Benchmark Assemblies producing neutron and gamma mixed fields

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- Neutron gamma (n,g) sources
- Instrumentation
- Benchmark assemblies
- Methodology of spectra measurement
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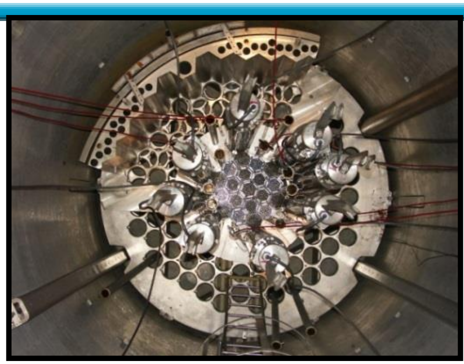
- Methodology of MCNP calculation
- Examples of C/E comparison use of HPD
- Use of spectrometry measurements on Fe-benchmarks for improvement of cross section XS-Fe56(n,el),
- References

CVR Research Infrastructure

CVŘ Centrum výzkumu Řež



Research Reactors LVR-15 and LR-0

- Validation of various XS (Si, FLIBE, Pb, graphite ..)
- SACS (validation of dosimetrical xs, fission spectra)
- Mock-Up experiments (VVER-1000 reactor dosimetry)
- Transmision experiments in Si beam (Pb, Fe)

- **Point neutron sources ^{252}Cf, AmBe, ^{238}PuBe**
  - SACS
  - Leakage spectra

- **Neutron DT generator**
  - Integral experiments

Neutron and gamma (n,g) sources 1

Research Centre Rez:

Izotopic sources

- **Cf-252 (n,g), Q=3.5E8 n/s, (pneumatic post transport – Flexo Rabbit)**
- **Am-Be (n,g)**
- **Pu-Be (n,g)**

Reactors

- **LR-0 reactor (n,g) P=1kW, φ_{th}= 1E12 n/scm^2**
- **LVR-15 reactor (n,g), P=10MW, φ_{th} = 1E14 n/scm^2 + 10 filtered neutron channels**

Neutron generator

- **14 MeV, D-T reaction („fusion source“), gas sealed tube, Q= 1E09 n/s**

Common gamma sources: Co-60, Cs-137, Ba-133, …

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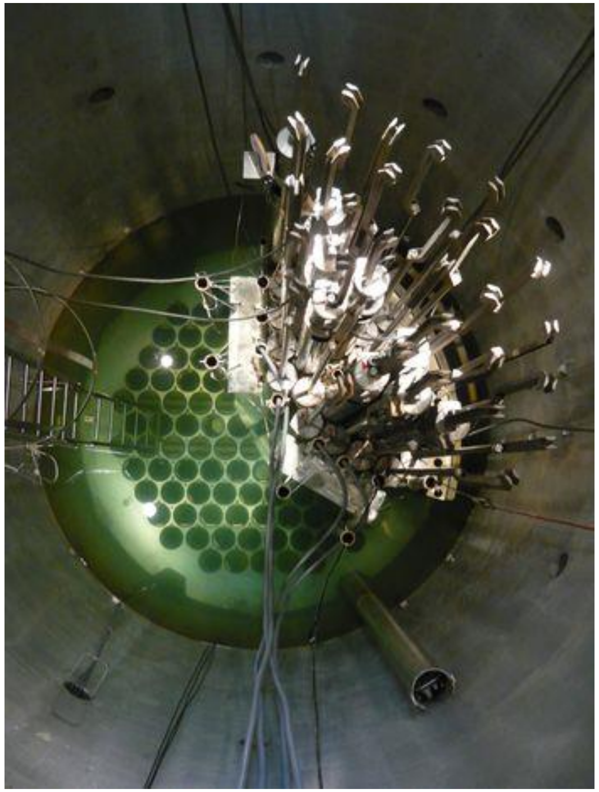
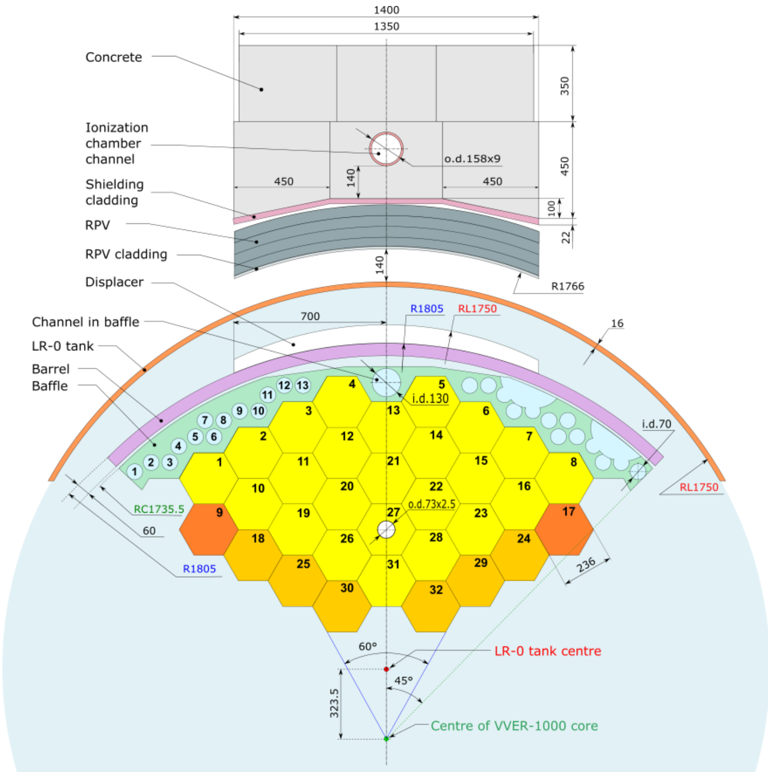
Nuclear Physics Institute (Czech Academy of Science):

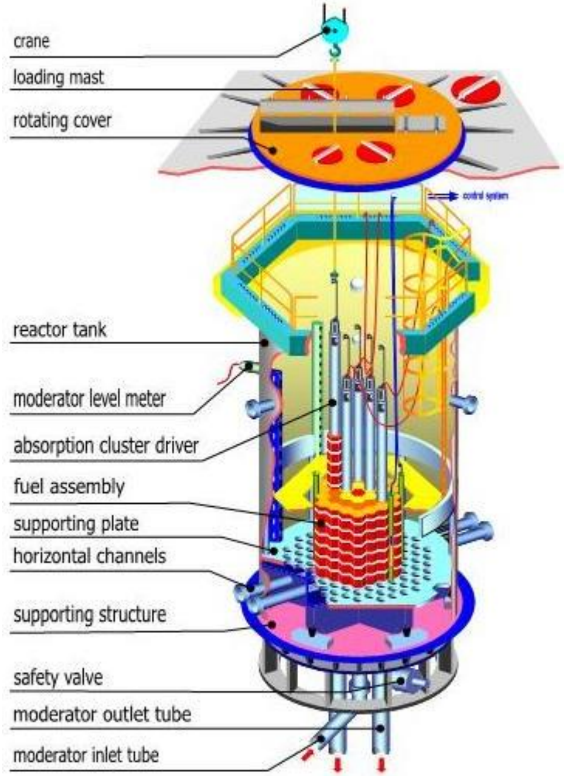
Quasi monoenergetic neutrons, available in NPI Rez accelerator, E_{mean}< 30MeV)

UJV: PET

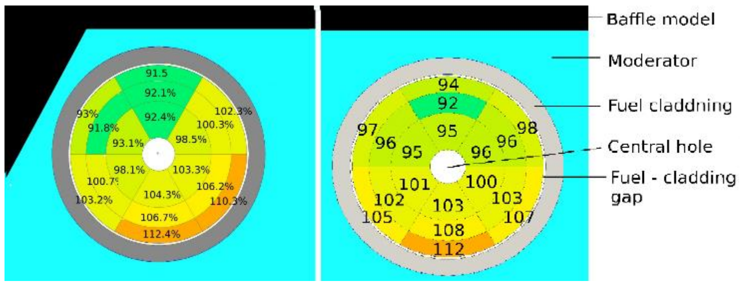
Neutron gamma (n,g) sources 2
Reactor LR-0



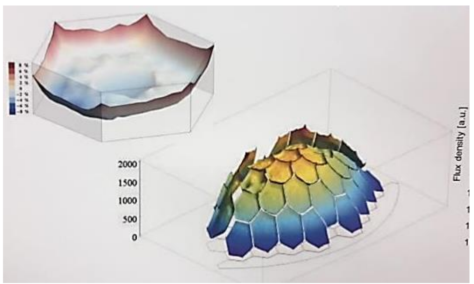




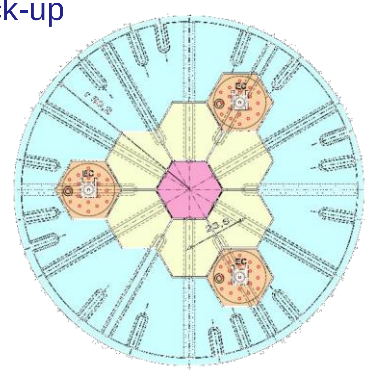
VVER-1000 reactor core mock-up



Flux density distribution
in Fuel Pin - MCNP

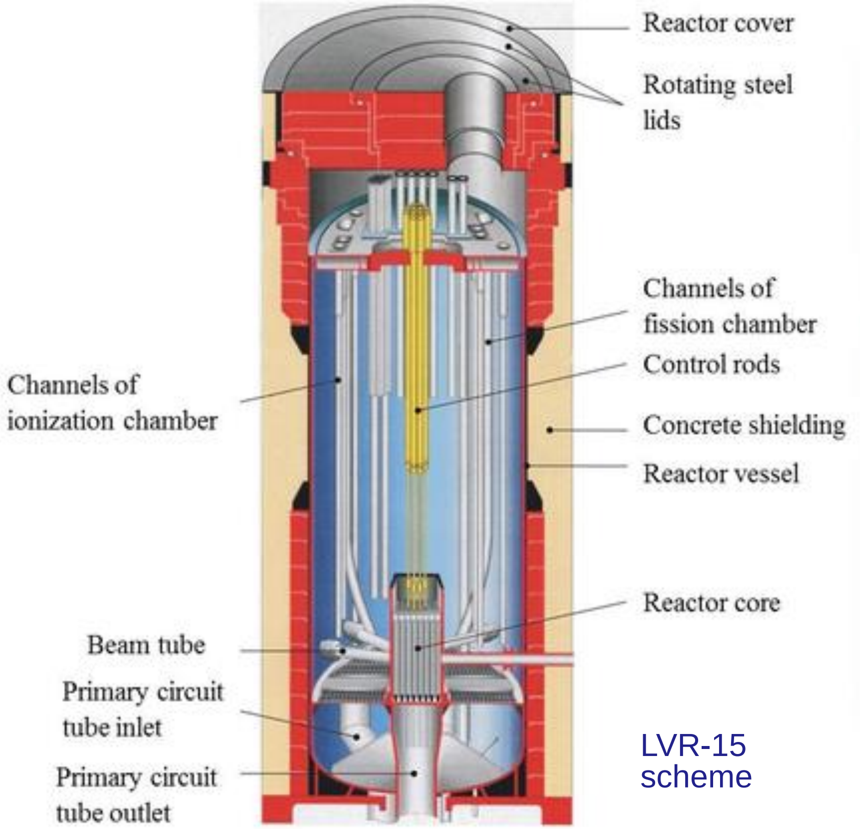


Flux density distribution
in reactor core
and FA MCNP calculation



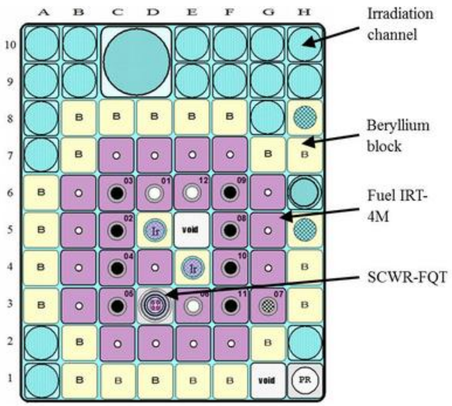
Special reactor core

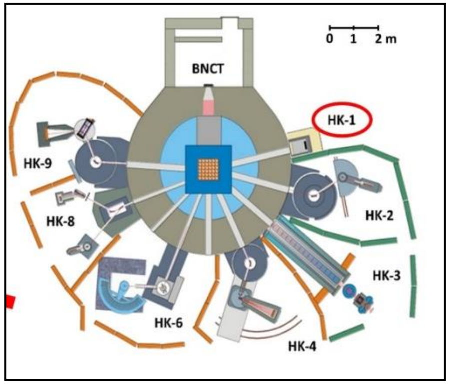
Neutron gamma (n,g) sources 3
Reactor LVR-15



LVR-15 scheme

LVR-15 reactor core



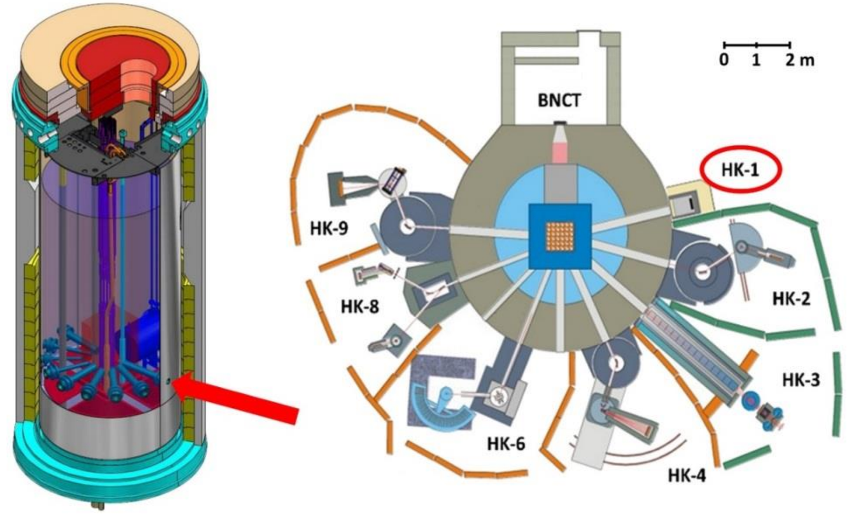


Irradiation channels

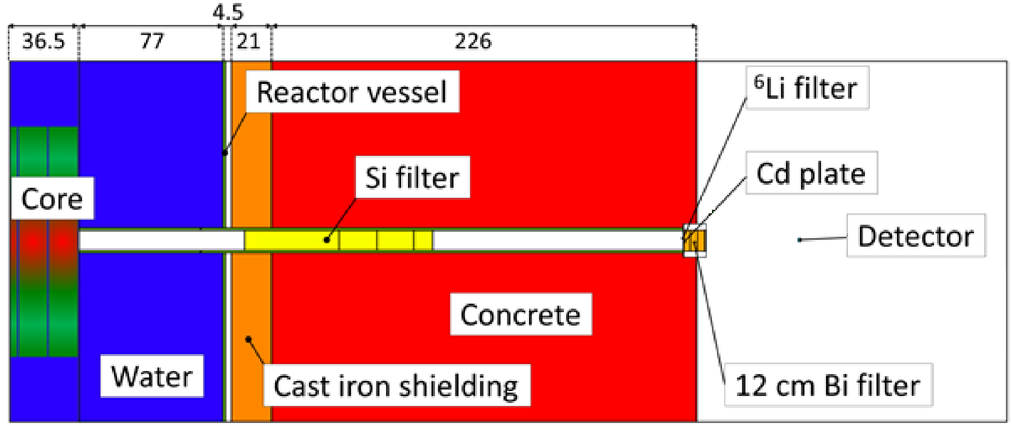
IRT-4 LVR-15 FA

Si-filtered beam at LVR-15

Shielding box with Si filter



Position of Si-filtered beam in LVR-15 - HK-1

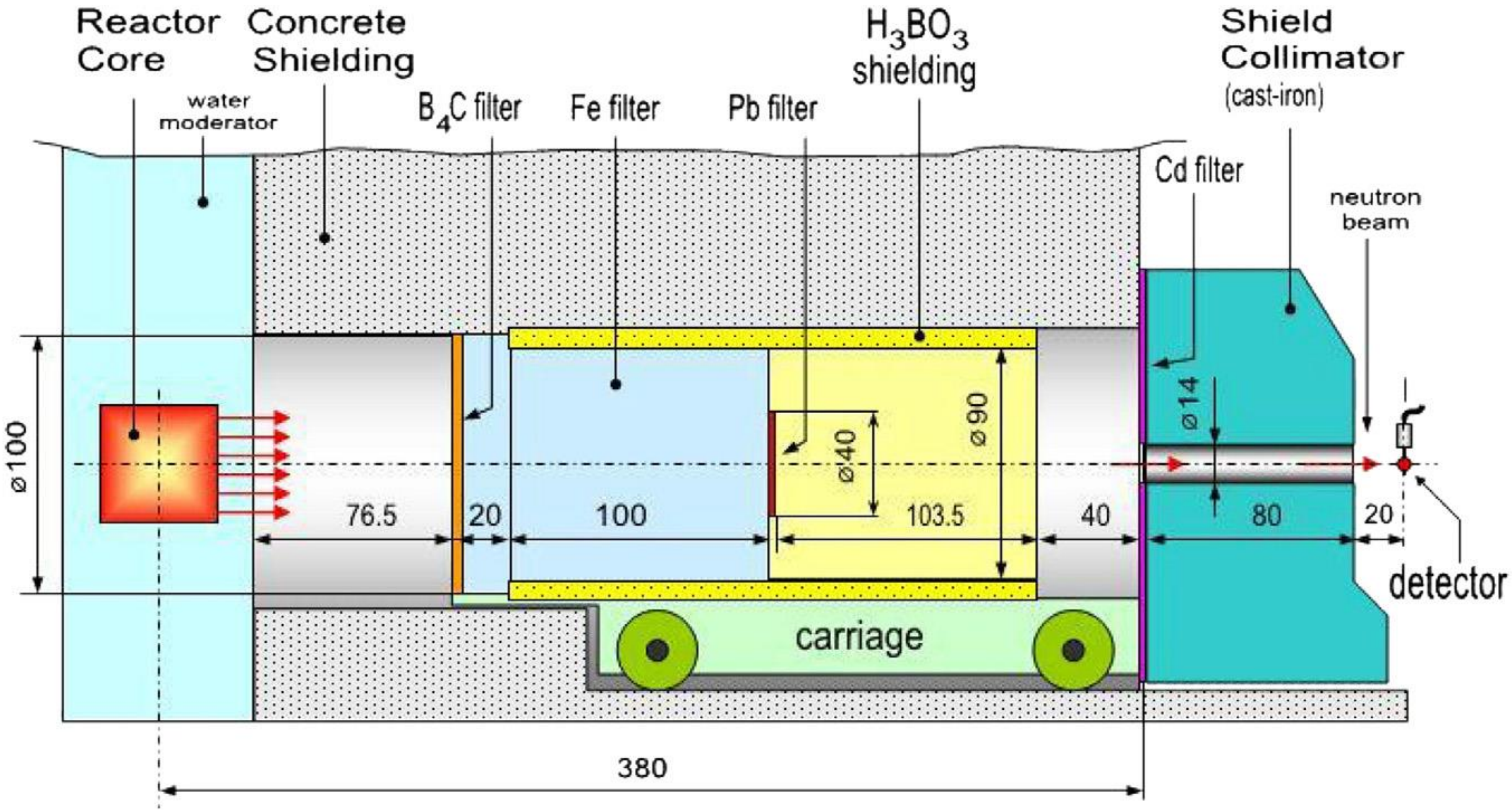


LVR-15 experimental channel HK-1

Silicon filtered beam spectrum contains characteristic peaks.

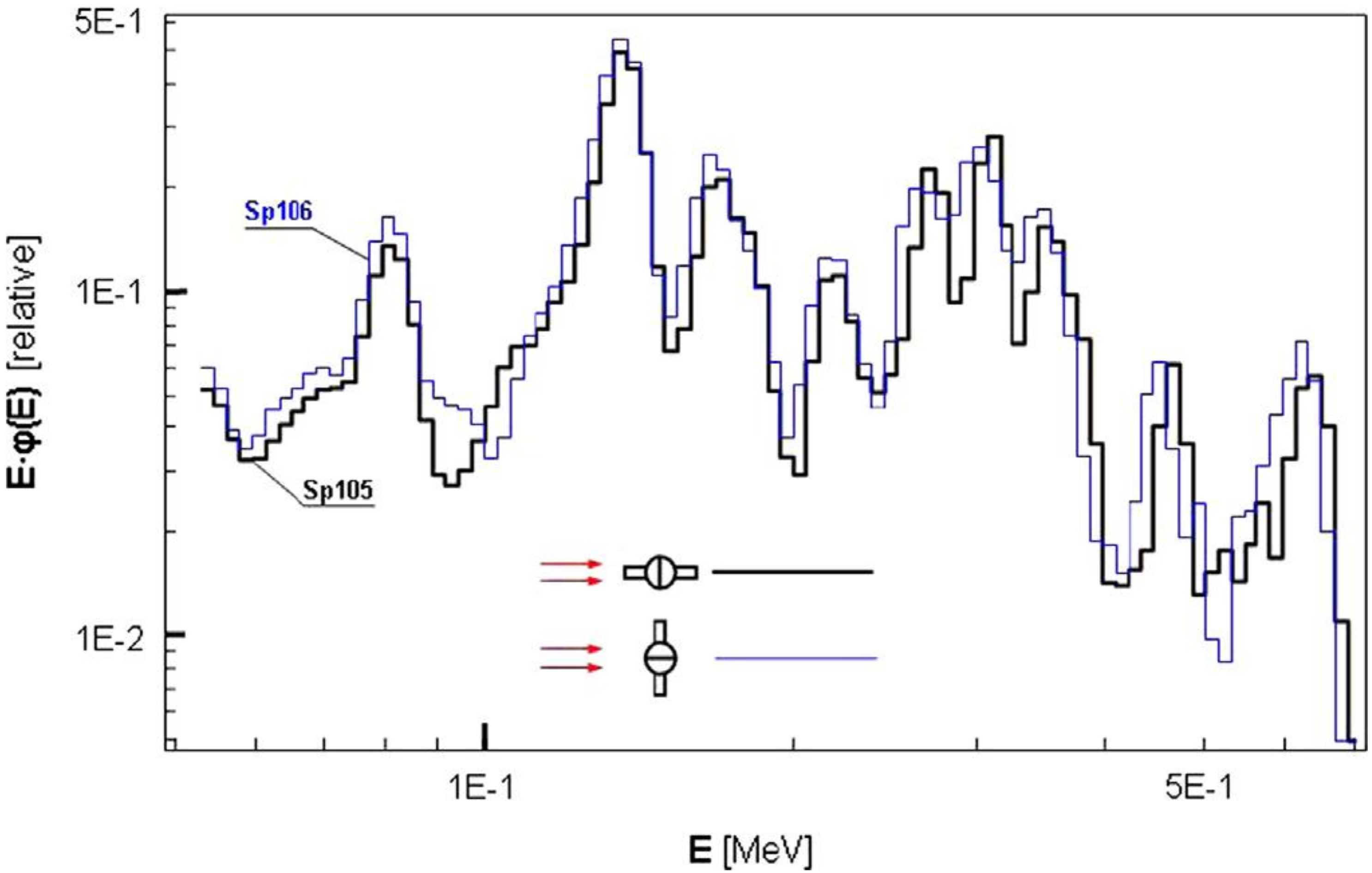
Suitable tool for validation of detectors and methods used in fast neutron spectrometry.

Iron filtered beam assembly – LVR-15



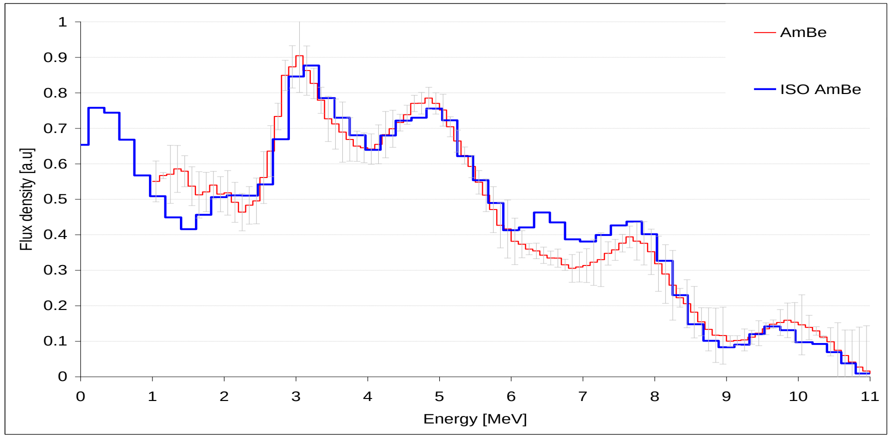
Location of therm column TK-10 in LVR-15
(all dimensions are in cm).

LVR-15 Fe filtered beam exploitation



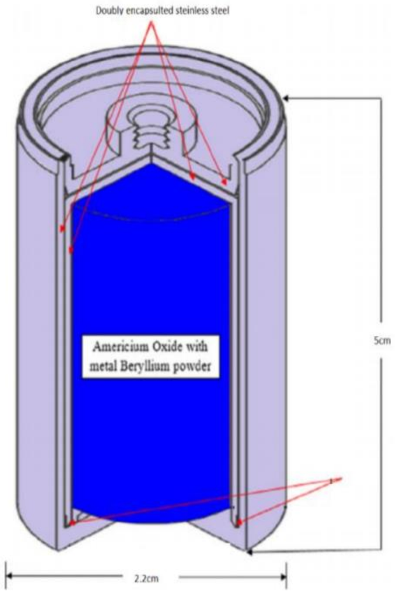
Influence of neutron beam angle relatively to detector axis, HV=2.8 kV, detector HPD of NOK-440 type.

Neutron source 4 – Am-Be

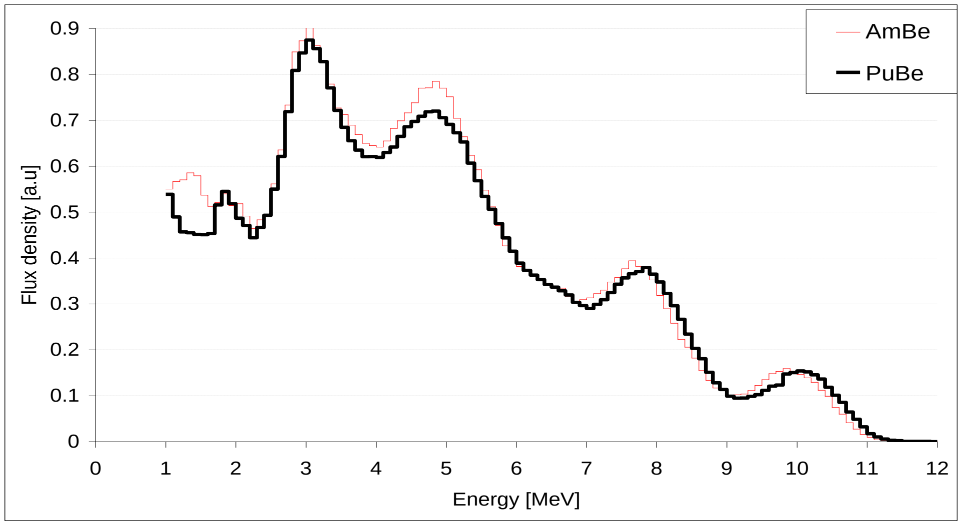


AmBe and ISO "standard" spectrum comparison

- **AmBe is not standard, every source is „unique"**
  - Source construction
  - Porosity
  - AmO_2, Be grain size, density
- **However measured AmBe spectra is close to „tabulated values" (ISO AmBe)**
- **AmBe and ^{238}PuBe available in CVR**



AmBe source in double coated stainless steel box



AmBe/PuBe spectrum comparison

Neutron source 5 - Cf-252

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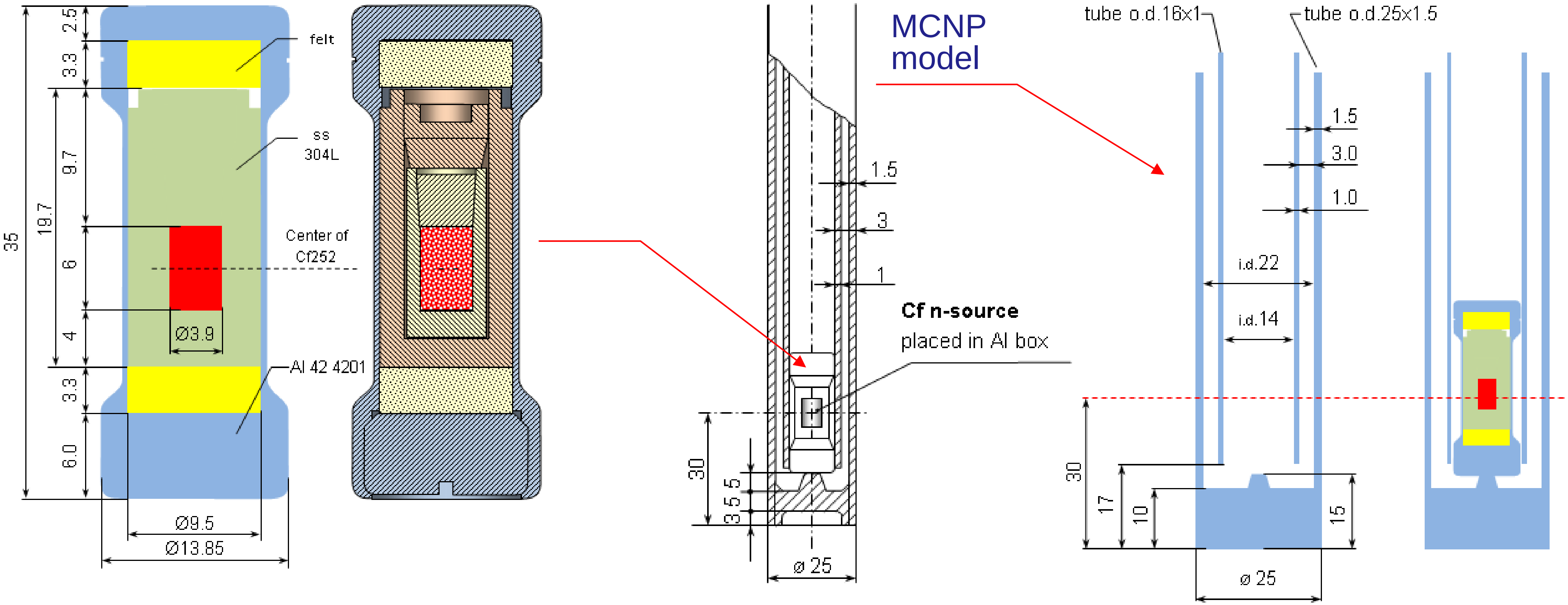
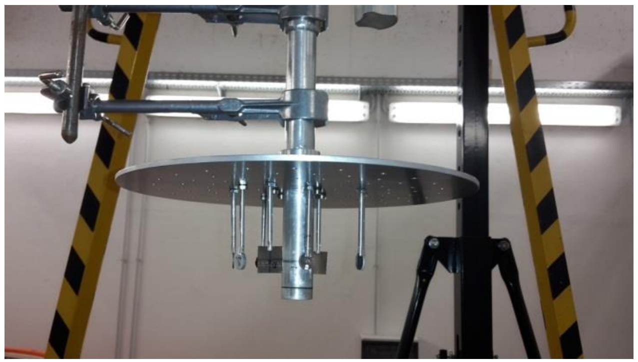


Transport box for Cf-252 neutron source (right)

Q=3.5E8 n/s (20.6.2019)



Instrumentation - Flexo-Rabbit Ending

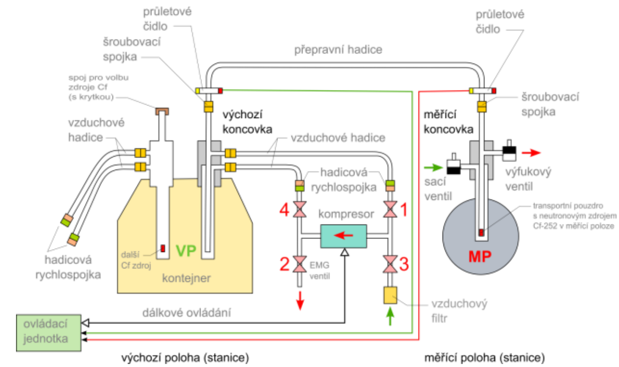
Irradiation Box for
powder material “bulk”
activation “foils”
FLiBe, NaF,…
with Flexo-Rabbit ending

AF placement at the
surface of Fe 50 cm
On the left-top
is Al Flexo-Rabbit ending

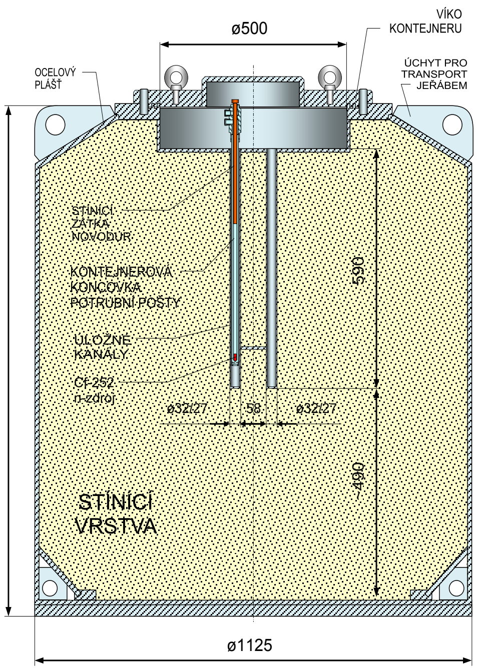
Shielding container and Flexo Rabbit

Flexo-Rabbit nosle/ending (AF irradiation)

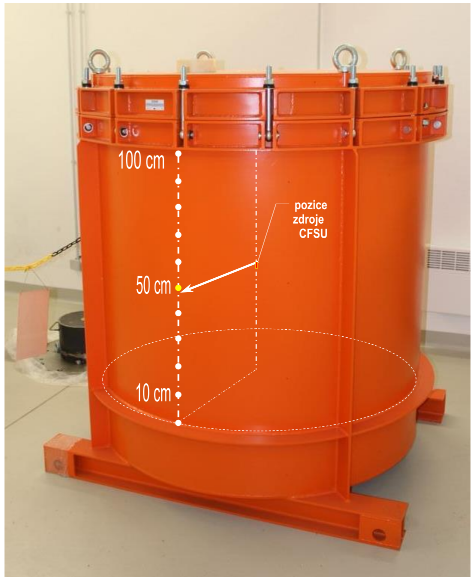
Transport container with Cf-252



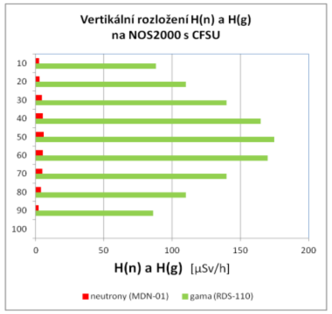
Principal scheme of Flexo-Rabbit



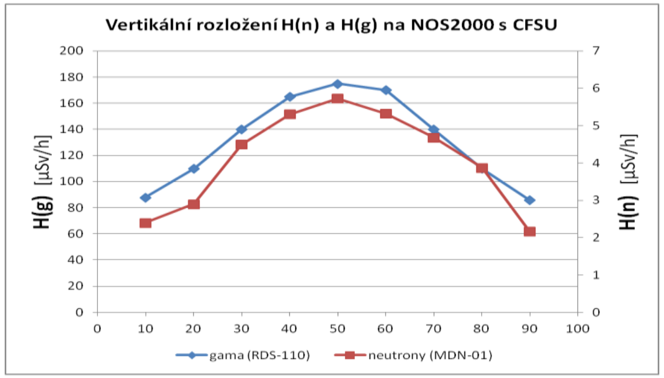
Shielding container



Transport container (ADR)



Pozice na NOC2000	gama (RDS-110)	neutrony (MDN-01)
[cm]	[µSv/h]	[µSv/h]
100	x	x
90	86	2,2
80	110	3,9
70	140	4,7
60	170	5,3
50	175	5,7
40	165	5,3
30	140	4,5
20	110	2,9
10	88	2,4



Neutron and gamma flux distribution

Principal scheme of leakage neutron spectra measurement

Principal scheme of the leakage neutron spectrum measurement

Iron sphere of diam. 100cm.

Shadow Cone:
Fe – iron,
PE+B
(polyethylene
with boron)

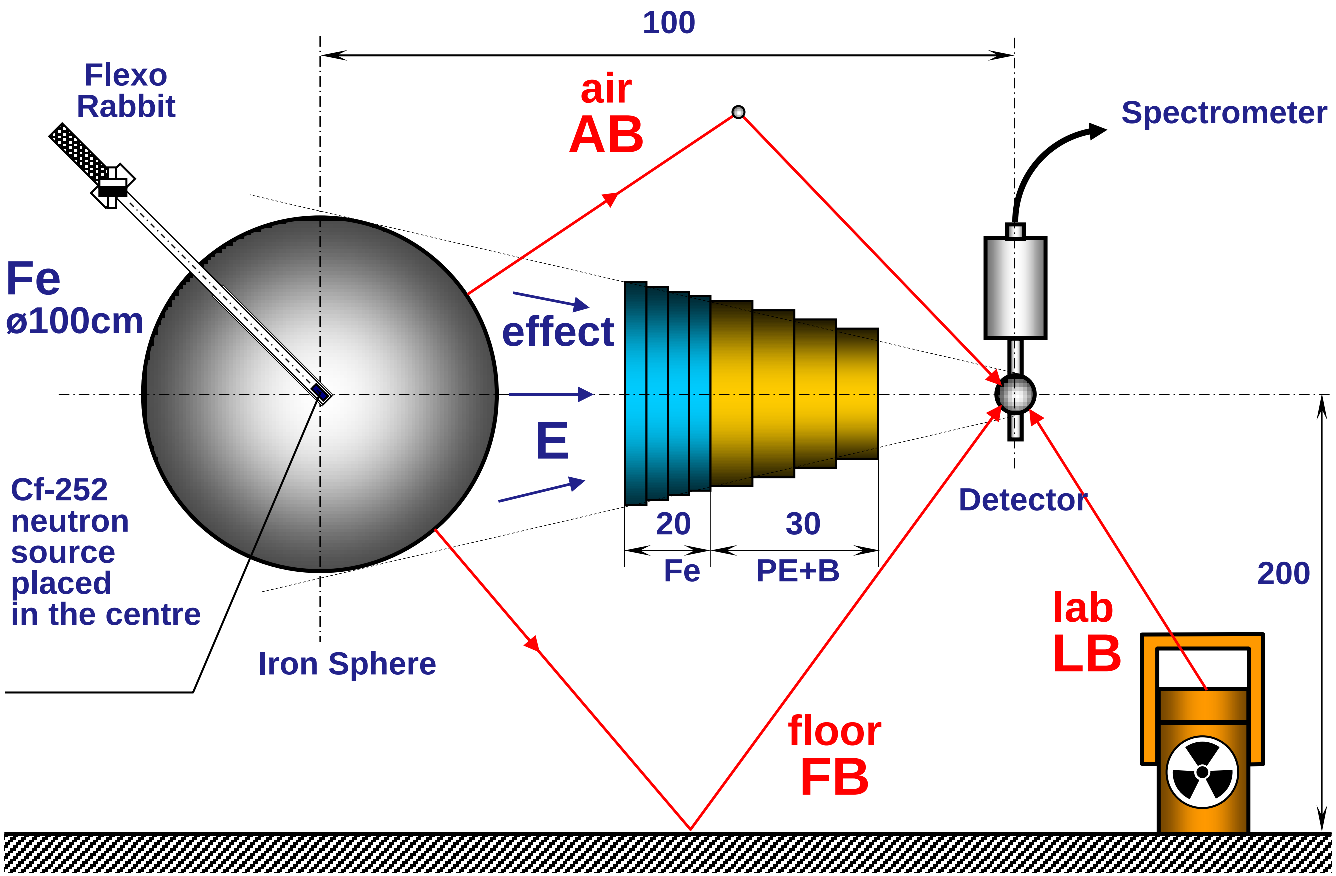
Other assemblies are simmilar

EFFECT E EVALUATION

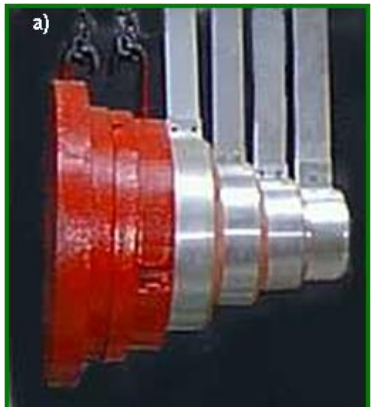
A = E + AB + FB + LB - meas. without shadow cone

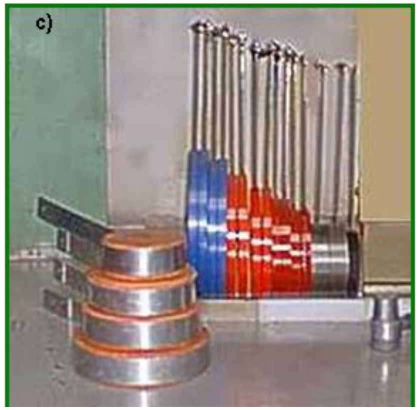
B = AB + FB + LB - meas. with shadow cone

E = A - B



Benchmark assemblies 1



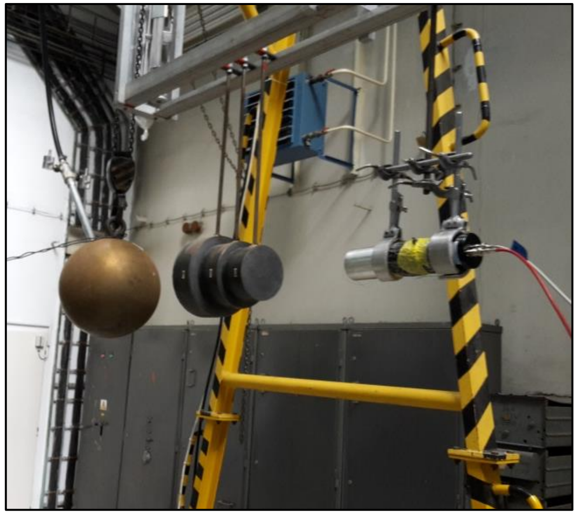


Shielding Cones

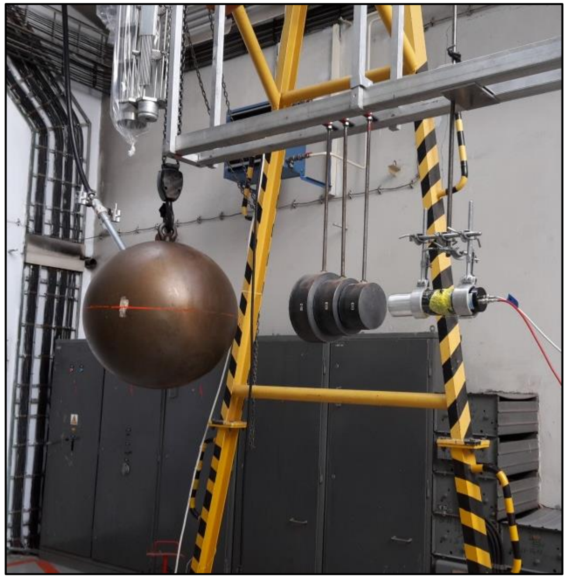
Fe 100 cm
E_n<1MeV - neutrons

Spherical assemblies:
H_2O, D_2O, Fe, Ni

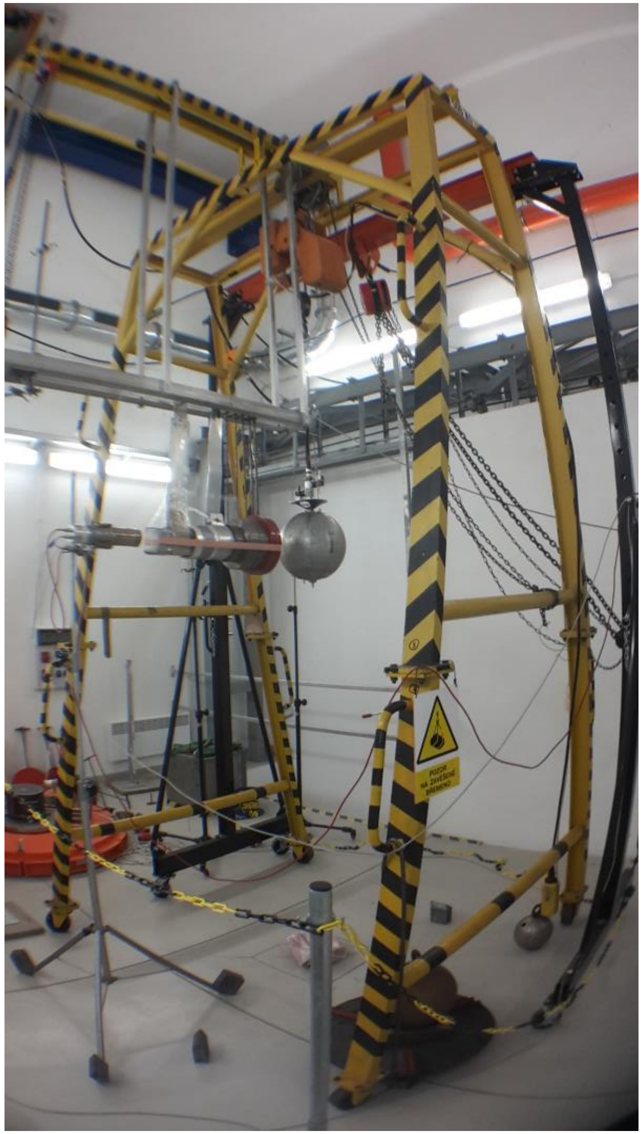
Benchmark assemblies 2



Fe 20cm gamma

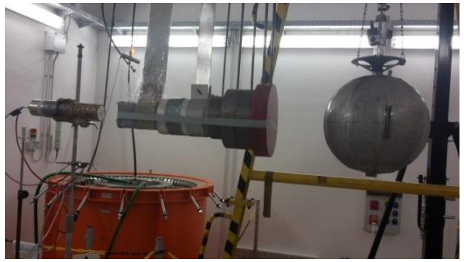


Fe 50cm gamma

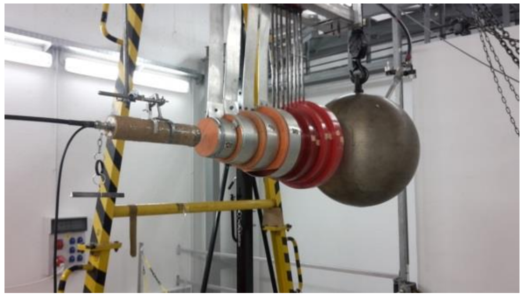


Cf-252 hall view

Stainless Steel cube 40x40x40cm



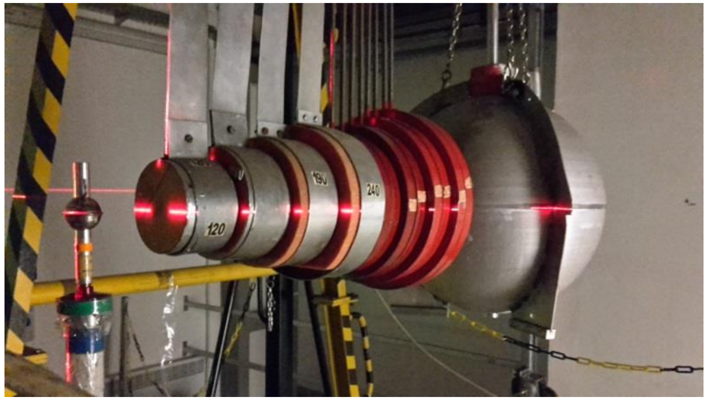
D_2O o.d.30 cm



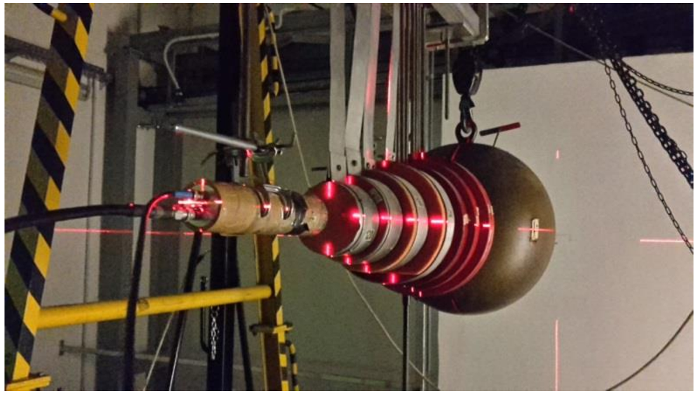
Fe 50cm neutrons

Benchmark assemblies 3

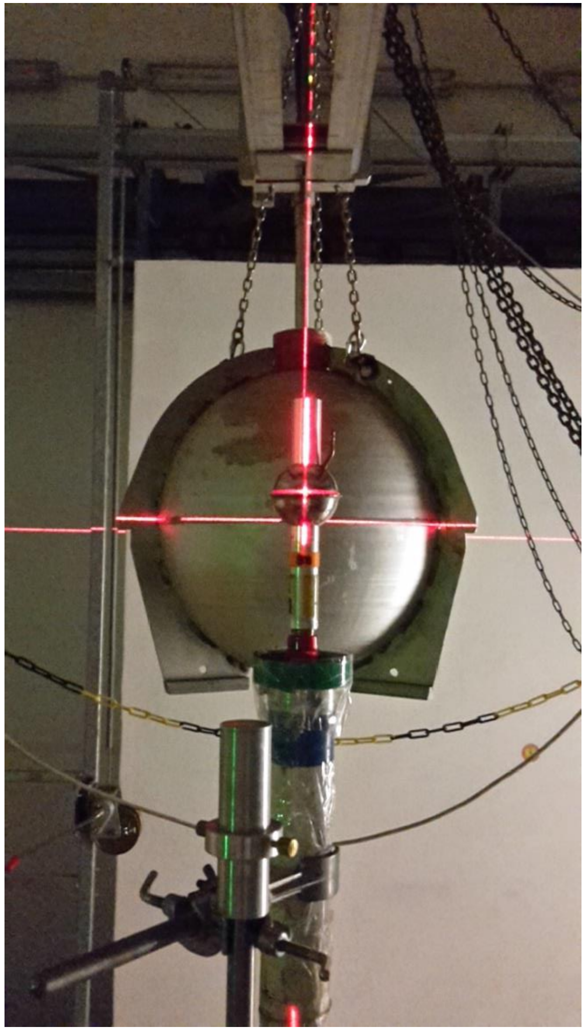
Fe 50cm neutrons
E_n<1 MeV



D_2O 50cm neutrons
Shielding Cone Fe, PE+B



Fe 50cm neutrons
E_n>1 MeV
(stilbene detector]



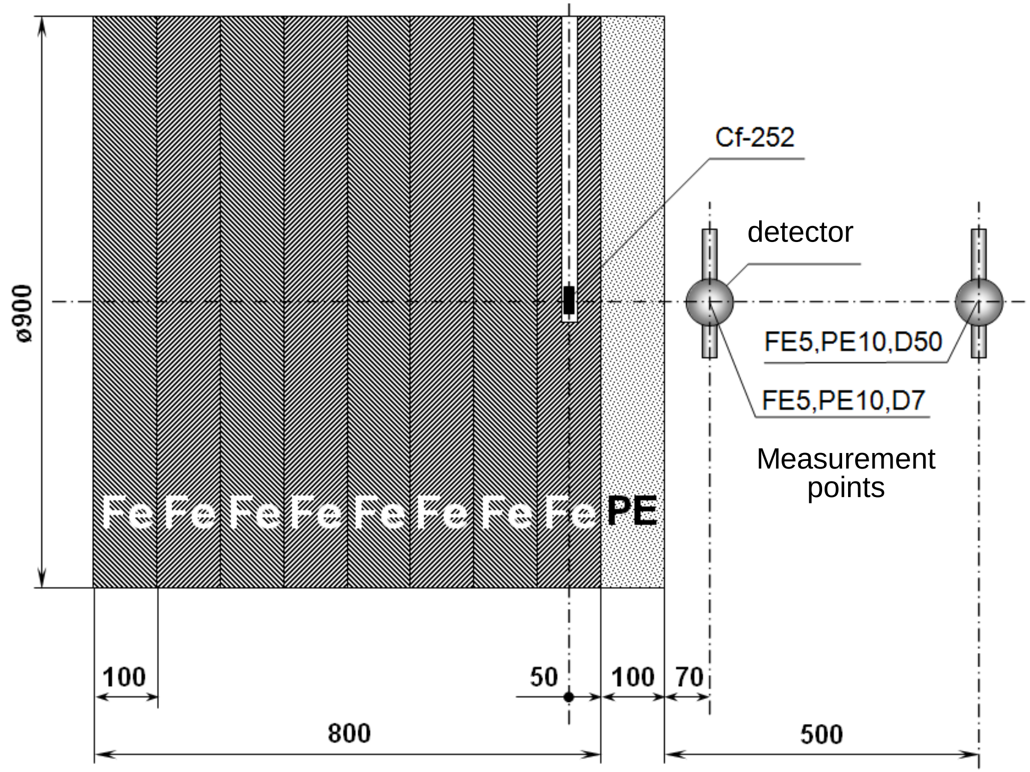
D_2O 50cm neutrons
E_n<1 MeV

Benchmark experiments 4

Fe 50 cm sphere placed in the height of 7 m above the hall floor (standard height is 2m)

Measurement of influence of Fe sphere distance from floor on the shape of neutron spectrum

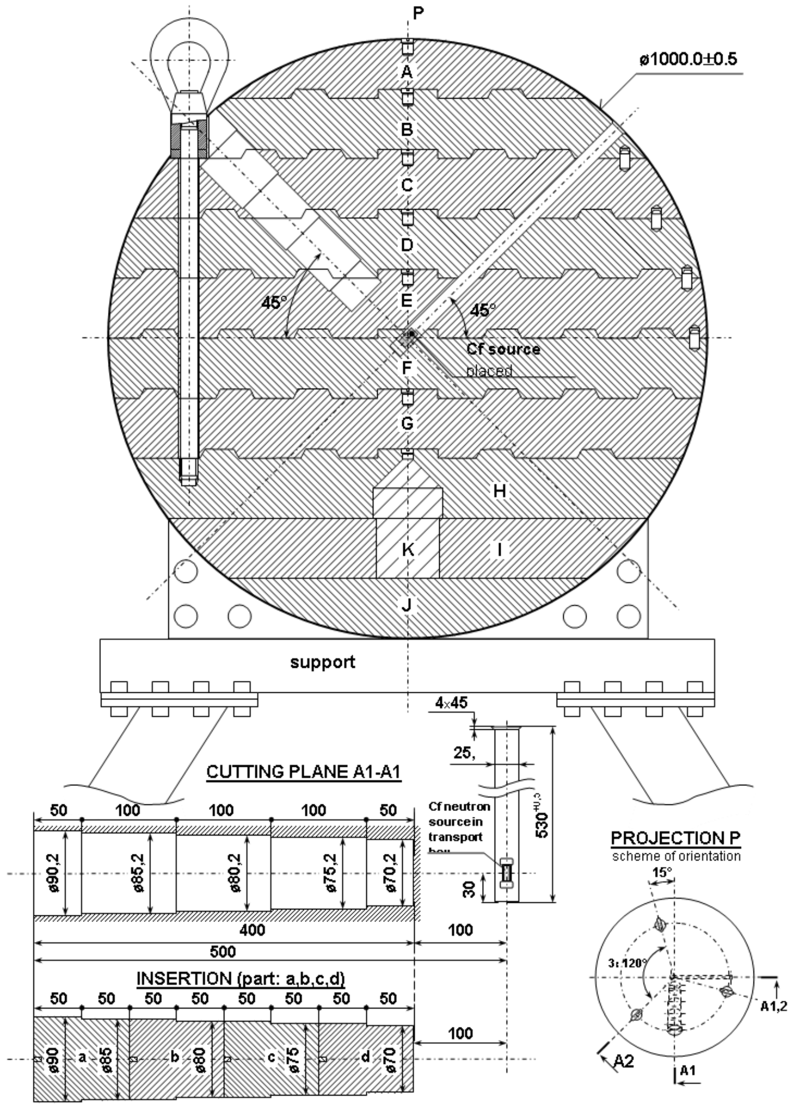
Fe cylinder and PE slab

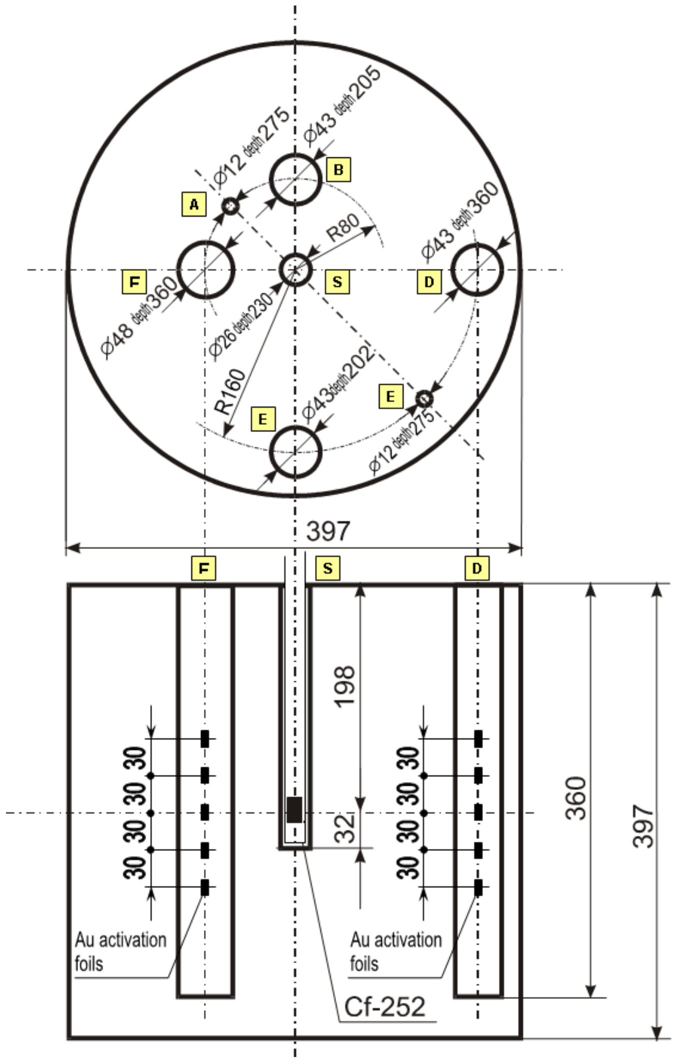


Fe cylinder anfd PE slab – all dimension are in mm

Fe cylinder
At the right side is parafine barrel thermal neutron laboratory standard

Benchmark assemblies – schemes
Fe 100 sphere allows measurement inside iron

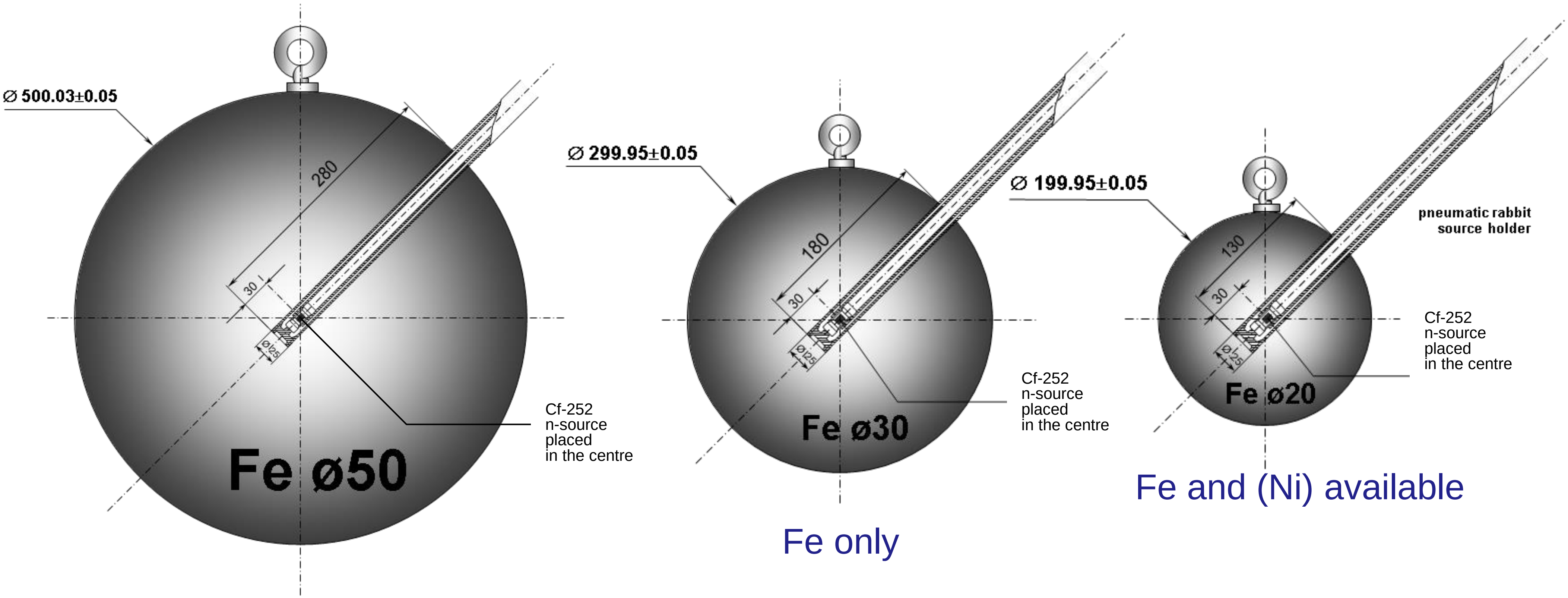




Fe 100 cm (~4 tones)
(only Fe)

Parafin barrel (cylinder)

Benchmark assemblies: Fe, Ni - spheres

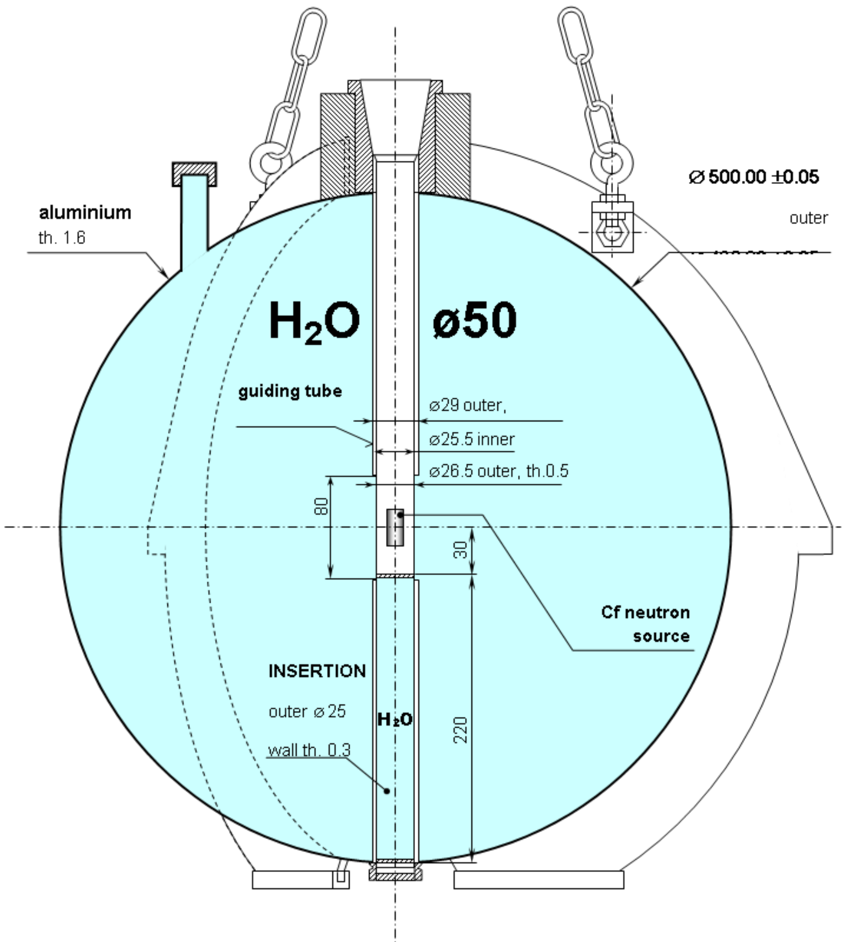


Fe and (Ni) available

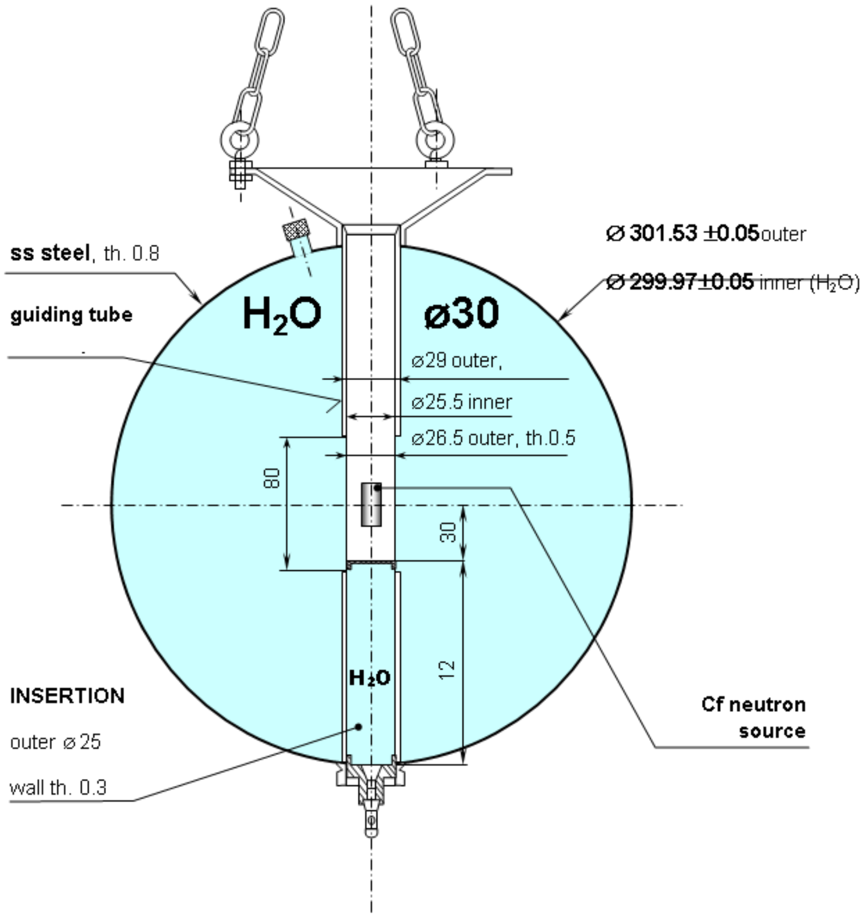
Fe only

Fe and Ni available

Benchmark assemblies: H_2O, D_2O - spheres

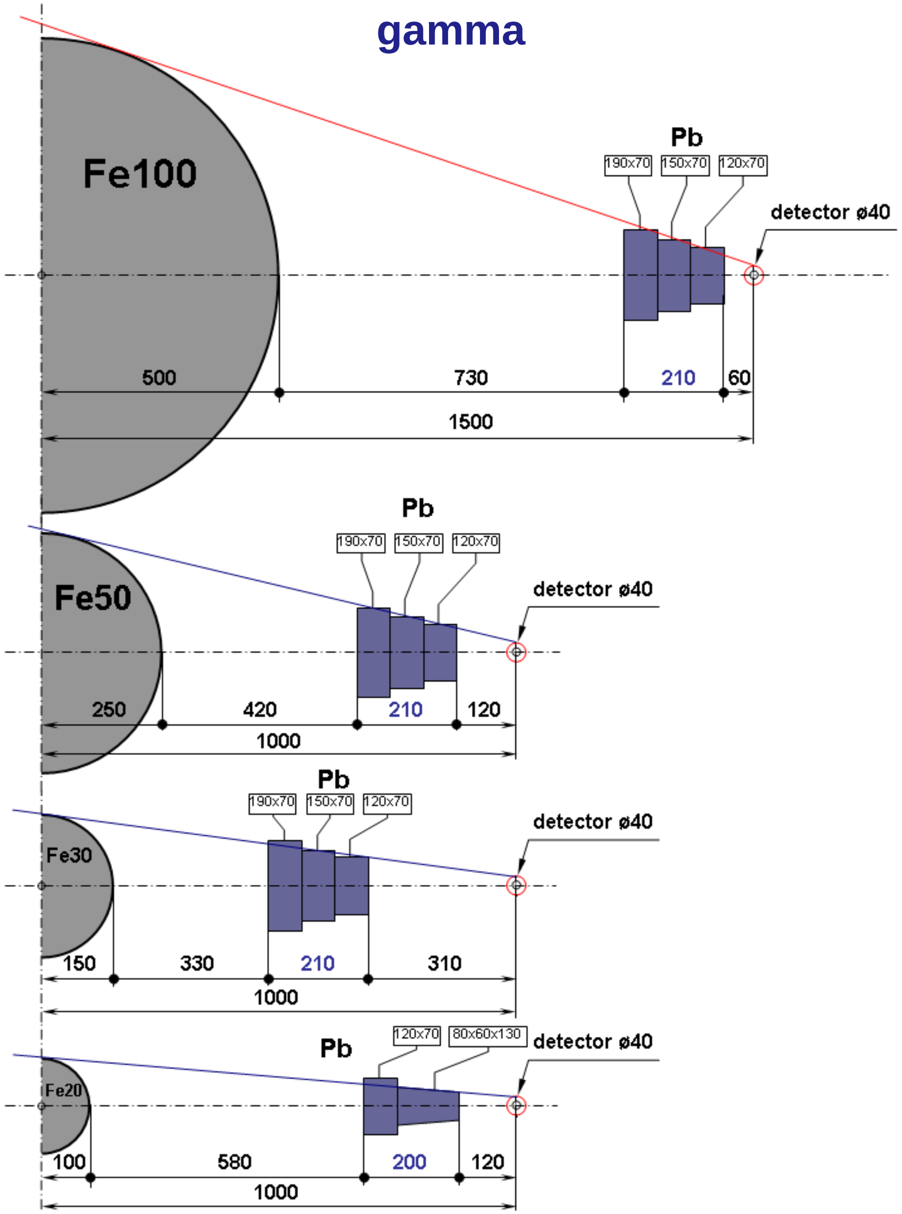


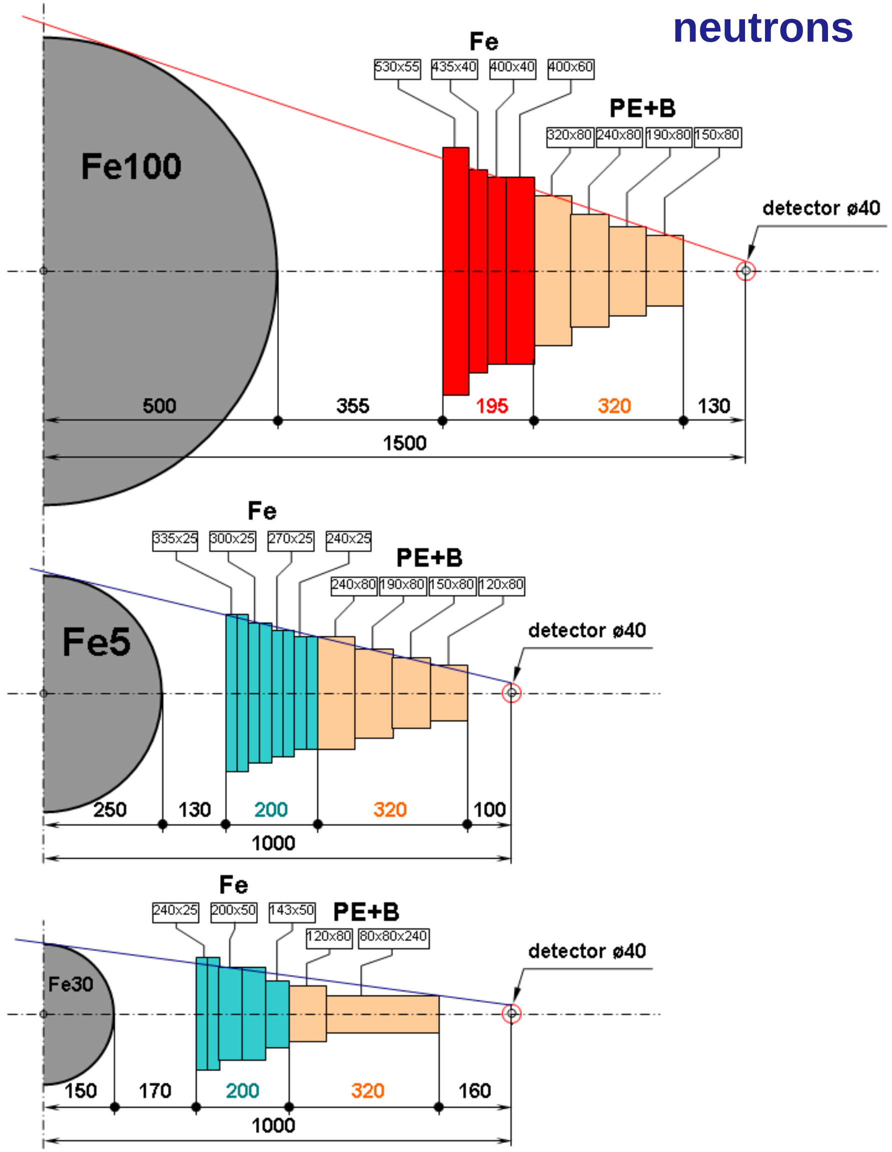
H_2O, D_2O available



H_2O, D_2O available

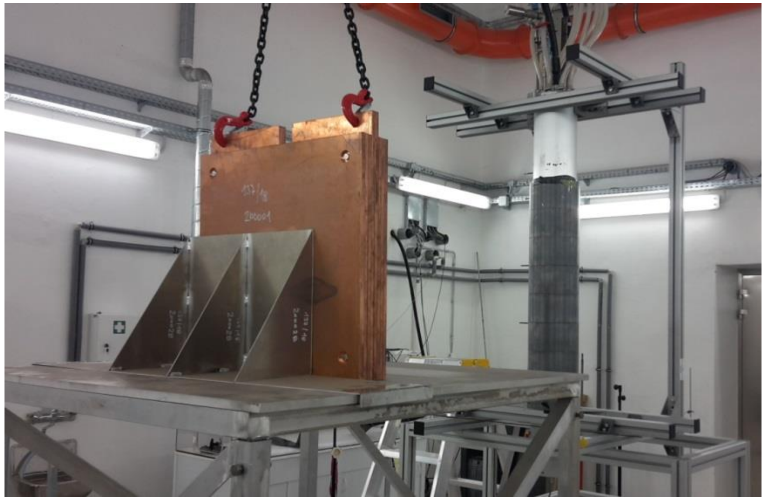
Shielding Cones for gamma and neutrons



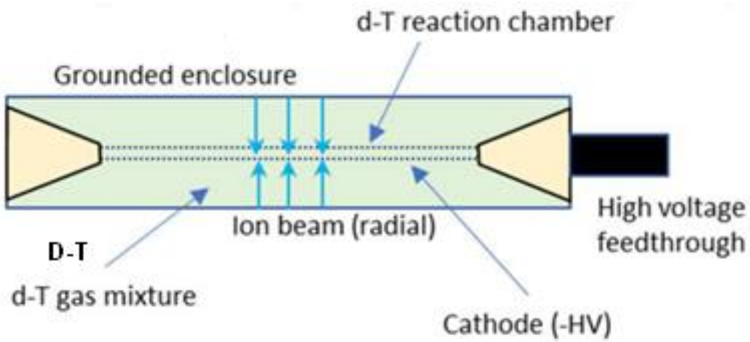


Neutron generator 14 MeV

NG – vertical position
with Pb shielding
of bremsstrahlung

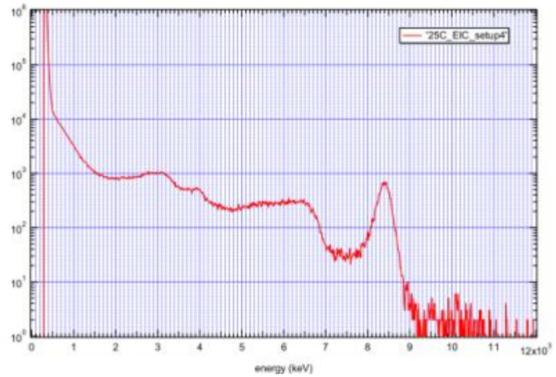


Cu and Pb slabs – for C/E **fusion** data validation



Principal scheme of NG
„sealed tube“

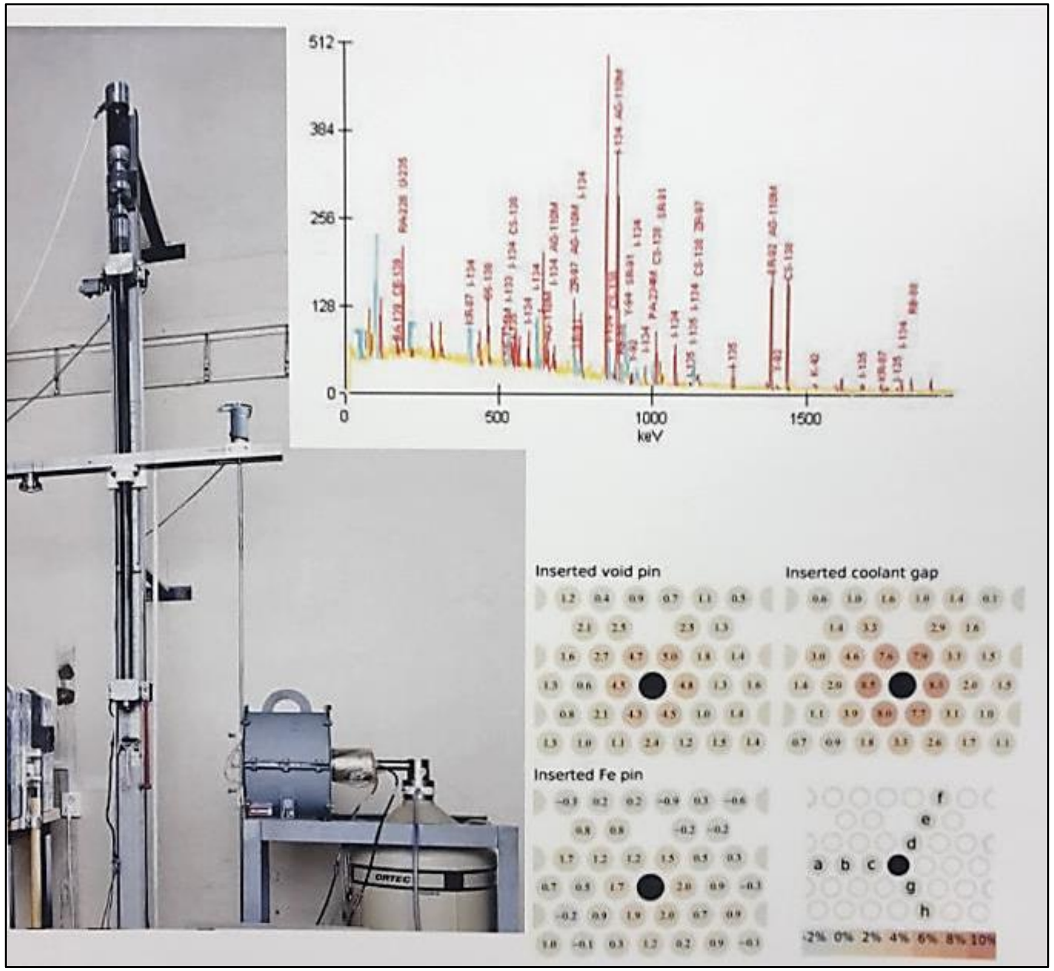
Max Q_{n14MeV} = ~1E9 n/s



Neutron spectrum measured
with diamond detector close
to the axial axis.
Peak confirms presence of
14 MeV neutrons.

HPGe Gamma spectrometry

HPGe detector and spectrometer for AF and irradiated samples measurement SW - GENIE2000



Laboratory for Gamma scanning laboratory:
Equipped with HPGe detector inside the lead shielding. Axially movable and rotating irradiated fuel pins are scanned to determine the fission products activity for fission rate distribution measurement in LR-0 reactor core

Stilbene spectrometry in LR-0 labs

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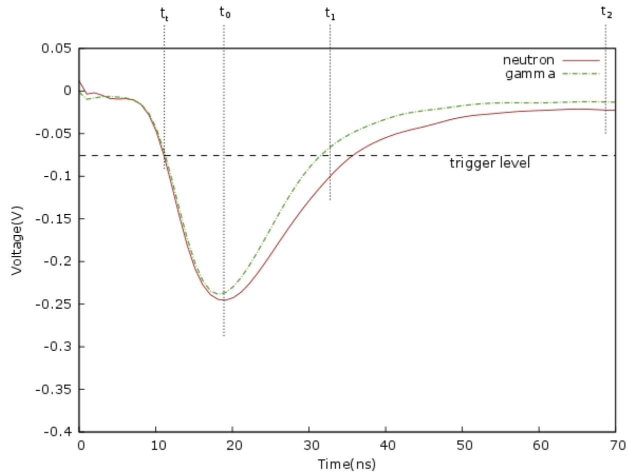
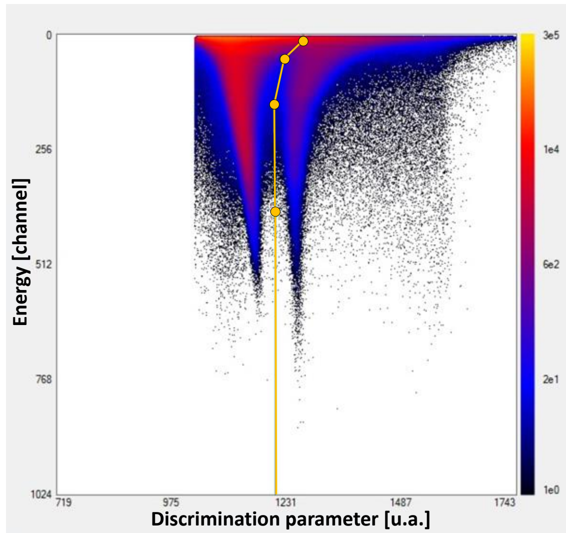
- **Measurement with stilbene scintillation spectrometry**
  - Pulse shape discrimination
  - Satisfactory resolution
- **Validated in Cf-252 and LVR-15 Si-filtered beam**



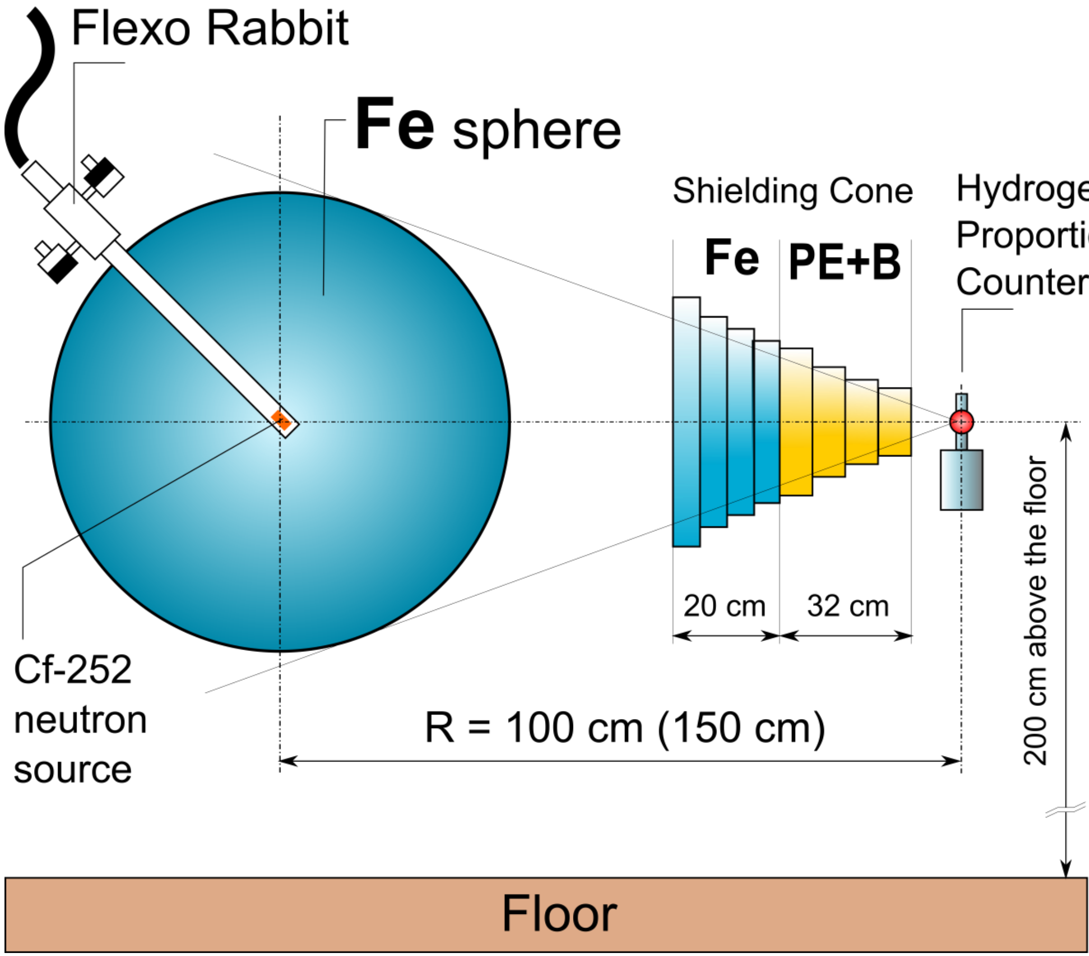
PSD principle – n/g pulse falling edge differs

Digital spectometer FD-13 with PSD
Stilbene Detector with Photomultiplier



PSD principle - n/g separation

Spherical benchmark assemblies (Fe,Ni,H_2O, D_2O,…)



Abbreviations used: **FE DIA100**, **R150**

It denotes Fe sphere of 100 cm diameter, R150 (cm)= distance „centre to centre“ (the sphere centre Cf to the centre of detector)

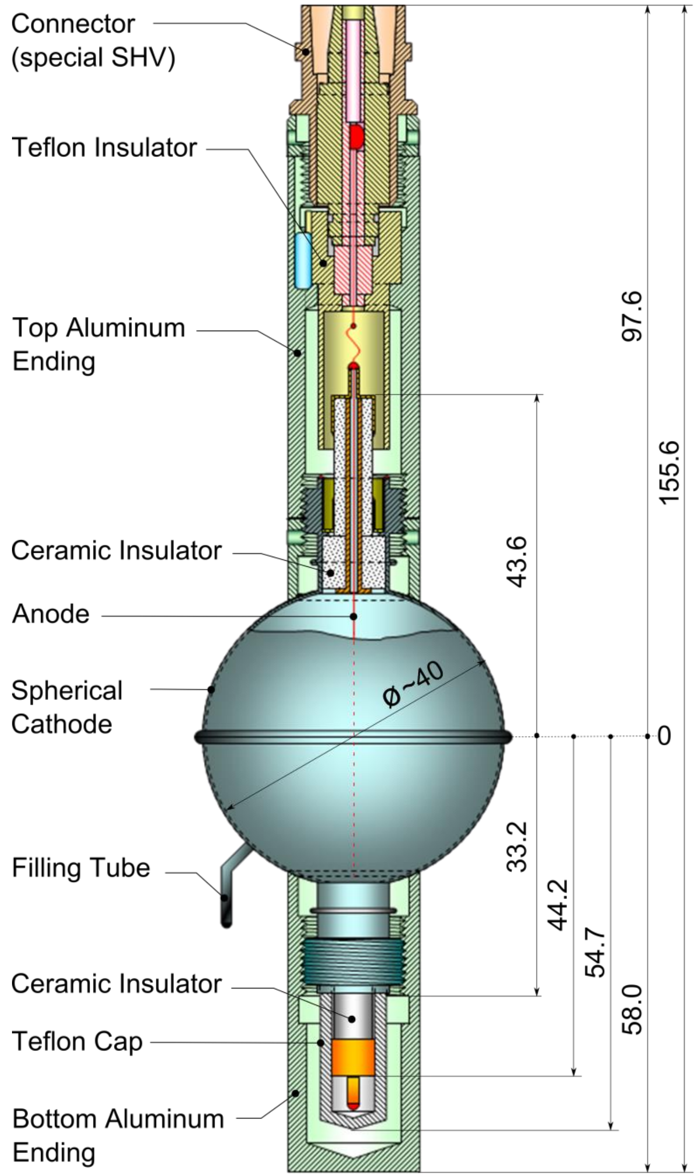
HPD Neutron spectrometry
(HPD = Hydrogen proportional detectors)

Detectors used with neutron spectrometers

Detector type	Type	Pressure	Dimension	Energy range [MeV]
Proportional Counter filled by Hydrogen (HPD)	NOK145 NOK445 NOK1045	100 kPa 400 kPa 1000 kPa	Ø 40 mm	0.01-0.3 0.2-0.8 0.5-1.3

HPD detectors of o.d. 40 mm (NOK type, Poland), and o.d. 30 mm (Czech Rep.), cylindrical protection covers made of boron and stainless steel are in background

NOK type HPD o.d. 45 mm



Methodology of MCNP calculation

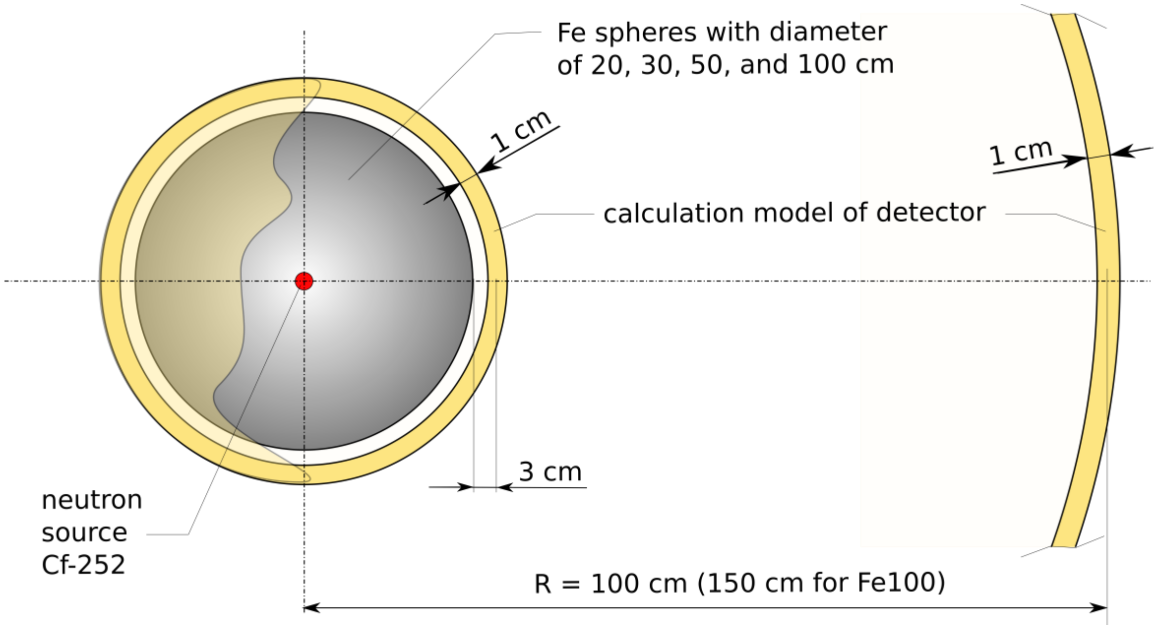
Calculations

The calculations were performed using Monte-Carlo program MCNP.

As for geometry description a simplified model was used which substitutes assembly elements with concentric spherical shells around the source.

Also the detector is represented by a **1 cm** thick spherical shell with radius equal to the real detector-source distance

(R=28 and 100 cm).



The energy bin structure of resulting tallies was chosen to be logarithmic, either with **40 or with 200 groups per decade**. Contemporary the energy scale with constant energy step (0.1MeV) is used in calculation for using in C/E comparison for stilbene.

Data libraries commonly used for MCNP calculation:

JEFF-3.1, JEFF-3.2, JEFF-3.3 (A.Blokhin, IPPE Obninsk, Russia)

ENDF/B-VIII.0 (CIELO) (J.Rejchrt, CVR Czech Republic)

Tab.1 FE DIA100, R53, C/E comparison, see Fig.1 (C/E= Calculation / Experiment)

Assembly FE DIA100, R53,					
En.range[MeV]		C/E			
From	To	ENDF/BVIII.0	JEFF-3.1	JEFF-3.2	JEFF-3.3
0.013	1.290	1.045	1.054	1.066	1.052
0.013	0.033	0.9138	0.9822	0.9867	0.9948
0.033	0.060	0.9005	1.015	0.9757	1.020
0.060	0.090	0.9702	0.9779	0.9781	0.9885
0.090	0.150	0.9934	1.003	1.008	1.006
0.150	0.200	1.037	1.018	1.021	1.008
0.200	0.250	1.028	1.021	1.022	1.013
0.250	0.289	1.036	1.017	1.023	1.005
0.289	0.333	1.333	1.245	1.276	1.230
0.333	0.367	1.305	1.269	1.303	1.268
0.367	0.410	1.191	1.183	1.216	1.170
0.410	0.520	1.033	1.089	1.115	1.079
0.520	0.780	1.089	1.07	1.102	1.062
0.780	1.060	0.7834	1.053	1.076	1.048
1.060	1.290	0.7584	0.8655	0.8912	0.8646

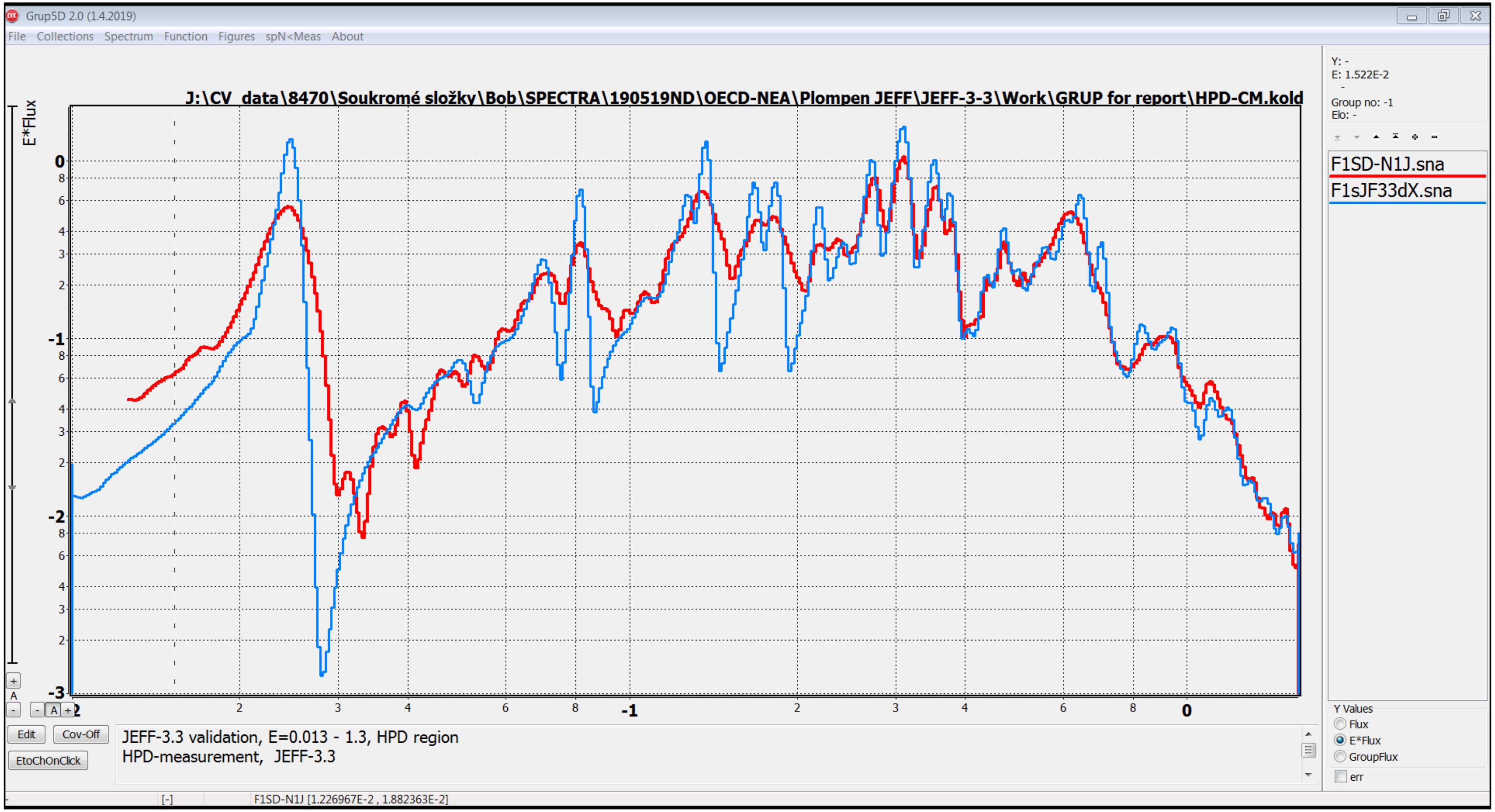
Green	D abs<5%
Orange	D=5-10%
Red	D>10%
Light blue	D=-(5-10%)
Dark blue	D< -10%

En=0.013-1.3MeV
(“HPD region”)

EXP: HPD

CALC:
ENDF/B-VIII.0
JEFF-3.1
JEFF-3.2
JEFF-3.3

Fig.1 FE DIA100, R53; C/E comparison (see tab.1)



En=0.013-1.3MeV =“HPD region”, 200gpd HPD measurement **(red)**, calculation JEFF-3.3 **(blue)**, (see tab.1)

Tab.2 FE 50, R100, C/E comparison, see Fig.2

Assembly FE DIA50, R100					
En.range[MeV]		C/E			
From	To	ENDF/BVIII.0	JEFF-3.1	JEFF-3.2	JEFF-3.3
1.0	10.0	0.8442	0.9746	0.9744	0.9756
1.0	1.2	0.8396	0.8963	0.8964	0.8748
1.2	1.4	0.8781	0.9853	0.9850	0.9905
1.4	1.6	0.7347	0.8640	0.8622	0.8800
1.6	1.8	0.9308	1.0690	1.0690	1.0970
1.8	2.0	0.8911	1.0690	1.0710	1.0950
2.0	3.0	0.8390	1.1020	1.1020	1.1150
3.0	4.0	0.8102	1.1850	1.1870	1.1910
4.0	5.0	0.8416	1.1250	1.1170	1.1130
5.0	6.0	0.8557	1.0060	1.0070	1.0030
6.0	7.0	0.8708	1.0270	1.0280	1.0300
7.0	8.0	0.8755	1.0350	1.0370	1.0500
8.0	9.0	0.9337	1.1030	1.1020	1.1140
9.0	10.0	0.8906	1.0280	1.0430	1.0580
10.0	12.0	0.8707	0.9366	0.9324	0.9408
12.0	14.0	0.7554	0.7897	0.7423	0.7728
14.0	16.0	0.6235	0.5624	0.5850	0.5581

(green)	D abs<5%
(orange)	D=5-10%
(red)	D>10%
(light blue)	D=-(5-10%)
(dark blue)	D< -10%

En= 0.8-16 MeV
(„stilbene region")

EXP: F5-mean-4in
(mean value from 4 independent measurements)

CALC:
ENDF/B-VIII.0
JEFF-3.1
JEFF-3.2
JEFF-3.3

Fig.2, Assembly FE DIA50, R100, C/E , En=0.8-17MeV, stilbene region,
Experiment: F5-mean-4in (=mean from 4 independent measurements), (red)
Calculation: JEFF-3.3 (blue) (see Tab.2)

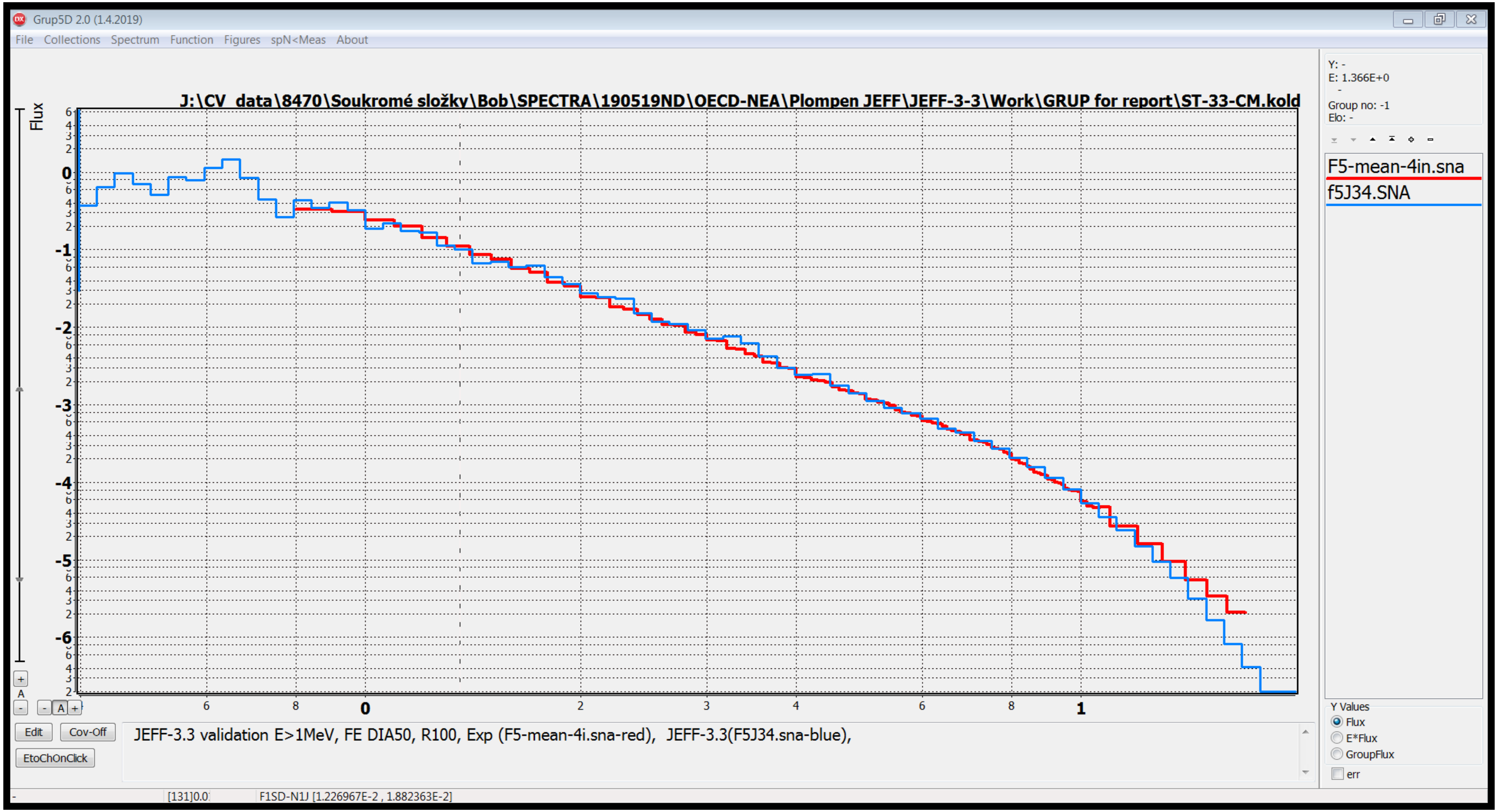
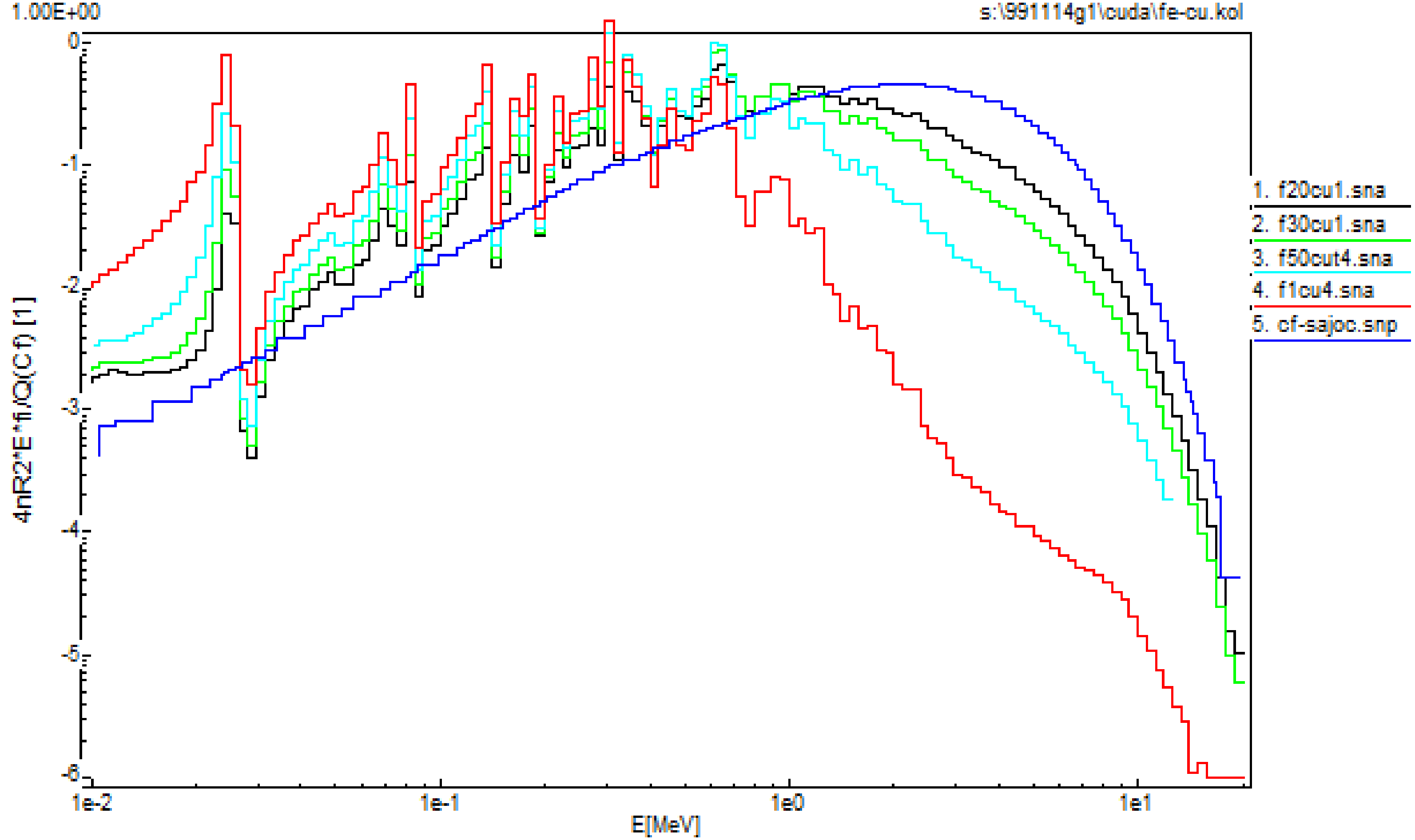


Fig.3a, FE DIA20,30,50,100, R100 (150), neutron spectra calculation (P.Cuda)



Fe spheres, o.d. 20,30,50,100cm**, n-spectrum**
Calculation - Cuda (Military Academy, Brno, Czech. Rep.); bare Cf - blue

Fig.3b, FE DIA20,30,50,100, R100 (150) gamma spectra calculation (P.Cuda)

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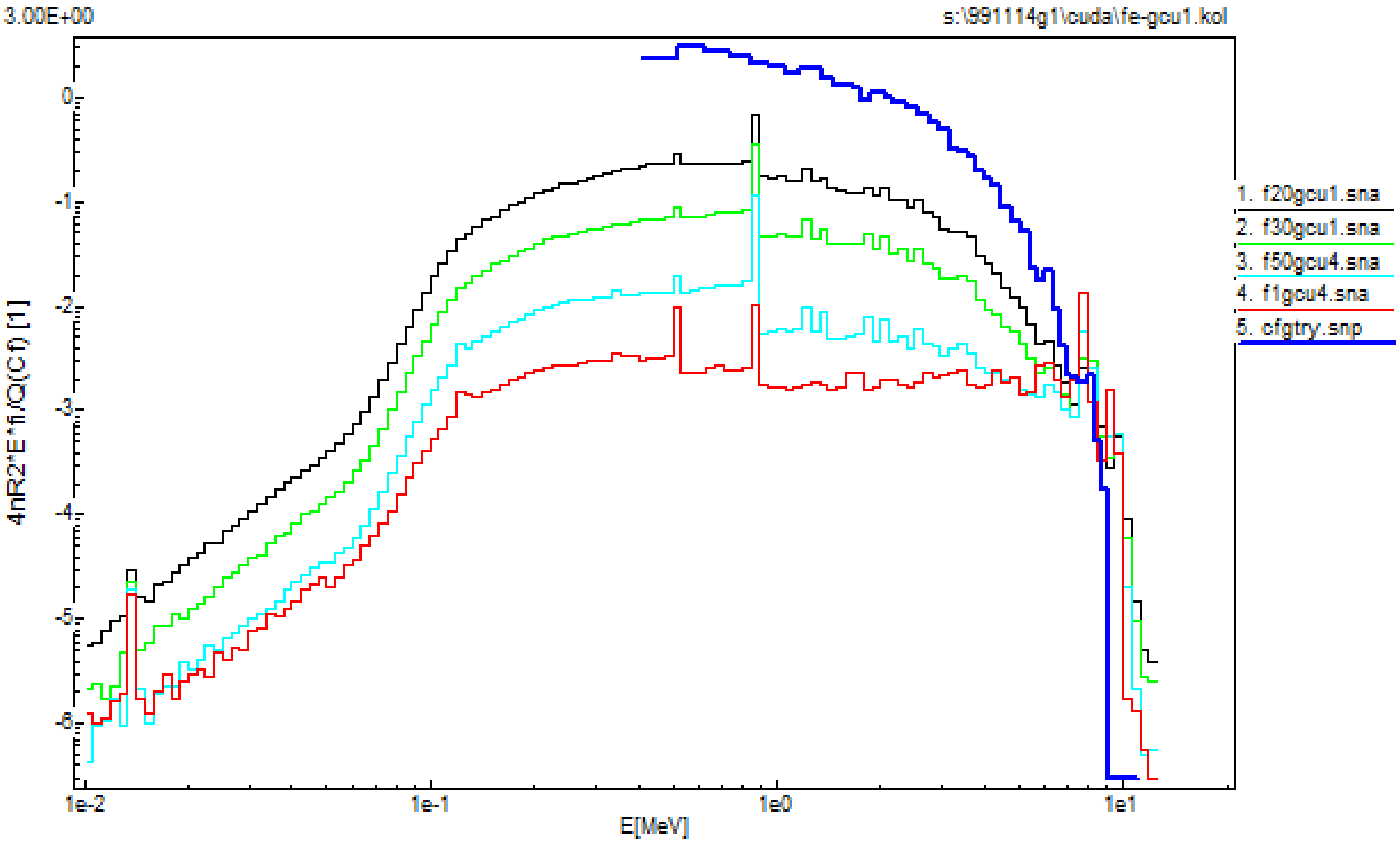

Fe spheres, o.d. 20,30,50,100cm, **g-spectrum ,** Calculation - Cuda , Input Cf-252 gamma (L.Trykov , IPPE Obninsk, Russia, measured by stilbene, blue)

Tab.3 Assembly FE DIA 20,30,50,100 C/E comparison, dependence C-E on Fe thickness , see Fig.3

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Energy range[MeV]		Integral values[1]								dependence C/E on Fe thicknes
		Fe20		Fe30		Fe50		Fe100		
from	to	CAL/EXP	U[%]	CAL/EXP	U[%]	CAL/EXP	U[%]	CAL/EXP	U[%]	
0,1	1,3	1,135	0,65	1,117	0,53	1,094	0,29	1,145	0,49	nearly const.
0,1	0,2	1,124	2,85	1,142	1,9	1,125	0,94	1,151	1,01	nearly const.
0,2	0,4	1,182	1,96	1,178	1,41	1,149	0,62	1,198	0,79	nearly const.
0,4	0,8	1,192	0,75	1,150	0,64	1,115	0,32	1,119	0,75	decrease slowly
0,8	1,0	1,128	1,35	1,101	1,29	1,009	0,68	0,775	2,22	decrease
1,0	1,3	0,974	1,32	0,901	1,25	0,773	0,76	0,538	3,28	decrease rapidly

C/E>1,15

C/E>1,10

0,9<0C/E<1,1

C/E<0,9

C/E<0,8

Fig.3 Assembly FE DIA 20,30,50,100, 40gpd, C/M dependence C-E on Fe thickness, see tab.3

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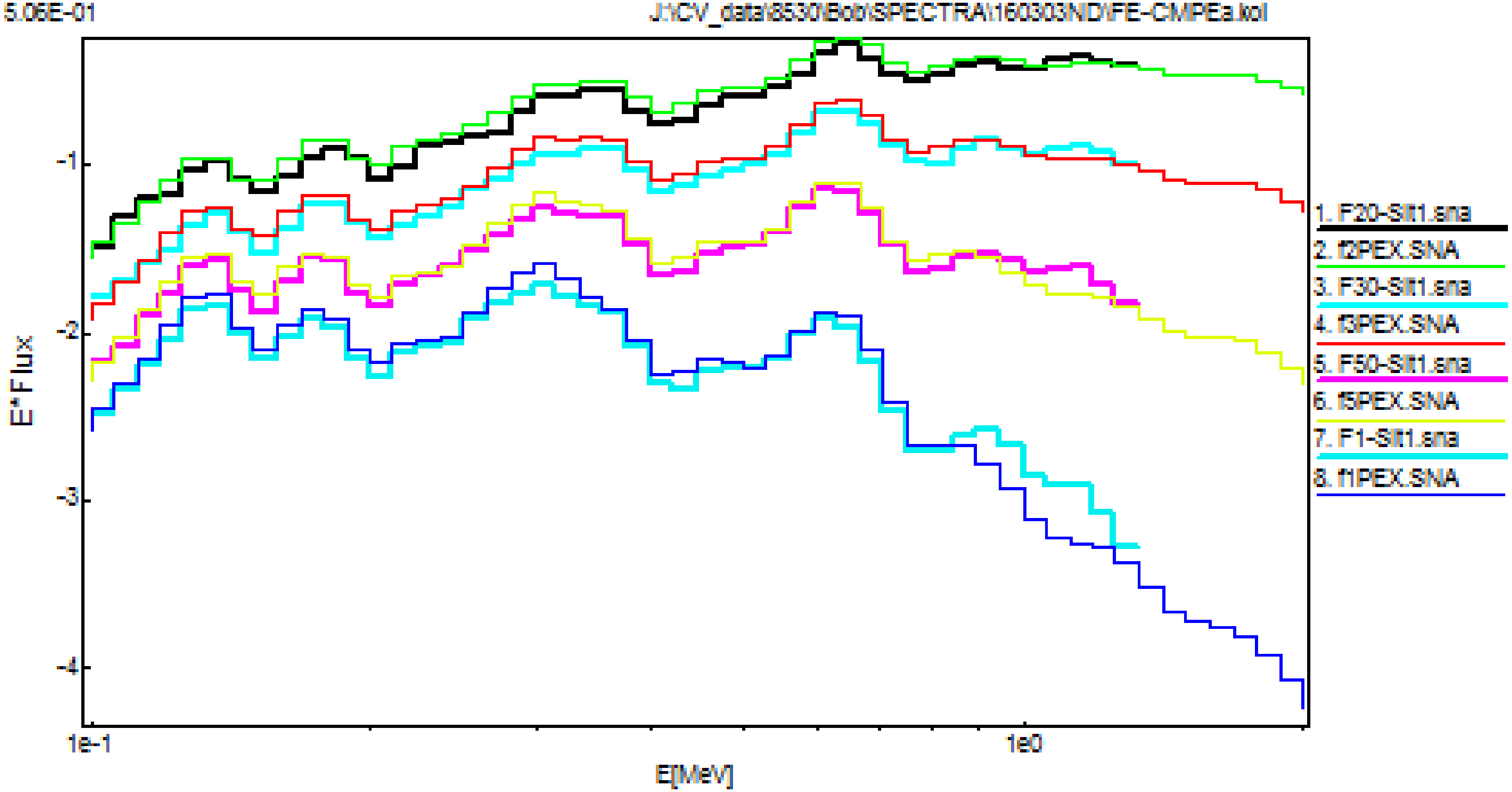


Spectra are normalized by factor: 1,3,10,30, (in this Figure).

Measurement: HPD (CVR Rez) (thick); **Calculation:** data Perey used, (thin)

Conclusion: The the biggest sphere (FE100) brings the biggest difference for C/E in energy region **E_n = 0.85-1.3 MeV**

Example of use of HPD spectrometry measurements on Fe-benchmarks for improvement of cross section XS-Fe56(n,el), Fig.4

For years it has been stated that :

- **calculations overestimate measured spectra in region around 300keV by about 20-40 % and also around 600keV MeV by about 12-15% ,Fig.1 and Tab.1**
- **The problem around 300keV (C/E) grows with iron thickness**

See references, ND 2013, ND2016, JEFF–ND weeks,…

To our great pleasure, the IAEA-NDS has begun to look into this issue in more detail (A.Trkov, R.Capote, S.Simakov,..) see [9], ND 2019,

There is briefly described the part of the work concerning the use of n- spectra measured in RC Rez.

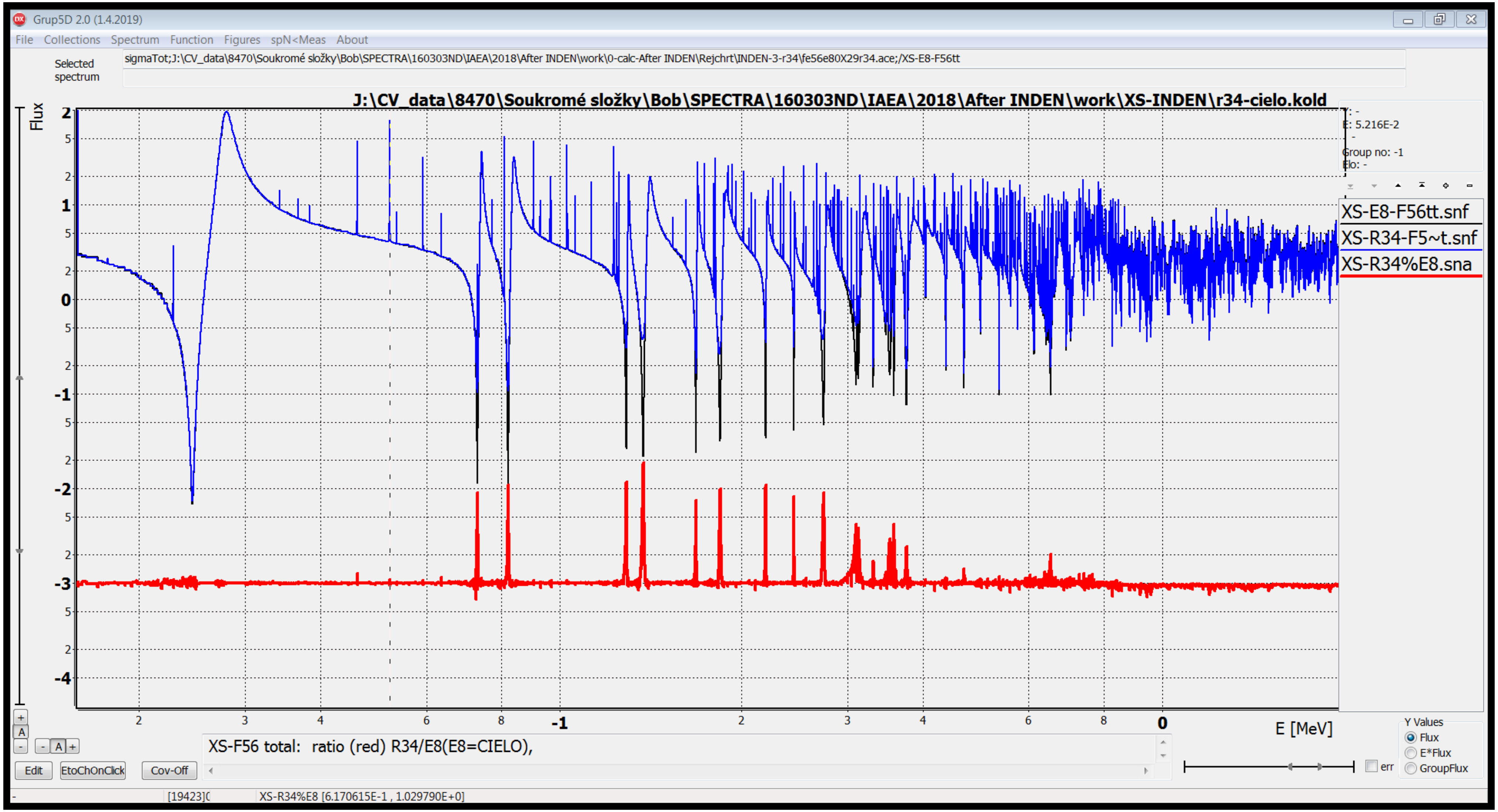
Demonstration of HPD n-neutron spectrometry properties, See Fig.1

Measurement and calculations use 200gpd energy structure. (200 gpd represents 200 groups per decade, it is lethargy step about 1%.)

Spectrometer with HPD has relatively good resolution. In energy interval 200-400keV is possible to observe:4-6peaks (218,242,272,309,352,375 keV) - only by some HPD detectors. See Fig.1.

Other spectrometers which use for example stilbene or TOF method resolves usually only one peak at 300keV in the 200-400 keV region.

Fig.4, XS-Fe56(n,tot), black=CIELO(ENDF/B-VIII.0), blue=R34 (working version of corrected XS) red=ratio R34/CIELO, norm=1000



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9) B.Jansky (1), J.Rejchrt (1), A.Blokhin (2),

1) Neutron spectra measurement and calculation using data libraries CIELO and JEFF in Iron and Oxygen benchmark.

2) Analyse of XS - Fe56(n,el) corrections for En = 0.05-0.7MeV

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Thank you for your attention!