Virtual Presentation

NINTH INTERNATIONAL CONFERENCE ON RADIATION IN VARIOUS FIELDS OF RESEARCH

June 14-18, 2021 | Hunguest Hotel Sun Resort | Herceg Novi | Montenegro

SuperSYNTH

MCNP6

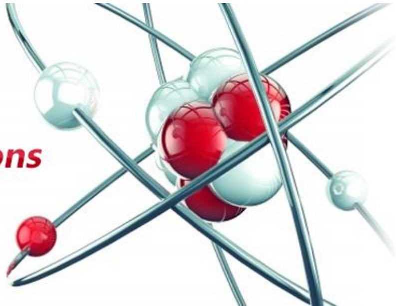
Monte Carlo Simulation Methods for Gamma-ray Metrology

GESPECOR

EFFTRAN

Ciprian Coşar[1,2,] Aurelian Luca[2], Cătălin Matei[3], Maria Sahagia[1,2]

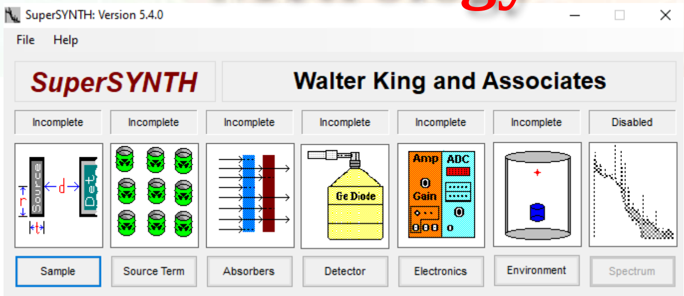
1. Faculty of Physics, University of Bucharest, Măgurele România
2. Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering, Măgurele, România
3. Department ELI-NP, Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering, Măgurele, România



Content

- Software for Gamma-ray Metrology
- (SuperSYNTH, MCNP 6.2, FITZPEAKS Gamma-ray Analysis Software, EFFTRAN, GESPECOR)
- Europium Standardized Source ^{152}Eu Data
- Uranium Ore Data (^{234}U, ^{235}U, ^{238}U)
- Thorium Ore Data (^{232}Th)
- Radium Ore Data (^{226}Ra)
- Discussions
- Conclusions
- References

Software for Gamma-ray Metrology



The software is window based, each one is designed to define the setup.

- ***Sample Window***, here we tell how our source is (point, sphere, cylinder, disc,) also the distance from source to detector.
- ***Source Term Window***, is where we set the chemical element, radionuclide, activity,
- ***Detector Window*** is where we describe the detector characteristics and material of the active part
- ***Electronic Window*** here we define the energy calibration of the setup, gain of the setup, ADC channel number & live time,
- ***Environment window*** is where we define the shield surrounding the detector.
- After all the **6 windows** are parametrized correctly than we proceed to running them in MCNP.

- Monte Carlo N-Particle Transport is a general-purpose, continuous-energy, generalized-geometry, time-dependent, Monte Carlo radiation transport code designed to track many particle types over broad ranges of energies and is developed by Los Alamos National Laboratory.
- Specific areas of application include, but are not limited to, radiation protection and dosimetry, radiation shielding, radiography, medical physics, nuclear criticality safety.
- Important standard features that make MCNP very versatile and easy to use include a powerful general source, criticality source, and surface source; both geometry and output tally plotters; a rich collection of variance reduction techniques; a flexible tally structure; and an extensive collection of cross-section data.
- The key value MCNP provides is a predictive capability that can replace expensive or impossible-to-perform experiments. It is often used to design large-scale measurements providing a significant time and cost savings to the community.

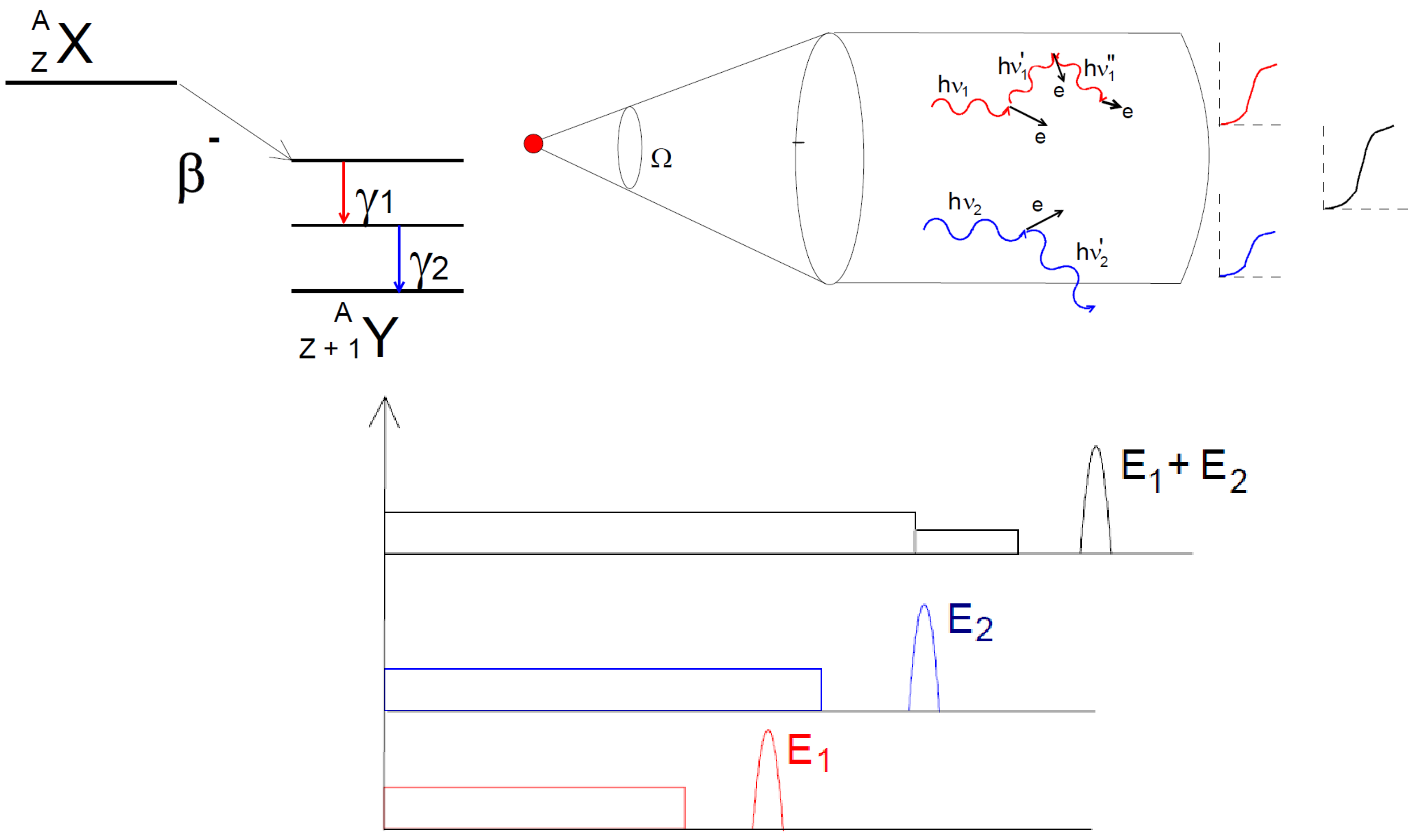
Correction for coincidence summing

In many experiments, it has been observed that the relative areas of the peaks change with the distance between source and detector, some increasing, others diminishing.

This effect is the result of simultaneous detection of X and gamma-ray lines in true coincidence.

When a radionuclide has a complex decay scheme, and there can be simultaneous detection of pulses resulting from transition cascades.

- This phenomenon has two different types of effects: loss of counting in the corresponding full-energy peaks and spectra,
- and creation of additional pulses in the background noise together with energy "sum" peaks equal to the sums of the energies



Effects of coincidence summing in a photon spectrum courtesy of ETNA Software Manual (English Format)

Coincidence Summing Correction Software Employed

Efftran software

A deterministic code was developed for the calculation of true coincidence summing correction factors and has been incorporated into the EFFTRAN tool and was verified against the results of a state-of-the-art full Monte Carlo code. The two sets of results matched on average within 1%. The EFFTRAN code is free software, available from the authors on request.[1,2,3]

1. Vidmar, T. EFFTRAN - A Monte Carlo efficiency transfer code for gamma-ray spectrometry. Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip. **550**, 603–608 (2005).
2. Vidmar, T. & Kanisch, G. Intrinsic error of the point-source and the LS-curve approximations in treatment of true coincidence summing. Appl. Radiat. Isot. **68**, 1785–1788 (2010).
3. Vidmar, T. et al. Equivalence of computer codes for calculation of coincidence summing correction factors - Part II. Appl. Radiat. Isot. **109**, 482–486 (2016).

Gespecor Software

In GESPECOR two methods for the computation of coincidence correction factors are provided. The first is a general Monte Carlo computation. This method is accurate, can be applied to any experimental situation included in GESPECOR, but it is time consuming. This method is called STANDARD and it is the default method implemented in GESPECOR. The other method is restricted to the case of well type detector measurements. This method is called ANALYTICAL or FAST METHOD FOR WELL DETECTORS (FAST W.D.).

Arnold, D., & Sima, O. (2004). Extension of the efficiency calibration of germanium detectors using the GESPECOR software. *Applied Radiation and Isotopes*, *61*(2–3), 117–121. https://doi.org/10.1016/j.apradiso.2004.03.031

Arnold, D., & Sima, O. (2004). Application of GESPECOR software for the calculation of coincidence summing effects in special cases. *Applied Radiation and Isotopes*, *60*(2–4), 167–172. https://doi.org/10.1016/j.apradiso.2003.11.011

Arnold, D., & Sima, O. (2006). Calculation of coincidence summing corrections for X-ray peaks and for sum peaks with X-ray contributions. *Applied Radiation and Isotopes*, *64*(10–11), 1297–1302. https://doi.org/10.1016/j.apradiso.2006.02.051

Sima, O., & Arnold, D. (2000). Accurate computation of coincidence summing corrections in low level gamma-ray spectrometry. *Applied Radiation and Isotopes*, *53*(1–2), 51–56. https://doi.org/10.1016/S0969-8043(00)00113-5

Sima, O., & Arnold, D. (2008). A tool for processing decay scheme data that encompasses coincidence summing calculations. *Applied Radiation and Isotopes*, *66*(6–7), 705–710. https://doi.org/10.1016/j.apradiso.2008.02.007

Sima, O., & Arnold, D. (2012). Precise measurement and calculation of coincidence summing corrections for point and linear sources. *Applied Radiation and Isotopes*, *70*(9), 2107–2111. https://doi.org/10.1016/j.apradiso.2012.02.082

Software for Gamma-ray Metrology

The FitzPeaks Gamma-ray Analysis Software is a combined research and general purpose gamma-ray spectroscopy analysis and calibration program capable of operating on spectral data from a variety of different manufacturer's systems. It is designed to run under all 32 bit versions of Microsoft® Windows™

The main algorithms used for finding and fitting peaks, and performing the quantitative analysis are based on methods presented in a paper describing the program SAMPO80 produced by M.J. Koskelo, P.A. Aarnio and J.T. Routti of the Helsinki University of Technology, Finland.

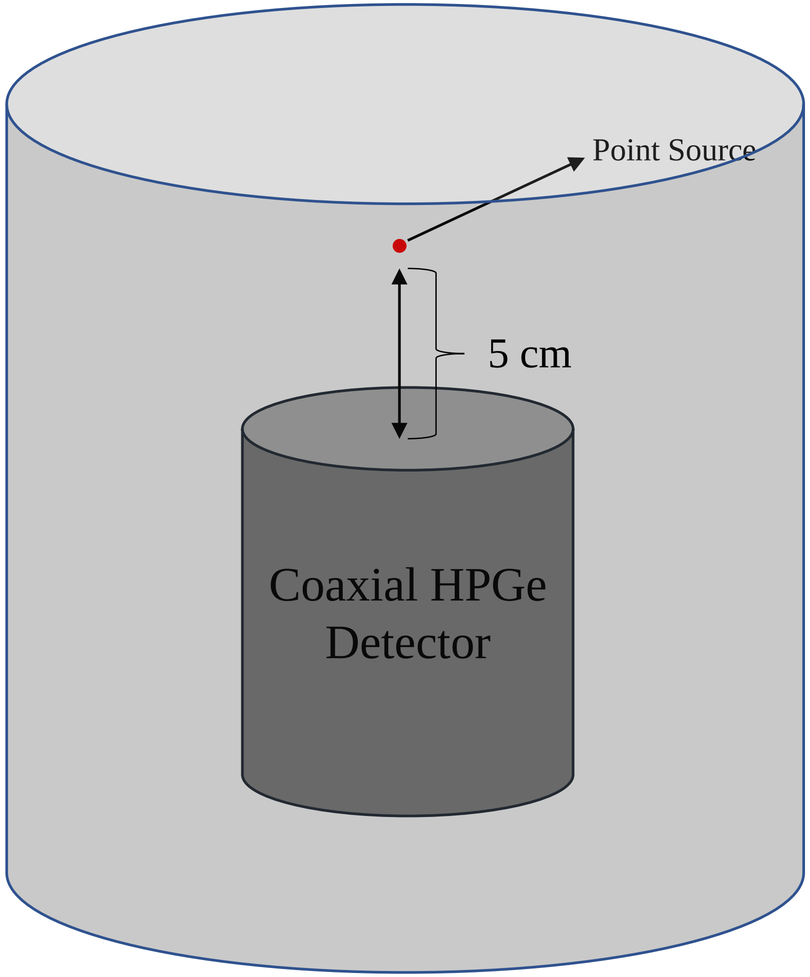
The peak fitting is performed using a linear least squares routine, fitting the data to a Gaussian function with an exponential tail on either the low energy, or both sides of a peak.

M.J.KoskeloP.A.AarnioJ.T.Routti, **SAMPO80: Minicomputer program for gamma spectrum analysis with nuclide identification,** Comp. Phy. Com., Vol 24, Issue 1, Sept–Oct 1981, Pages 11-35

https://www.jimfitz.co.uk/fitzpeak.htm

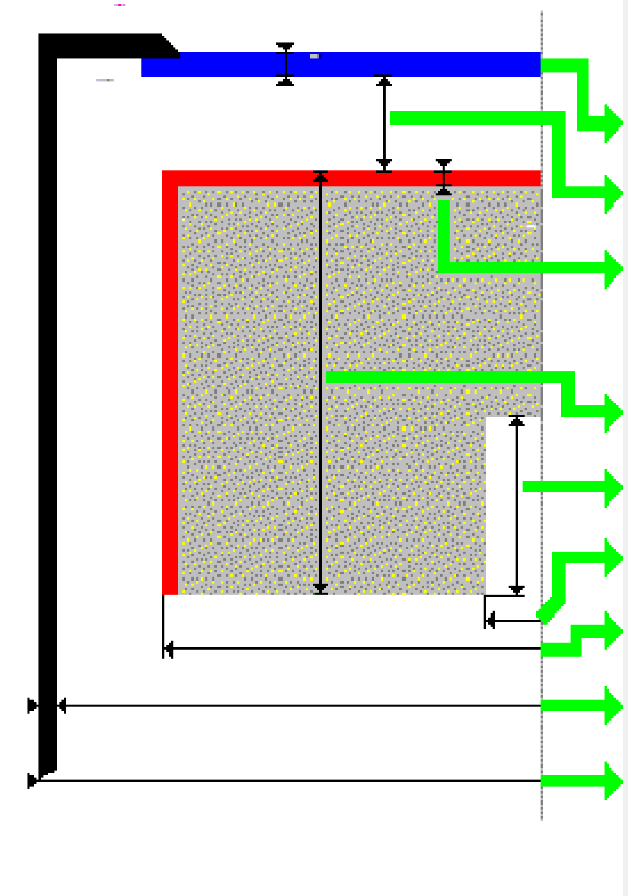
Simulation Details

- Detector material: High-Purity Germanium (HPGe)
- Source type: Point Source
- Distance Detector-to-Source: 5 cm
- Activity of the sources: 10.000(Bq)/0.27 (μCi)
- Gain selector: 1 keV/channel
- Counting time: 200.000 seconds, 2.3 days
- Channel number: 4096
- Absorber details: **N/A**, no absorber used!
- The whole experiment was conducted under a simulated lead shield, much like the real detector is placed
- Sources used in Experiment:
  1. ^{152}Eu,
  2. ^{226}Ra in secular equilibrium,
  3. Uranium ore (^{234}U+^{235}U+^{238}U) in secular equilibrium,
  4. Thorium Ore (^{232}Th) in secular equilibrium



Detector Crystal Parameters

Detector properties



		±	
Detector window material identifier:	Al (Aluminium)		
Detector window thickness:	1.3	0	mm
Detector crystal - window distance:	3	0	mm
Detector crystal dead zone thickness:	0.03	0	µm
Detector crystal material identifier:	Ge (Germanium)		
Detector crystal thickness:	46	0	mm
Detector crystal hole depth:	32.7	0	mm
Detector crystal hole diameter:	9.3	0	mm
Detector crystal diameter:	58.8	0	mm
Detector side cap thickness:	1.3	0	mm
Detector side cap diameter:	70	0	mm
Detector side cap material identifier:	Al (Aluminium)		

S/N 47-TP22323A

HPGe model GEM25P4

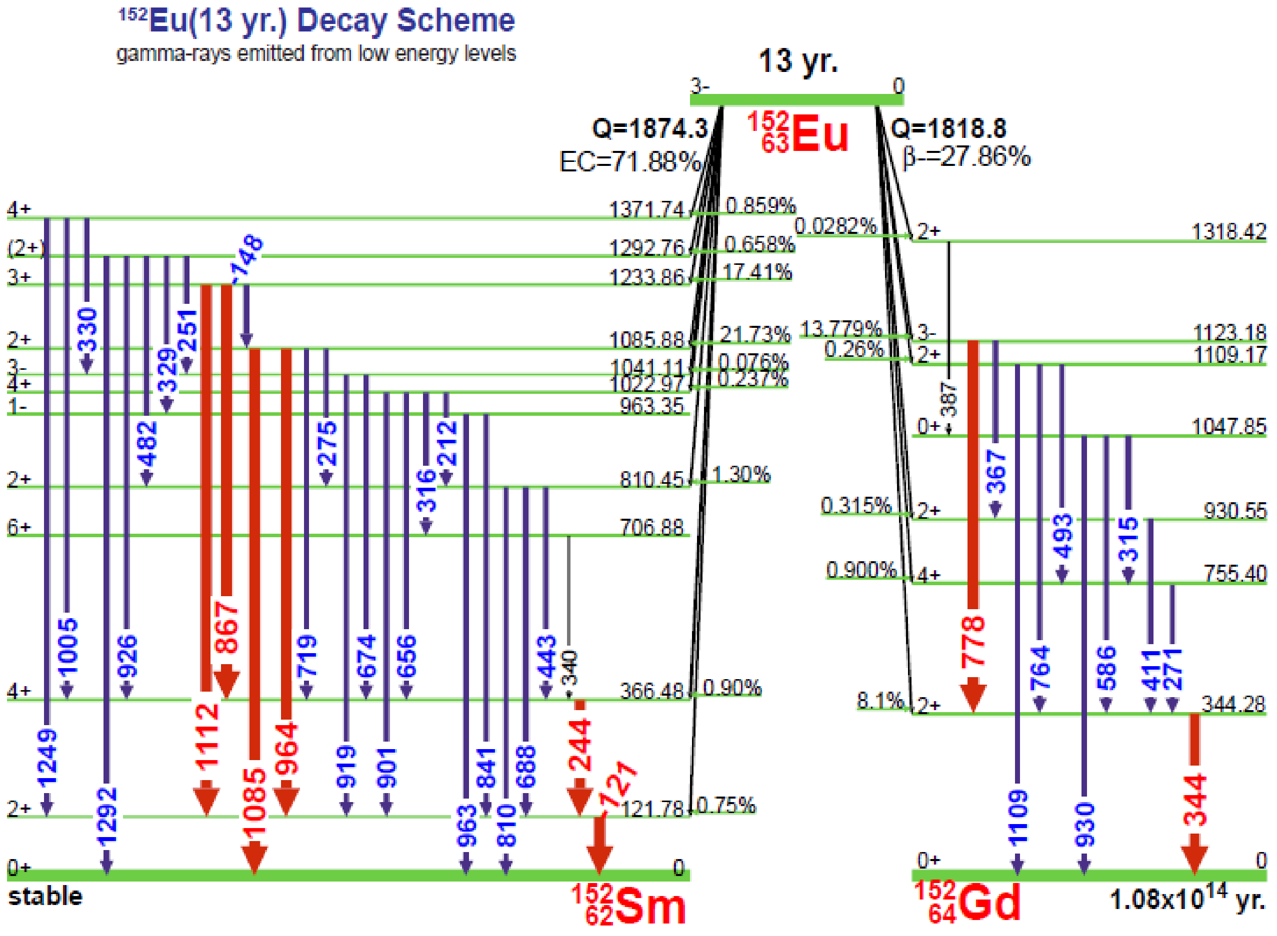
ORTEC AMETEK

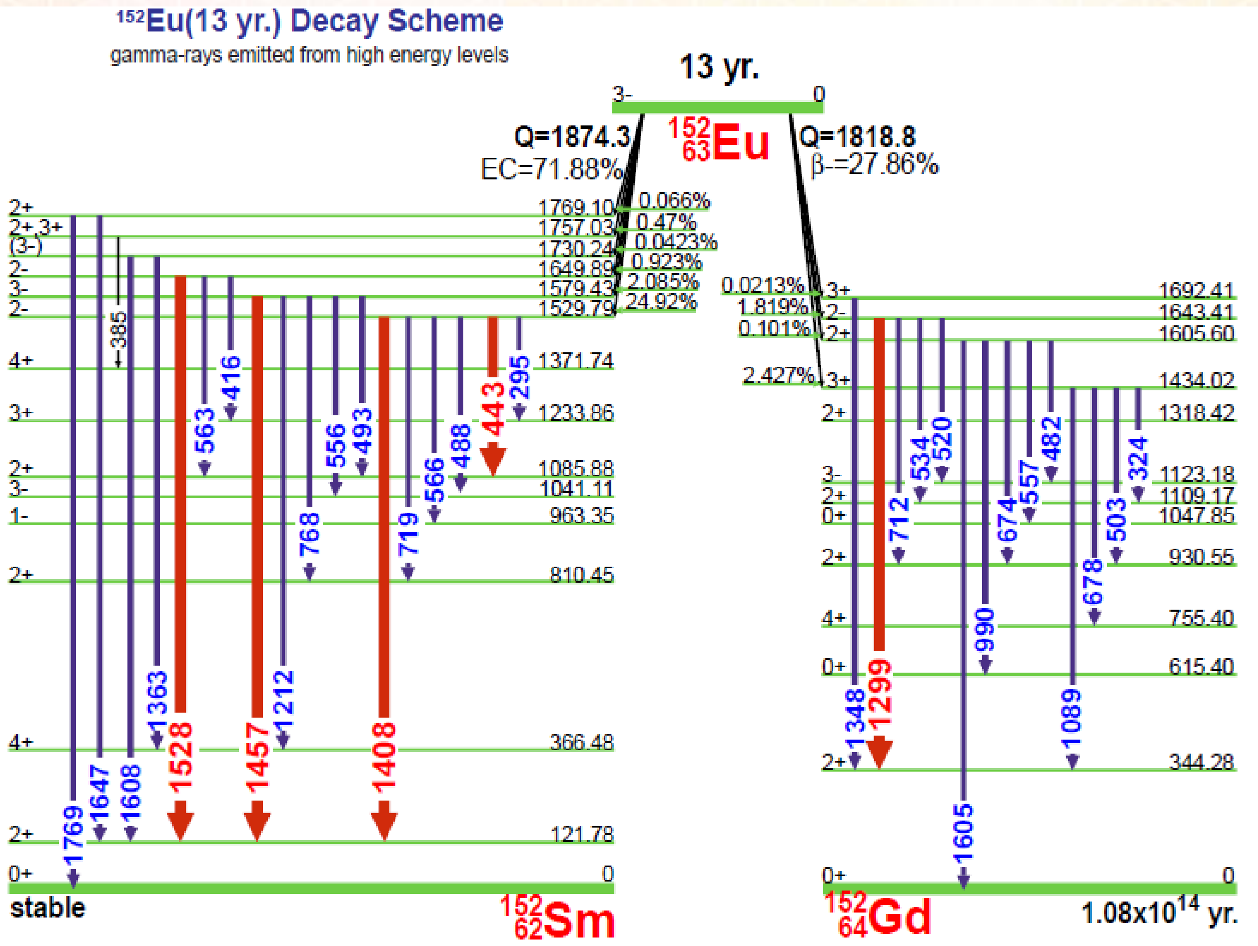
Image courtesy of ETNA Software

http://www.lnhb.fr/rd-activities/spectrum-processing-software/

Europium
Eu-152

NINTH INTERNATIONAL
CONFERENCE ON RADIATION
IN VARIOUS FIELDS OF RESEARCH
June 14-18, 2021 | Hunguest Hotel Sun Resort | Herceg Novi | Montenegro





https://gammaray.inl.gov/SiteAssets/catalogs/ge/pdf/eu152.pdf

Europium Eu-152

	Eu-152					**EFFTRAN**	**GESPECOR**	
Chemical Element	Nuclide	Type of Decay	Energy	Area	Err.(%)	**Correction Factor**	**Correction Factor**	Err.(%)
Europium	EU-152	EC	121.780	1.22E+07	0.20	**1.0751**	**1.0858**	0.0350
Europium	EU-152	EC	244.700	2.50E+06	0.30	**1.1103**	**1.1167**	0.0630
Europium	EU-152	EC	295.940	1.06E+05	5.80	**1.1204**	**1.1373**	0.0900
Europium	EU-152	BETA- (-β)	344.280	6.56E+06	0.20	**1.0255**	**1.0538**	0.1200
Europium	EU-152	BETA- (-β)	367.790	1.56E+05	6.50	**1.0799**	**1.1616**	0.1100
Europium	EU-152	BETA- (-β)	411.120	4.56E+05	1.00	**1.0631**	**1.1268**	0.0870
Europium	EU-152	EC	443.960	5.77E+05	0.90	**1.0969**	**1.1020**	0.0760
Europium	EU-152	BETA- (-β)	586.270	1.77E+05	3.90	**1.0534**	**1.1088**	0.1600
Europium	EU-152	BETA- (-β)	678.620			**1.0798**	**1.1628**	0.1500
Europium	EU-152	EC	686.610	1.36E+05	4.20	**1.0889**	**1.0973**	0.1400
Europium	EU-152	EC	688.670			**1.0678**	**1.0290**	0.0620
Europium	EU-152	BETA- (-β)	778.900	1.50E+06	0.50	**1.0377**	**1.0728**	0.1700
Europium	EU-152	EC	810.450			**0.9792**	**0.9303**	0.1200
Europium	EU-152	EC	867.380	5.89E+05	0.90	**1.1250**	**1.1293**	0.1600
Europium	EU-152	EC	919.340			**1.0972**	**1.0870**	0.1800
Europium	EU-152	EC	963.390	1.42E+06	0.50	**1.0452**	**1.0425**	0.0960
Europium	EU-152	EC	964.080			**1.0822**	**1.0562**	0.1800
Europium	EU-152	EC	1005.270	4.22E+04	13.70	**1.1233**	**1.1267**	0.2200
Europium	EU-152	EC	1085.840	1.06E+06	0.40	**1.0089**	**0.9709**	0.0990
Europium	EU-152	BETA- (-β)	1089.740			**1.0311**	**1.0551**	0.1000
Europium	EU-152	BETA- (-β)	1109.170			**0.9876**	**0.9654**	0.1800
Europium	EU-152	EC	1112.080	1.26E+06	0.30	**1.0685**	**1.0291**	0.1500
Europium	EU-152	EC	1212.950	1.46E+05	2.60	**1.1217**	**1.1268**	0.1800
Europium	EU-152	BETA- (-β)	1299.140	9.60E+04	2.30	**1.0380**	**1.0731**	0.1700
Europium	EU-152	EC	1408.010	1.47E+06	0.20	**1.0740**	**1.0408**	0.2000
Europium	EU-152	EC	1457.640	3.15E+04	4.00	**0.9930**	**0.8838**	0.1900
Europium	EU-152	EC	1528.100	1.57E+04	7.10	**1.0507**	**0.9805**	0.2600

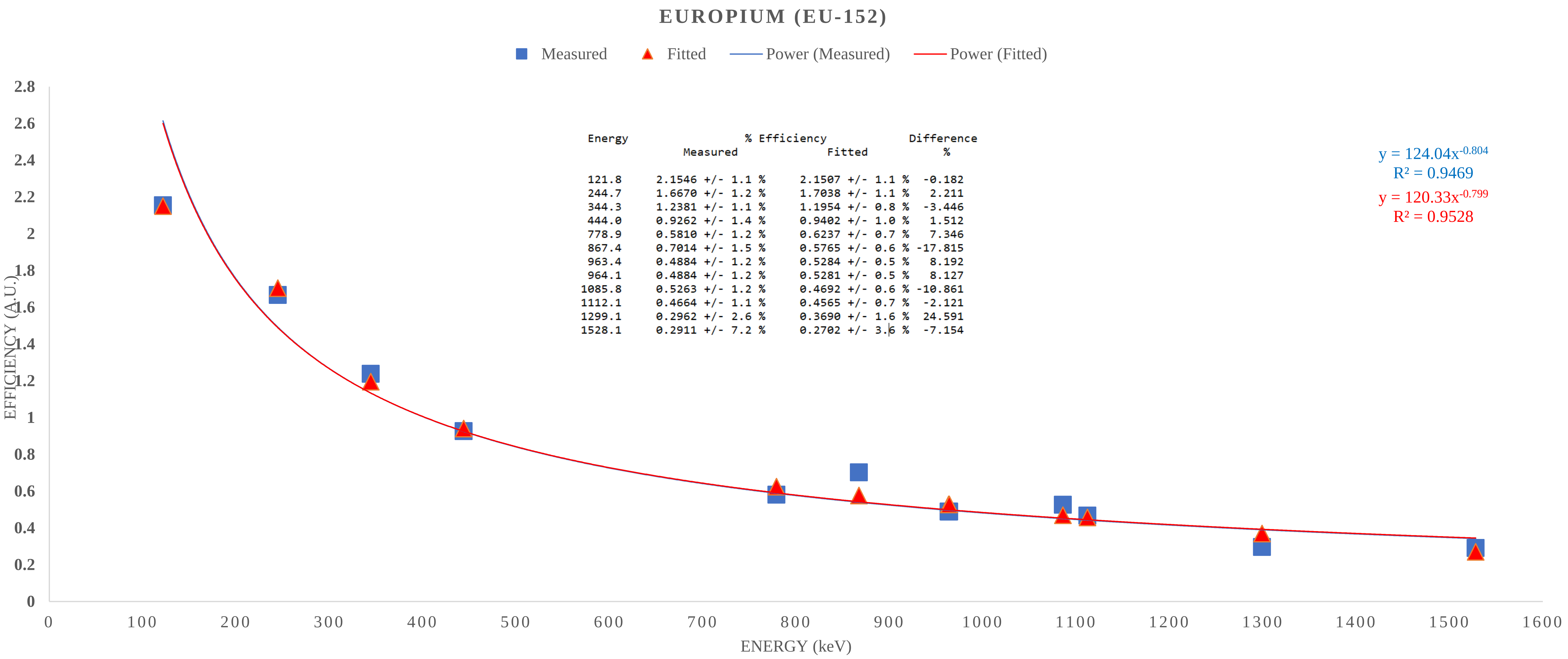
Europium Eu-152

Eu-152				
Corrected Peak Area (EFFTRAN)	Total Err.(%)	**Corrected Peak Area (Gespecor)**	Total Err.(%)	Difference
1.31E+07	0.2350	**1.32E+07**	0.2350	1.88E+06
2.78E+06	0.3630	**2.79E+06**	0.3630	5.37E+05
1.19E+05	5.8900	**1.21E+05**	5.8900	2.56E+04
6.72E+06	0.3200	**6.91E+06**	0.3200	5.02E+05
1.68E+05	6.6100	**1.81E+05**	6.6100	3.41E+04
4.85E+05	1.0870	**5.14E+05**	1.0870	8.00E+04
6.33E+05	0.9760	**6.36E+05**	0.9760	1.09E+05
1.86E+05	4.0600	**1.96E+05**	4.0600	2.68E+04
0.00E+00	0.1500	**0.00E+00**	0.1500	0.00E+00
1.48E+05	4.3400	**1.49E+05**	4.3400	2.42E+04
0.00E+00	0.0620	**0.00E+00**	0.0620	0.00E+00
1.56E+06	0.6700	**1.61E+06**	0.6700	1.59E+05
0.00E+00	0.1200	**0.00E+00**	0.1200	0.00E+00
6.63E+05	1.0600	**6.65E+05**	1.0600	1.41E+05
0.00E+00	0.1800	**0.00E+00**	0.1800	0.00E+00
1.49E+06	0.5960	**1.48E+06**	0.5960	1.22E+05
0.00E+00	0.1800	**0.00E+00**	0.1800	0.00E+00
4.74E+04	13.9200	**4.76E+04**	13.9200	9.95E+03
1.07E+06	0.4990	**1.03E+06**	0.4990	-2.24E+04
0.00E+00	0.1000	**0.00E+00**	0.1000	0.00E+00
0.00E+00	0.1800	**0.00E+00**	0.1800	0.00E+00
1.35E+06	0.4500	**1.30E+06**	0.4500	1.22E+05
1.64E+05	2.7800	**1.64E+05**	2.7800	3.42E+04
9.97E+04	2.4700	**1.03E+05**	2.4700	1.02E+04
1.57E+06	0.4000	**1.53E+06**	0.4000	1.66E+05
3.13E+04	4.1900	**2.78E+04**	4.1900	-4.36E+03
1.65E+04	7.3600	**1.54E+04**	7.3600	4.83E+02

Europium Eu-152

NINTH INTERNATIONAL CONFERENCE ON RADIATION IN VARIOUS FIELDS OF RESEARCH

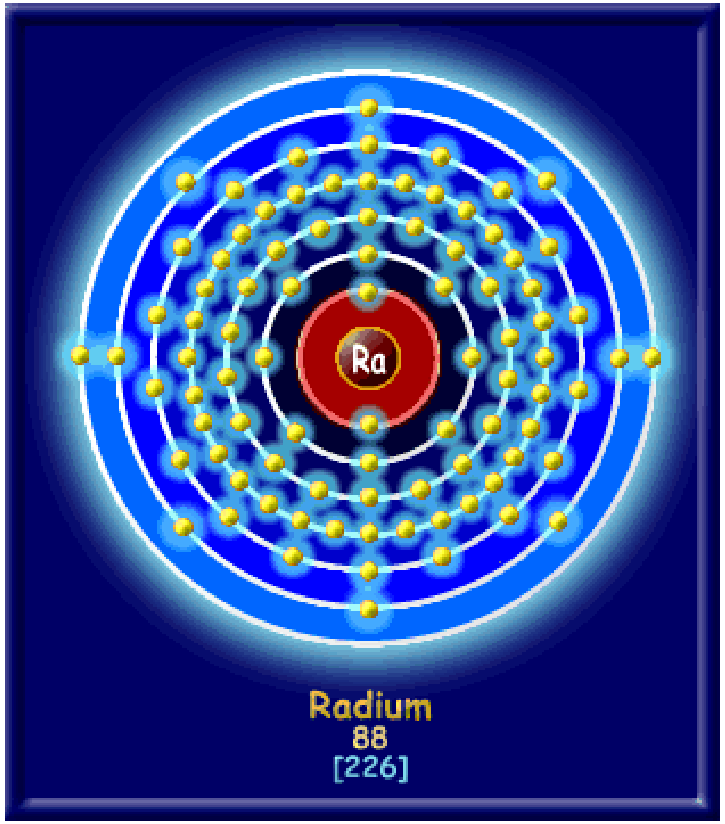
June 14-18, 2021 | Hunguest Hotel Sun Resort | Herceg Novi | Montenegro



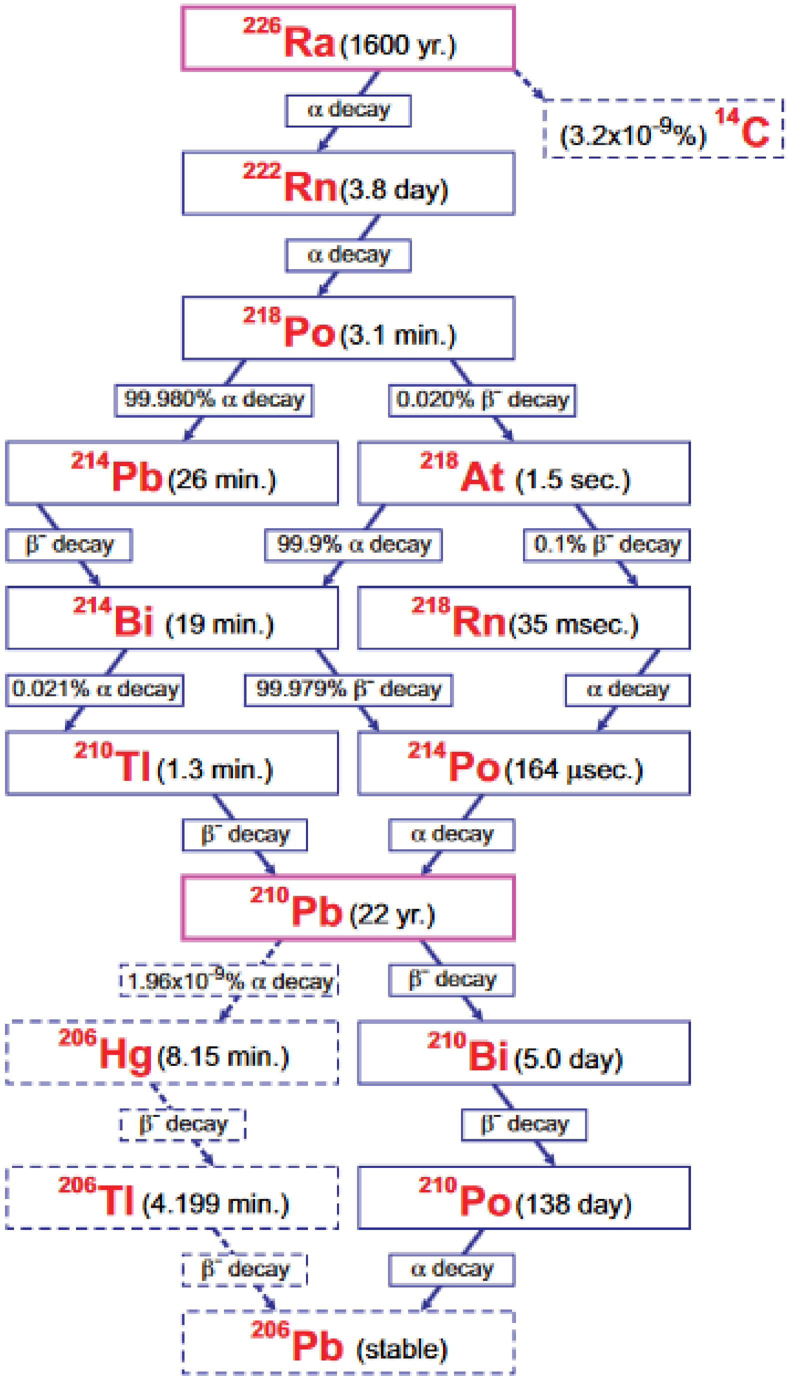
Energy	% Efficiency Measured	% Efficiency Fitted	Difference %
121.8	2.1546 +/- 1.1 %	2.1507 +/- 1.1 %	-0.182
244.7	1.6670 +/- 1.2 %	1.7038 +/- 1.1 %	2.211
344.3	1.2381 +/- 1.1 %	1.1954 +/- 0.8 %	-3.446
444.0	0.9262 +/- 1.4 %	0.9402 +/- 1.0 %	1.512
778.9	0.5810 +/- 1.2 %	0.6237 +/- 0.7 %	7.346
867.4	0.7014 +/- 1.5 %	0.5765 +/- 0.6 %	-17.815
963.4	0.4884 +/- 1.2 %	0.5284 +/- 0.5 %	8.192
964.1	0.4884 +/- 1.2 %	0.5281 +/- 0.5 %	8.127
1085.8	0.5263 +/- 1.2 %	0.4692 +/- 0.6 %	-10.861
1112.1	0.4664 +/- 1.1 %	0.4565 +/- 0.7 %	-2.121
1299.1	0.2962 +/- 2.6 %	0.3690 +/- 1.6 %	24.591
1528.1	0.2911 +/- 7.2 %	0.2702 +/- 3.6 %	-7.154

Radium Ore
Ra-226

NINTH INTERNA
CONFERENC
IN VARIOUS FIEL
June 14-18, 2021 | Hunguest Ho



^{226}Ra Decay Chain



https://gammaray.inl.gov/SiteAssets/catalogs/ge/pdf/ra226_new.pdf

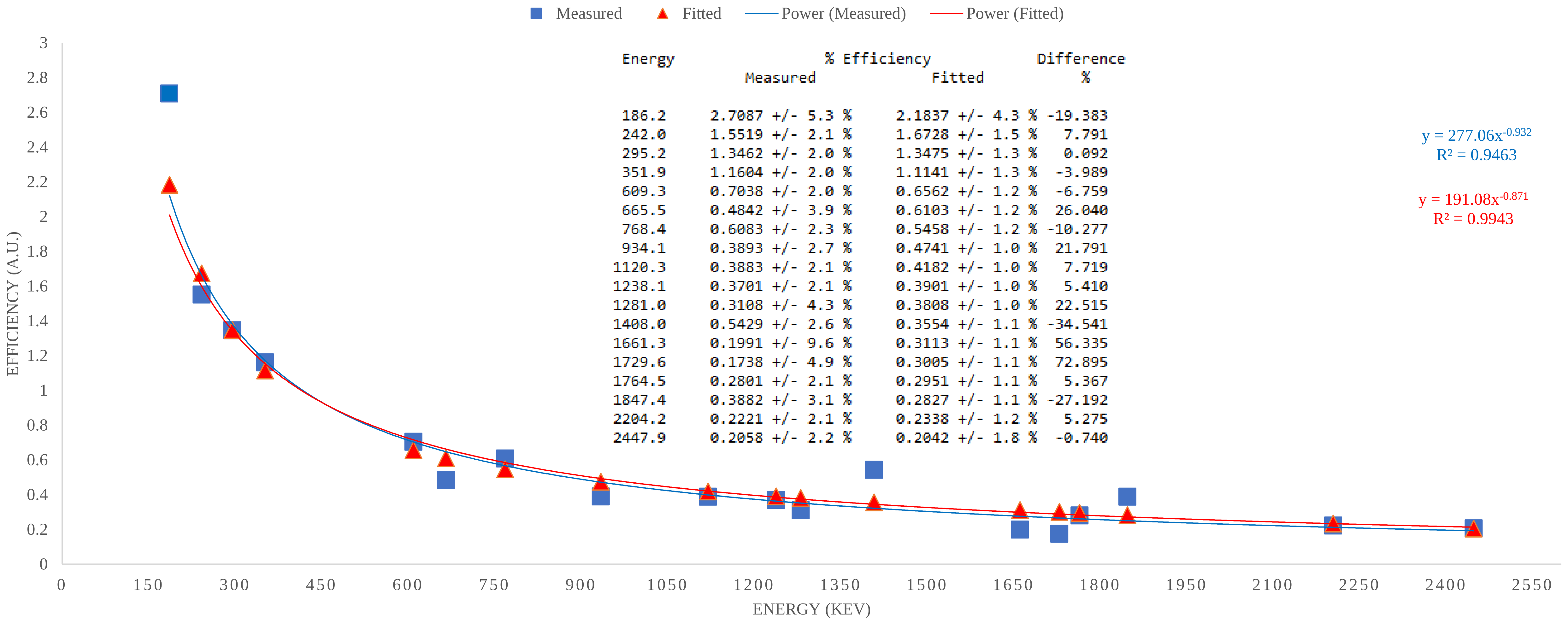
Radium Ore Ra-226

	Radium & Daughter Nuclides					**EFFTRAN**	**GESPECOR**	
Chemical Element	Nuclide	Type of Decay	Energy	Area	Err.(%)	**Correction Factor**	**Correction Factor**	Err.(%)
Uranium/Radium	RA-226	ALPHA	186.21	1.66E+06	1.0	**1.0000**	**1.0000**	0.0570
Uranium	U-235	ALPHA	205.31			**1.0000**	**1.0057**	0.0540
Uranium/Radium	PB-214	BETA-	351.93	8.49E+06	0.1	**1.0000**	**1.0007**	0.0850
Uranium/Radium	BI-214	BETA-	609.32	6.44E+06	0.1	**1.0330**	**1.0709**	0.1600
Uranium	PA-234M	BETA-	1001.03			**0.9990**	**0.9956**	0.1300
Uranium/Radium	BI-214	BETA-	1120.29	1.29E+06	0.5	**1.0370**	**1.0776**	0.1500
Uranium/Radium	BI-214	BETA-	1238.11	4.43E+05	0.8	**1.0350**	**1.0728**	0.2000
Uranium/Radium	BI-214	BETA-	1377.67	3.18E+05	1.0	**0.9840**	**0.9518**	0.1800
Uranium/Radium	BI-214	BETA-	1764.54	9.08E+05	0.8	**0.9990**	**0.9960**	0.1700
Uranium/Radium	BI-214	BETA-	2204.07	2.46E+05	0.9	**0.9990**	**0.9962**	0.2900

Radium & Daughter Nuclides				
Corrected Peak Area (EFFTRAN)	Total Err.(%)	**Corrected Peak Area (Gespecor)**	Total Err.(%)	Difference
1.66E+06	1.0570	**1.66E+06**	1.0570	0.00E+00
0.00E+00	0.0540	**0.00E+00**	0.0540	0.00E+00
8.49E+06	0.1850	**8.50E+06**	0.1850	5.60E+03
6.65E+06	0.2600	**6.89E+06**	0.2600	6.38E+05
0.00E+00	0.1300	**0.00E+00**	0.1300	0.00E+00
1.34E+06	0.6500	**1.39E+06**	0.6500	1.40E+05
4.59E+05	1.0000	**4.76E+05**	1.0000	4.56E+04
3.13E+05	1.1800	**3.03E+05**	1.1800	-2.12E+04
9.07E+05	0.9700	**9.05E+05**	0.9700	-4.54E+03
2.46E+05	1.1900	**2.45E+05**	1.1900	-1.18E+03

Radium Ore Ra-226

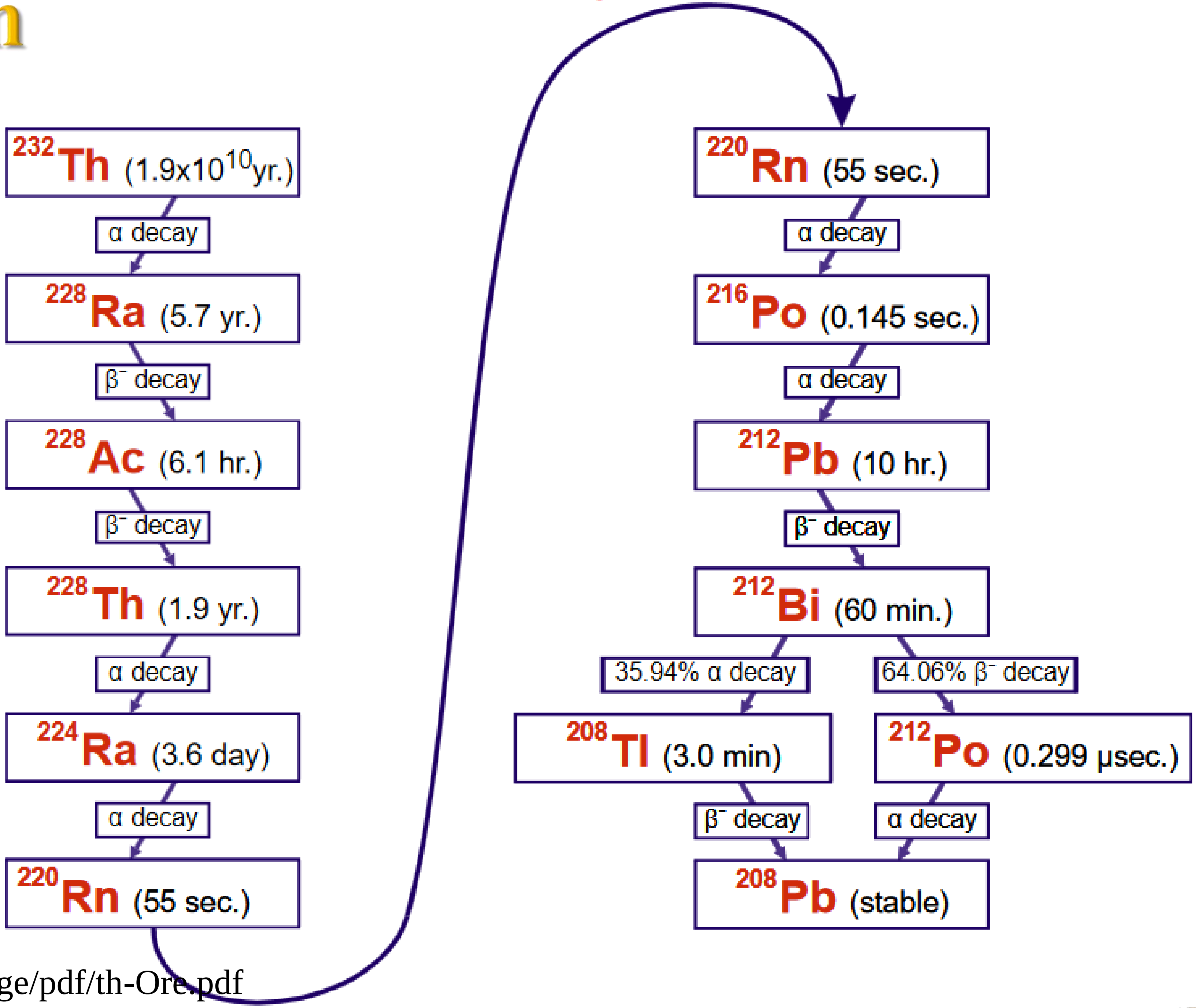
RADIUM AND DAUGHTER NUCLIDES (RA-226)



Energy	% Efficiency Measured	% Efficiency Fitted	Difference %
186.2	2.7087 +/- 5.3 %	2.1837 +/- 4.3 %	-19.383
242.0	1.5519 +/- 2.1 %	1.6728 +/- 1.5 %	7.791
295.2	1.3462 +/- 2.0 %	1.3475 +/- 1.3 %	0.092
351.9	1.1604 +/- 2.0 %	1.1141 +/- 1.3 %	-3.989
609.3	0.7038 +/- 2.0 %	0.6562 +/- 1.2 %	-6.759
665.5	0.4842 +/- 3.9 %	0.6103 +/- 1.2 %	26.040
768.4	0.6083 +/- 2.3 %	0.5458 +/- 1.2 %	-10.277
934.1	0.3893 +/- 2.7 %	0.4741 +/- 1.0 %	21.791
1120.3	0.3883 +/- 2.1 %	0.4182 +/- 1.0 %	7.719
1238.1	0.3701 +/- 2.1 %	0.3901 +/- 1.0 %	5.410
1281.0	0.3108 +/- 4.3 %	0.3808 +/- 1.0 %	22.515
1408.0	0.5429 +/- 2.6 %	0.3554 +/- 1.1 %	-34.541
1661.3	0.1991 +/- 9.6 %	0.3113 +/- 1.1 %	56.335
1729.6	0.1738 +/- 4.9 %	0.3005 +/- 1.1 %	72.895
1764.5	0.2801 +/- 2.1 %	0.2951 +/- 1.1 %	5.367
1847.4	0.3882 +/- 3.1 %	0.2827 +/- 1.1 %	-27.192
2204.2	0.2221 +/- 2.1 %	0.2338 +/- 1.2 %	5.275
2447.9	0.2058 +/- 2.2 %	0.2042 +/- 1.8 %	-0.740

Thorium Ore

Th Ore Decay Chain



https://gammaray.inl.gov/SiteAssets/catalogs/ge/pdf/th-Ore.pdf

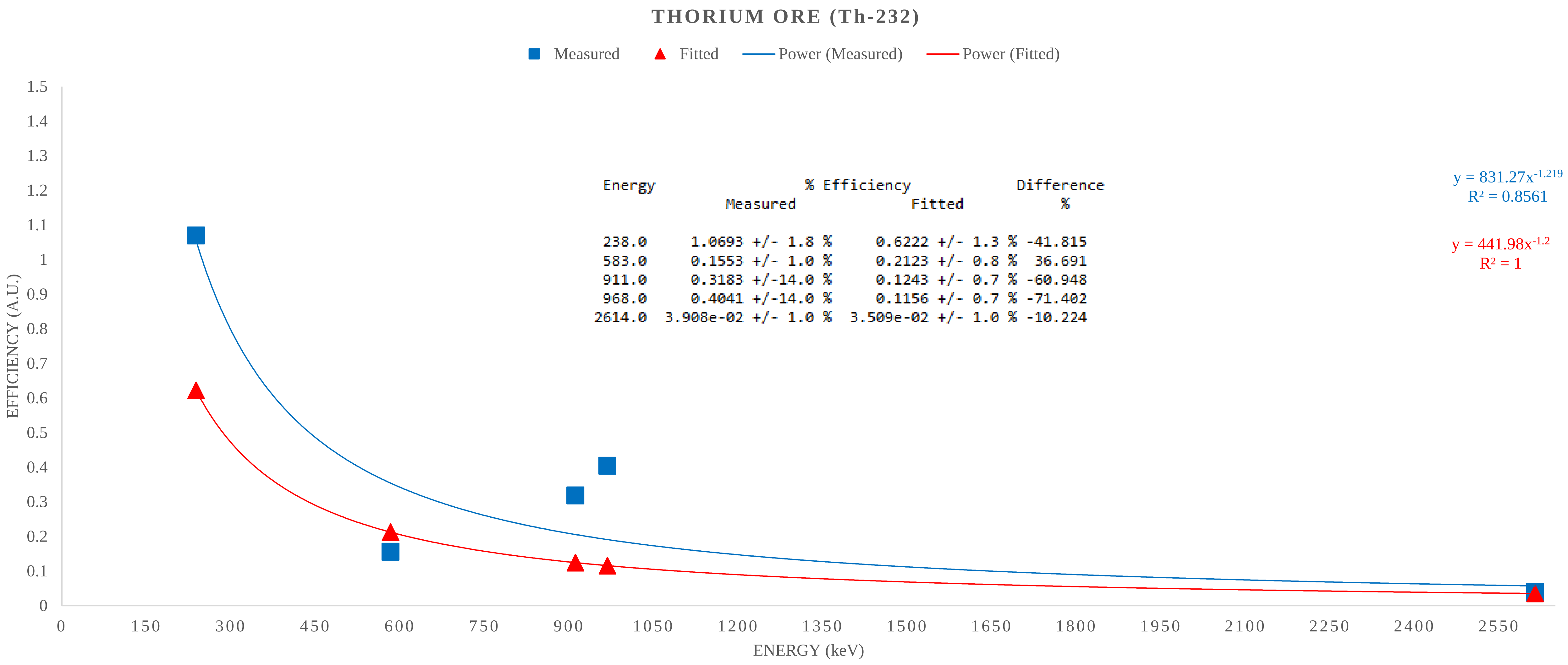
Thorium Ore

NINTH INTERNATIONAL CONFERENCE ON RADIATION IN VARIOUS FIELDS OF RESEARCH
June 14-18, 2021 | Hunguest Hotel Sun Resort | Herceg Novi | Montenegro

	Thorium Ore					**EFFTRAN**	**GESPECOR**	
Chemical Element	Nuclide	Type of Decay	Energy	Area	Err.(%)	**Correction Factor**	**Correction Factor**	Err.(%)
Thorium	AC-228	BETA-	18.420			**1.0720**	**1.1159**	0.0900
Thorium	AC-228	BETA-	99.500			**1.0700**	**1.0182**	0.0630
Thorium	PB-212	BETA-	238.630	9.09E+06	0.3	**1.0000**	**1.0148**	0.1100
Thorium	AC-228	BETA-	338.320	2.35E+06	1	**1.0080**	**1.0146**	0.2000
Thorium	TL-208	BETA-	583.190	2.67E+06	0.3	**1.0410**	**1.1721**	0.0340
Thorium	BI-212	BETA-	727.330	5.72E+05	2.8	**1.0110**	**1.0001**	0.0430
Thorium	TL-208	BETA-	860.560	2.05E+05	7.3	**1.0070**	**1.0220**	0.1700
Thorium	AC-228	BETA-	911.200	1.94E+06	0.9	**1.0090**	**1.1038**	0.1600
Thorium	AC-228	BETA-	968.970	1.39E+06	0.4	**1.0090**	**1.0879**	0.0820
Thorium	TL-208	BETA-	2614.510	7.89E+05	0.2	**1.0510**	**1.0160**	0.1400

Thorium Ore				
Corrected Peak Area (EFFTRAN)	Total Err.(%)	**Corrected Peak Area (Gespecor)**	Total Err.(%)	Difference
0.00E+00	0.0900	**0.00E+00**	0.0900	0.00E+00
0.00E+00	0.0630	**0.00E+00**	0.0630	0.00E+00
9.09E+06	0.4100	**9.23E+06**	0.4100	1.33E+05
2.37E+06	1.2000	**2.38E+06**	1.2000	5.25E+04
2.78E+06	0.3340	**3.13E+06**	0.3340	5.02E+05
5.78E+05	2.8430	**5.72E+05**	2.8430	6.33E+03
2.07E+05	7.4700	**2.10E+05**	7.4700	5.85E+03
1.96E+06	1.0600	**2.14E+06**	1.0600	2.00E+05
1.40E+06	0.4820	**1.51E+06**	0.4820	1.25E+05
8.29E+05	0.3400	**8.02E+05**	0.3400	5.27E+04

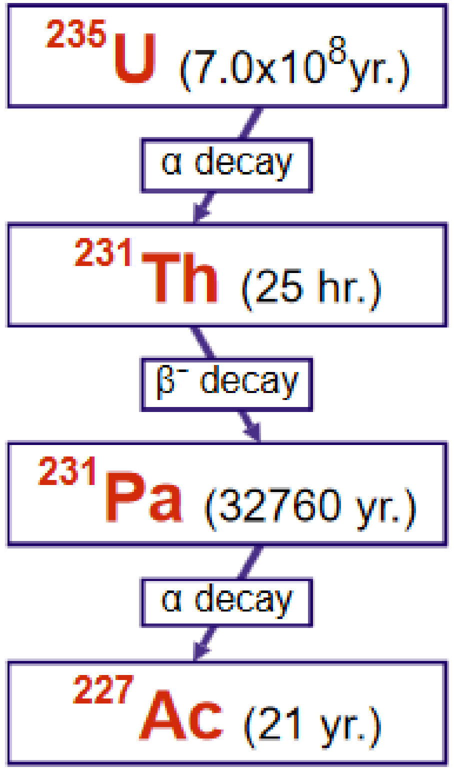
Thorium Ore



Energy	% Efficiency Measured	% Efficiency Fitted	Difference %
238.0	1.0693 +/- 1.8 %	0.6222 +/- 1.3 %	-41.815
583.0	0.1553 +/- 1.0 %	0.2123 +/- 0.8 %	36.691
911.0	0.3183 +/-14.0 %	0.1243 +/- 0.7 %	-60.948
968.0	0.4041 +/-14.0 %	0.1156 +/- 0.7 %	-71.402
2614.0	3.908e-02 +/- 1.0 %	3.509e-02 +/- 1.0 %	-10.224

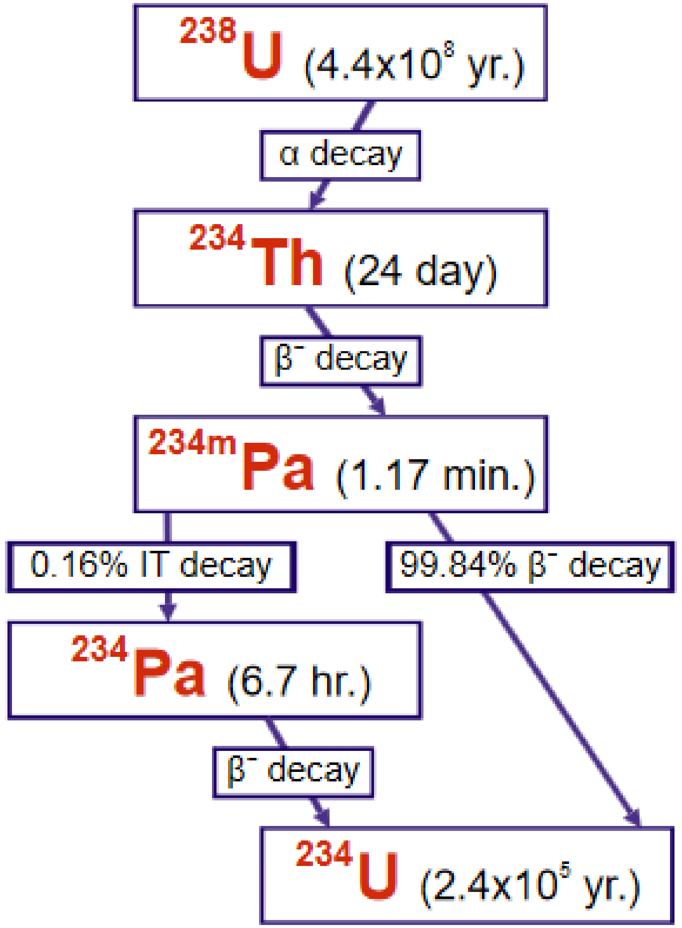
Uranium Ore

^{235}U Decay Chain



See ^{227}Ac for Chain completion

^{238}U Decay Chain



See ^{234}U for Chain completion

https://gammaray.inl.gov/SiteAssets/catalogs/ge/pdf/u-Ore.pdf

Uranium Ore

Uranium Ore					**EFFTRAN**	**GESPECOR**	
Nuclide	Type of Decay	Energy	Area	Err.(%)	**Correction Factor**	**Correction Factor (1/Fc)**	Err.(%)
TH-234	BETA-	63.29			**1.0010**	**1.0000**	0.0170
TH-234	BETA-	92.38			**1.0000**	**1.0000**	0.0210
U-238	ALPHA	113.5			**1.0010**	**1.0000**	0.0440
U-235	ALPHA	143.76	5.30E+06	0.6	**1.0040**	**1.0034**	0.0480
U-235	ALPHA	163.33	2.79E+06	1.1	**1.0020**	**1.0093**	0.0510
U-235	ALPHA	185.71	2.39E+07	0.2	**1.0040**	**1.0034**	0.0530
RA-226	ALPHA	186.21			**1.0000**	**1.0000**	0.0570
U-235	ALPHA	205.31	2.10E+06	1.6	**1.0000**	**1.0057**	0.0540
PB-214	BETA-	351.93			**1.0000**	**1.0007**	0.0850
BI-214	BETA-	609.32			**1.0330**	**1.0709**	0.1600
PA-234M	BETA-	1001.03	7.80E+04	0.7	**0.9990**	**0.9956**	0.1300
BI-214	BETA-	1120.29			**1.0370**	**1.0776**	0.1500
BI-214	BETA-	1238.11			**1.0350**	**1.0728**	0.2000
BI-214	BETA-	1377.67			**0.9840**	**0.9518**	0.1800
BI-214	BETA-	1764.54			**0.9990**	**0.9960**	0.1700
BI-214	BETA-	2204.07			**0.9990**	**0.9962**	0.2900

Uranium Ore

Corrected Peak Area (EFFTRAN)	Total Err.(%)	**Corrected Peak Area (Gespecor)(1/Fc)**	Total Err.(%)	Difference
0.00E+00	0.0170	**0.00E+00**	0.0170	0.00E+00
0.00E+00	0.0210	**0.00E+00**	0.0210	0.00E+00
0.00E+00	0.0440	**0.00E+00**	0.0440	0.00E+00
5.32E+06	0.6480	**5.31E+06**	0.6480	3.92E+04
2.80E+06	1.1510	**2.82E+06**	1.1510	3.14E+04
2.40E+07	0.2530	**2.40E+07**	0.2530	1.77E+05
0.00E+00	0.0570	**0.00E+00**	0.0570	0.00E+00
2.10E+06	1.6540	**2.11E+06**	1.6540	1.19E+04
0.00E+00	0.0850	**0.00E+00**	0.0850	0.00E+00
0.00E+00	0.1600	**0.00E+00**	0.1600	0.00E+00
7.79E+04	0.8300	**7.76E+04**	0.8300	-4.21E+02
0.00E+00	0.1500	**0.00E+00**	0.1500	0.00E+00
0.00E+00	0.2000	**0.00E+00**	0.2000	0.00E+00
0.00E+00	0.1800	**0.00E+00**	0.1800	0.00E+00
0.00E+00	0.1700	**0.00E+00**	0.1700	0.00E+00
0.00E+00	0.2900	**0.00E+00**	0.2900	0.00E+00

Results
Discussions

Eu – 152

Performed very good main peaks could be analyzed with the help of the Fitzpeaks

Ra – 226 & Daughter Nuclides

Performed well main peaks were found with the help of Fitzpeaks

Thorium Ore (Th - 232)

Main peaks found with Fitzpeaks but no other peaks

Uranium Ore (U-234, U-235,U-238 & Daughter Nuclides)

Few peaks have been found comparing the method used with other sources it’s a clear indication that we need to revisit the Uranium source

Conclusions

An all spectra the same method was applied, but Uranium source was a tricky one as it did not behave as expected but if we look into the daughter chain of the Uranium we can see that there are number of radioisotopes which have low probability of emission compared to the probabilities of ^{152}Eu.

The results for both Thorium and Uranium would need a rethinking and reevaluation and based on these new methods we will proceed further.

One assumption for the Uranium side was low activity chosen for this experiment, (10.000 Bq) which is rather low for the entire chain.
Second assumption was the acquisition time used of 200.000 sec (2.3 days).
Third assumption is that based on the low activity+low acquisition time it could happen that not all radionuclides from the decay chains of Thorium and Uranium ores to get accounted for.

So the next step prior to publishing the Thorium and Uranium Data we will like to make some adjustments to the activities and acquisition time of the proposed spectra

Selected References

Vidmar, T. EFFTRAN - A Monte Carlo efficiency transfer code for gamma-ray spectrometry. Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip. **550**, 603–608 (2005).

Ramebäck, H. et al. On the accuracy of gamma spectrometric isotope ratio measurements of uranium. Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip. **815**, 57–61 (2016).

Nikolic, J., Vidmar, T., Jokovic, D., Rajacic, M. & Todorovic, D. Calculation of HPGe efficiency for environmental samples: Comparison of EFFTRAN and GEANT4. Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip. **763**, 347–353 (2014).
Vidmar, T. et al. Testing efficiency transfer codes for equivalence. Appl. Radiat. Isot. **68**, 355–359 (2010).

Vidmar, T. & Kanisch, G. Intrinsic error of the point-source and the LS-curve approximations in treatment of true coincidence summing. Appl. Radiat. Isot. **68**, 1785–1788 (2010).

Vidmar, T. et al. Equivalence of computer codes for calculation of coincidence summing correction factors - Part II. Appl. Radiat. Isot. **109**, 482–486 (2016).

http://www.lnhb.fr/icrm_gs_wg/icrm_gs_wg_benchmarks

M. C. Lépy et. al. 2019

Thank You!
For your patience