REACTION RATES IN 237-Np EXPOSED TO SPALLATION NEUTRONS IN Pb TARGET AND U-BLANKET SYSTEM BY RELATIVISTIC DEUTERONS OF 4 GeV

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“Energy&Transmutation” - Experiments

Energy [GeV] Protons	Start	Time of irradiation [minute]	Ip (integr. on target) [*E13]	Ip per sec on target [*E8]	Public.
0.7	27Jun04	531	0.88(4)	2.63	Jaipur
1.0	30Nov03	423	2.93(13)	11.5	Conf. To., Santa Fe
1.5	11Dec01	723	1.10(5)	2.54	Prepr., NIM
2.0	27Jun03	463	1.18(15)	4.25	Santa Fe

Number of gamma-spectra measured during each experiment

Proton energy [GeV]	0.7	1	1.5	2
RA samples (+ 127I)	55	80	31	76
Monitors ^{27}Al	12	16	12	13
Monitors ^{139}La	40	33	29	34
HPGe calibration	144	11	60	50
Threshold foils	106	–	208	60
Background and RA-samples before irr.	11	18	16	11
Total number	**368**	**158**	**356**	**244**

All 1126

“Energy&Transmutation” or “GAMMA-3” Experiments

Energy [GeV] Deuterons	Start	Time of irradiation [minute]	Ip (integr. on target) [*E13]	Ip per sec on target [*E8]	Setup
2.5	30Nov05	540	0.65(10)	2.01	“E+T”
1.6	18Dec06	399	1.73(25)	7.23	“E+T”
2.33	17Mar07	1517	1.70(10)	1.87	“Gamma-3”
4.0	25Nov09	1068	0. 78 (8)	1.31	“E+T”

Scientific program

Physical aspects of electronuclear method of energy production and transmutation of radioactive waste

- Investigation of the formation of residual nuclei in reaction induced by 660 MeV protons interacting with the radioactive targets: 129I, 237Np, 241Am, 238U, 239Pu, 232Th, 235U, 238Pu. Experiment + theoretical calculation (LANL).

- Transmutation studies on long-lived radioactive waste nuclides 129I, 237Np, 238Pu, 239Pu and 241Am, **232Th, 238U** in the field of secondary neutrons using nuclear spectroscopy methods. Projects GAMMA-2,3 ENERGY+TRANSMUTATION,

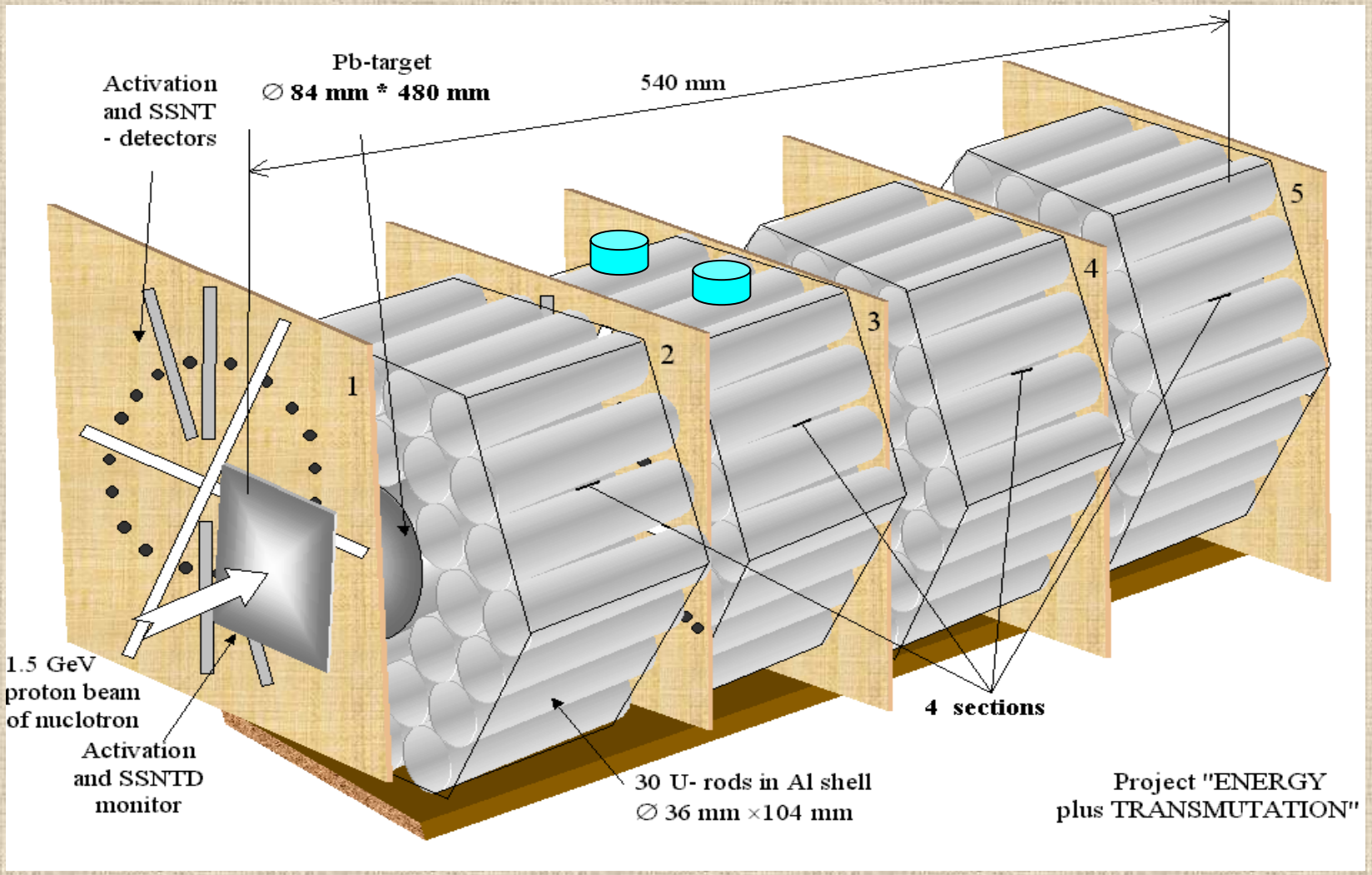
- Energy and intensity distributions of neutrons around the target assembly using nuclear spectroscopy methods, solid state nuclear track detectors (SSNTD), uranium sensors and nuclear emulsion techniques.
  Theoretical calculations of neutron spectra and reaction yields (MCNPX).

Nuclotron

- SuperConducting, strong focusing synchrotron
- Constructed during 1987-1992 at the Veksler and Baldin Laboratory of High Energies, JINR Dubna
- The nuclotron ring (circumference 251.5 m) is installed in the tunnel around the synchrophasotron, the nuclotron median plane is at 3.7 m below the synchrophasotron one
- The total cold mass ~ 80 tons
- Accelerates protons up to $\mathbf{T_{kin}}$**~ 12.8 GeV** and nuclei (including ^{238}U) up to T_{kin}~ 6 GeV/A (for Z/A = 1/2)
- Intensity ~ $\mathbf{10^{11}}$ **protons per cycle**, plan for the future ~ 10^{13}
- **Extraction time ~ 10 s;** Repetition rate 0.5 – 1.0 p.p.s
- 96 SC dipoles for max. field 2.2 T, 64 SC quadrupoles (hyperbolic shaped poles); the cooling is performed by 2-phase He flow
- Operational temperature is 4.5-4.7 K
- Vacuum inside a beam pipe is about 10^{-10} - 10^{-11} Torr
- Consumed power 1.5 MW

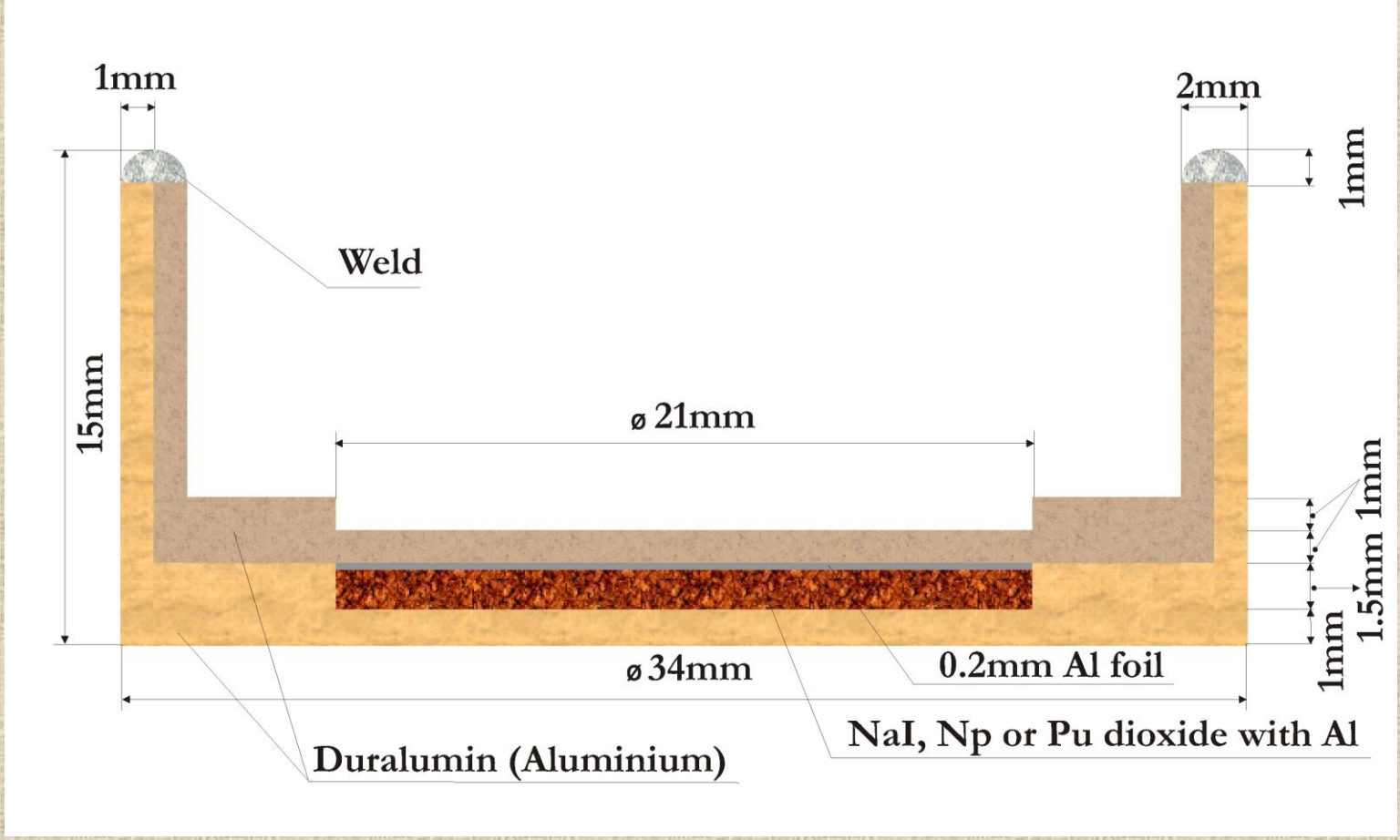
The beam extraction area of the Nuclotron ring

Schematic representation of the U/Pb assembly with four section of uranium blankets around a massive lead target



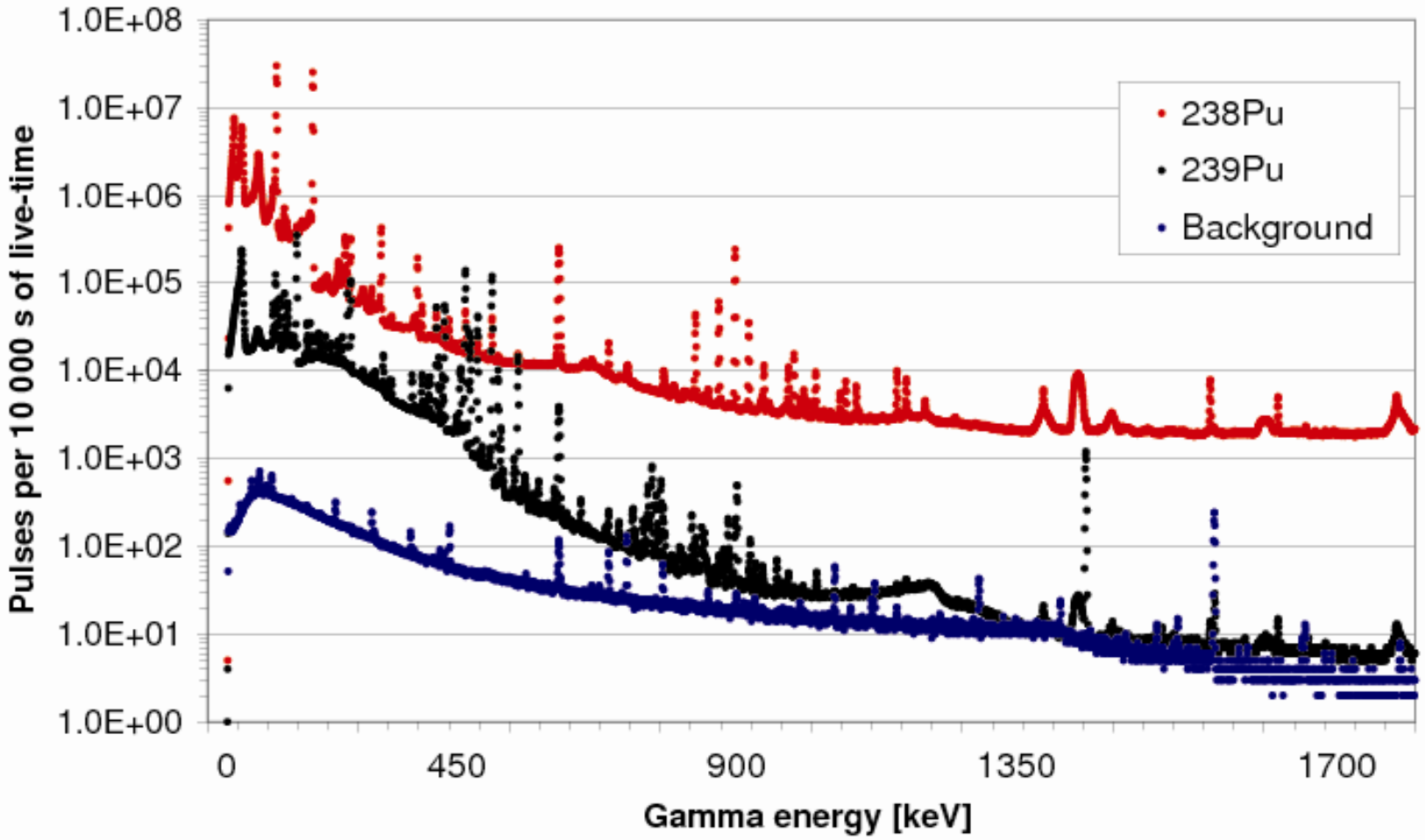
Photography of **“Energy&Transmutation”** Pb/U assembly outside the shielding before fixing of detectors

General view of the assembly with all detectors and radioactive samples fixed on it


1mm
2mm
1mm
Weld
15mm
ø 21mm
1mm
1mm
1.5mm
ø 34mm
0.2mm Al foil
NaI, Np or Pu dioxide with Al
Duralumin (Aluminium)

Radioactive samples properties for 4 GeV experiment

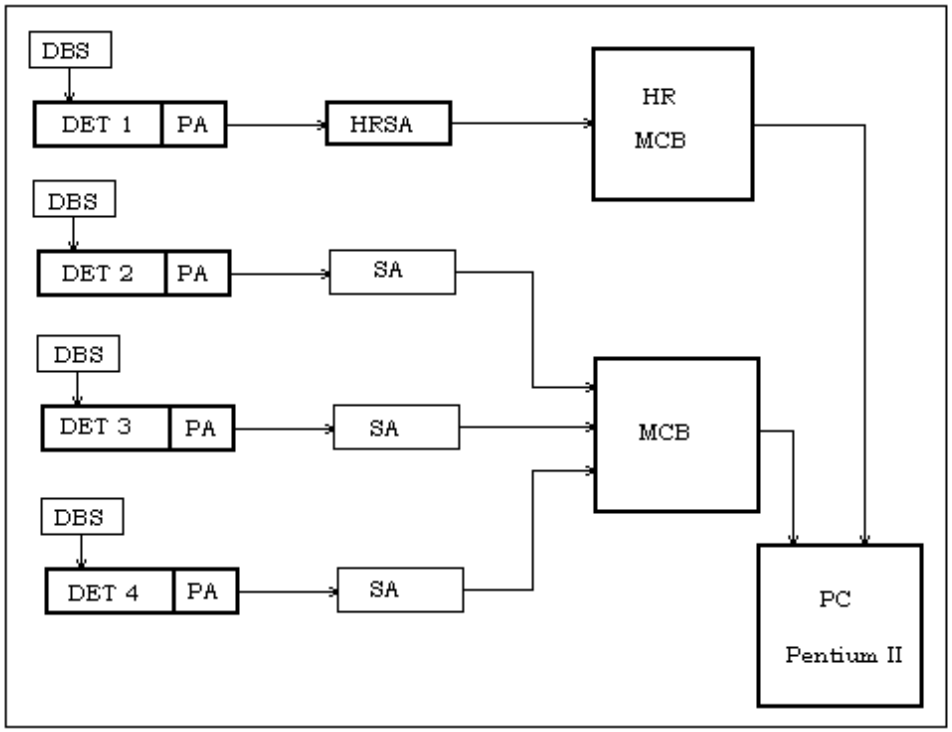
Nuclei	Half-life [y]	Weight [g]	Activity [GBq]	Isotopes Purity [%]	Alpha-particles Energy [MeV}
129-I	1.57E+7	0.772	0.0034	82.9+127I	-
237-Np	2.14E+6	0.987	0.0289	100	4788, 4771
238-Pu	87.74	0.0516	32.4	72.9+239Pu	5499, 5456
239-Pu	2.41E+4	0.579	1.17	99.9	5157, 5144
241-Am	432.2	0.183	23.2	100	5486,5443
232-Th	1.405E+10	0.186	13 Bq	100	
Nat-U	4.468E+9	0.342	707 Bq	100	


1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
1.0E+00
Pulses per 10 000 s of live-time
0
450
900
1350
1700
Gamma energy [keV]
238Pu
239Pu
Background

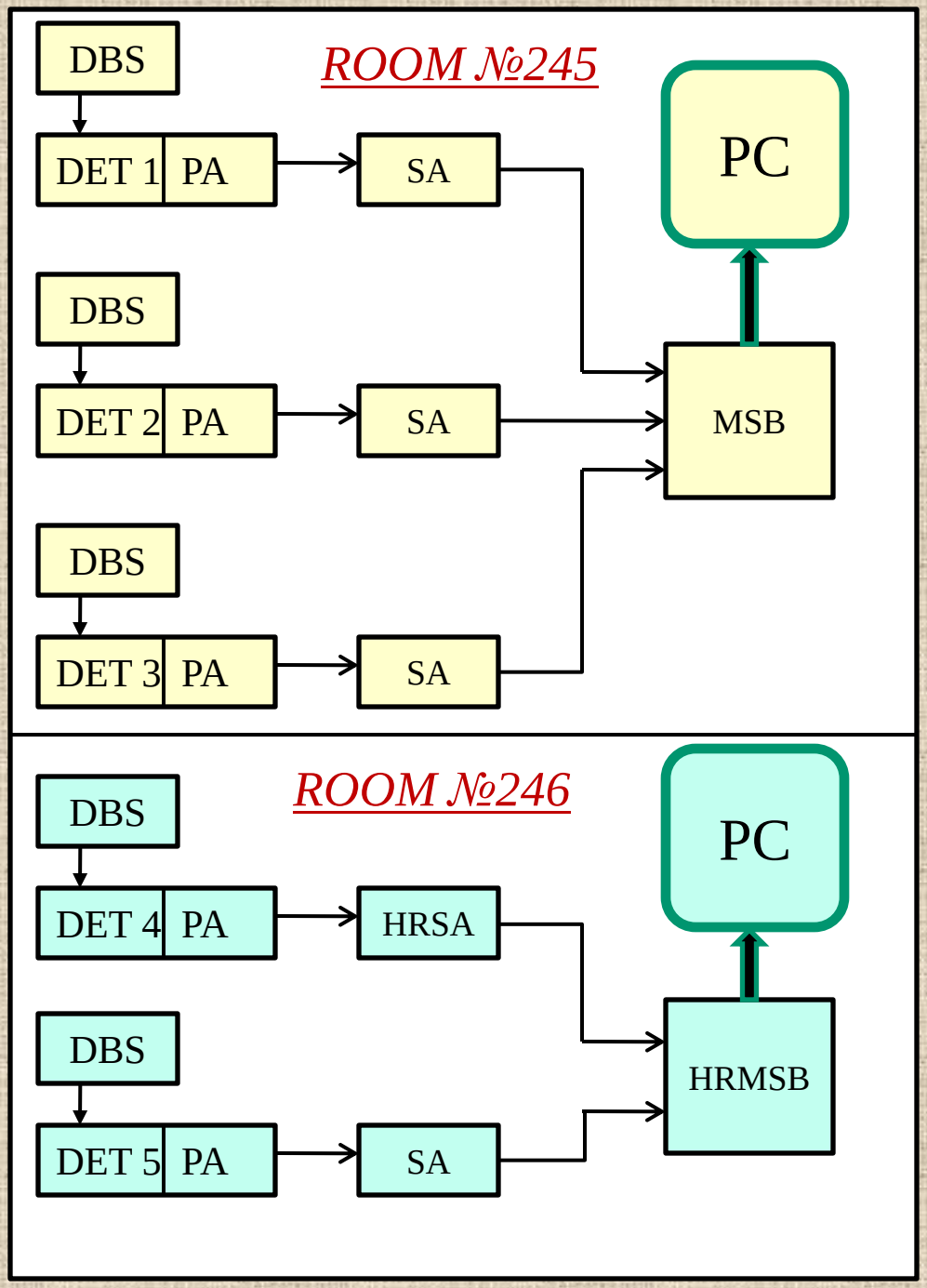
HPGe detectors

	CANBERRA GR-1819	ORTEC(old) GMX-23200	ORTEC(new1) GMX-20190	ORTEC(planar) GeLP-36360/13	ORTEC(new2) GMX-30
Resolution [keV] (Eg=1332keV)	1.78 keV	1.86 keV	1.80 keV	335 eV At 5.9 keV 580 eV At 122 keV	1.80 keV
Relative efficiency [%] (Eg=1332keV	18.9	27.7	28.3	Dia. 36 mm Heig. 13 mm	32.9
Absorbing layer Be, Al, Ge	0.50 mm 0.3 μm	1.27 mm 0.3 μm	0.50 mm 0.3 μm	0.254 mm 0.3 μm	1.27 mm 0.3 μm

High-Rate Spectroscopy with a HPGe Detectors for Gamma Rays or for X-Rays



ABBREVIATION	DENOMINATION	FIRM, MODEL
DBS	Detector Bias Supply	
DET 1	HPGe Detector	ORTEC GMX 23200
DET 2	HPGe Detector	CANBERRA SR 1819
DET 3	HPGe Detector	ORTEC GMX 20190
DET 4	Planar HPGe Detector	ORTEC GLP-36360/13
PA	The Preamplifiers and HV Filters are part of the Detector Capsule	
MCB	Multichanell Buffer	ORTEC 919
HRMCB	High-Rate Multichanell Buffer	ORTEC 921
HRSA	High-Rate Amplifier	ORTEC 973
SA	Spectroscopy Amplifier	CANBERRA 2024, 2026, 2020



High-Rate Spectroscopy with a HPGe Detectors for Gamma Rays or for X-Rays

ABBREVIATION	DENOMITION	FIRM, MODEL
DBS	Detector Bias Supply	
DET 1	HPGe Detector	ORTEC GMX-20190
DET 2	HPGe Detector	ORTEC GMX-30
DET 3	Planar HPGe Detector	ORTEC GeLP-36360/13
DET 4	HPGe Detector	CANBERRA GR-1819
DET 5	HPGe Detector	ORTEC GMX-23200
PA	The Preamplifiers and HV Filters are part of the	
MCB	Detector Capsule Multichanell	ORTEC 919
HRMCB	Buffer High-Rate Multichanell	ORTEC 921
HRSA	Buffer High-Rate	ORTEC 973
SA	Amplifier Spectroscopy Amplifier	CANBERRA 2024,2026,2020

"E + T",Nov2009, measurements of gamma-spectra

Participants	Samples	Spectra	Participants	Samples	Spectra
Adam, Solnyshkin, Stegajlov Tsoupko-Sitnik	RA-detectors, 7 Thresh. det., 18	64, A 132, B	Hashemi- Nezhad Borger Bhatia	Pb, Bi, Th, U, 12	55, C
Wagner Svoboda	Thresh. det., 102 Monitors, 41	292, D	Voronko Sotnikov	Hf, Zr, U, 9	26, A
Szuta, Kilim, Strugalska- Gola Bielewicz	Y, 35	134, E	Westmeier Vladimirova	Al-monitor, 4 La, 15	57, F
	Det. 203	Sp. 622		Det. 40	87(57)

1. Data handling.

ENGCOR5

PUREGAM3

ISOMER

EFFCOR5

MIDLIT3

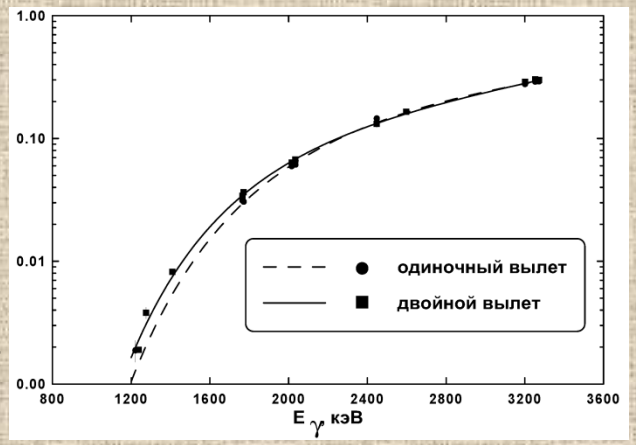
TRANSCS

Вход: $N_\gamma(i)_{Deimos} \quad N_\gamma(i) \rightarrow E_\gamma(i)$

$$\left|E_\gamma - E'_\gamma\right| \ln\sqrt{a^2 + (\Delta E_\gamma)^2 + (\Delta E'_\gamma)^2}$$

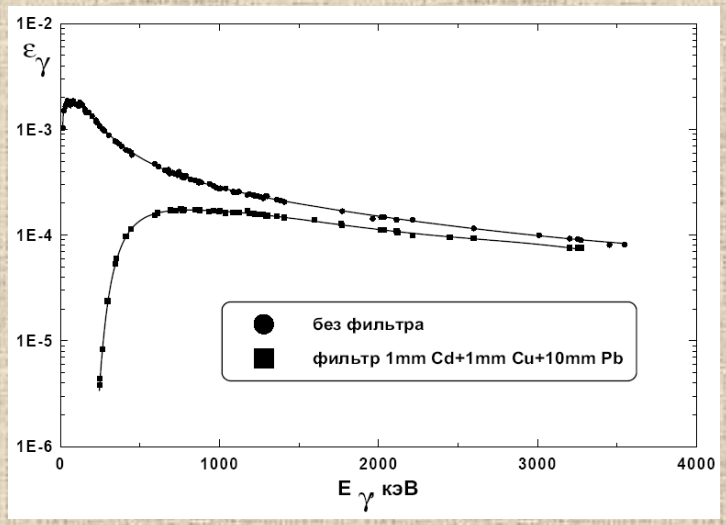
$$\frac{I_\gamma^{SEP,DEP}}{I_\gamma} = \exp\left(\sum_{i=0}^{4} a_i ((\ln(E_\gamma))^i)\right)$$

$$S_\gamma(E_\gamma^i) = \left\{ \begin{array}{l} Ae^{-\lambda_a t_2(i)}(1-e^{-\lambda_a t_{3,r}(i)}) + \\ +Be^{-\lambda_b t_2(i)}(1-e^{-\lambda_b t_{3,r}(i)}) \end{array} \right\} \frac{t_{3,l}(i)}{t_{3,r}(i)}$$



$$I_\gamma^n = S_\gamma^n / \exp\left(\sum_{i=0}^{8} b_i ((\ln(E_\gamma))^i)\right)$$

$$K = \frac{I_\gamma^{lit} \cdot I_{\gamma,max}^{exp}}{I_\gamma^{exp} \cdot I_{\gamma,max}^{lit}}; \quad I_\gamma^{lim}; \quad K \le 1$$



$$\sigma_a(E_\gamma^j) = \frac{S_i(E_\gamma^j)\lambda_a t_{3,r}}{N_p N_t \varepsilon_\gamma I_\gamma(E_\gamma^j)(1-e^{-\lambda_a t_1})e^{-\lambda_a t_2}(1-e^{-\lambda_a t_{3,r}})t_{3,l}}$$

Number of protons (Np), Reaction rate R(Ar,Zr)

$$Q(Ar,Zr,i,j)=\frac{S(i,j)\cdot\eta_A(At,Zt,j)\cdot\eta_B(\lambda).\eta_C(j)\cdot\eta_D\cdot\lambda}{\varepsilon_\gamma^{abs}(j)\cdot I_\gamma(j)\cdot(1-e^{-\lambda\cdot t_1})\cdot e^{-\lambda\cdot t_2(i)}\cdot(1-e^{-\lambda\cdot t_{real}(i)})}\cdot\frac{t_{real}(i)}{t_{live}(i)}$$

$N_p = Q(A_r,Z_r)/(\sigma(A_r,Z_r).N_t)$

$N_t = N_{Avo}.m/(A.S)$

$$R(\mathrm{Ar,Zr})=\frac{Q(\mathrm{Number\ of\ produced\ nuclei(Ar,Zr)})}{(1\,\mathrm{target\ isotope\ atom})\bullet(1\,\mathrm{incident\ proton})}$$

$$R=\int_{E(thr)}^{\infty}\sigma(E_n)\Phi(E_n)dE_n$$

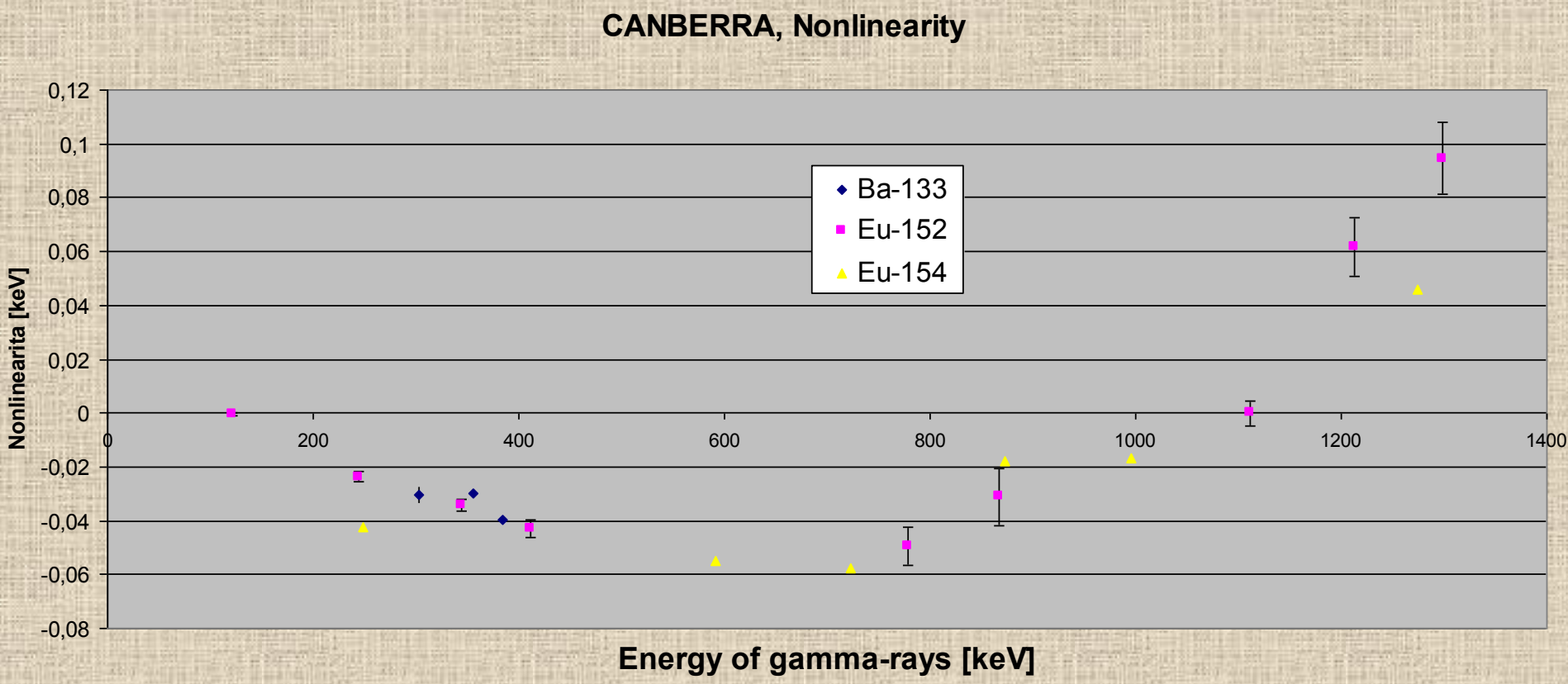
Monitor

	W.Westmeier	V.Wagner	A.Potapenko
Id, operator	2.561E13	2.47E13	
Id, Al 10cmx10cm		1.99E13	
Id, Al, diam. 16 cm	1.398(148)E13		
Id, Al, diam. 8 cm	7.873(808)E12		
Id on Pb	56.3%	92%	91.8%
Shape of beam		Xc = 0.235 cm Yc = 0.190 cm FWHMx=1.53 cm FWHMy=1.77 cm	Xc = 0.240 cm Yc = 0.170 cm FWHMx=2.10 cm FWHMx=1.80 cm

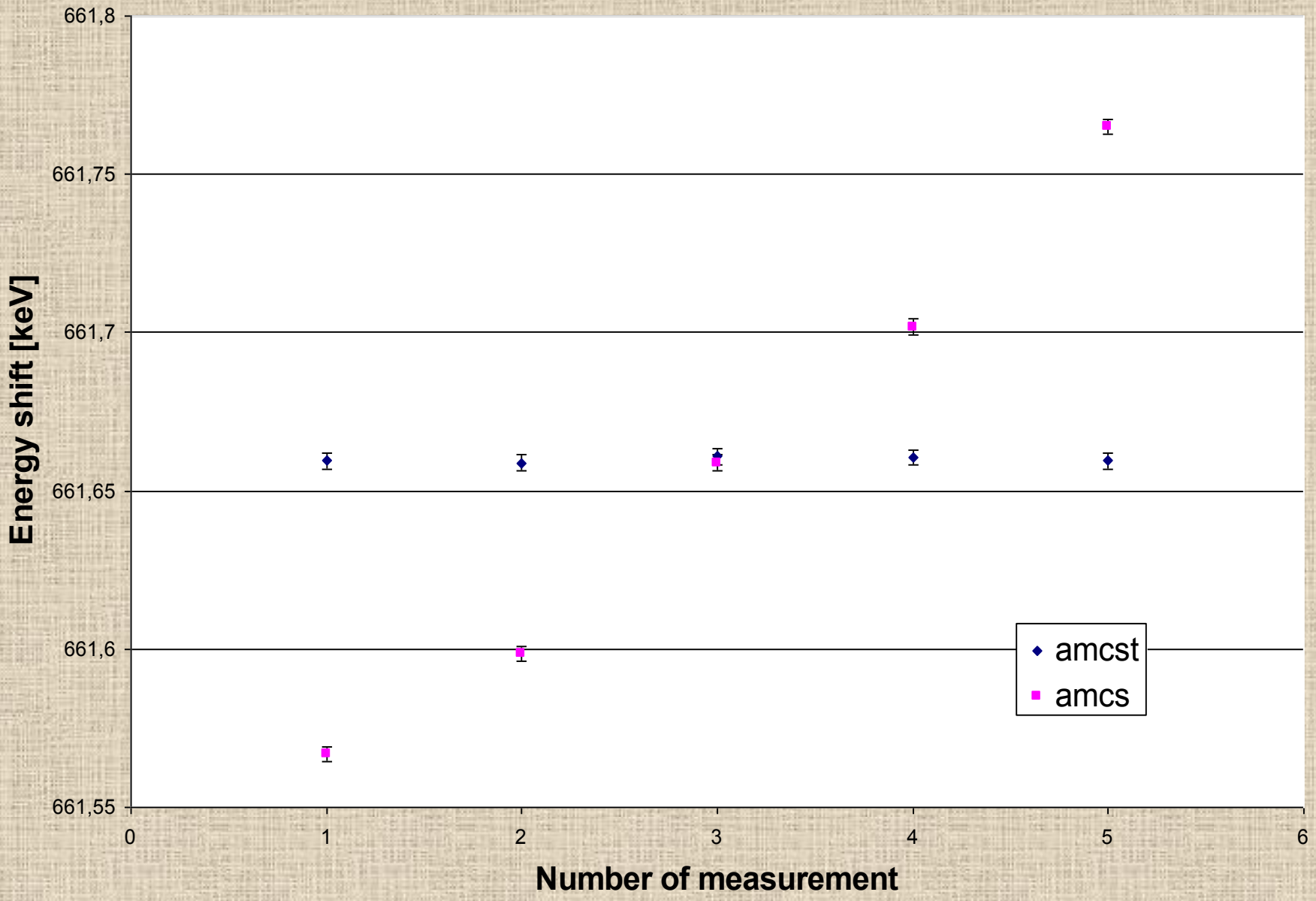
Isotope Energy[keV]	I_g [%]	**$T_{1/2}$(Library)** $T_{1/2}$(Exper.)	**<R>** R	**Number of spectra**
Sr-91		**9.63(5) h**	**6.6(13)E-27**	
749.75	23.61		6.1(14)E-27	1
1024.3	33		9.8(34)E-27	1
Sr-92		**2.710(10) h**	**5.52(58)E-27**	
1383.93	90.0	3 h	5.52(58)E-27	2
97Zr		**16.91(5) h**	**8.34(52)E-27**	
658.08	98	16.4(10) h	7.88(48)E-27	5
743.36	93	16.1(8) h	8.93(54)E-27	5
99Mo		**65.94(1) h**	**1.36(46)E-26**	
739.5	12.13		1.36(46)E-26	1
105Ru		**4.44(2) h**	**4.22(71)E-27**	
724.21	47	4.7 h	4.22(71)E-27	2
129Sb		**4.40(1) h**	**4.46(99)E-27**	
812.8	43		4.46(99)E-27	1
132Te		**3.204(13) d**	**6.76(32)E-27**	
630.19	13.3		1.00(36)E-26	1
667.718	99	3.69(22) d	6.25(39)E-27	7
772.6	75.6	2.99(17) d	7.18(45)E-27	7
954.55	17.6	2.6(4) d	7.41(80)E-27	6
I-133		**20.8(1) h**	**9.86(79)E-27**	
529.87	86.3	24.1(26) h	9.86(79)E-27	6

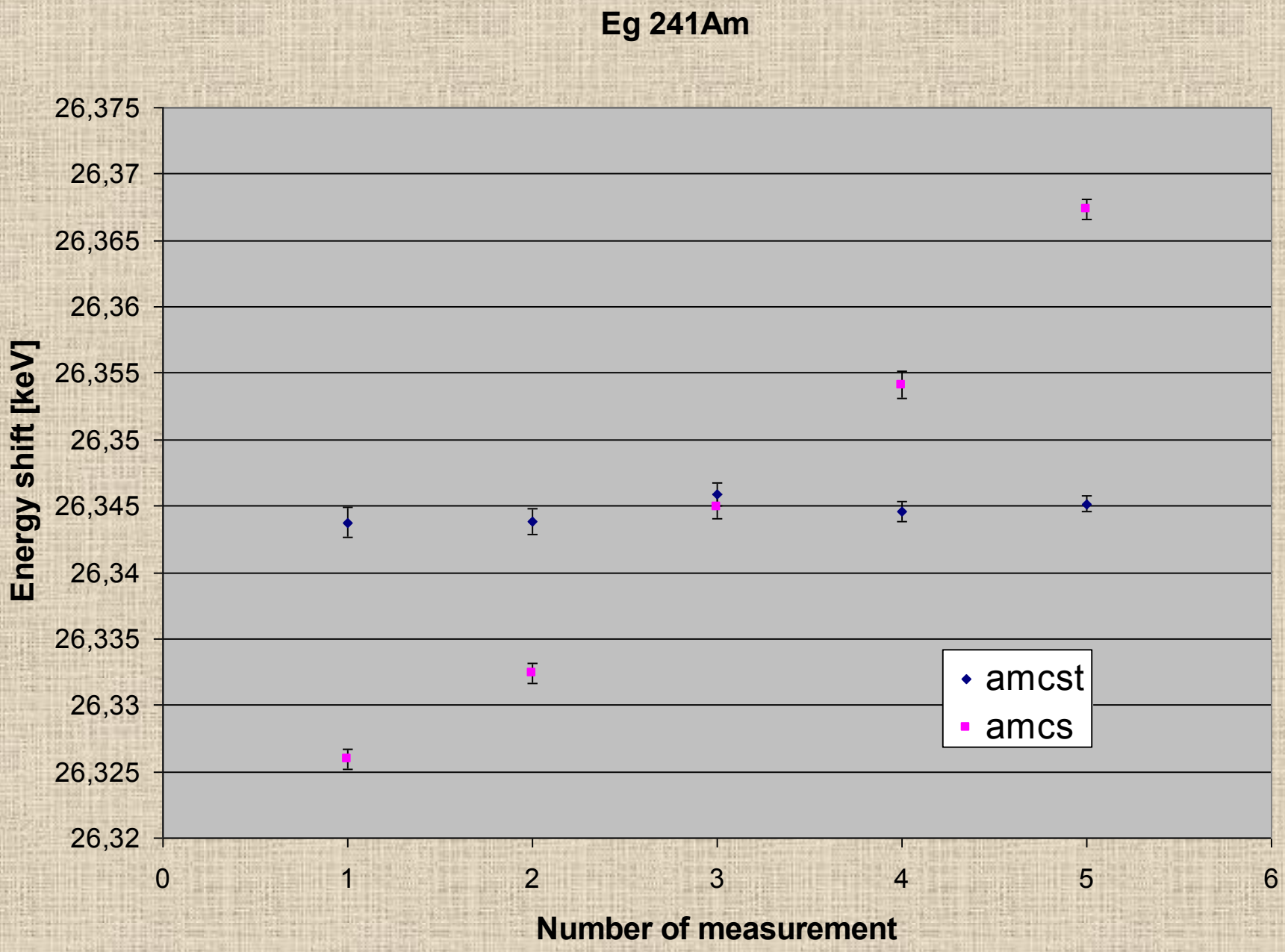
Isotope Energy[keV]	I_g [%]	**$T_{1/2}$(Library)** $T_{1/2}$(Exper.)	**<R>** R	**Number of spectra**
I-135		**6.570(20) h**	**1.04(7)E-26**	
546.557	7.2		2.38(59)E-26	1
836.804	6.73		1.05(46)E-26	1
1038.76	8.01	10 h	1.23(25)E-26	2
1131.511	22.74	9(4) h	7.9(12)E-27	3
1260.409	28.9	7.9(7) h	1.08(9)E-26	4
1457.56	8.73	30 h	1.16(20)E-26	2
1678.027	9.62	4.5 h	9.9(14)E-27	2
1706.459	4.13	10 h	1.22(25)E-26	2
1791.196	7.77		1.09(27)E-26	1
Ba-140		**12.752(3) d**	**8.1(21)E-27**	
487.021	45.5		2.20(46)E-26	1
815.772	23.28	9.1 d	1.04(15)E-26	2
867.846	5.5		1.46(49)E-26	1
1596.210	95.4	-1 (13) d	5.67(110)E-27	5
Np-238		**2.117(2) d**	**7.07(12)E-25**	
882.63	0.87	2.12(12) d	7.27(40)E-25	7
918.69	0.59	2.19(16) d	6.83(43)E-25	7
923.98	2.86	2.10(5) d	7.04(31)E-25	7
936.61	0.40	2.08(24) d	6.42(51)E-25	7
941.38	0.54	1.72(18) d	7.36(56)E-25	6
962.77	0.70	2.09(10) d	7.86(44)E-25	7
984.45	27.8	2.089 (13) d	7.03(29)E-25	7
1025.87	9.6	2.103(19) d	7.00(31)E-25	7
1028.54	20.3	2.096(13) d	6.99(30)E-25	7

THANK YOU FOR YOUR ATTENTION!

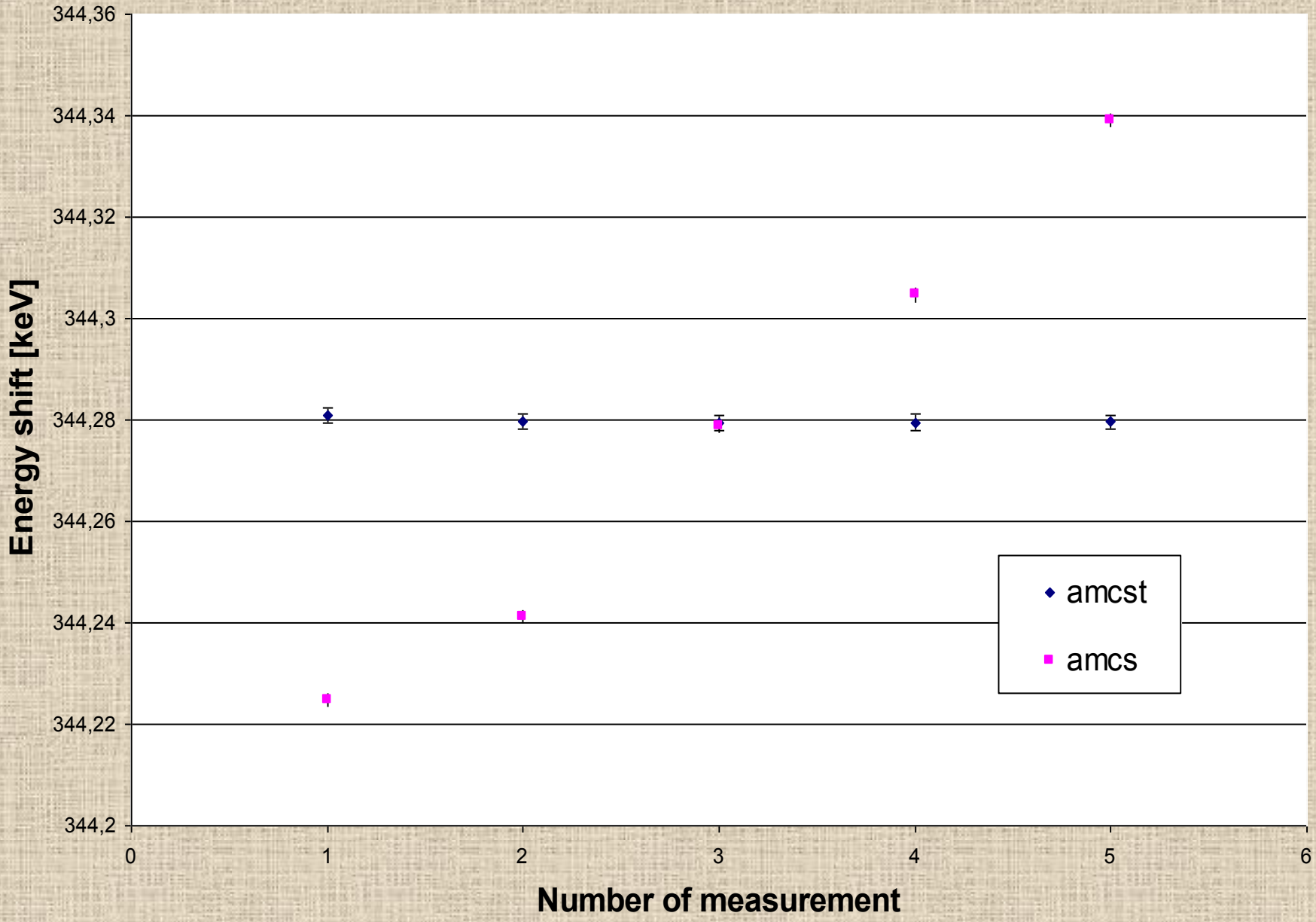

CANBERRA, Nonlinearity
Nonlinearita [keV]
0,12
0,1
0,08
0,06
0,04
0,02
0
-0,02
-0,04
-0,06
-0,08
0
200
400
600
800
1000
1200
1400
Ba-133
Eu-152
Eu-154
Energy of gamma-rays [keV]

Eg 137Cs


661,8
661,75
661,7
661,65
661,6
661,55
Energy shift [keV]
0
1
2
3
4
5
6
Number of measurement
amcst
amcs


Eg 241Am
26,375
26,37
26,365
26,36
26,355
26,35
26,345
26,34
26,335
26,33
26,325
26,32
Energy shift [keV]
0
1
2
3
4
5
6
Number of measurement
amcst
amcs

Eg 152Eu


344,36
344,34
344,32
344,3
344,28
344,26
344,24
344,22
344,2
Energy shift [keV]
0
1
2
3
4
5
6
Number of measurement
amcst
amcs

Phasotron

- Set during 1979-1984 by reconstruction of old synchrophasotron at the Laboratory of Nuclear Problems, JINR Dubna
- Accelerates protons up to (659±6) MeV
- Intensity ~ 10^{13} protons
- Electrical current ~ 2 μA
- Bunches (with length of ~ 10 ns) follow in ~ 70 ns intervals
- Modulation frequency 250 Hz

Phasotron

1. Data handling.

ENGCOR5

PUREGAM3

ISOMER

EFFCOR5

MIDLIT3

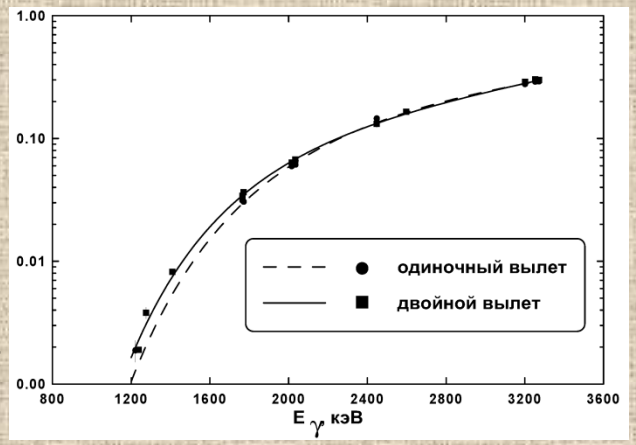
TRANSCS

Вход: $N_\gamma(i)_{Deimos} \quad N_\gamma(i) \rightarrow E_\gamma(i)$

$$\left|E_\gamma - E'_\gamma\right| \ln\sqrt{a^2 + (\Delta E_\gamma)^2 + (\Delta E'_\gamma)^2}$$

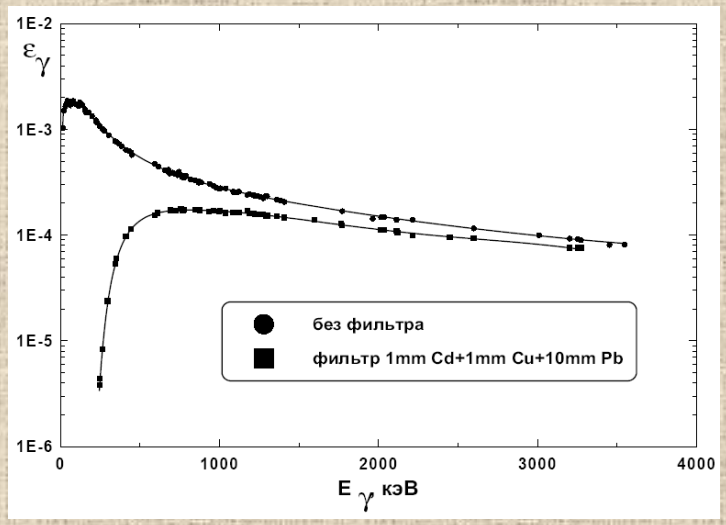
$$\frac{I_\gamma^{SEP,DEP}}{I_\gamma} = \exp\left(\sum_{i=0}^{4} a_i ((\ln(E_\gamma))^i)\right)$$

$$S_\gamma(E_\gamma^i) = \left\{ \begin{array}{l} Ae^{-\lambda_a t_2(i)}(1-e^{-\lambda_a t_{3,r}(i)}) + \\ +Be^{-\lambda_b t_2(i)}(1-e^{-\lambda_b t_{3,r}(i)}) \end{array} \right\} \frac{t_{3,l}(i)}{t_{3,r}(i)}$$



$$I_\gamma^n = S_\gamma^n / \exp\left(\sum_{i=0}^{8} b_i ((\ln(E_\gamma))^i)\right)$$

$$K = \frac{I_\gamma^{lit} \cdot I_{\gamma,max}^{exp}}{I_\gamma^{exp} \cdot I_{\gamma,max}^{lit}}; \quad I_\gamma^{lim}; \quad K \le 1$$



$$\sigma_a(E_\gamma^j) = \frac{S_i(E_\gamma^j)\lambda_a t_{3,r}}{N_p N_t \varepsilon_\gamma I_\gamma(E_\gamma^j)(1-e^{-\lambda_a t_1})e^{-\lambda_a t_2}(1-e^{-\lambda_a t_{3,r}})t_{3,l}}$$