Yields of Gamma Radiation of ^{235}U

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Specification of ^{234}Th lines yields in 2004

ENSDF before 2004, yields of radiation of ^{234}Th (the child of ^{238}U):
92.38 keV – 2.81(26) ,
92.80 keV – 2.77(26).

The study of Abousahl, S. et. al., NIM A 517 (2004) 211-218, where the yields of ^{234}Th lines are specified:
92.38 keV – 2.13(20),
92.80 keV – 2.10(20).

Deviation is ~30%
The ratio between these lines of ^{234}Th and the 93.35 keV characteristic line of Th, used for the analysis of uranium enrichment:

$$I_{92.38}/I_{93.35} = 0.484(45),\ I_{92.80}/I_{93.35} = 0.484(45)$$

Spectrometers and samples

Equipment:

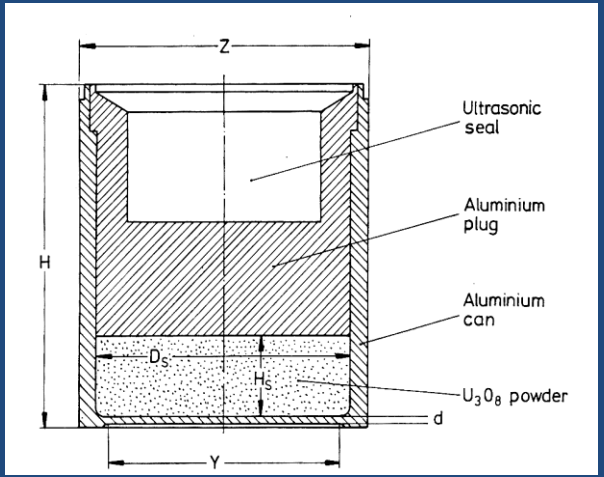
- Detector - LEGe GL0515R, S=500 mm^2 d=15 mm, input window – 0.5 mm Al.
- Detector - LEGe GL1015R, S=1000 mm2 d=15 mm, input window – 0.5 mm Al.
- InSpector Portable Spectroscopy Workstation, Model 1200UPU.
- LSRM SpectraLineNM uranium isotopic software.

Samples:

- Uranium Isotopic Standard Reference Material SRM 969 (NBS, USA) – 5 reference samples with 235U enrichment in the range 0.3 – 4.4 %.
- Uranium Isotopic Certified Reference Material CRM 146 (NBS, USA) – 3 reference samples with 235U enrichment in the range 20 – 93 %.

Standard Reference Material SRM 969

Material: U_3O_8 powder, m = 200 g, ρ = 2.5 g/cm^3;
Externals: Z = 80 mm, H = 90 mm;
Sample volume: D_S = 70 mm, H_S = 20.8 mm;
Al window thickness: d = 2 mm.



Certified abundances in SRM 969 (mass fractions):

	SRM 031		SRM 071		SRM 194	
	C, %	1σ, %%	C, %	1σ, %%	C, %	1σ, %%
U-234	0.0020	5.0	0.0052	1.9	0.0171	0.6
U-235	**0.3166**	**0.06**	**0.7119**	**0.07**	**1.9420**	**0.07**
U-236	0.0146	1.0	0.0000	0.0	0.0003	16.7
U-238	99.6668	2.0E-04	99.2828	2.0E-04	98.0406	9.2E-04

	SRM 295		SRM 446	
	C, %	1σ, %%	C, %	1σ, %%
U-234	0.0279	0.7	0.0359	0.4
U-235	**2.9492**	**0.07**	**4.4623**	**0.07**
U-236	0.0033	3.0	0.0068	1.5
U-238	97.0196	1.5E-03	95.4950	1.7E-03

Certified Reference Material CRM 146

Material: U_3O_8 powder, m = 230 g, ρ = 3.78 g/cm^3;
Externals: Z = 80 mm, H = 90 mm;
Sample volume: D_S = 70 mm, H_S = 15.8 mm;
Al window thickness: d = 2 mm.

Certified abundances in CRM 146 (mass fractions):

	NBL 0041		NBL 0042		NBL 0043	
	C, %	1σ, %%	C, %	1σ, %%	C, %	1σ, %%
U-234	0.1486	0.12	0.3718	0.13	0.9800	0.15
U-235	**20.1070**	**0.05**	**52.4880**	**0.04**	**93.1703**	**0.003**
U-236	0.1973	0.3	0.2645	0.11	0.2937	0.4
U-238	79.5470	1.3E-02	46.8760	4.6E-02	5.5559	4.8E-02

U/Pu InSpector System

GL0515R:
FWHM=600 eV
at 122 keV

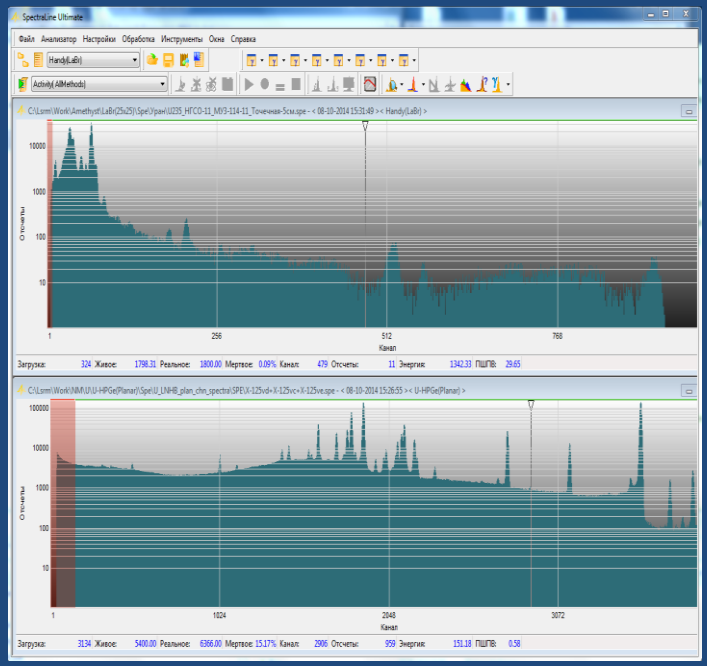
GL1015R:
FWHM=550 eV
at 122 keV

SpectraLineUltimate software package

Gamma-spectrometric analysis both for semiconducting and for scintillation spectrometers -HPGe,NaI,LaBr,CdTe

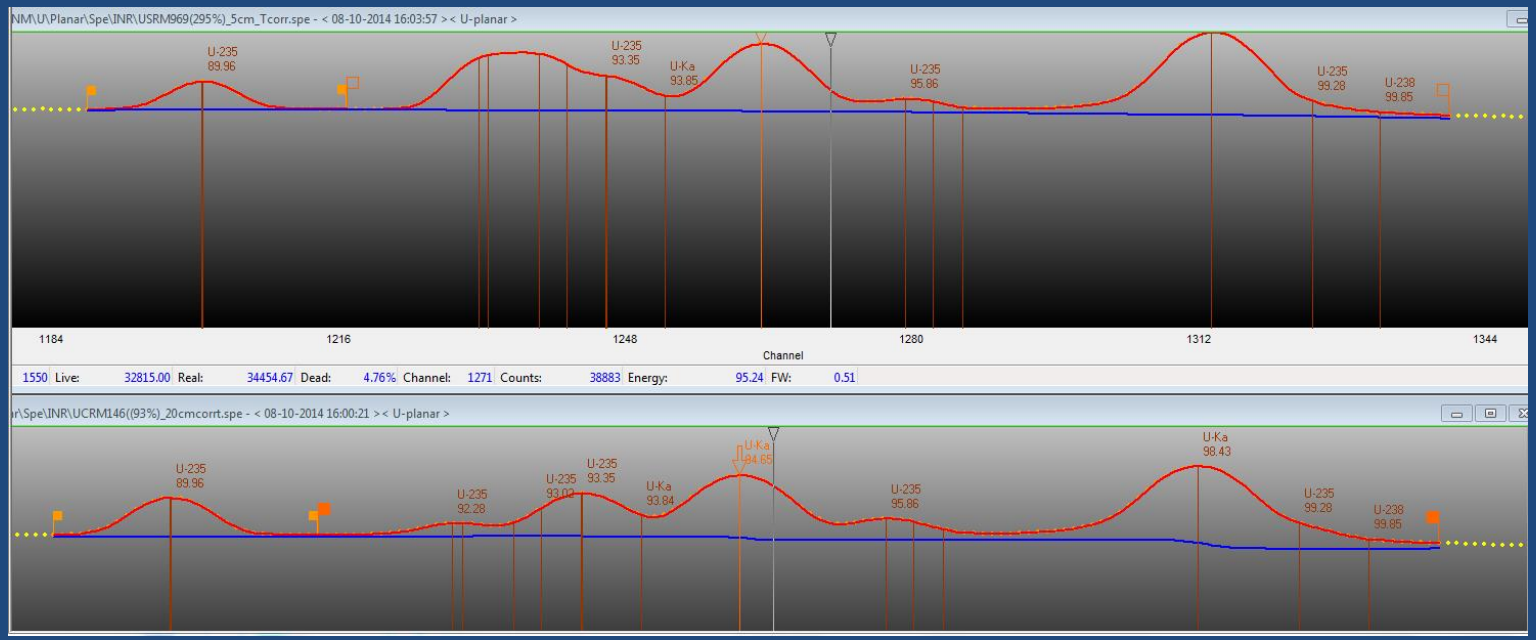
The features of the software package are listed below:

- An adequate description of the gamma lines.
- Consideration of the Lorentz broadening for the description of the X-ray lines.
- The yields ratio between the lines of one nuclide is taken into account at the approximation of informative intervals of the spectrum.
- **All** the informative intervals of the spectrum are processed simultaneously. At the boundaries of informative intervals the background steps under them are smoothed under the condition of continuity of the spectrum and its first derivative.
- The contribution of the peaks of the random summation is taken into account.



http://www.en.lsrm.ru/products/lsrm_2010_package/spectralineultimate

Parts of spectra (88-100keV) of samples with low and high level of enrichment



Efficiency calibration of spectrometer

Lines used for calculation of registration efficiency below the K-edge

Nuclide	Energy, keV	I (Intensity), gammas per 100 decays	ΔI, gammas per 100 decays	Δε, %
^{231}Th	84.214	6.7	0.07	1.7
	102.270	0.441	0.011	2.5
^{234}U	53.2	0.123	0.002	3
^{234}Th	63.290	3.75	0.08	2.5

Efficiency calibration of spectrometer

Lines used for calculation of registration efficiency above the K-edge

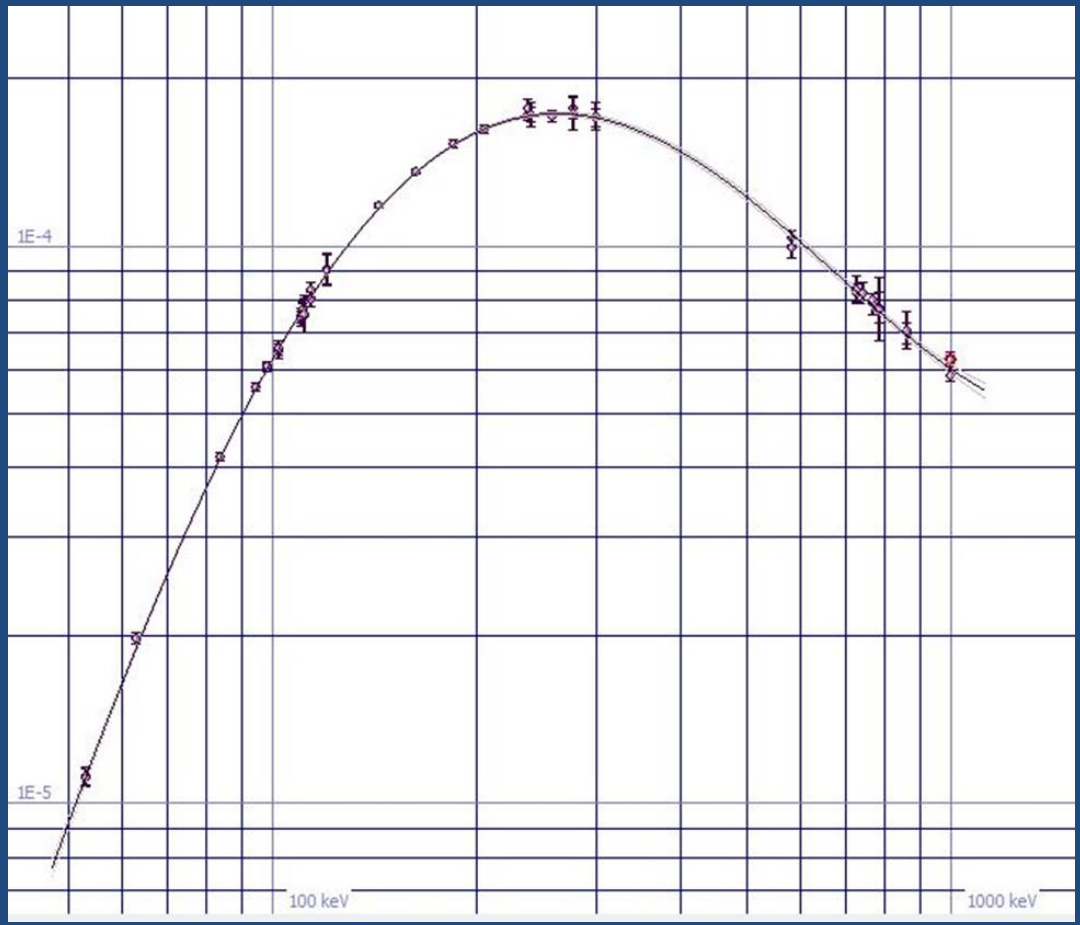
Nuclide	Energy, keV	I (Intensity), gammas per 100 decays	ΔI, gammas per 100 decays	Δε, %
^{235}U	143.767	11.00	0.08	0.8
	163.356	4.97	0.04	0.9
	185.715	57.0	0.3	1.0
	205.31	5.01	0.05	1.1
^{234}U	120.900	0.0342	0.0005	6
^{238}U	766.321	0.323	0.004	2
	1001.026	0.847	0.008	1.5
^{228}Th	238.62	42.2	0.556	2.5
	583.191	29.6	0.49	3

Efficiency curve correction for the K-edge jump

$$\frac{\varepsilon_{E<115.6}}{\varepsilon_{E>115.6}} = 3.916$$

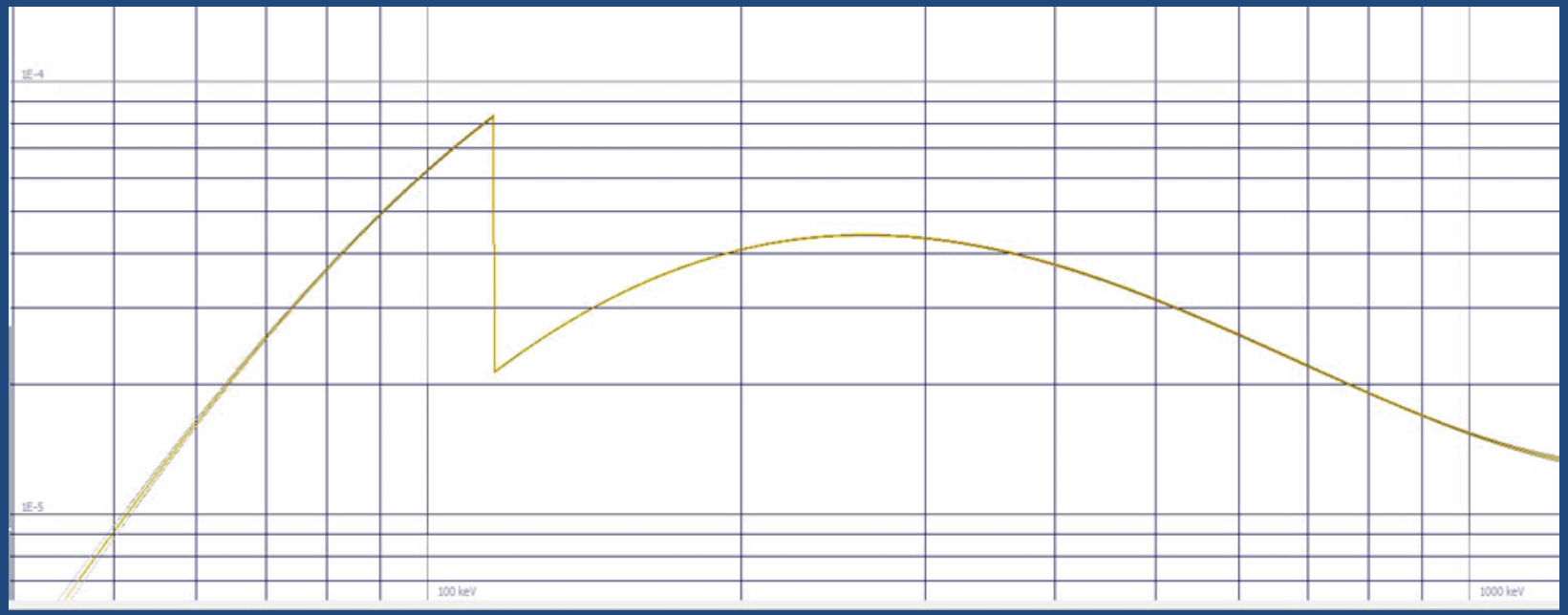
Approximation of registration efficiency by one polynomial of 4 degree

$$\lg(\varepsilon(E)) = \sum_{i=0}^{4} a_i \cdot (\lg(E))^i$$



Registration efficiency calibration of spectrometer

The inversed transformation of the curve for the jump below the K-edge



The results of the measurement of 93.35 keV line yield

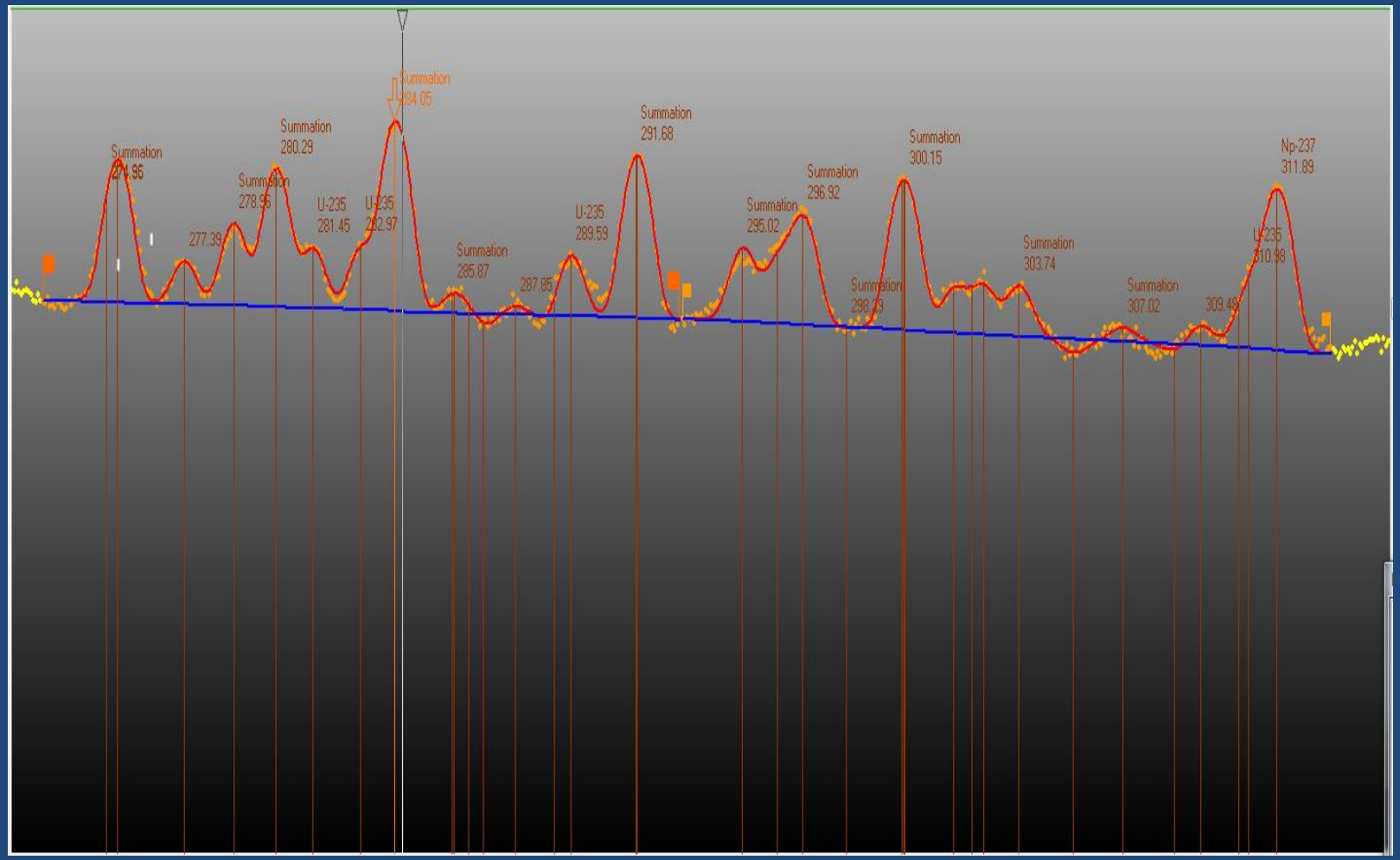
Spectrometer	Sample	$I_{93.35}$
GL1015R	CRM52	4.83(6)
GL1015R	CRM93	4.83(6)
GL0515R	CRM52	4.88(6)
GL0515R	CRM93	4.85(6)
average value		**4.85(6)**

Measurement of the yields ratio

The yields of the lines of 92.38 keV, 92.80 keV $^{238}U(^{234}Th)$ and 93.35 keV ^{235}U and their ratios

	ENSDF before 2004 and NuDat	ENSDF and NuDat	LNHB 2011/53	This study
$I_{92.38}$	2.81(26)	2.13(20)	2.18(19)	2.350(30)
$I_{92.80}$	2.77(26)	2.10(20)	2.15(19)	2.423(30)
$I_{93.35}$	5.81(11)	5.54(14)	5.76(14)	4.850(33)
$I_{92.38}/ I_{93.35}$	0.484(45)	0.384(40)	0.370(40)	0.4845(15)
$I_{92.80}/ I_{93.35}$	0.477(45)	0.379(40)	0.373(40)	0.4997(30)

Contribution of sum peaks of 270-315 keV



Measurement of the yields of lines of ^{235}U in equilibrium With ^{231}Th

E,keV	I (Intensity), gammas per 100 decays	
	LNHB 2011/53	This study
58.57	0.477(6)	0.471(7)
74.94	0.051(6)	0.036(9)
89.95	1.01(3)	1.02(3)
89.957	3.56(9)	3.04(6)
92.288	0.37(4)	0.41(4)
93.351	5.76(14)	4.85(6)
95.869	0.59(7)	0.69(7)
96.09	0.091(11)	0.093(9)
99.278	0.137(6)	0.149(12)
104.819	2.06	0.606(18)
105.604		1.16(3)
106.239		0.0411(19)
108.582	0.685	0.443(13)
108.955		0.0119(5)
109.442		0.097(6)
109.18	1.66(13)	1.45(3)
115.45	0.03(1)	0.03(1)
194.94	0.63(1)	0.63(4)
198.9	0.036(2)	0.044(2)
202.11	1.08(2)	1.09(1)

Measurement of the yields of lines of ^{235}U in equilibrium With ^{231}Th

E,keV	I (Intensity), gammas per 100 decays	
	LNHB 2011/53	This study
205.31	5.02(3)	5.01(5)
215.28	0.029(3)	0.0295(5)
221.38	0.118(5)	0.116(10)
228.78	0.0074(4)	0.070(2)
233.5	0.038(4)	0.0287(4)
240.87	0.074(4)	0.067(1)
246.84	0.055(3)	0.054(1)
266.47	0.0078(6)	0.060(3)
275.35	0.051(6)	0.0153(4)
275.49	0.032	
275.4 (сумма)	0.083	0.0153(4)
281.42	0.0063	0.039(5)
282.94	0.0063	0.043(5)
289.56	0.0074	0.004(2)
291.65	0.040(6)	0.019(2)
301.7	0.0053	0.0022(3)
345.9	0.04	0.034(5)
387.84	0.04(6)	0.037(3)

The Main Results

$I_{93.35}$	
5.76(14)	4.85(6)
$I_{92.38}/ I_{93.35}$	
0.4845(45)	0.4845(15)
$I_{92.80}/ I_{93.35}$	
0.477(45)	0.4997(30)