BENCHMARKING OF ACTIVATION RATE IN SPECIAL CORE IN LR-0 REACTOR

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LR-0 reactor, Research Centre Rez

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Outline

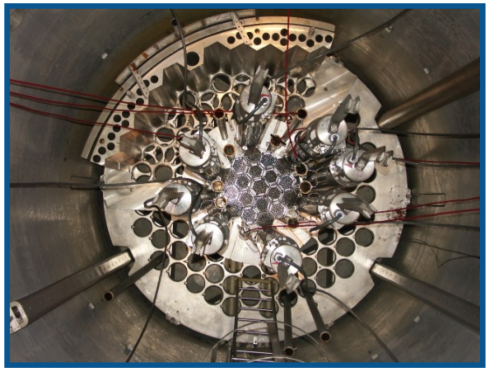
- LR-0 reactor introduction
- Background experiments for benchmarking
- Reaction rates measurements
- Validation of SACS/PFNS
- Conclusions

Research Centre Rez

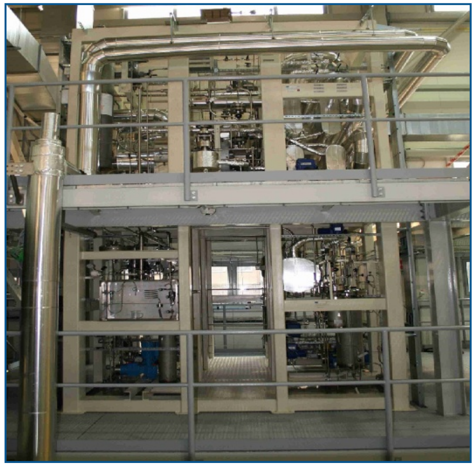
- Located in narrow Vltava river valley near Prague (Czech capital) in central Europe
- Member of the UJV Group
- Major research infrastructure
- ~350 experts, engineers and technicians
- Partner of universities in educating new generation of experts
- Member of international research consorcia in European research programmes

Research Infrastructure

- RESEARCH REACTOR LVR-15



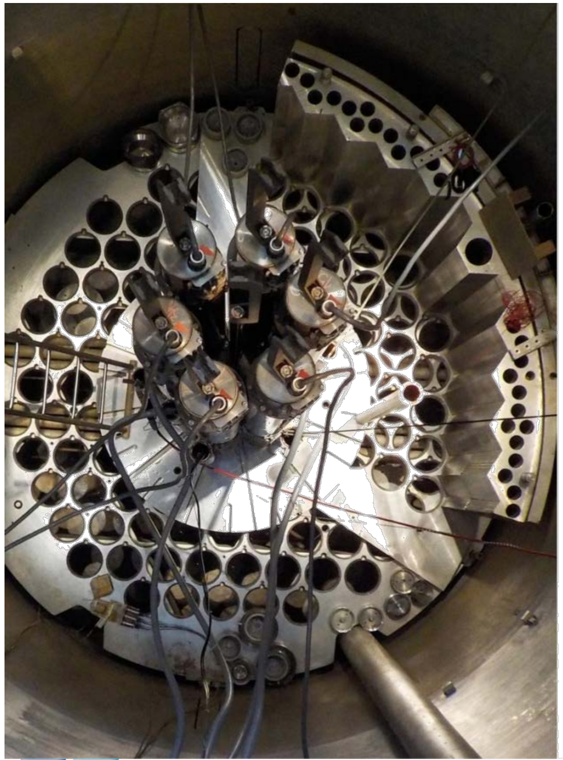
- RESEARCH REACTOR LR-0

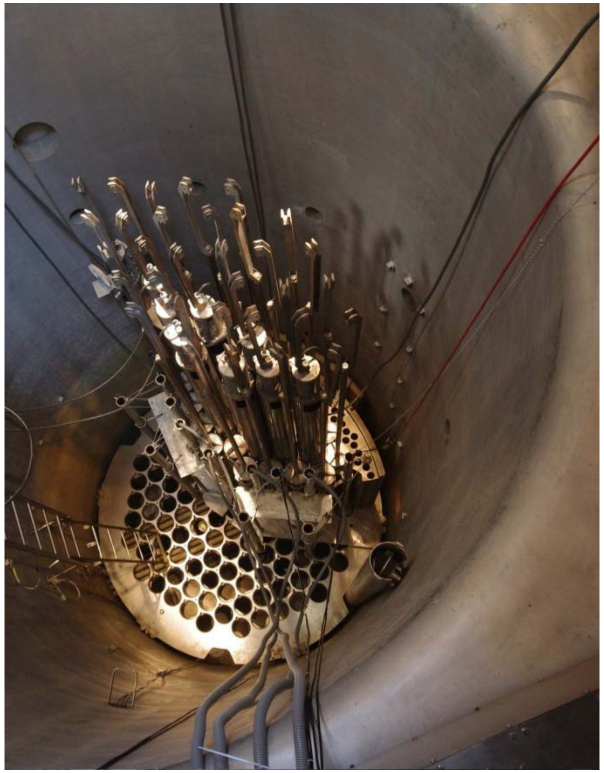


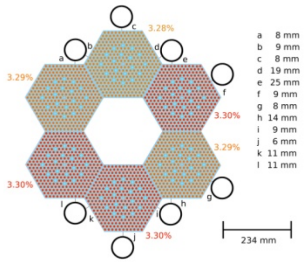
- Technological Loops / SCWL, HTHL
- Other laboratories

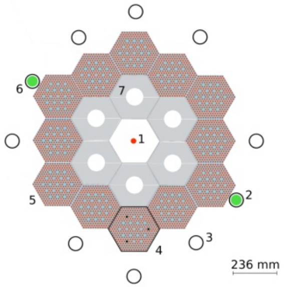
LR-0 reactor

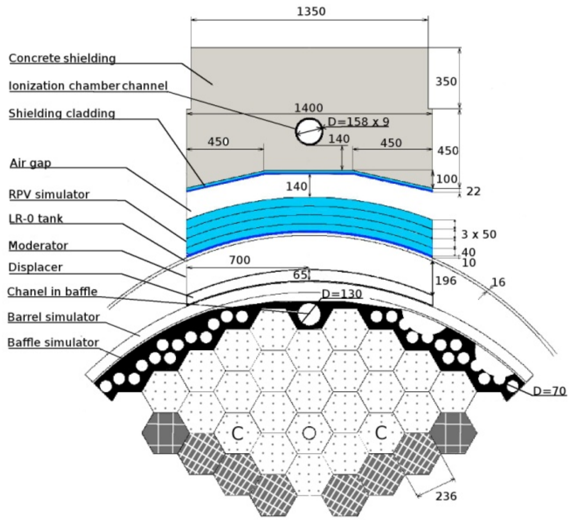
- **Flexible reactor with flexible core arrangements**
- **Well defined fuel and components => benchmarking of many experiments (insertion cores with graphite and FLINA will be evaluated in 2017 IRPhE meeting)**











Experimental program at LR-0 reactor group

- **Experimental possibilities :**
  - VVER-1000 physics
  - Insertion core physics

- **Used methods:**
  - N/G spectroscopy for ex-core and in-core measurement
    - Stilbene (neutron 0.8 – 20 MeV; gamma 0.1 – 10 MeV)
    - Hydrogen proportional counter (0.1 MeV – 1.3 MeV)
  - Gamma spectroscopy (HPGe) for irradiated samples and fuel measurement
  - Measurement of delayed neutrons
  - Measurement of critical parameters

Benchmarked parameters

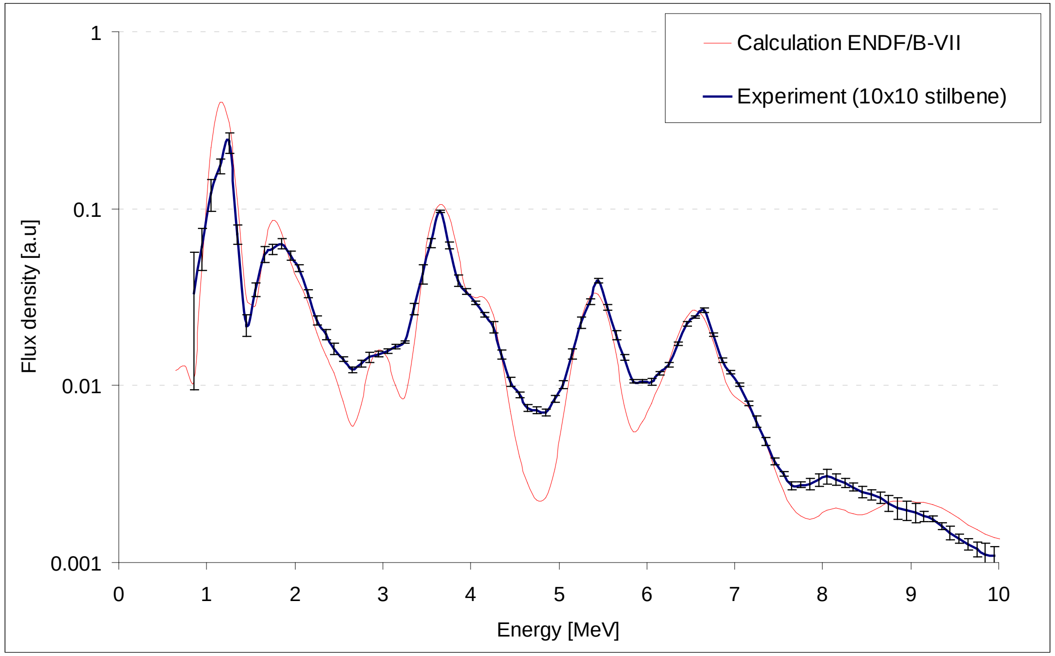
- **Keff**
  - Small cores, VVER-1000 Mock-Up – measurement of effect of various disturbances
- **Neutron spectra**
  - Positions in simulators of VVER-1000 structural components
  - Material insertions in central position of special cores
  - Leakage spectra (Fe, Ni spheres – in Cf experiments)
- **Reaction rates**
  - Activation monitors in VVER-1000 structural components
  - Activation of fuel (fission density profiles with selected fission products)
  - Activation monitors in special irradiation cavity of small cores

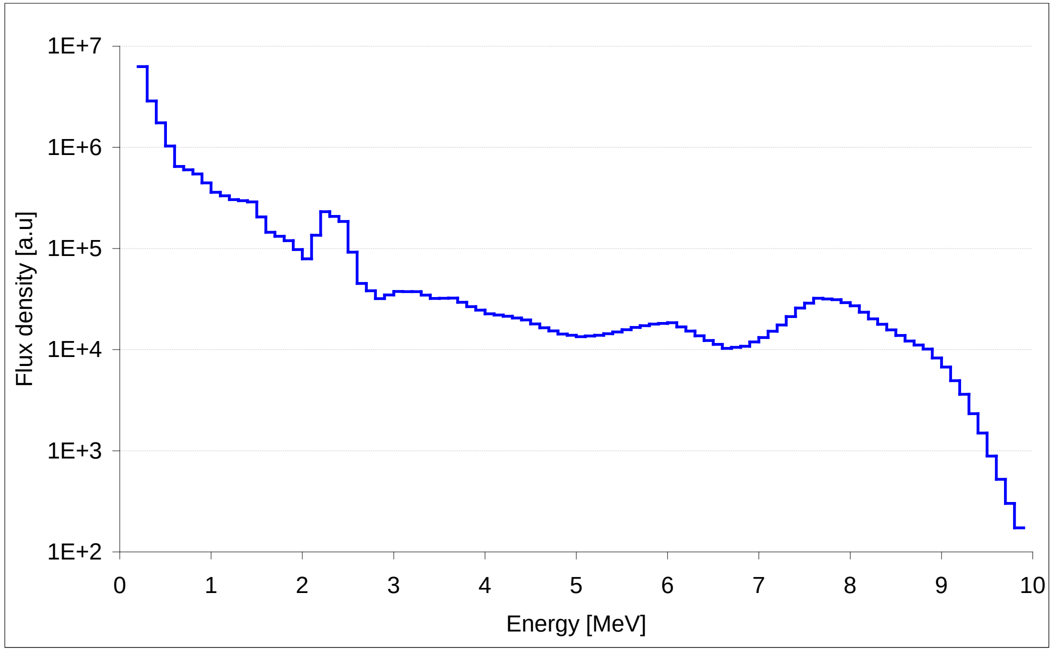
Experimental arrangement

- Irradiated fuel measurement lab
- Irradiated samples measurement lab
- LSNM lab (neutron sources, Fe, Ni spheres)

Neutron and gamma spectroscopy for in-core measurements

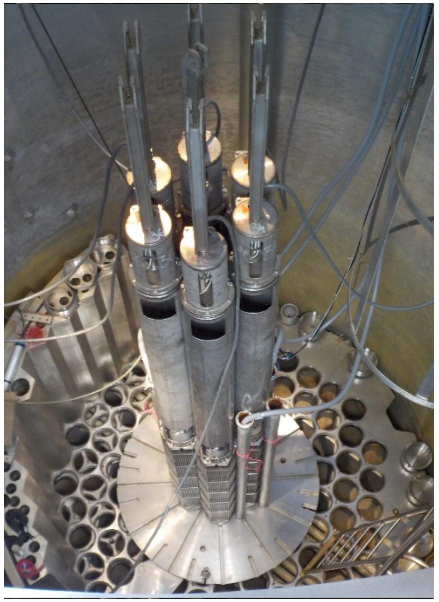
- New digital aparatus (high count rate)
- Neutron and gamma fluxes measurement
- Organic scintillators
- Excellent calibration field 1m Si

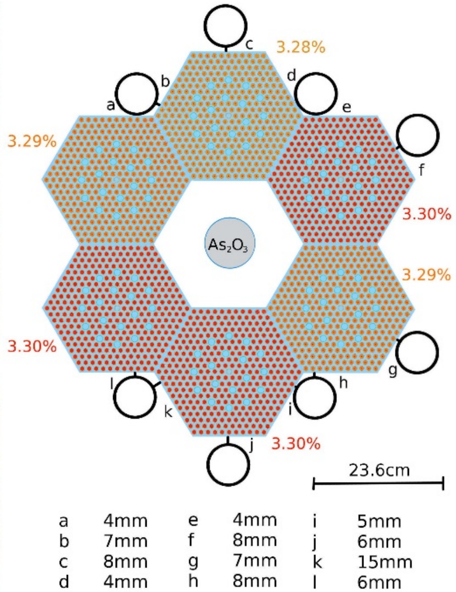


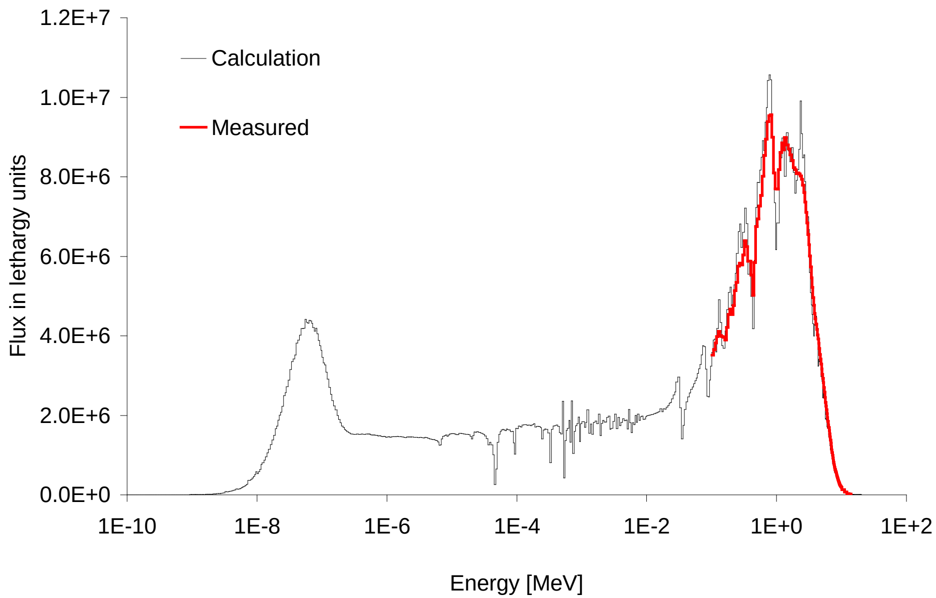


Integral cross section measurement

- **Reference neutron field (verified fission distribution, spectra and reactivity parameters) The used core is accepted as ICSBEP benchmark**
- **Well defined target/detector arrangement**

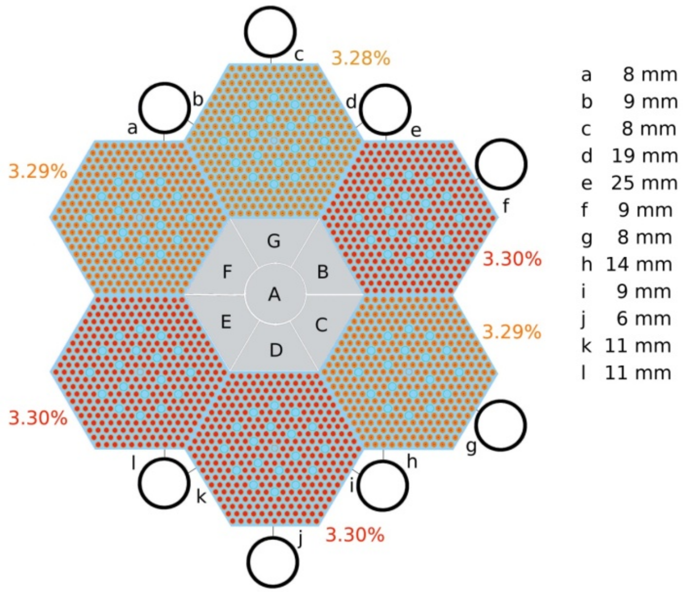


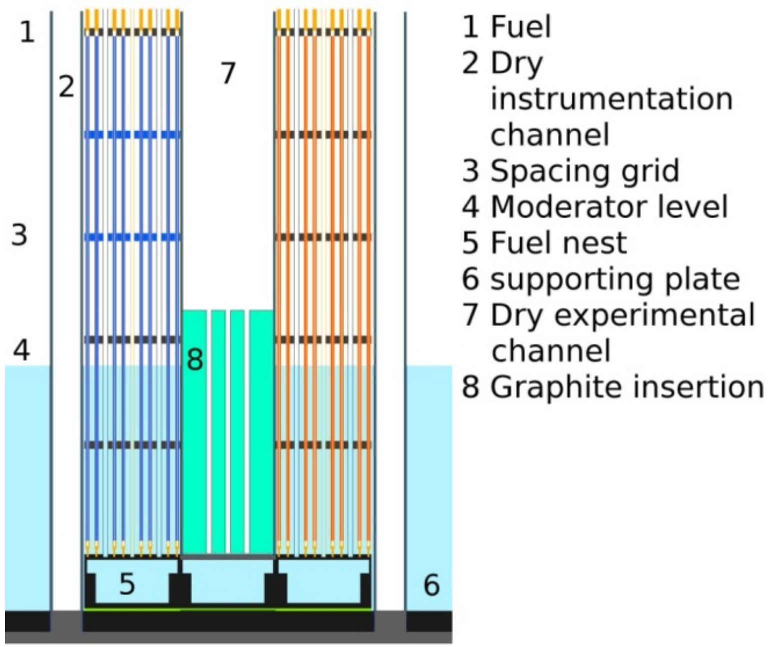




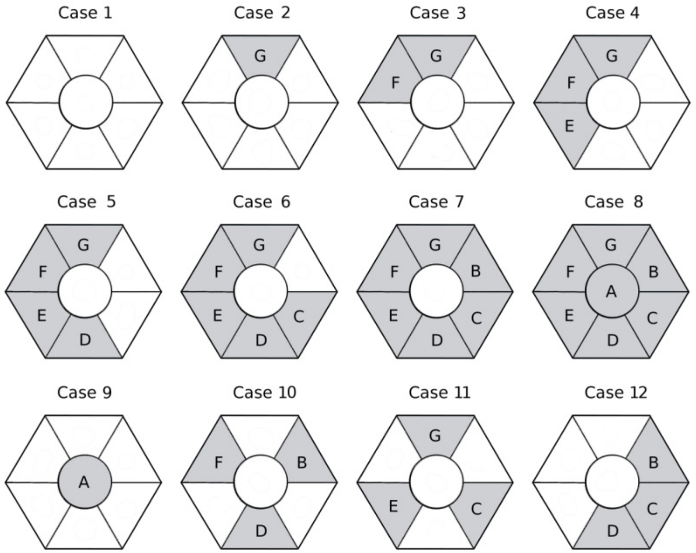
Reactivity insertions

- **Critical parameters measurements for every case will give extensive database for evaluation**
  - Comparison to empty channel
  - Comparison to full graphite channel
- **Study of transient processes help to evaluate delayed neutron characteristics with different central channel reflector**





Insertion cores – effect on driver core

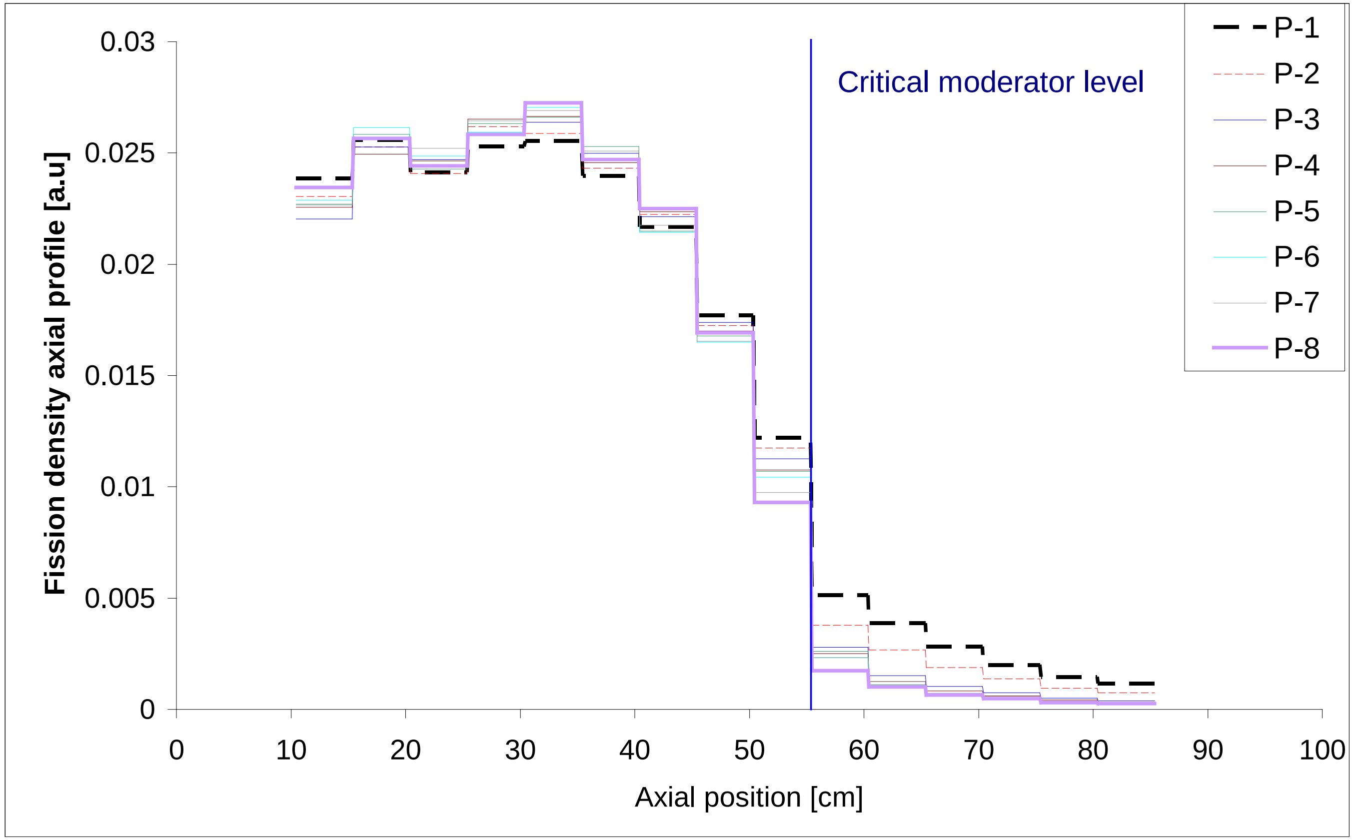


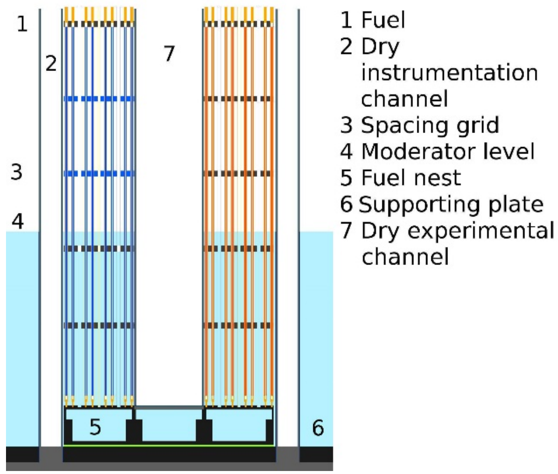
	Graphite position	Hcr [cm]	δρ/δH [pcm/cm]	ENDF/B-VII.0	JEFF-3.1	JENDL-3.3
1	-	55.65	257.36	183	50	-92
2	G	53.34	294.85	173	37	-126
3	F G	51.08	254.99	158	4	-116
4	E F G	49.13	263.29	134	2	-122
5	D E F G	47.45	360.46	138	13	-168
6	C D E F G	45.84	362.2	111	-5	-163
7	B C D E F G	44.43	368.65	168	35	-129
8	A B C D E F G	43.29	438.26	134	-10	-141
9	A	54.07	271.91	200	58	-67
10	B D F	48.9	216.09	99	-32	-179
11	C E G	48.89	242.51	120	-29	-197
12	B C D	48.85	247.89	112	-16	-172

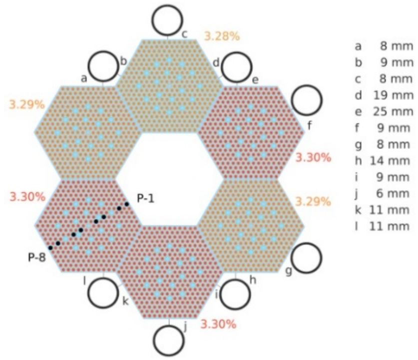
•Kostal et al, Ann. Nucl. Energy, 87 (2016), pp 601–611

Fission profile validation

- **HPGe spectroscopy of irradiated fuel (possible markers: hours living ^{92}Sr, ^{91}Sr, ^{135}I, ^{88}Kr or week living ^{103}Ru, ^{140}Ba, ^{131}I, ^{95}Zr**
- **With use of calculated correction factors arbitrary fission density profile can be determined**
  - Correction to collimator transmission effect (inflections in axial fission distribution)
  - Correction to spectra shift (yield vs. spectra shape – moderated in water fast in dry fuel lattice)



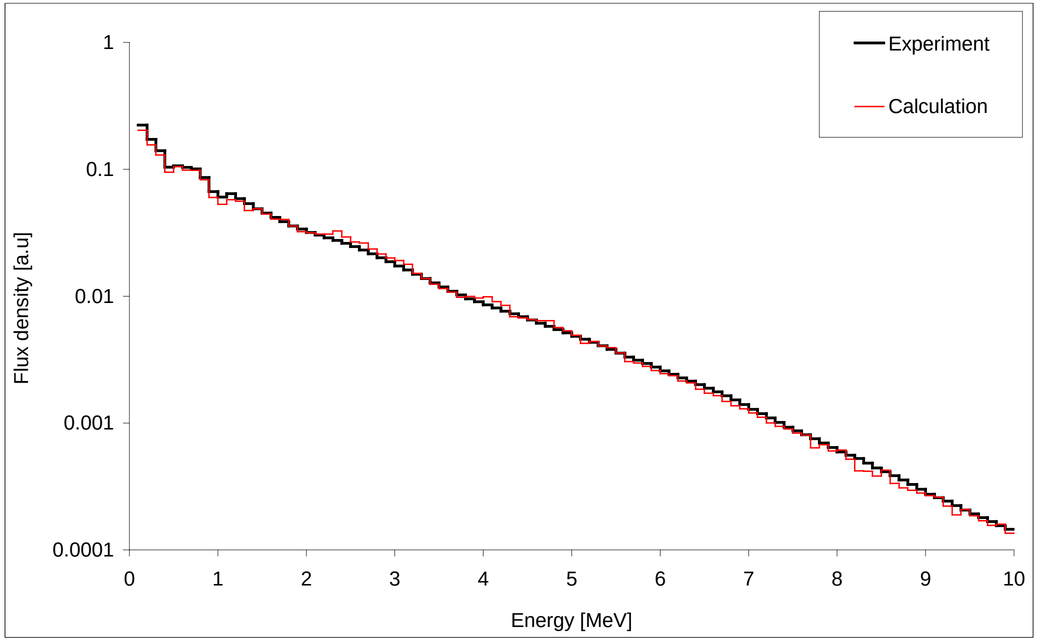


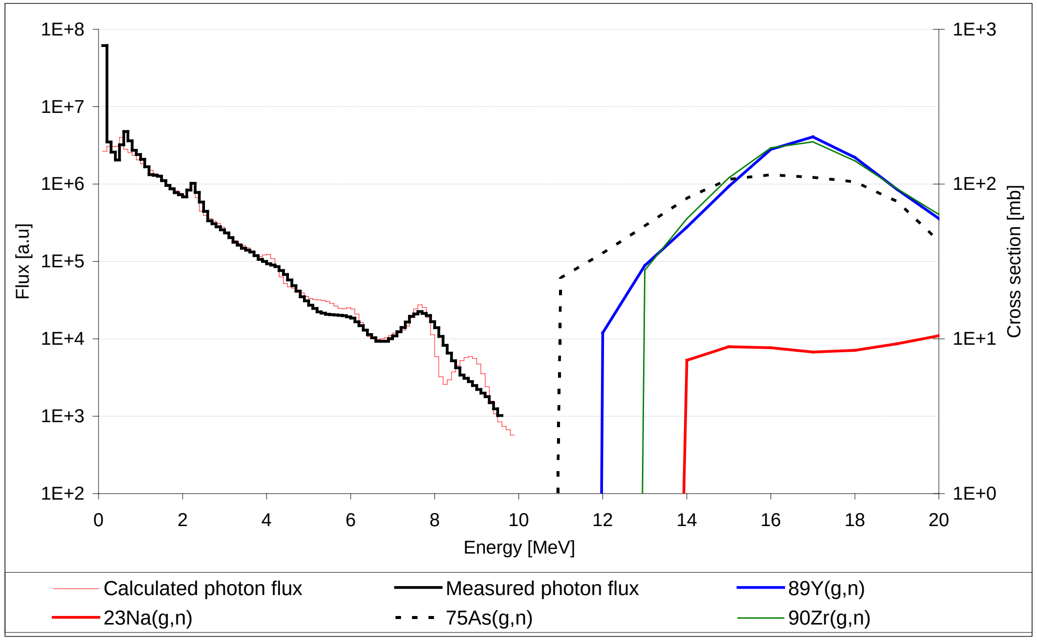


•Kostal et al, Ann. Nucl. Energy, 90 (2016), pp 450–458

Definition of N/G field

- **The field is defined by**
  - Flux distribution (reaction rates of activation monitors Au, Ni)
  - Neutron spectra
  - Gamma spectra (it was proven that (g,n) is negligible
  - Connection to emission density profile
  - Keff (models assume critical reactor)

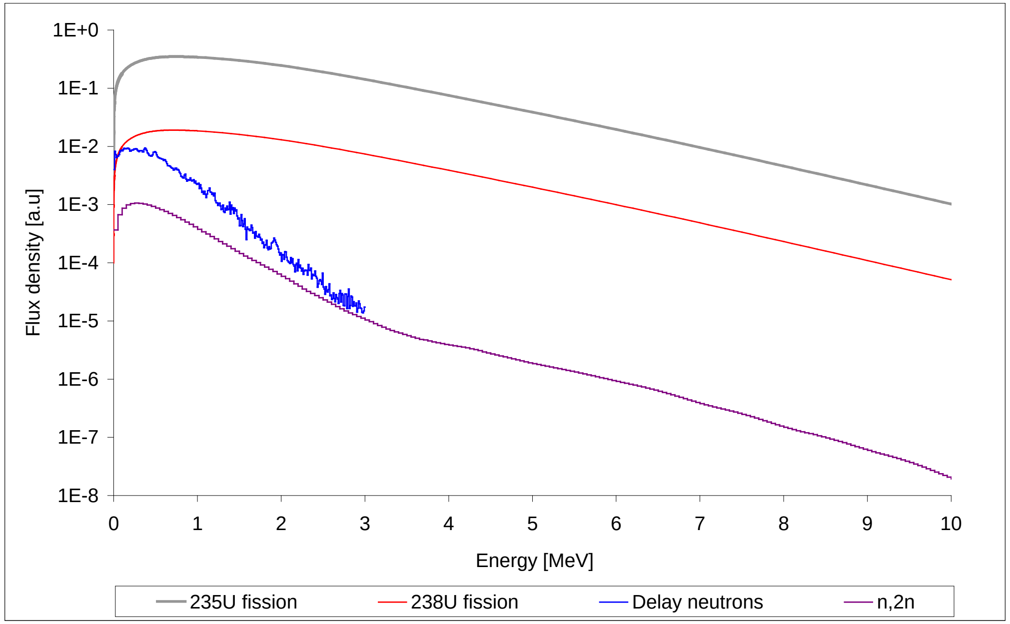


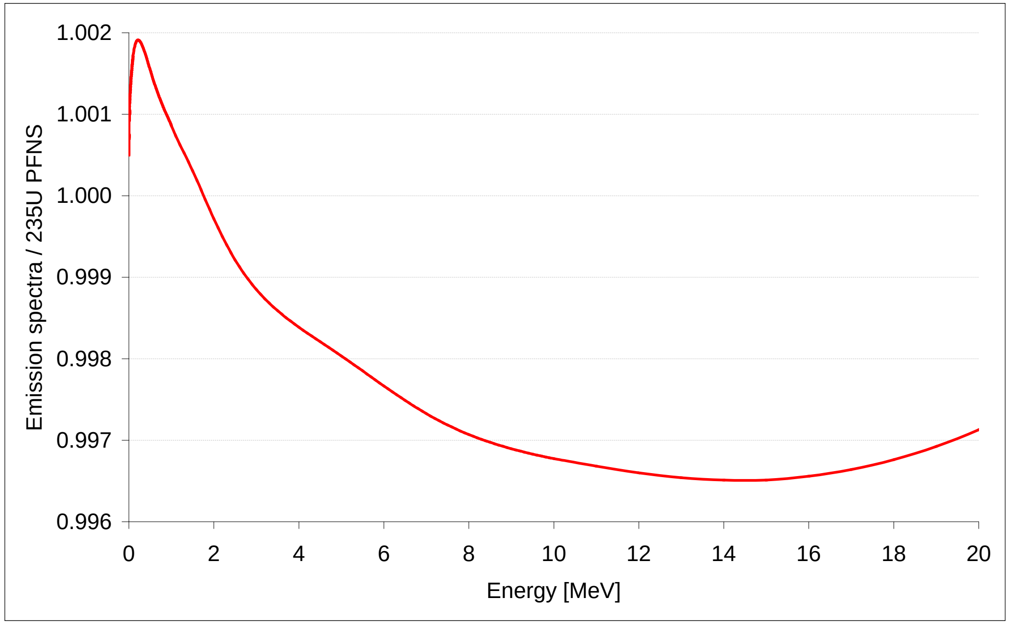


Neutron spectra in special core

- **Neutrons in fuel**
  - 235U fission neutrons
  - 238U fission neutrons
  - Delay neutrons
  - Neutrons from (n,2n) reactions
  - Gamma fission neutrons effect is negligible
  - Same shape of 235-238U

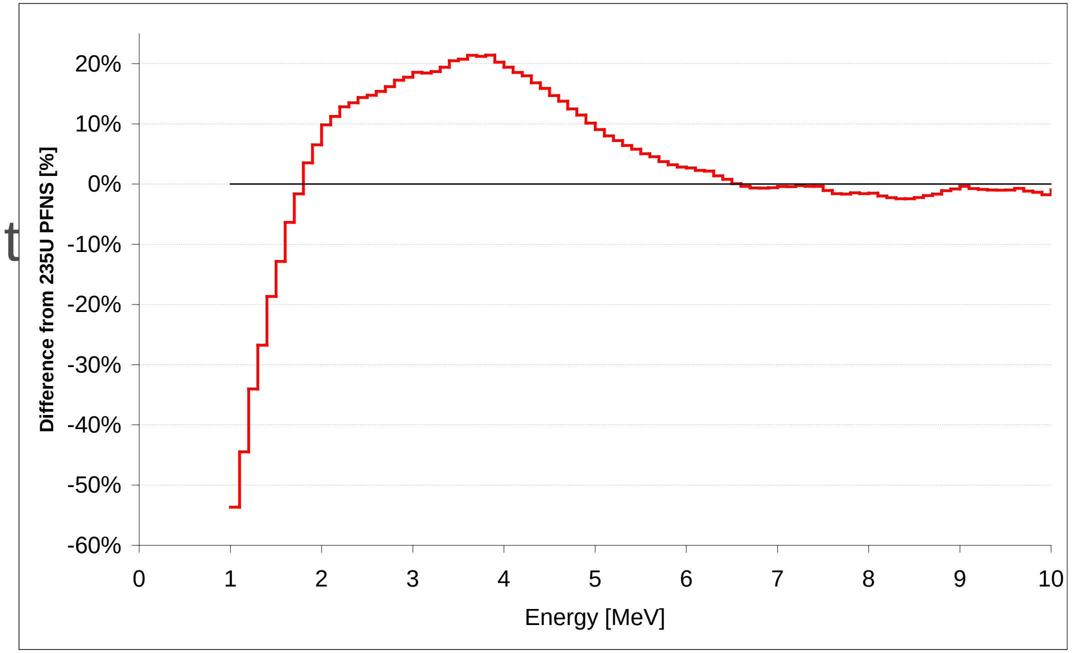
Type of origin	^{235}U	^{238}U
fission	0.93857	0.05348
delay	0.00614	0.00083
n,2n	2.5E-5	0.00093
photo-fission	5.9E-7	1.2E-5

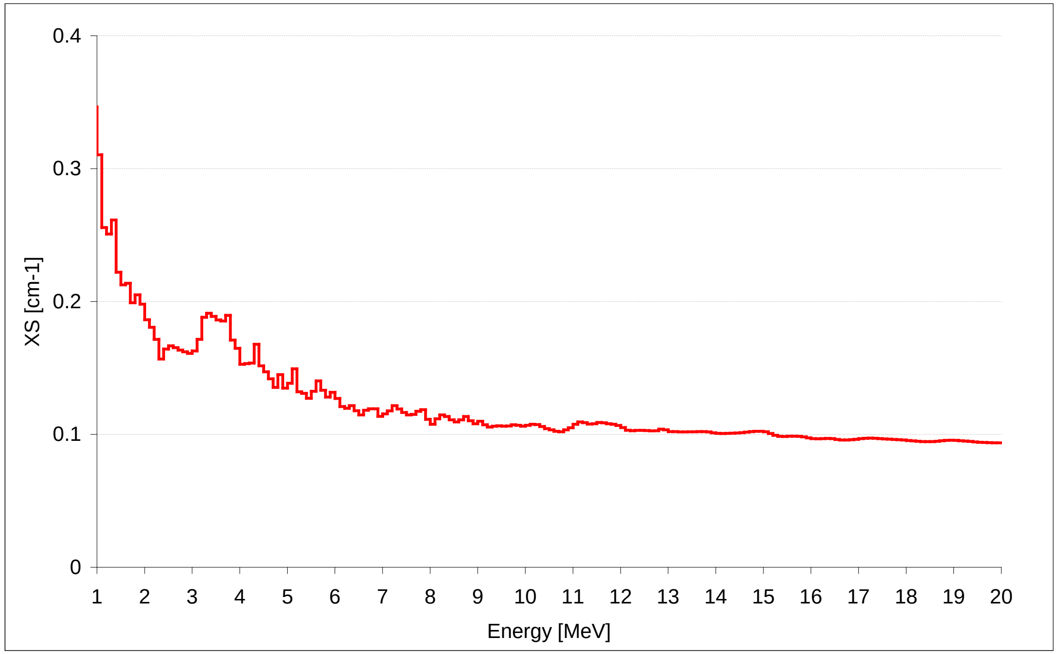




Neutron spectra in central cavity

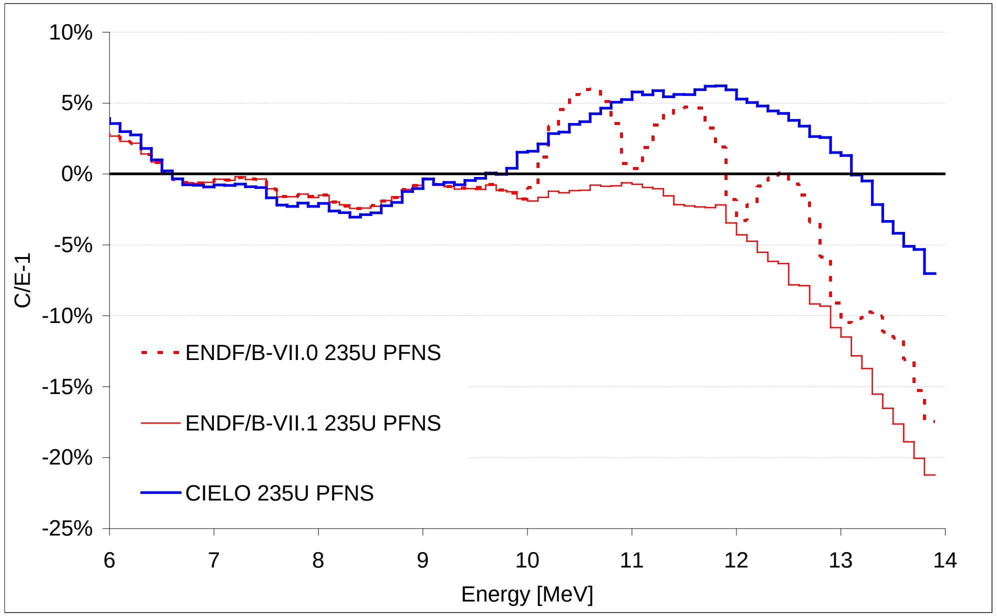
- **Neutrons in irradiation cavity**
  - The emission neutron spectra is nearly same as 235U PFNS but it is affected by core components
    - Neutron transport in fuel
    - Neutron transport in moderator
    - Neutron transport in core structural components

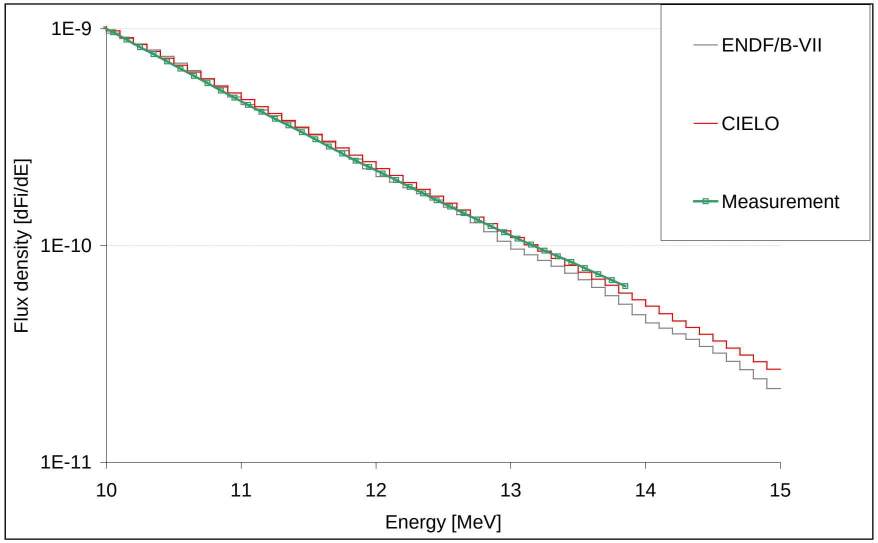


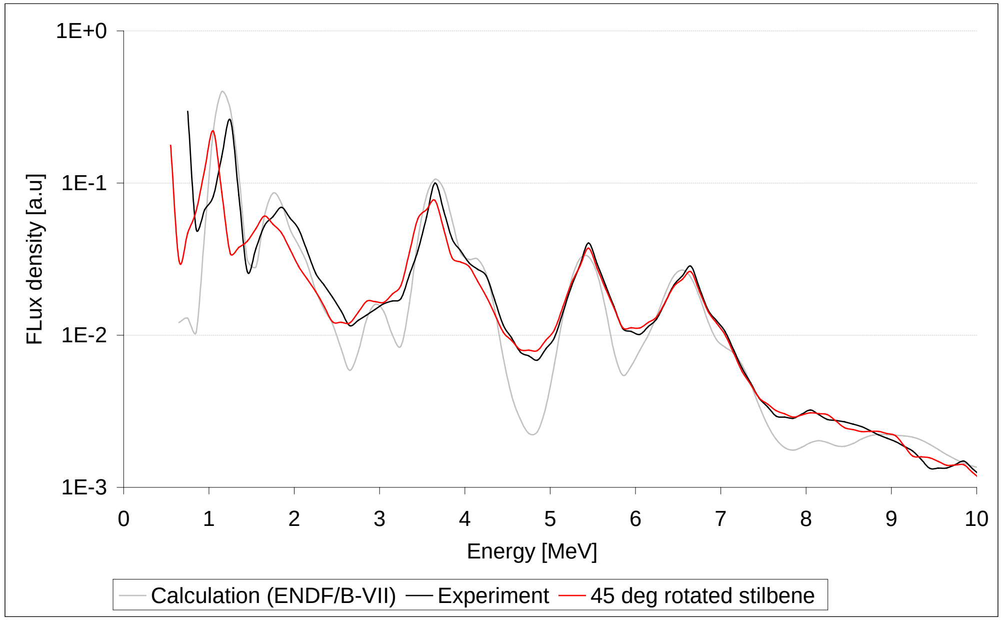


Spectra in special core II.

- C-E Normalization 6 – 10 MeV
- The calibration was tested in Si beam
- In the LR-0 the neutrons have about 45 deg angle to optical axis (the effect of anisotropy was tested in Si beam as well)







Integral cross section measurement - cont.

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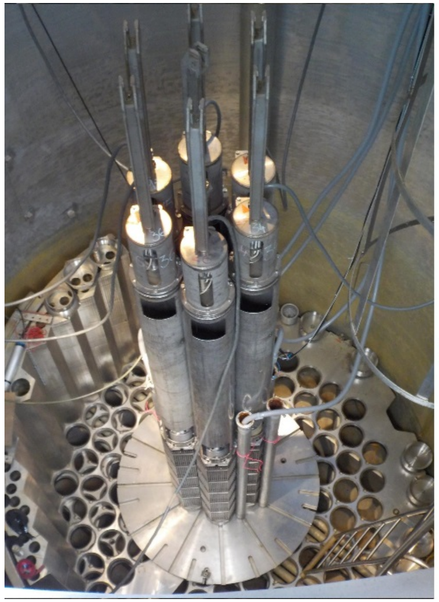
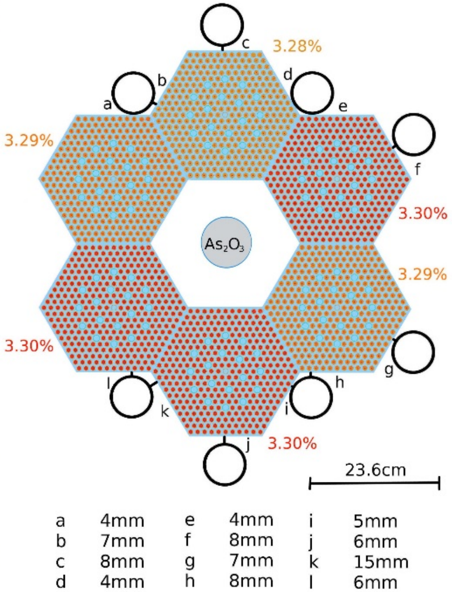
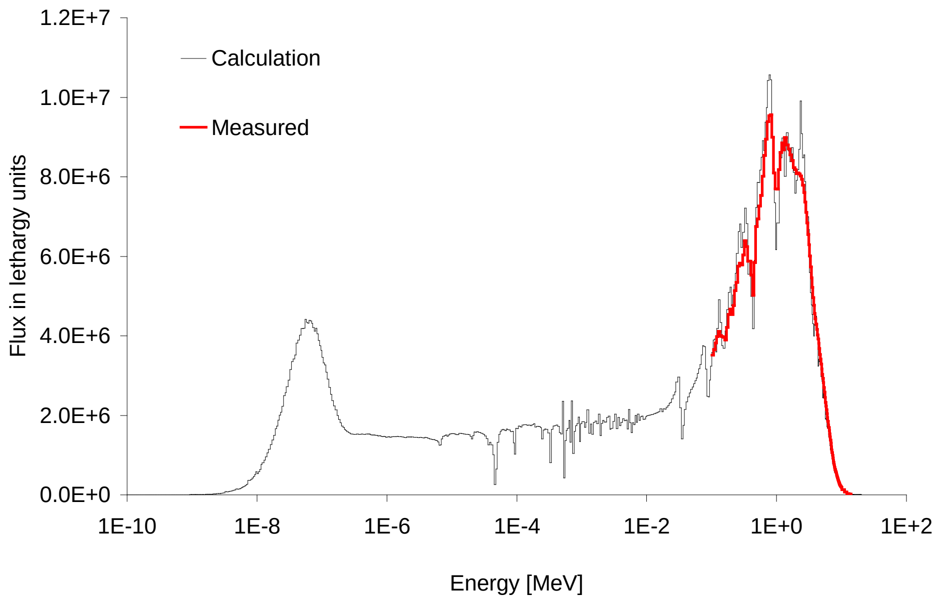
- Well defined target/detector arrangement

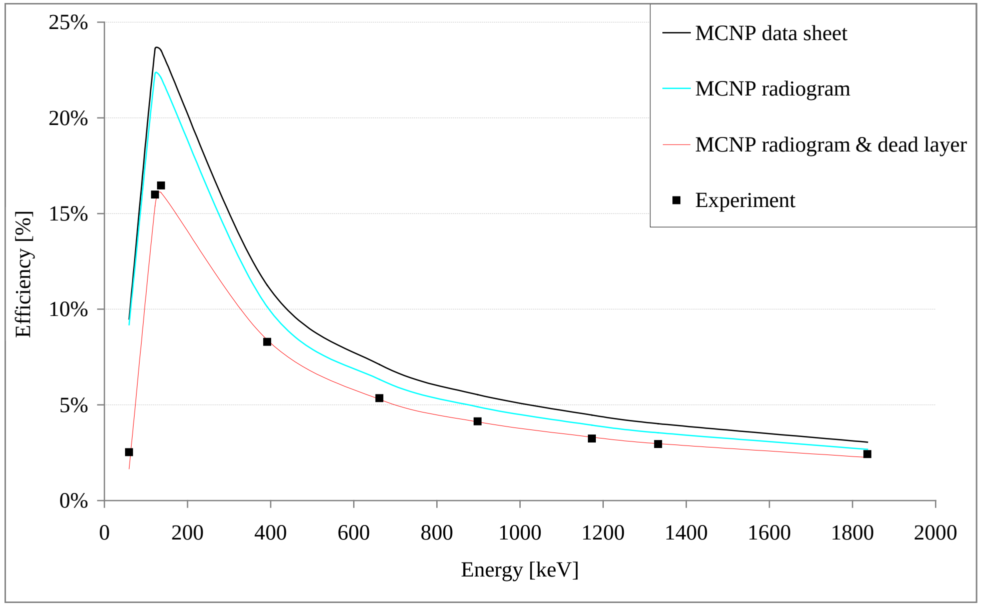


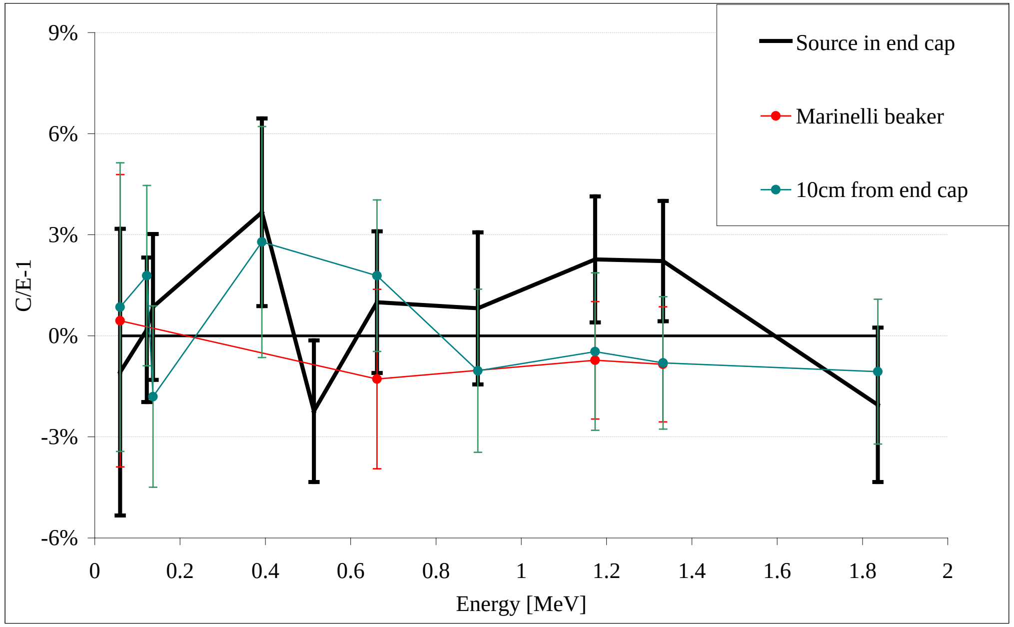


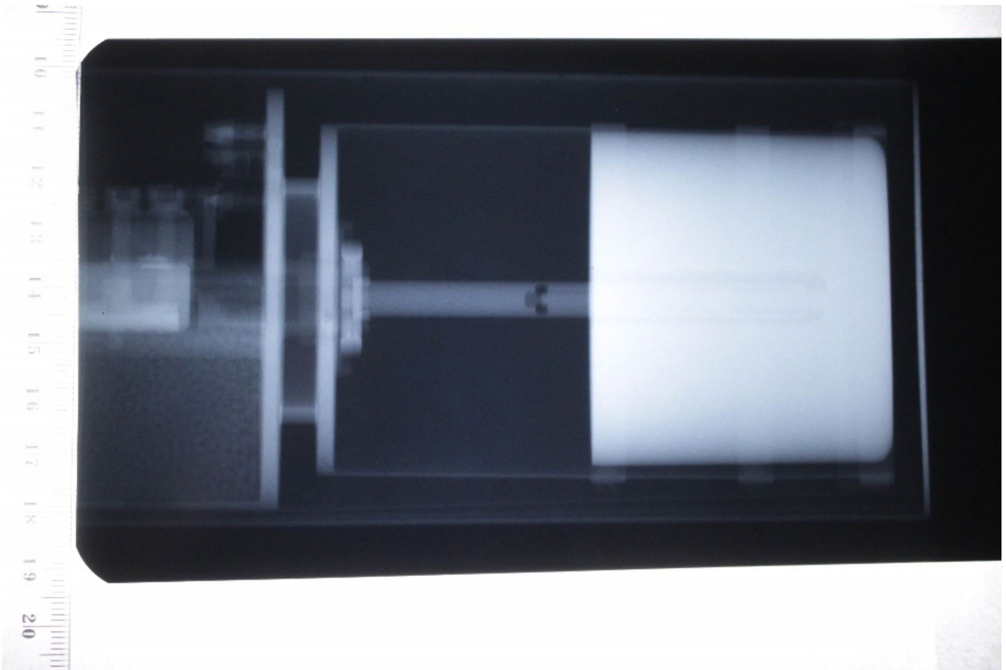


Correct determination of target gamma activity

- Most important is detector sensitivity !!!
- Large sample needs proper detector characterization (calculated efficiency)
  - Experimentally measured insensitive layer and detector dimensions

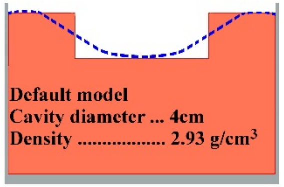


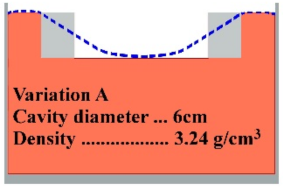


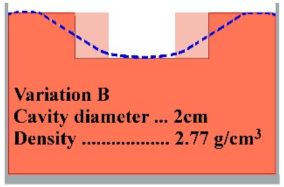


Definition of target

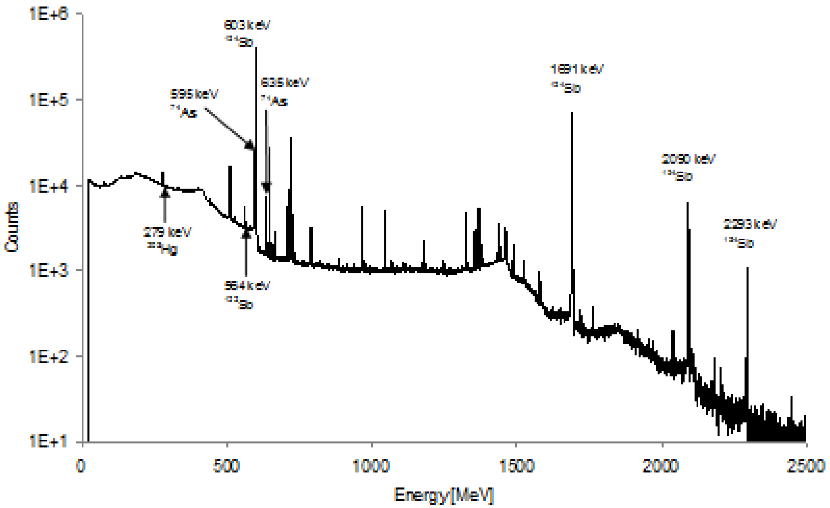
- **Important for correct definion of gamma source in HPGe (assuming low XS and homogenous product distribution as n/g field is homogenous)**

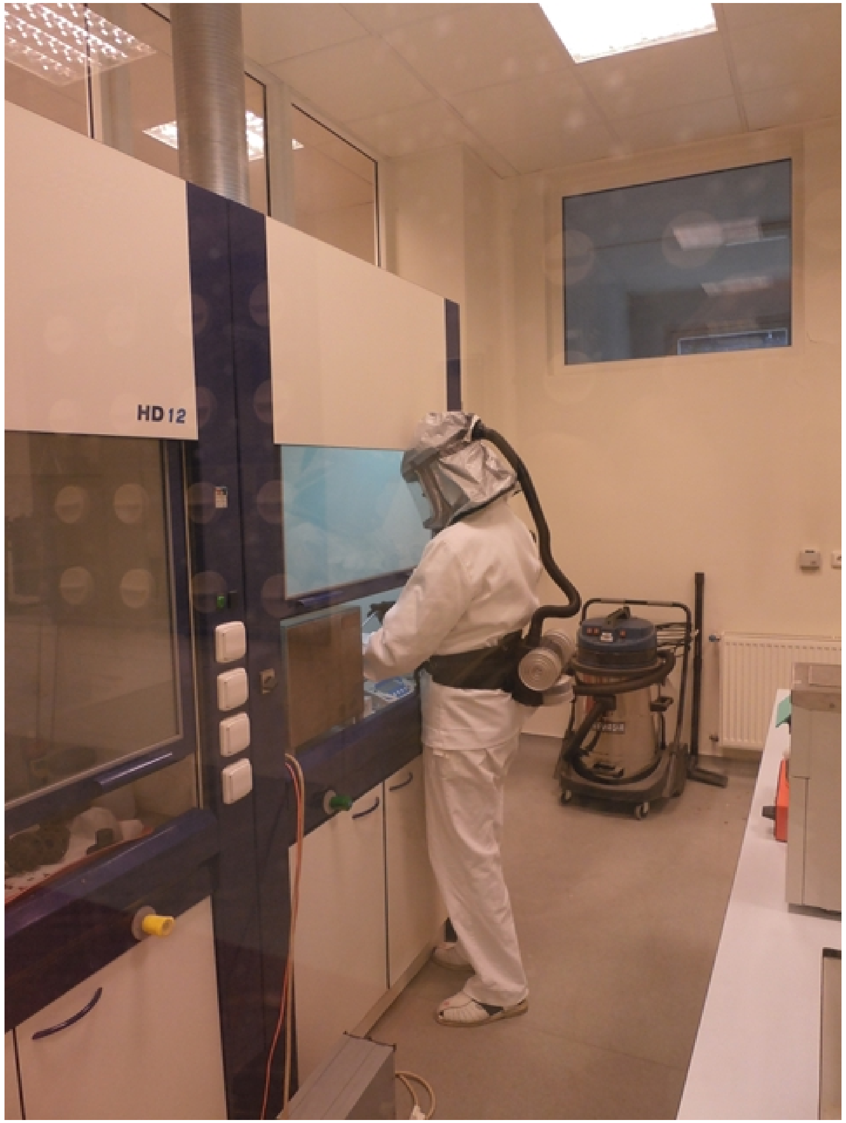






- **Parasitic gammas effect**
  - Impurities
  - Concurent reactions … 23Na(n,2n) x 23Na(n,g)





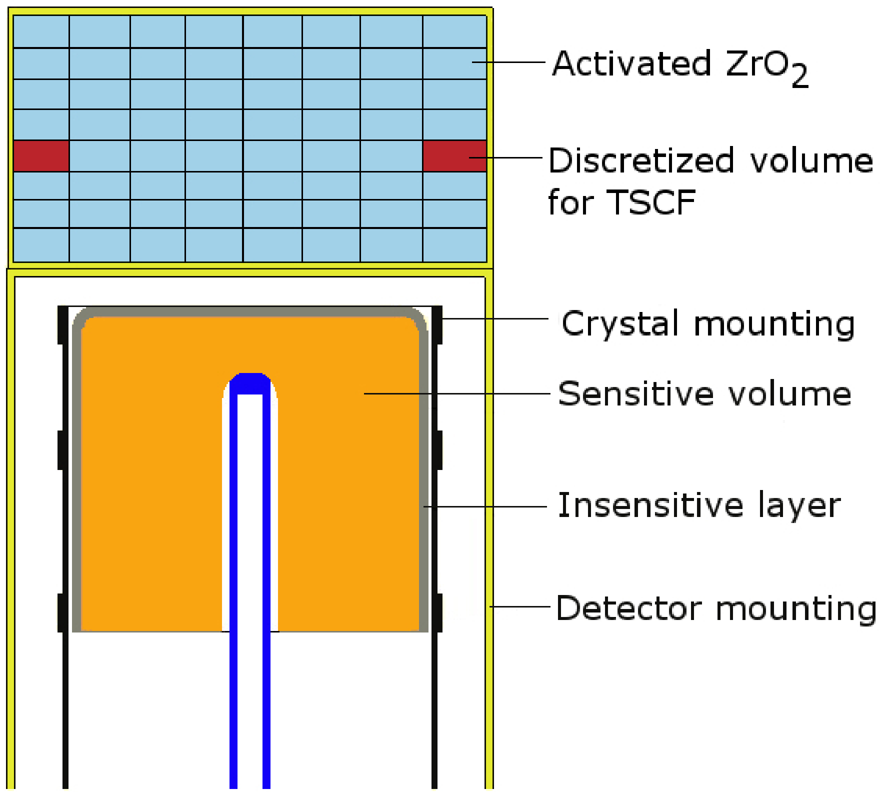
True summation correction factor

- **Coincidences decreases true count rate**

$$A(E) = \frac{C(E).\lambda}{\varepsilon(E)\cdot\eta^{P}(E)\cdot T_C\cdot(1-e^{-\lambda TR})\cdot F^{S}(E)}$$

- **Easily defined for point source**

$$F^{S}(909.keV) = 1 - 0.4548\times\eta^{T}(511.keV)$$

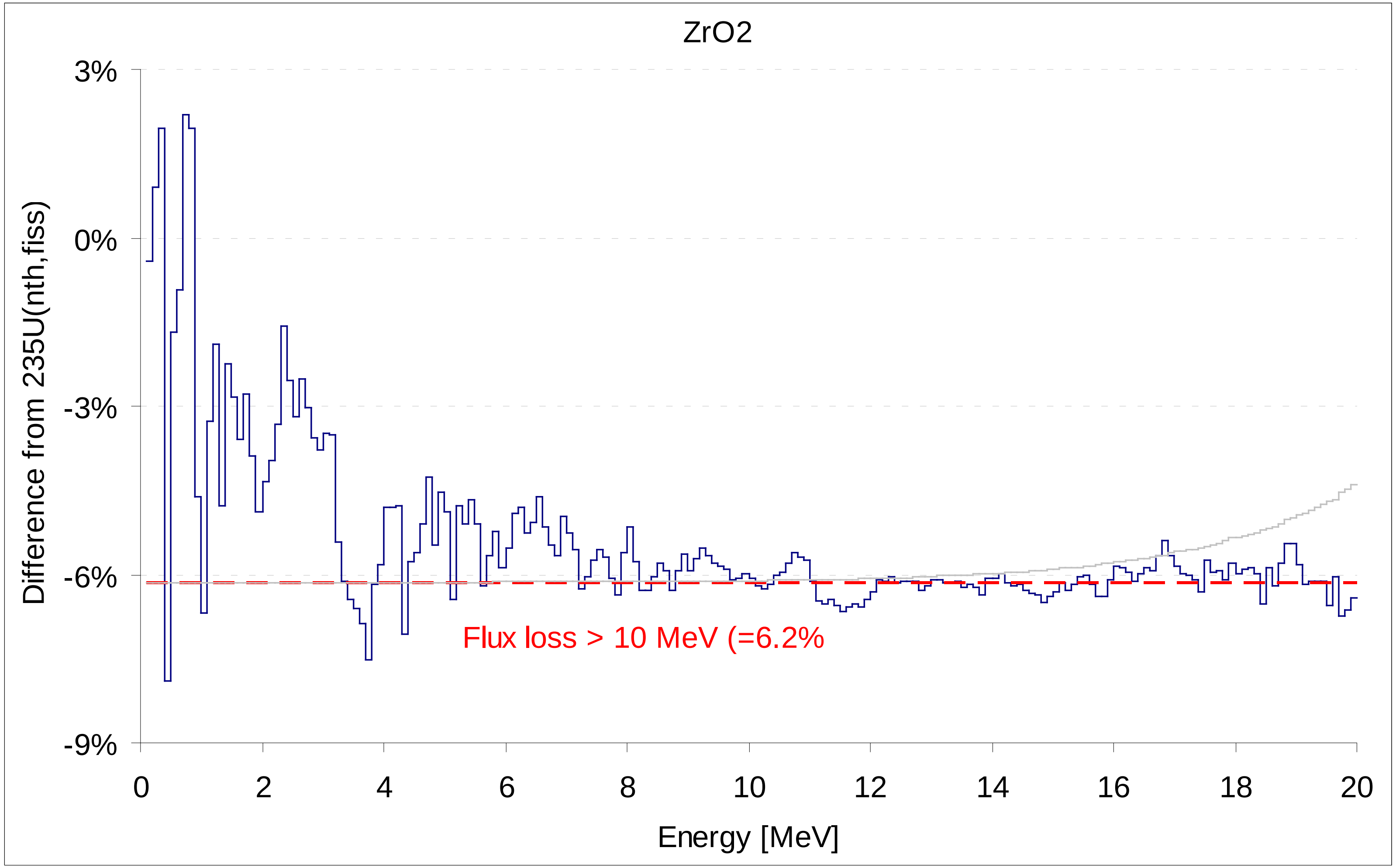


$$A(909keV) \approx \frac{1}{\eta^{P}(909keV)\cdot\left(1-0.4548\times\eta^{T}(511.keV)\right)}$$

Point approx. 0.969
Volume source 0.961

Spectral shift correction

- **Determined calculationally as 235U SACS and SACS**



Results for samples carried out in LR-0

	E 50% [MeV]	^{235}U SACS [barn]	C/E-1 of reaction rates with IRDFF XS	
			ENDF/B-VII	CIELO
$^{75}As(n,2n)$	12.67	0.323	-4.6%	-1.2%
$^{89}Y(n,2n)$	13.70	0.172	-9.1%	0.5%
$^{90}Zr(n,2n)$	14.22	0.107	-12.2%	-0.4%
$^{23}Na(n,2n)$	15.23	0.004	-12.5%	6.7%

Conclusions

- Spectrum averaged cross sections of 23Na(n,2n), 90Zr(n,2n), 89Y(n,2n), 75As(n,2n) were derived from measurement of spectra and reaction rates in LR-0.
- Results are in good agreement with previously published data.
- The measured reaction rates were used to validate PFNS data from CIELO and ENDF/B-VII.
- CIELO shows good agreement while ENDF systematically underestimates the reaction rates, which might indicate problems of PNFS in the high energy region above 10MeV.

- Thank you for your attention

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