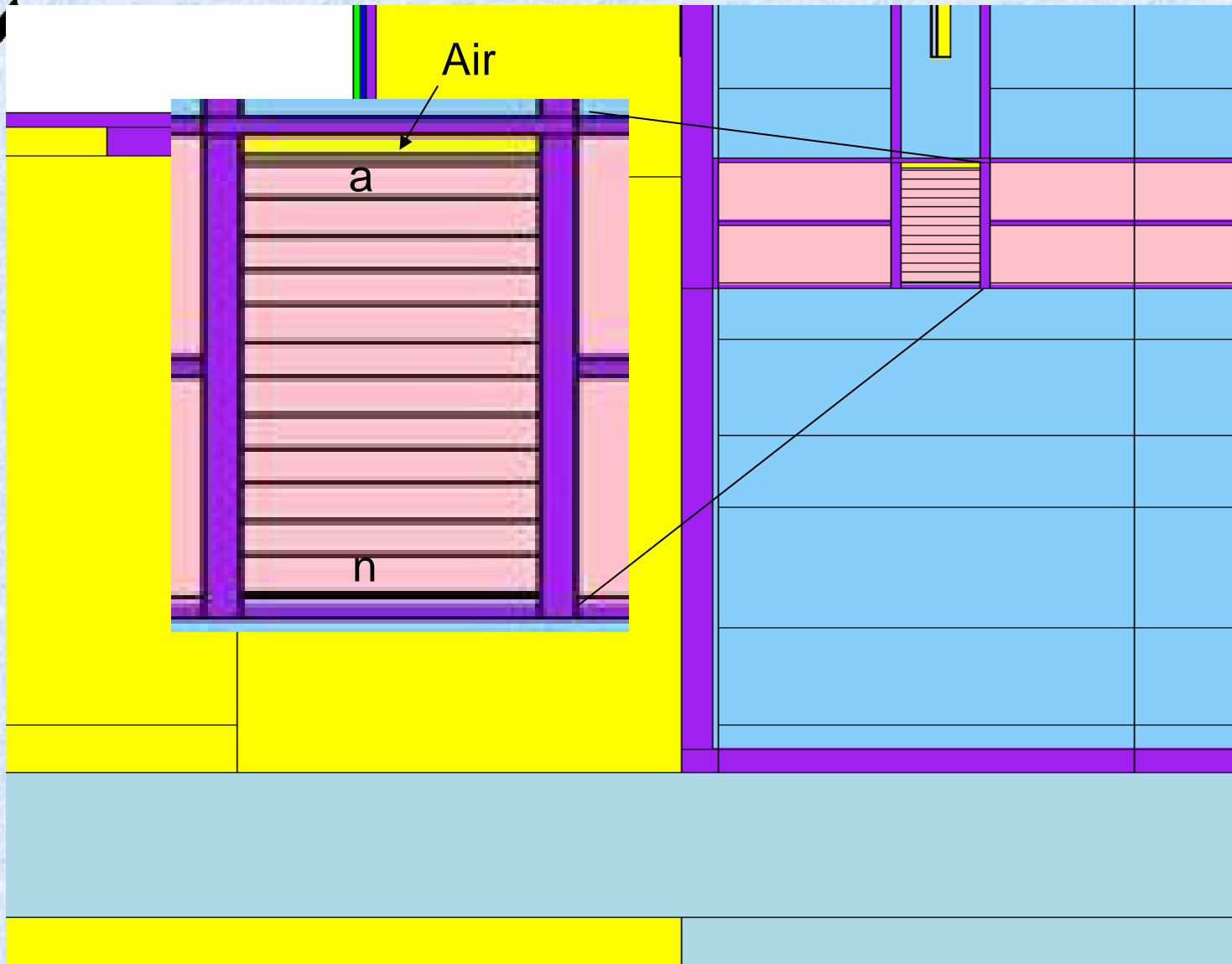


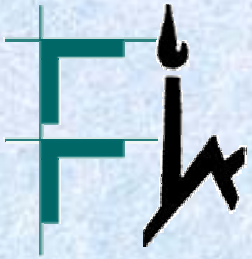


TBM Experiment and MCNP Model



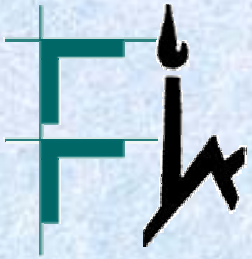
TBM Experiment and MCNP Model





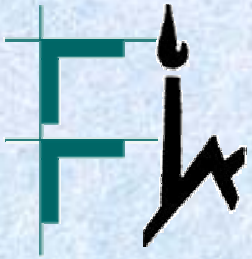
Nuclear Data

- **Reference data for neutron transport calculation:**
 - *EFF2.4 or newer*
 - *^9Be : EFF3.05(JEFF3.1T), local ACE-file*
 - *^6Li : EFF2.4(ENDF/B-V)*
 - *^7Li : EFF2.4*
 - *^{16}O : EFF2.4(ENDF/B-VI)*
- **Comparison with FENDL2.0, FENDL2.1**
 - *^9Be : JENDL-FF, ENDF/B-VI.8*
 - *$^{6,7}\text{Li}$: ENDF/B-VI.0, ENDF/B-VI.8*
 - *^{16}O : JENDL-FF, ENDF/B-VI.8*



Nuclear Data

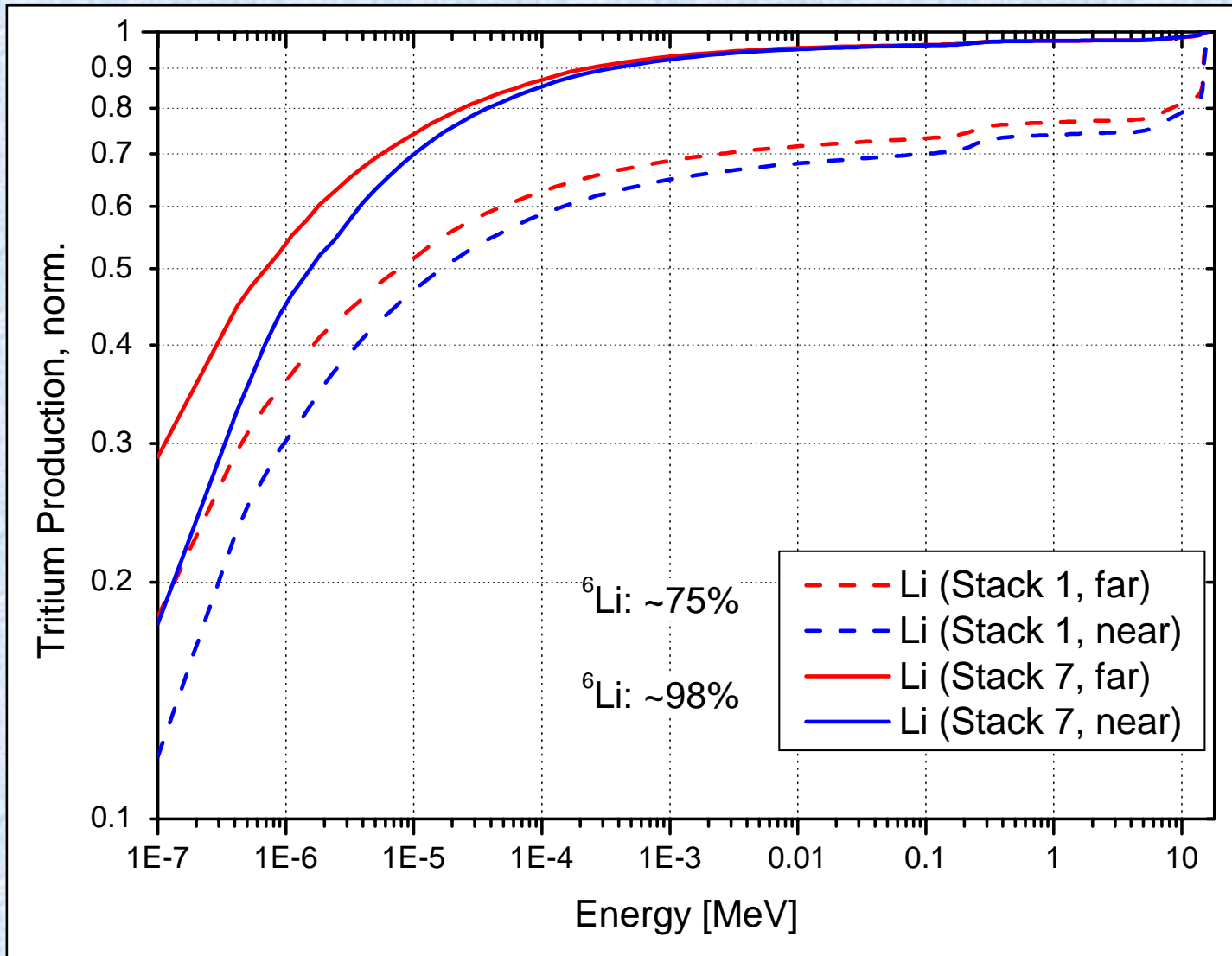
- **Covariance data:**
 - ^9Be : *EFF3*
 - ^6Li : *EFF2.3 (=ENDF/B-V) mt=2,105*
 - ^6Li : *IRDF-90 (=ENDF/B-VI) mt=105*
 - ^7Li : *FENDL2 (=ENDF/B-VI)*
 - ^{12}C : *EFF2.4*
 - ^{16}O : *JENDL3.3 mt=4*

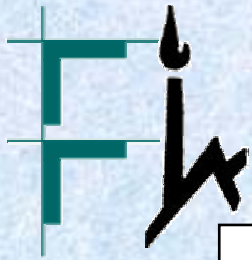


Results – Calculation and Experiment

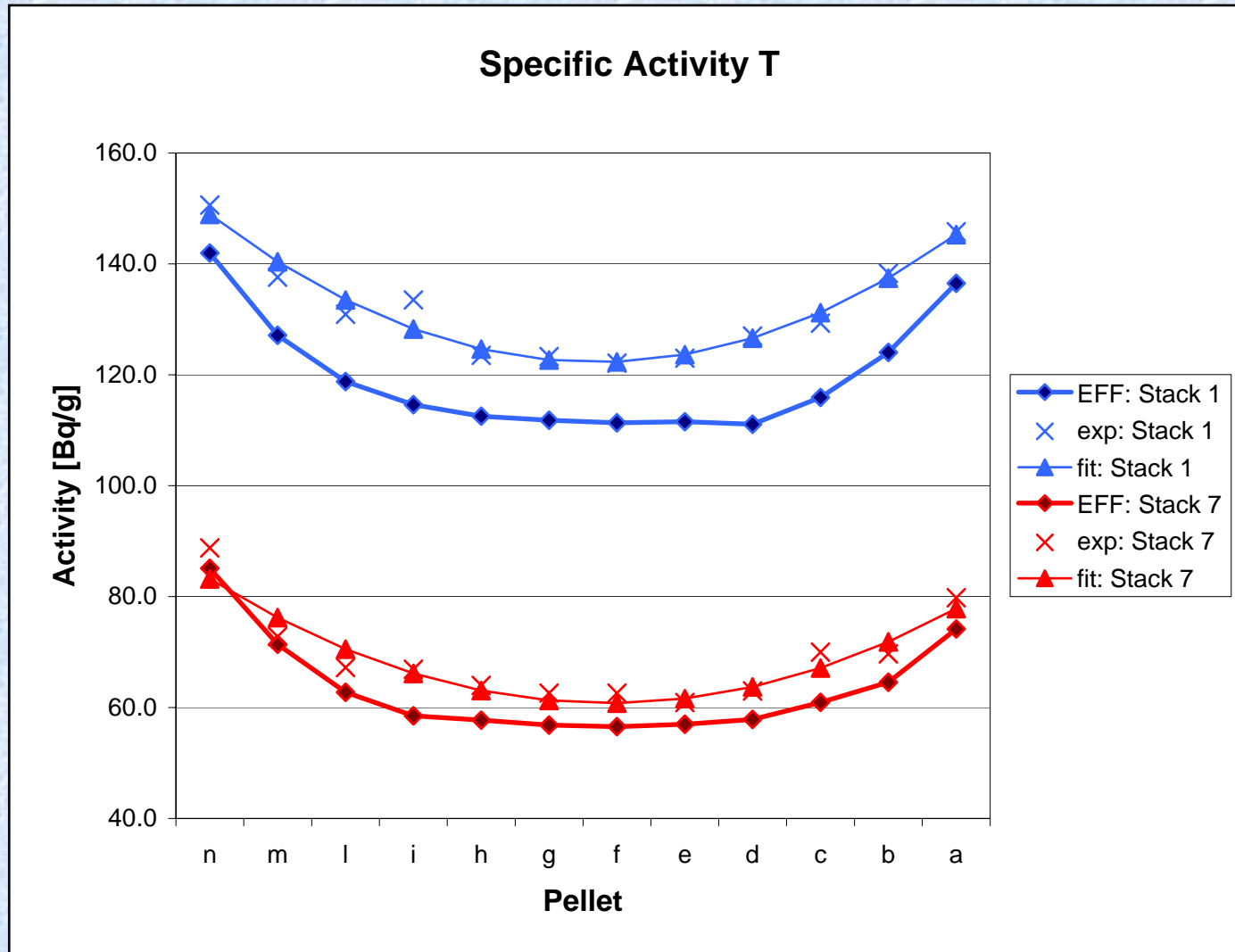
- **MCNP4C with FNG-Source**
 - *TPR in individual pellets*
 - *EFF: few minor isotopes from FENDL2, ENDF/B-VI*
 - *FENDL2.1: few isotopes from FENDL2, ENDF/B-VI, EFF (Molybdenum)*
 - *FENDL2: few isotopes from EFF (Molybdenum)*
- **MCSSEN**
 - *Sensitivities/uncertainties in pellet stacks*
- **Experimental values**
 - *Specific Activity by β -counting in liquid scintillator*
 - *Fitted by a second order polynomial*

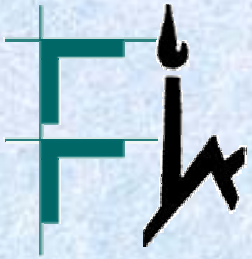
Results – cumulative TPR





Results – Specific Activity



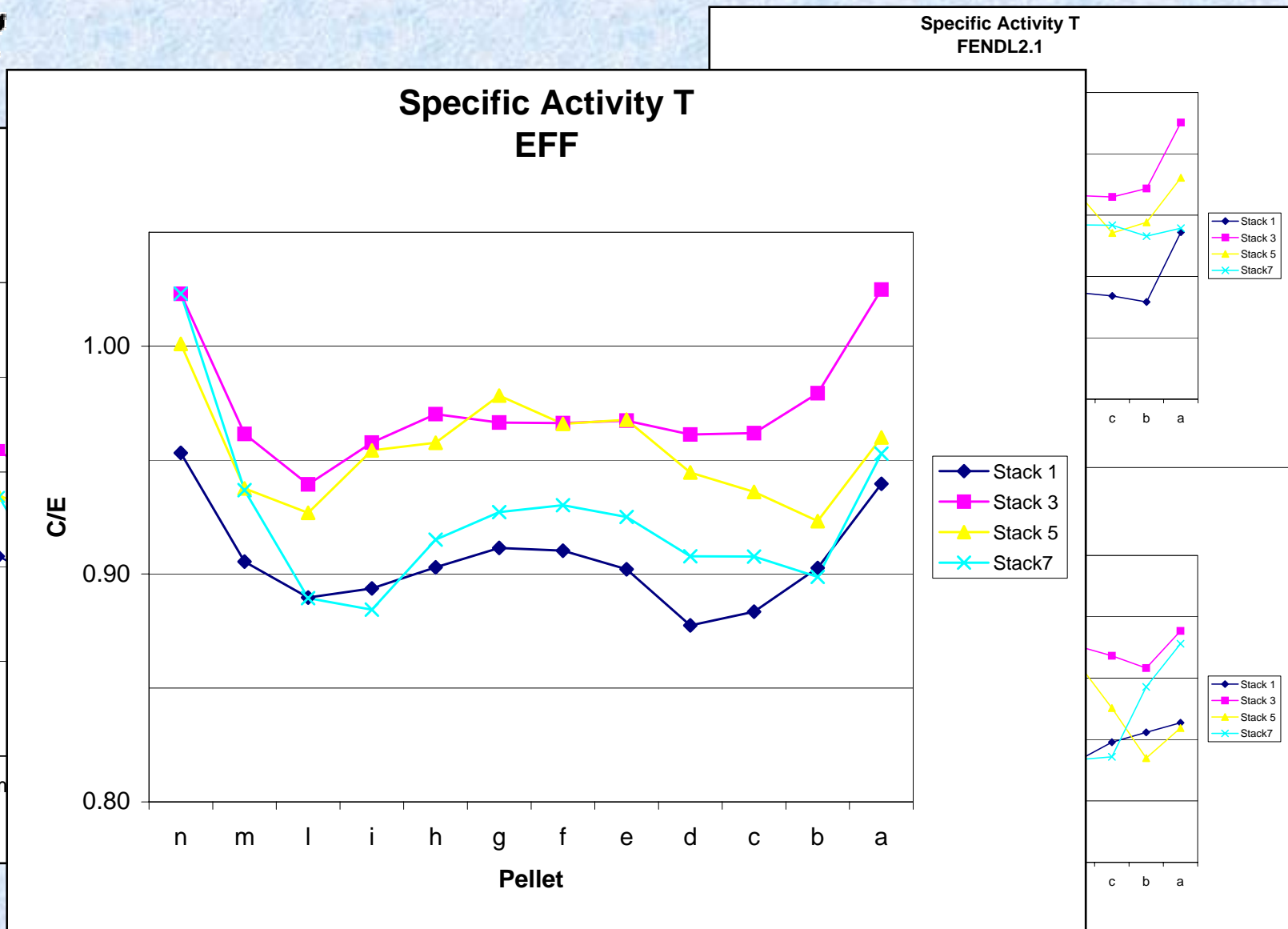


Results – TPR Profile

- **TPR profiles along stack height are roughly flat:**
 - *but peaking near center (due to ${}^7\text{Li}(n,n')$) and far away (by $1/v$ cross section ${}^6\text{Li}(n,t)$)*
- **${}^7\text{Li}$ -contribution to TPR ranges from about 25% to 2 %, decreasing with increasing depth**
- **Experimental values show scatter about a flat analytical behaviour along stack height**
 - *Fitted by quadratic functional*

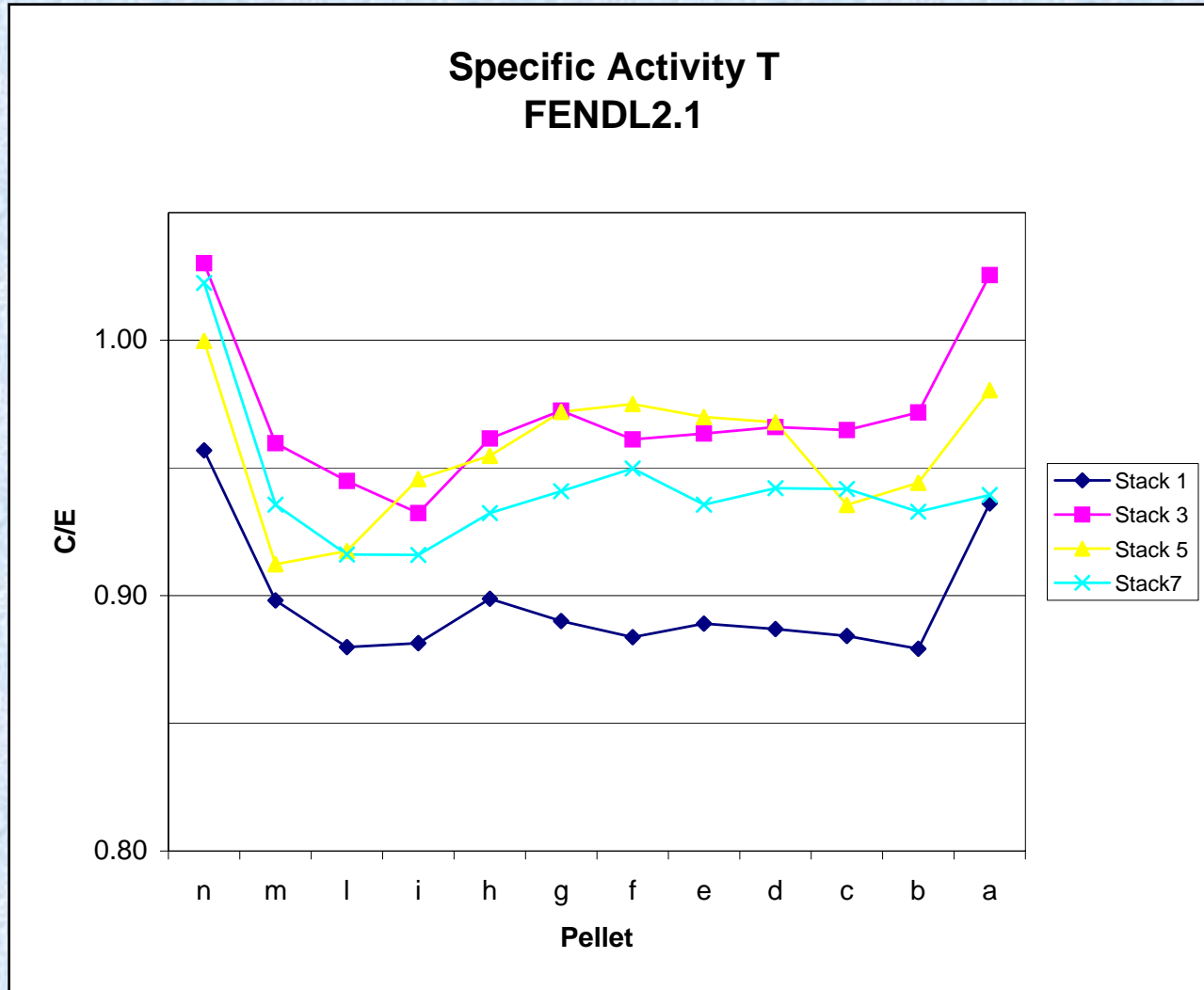


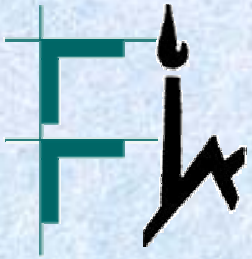
Results – C/E



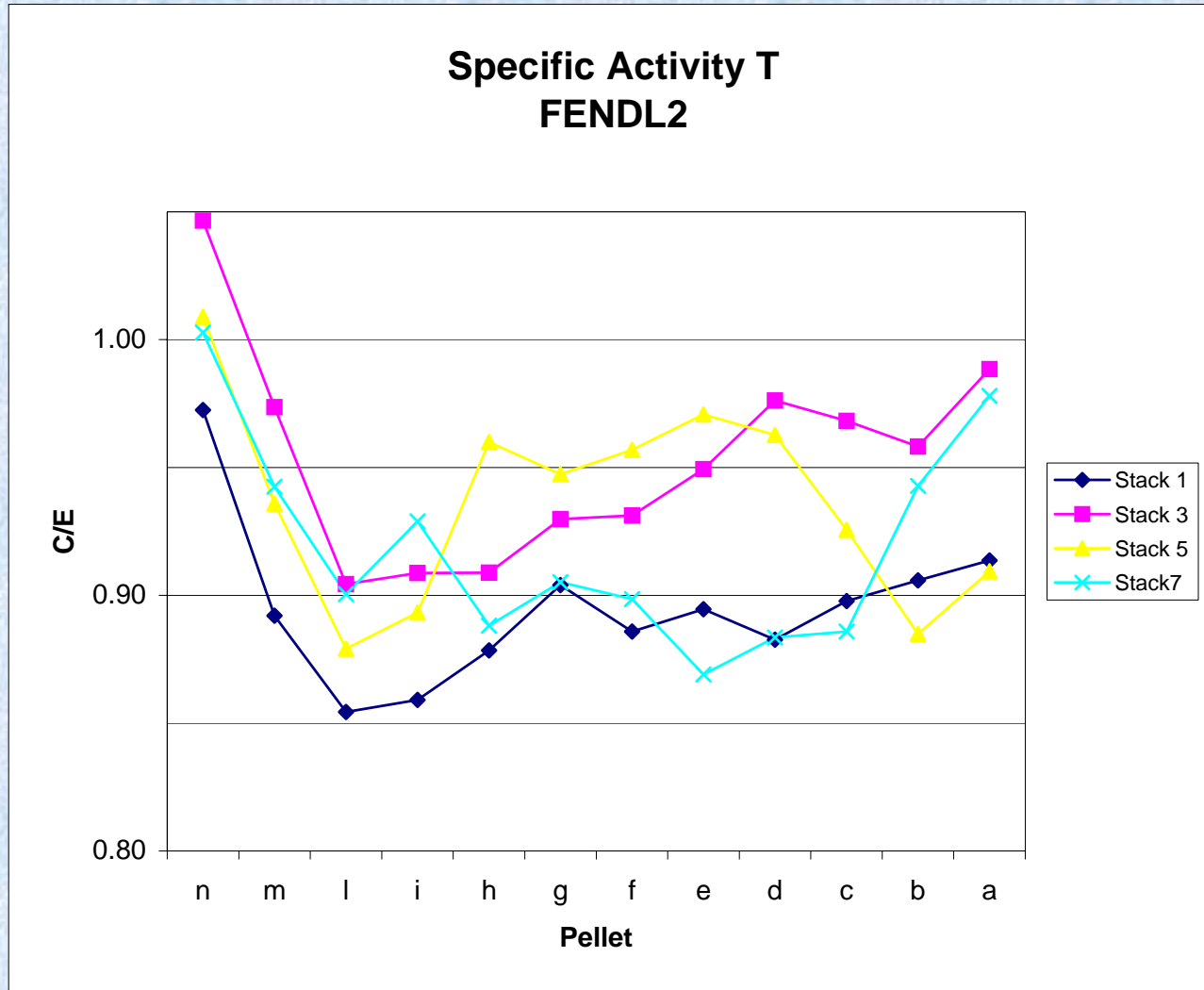


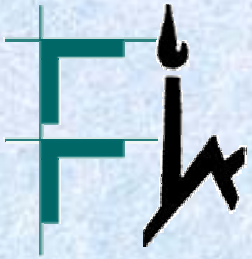
Results – C/E





Results – C/E





Results – C/E

- **C/E (fitted) show mainly slight underestimation for all nuclear data libraries, EFF performs scarcely better**
 - *Stack 1 (near source) with worst results: C/E 0.90*
 - *Stack 3 with best results: C/E 0.95...0.97*



Results

Main integrated sensitivities (%/%)

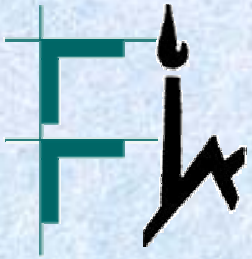
Mat	MT	Li6-S1	Li6-S3	Li6-S5	Li6-S7	Li7-S1	Li7-S3	Li7-S5	Li7-S7
<i>Be9</i>	2	1.999	2.091	1.784	1.672	0.048	-0.001	-0.053	-0.130
	16	0.716	0.710	0.664	0.611	-0.016	-0.191	-0.398	-0.619
<i>Li6</i>	105	0.326	0.248	0.179	0.152	0.000	0.000	0.000	0.000
<i>Li7</i>	4	0.001	0.001	0.000	0.000	0.990	0.982	0.972	0.960
<i>O16</i>	2	-0.045	-0.044	-0.073	-0.088	-0.026	-0.023	-0.035	-0.056
	4	0.003	-0.001	-0.002	-0.005	-0.014	-0.026	-0.042	-0.063
	107	-0.008	-0.009	-0.011	-0.013	-0.012	-0.021	-0.031	-0.042
<i>C12</i>	2	-0.008	-0.024	-0.022	-0.024	-0.008	-0.009	-0.010	-0.018
	51	0.001	0.001	0.001	-0.001	-0.002	-0.004	-0.006	-0.009
	53	0.000	0.000	0.000	-0.001	-0.002	-0.002	-0.003	-0.004
	91	0.001	0.001	0.000	0.000	-0.002	-0.003	-0.005	-0.006
	107	-0.001	-0.001	-0.002	-0.002	-0.002	-0.003	-0.005	-0.006



Results

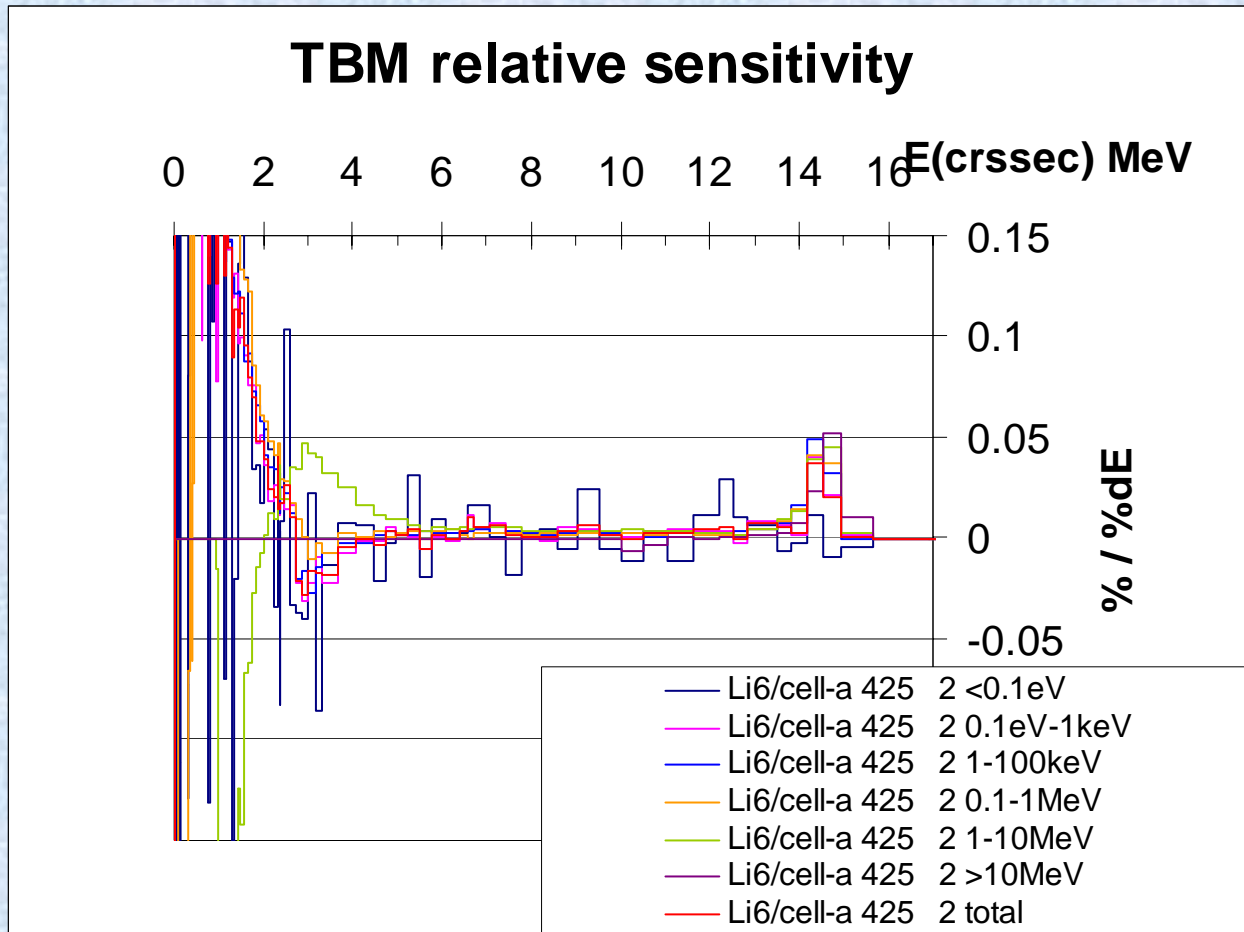
Integrated sensitivities of energy-dependant TPR to ⁹Be

mat	mt	rel-sen-of-all-responses (%/%)						
		<0.1eV	0.1eV-1ke	1-100keV	0.1-1MeV	1-10MeV	>10MeV	total
<i>Li-6/Stack1</i>								
<i>Be9</i>	2	4.216	1.982	0.679	0.036	0.008	0.035	1.999
	16	0.673	0.724	0.766	0.699	0.421	-0.064	0.716
<i>Li-6/Stack7</i>								
<i>Be9</i>	2	4.480	1.263	-0.225	-0.697	-0.464	-0.173	1.672
	16	0.635	0.616	0.546	0.404	0.065	-0.733	0.611
<i>Li-7/Stack1</i>								
<i>Be9</i>	2					0.136	0.031	0.048
	16					0.230	-0.065	-0.016
<i>Li-7/Stack7</i>								
<i>Be9</i>	2					-0.034	-0.186	-0.130
	16					-0.417	-0.736	-0.619



Results

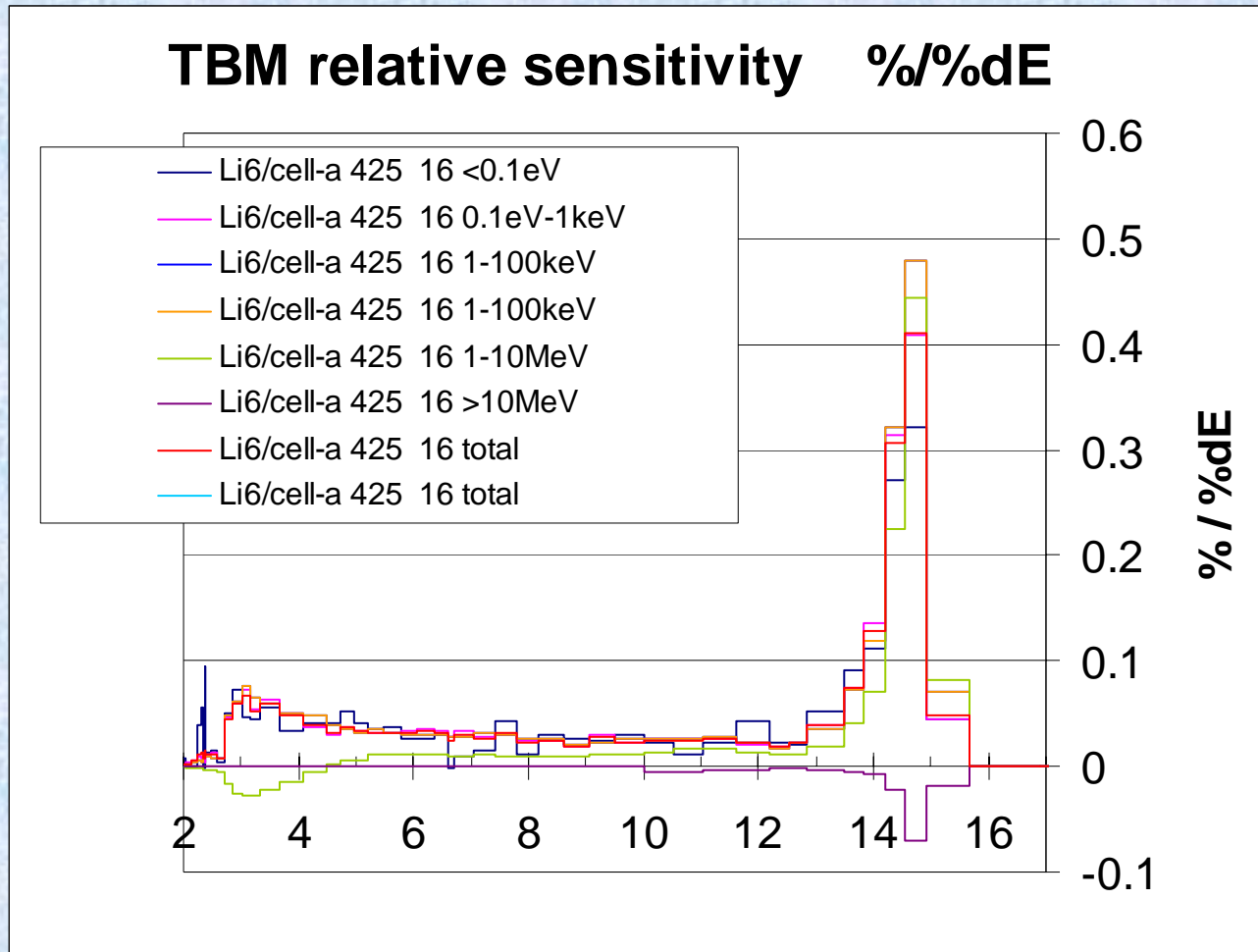
Sensitivity of TPR by ${}^6\text{Li}$ in stack 1 to elastic scattering c.s. of ${}^9\text{Be}$





Results

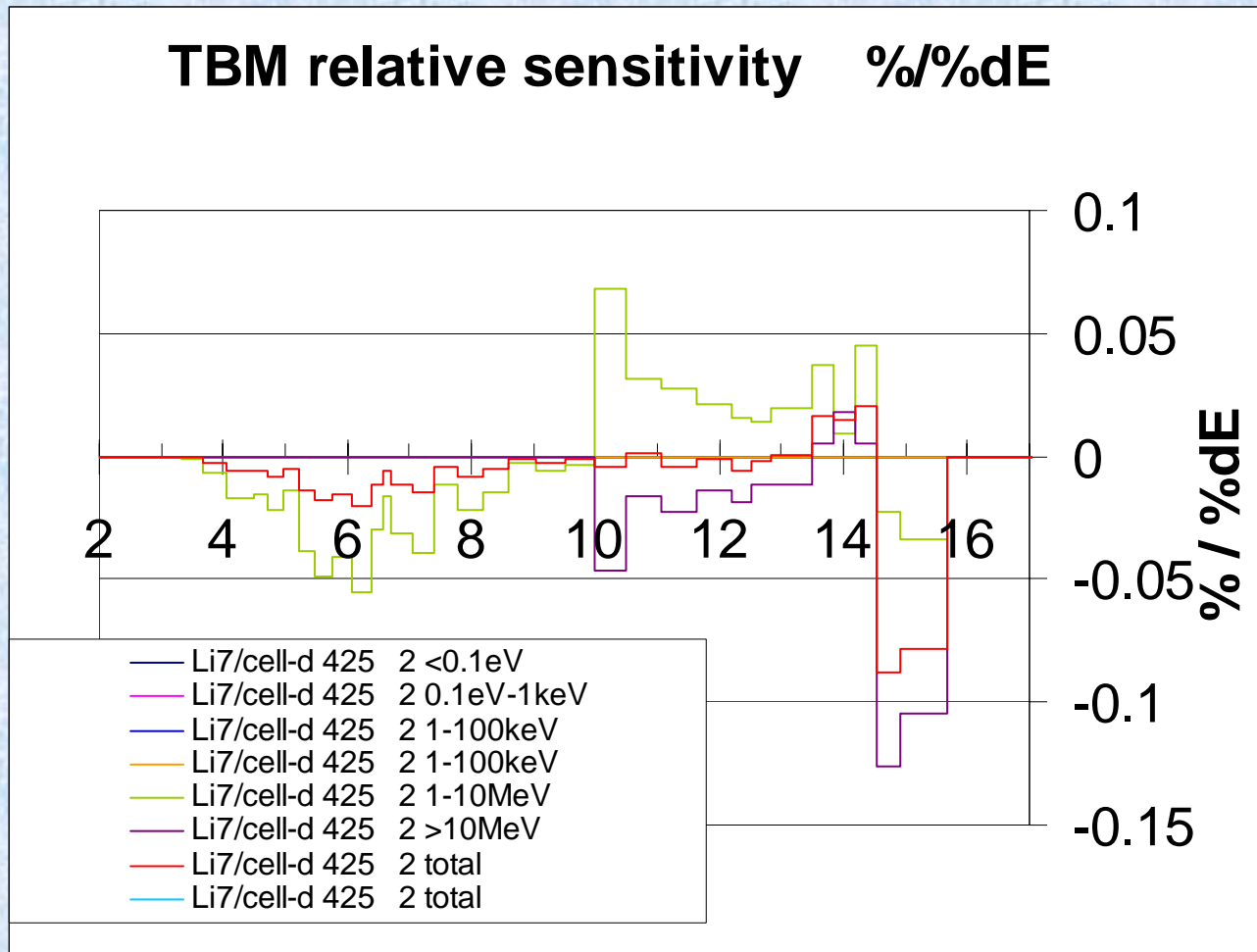
Sensitivity of TPR by ${}^6\text{Li}$ in stack 1 to $(n,2n)$ c.s. of ${}^9\text{Be}$





Results

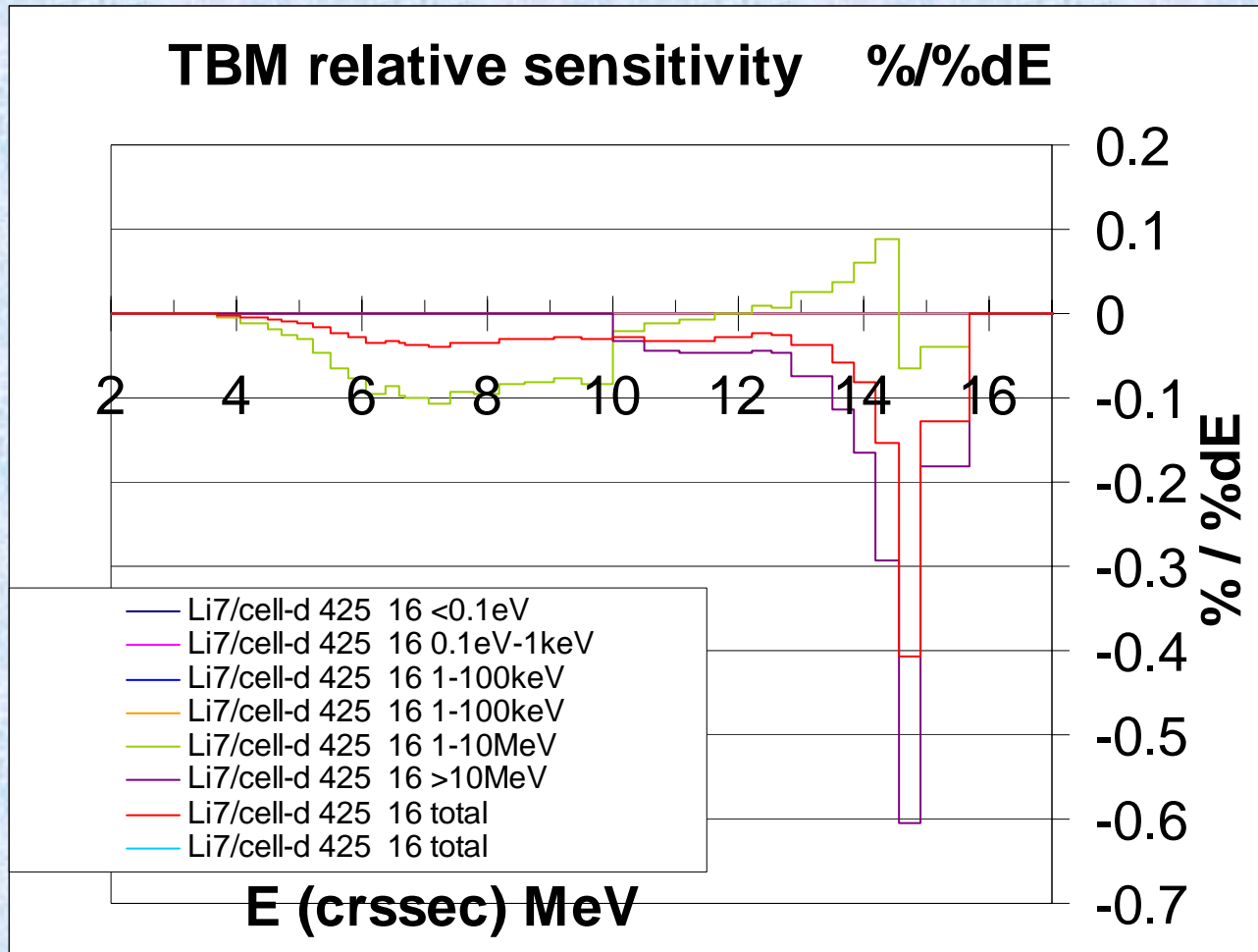
Sensitivity of TPR by ^7Li in stack 7 to elastic scattering c.s. of ^9Be





Results

Sensitivity of TPR by ${}^7\text{Li}$ in stack 7 to $(n,2n)$ c.s. of ${}^9\text{Be}$





Results

Cross-section induced uncertainty due to ^9Be and other isotopes

response-energy	Uncertainty due to Be9			
	Li6-S1	Li6-S7	Li7-S1	Li7-S7
<0.1eV	4.17%	4.16%		
0.1eV-1keV	2.51%	1.70%		
1-100keV	2.24%	1.35%		
0.1-1MeV	2.32%	1.02%		
1-10MeV	1.84%	0.65%	1.72%	1.01%
>10MeV	0.42%	2.65%	0.42%	2.68%
<i>total</i>	2.53%	1.89%	0.10%	1.84%

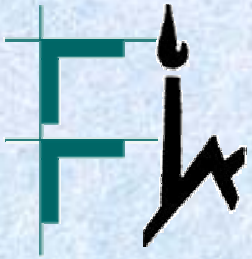
Detektor	Be9	Li6	Li7	O16	C12	total
<i>Li-6/Stack1</i>	2.53%	0.19%	0.06%	0.13%	0.03%	2.54%
<i>Li-6/Stack3</i>	2.45%	0.11%	0.02%	0.15%	0.03%	2.46%
<i>Li-6/Stack5</i>	2.19%	0.08%	0.02%	0.18%	0.03%	2.20%
<i>Li-6/Stack7</i>	1.90%	0.07%	0.08%	0.21%	0.03%	1.91%
<i>Li-7/Stack1</i>	0.11%	0.01%	1.15%	0.24%	0.06%	1.18%
<i>Li-7/Stack3</i>	0.64%	0.01%	1.87%	0.36%	0.09%	2.01%
<i>Li-7/Stack5</i>	1.25%	0.01%	2.33%	0.52%	0.13%	2.70%
<i>Li-7/Stack7</i>	1.85%	0.00%	2.47%	0.73%	0.17%	3.18%



Results

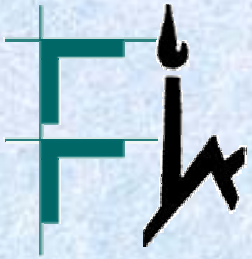
Combined uncertainties

Stack	Li6 tally	Li7 tally	Li total	Li-tot std	Li-tot	Li-tot std	Li-tot std	Li-tot std
	[T/sn/s]	[T/sn/s]	[T/sn/s]	MC	CS	CS+MC	Exp.	CS+MC+E
1	1.31E-05	5.09E-06	1.82E-05	1.33%	2.16%	2.54%	5.80%	6.33%
3	1.81E-05	1.68E-06	1.98E-05	1.45%	2.42%	2.82%	5.80%	6.45%
5	1.54E-05	6.82E-07	1.60E-05	1.69%	2.22%	2.79%	5.80%	6.44%
7	9.36E-06	2.99E-07	9.66E-06	2.15%	1.95%	2.91%	5.80%	6.49%



Results – Sensitivities/Uncertainties

- **Large sensitivities due to ^9Be**
 - ^6Li -TPR sensitiv to elastic scattering
 - ^7Li -TPR sensitive to $(n,2n)$ only in large depth
- **Large direct sensitivity of ^7Li -TPR due to ^7Li**
- **Cross section induced uncertainties**
 - For ^6Li -TPR ($\sim 2.5\% \dots 2\%$) due to ^9Be only
 - For ^7Li -TPR ($\sim 1\% \dots 3\%$) due to ^9Be and ^7Li , larger in larger depth
- **Total uncertainties**
 - MCNP: $1.3\% \dots 2.1\%$, CS: $2\% \dots 2.4\%$, EXP: 5.8%
 - Total: 6.5%



Conclusions

- TPR in Li_2CO_3 pellets calculated by MCNP4C, sensitivities and uncertainties by MCSEN using EFF (FENDL2/2.1 for comparison)
- C/E on average between 0.90 and 0.97
→ TBR calculations conservative
- Main sensitivities of TPR due to ^9Be , (n,2n) important for ^7Li -contribution in the bulk
- Small uncertainties (~2%) from cross-section data, mainly by ^9Be and ^7Li (for the minor ^7Li -contribution)
- Total uncertainties (~6.5%) dominated by experimental values