DEVELOPMENT OF A REAL-TIME DETECTION STRATEGY FOR MATERIAL ACCOUNTANCY AND PROCESS MONITORING DURING NUCLEAR FUEL REPROCESSING USING THE UREX+3A METHOD

A Thesis

by

BRADEN GODDARD

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2009

Major Subject: Nuclear Engineering

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Approved by:

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ABSTRACT

Development of a Real-Time Detection Strategy for Material Accountancy and Process Monitoring during Nuclear Fuel Reprocessing Using the UREX+3a Method.

(December 2009)

Braden Goddard, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Sean M. McDeavitt

Reprocessing nuclear fuel is becoming more viable in the United States due to the anticipated increase in construction of nuclear power plants, the growing stockpile of existing used nuclear fuel, and a public desire to reduce the amount of this fuel. However, a new reprocessing facility in non-weapon states must be safeguarded and new reprocessing facilities in weapon states will likely have safeguards due to political and material accountancy reasons. These facilities will have state of the art controls and monitoring methods to safeguard special nuclear materials, as well as to provide real-time monitoring. The focus of this project is to enable the development of a safeguards strategy that uses well established photon measurement methods to characterize samples from the UREX+3a reprocessing method using a variety of detector types and measurement times.

It was determined that the errors from quantitative measurements were too large for traditional safeguards methods; however, a safeguards strategy based on qualitative

gamma ray and neutron measurements is proposed. The gamma ray detection equipment used in the safeguard strategy could also be used to improve the real-time process monitoring in a yet-to-be built facility. A facility that had real-time gamma detection equipment could improve product quality control and provide additional benefits, such as waste volume reduction. In addition to the spectral analyses, it was determined by Monte Carlo N Particle (MCNP) simulations that there is no noticeable self shielding for internal pipe diameters less than 2 inches, indicating that no self shielding correction factors are needed. Further, it was determined that HPGe N-type detectors would be suitable for a neutron radiation environment. Finally, the gamma ray spectra for the measured samples were simulated using MCNP and then the model was extended to predict the responses from an actual reprocessing scenario from UREX+3a applied to fuel that had a decay time of three years. The 3-year decayed fuel was more representative of commercially reprocessed fuel than the acquired UREX+3a samples.

This research found that the safeguards approach proposed in this paper would be best suited as an addition to existing safeguard strategies. Real-time gamma ray detection for process monitoring would be beneficial to a reprocessing facility and could be done with commercially available detectors.

DEDICATION

This thesis is dedicated to my mother, Petra Goddard (11/7/1954 - 11/7/2001)

ACKNOWLEDGEMENTS

I would like to thank the following people for their contributions to this thesis: (1) Candido Pereira for teaching me about UREX+ reprocessing and about centrifugal contactors; (2) Douglas Peplow and Stephen Bowman for creating a software program which converts ORIGEN outputs into MCNP source definition inputs; (3) Claudio Gariazzo for teaching me how to use the gamma ray detectors I needed for my research; (4) John Ford, Daniel Reece, and Leslie Braby for helping me analyze the gamma ray spectra; (5) Jeffrey Hausaman for helping me brainstorm solutions to problems faced throughout my research; (6) Eric Rauch for being one of the best teaching assistants ever and letting me use his thesis as a template; and (7) Lori Pace for proofreading my reports and thesis.

NOMENCLATURE

ANCC	Active Neutron Coincidence Counters
ANL	Argon National Laboratories
ATM	Approved Testing Material
COEX	Co-Extraction
CZT	Cadmium Zinc Telluride
FP	Fission Product
FPs	Fission Products
FPEX	Fission Product Extraction
FWHM	Full Width Half Maximum
GEB	Gaussian Energy Broadening
HPGe	High Purity Germanium
IAEA	International Atomic Energy Agency
LaBr	Latium Bromide
Ln	Lanthanides
MCA	Multi Channel Analyzer
MCNP	Monte Carlo N Particle
NaI	Sodium Iodide
NERI-C	Nuclear Energy Research Initiative for Consortia
NPEX	Neptunium Plutonium Extraction
NPT	Non-Proliferation Treaty
ORIGEN	Oak Ridge Isotope Generation and Depletion Code

ORNL	Oak Ridge National Laboratories
PNCC	Passive Neutron Coincidence Counters
PUREX	Plutonium Uranium Extraction
PWR	Pressurized Water Reactor
ROI	Region of Interest
SQ	Significant Quantity
TALSPEAK	Trivalent Actinide Lanthanide Separations by Phosphorus-Reagent Extraction from Aqueous Complexes
TBP	Tributyl Phosphate
TRU	Transuranic
TRUs	Transuranics
TRUEX	Transuranic Extraction
UREX	Uranium Extraction

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CHAPTER I

INTRODUCTION

There is a renewed and increasing interest in building new nuclear power plants. This is evident in the recently proposed and current construction of 26 reactors in the United States and 97 reactors throughout the world.[1] At the same time, there are remaining issues regarding the disposition of used nuclear fuel produced by future, current, and past nuclear energy systems. Previously proposed and attempted solutions, such as permanent geological storage, have met resistance and non-acceptance from the public.[2] Various methods for reprocessing have been tried and implemented around the world and with the recent scale-back (or perhaps cancellation) of the proposed Yucca Mountain geological repository, interest in reprocessing has also been increasing as a possible solution to the nuclear waste issue.

Used nuclear fuel from a typical light water reactor contains a large collection of Fission Product (FP) isotopes that span the periodic table from ^{72}Fe to ^{167}Er. In addition, used nuclear fuel contains radioactive activation products and transuranic (TRU) actinide elements, such as Pu, Np, Am, and Cm. The FP, U, and TRU isotopes emit gamma rays with unique energy spectra that are characteristic to each of the individual isotopes. These unique spectra can be observed and quantified by a variety of existing detectors and used to determine the total mass of that specific isotope in a container or process flow geometry.

This thesis follows the style of *Nuclear Technology*.

The ability to qualitatively track all elements throughout a reprocessing facility would aid facility operators in determining separation efficiencies of various chemical separation processes. If the facility knew that its separation efficiencies were too low the facility operators could take steps to optimize the separation chemistry in a real-time manner before previously separated products become grossly contaminated with impurity isotopes. Implementing real-time gamma ray detection could dramatically improve the product control in a facility which would lead to waste volume reductions, optimized reagent utilization, and other benefits.

The Uranium Extraction Plus (UREX+) reprocessing methods are a family of Tributyl Phosphate (TBP) based chemical processes designed to incorporate sequential aqueous solvent extraction schemes with an optional final scrub using ion exchange methods to separate U, selected FP, and TRU elements from dissolved used nuclear fuel. The various processing steps are still under development by the United States Department of Energy, but the high level flow diagram depicting the sequence of operations is shown in Figure 1. This particular flow diagram represents the UREX+3a method where the products include U, Tc, a mix of Cs and Sr isotopes, the Lanthanide (Ln) isotopes, the TRUs, and the remaining FP waste stream.

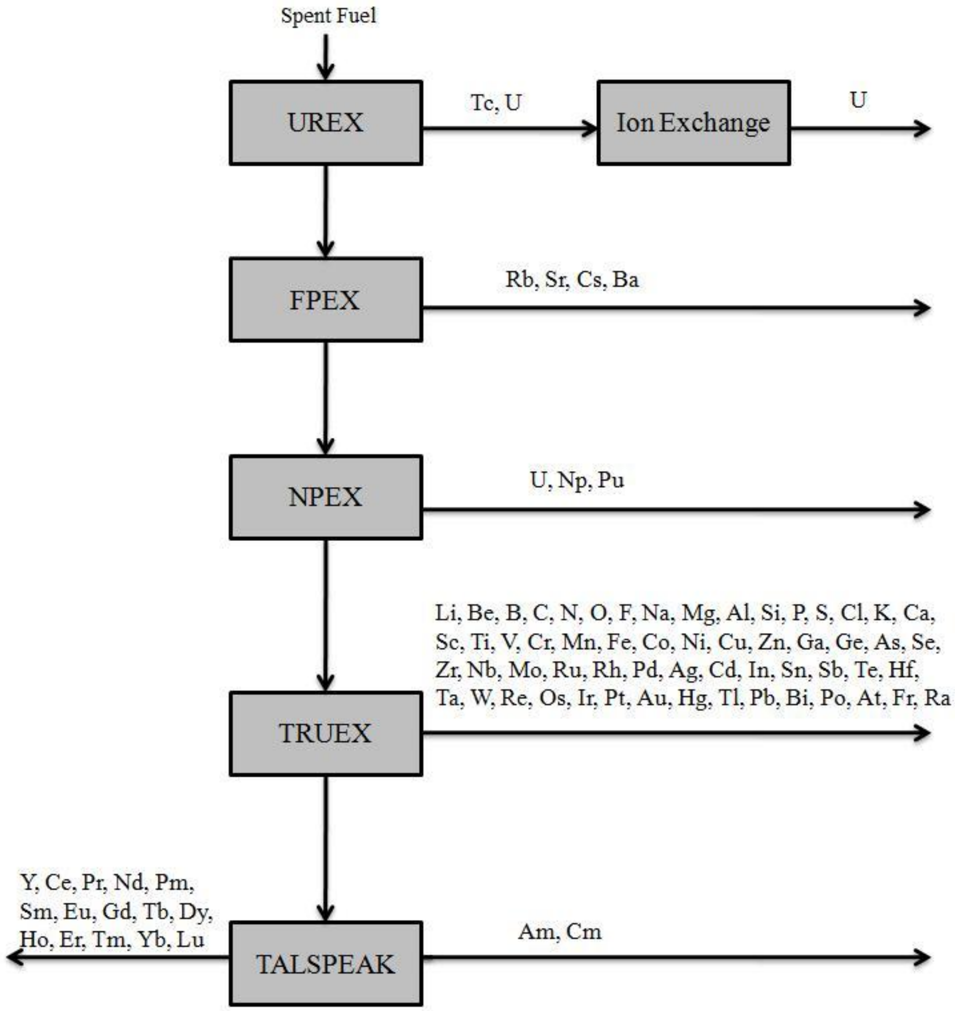

Figure 1. High-level process flow diagram for the UREX+3a separations method.

Quantitatively keeping track of where U and TRU isotopes are throughout a facility designed to implement the UREX+ method is of significant concern from safeguards and security viewpoints. Safeguards are important internationally since nations which did not possess nuclear weapons when signing the Non-Proliferation Treaty (NPT) in 1968 are now considered non-weapons states, regardless if they currently have nuclear weapons or not. By signing the NPT, these non-weapons states must certify that they are not diverting nuclear material. This certification is done through the International Atomic Energy Agency (IAEA). Since all measurements have some error associated with them, the IAEA allows for some material to be unaccounted for. This measurement error must be such that three times the one sigma uncertainty is less than one Significant Quantity (SQ). One SQ is the approximate amount of nuclear material which the IAEA considers sufficient for a state to manufacture its first nuclear explosive, taking into account process manufacturing losses.[3] Table 1 gives a list of how much material is needed to be considered one SQ for different isotopes.[4] The IAEA currently does not have a method in place to safeguard UREX+ reprocessing facilities. The safeguards in place at current commercial reprocessing facilities, such as the Rokkasho or La Hague sites, use costly and time consuming destructive analysis of samples taken through the reprocessing process.[5][6] If a real-time material accountancy measurement could be developed, it would conserve resources and man hours.

Table 1. Values of one SQ for different isotopes.[4]

Material	Mass Quantity
Pu[a]	8 kg
^{233}U	8 kg
^{235}U, greater than 20% enriched	25 kg of ^{235}U
^{235}U, less than 20% enriched	75 kg of ^{235}U
Th	20000 kg

[a]Pu with an isotopic fraction of greater than or equal to 80% ^{238}Pu is exempt.

One of the challenging issues for gamma ray analysis is that the characteristic spectra from the individual isotopes tend to overlap when gathered into a large collection of isotopes, such as that found in solid or dissolved used nuclear fuel. Even so, there are some high yield characteristic gamma rays that may be targeted for monitoring. Table 2 provides a list of these high yield gamma rays from various U and TRU isotopes of interest to safeguards.[(4)]

Table 2. High yield gamma rays from various U, Pu, and Am isotopes.[(4)]

Isotope	Energy [keV]	Activity [γ/g-s]
^{234}U	120.9	9.35×10^{4}
^{235}U	143.8	8.40×10^{3}
	185.7	4.32×10^{4}
^{238}U	766.4[a]	2.57×10^{1}
	1001.0[a]	7.34×10^{1}
^{238}Pu	152.7	5.90×10^{6}
	766.4	1.387×10^{5}
^{239}Pu	129.3	1.436×10^{5}
	413.7	3.416×10^{4}
^{240}Pu	45.2	$3.80 \text{ X } 10^{6}$
	160.3	3.37×10^{4}
	642.5	1.044×10^{3}
^{241}Pu	148.6	7.15×10^{6}
	208.0[b]	2.041×10^{7}
^{241}Am	59.5	4.54×10^{10}
	125.3	5.16×10^{6}

[a]From the ^{238}U daughter ^{234m}Pa. Equilibrium assumed.
[b]From the ^{241}Pu daughter ^{237}U. Equilibrium assumed.

The research described in this thesis is part of a larger effort sponsored by the United States Department of Energy's Nuclear Energy Research Initiative for Consortia (NERI-C) to investigate real-time detection and safeguard strategies for UREX+ reprocessing facilities. There are three universities involved in the program, Texas A&M University, Purdue University, and University of Illinois at Chicago as well as Argon National Laboratory (ANL). The focus of Texas A&M University is, (1) safeguard strategy development for a UREX+1a reprocessing facility, (2) detection strategy for the UREX+3a separations process (this thesis), and (3) gamma ray detector assembly and system design. Purdue University is working on the development of a novel detector for neutron and alpha spectroscopy.[7] University of Illinois at Chicago is investigating centrifugal contactor corrosion characterization and hold-up analysis.[8][9] Argonne National Laboratory is acting as the project liaison to the national program by providing UREX+ samples, allowing the university researchers to use their facilities, and providing valuable chemical processing data and information.

CHAPTER II

BACKGROUND

II.A. Radiation Detection

Gamma rays are one of the most common forms of radiation and they are created when an atom in an excited state transitions to a lower energy state. The difference between the energy level of the excited state and its lower energy level is equal to the energy of the gamma ray. Many atoms have several energy levels which it can transition to, thus allowing for multiple gamma ray energies to be present when examining a given isotope. Figure 2 shows the different energy levels and corresponding gamma ray energies for the ^{231}Th atom, the immediate daughter product of ^{235}U after alpha particle decay.[10] As can be seen in Figure 2, there is a specific probability that the atom will transition to a particular energy level. These probabilities correspond to the frequency of detecting the presence of a gamma ray with that specific energy. Figure 3 shows a typical gamma spectrum from low enriched uranium (i.e., ~1 to 20 atom percent ^{235}U), using a High Purity Germanium (HPGe) detector.[4] It can be seen in Figure 3 that the 185.72 keV ^{235}U gamma ray is detected more often than the other ^{235}U gamma rays. This is due to the fact that the emission of a 185.72 keV gamma ray has a higher probability than other photons from that isotope. More information concerning the different energy levels and decay paths of radioactive isotopes can be found in any introductory nuclear physics text, such as *Modern Physics for Engineers* by Oldenberg and Rasmussen.[11]

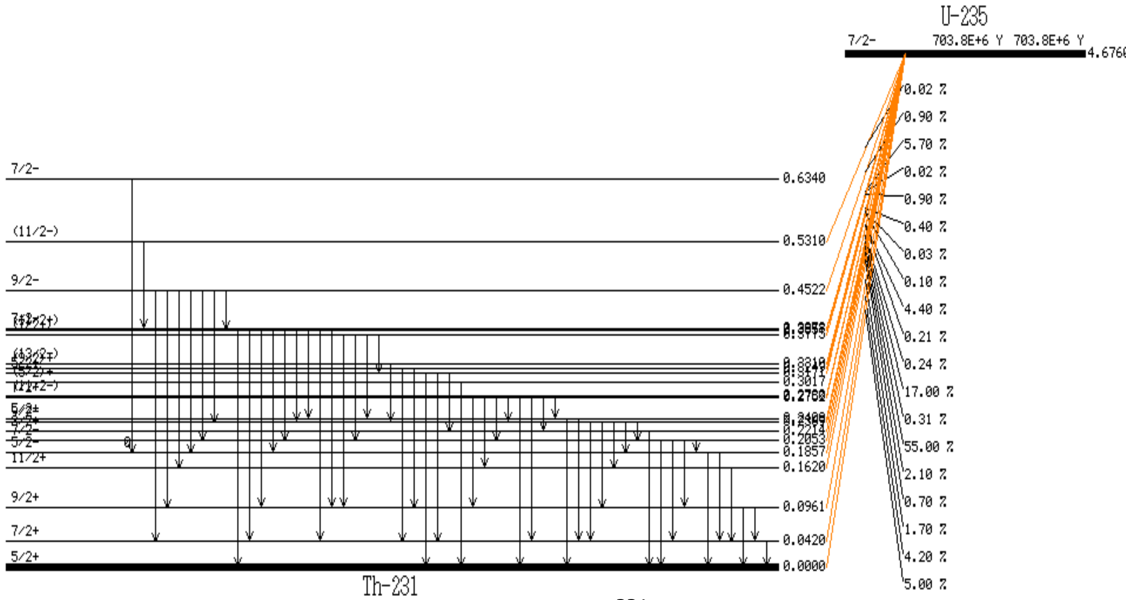

Figure 2. The different energy levels of a ^{231}Th atom and the corresponding probabilities of the gamma ray energies it can emit.[(10)]

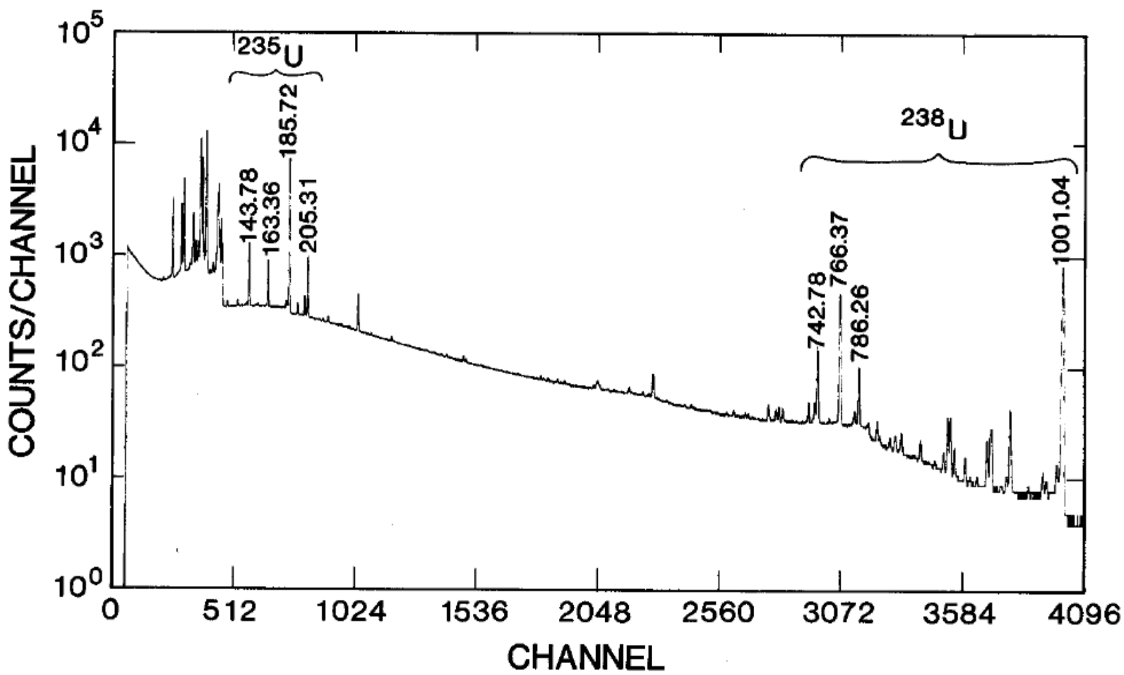

Figure 3. A typical gamma spectrum of low enriched uranium using an HPGe detector.[(4)]

There are many different commercially available gamma ray detectors. These detectors range from the simple and low cost Geiger-Müller counter, which can only measure the total number of gamma rays detected, to the more complicated and expensive HPGe detectors which can determine the energy of each gamma ray detected with high precision. For nuclide identification measurements, a gamma ray detector that can discriminate between photons of different energies is required. Most detectors that can discriminate between photon energies may be classified into two general types, scintillators and semiconductors.

Scintillators, which usually have lower gamma ray energy resolution than semiconductors, operate in the flowing manner. A gamma ray is absorbed by an atom in the scintillator crystal and emits an electron with energy equal to the gamma ray energy minus the electron binding energy; this is the photoelectric effect. This electron travels through the scintillator crystal, removing electrons in the inner most electron shell of the scintillator atoms which it comes in contact with. When the outer electrons of these ionized atoms fill their inner electron hole, they emit photons with the same wavelength as visible light. This light is collected at one end of the scintillator crystal where a photocathode converts the light into a beam of electrons. The number of these electrons is then increased by a photomultiplier tube to create an electrical pulse. The intensity of this electrical pulse is proportional to the energy of the gamma ray initially absorbed in the scintillator crystal. Two examples of scintillation crystal materials which are commonly used in gamma detectors are Lanthanum Bromide (LaBr) and Sodium Iodide (NaI).[(12)]

A semiconductor detector has two semiconducting materials in contact with each other. One material is doped with atoms that have slightly more valance electrons, creating an excess amount of electrons, while the other material is doped with atoms that have slightly less valance electrons, creating a shortage of electrons. Where these two materials touch a band gap is created. This is an electrically neutral zone which prevents the flow of electrons from one material to the other. When a gamma ray is absorbed, by either of these materials, and emits an electron, this electron is drawn towards the band gap. The energy of this electron is equal to the energy of the gamma ray, minus the electron binding energy, thus allowing it to overcome the energy required to cross the band gap. As the electron crosses the band gab it creates a flow of charge through the detector. The intensity of this pulse is proportional to the absorbed gamma ray energy. Two examples of semiconductor detector materials which are commonly used are HPGe and Cadmium Zinc Telluride (CZT). A more in-depth discussion of both scintillators and semiconductors can be found in the text *Radiation Detection and Measurement* by Knoll.(12)

It should be noted that there are many different types of HPGe detectors commercially available, each having their own advantages and disadvantages. The five most common types of HPGe detectors are low energy, broad energy, coaxial (P-type), reverse-electrode (N-type), and well.(4) Only the P-type (most common) and the N-type (good characteristics for operation in a neutron radiation environment) detectors were used in this research. The N-type detectors characteristics are discussed in more depth in chapter V, in section C.

A decision to choose one detector type over another is often determined by the energy resolution required. Figure 4 shows the difference between a high energy resolution HPGe detector measurement and a low energy resolution NaI detector measurement of highly enriched uranium (i.e., above 20 atom percent ^{235}U). Although the 186 keV gamma ray is visible in both of the detector's spectra, only the HPGe detector can identify the shorter neighboring gamma ray peaks.[(5)]

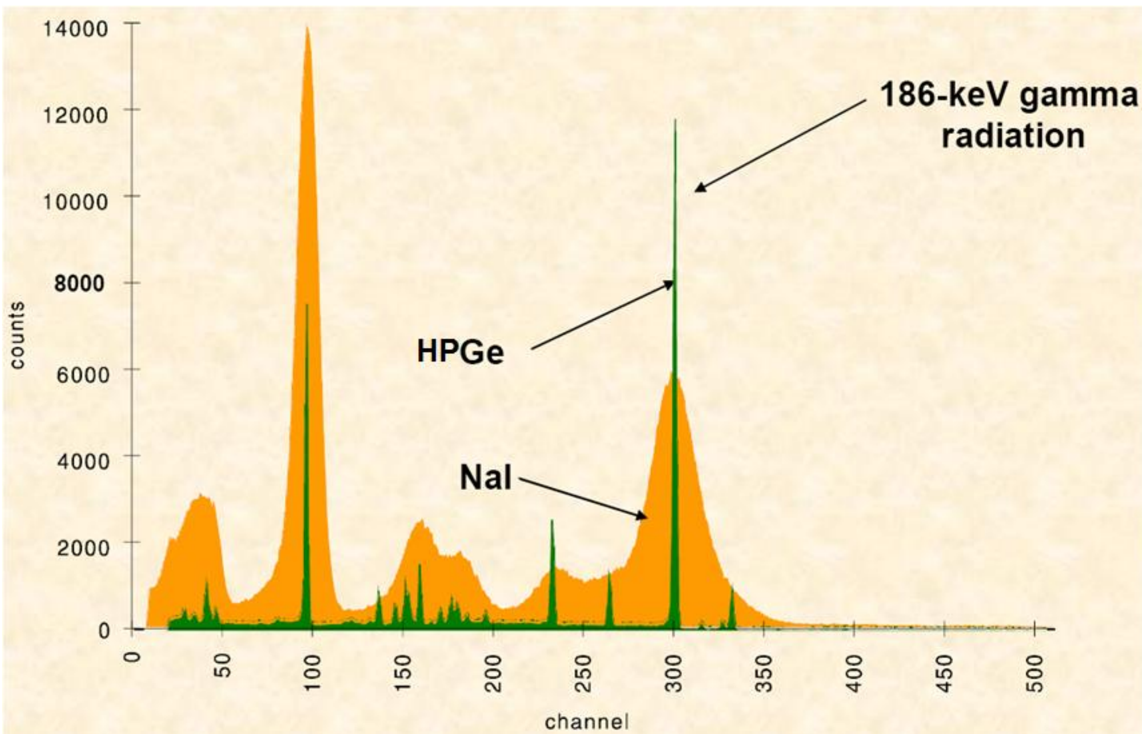

Figure 4. Comparison between a high energy resolution HPGe detector and a low energy resolution NaI detector measurement of highly enriched uranium.[(5)]

There are several resources available that describe the theory and methods used to characterize the gamma spectra of nuclides and of used nuclear fuel.[(4)(12)(13)(14)] By accurately measuring the energies of gamma rays, the peak heights, and determining the ratios of related peak heights, the isotopes which the gamma rays come from can be determined. There are some peaks in gamma ray spectra which do not come from the full energy absorption of a gamma ray, photoelectric effect. For the measurements taken in this research, these peaks are usually from positron annihilation, which creates two photons with the rest mass energy of an electron, 511 keV.(12) Another common peak in high activity samples is a sum peak. This peak is created when two gamma rays are detected at the same time, thus creating the illusion of detecting a gamma ray with energy equal to the sum of their energies. There are other types of gamma ray peaks which can be created in a gamma spectrum, but they are less common and were not visible in the measurements taken during this research.

While the focus of this thesis is on gamma detection, the radioactive isotopes in used nuclear fuel also emit alpha, beta, and neutron radiation and so the characteristics and detection methods for each type will be summarized here. Like gamma rays, alpha particles have unique energies which can be measured and analyzed to identify which nuclide they came from. Nearly all alpha particles generated within used nuclear fuel come from the TRU isotopes. These isotopes emit alpha particles with energies ranging from 4 MeV to 6 MeV, much higher than most gamma rays which are in the range of 0.1 MeV to 1.5 MeV. This difference in energy allows for alpha particle spectroscopy measurements to be made in a high background gamma ray environment. TRU isotopes that have higher atomic numbers or lager atomic mass typically emit alpha particles with higher energies. Figure 5 show a typical alpha particle energy spectrum from a sample containing, ^{209}Po, ^{210}Po, ^{239}Pu, and ^{241}Am.(15) It can be seen from Figure 5 that due to the good energy resolution and the wide energy range over which alpha particles are created, alpha spectroscopy would allow for the quick identification of the TRU isotopic composition of a material.

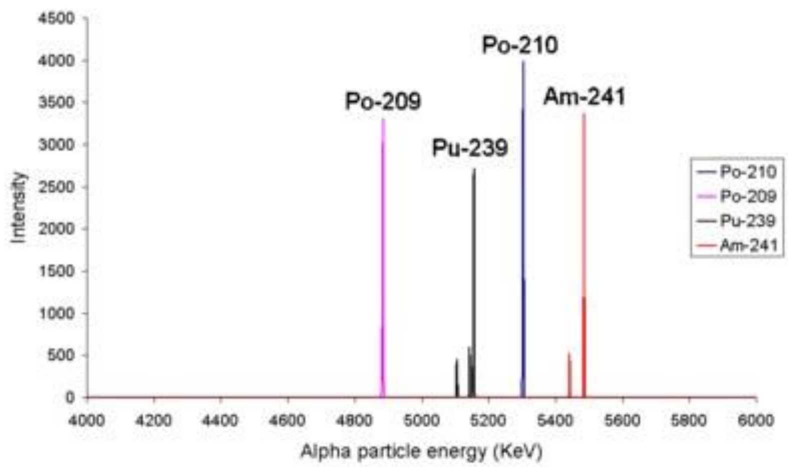

Figure 5. A typical alpha particle energy spectrum from a sample containing, ^{209}Po, ^{210}Po, ^{239}Pu, ^{241}Am.[(15)]

However, alpha particles, unlike gamma rays, are charged particles, thus allowing them to be easily attenuated by very thin materials or even several centimeters of air at atmospheric pressure. Because of this, current alpha particle spectroscopy requires that a sample of the radioactive material be thinly plated onto a flat surface. This plated surface is then placed into a sealed chamber, which contains a detector a few centimeters away from the plated surface, and a vacuum is pulled on the chamber. If the radioactive material plated onto the surface is too thick or the vacuumed chamber contains too many particles, the alpha particles emitted from the surface will be attenuated or slowed down, thus broadening the lower energy tail of the alpha spectroscopy peaks. If the alpha spectroscopy peaks broaden too much, identification of the radioactive isotopes becomes more challenging. The time required to correctly plate a radioactive sample onto a flat surface and collect an alpha particle spectrum of it, prevents alpha particles from being used for real-time measurements. On the other hand, due to the potential benefits of real-time alpha particle spectroscopy, a metastable fluid alpha particle detector system is being developed at Purdue University as part of the larger research NERI-C program.[7]

Beta particles are almost never used for identifying what radioactive isotopes are present in a material because of several significant difficulties. Beta particles, like alpha particles, are charged particles and thus continuously lose energy as they pass through a material. Because of this, radioactive materials which emit beta particles are typically plated to a flat surface and measured in the same manner as alpha particles. Although beta particles are attenuated less then alpha particles, allowing for larger tolerances during the sample preparation and measurement procedures, a real-time energy spectrum cannot be acquired using current detector designs. Another difficulty with beta particles that must be overcome is that, unlike gamma rays and alpha particles, beta particles do not have unique energies. Instead, they have a unique combined antineutrino and beta particle energy. Because of this, an energy spectrum from beta particles appears as a continuous energy curve stretching from an energy of zero to that of the combined antineutrino and beta particle energy.

A typical beta particle energy spectrum from ^{32}P can be seen in Figure 6.[16] It can be seen from this figure that there is both a unique maximum and average beta particle energy, however, identifying which isotope a beta particle originated from based on the average and maximum energy is difficult for radioactive materials that emit one energy of beta particles and extremely challenging (if not impossible) if a material emits several different types of beta particle with different energy ranges. The last difficulty that must be over come when measuring beta particles is that many of the actinides of interest to safeguards and process monitoring do not emit beta particles at high enough rates to be useful for nuclide identification.

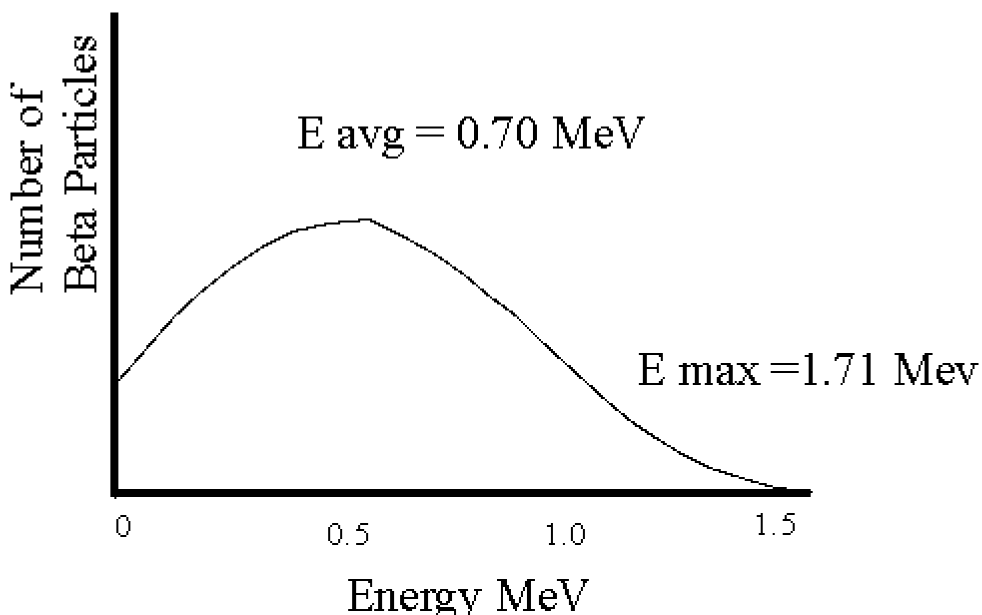

Figure 6. A typical beta particle energy spectrum from ^{32}P.[16]

Neutrons are also emitted from used nuclear fuel and most of them come from TRUs by means of an alpha-n reaction or fission, both spontaneous and induced. Neutrons from an alpha-n reaction are created by an alpha particle striking a light nuclide, such as fluorine, oxygen, or carbon, and ejecting a neutron. Neutrons from an alpha-n reaction will not have discrete energies due to the high probability of the alpha particle losing some of its energy before being absorbed by the light nuclide. Figure 7 shows the non-discrete neutron energy spectrum from a ^{238}Pu-C material and a ^{239}Pu-Be material.[4]

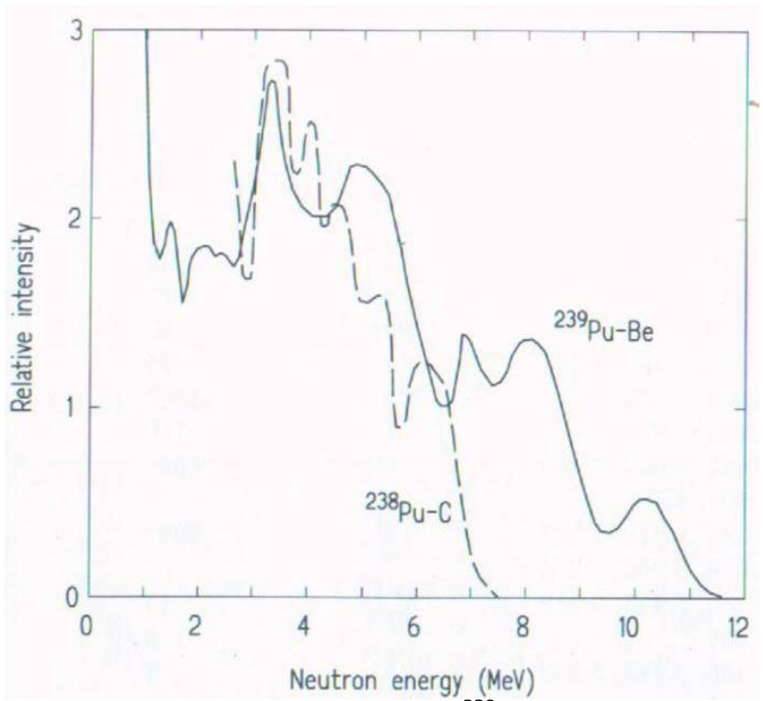

Figure 7. Neutron energy spectrum from a ^{238}Pu-C material and a ^{239}Pu-Be material.[4]

Neutrons created from either spontaneous fission or neutron induced fission also do not have discrete energies. The energy distribution from these neutrons follows the Watt fission spectrum, seen in Figure 8.[4] Non-discrete neutron energies combined with the fact that neutron detectors have poor, if any, neutron energy spectrum capabilities makes neutron energy spectra of little use for nuclide identification.

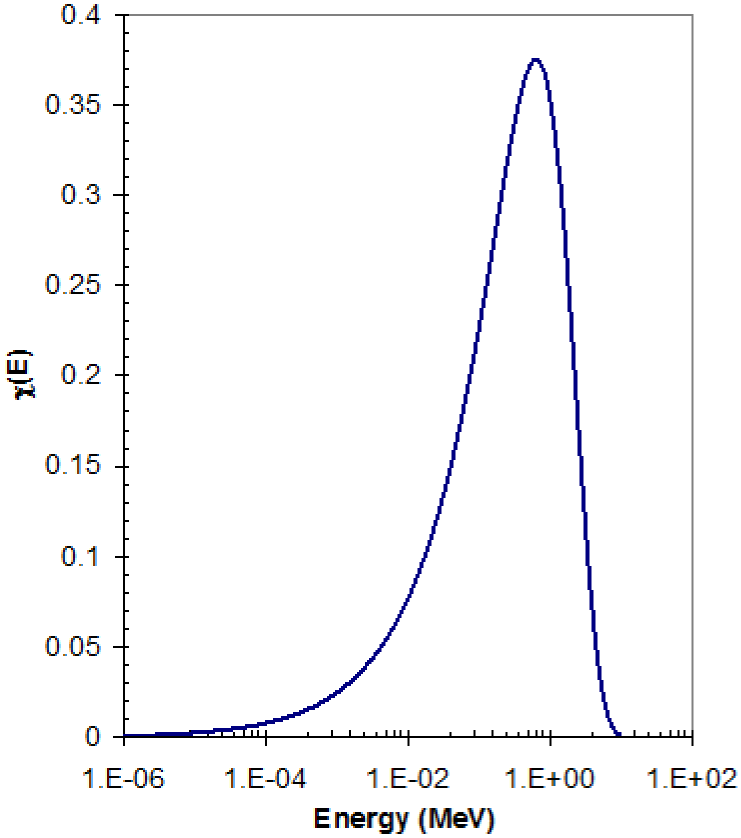

Figure 8. Prompt fission neutron energy spectrum.[(4)]

Most neutron detectors, such as ^{3}He tubes, BF3 tubes, and fission chambers, work under the same principal; a neutron is absorbed in the detector by either the gas inside the tube or by a thin coating of material on the inside wall of the tube. When the neutron is absorbed, the atom undergoes an exothermic reaction and emits a charged particle. This charged particle travels through the gas inside the tube, ionizing it, and thus creating an electrical pulse. This pulse is not proportional to the neutron energy. Instead, it depends upon the isotope that absorbed the neutron and what charged particle ionized the internal tube gas. Neutron detectors which try to measure the energy spectrum of a neutron source do so by combining different thicknesses of polyethylene with strong thermal neutron energy absorbing materials, such as cadmium. Most neutron detectors are surrounded by polyethylene, or other light elements, to cause the neutrons to scatter, and thus slow them down. As neutrons slow down, the likelihood of them undergoing an absorption reaction increases. Figure 9 shows the cross section of ^{3}He (n, p) reaction, ^{10}B (n, α) reaction, and ^{6}Li (n, α) reaction as a function of incident neutron energy.[(4)]

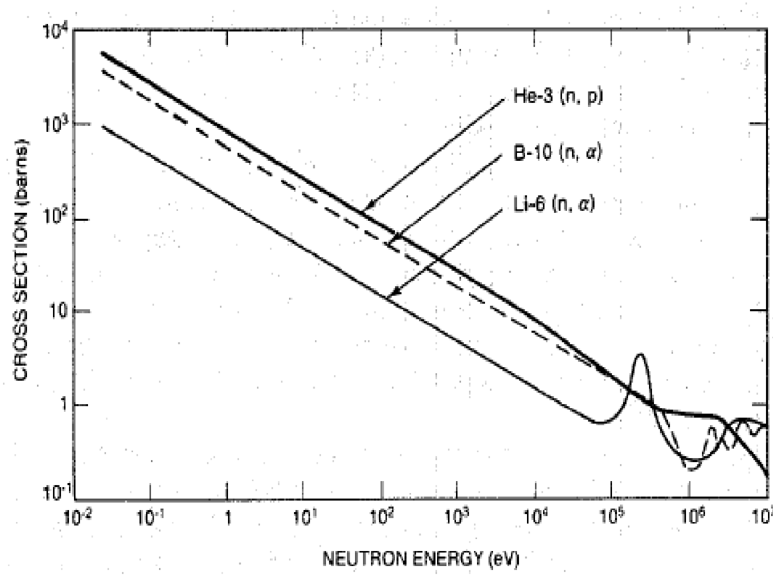

Figure 9. Cross section of ^{3}He (n, p) reaction, ^{10}B (n, α) reaction, and ^{6}Li (n, α) reaction as a function of incident neutron energy.[(4)]

One of the significant differences between neutrons which come from an alpha-n reaction and fission, is that alpha-n neutrons are created individually for each reaction while neutrons created from fission are created in bunches, ranging from zero neutrons to eight. By making time sensitive neutron measurements to determine if neutrons are being created individually or in bunches, it can be determined if the neutron source is an alpha-n reaction or fission. Neutron detectors that do this are called coincidence counters and can be operated in two different modes. The first mode, Passive Neutron Coincidence Counters (PNCC), passively measures a radioactive material, thus determining if the material spontaneously fissions. The second mode, Active Neutron Coincidence Counter (ANCC), actively interrogates a radioactive material with neutrons, thus determining whether the material is fissionable or spontaneously fissions. A more in-depth discussion of active and passive neutron coincidence counting can be found in the thesis *Development of a Portable Neutron Coincidence Counter for Field Measurements of Nuclear Materials Using the Advanced Multiplicity Capabilities of MCNPX 2.5.F and the Neutron Coincidence Point Model* by Angela L. Thornton.[17]

The majority of real-time measurement research for reprocessing facilities currently being conducted is focused on non-radiation measurements. These measurements consist of fluid flow, temperature, density, ultraviolet light, conductivity, and chemical compositions.[18] Although these measurements would provide valuable information from a process monitoring standpoint, they would be of little benefit for safeguards purposes. The above fluid characteristics could be faked by a knowledgeable adversary, thus allowing him to divert nuclear material without detection. Measurements of gamma rays with unique energies are much more difficult for a safeguards adversary to fake. Much of the previous research on near-real-time measurements investigated methods which would take a small sample of the extraction stream and analyze it, sometime destroying the sample in the process. One technique which seems more promising than others in Hybrid K-Edge / X-Ray Fluorescence.[6]

This technique sends a beam of X-rays of varying energy through a small sample. These X-rays are both attenuated by the sample and generate X-ray fluorescence photons. By measuring the fraction of X-rays that are attenuated at specific energies and the amount of fluorescence X-rays which are emitted by the sample, the total mass of U and Pu in the sample can be determined. Although this method relies on the nuclear properties of U and Pu, thus making it difficult to fake, it also relies on the assumption that the sample taken has not been tampered with and is representative of the extraction stream which it came from.

There are only two operating commercial reprocessing plants in non-weapons states, Japan's Tokai and Rokkasho facilities, both of which use the Plutonium Uranium Extraction (PUREX) process.(19) La Hague, a PUREX commercial reprocessing plant in France (a weapons state), also performs safeguards measurements even though it is not required by the NPT. Quantitative safeguards measurements done at these facilities rely on expensive and time consuming Isotope Dilution Mass Spectrometry techniques.(6) Although these methods are precise enough to meet the IAEA goal of less than one SQ unaccounted for every material balance period, they are not done in real-time and cost the facility and the IAEA significant resources and man-hours. Other quantitative measurements are done at a reprocessing facility, however they are often a total gamma ray or neutron count from used nuclear fuel rods when they first arrive that the facility. No accurate composition information is gathered from these measurements; just a rough estimate of burn-up and the date the fuel was discharged from its reactor. Containment and surveillance is also used at reprocessing facilities for safeguards purposes.

Surveillance, mainly video cameras and radiation alarms, can be operated and analyzed automatically using image recognition, thus reducing their operational costs.[20] The disadvantage to unmanned surveillance systems is that a knowledgeable adversary could overcome this safeguards barrier. Containment, which consists mainly of locks and walls, is effective and cheap, however, the locations where containment can be used are limited.

II.B. Reprocessing

There are several different aqueous process methods to reprocess used nuclear fuel. Some of the more common methods include PUREX, UREX+, and Co-Extraction (COEX). All three of these processes are based on a TBP solvent liquid-liquid extraction process to separate Pu and other elements from unwanted fission products. The PUREX process was one of the first non-batch reprocessing methods to be invented, with the first plant becoming operational in 1955.[21] The main purpose of PUREX was to remove high purity Pu from used nuclear fuel to be used in nuclear weapons. The COEX process was invented for commercial reprocessing facilities to reduce the proliferation issues concerning the extraction of pure Pu during the PUREX process. The COEX process is identical to the PUREX process except that the Pu extracted from used nuclear fuel is in a 50/50 mixture with U.[22] This Pu/U product is well suited as a fuel form for Mixed Oxide Reactors, but requires additional chemical processing to be useable for a nuclear weapon.

One of the most recent reprocessing methods to be invented is the UREX+ process. The main differences between the PUREX and UREX+ process is that the UREX+ process separates the bulk of the uranium as the first stage of the operation; uranium makes up the majority of the fuel material to be reprocessed. Because of chemical similarities, technetium is separated with the uranium and is later removed from the UREX uranium stream by ion exchange. Since U comprises approximately 95% of used nuclear fuel, removing it first minimizes the scale of the follow-on processing established to isolate the other isotopes of interest.[22] The second extraction process is still under development but the most likely form is called the Fission Product Extraction (FPEX) method and it extracts the highly radioactive isotopes of Sr and Cs for short term decay storage. The heat and radiation field created by these isotopes affect the chemical reactions and bonds, thus allowing for better chemical separations after their removal.

By removing these elements first, the UREX+ process generates less chemical waste than the PUREX process. The UREX+ process also has the advantage over the PUREX process in that it has the option to separate different elements contained within used nuclear fuel more discretely. As seen in Table 3, there are multiple separations strategies being proposed. By separating the elements more discretely the areas of waste management and new fuels design will have better control over the composition of their materials. As noted in Table 3, all UREX+ methods extract U and Tc as the first step and Sr and Cs as the second step. The distinctive separations after these two steps provide the defining logic for naming the variations of UREX+ from UREX+1 to UREX+4.

Table 3. A list of different UREX+ separation methods and the UREX and COEX separation streams.

Process	Product #1	Product #2	Product #3	Product #4	Product #5	Product #6	Product #7
PUREX	TRUs/Ln/FPs	U	Pu				
COEX	TRUs/Ln/FPs	U	U/Pu				
UREX+1	U	Tc	Cs/Sr	TRUs/Ln	FPs		
UREX+1a	U	Tc	Cs/Sr	TRUs	FPs/Ln		
UREX+1b	U	Tc	Cs/Sr	U/TRUs	FPs/Ln		
UREX+2	U	Tc	Cs/Sr	Pu/Np	Am/Cm/Ln	FPs	
UREX+2a	U	Tc	Cs/Sr	U/Pu/Np	Am/Cm/Ln	FPs	
UREX+3	U	Tc	Cs/Sr	Pu/Np	Am/Cm	FPs/Ln	
UREX+3a	U	Tc	Cs/Sr	U/Pu/Np	Am/Cm	FPs/Ln	
UREX+4	U	Tc	Cs/Sr	Pu/Np	Am	Cm	FPs/Ln
UREX+4a	U	Tc	Cs/Sr	U/Pu/Np	Am	Cm	FPs/Ln

The UREX+3a method was chosen for this research because it is one of the more likely UREX+ methods to be implemented in a commercial-scale reprocessing facility.(23) Also, several national laboratories, including ANL, have done laboratory scale experiments with the UREX+3a process and have samples available for each of the steps in the separation process.

The UREX+3a process uses five consecutive elemental separation processes to extract desired elements from used nuclear fuel. The descriptions that follow are based on lab-scale demonstrations.(24) The first separation process, UREX, removes U and Tc from dissolved used nuclear fuel, which is in a TBP n-dodecane solution, by using a reductant/complexant. This reductant/complexant extracts over 90% of the U and over

95% of the Tc. The U/Tc loaded solvent is sent through a scrub process where nitric acid at dilute concentrations is used to remove any impurity elements, in particular Np and Pu. After scrubbing, the Tc is removed from the solvent by means of ion exchange. The raffinate of the UREX process, non U and Tc bearing stream, is sent into the feed stage of the Cs/Sr extraction process. The Cs/Sr is removed using a solvent extraction process in which the exact chemical composition of the solvent used is still under development. The Cs/Sr loaded solvent is then sent through a scrub process where nitric acid at moderate concentrations is used to remove impurity elements. The loaded solvent product after scrubbing contains over 97% of the Cs and Sr. The raffinate continues on to an evaporation stage to reduce the chemical volume and thus increase the concentration of nitric acid. This step also destroys the reductant/complexant added in the UREX process and converts the Np and Pu to the (IV) extractable oxide state.

After the concentration of nitric acid has increased to the desired level, the process stream is sent to the feed of the Neptunium Plutonium Extraction (NPEX) process. The same solvent reductant/complexant as was used in the UREX process is added in the NEPX process to remove over 99% of the Pu, over 99% of the Np, and the remaining U. The raffinate of the NPEX process is then sent to the feed of the Transuranic Extractions (TRUEX) process where a solvent of 0.2 M CMPO [octyl(phenyl)-N,N-diisobutylcarboylmethyl-phosphine oxide] and 1.4 M TBP diluted by n-dodecane is added. This solvent extracts the remaining FPs, excluding the Ln. Three scrubbing agents are used on the loaded solvent, oxalic acid, moderately concentrated nitric acid, and a weak complexant salt, to remove impurity elements. The product stream from the TRUEX process, Ln, Am, and Cm, is sent to the feed of the final separations process, Trivalent Actinide Lanthanide Separations by Phosphorus-Reagent Extraction from Aqueous Complexes (TALSPEAK). This product is combined with 1 M bis-(2-ethylhexyl) phosphoric acid with a latter striping step using a mixture of dithiophosphoric Acid and lactic acid to extract the Am and Cm from the Ln elements. The recovery of Am and Cm is over 99.5%.(24)(25)

The physical mechanism which mixes the solvent chemicals into the dissolved used nuclear fuel is not UREX+ specific. However, for real-time detection applications centrifugal contactors should be used. This is due to the fact that centrifugal contactors mix the solvent and feed chemicals together and separate the product from raffinate quickly, less than a minute. This prevents most daughter products from building up before a gamma ray measurement can be taken. Centrifugal contactors operate by mixing the feed and solvent streams together in the outer wall of a small, less than a 0.5 m^3, contactor. Figure 10 shows a diagram of a typical centrifugal contactor.(23) The contactor spins at high speeds, the actual speed depends on the contactor, intimately mixing the chemicals as they travel down to the bottom outer wall of the contactor. By intimately mixing the two chemicals together, a large surface area for the chemical reaction to take place is created, thus speeding up the chemical separation process. After reaching the bottom outer wall of the contactor, the solvent feed mixture is pulled up through the center of the contactor, where the lighter loaded solvent is separated to the center by centrifugal forces while the heaver aqueous product is separated to the outer inside wall of the contactor. When the separated chemicals phases reach the top of the contactor they are removed and sent to the next centrifugal contactor, for further separations.[23]

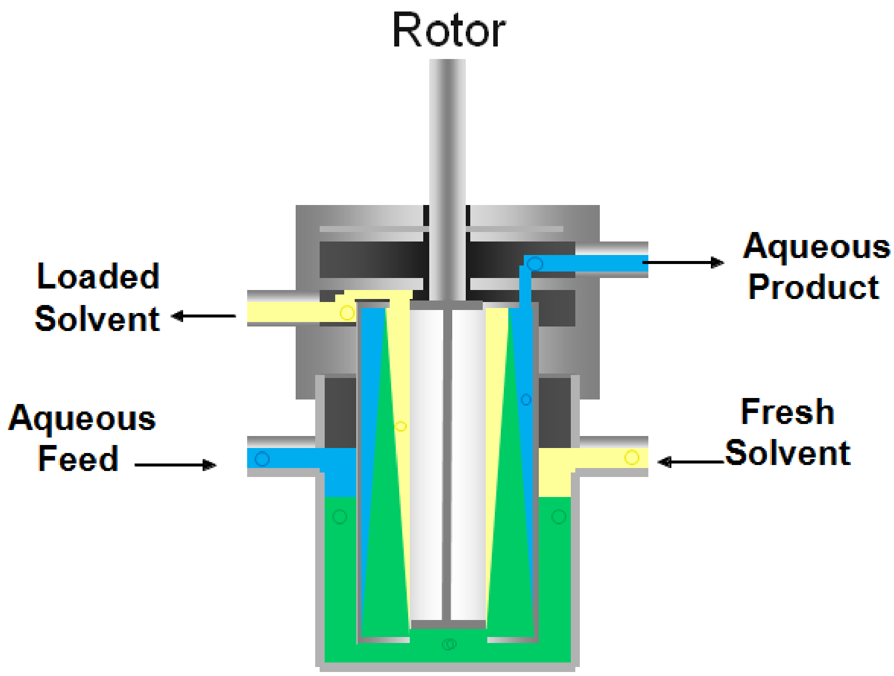

Figure 10. Schematic of a centrifugal contactor.[23]

Other mixing methods, such as mixer settlers or pulse columns, take longer for the feed and solvent fully react with each other. This is due to a smaller surface area with which the chemicals can react with each other. This can be seen in the design of mixer settlers which vibrate to mix the chemicals together and then stopping to allow gravitational forces to separate the denser aqueous product from the lighter loaded solvent. This is repeated until an acceptable fraction of the feed and solvent volumes have reacted with each other. Pulse columns function by filling different compartments of a column, which are separated by plates with small holes, with the feed and solvent. Pressure pulses are then sent through the column causing the feed and solvent to bubble up through the small holes separating each column compartment. This bubbling process allows for a greater level of contact between the feed and the solvent, thus increasing the chemical reaction rate. After an acceptable fraction of the feed and solvent volumes have reacted with each other, the pulse column separates the denser aqueous product from the lighter loaded solvent by means of bouncy forces.

CHAPTER III

EXPERIMENTS

III.A. UREX+3a Samples

Nine different UREX+3a samples were acquired from ANL for the measurements completed under this project. These samples were taken from different solutions extracted during a UREX+3a demonstration; the solutions were drawn from different stages of the separations process and therefore should contain the distinctive isotopes required to emit characteristic gamma spectra, as can be seen in Table 4. It is important to note that samples were not available from the TALSPEAK raffinate (Am, and Cm) or the TALSPEAK product (Ln) and the absence of these samples are reflected in Figure 1 and Table 4.

Table 4. Elements in each UREX+3a sample and dilution factors.

Sample Number	Location	Elemental Content	Dilution Factor
1	Dissolved fuel	Everything	8772
2	UREX raffinate	Everything Except Tc	1072
3	UREX product	Tc, U	1
4	FPEX raffinate	Everything Except Tc, Sr, Rb, Cs, Ba	50.33
5	FPEX product	Sr, Rb, Cs, Ba	386.26
6	NPEX raffinate	FPs, Ln, Am, Cm	33.07
7	NPEX product	U, Np, Pu	28.37
8	TRUEX raffinate	FPs	1
9	TRUEX product	Ln, Am, Cm	23.64

The original fuel solution for the ANL demonstration was created by dissolving four different reactor fuels together into a single process solution. The original fuels came from the Approved Testing Material (ATM) demonstrations ATM-101, ATM-103, and ATM-106 along with a single sample of high burn-up fuel from the H.B. Robinson PWR (Pressurized Water Reactor). Additional information on these fuels can be seen in Table 5 or the Materials Characterization Center ATM reports.[26][27][28][29] It should be noted that the fuel from the H.B. Robinson PWR was irradiated for seven non-continuous core cycles. The fuel was irradiated in the H.B. Robinson core for cycles 4 through 8 and removed in 1982. It was then irradiated again in 1992 for cycle 15 and 16, being discharged on April 28, 1995.

Table 5. Information about the used nuclear fuels used to create the samples.

Fuel	Mass Used [g]	Burn-up [GWd/MTU]	Discharge Date
ATM-101	415.95	28.03	1974
ATM-103	58.97	29.80	1980
ATM-106	59.12	42.32	1980
High burn-up H.B. Robinson PWR fuel	7.89	76	1995

The source sample solutions were created during the summer of 2007 during the noted UREX+3a process demonstration at ANL. For this project, small portions of the test solutions were diluted using the dilution factors in Table 4 and then 0.5 mL of the dilute solution was dried to powder in preparation for shipment to Texas A&M University in December 2008. Each sample consisted of dried powder at the bottom of a heat sealed Teflon bottle. Figure 11 shows a picture of all nine samples.

Figure 11. Picture of all nine UREX+3a samples.

III.B. Neutron Counting

To insure that no neutron damage would be induced in the gamma counting equipment or the researchers, neutron measurements of the samples were made. Eight ^{3}He tubes, connected in parallel, were places in polyethylene blocks and arranged around an aluminum sample stand. Additional one and two inch thick slabs of polyethylene were placed on the outside of the ^{3}He polyethylene blocks to reflect neutrons back into the ^{3}He tubes. Figure 12 shows a picture of this neutron detector apparatus.

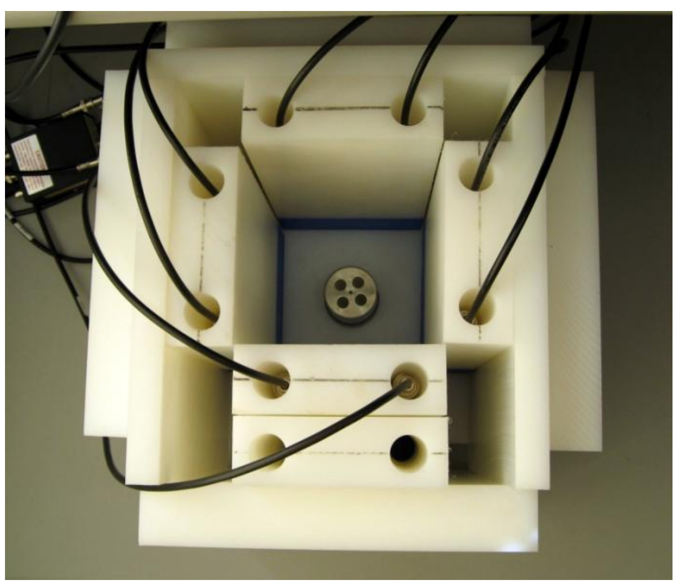

Figure 12. Picture of the neutron detector apparatus.

A ^{252}Cf standard was used to calculate the detector efficiency. It was assumed that the average speed for neutrons emitted from the ^{252}Cf standard would be approximately equal to those of the samples, 2.1 MeV.[30] The ^{252}Cf standard had an initial activity of 0.54061 mCi on August 8, 2005. Using the standard decay equation, Equation 1, and the half-life, 2.645 years, the activity on the date of a current measurement can be determined.[12][31] By multiplying this value to the probability of fission, 3.09%, and the average number of neutrons emitted per fission, 3.73, the theoretical number of neutrons emitted from the ^{252}Cf standard per second can be calculated.[4] After the ^{252}Cf standard was removed from the room and placed in a shielded container, measurements of the samples and background were made. All measurements taken were made with Nuclear Instrumentation Modules with each count lasting 300 seconds and all error calculations were done according to the standard error propagation formula for addition or subtraction, shown in Equation 2 and 3.[12]

$$A(t) = A_o e^{\frac{-t*Ln(2)}{T_{1/2}}} \qquad \text{Eq. 1}$$

$$u = x \pm y \qquad \text{Eq. 2}$$

$$\sigma_u = \sqrt{\sigma_x^2 + \sigma_y^2} \qquad \text{Eq. 3}$$

where $A(t)$ is the activity at time t, A_o is the initial activity, t is the time between the initial and current activities, and $T_{1/2}$ is the half-life of the isotope decaying. The variable x represents the counts from measurement one, y is the counts from measurement two, and u is the sum or difference of the counts for measurements one and two. Also, σ_x is the error of the counts for measurement one, σ_y is the error of the counts for measurement two, and σ_u is the error of the counts for the sum or difference of measurement one and two.

Measurements of the samples were completed starting with the samples expected to exhibit the largest neutron yield. Unfortunately the equipment stopped working after measuring samples 5 through 9, background, and the ^{252}Cf standard. This is not a problem since the higher neutron yield samples had neutron emission rates much lower than any level which would warrant concern, as seen in Table 6.

Table 6. Measured and calculated neutron data.

Measurement	Counts	C-BG	n/s	+ Error	- error
^{252}Cf	298157	298145	1025200	205040	102520
1	-	-	-	-	-
2	-	-	-	-	-
3	-	-	-	-	-
4	-	-	-	-	-
5	25	13	45	23	21
6	23	11	38	22	21
7	18	6	21	19	19
8	28	16	55	24	22
9	20	8	28	20	20
Background	12	-	42	3	3

III.C. Gamma Spectra

Before making any gamma spectral measurements, dose rate measurements were made for each sample. A Thermo Scientific Interceptor detector, which contains three CZT crystals, was used to determine the dose rate from each sample. The detector was placed against the bottom of each sample and measured until the dose rate reading stabilized. Table 7 gives a list of the contact dose rates and the corresponding errors for each sample.

Table 7. List of dose rates, on contact, and corresponding errors of each sample.

Sample #	1	2	3	4	5	6	7	8	9
mRem/hr	0.5 ± 30%	2.4 ± 30%	~0	1.4 ± 30%	1.8 ± 30%	1.1 ± 30%	~0	0.1 ± 30%	1.6 ± 30%

In order to determine what type of gamma ray measurement would provide good results while remaining inexpensive and quick, a matrix of detector types and measurement times where created. The detector types considered were, HPGe P-type, HPGe N-type, LaBr, and NaI. The measurement times ranged from 10 seconds to 21600 seconds and were measured in life-time and not real-time. The complete matrix of measurements can be seen in Table 8.

Table 8. Detector type and measurement time matrix.

Detector Types	Measurement Times [seconds]					
HPGe N-type	10	600	3600	3600[ab]	7200[ab]	21600[ab]
HPGe P-type	10	600	-	-	-	-
LaBr	10	600	-	-	-	-
NaI	10	600	-	-	-	-

[a]For sample 7 only.
[b]Smaller energy width per channel.

All four detectors used the same sample and shielding geometry, consisting of the sample bottom touching the front center of the detector and 2 inches of lead shielding on the sides, bottom, and front of the detector. The detector geometry for an HPGe measurement can be seen in Figure 13. The top of the detector was left unshielded to allow for samples to be easily changed. The back of the detector was not shielded due to the large size of the liquid nitrogen container or detector equipment.

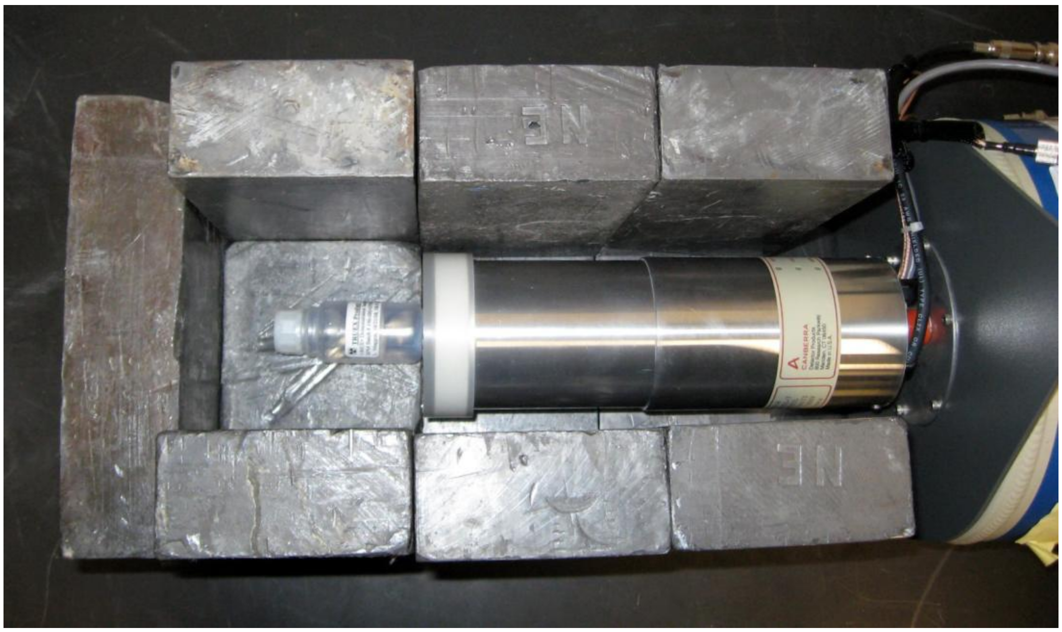

Figure 13. Geometry for an HPGe gamma ray measurement.

All gamma ray measurements were taken in a gamma ray measurement room which contained several µCi standards of varying isotopes. To account for the background radiation in the room, background measurements where made with and without the lead shielding. These life-time measurements were 43200 seconds and 10800 seconds long respectively. Gamma ray spectrum from both of these measurements can be seen in Appendix A.

All HPGe N-type gamma ray measurements where made with a Canberra Reverse Electrode Closed-End Coaxial GR1018 detector. The Full Width Half

Maximum (FWHM) energy resolution at 1330 keV was 1.77 keV, with a relative efficiency of 10%, and a bias voltage of -3000 V dc. The Canberra software program Genie 2000 and a Multi Channel Analyzer (MCA) with 8192 channels were used to acquire the gamma ray spectra. For measurement times consisting of 10, 600 and 3600 seconds the energy range was set to approximately 0 to 1.4 MeV. Due to the complex nature of Pu gamma ray peaks, longer measurements with energy ranges set to approximately 0 to 0.5 MeV were made on sample 7. The FWHM for the HPGe N-type detector was determined at three different energies. The energies were 277, 384, and 1274 keV and had FWHM vales of 1.36, 1.45, and 1.94 keV respectively. This information was later used in the software program Monte Carlo N Particle (MCNP) to model the energy resolution of this detector.

All HPGe P-type gamma ray measurements where made with a Canberra Closed-End Coaxial GC2020 detector. The FWHM energy resolution at 1330 keV was 2.0 keV, with a relative efficiency of 20%, and a bias voltage of 5000 Vdc. The Canberra software program Genie 2000 and a MCA with 8192 channels were used to acquire the gamma ray spectra. The gamma spectrum energy range was set to approximately 0 to 1.4 MeV.

All LaBr gamma ray measurements were made with a Canberra 2x1.5 inch LaBr crystal. The gamma spectra were acquired using an Inspector 1000 with 1024 channels and analyzed using the Canberra software program Genie 2000. The gamma spectrum energy range was set to approximately 0 to 1.5 MeV.

All NaI gamma ray measurements were made with a Canberra 2x2 inch NaI crystal. The gamma ray spectra were acquired using an Inspector 1000 with 1024 channels and analyzed using the Canberra software program Genie 2000. The gamma spectrum energy range was set to approximately 0 to 1.5 MeV.

Calibration measurements were taken at the start of every day to insure that no energy drift occurred in the detectors. The 662 keV ^{137}Cs and 1173 keV and 1333 keV ^{60}Co gamma rays were used as the calibration peaks. All gamma spectrum measurements for the HPGe N-type, HPGe P-type, LaBr, and NaI can be seen in Appendixes A, B, C, and D respectively.

CHAPTER VI

RESULTS

VI.A. Neutron Data

In order to determine the neutron detector efficiency, a ratio of the number of neutrons measured from the ^{252}Cf standard, 298157 counts per second, was divided by the theoretical number of neutrons emitted, 1025200 neutrons per second. This ratio gave a detector efficiency of 29.08%. The neutron count rate for each sample measured was divided by this efficiency, thus giving the number of neutrons emitted per second. Error calculations were done using the standard error propagation formula for addition or subtraction, Equations 2 and 3, and multiplication, Equations 4 and 5.(12) Table 6 gives the measured and calculated neutron data.

$$u = x \cdot y \qquad \text{Eq. 4}$$

$$\left(\frac{\sigma_u}{u}\right) = \sqrt{\left(\frac{\sigma_x}{x}\right)^2 + \left(\frac{\sigma_y}{y}\right)^2} \qquad \text{Eq. 5}$$

where x is the counts from measurement one, y is the counts from measurement two, and u is the product of the counts from measurements one and two. σ_x is the error of the counts for measurement one, σ_y is the error of the counts for measurement two, and σ_u is the error of the counts for the products of measurement one and two. The neutron emission rates were far below any value which would harm the gamma ray detectors or the researchers.

VI.B. Gamma Ray Data

The dead-times for each gamma ray measurement have been tabulated in Appendix E. These dead-time values are important since the measurements were made in life-time mode, thus artificially causing the measurements of the high activity samples to have higher counts. Appendix E also contains the lists of isotopes which were identified in each measurement. There is a distinction between isotopes identified and those that would be present in a commercial facility. This is due to two things. First, the samples built up daughter product for the 1.5 years from when the samples were separated in the summer of 2007 and when they were measured in December 2008. In a commercial facility, the time between separation and measurement would most likely be very short, thus preventing the detection of many daughter products. A second distinction between isotopes identified and those that would be present in a commercial facility is due to background radiation from the surrounding unshielded cinder blocks. These gamma rays would not be present in a commercial facility. Although radiation from the radioactive standards in the room were shielded by lead surrounding the detector, the unshielded top allowed the natural radioactivity of the cinder blocks to interfere with the detector. Due to the low radioactivity within the cinder blocks their impact can only be seen in long measurements of low activity samples. Figure 14 shows a one hour HPGe measurement of sample 3, the U and Tc bearing stream, which had a dead-time of 0.07%. The isotopes present in the cinder blocks can be easily identified by looking at the peaks present in the shielded background measurement. The background measurements can be seen in Appendix A.

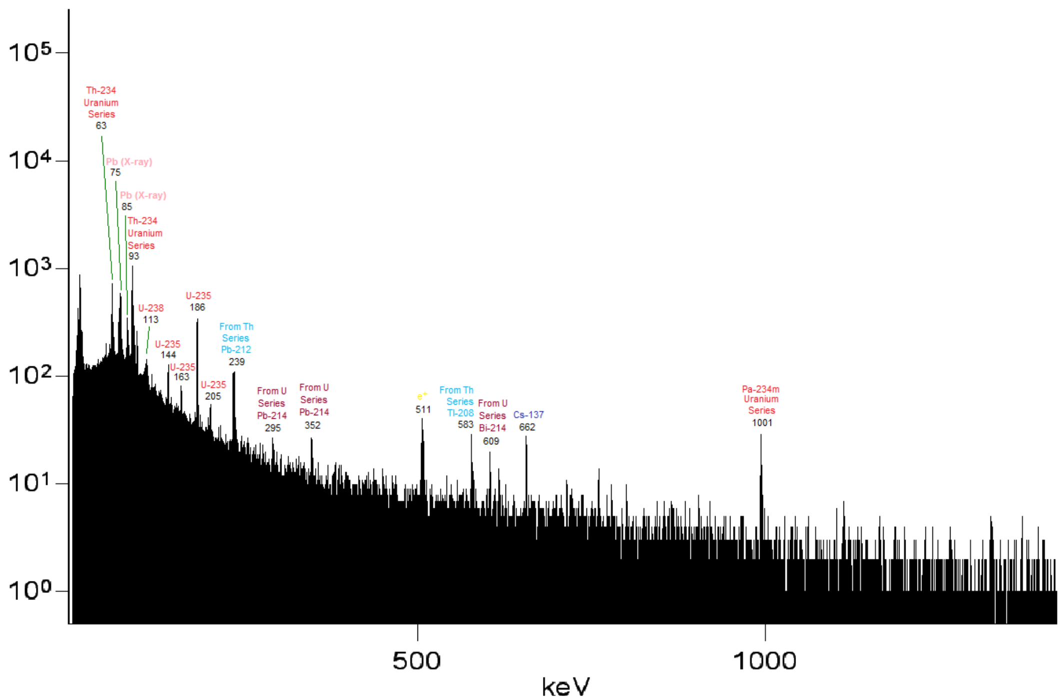

Figure 14. A 3600 second measurement of sample 1 using an HPGe N-type detector showing the undesired background isotopes.

The peaks in the gamma ray spectra were identified using tabulated gamma ray tables and online gamma ray databases.[32][10] Of all the gamma ray measurements taken, there are only four well defined peaks that could not be identified: 291 keV, 371 keV, 917 keV, and 1319 keV in samples 4, 6, and 9. It is suspected that these gamma rays come from Ln since they appear whenever Eu peaks are visible.

The total counts and corresponding error for isotopes of interest for measurements of interest were determined using the Canberra software program Genie

2000. The counts and corresponding error for a 21600 second count of sample 7 using an HPGe N-type detector can be seen in Table 9. The errors for the counts of the Pu peaks in Table 9 are too large for safeguards strategies based on quantitative measurements. It is suspected that longer count times or higher activity sample would not decrease the error to values that would be useable. This conclusion was drawn from the International Target Value IAEA document which states that the current accuracy of gamma ray Pu isotopic ratio measurements is 0.7% to 5.0%.[33] A complete list of counts and corresponding error for isotopes of interest for measurements of interest can be found in Appendix F.

Table 9. Counts and corresponding error for a 21600 second HPGe N-type detector measurement of sample 7.

Energy [keV]	Isotope	ROI Start	ROI End	Area [counts]	Error [%]	
129	^{239}Pu	1877	1918	1137	±	9.73%
148	^{241}Pu	2161	2201	3027	±	3.59%
153	^{238}Pu	2223	2256	898	±	9.86%
161	^{240}Pu	2337	2379	699	±	13.93%
164	^{241}Pu	2389	2431	595	±	15.35%

The resolution of the LaBr and NaI measurements are too low to be able to identify unwanted impurity isotopes or identify individual Pu peaks. This can be seen in Figures 15, 16, and 17 which shows a 10 minute measurement of sample 8 using an HPGe, LaBr, and NaI detector respectively. Because good energy resolution is needed only HPGe detectors should be used for gamma ray measurements for process monitoring or safeguards strategies proposed in this thesis.

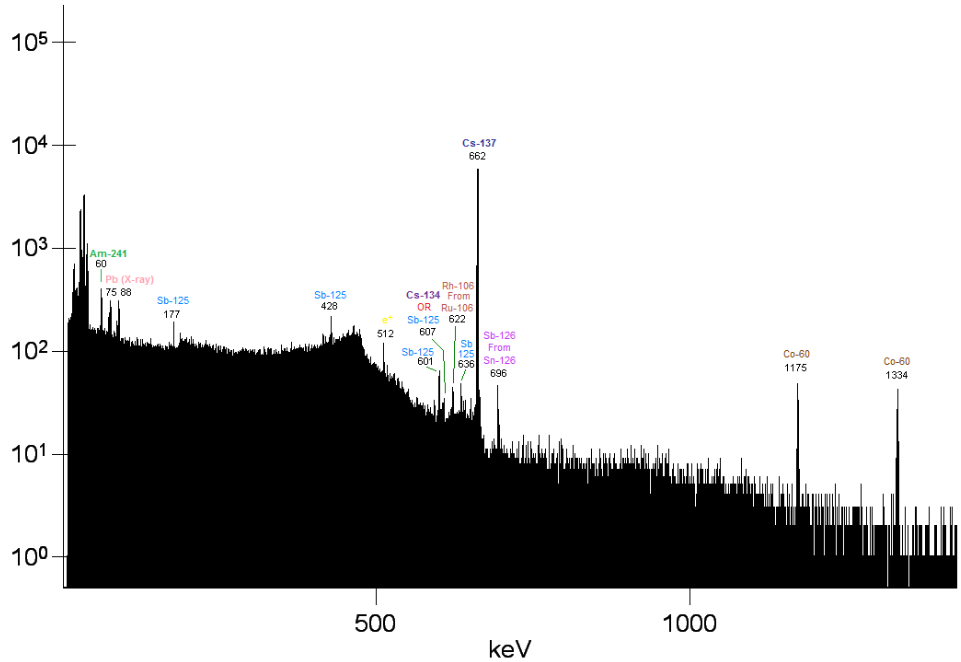

Figure 15. A 600 second measurement of sample 8 using an HPGe N-type detector showing good energy resolution.

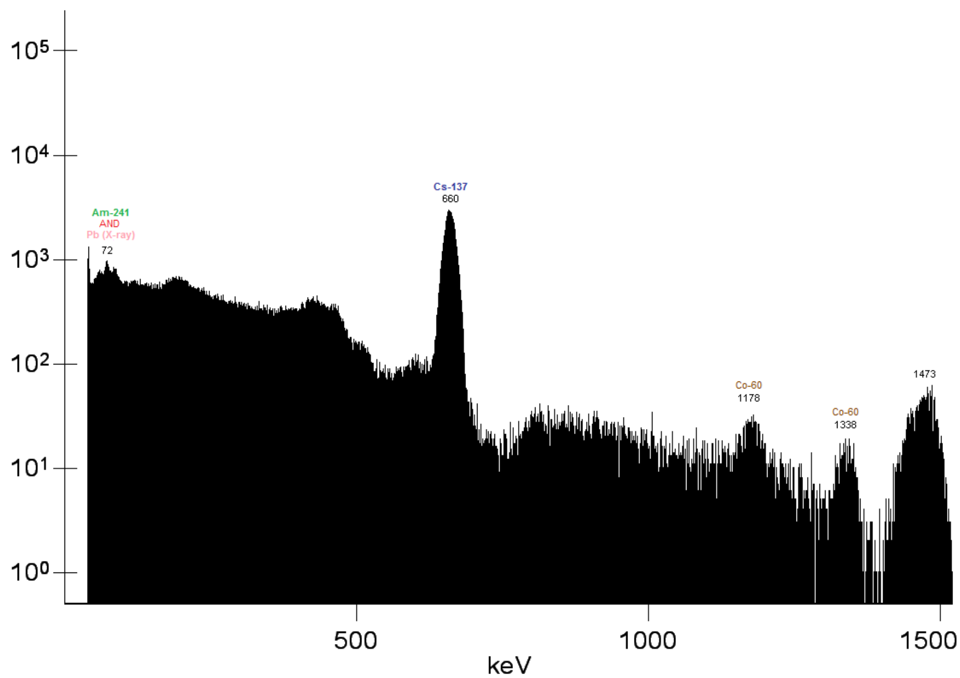

Figure 16. A 600 second measurement of sample 8 using a LaBr detector showing poor energy resolution.

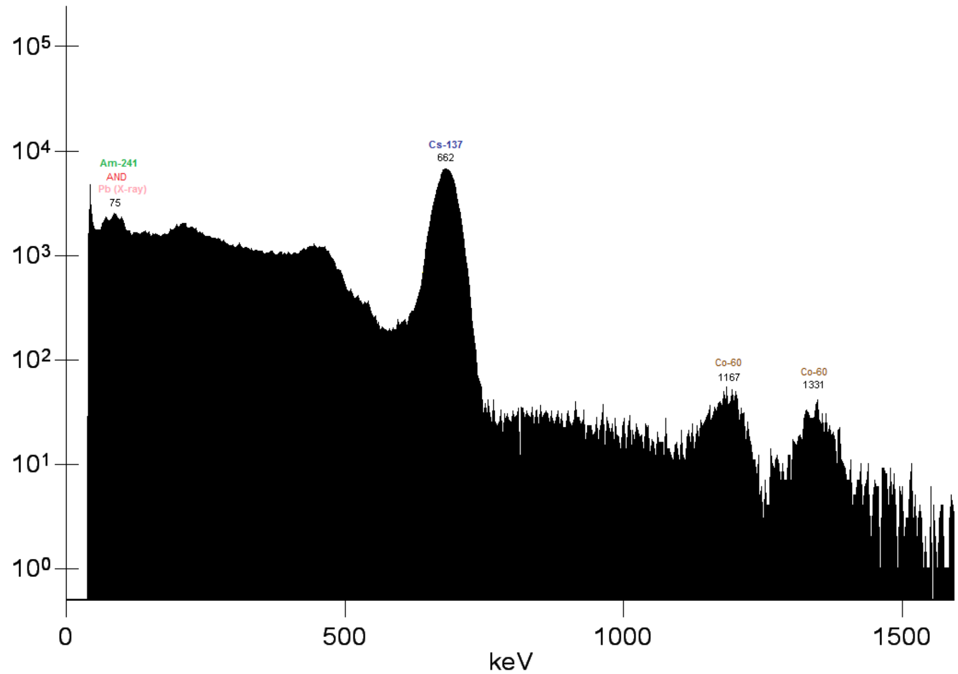

Figure 17. A 600 second measurement of sample 8 using a NaI detector showing poor energy resolution.

CHAPTER V

DISCUSSION

V.A. Process Monitoring

A reprocessing facility that is designed to implement real-time radiation monitoring and isotope characterization will have better process monitoring on its extraction streams. This would allow facility operators to manage the chemical separation processes with precise control. This is important since every nuclear fuel rod has a slightly different enrichment, burn-up, and decay time, thus causing its elemental composition to be different. Nuclear fuels that have different elemental compositions may require different ratios of solvents to be added or additional centrifugal contactor separation stages. Another advantage to this type of process monitoring is the ability to measure the fraction of impurities which are being extracted into the facilities product material.

An example of this point was observed during these experiments, as noted in Figure 18 where the 662 keV gamma ray peak from ^{137}Cs is present in sample 7, which is only supposed to contain U, Np, and Pu. Table 2 lists what elements would be present in each extraction stream under normal operating conditions. The ^{212}Pb, ^{214}Pb, and, ^{214}Bi peaks in sample 7 are due to background radiation from U daughter products in nearby cinder blocks. Sample 7 has a slight amount of Cs impurities, which can be detected within 600 seconds, as can be seen in Figure 19. This measurement time is longer than it would be in a commercial reprocessing facility due to the low activity of the sample, dead-time of 1.41%. It should be noted that ^{239}Np, daughter product from ^{243}Am, gamma ray peaks would also be present in the gamma spectrum in a commercial facility due to quickly measuring the extraction stream after separating the elements. Although the ^{137}Cs peak is small, its energy is much larger than the other peaks, creating unwanted additional dose to workers who will be converting the extraction stream into nuclear fuel, transporting the fuel, and loading the fuel into a reactor. Real-time gamma ray detection for process monitoring would allow operators to detect whether the amount of impurities in their product material was above a predetermined threshold limit, thus allowing them to stop the extraction stream before contaminating any previously acquired product material. How quickly impurities could be noticed in extraction streams depends on the activity of the extraction stream as well as the amount and isotopic identity of the impurity.

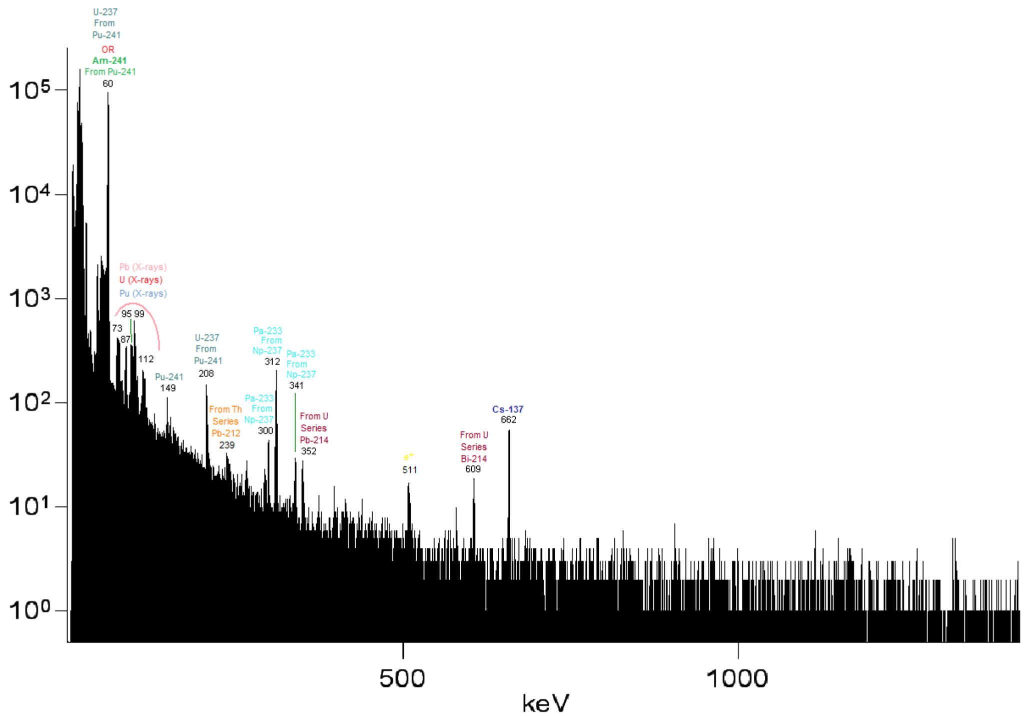

Figure 18. A 3600 second measurement of sample 7 using an HPGe N-type detector showing the undesired presence of ^{137}Cs.

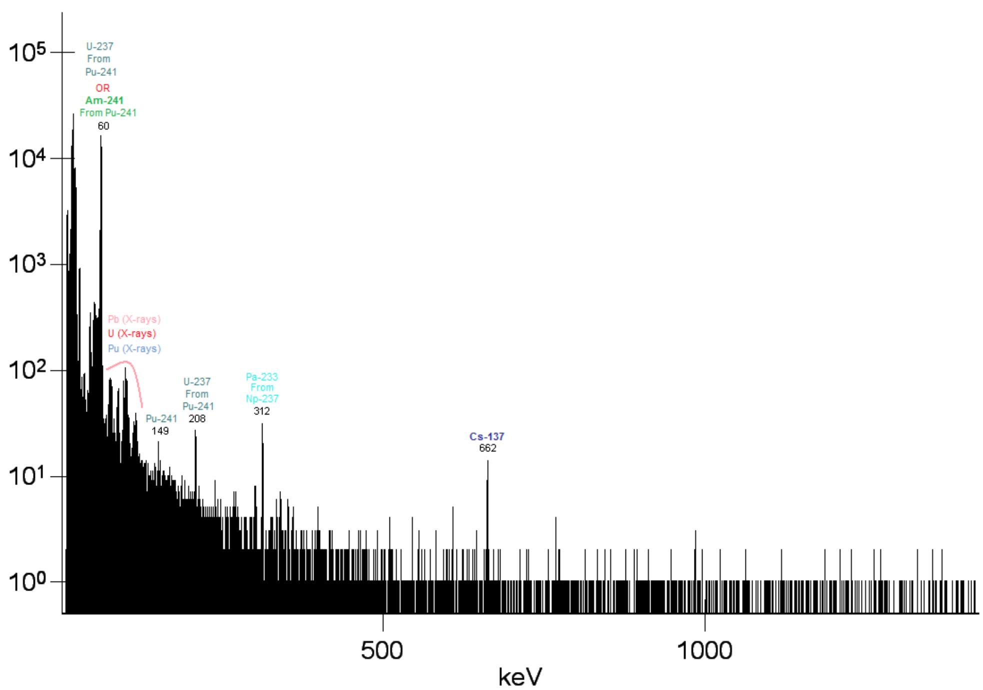

Figure 19. A 600 second measurement of sample 7 using an HPGe N-type detector showing the quick detection of the ^{137}Cs impurity.

V.B. Real-Time Detection of TRUs

The ability to quantitatively track TRUs, Pu in particular, is of great importance to safeguards. However, as discussed in Chapter VI section B the error in the total counts of the Pu peaks are too large to quantitatively measure the amount of Pu. Real-time qualitative gamma ray detection can be useful for safeguarding a facility if it can be shown that there is no Pu in any of the non Pu bearing extraction streams. This may be possible through a combination of ANCC, PNCC, and HPGe gamma ray detectors. Figure 20 shows a proposed arrangement of these detectors to monitor for significant amounts of TRUs leaving the extraction system through undesired paths.

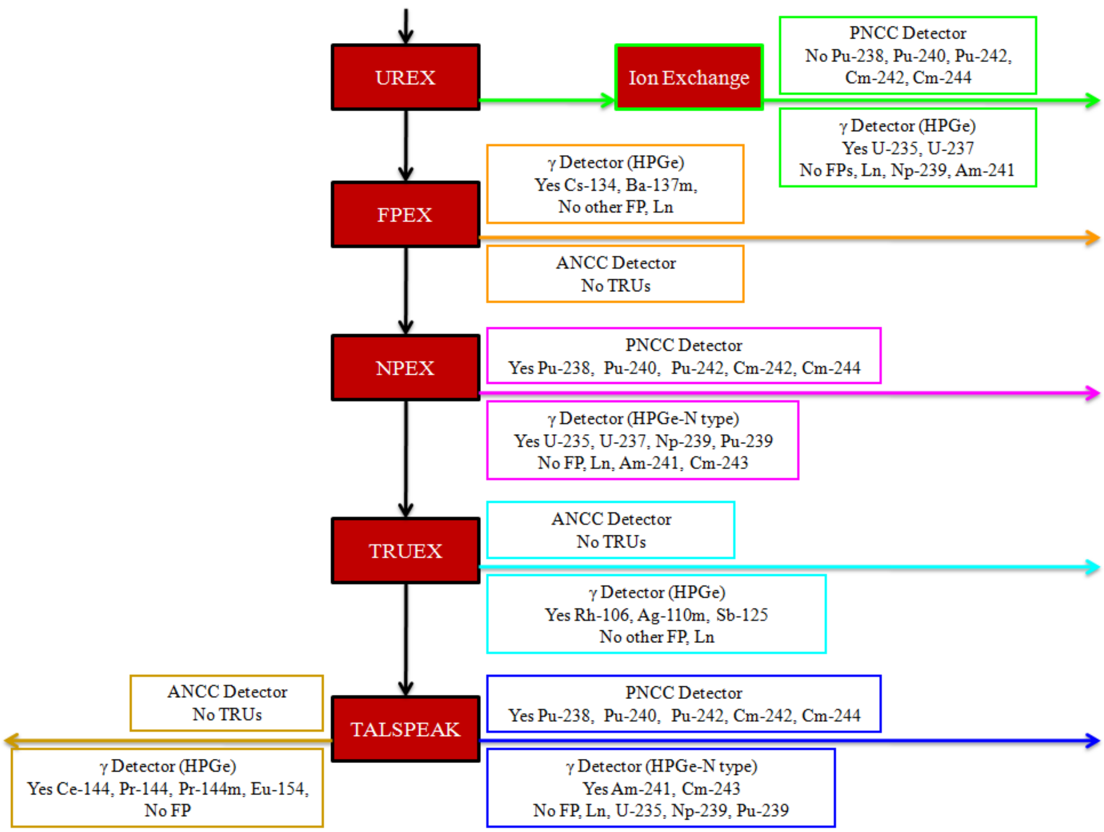

Figure 20. A detection scheme for the UREX+3a process to prevent significant amounts of TRUs from leaving the system through undesired paths.

Under the proposed monitoring scheme, The UREX product stream, which under normal operation only contains Tc and U, would be monitored using PNCC and HPGe detectors. The PNCC can confirm that no spontaneously fissioning isotopes such as ^{238}Pu, ^{240}Pu, ^{242}Pu, ^{242}Cm, or ^{244}Cm are present in the stream while the HPGe detector can confirm the presence of ^{235}U and ^{237}U and the absence of higher activity isotopes, such as FPs, ^{239}Np, ^{241}Pu, or ^{241}Am. The FPEX product, which under normal operation only contains Rb, Sr, Cs, and Ba, would be monitored using an ANCC to confirm that no fissile isotopes are in the stream, which would include all the TRUs. The NPEX product, which under normal operation only contains U, Np, and Pu, would be monitored with a HPGe detector to confirm the presence of ^{237}U, ^{239}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, and ^{241}Pu, while confirming the absence of FPs, ^{241}Am and ^{243}Cm. The TRUEX raffinate, which under normal operation only contains the remaining FPs, would be monitored with an ANCC to confirm that no fissile isotopes are in the stream, which would include all the TRUs. The TALSPEAK product, which under normal operation only contains Am and Cm, would be monitored with an HPGe detector to confirm the presence of ^{241}Am and ^{243}Cm and the absence of FPs, ^{237}U, ^{239}Np, and ^{241}Pu. Finally, the TALSPEAK raffinate, which under normal operation only contains Ln, would be monitored with an ANCC. The ANCC can confirm that no fissile isotopes are in the stream, which would include all the TRUs.

The amount of Pu which could be diverted down the UREX or TALSPEAK product extraction streams before being detected by an HPGe is discussed in more detail later in this chapter in section E. A PNCC Pu detection ability for the UREX extraction stream needs further investigation. ^{238}U spontaneously fissions 5.4×10^{-5} percent of the time per decay.[4] Although this number is very small, the majority of used nuclear fuel is ^{238}U, thus posing the possibility for Pu to be diverted down this extraction stream without significantly increasing the spontaneous fission rate above what would be expected. Further research into the amount of Pu needed to increase the spontaneous fission rate above what would be expected must be looked into before implementing this qualitative safeguards detection scheme.

V.C. Neutron Damage to Detector

When neutrons interact with the crystal structure of germanium they can create defects. These defects interfere with the flow of charge through the crystal after absorbing a gamma ray. This interference causes the amount of charge collected by the detector system to be less precise, thus reducing the energy resolution of the detector. If the sample to be measured has a complex narrow energy gamma ray spectrum, such as Pu, an HPGe detector being irradiated by neutrons quickly loses the ability to distinguish the individual gamma ray peaks. The amount of time an HPGe detector can operate in a neutron radiation environment before becoming ineffective at identifying individual gamma rays is difficult to determine. There are many factors which are unknown at this time, such as the neutron emission rate from the radioactive fluid, distance from the extraction stream to the detector crystal, volume of the extraction stream pipe, flow rate of the radioactive fluid, and the extent of the loss of resolution before the detector system can no longer perform as required. An estimate from the radiation detector manufacturer ORTEC, gives an estimate for the threshold of a 30% efficient HPGe N-type detector at a neutron fluence of $4x10^9$ n/cm^2.[34] In order to estimate the detector lifetime in a reprocessing facility radiation field, this estimate was combined with the following assumed parameters: (1) the facility throughput is 1000 MTU/yr, (2) the specific neutron emission rate is $6.9x10^8$ n/sec/MTU, (3) the fraction of neutrons that interact with the detector crystal of 5%, (4) fluid flowing in the extraction stream is near the detector for 2 sec, and (5) the cross-sectional area of the detector crystal is 22.1 cm^2. All of these together yield a rough approximation of 15 months before the detector would need to be replaced or repaired.

One common method of restoring the resolution of an HPGe detector is through annealing the crystal. For an N-type HPGe detector, the annealing time and temperature required to anneal out all the crystal defects is 24 hours at 100°C. This annealing process can be done as many times as is required without any loss of energy resolution or damage to the crystal.[34] This is not true for an HPGe P-type detector, which requires 168 hours of annealing at 120°C with the loss of significant energy resolution after annealing.[34] Because of this, it is suggested that HPGe P-type detectors should not be used for gamma ray detection in a reprocessing facility. The HPGe N-type detectors are commercially available with built in annealing equipment.[35]

V.D. Used Fuel Simulations

Because the fuels from which the UREX+3a samples, used in this research, were comprised of do not represent what would most likely be reprocessed in a commercial facility, the Oak Ridge Isotope Generation and Depletion Code (ORIGEN) was used to simulate the isotopics of fuel more likely to be reprocessed. The version of ORIGEN used was ORIGEN ARP. The fuel simulated is a 17x17 PWR, 44 GWd/MTU fuel with an initial enrichment of 4% ^{235}U. This fuel was burned at a specific power of 40 MW/MTU for 1100 days. After discharge it was allowed to decay for 3 years before being reprocessed. This fuel is representative of nuclear fuel currently being burned in commercial nuclear plants; this fuel will be referred to as Simulated Fuel. Also, it is speculated by some researchers that if reprocessing were to take place it would be the more recently burned, higher Pu content, fuel which would be reprocessed first. To insure that ORIGEN was correctly generating fuel isotopics, the isotopics from ORIGEN were compared to used nuclear fuel nuclide composition benchmark data.(35) The simulation isotopics and benchmark data compared well with each other.

The isotopic from ORIGEN were used as input for MCNP simulations to give a simulated representation of what the gamma spectra would look like from fuel that was commercially reprocessed at each of the stages where measurements were made from the UREX+3a samples. The version of MCNP that was used was MCNP5. In order to model the detector energy resolution in MCNP the Gaussian Energy Broadening (GEB) card was used. This card broadens the gamma ray peaks based on the energy dependent Equation 6. The value of a, b, and c where algebraically solved for using the three measured FWHM values of 1.36, 1.45, and 1.94 keV and the corresponding gamma ray energy values of 277, 384, and 1274 keV. This gave the result of a = 0.000853482, b = 0.000962040, and c = 0.000733352.

$$FWHM = a + b\sqrt{E + cE^2} \qquad \text{Eq. 6}$$

where the *FWHM* is the full width of the gamma ray peak at half its maximum value, *a*, *b*, and *c* are energy resolution specific coefficients, and *E* is the energy in MeV of the gamma ray peak.

The first step in modeling the gamma ray spectra was to accurately simulate the gamma spectra for an HPGe-N detector monitoring the UREX+3a samples in the experiment geometry. This was done by taking the measured isotopics after the UREX+3a chemical separations, in the summer of 2007, and decaying them until December 2008 using the decay algorithms in ORIGEN. The isotopic composition was then converted into a MCNP source definition format using software provided by Oak Ridge National Laboratories (ORNL).[36] This source definition was combined with the geometry and material types used in the actual measurements of the UREX+3a samples. An example MCNP input deck for sample 1 can be seen in Appendix G. For each MCNP simulation 2000 MegaHistories (2000 MH or 2000 million active histories) were run.[37] The MCNP simulations compared well to the actual measurements for some of the samples. For example, the MCNP simulation for sample 4 is very similar to the actual measurement, as seen in Figure 21. However, the MCNP simulation for sample 7 is quite different from the actual measurement, as seen in Figure 22.

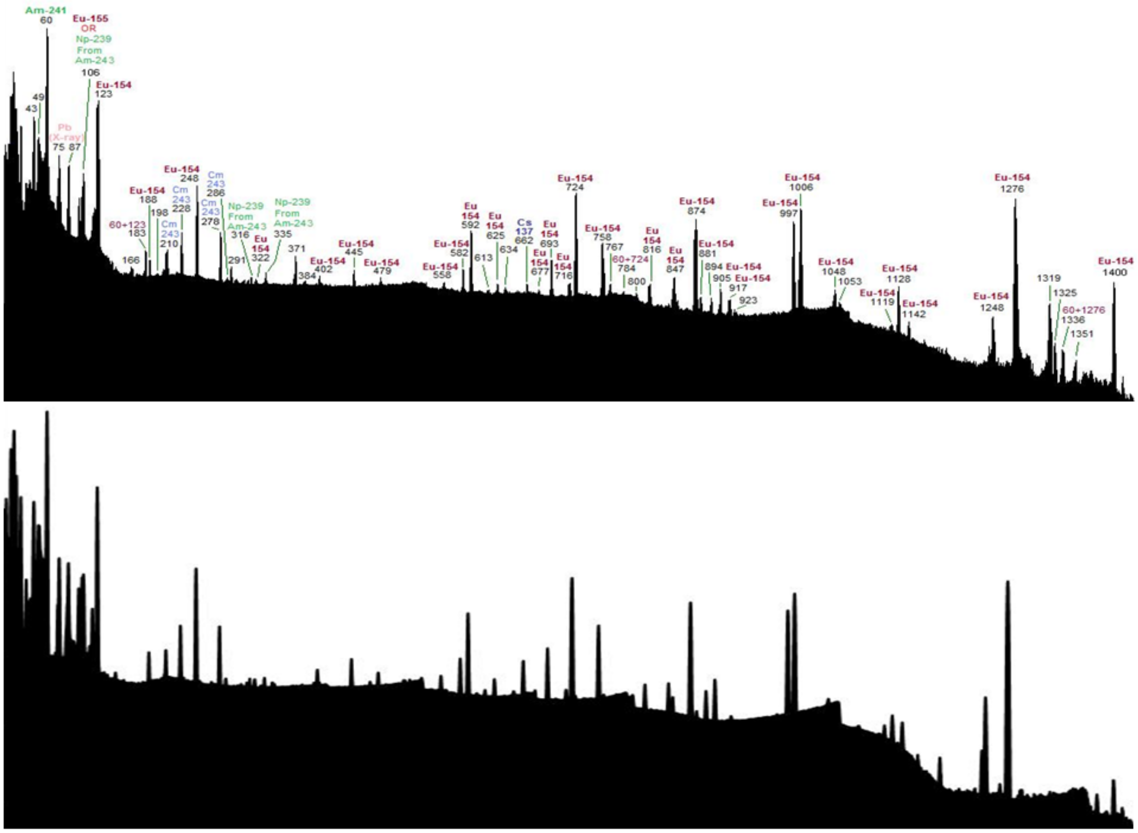

Figure 21. Comparison between a measured gamma ray spectrum (top) and one simulated in MCNP (bottom) for the UREX+3a sample 4.

The main difference between the sample 7 actual and simulated gamma ray measurements are large amounts of ^{154}Eu and ^{243}Cm in the MCNP simulation. Table 9 shows the isotopes that could be identified in samples for 3600 second HPGe N-type gamma ray measurement and corresponding MCNP simulations. There are several isotopes identified in the actual measurement for sample 3 and 7 which are from background radiation in the cinder blocks surrounding the detector setup. These isotopes are ^{208}Ti, ^{212}Pb, ^{214}Pb, and ^{214}Bi for sample 3 and ^{212}Pb, ^{214}Pb, and ^{214}Bi for sample 7. A simulation for sample 3 was not completed due to a lack of complete knowledge of the isotopic composition. The main differences between the actual measurements and the

MCNP simulation are: (1) no sum peaks in the simulation, (2) inconsistencies in ^{134}Cs and ^{137}Cs, (3) an abundance of ^{154}Eu and ^{243}Cm and a lack of ^{237}U in the sample 7 simulation, and (4) several isotopes in sample 8. A complete list of gamma ray spectra simulated for the UREX+3a samples can be seen in Appendix H.

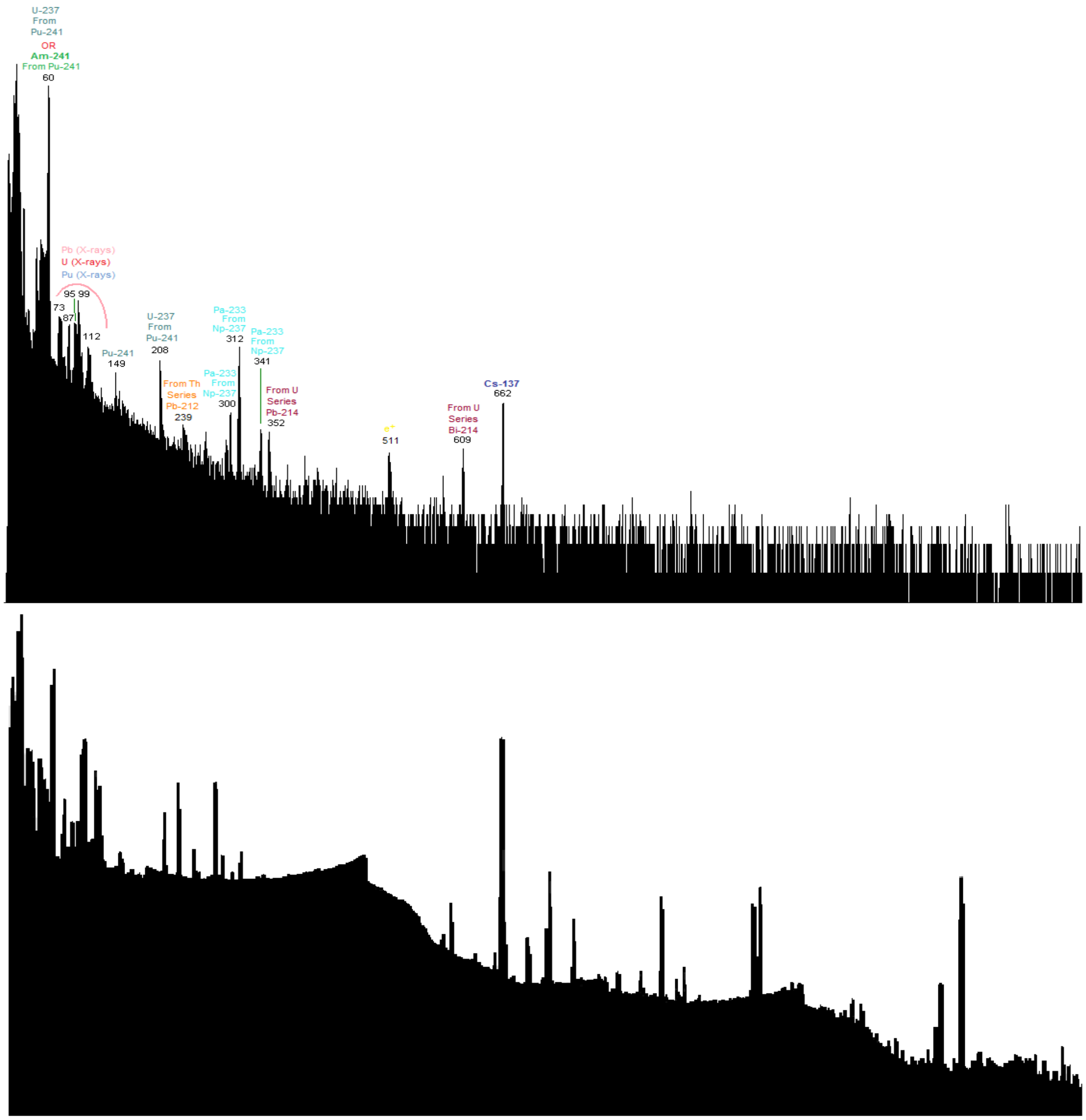

Figure 22. Comparison between a measured gamma ray spectrum (top) and one simulated in MCNP (bottom) for the UREX+3a sample 7.

Table 9. Isotopes that could be identified in a 3600 second HPGe N-type gamma ray measurement and corresponding MCNP simulations.

Sample #	Actual Measurement	MCNP Simulation
1	^{134}Cs, ^{137}Cs, ^{154}Eu, ^{241}Am	^{137}Cs, ^{154}Eu, ^{241}Am
2	^{134}Cs, ^{137}Cs, ^{154}Eu, ^{241}Am	^{137}Cs, ^{154}Eu, ^{241}Am
3	^{137}Cs, ^{208}Tl, ^{212}Pb, ^{214}Pb, ^{214}Bi, ^{234m}Pa, ^{234}Th, ^{235}U, ^{238}U	N/A
4	^{137}Cs, ^{154}Eu, ^{239}Np, ^{241}Am, ^{243}Cm	^{137}Cs, ^{154}Eu, ^{239}Np, ^{241}Am, ^{243}Cm
5	^{134}Cs, ^{137}Cs	^{137}Cs
6	^{137}Cs, ^{154}Eu, ^{239}Np, ^{241}Am, ^{243}Cm	^{137}Cs, ^{154}Eu, ^{239}Np, ^{241}Am, ^{243}Cm
7	^{137}Cs, ^{212}Pb, ^{214}Pb, ^{214}Bi, ^{233}Pa, ^{237}U, ^{241}Pu	^{154}Eu, ^{241}Am, ^{243}Cm
8	^{60}Co, ^{106}Rh, ^{125}Sb, ^{126}Sb, ^{134}Cs, ^{137}Cs	^{126}Sb, ^{126m}Sb, ^{137}Cs, ^{154}Eu, ^{243}Cm
9	^{154}Eu, ^{239}Np, ^{241}Am, ^{243}Cm	^{137}Cs, ^{154}Eu, ^{239}Np, ^{241}Am, ^{243}Cm

After the spectra for the UREX+3a samples were simulated successfully (with the discrepancies noted above), gamma spectra from the Simulated Fuel were created using the same geometry, material types, and detector data from the UREX+3a simulations. The same elemental fractions were used for each extraction stream but the ORIGEN isotopics for the Simulated Fuel were different due to different fuel histories. For each MCNP simulation 2000 MH were run. A complete list of Simulated Fuel gamma ray spectra can be seen in Appendix I. The gamma ray spectra from the Simulated Fuel have more short lived isotopes which complicate the gamma spectrum, as would be expected. For example, the 228 keV and 278 keV ^{243}Cm gamma rays are barely visible in the Simulated Fuel sample 9 gamma ray spectrum. This implies that the TALSPEAK raffinate would also have these peaks visible in its gamma ray spectrum. No Pu peaks are visible in the gamma ray spectrum of the Simulated Fuel sample 7. However, from to the notable difference between the simulated and measured UREX+3a simulation results for sample 7, the Simulated Fuel for the sample 7 point in the process should not be trusted. It cannot be determined from the spectra if the safeguards approach proposed in this paper would work for fuels similar to the Simulated Fuel due to the poor agreement of the simulation data with the experimental measurements for sample 7 and a lack of separation isotopics for the TALSPEAK raffinate and the UREX product.

V.E. Pu Sensitivity Simulations

The qualitative detection scheme proposed in this research has three main assumptions: first, the PNCC in the UREX stream will be able to detect noticeable amounts of Pu being diverted down this stream. Second, the HPGe detector in the UREX stream will be able to detect noticeable amounts of Pu being diverted down this stream. And third, the HPGe detector in the TALSPEAK stream will be able to detect noticeable amounts of Pu being diverted down this stream. In order to verify the latter two assumptions, MCNP simulations were conducted. It was assumed that UREX effluent stream contains 100 percent of the Tc and U. Varying Pu concentrations were added to simulate minor and significant diversion of Pu into the UREX stream. The TALSPEAK stream was assumed to contain 100 percent of the Am and Cm and, as above, varying Pu concentrations were added to simulate minor and significant diversion of Pu into the TALSPEAK stream. The MCNP simulation geometry was the same as discussed in section D of this chapter. The number of histories which were run for each simulation varied from 250 MH to 2000 MH. Both the isotopics for the ANL samples and Simulated Fuel were used in the simulations.

For the UREX stream, it was determined that noticeable amounts of Pu could be seen for Pu concentrations up to 0.01% for both the ANL sample isotopics and the Simulated Fuel isotopics. Figures 23 and 24 show the MCNP gamma spectra for a 0.01% Pu content for the UREX streams for the ANL sample isotopics and the Simulated Fuel isotopics. Table 11 shows which Pu isotopes could be identified for varying concentrations of Pu for both the ANL sample isotopics and the Simulated Fuel isotopics. Simulated gamma spectra for all the Pu fractions used can be seen in Appendix K. To determine the amount of Pu which corresponds to a 0.01% Pu diversion it was assumed that the size of the reprocessing plant was 1000 MTU per year and that 1% of the reprocessed fuel was Pu. Using these reasonable values, the maximum amount of Pu which can be diverted per year is 1 kg. This value is far less than 1 SQ and thus is not a safeguards concern.

Table 11. Pu isotopes that can be identified for various diverted fractions of Pu down the UREX extraction stream.

Pu Content	ANL Sample Isotopics	Simulated Fuel Isotopics
100%	^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu	^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu
10%	^{238}Pu, ^{239}Pu, ^{241}Pu	^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu
1%	^{238}Pu, ^{239}Pu, ^{241}Pu	^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu
0.1%	^{239}Pu, ^{241}Pu	^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu
0.01%	^{239}Pu	^{239}Pu, ^{241}Pu

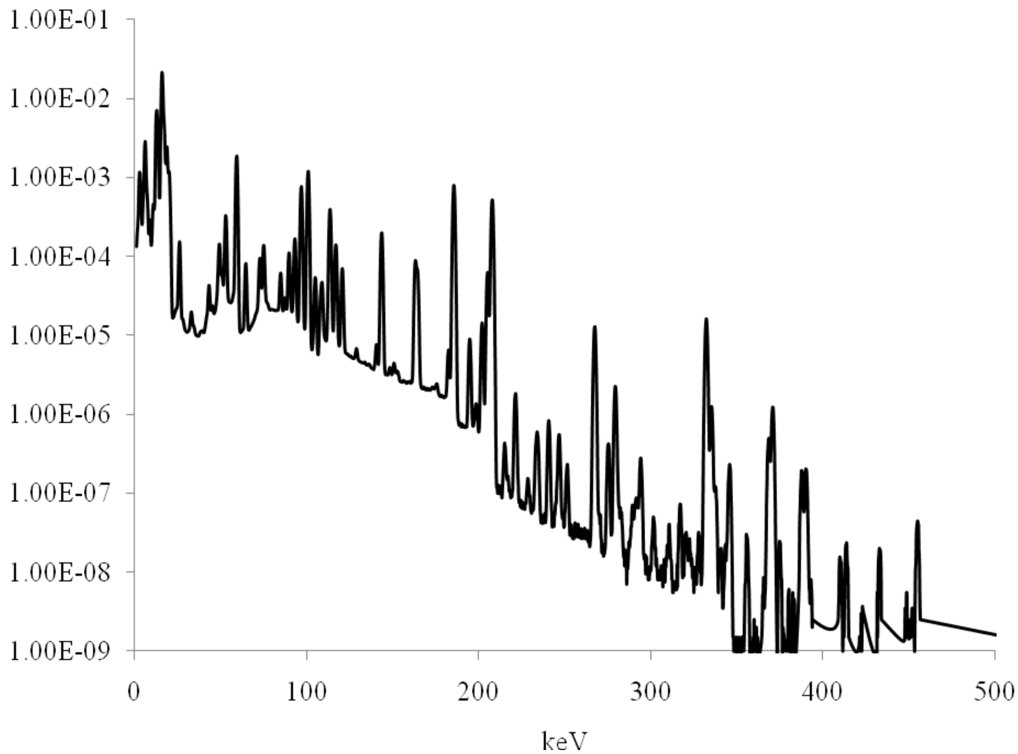

Figure 23. MCNP gamma spectrum simulation for the UREX extraction stream with 0.01% Pu diversion using the ANL sample isotopics.

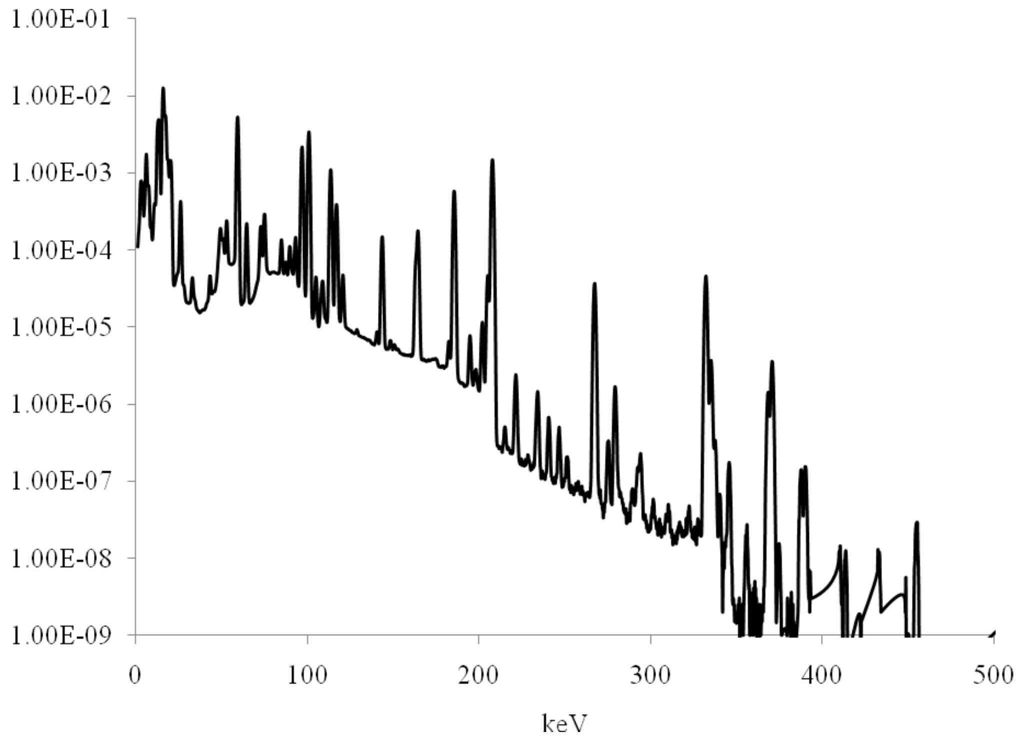

Figure 24. MCNP gamma spectrum simulation for the UREX extraction stream with 0.01% Pu diversion using the Simulated Fuel isotopics.

For the TALSPEAK stream, it was determined that noticeable amounts of Pu could be seen for Pu concentrations up to 100% for the ANL sample isotopics and 10% for the Simulated Fuel isotopics. Figures 25 and 26 show the MCNP gamma spectra for the TALSPEAK streams with a 100% Pu content for the ANL sample isotopics and a 10% Pu content for the Simulated Fuel isotopics. Table 12 shows which Pu isotopes could be identified for varying concentrations of Pu for both the ANL sample isotopics and the Simulated Fuel isotopics. Simulated gamma spectra for all the Pu fractions used can be seen in Appendix L. Using the same assumptions as above, a diversion of 100% of the Pu and 10% of the Pu corresponds to 10000 and 1000 kg a year. Both of these values are well above 1 SQ. Because of this, HPGe measurements are not sufficient and a different measurement technique must be used to verify that no significant amounts of Pu can be diverted down the TALSPEAK extraction stream.

Table 12. Pu isotopes that can be identified for various diverted fractions of Pu down the TALSPEAK extraction stream.

Pu content	ANL sample isotopics	Simulated Fuel isotopics
100%	^{238}Pu, ^{239}Pu, ^{241}Pu	^{238}Pu, ^{239}Pu, ^{241}Pu
10%	None	^{241}Pu
1%	None	None
0.1%	None	None
0.01%	None	None

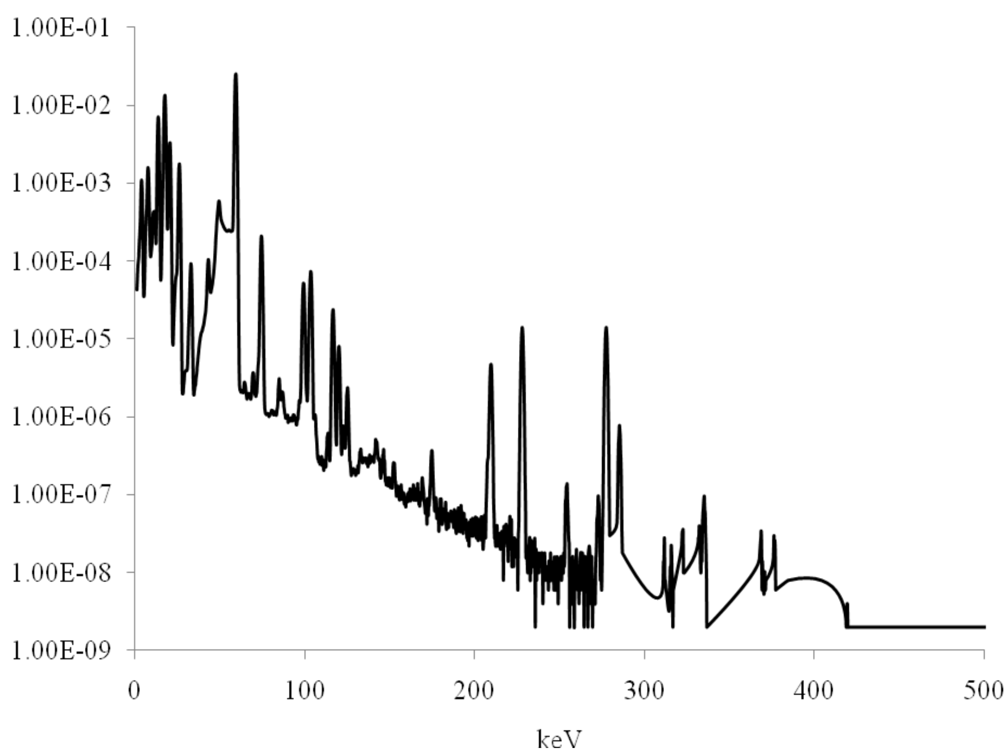

Figure 25. MCNP gamma spectrum simulation for the TALSPEAK extraction stream with 100% Pu diversion using the ANL sample isotopics.

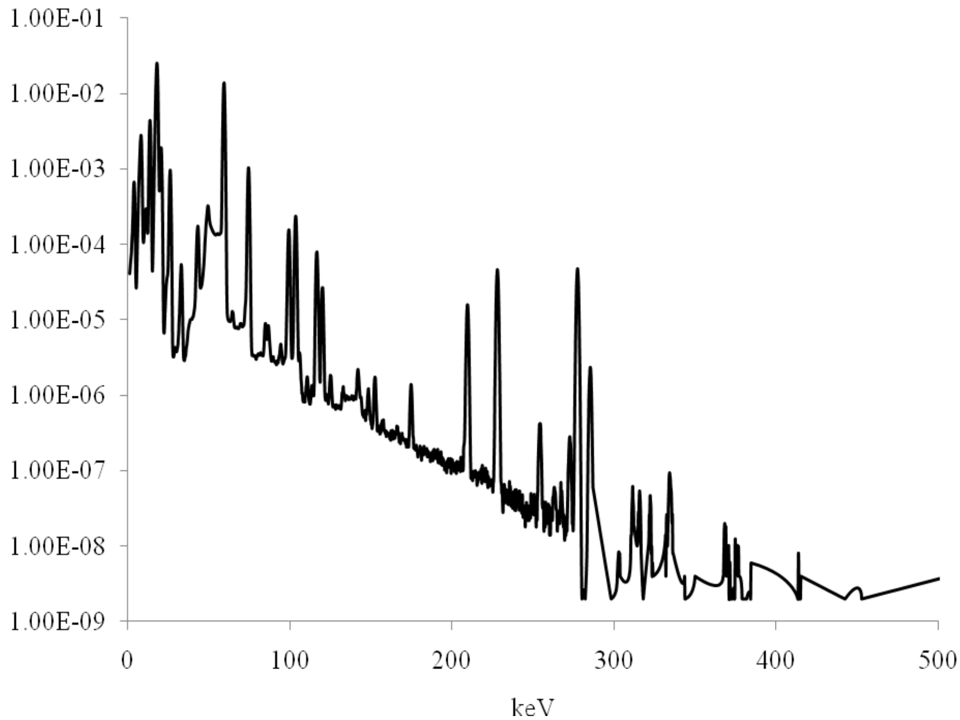

Figure 26. MCNP gamma spectrum simulation for the TALSPEAK extraction stream with 10% Pu diversion using the Simulated Fuel isotopics.

V.F. Self Shielding

A common problem which occurs when trying to measure gamma rays from bulk, dense, or high atomic number materials is that the radioactive material attenuates its own gamma rays. To address this problem for a used nuclear fuel reprocessing facility MCNP simulations were carried out. A model of a 2 inch inside diameter stainless steel 316, schedule 40, pipe was created in MCNP with an internal radioactive fluid composition based on proprietary information for ANL. A 2.6 cm diameter sphere of germanium was placed a distance of 40 cm away from the center of the pipe. The MCNP source definition came from the ORIGEN isotopic calculations for the Simulated Fuel, which was then converted into a MCNP source definition format using software provided by ORNL.[36] The internal radioactive pipe fluid geometry was simulated as a hollow cylinder on the inside of the pipe.

MCNP runs were carried out, with 250 MH per run, for varying cylinder fluid thicknesses. A F4 tally was used to determine the photon flux inside the germanium sphere. The result of this tally was then multiplied by the activity, in gamma rays per second, of the radioactive fluid in the pipe. Seven different radioactive fluid thicknesses were used to create a curve relating the photon flux inside the germanium sphere to the total mass of the radioactive fluid inside the pipe. This curve can be seen in Figure 23 for the FPEX product and Figure 24 for the NPEX product. A sample MCNP input deck for the self shielding calculations of the FPEX product can be found in Appendix J.

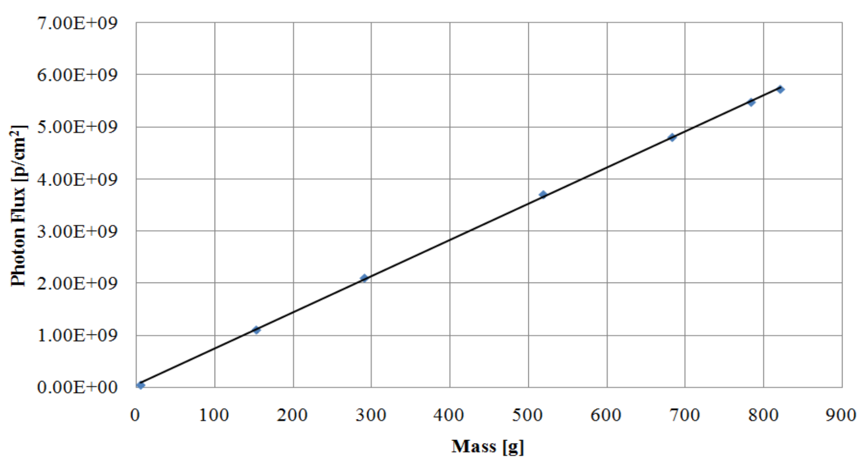

Figure 27. MCNP simulation showing that as the volume of FPEX product inside a pipe increases there is minimal self shielding affects.

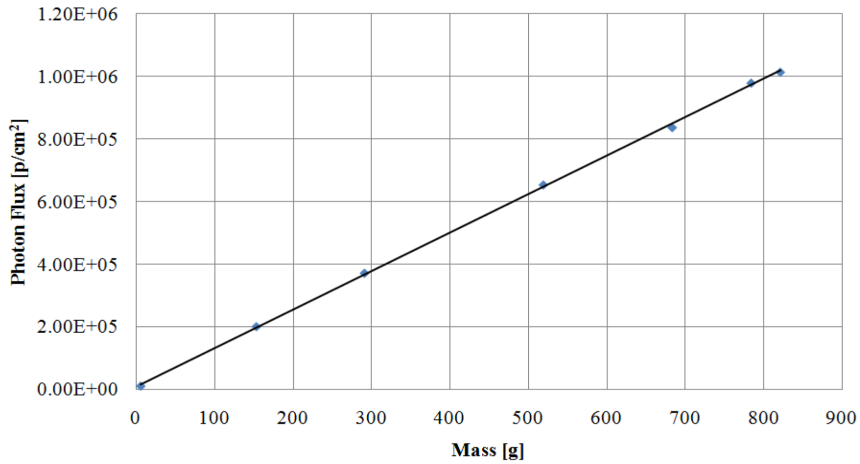

Figure 28. MCNP simulation showing that as the volume of NPEX product inside a pipe increases there is minimal self shielding affects.

If the radioactive fluid was significantly self shielding, the gamma rays which it was creating towards the center of the cylinder would have a smaller probability of reaching the sphere of germanium due to photon absorption in the radioactive fluid. This would create a curve which would level off and approach a limiting value. This limiting value would occur when the fluid was so thick that no gamma rays created near the center of the cylinder could reach the germanium sphere. However, since the curve in Figures 23 and 24 are linear it can be concluded that no significant amount of self shielding is occurring within the parameters explored by this calculation. The internal diameter pipe size of 2 inches was chosen based on estimates of what would be used in a commercial reprocessing facility.(23) Photons of low energies, such as those seen in the NPEX product, are more readily absorbed than higher energy photons, such as those from ^{137}Cs. However, the curve in Figure 24 can accurately be approximated as a straight line, thus indicating that even low energy photons are not significantly absorbed.

CHAPTER VI

SUMMARY AND CONCLUSIONS

VI.A. Summary

Reprocessing facilities in non-weapons states must be safeguarded and reprocessing facilities in weapons states will likely be safeguarded. Although real-time gamma ray measurements cannot quantitatively be used for safeguards, a qualitative approach combined with neutron coincidence counters was developed in this study. Real-time measurements can also be used for process monitoring purposes to insure that the elemental separations are occurring correctly. Real-time energy spectra from alpha or beta particles could improve the ability to safeguard a reprocessing facility significantly; current detector systems are not able to do this but another member of the consortium is developing a metastable fluid detector that has the potential of doing this.(7)

The diluted and dried UREX+3a samples used in this study represent the majority of stages processing stages, with the exception of the final TALSPEAK separation step. Also, the samples had been allowed to build up daughter products for 18 months before gamma spectra could be taken of them, making analysis of the gamma spectra difficult. However, they are from the UREX+3a process which is one of the more likely processes to be implemented in a commercial reprocessing facility.(23)

The fuels that the UREX+3a samples came from, for this research, are not representative of fuels that are likely to be commercially reprocessed. Because of this

ORIGEN and MCNP simulations were run to model both the UREX+3a samples as well as fuel similar to what would be commercially reprocessed. Several of the actual and simulated gamma ray spectra of the UREX+3a samples were very similar. Unfortunately sample 7 could not be accurately simulated and isotopic information was unavailable for the TALSPEAK product and UREX product. This prevented a clear conclusion of whether fuel similar to the Simulated Fuel could be safeguarded.

Neutron damage to HPGe detectors can reduce their gamma ray energy resolution over time. A solution to this problem is to anneal the detector periodically, thus removing any crystal defects in the detector. Annealing is best suited for an HPGe N-type detector. Self shielding calculations were done using MCNP to determine if there was a limiting internal pipe diameter for which gamma rays created at the center of the pipe could not penetrate the radioactive fluid and reach the detector. There is no significant self shielding for both high energy 662 keV and low energy Pu gamma rays for internal pipe diameters of less than or equal to 2 inches.

VI.B. Recommendations

Due to the limited gamma ray energy resolution of HPGe detectors it is recommended that a qualitative safeguards approach be used. It is also recommended that HPGe N-type gamma ray detectors be used due to their good resolution, neutron resistance, and their ability to quickly and fully anneal defects. A commercially available HPGe N-type detector with a build in annealing system should be used.

Due to the inability of HPGe gamma detectors to detect significant amounts of Pu being diverted down the TALSPEAK stream a different method to detect Pu must be used. This method will need to be able to measure the stream in real-time and be able to detect Pu concentrations as low as a few fractions of a percent. It is recommended that a Hybrid K-Edge Densitometer or a *Metastable Fluid* detector be looked into to fulfill this need.

Another area of further research is the measurement of recently separated bulk UREX+ extraction streams. This would allow for the characterization of gamma ray spectra that do not contain daughter products. This would also allow for geometry configuration experiments and neutron coincidence counter measurements for UREX+ facility activity extraction streams.

In conclusion, the research presented in this thesis contributes to the development of real-time process monitoring for the UREX+3a process as well as any process that uses aqueous elemental separations processes. The safeguards approach presented in this thesis should be considered for implementation alongside existing safeguards strategies.

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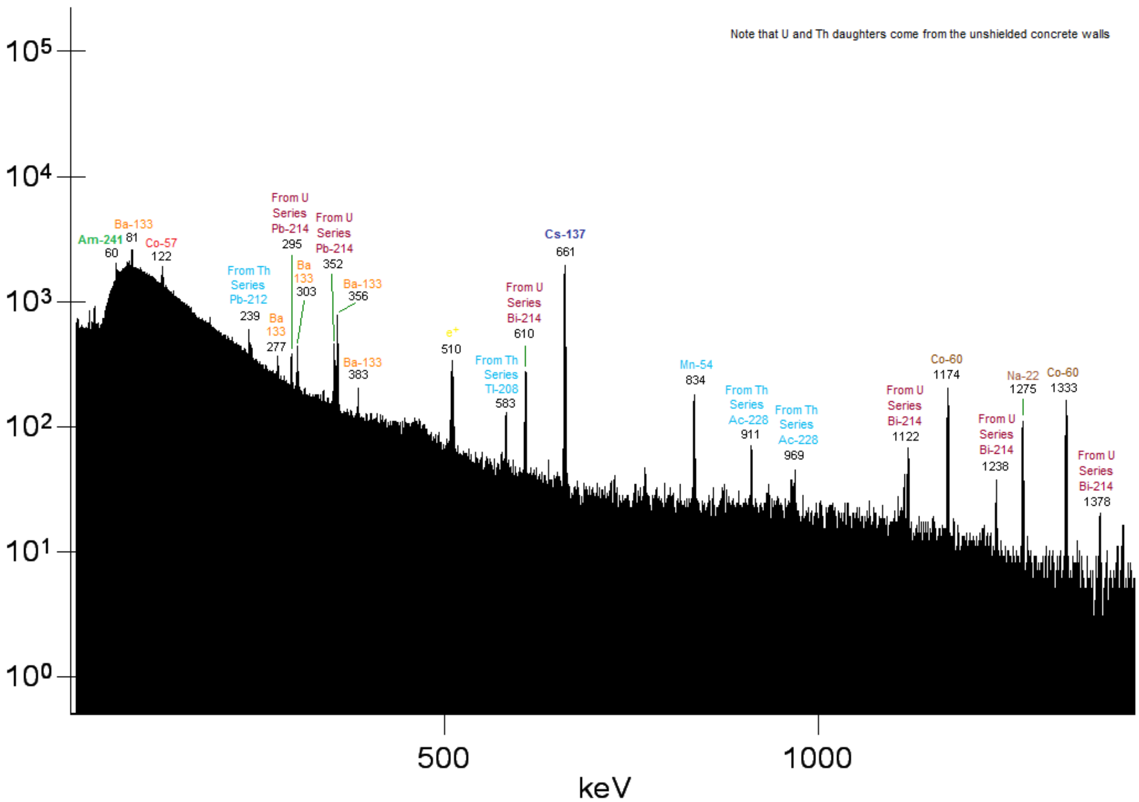
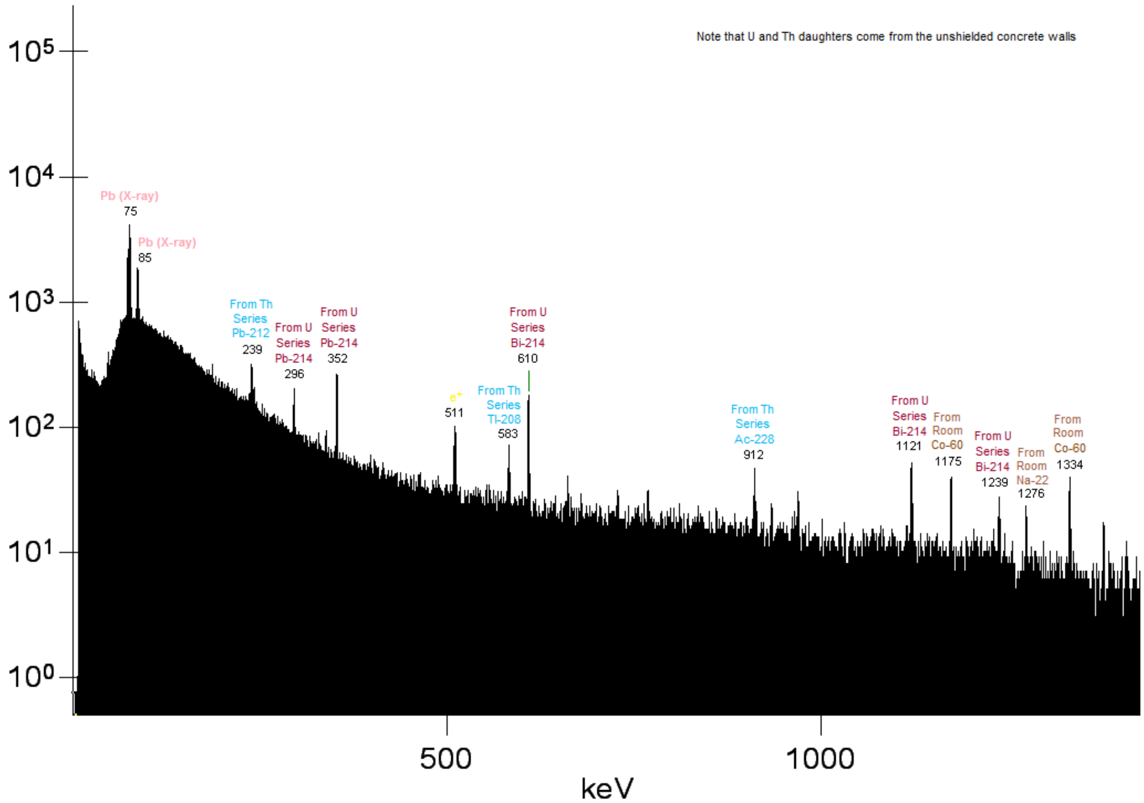
APPENDIX A

HPGe N-type gamma ray spectra. Units of the ordinate are in counts.

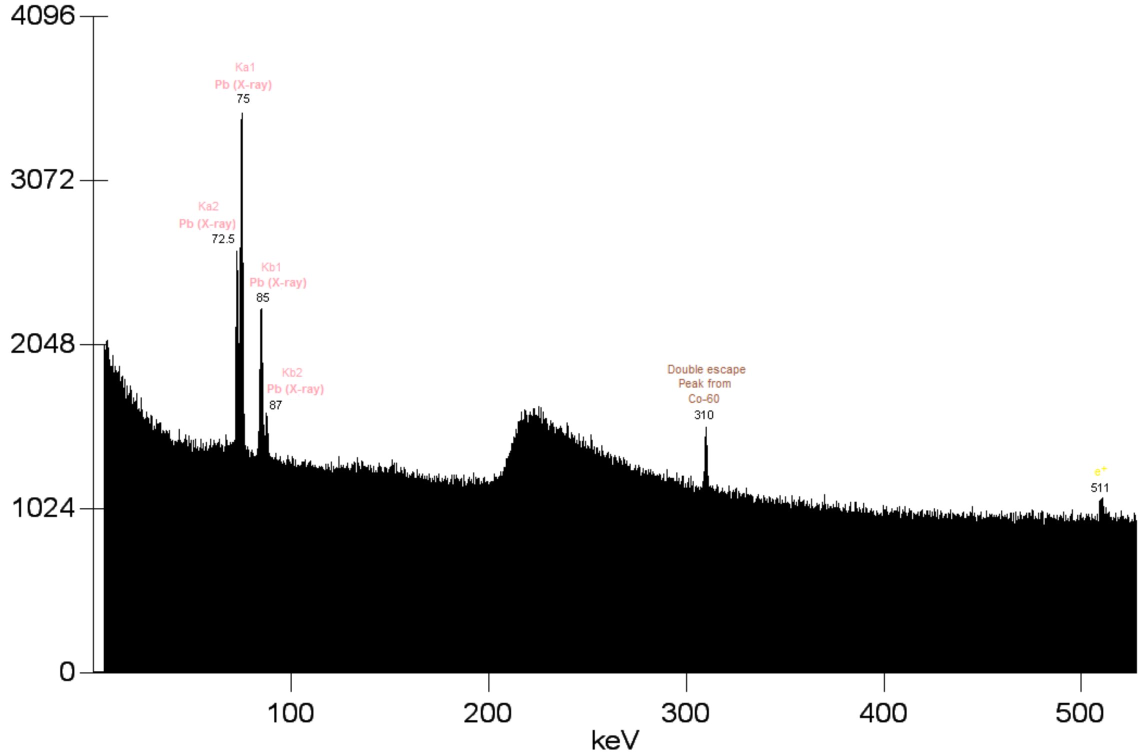
10800 second background measurement without Pb shielding



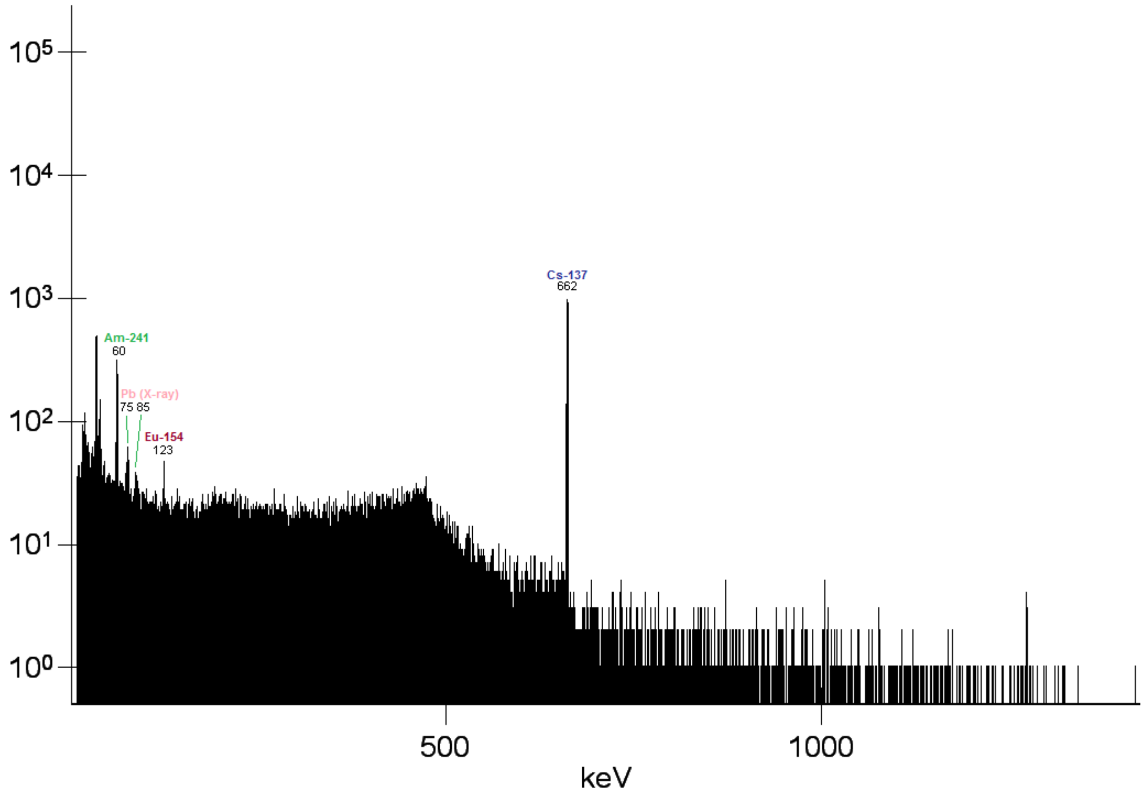
43200 second background measurement with Pb shielding



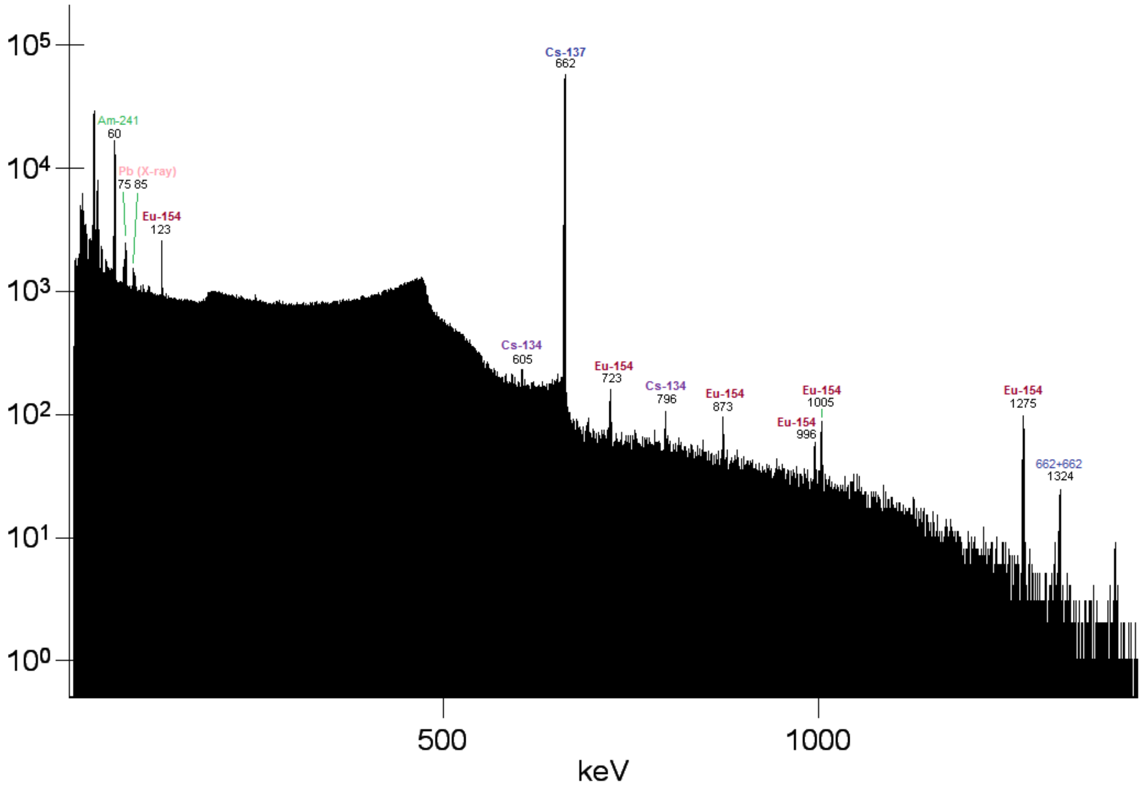
3600 seconds Pb X-rays measurement using Co-60 as the source



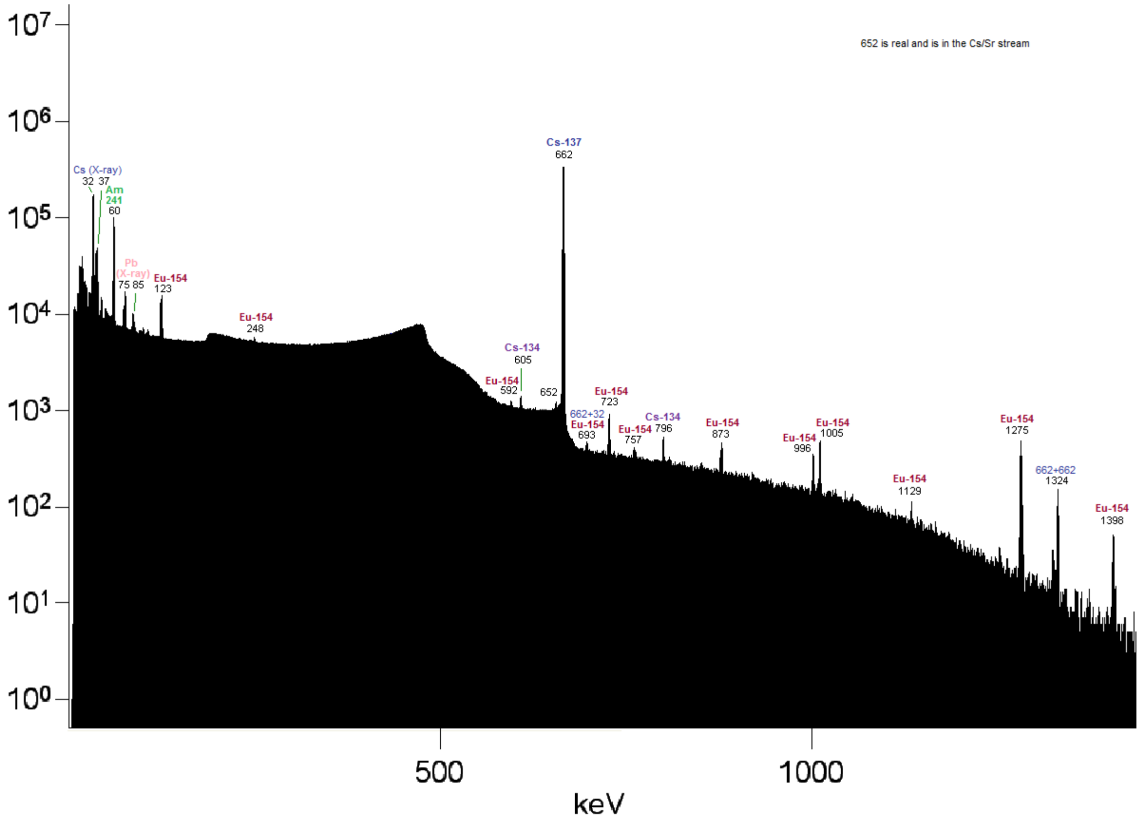
10 seconds Sample 1 measurement



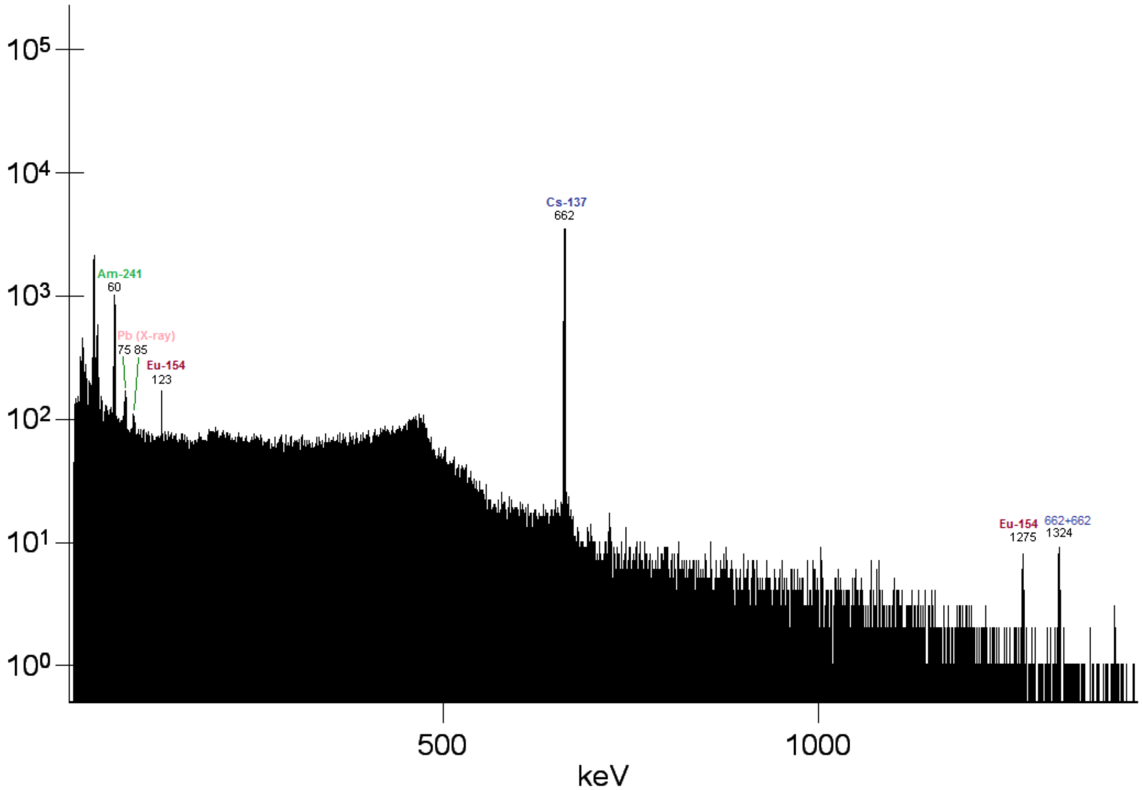
600 seconds Sample 1 measurement



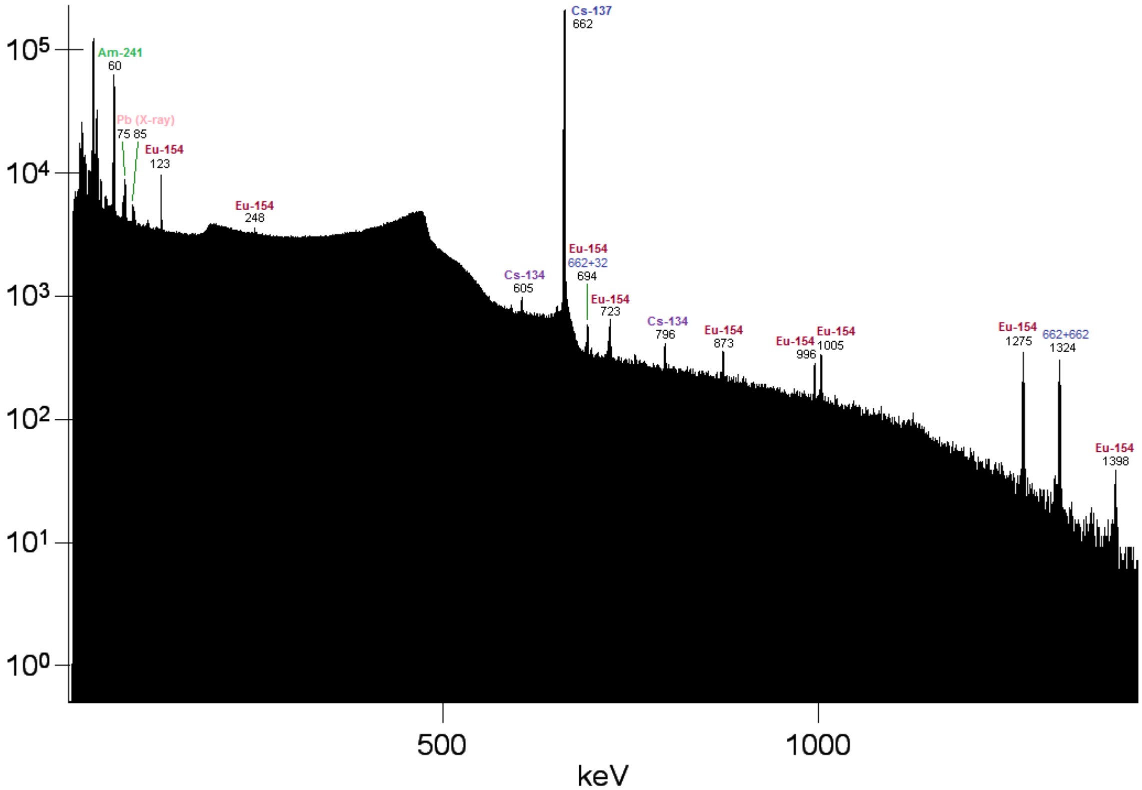
3600 seconds Sample 1 measurement



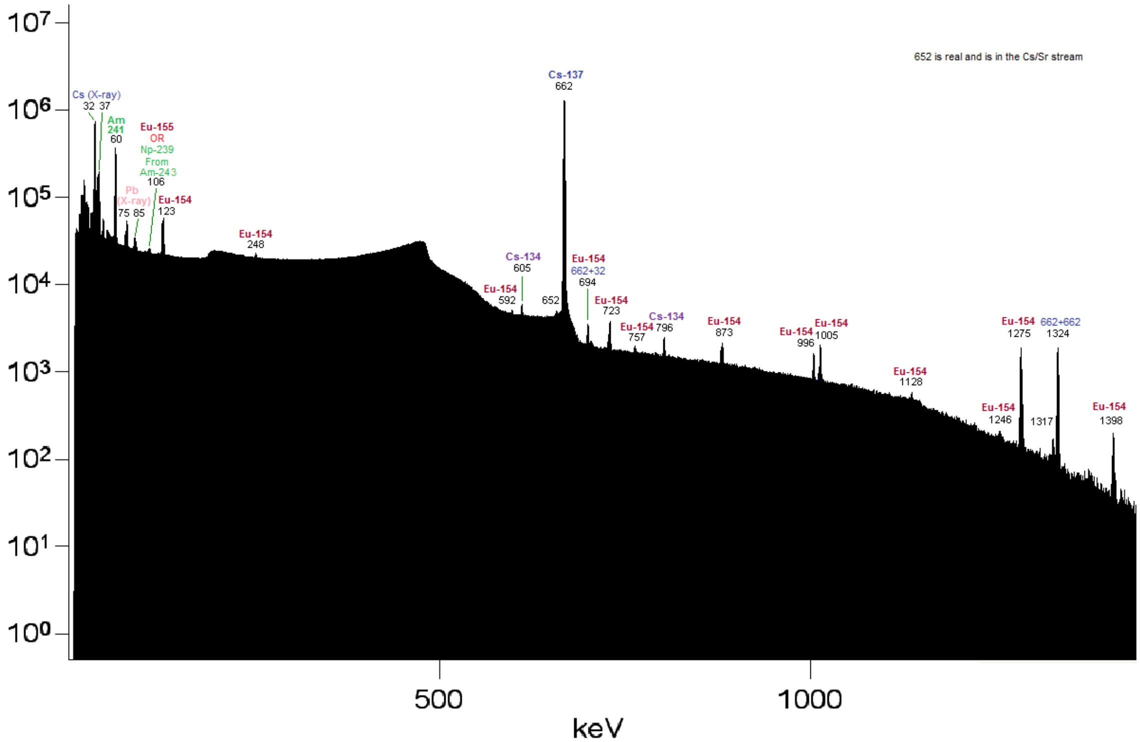
10 seconds Sample 2 measurement



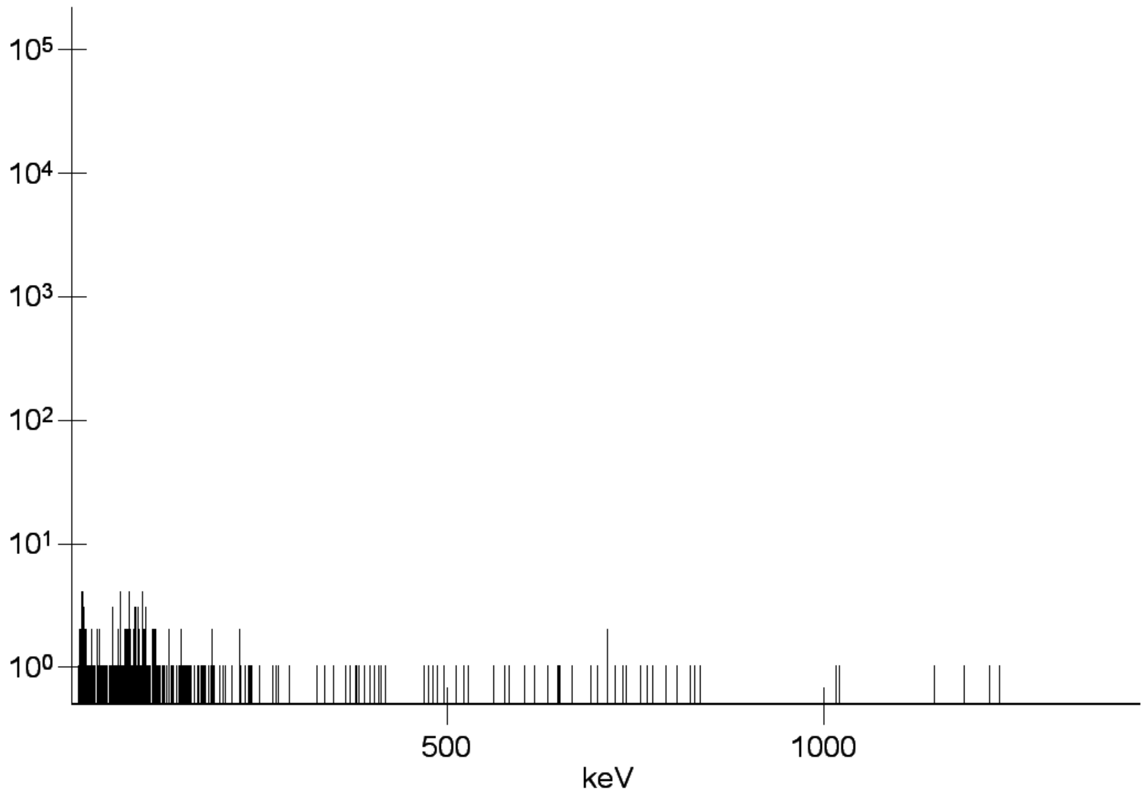
600 seconds Sample 2 measurement



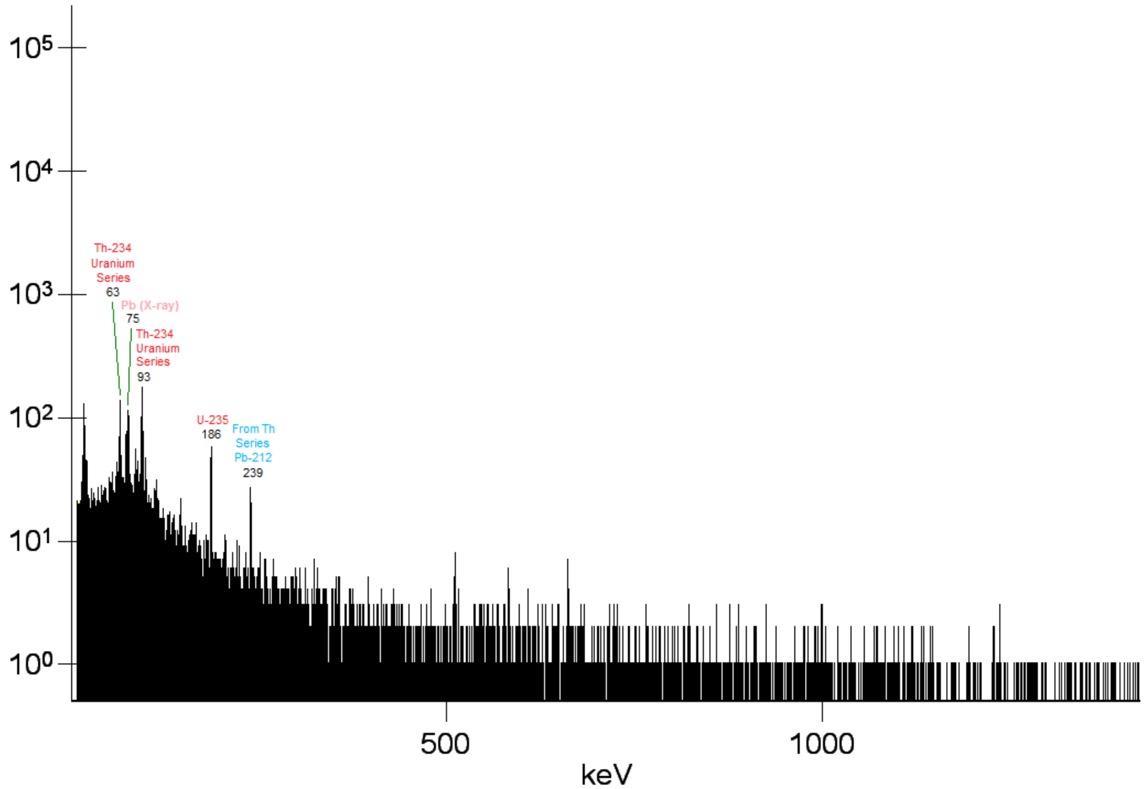
3600 seconds Sample 2 measurement



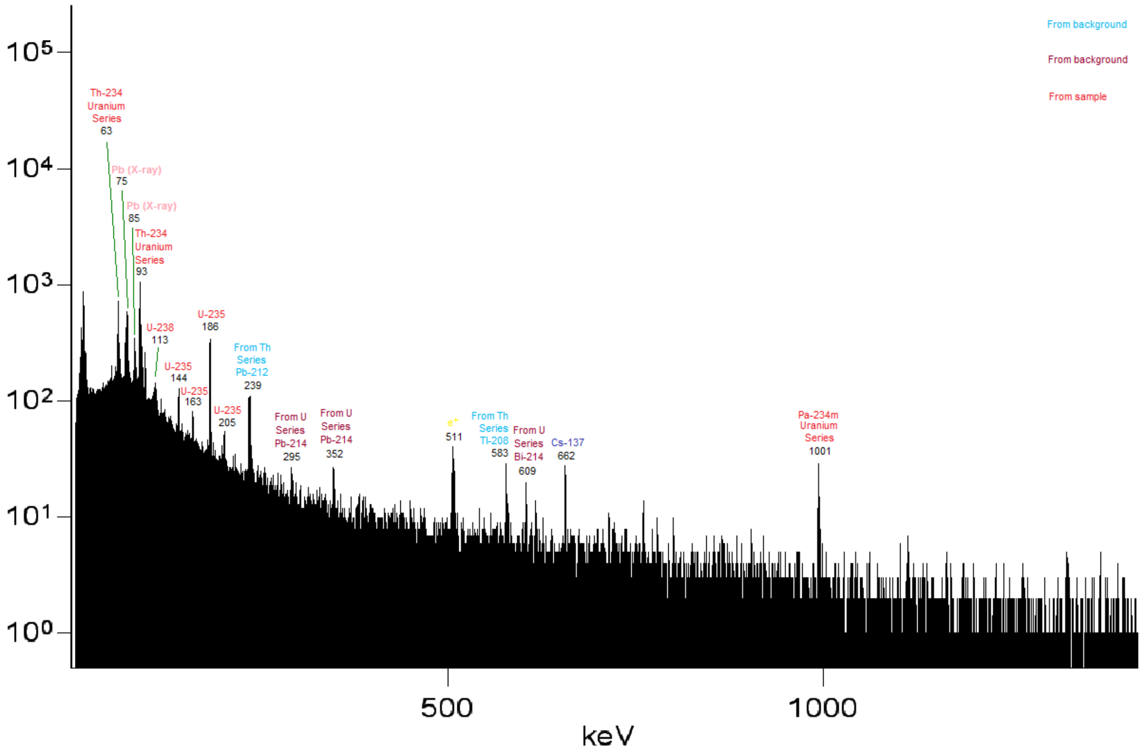
10 seconds Sample 3 measurement



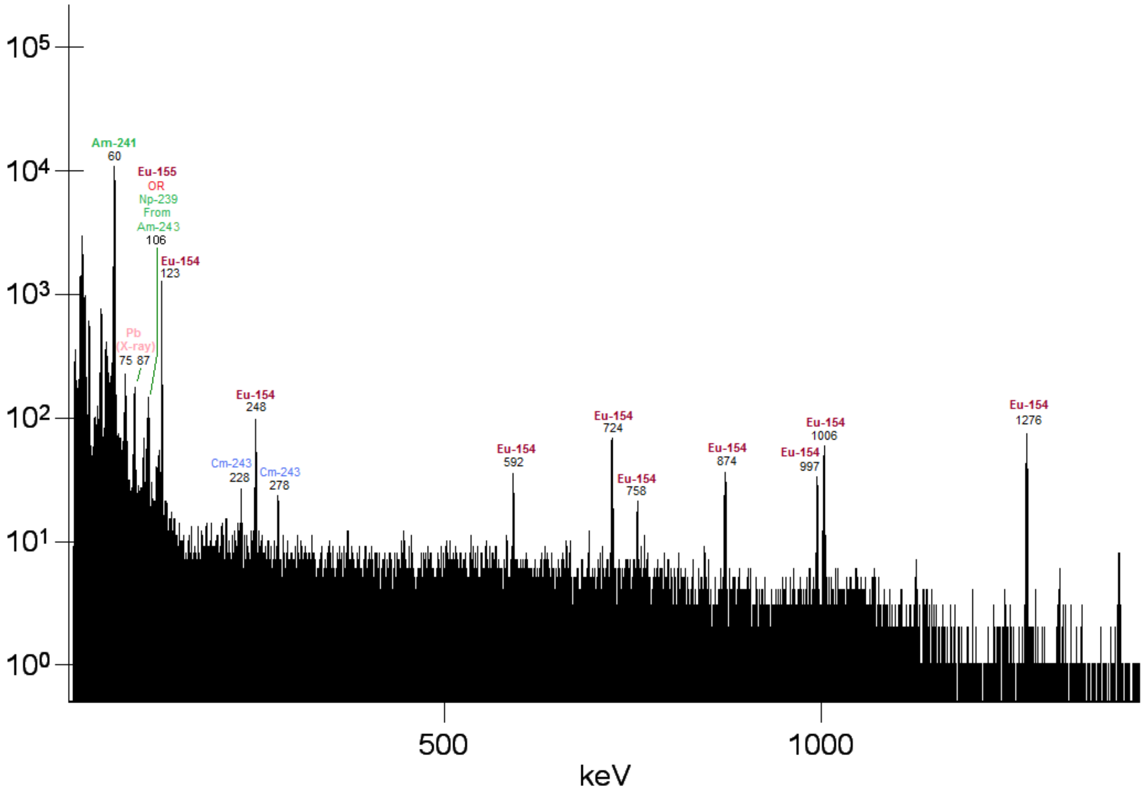
600 seconds Sample 3 measurement



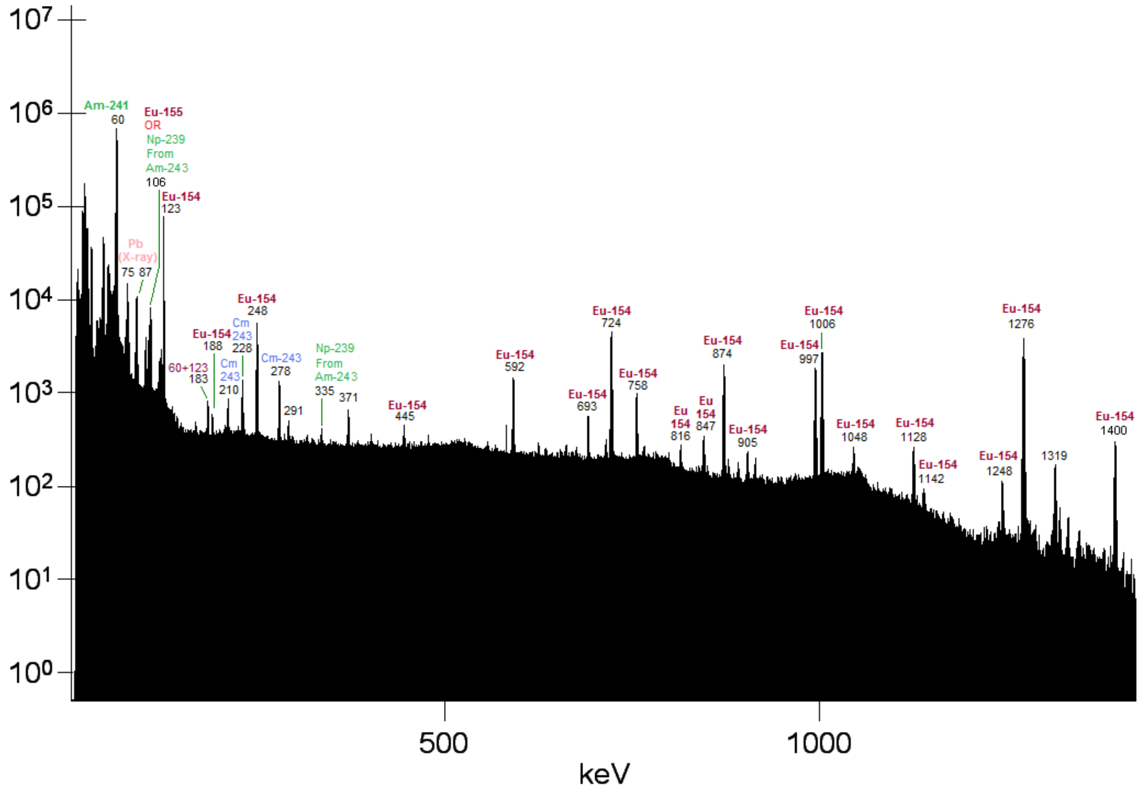
3600 seconds Sample 3 measurement



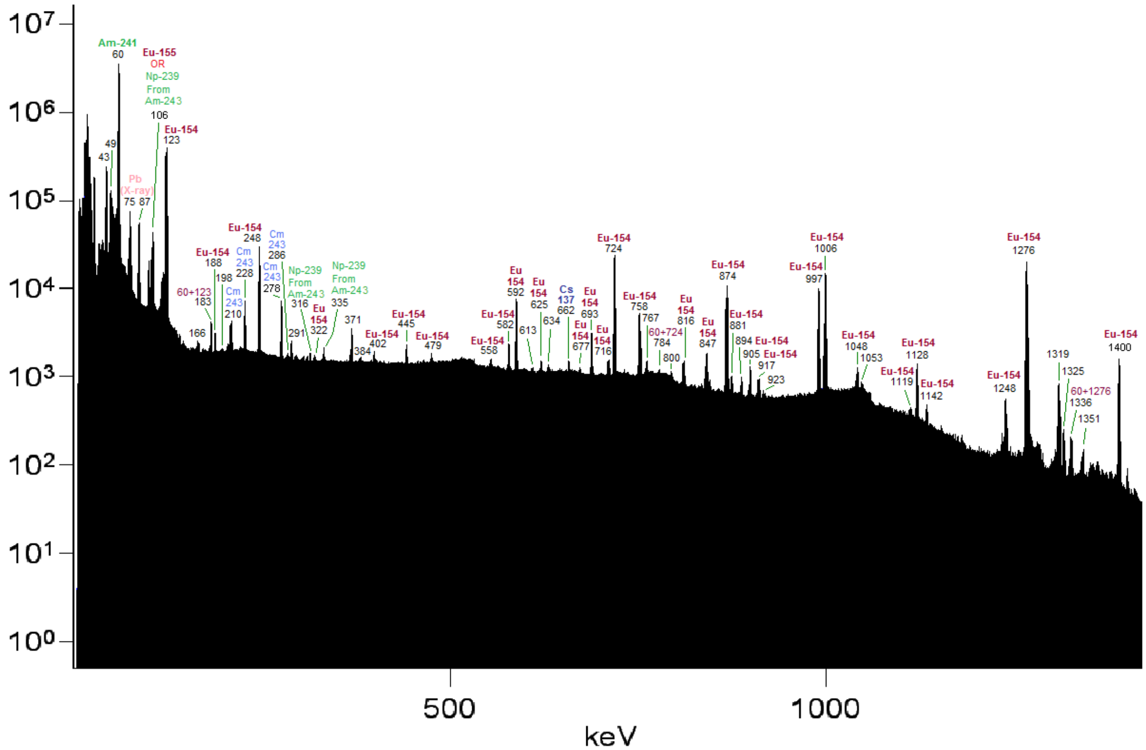
10 seconds Sample 4 measurement



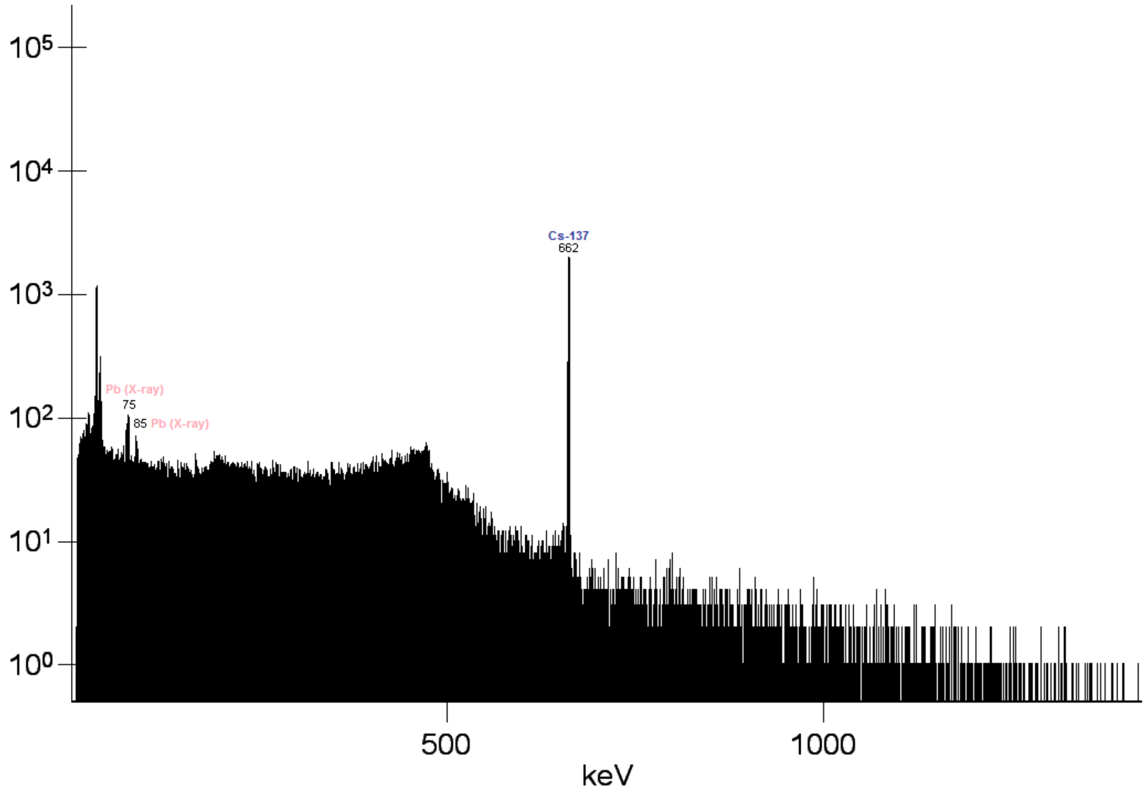
600 seconds Sample 4 measurement



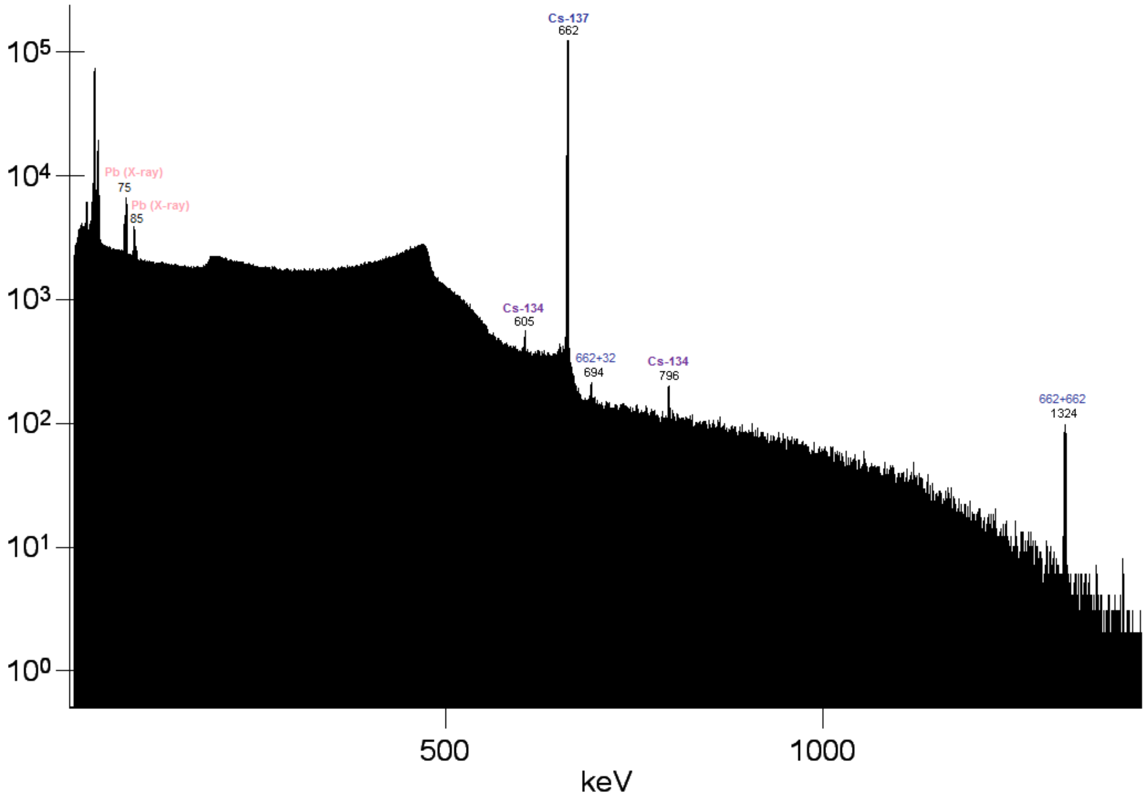
3600 seconds Sample 4 measurement



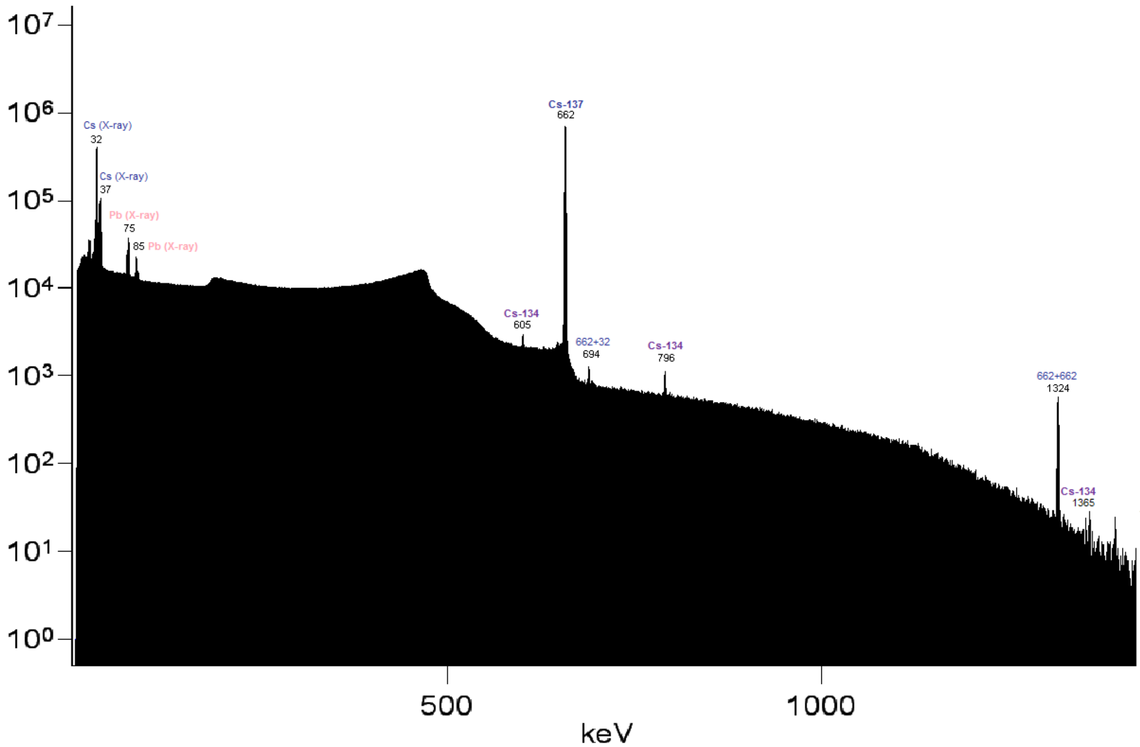
10 seconds Sample 5 measurement



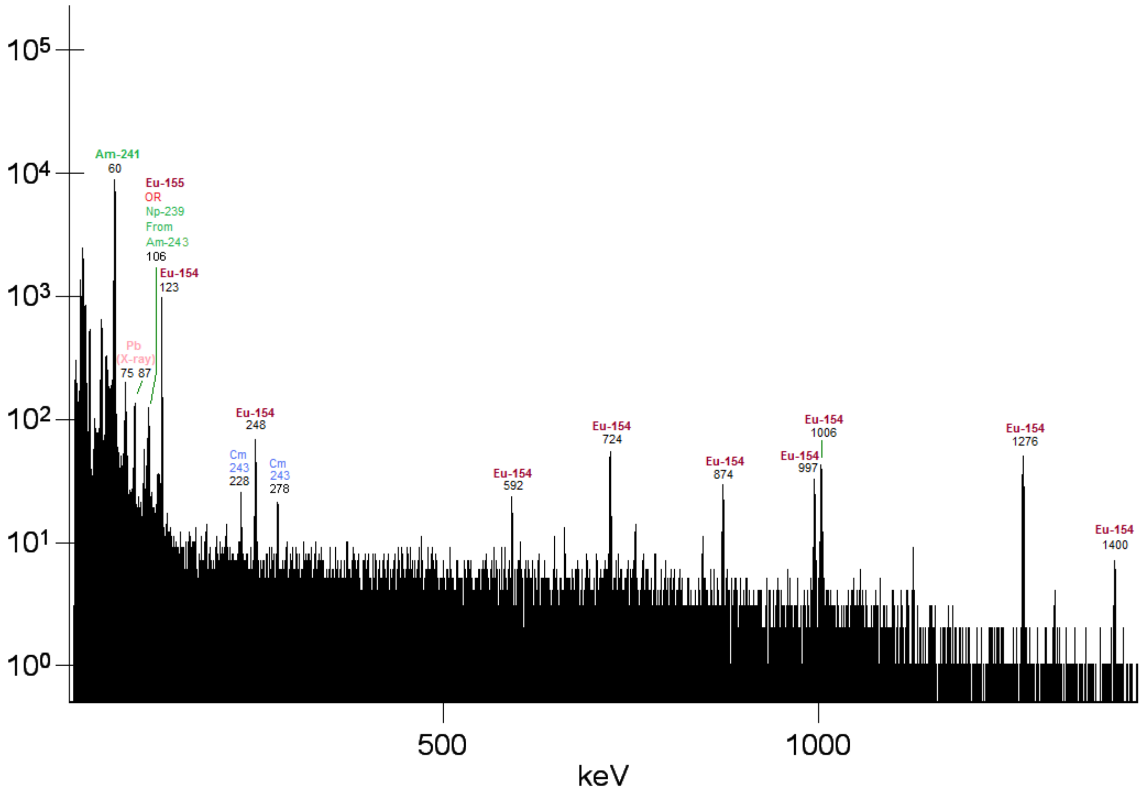
600 seconds Sample 5 measurement



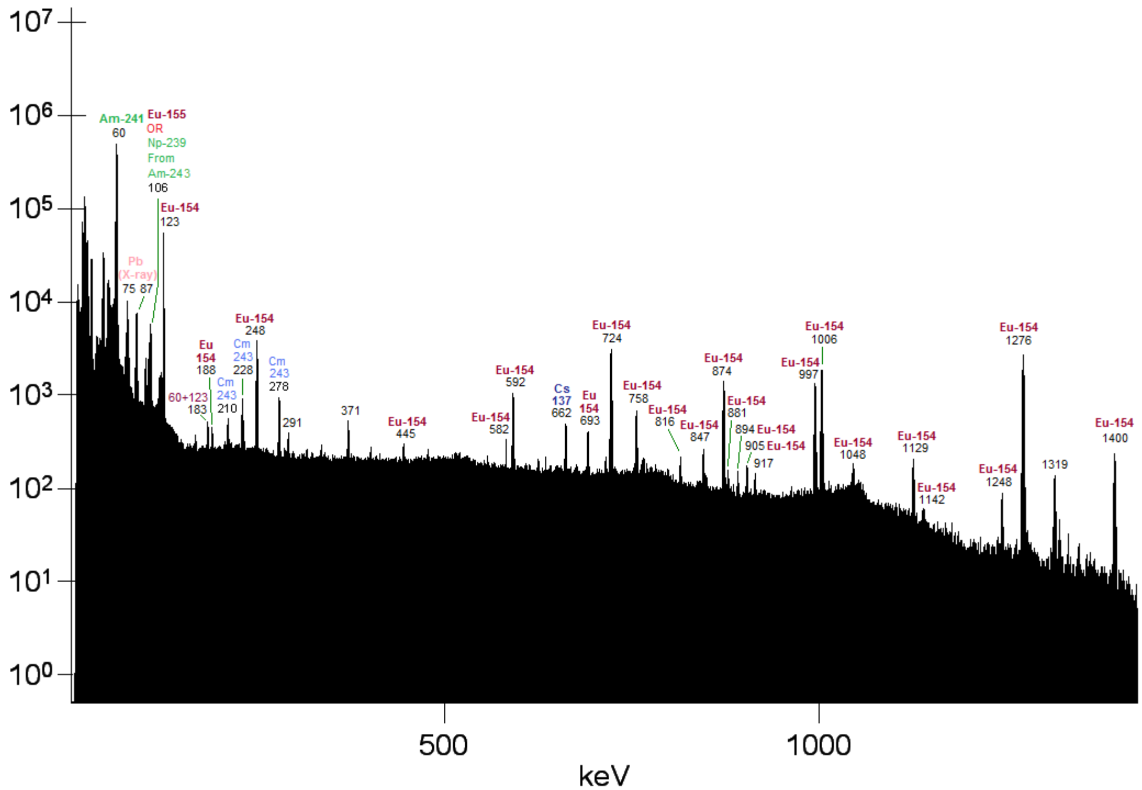
3600 seconds Sample 5 measurement



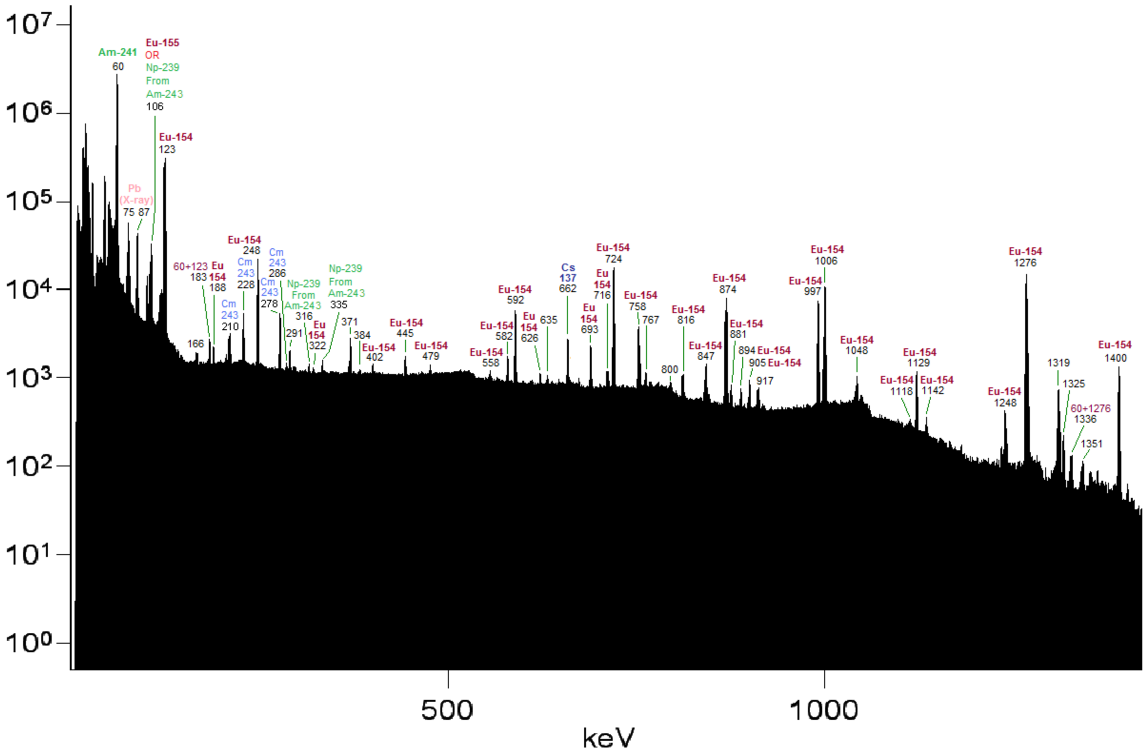
10 seconds Sample 6 measurement



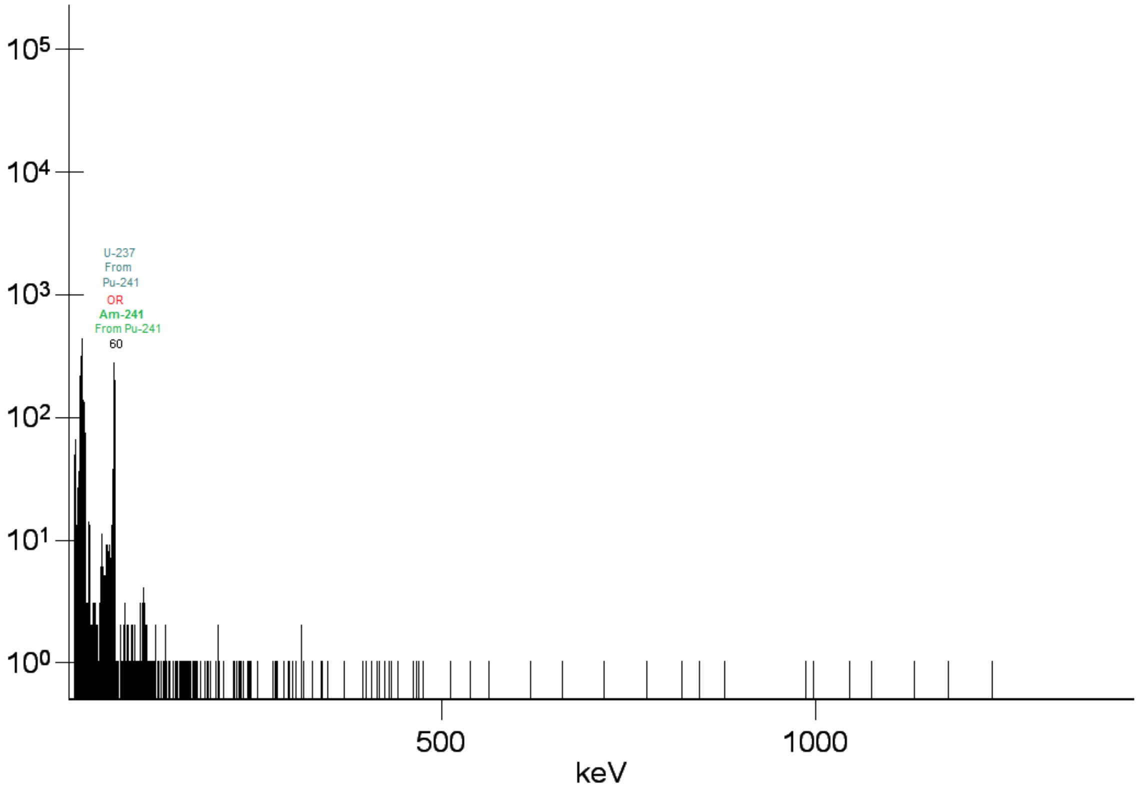
600 seconds Sample 6 measurement



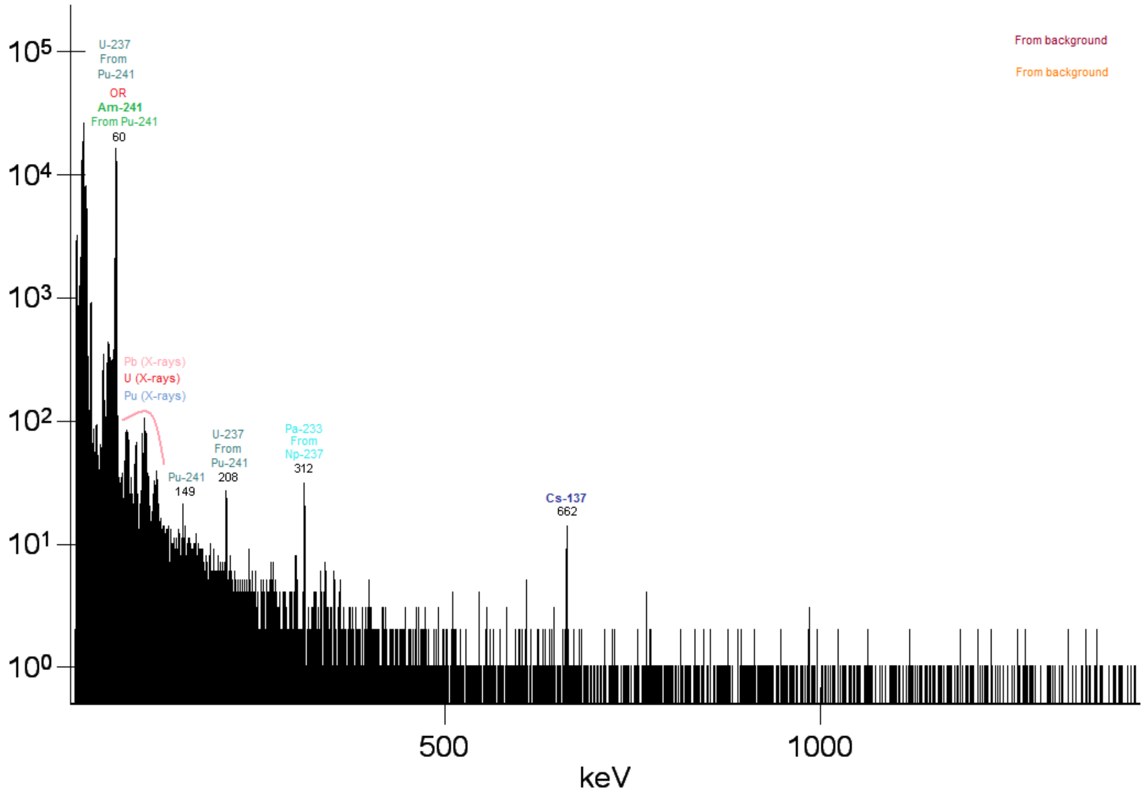
3600 seconds Sample 6 measurement



10 seconds Sample 7 measurement



600 seconds Sample 7 measurement



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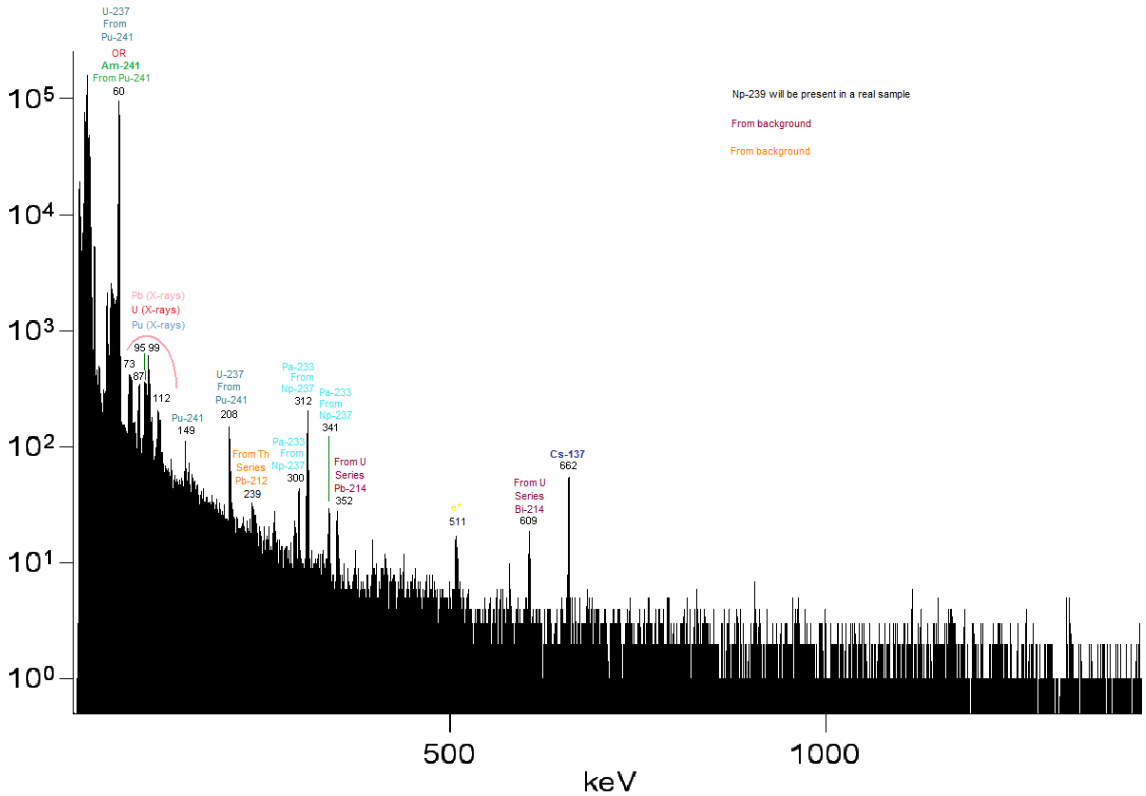
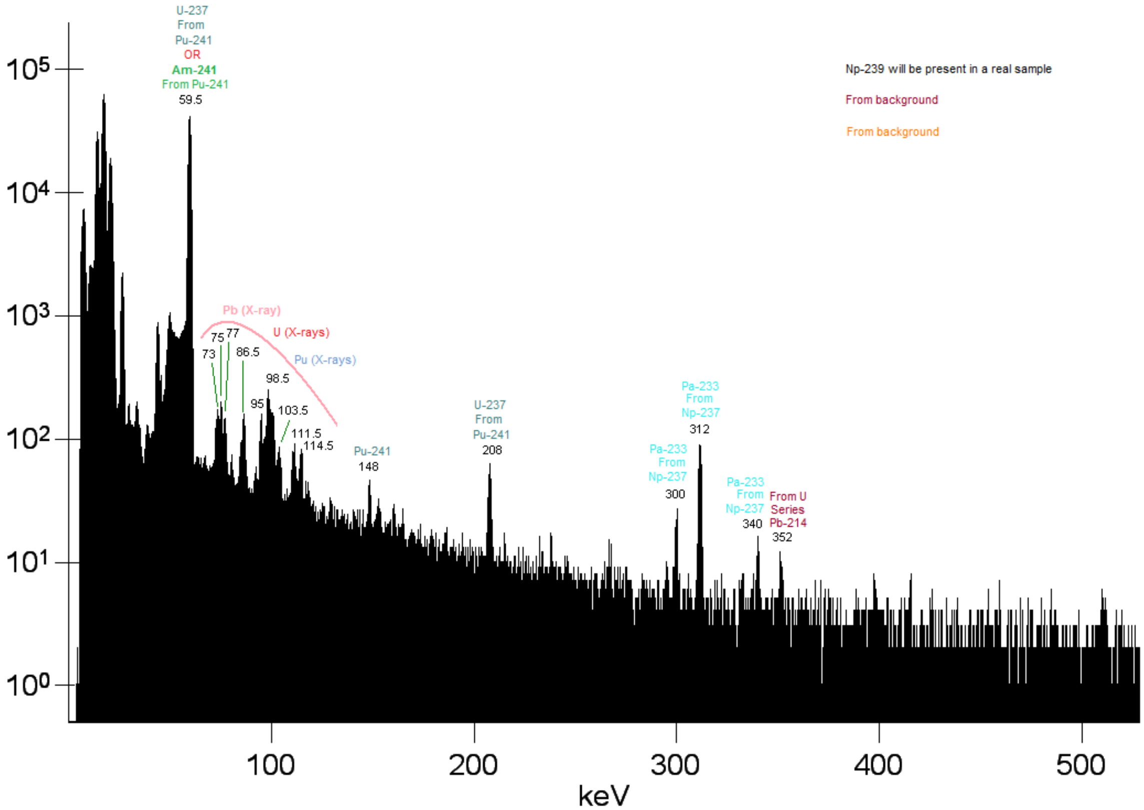
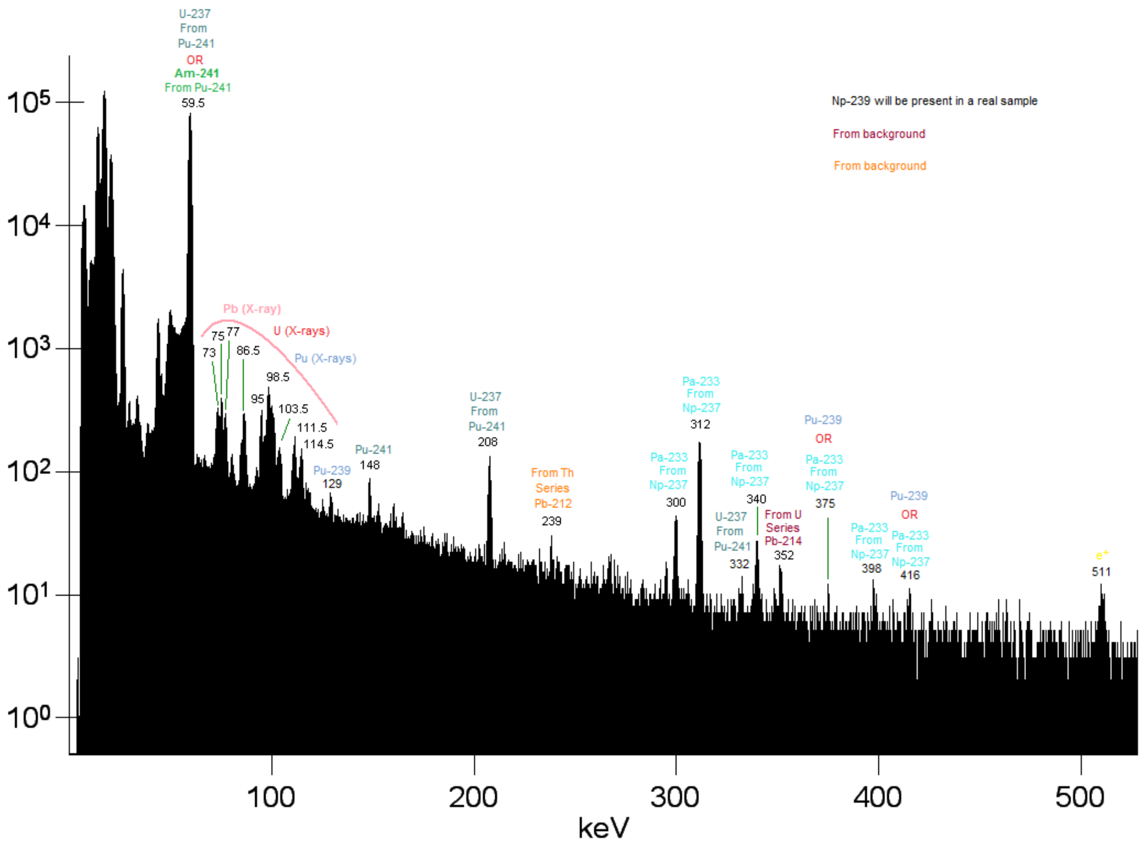


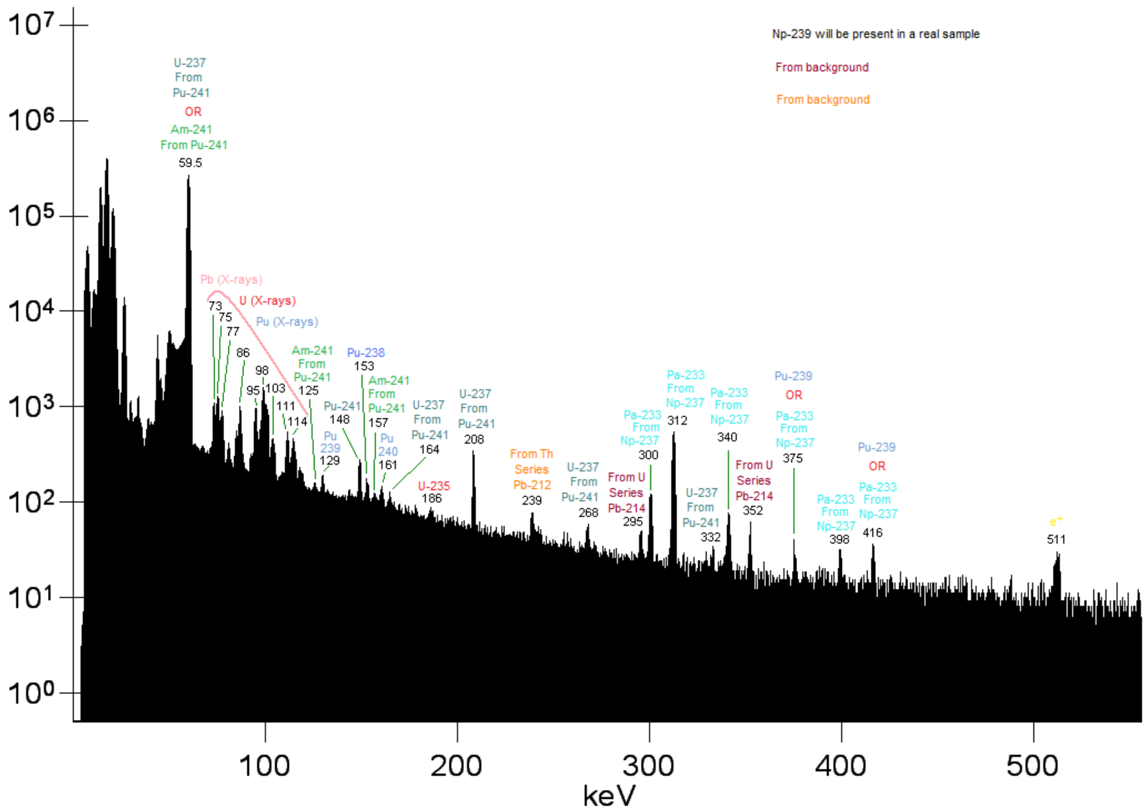
3600 seconds Sample 7 measurement with a smaller energy window



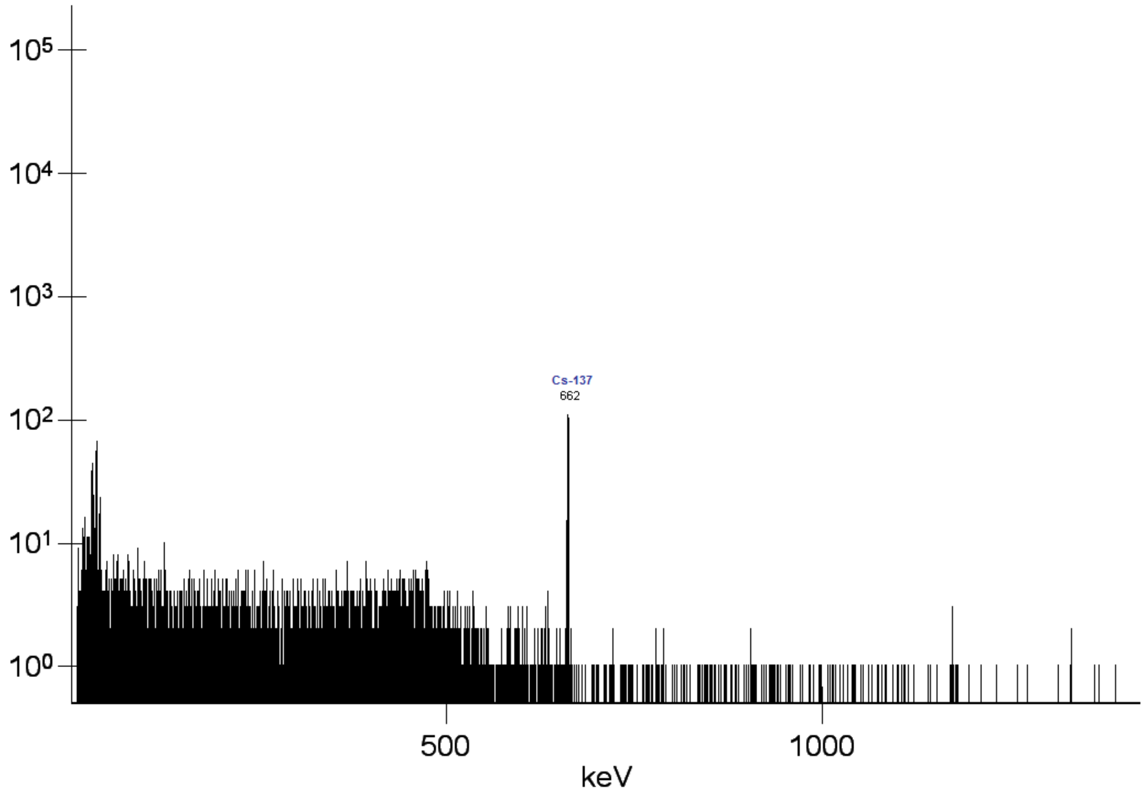
7200 seconds Sample 7 measurement with a smaller energy window



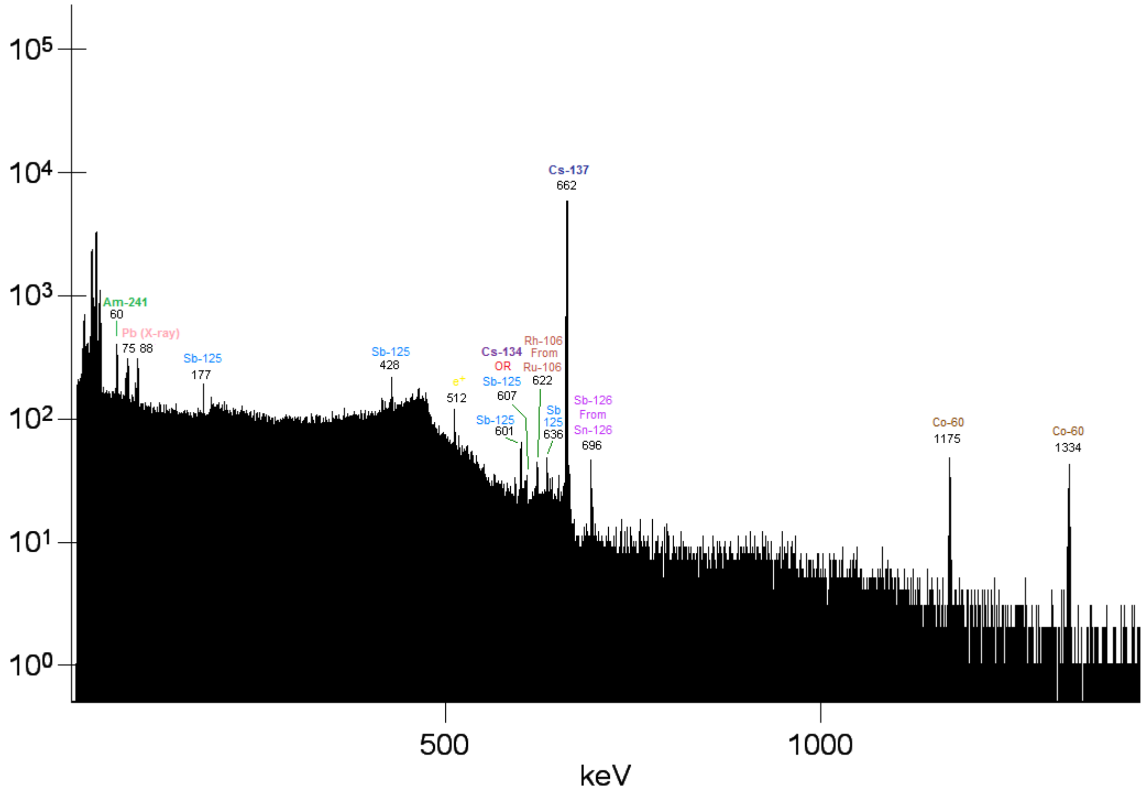
21600 seconds Sample 7 measurement with a smaller energy window



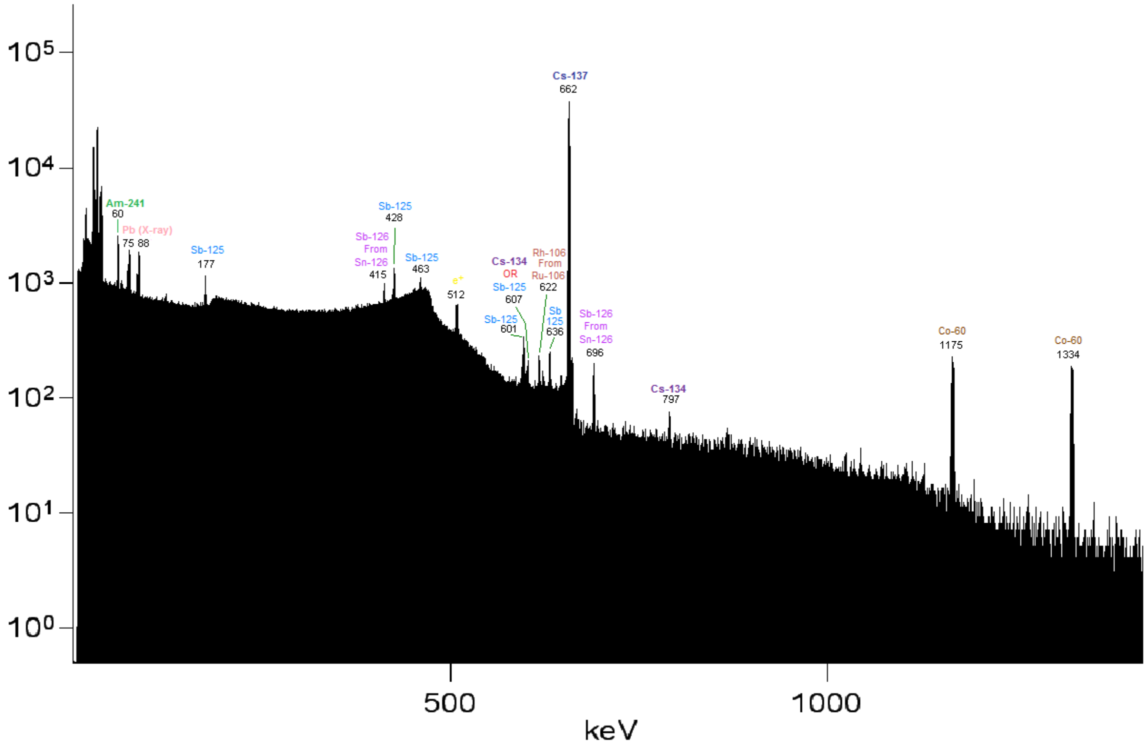
10 seconds Sample 8 measurement



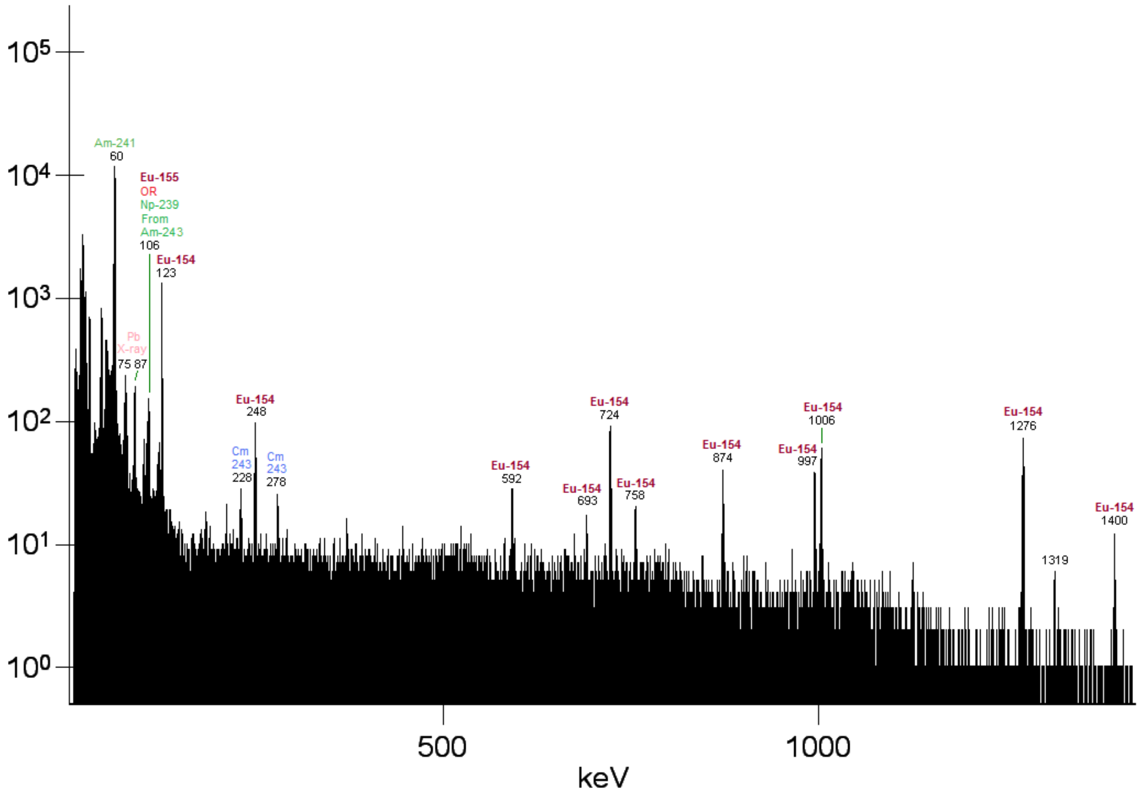
600 seconds Sample 8 measurement



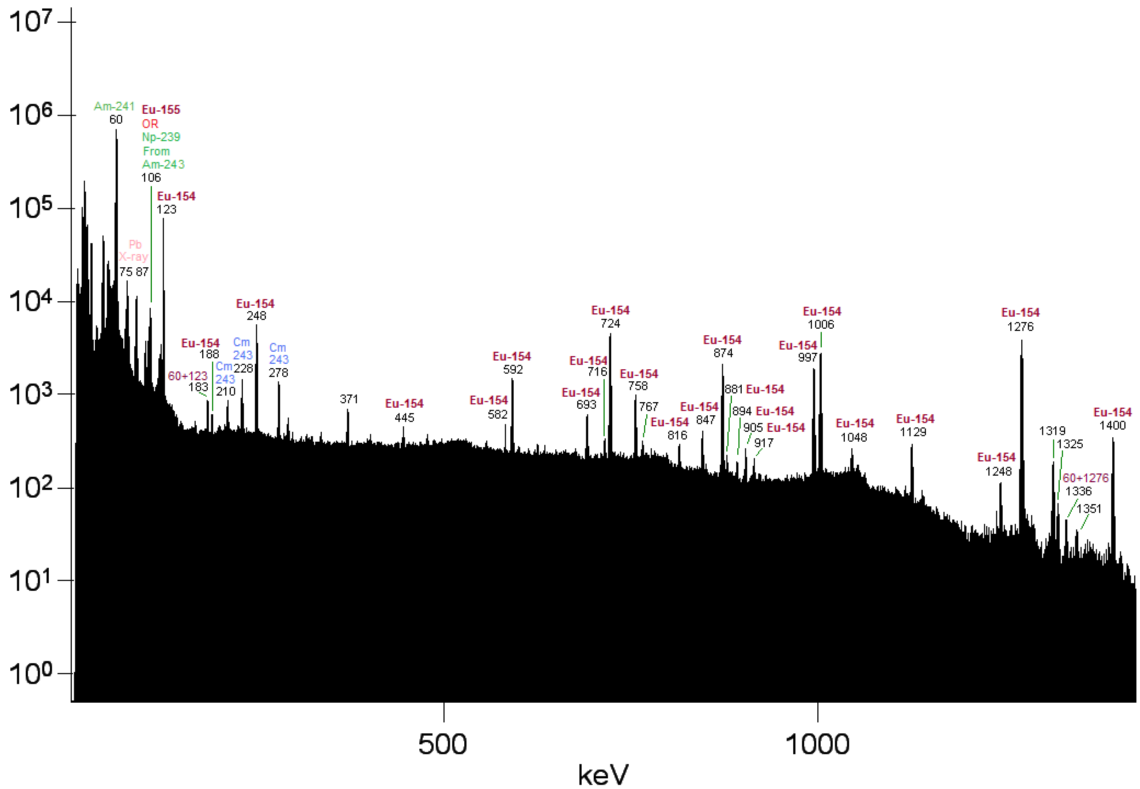
3600 seconds Sample 8 measurement



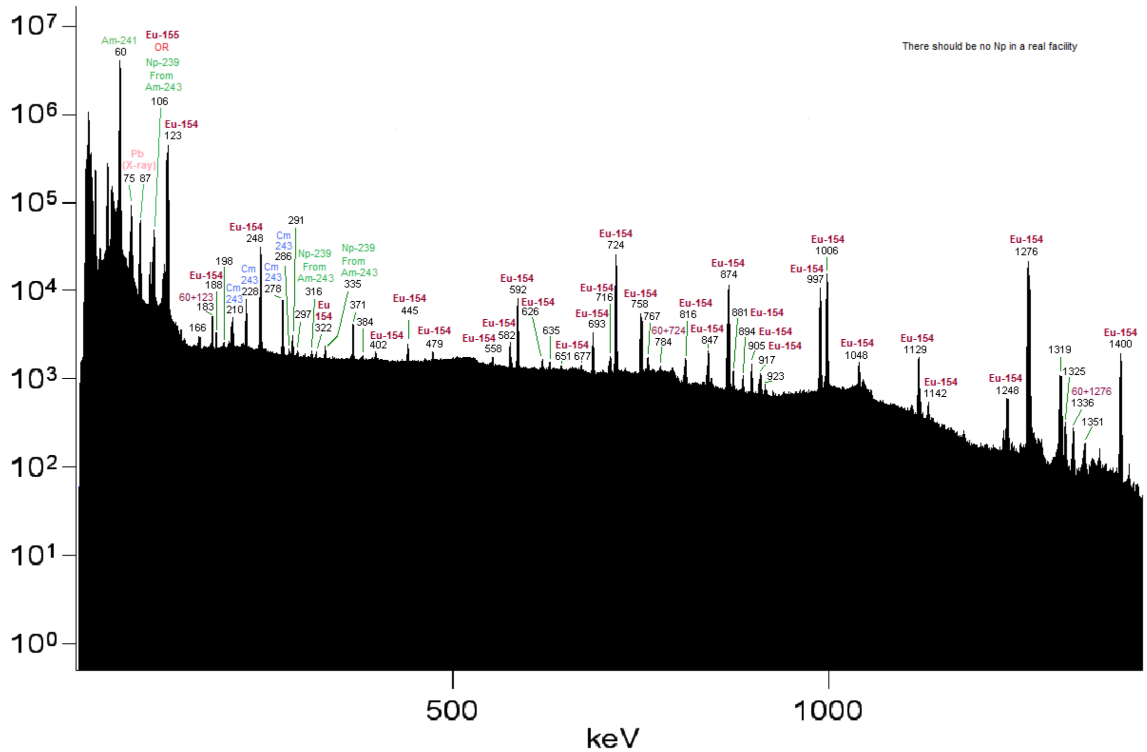
10 seconds Sample 9 measurement



600 seconds Sample 9 measurement



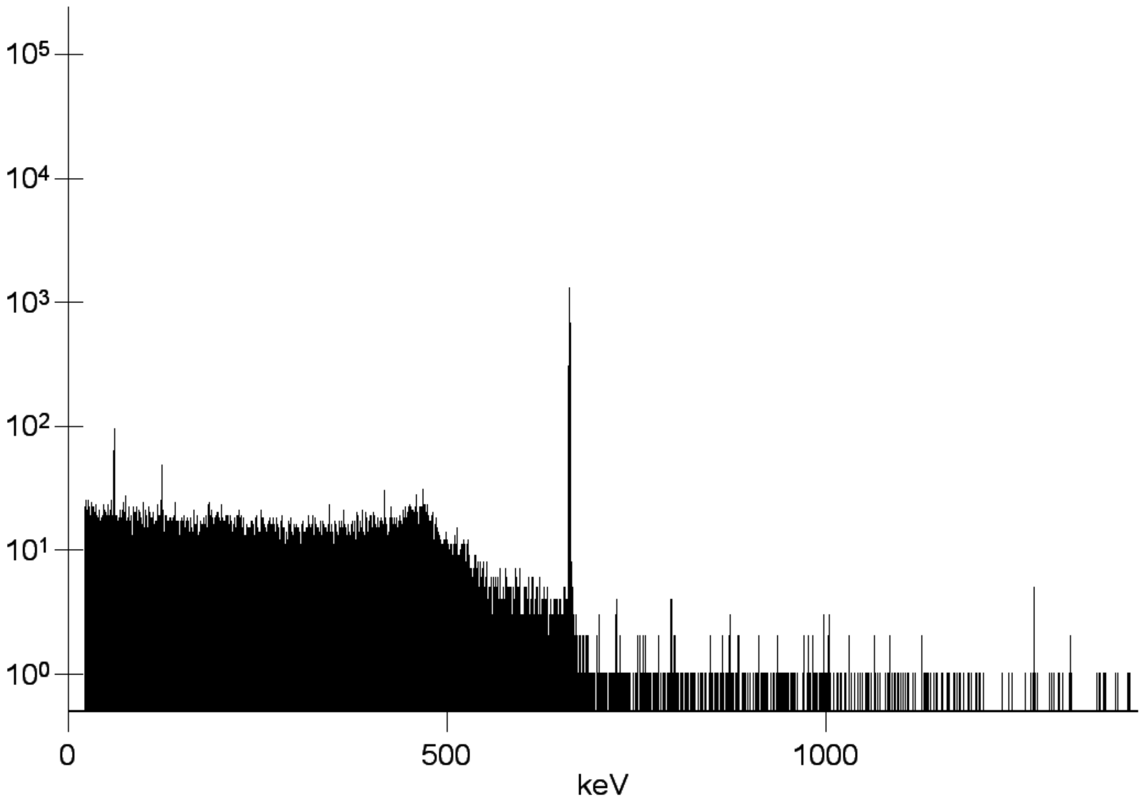
3600 seconds Sample 9 measurement



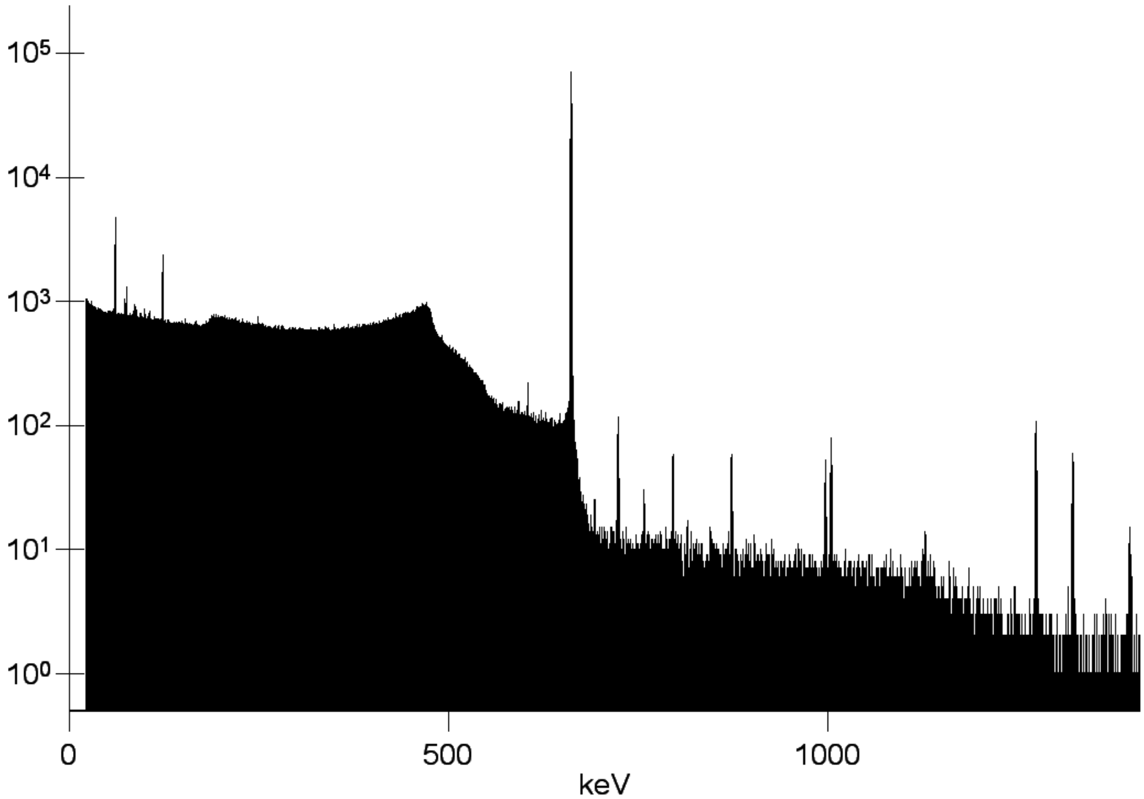
APPENDIX B

HPGe P-type gamma ray spectra. Units of the ordinate are in counts.

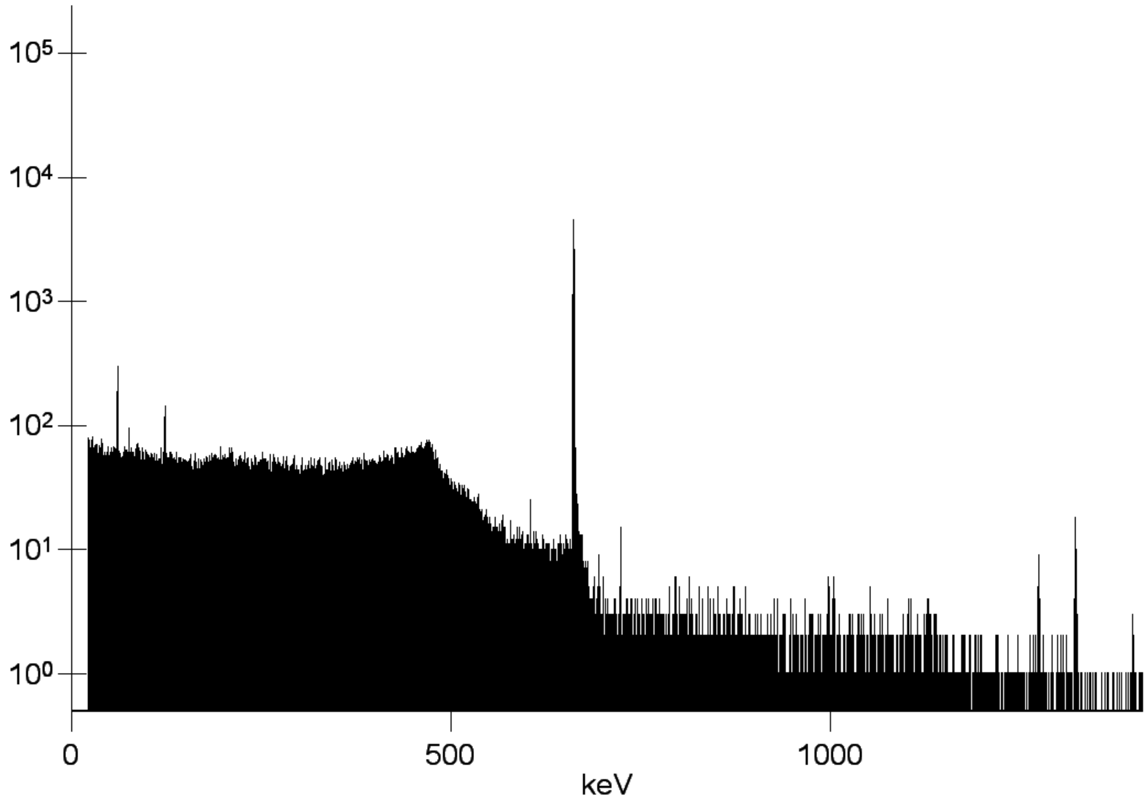
10 seconds Sample 1 measurement



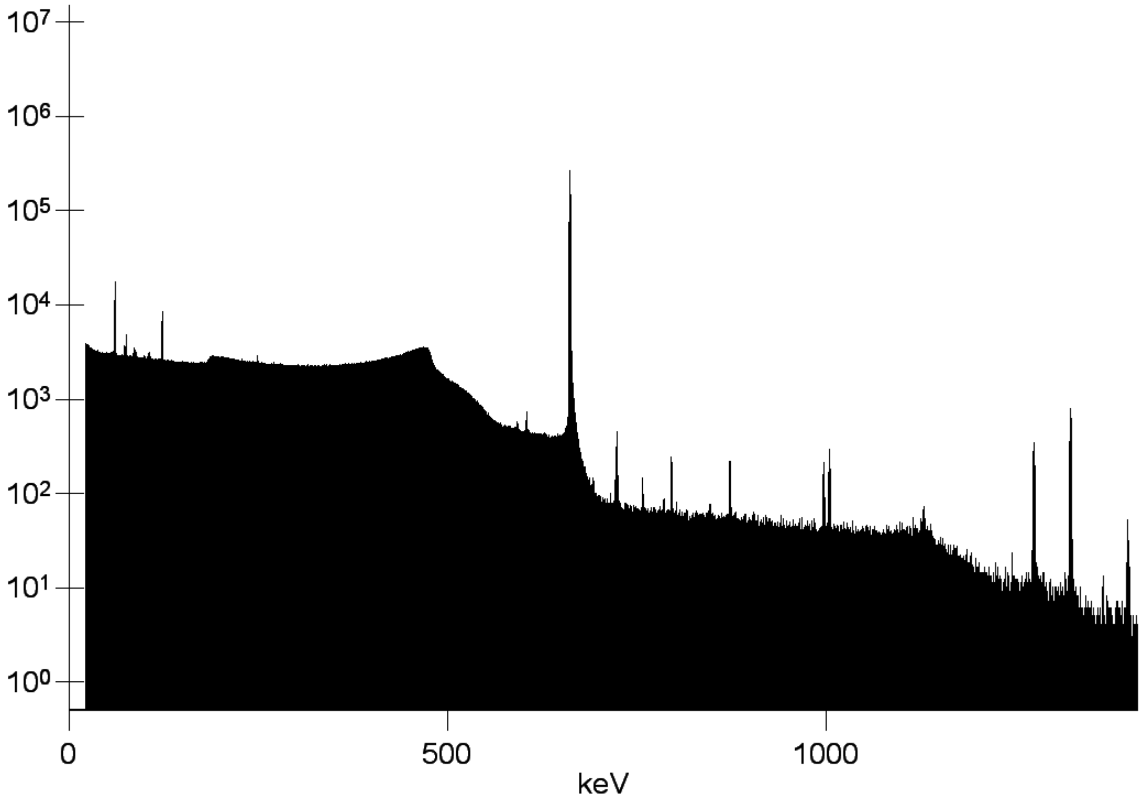
600 seconds Sample 1 measurement



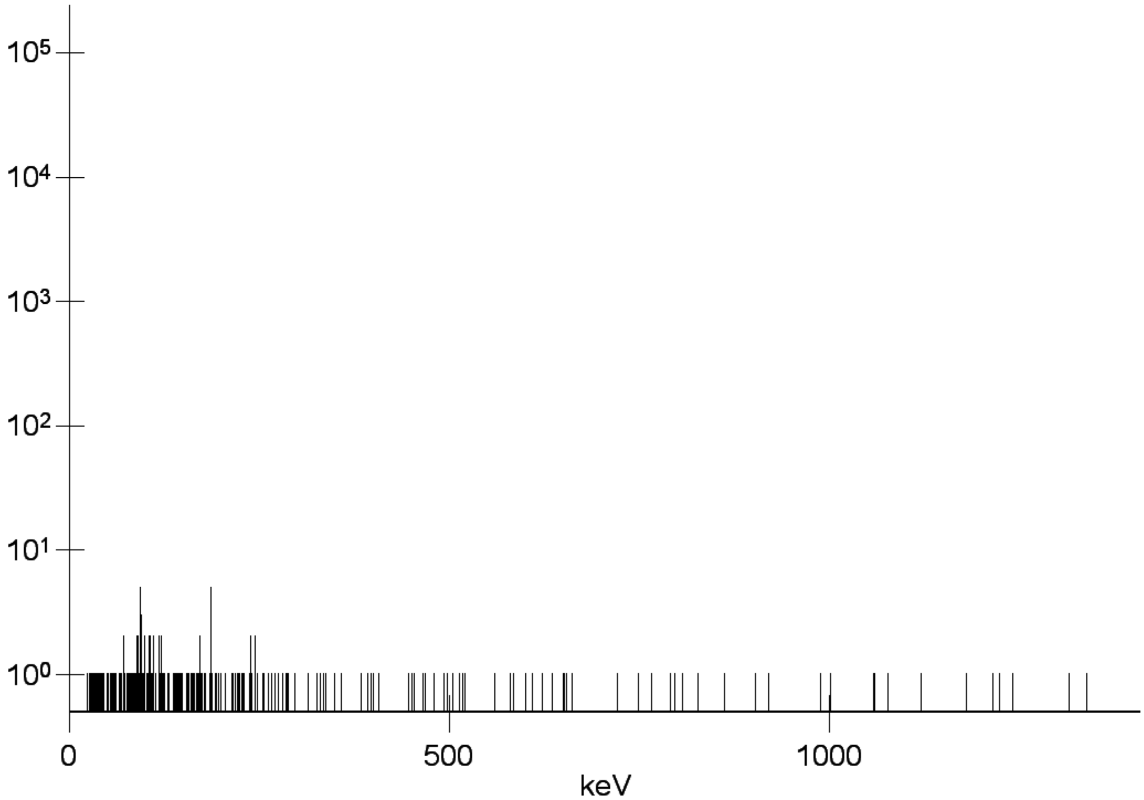
10 seconds Sample 2 measurement



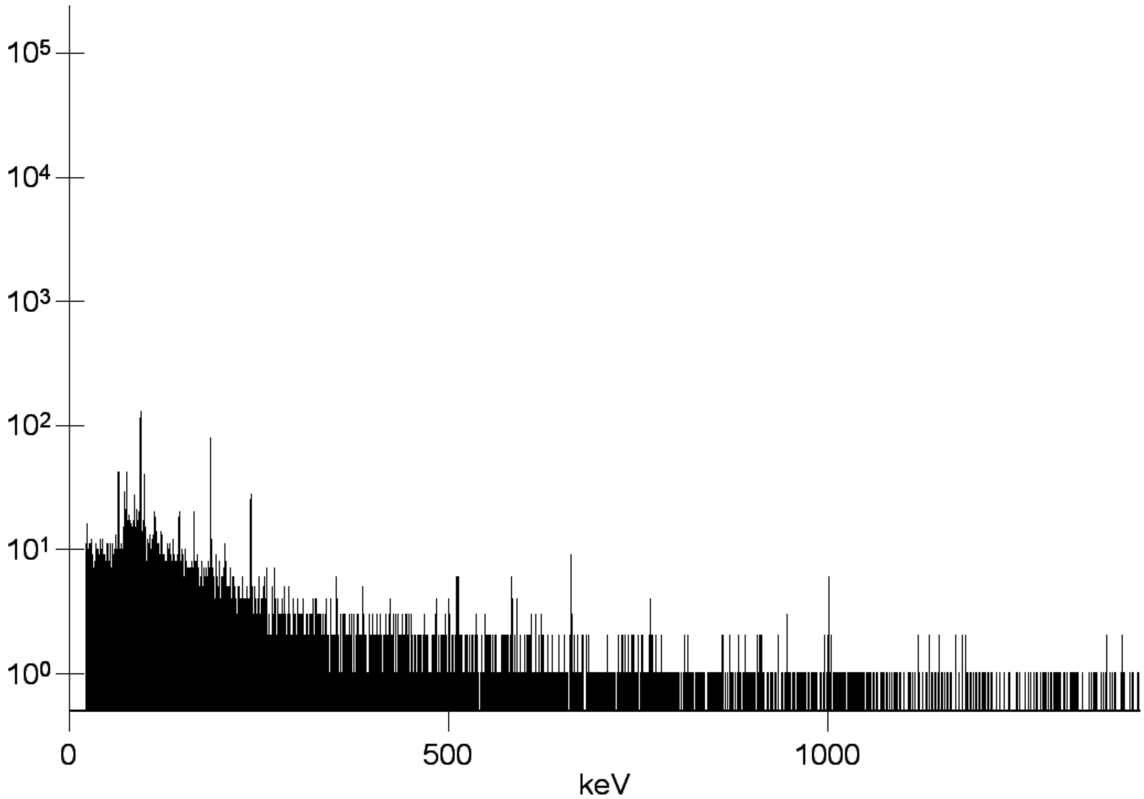
600 seconds Sample 2 measurement



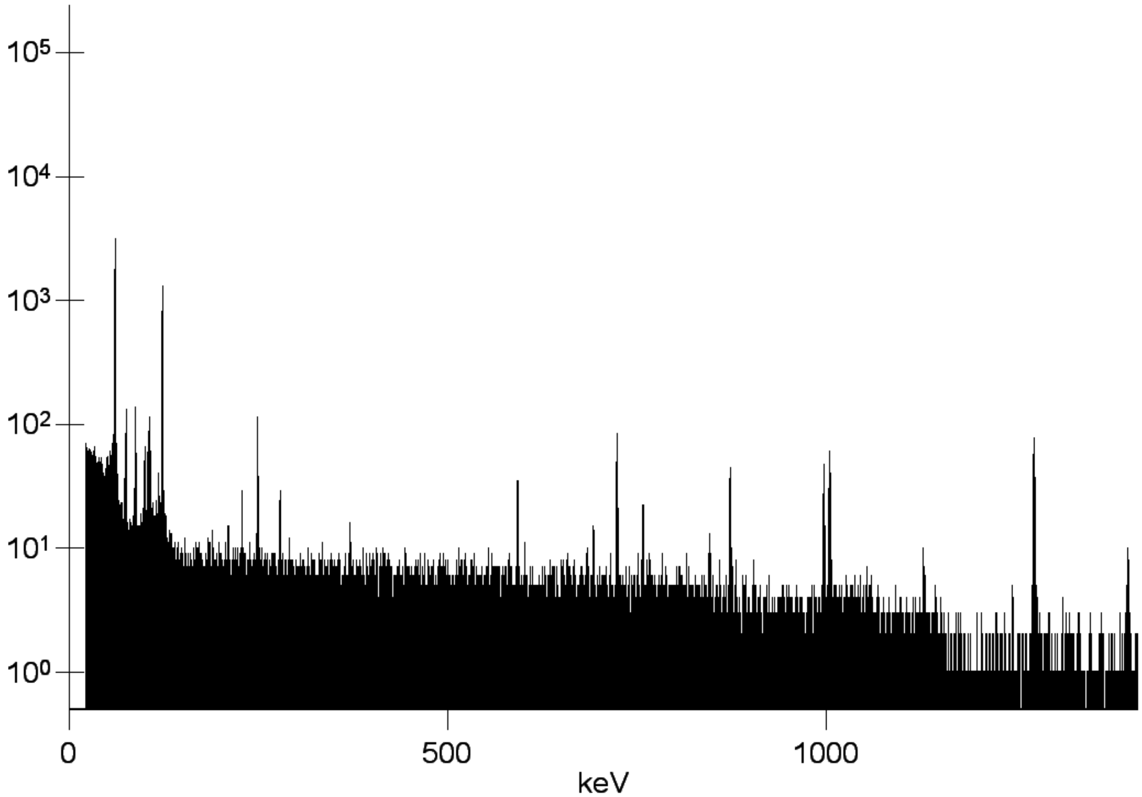
10 seconds Sample 3 measurement



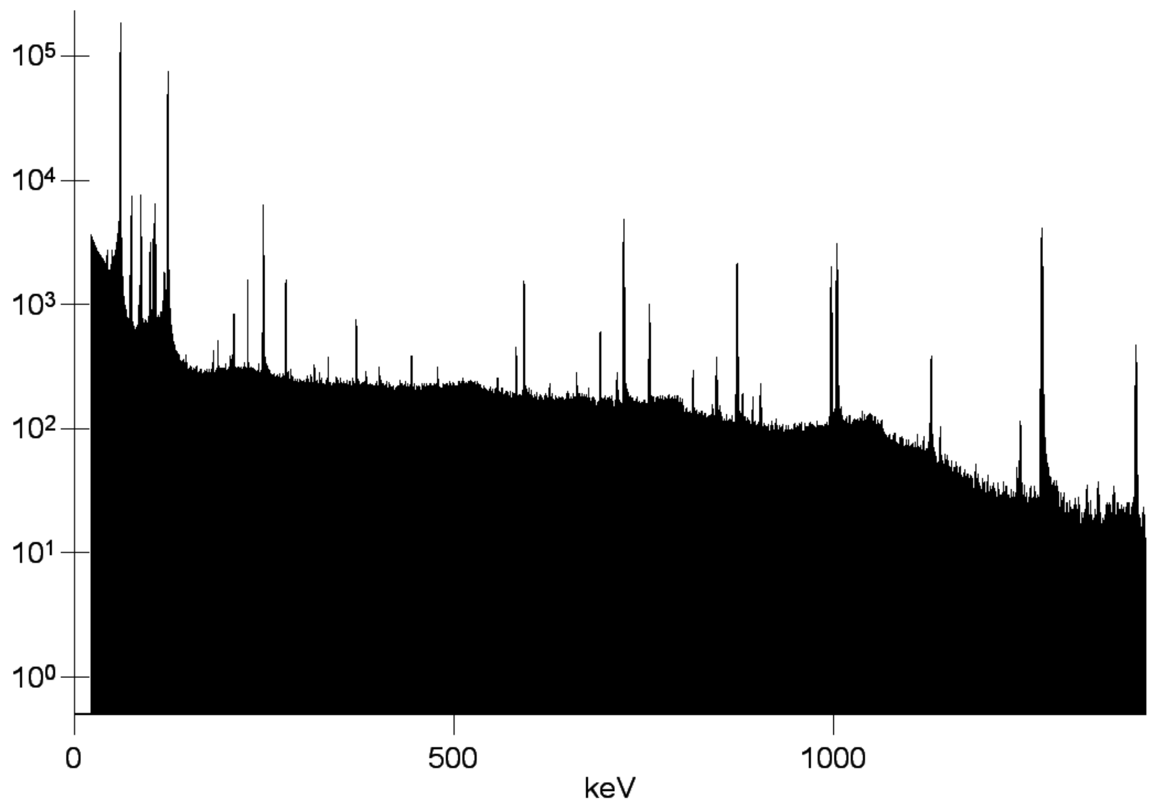
600 seconds Sample 3 measurement



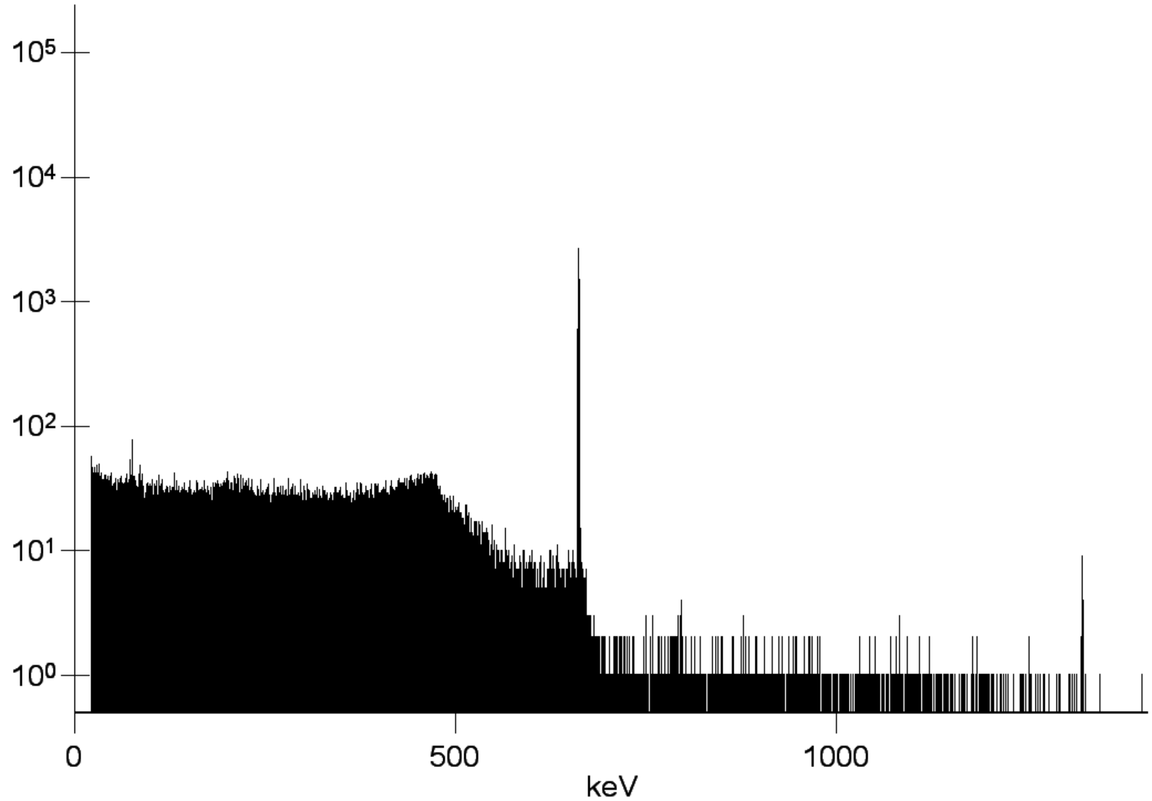
10 seconds Sample 4 measurement



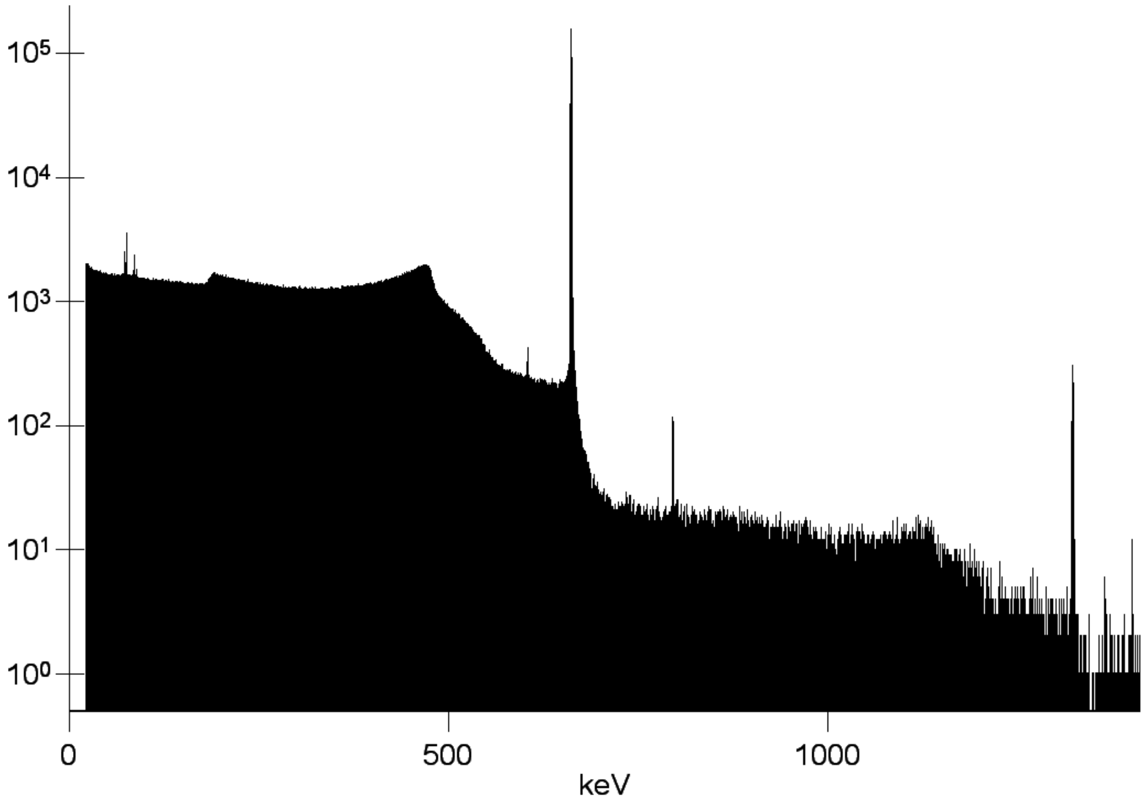
600 seconds Sample 4 measurement



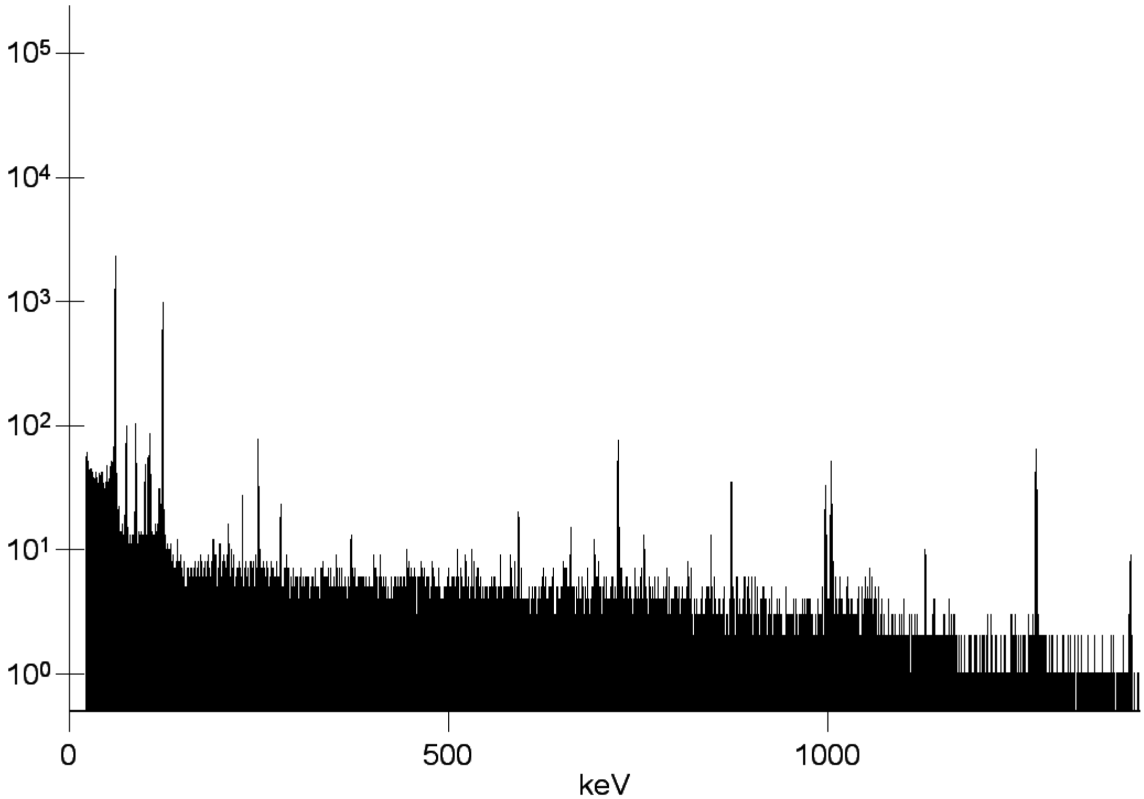
10 seconds Sample 5 measurement



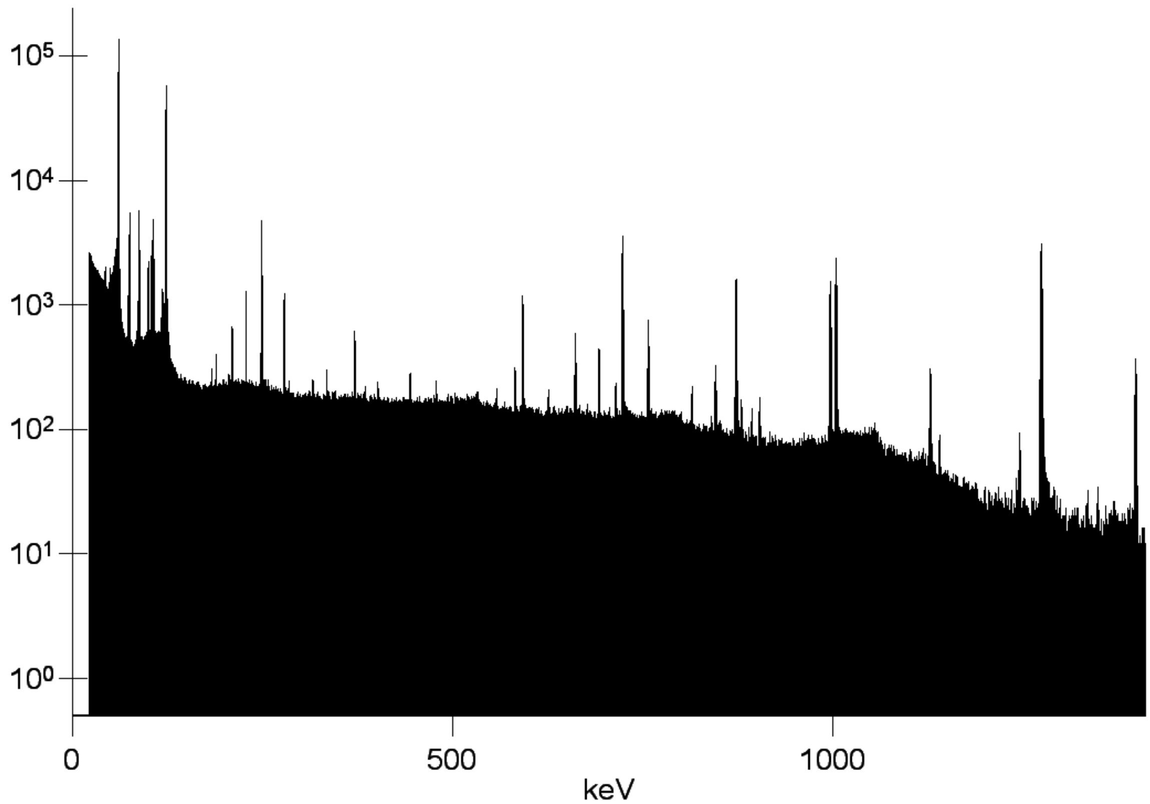
600 seconds Sample 5 measurement



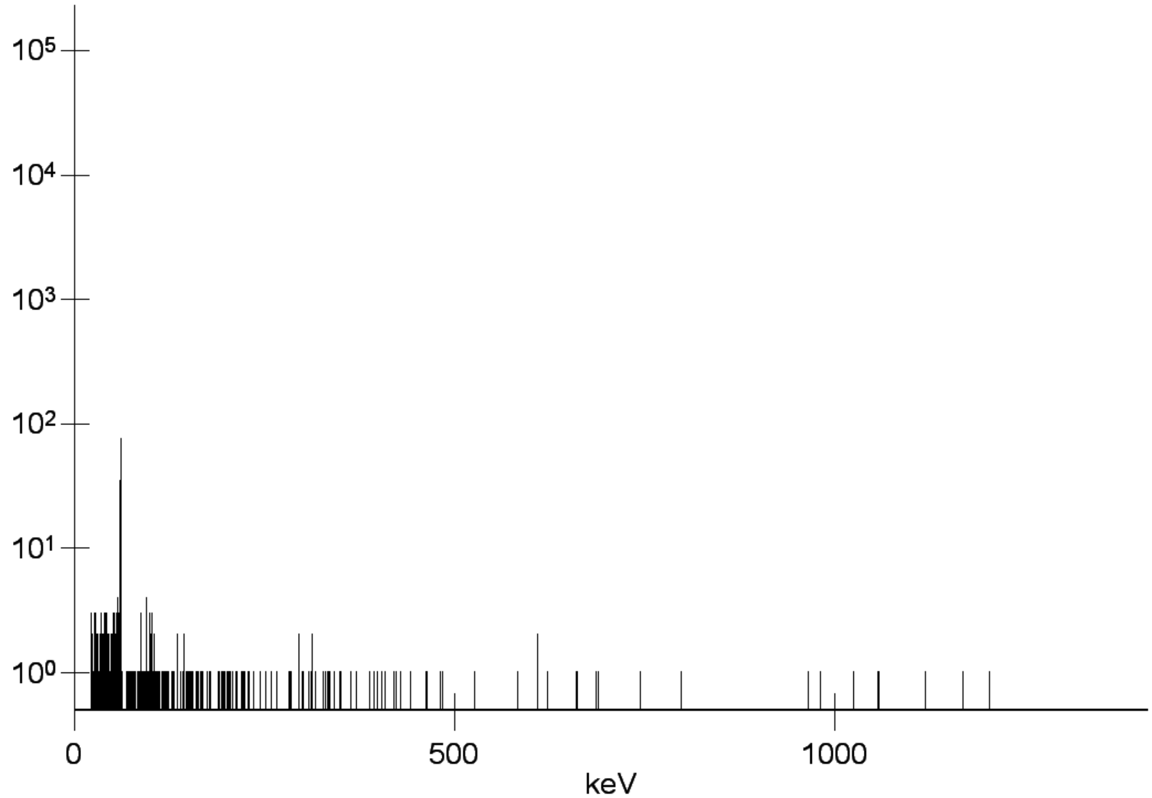
10 seconds Sample 6 measurement



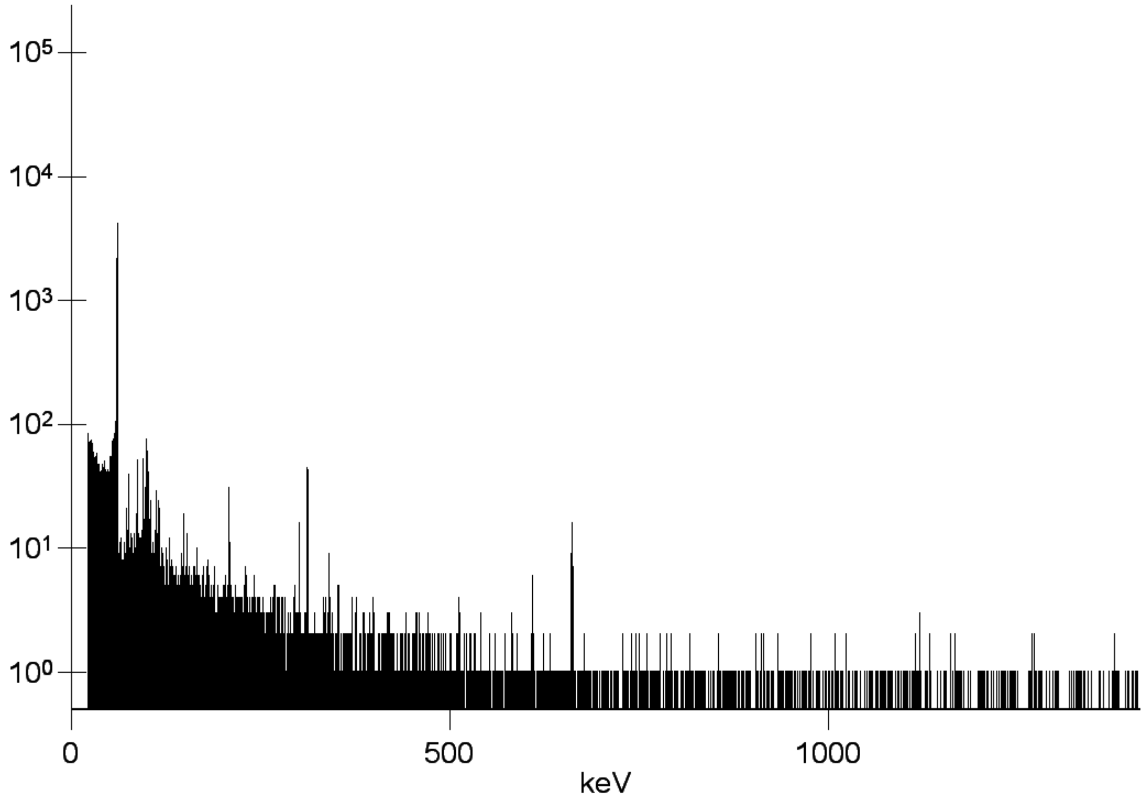
600 seconds Sample 6 measurement



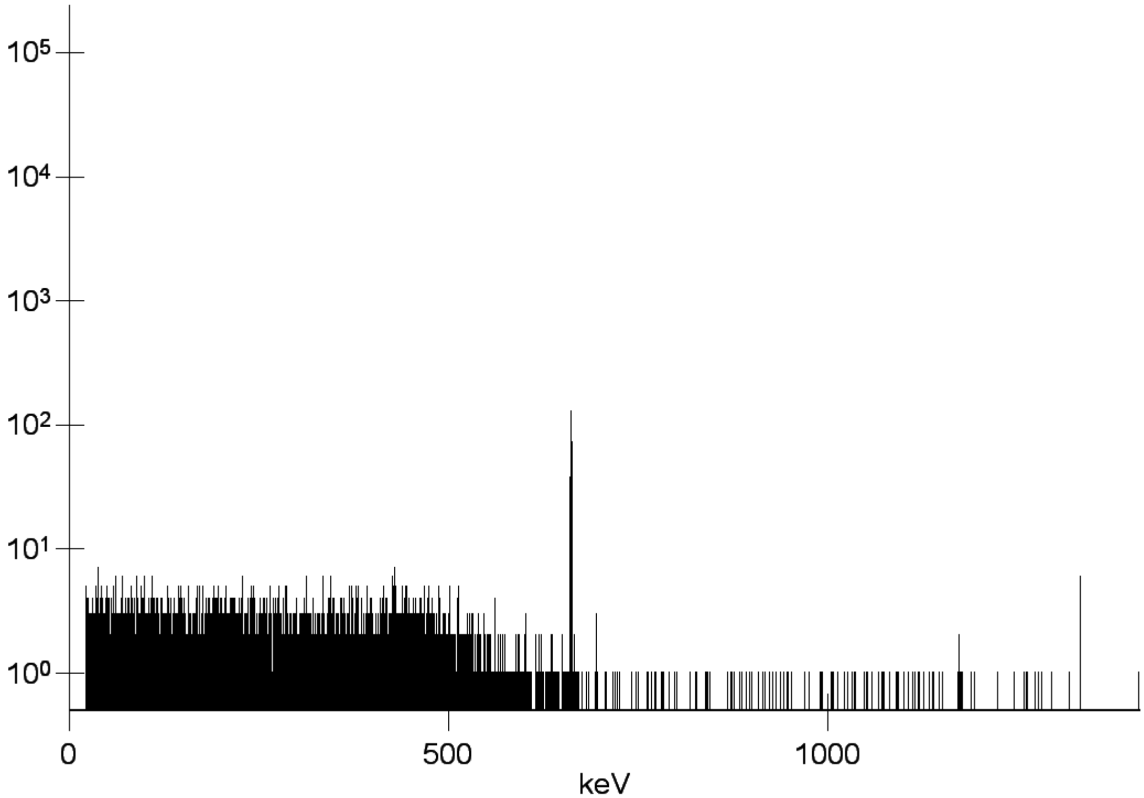
10 seconds Sample 7 measurement



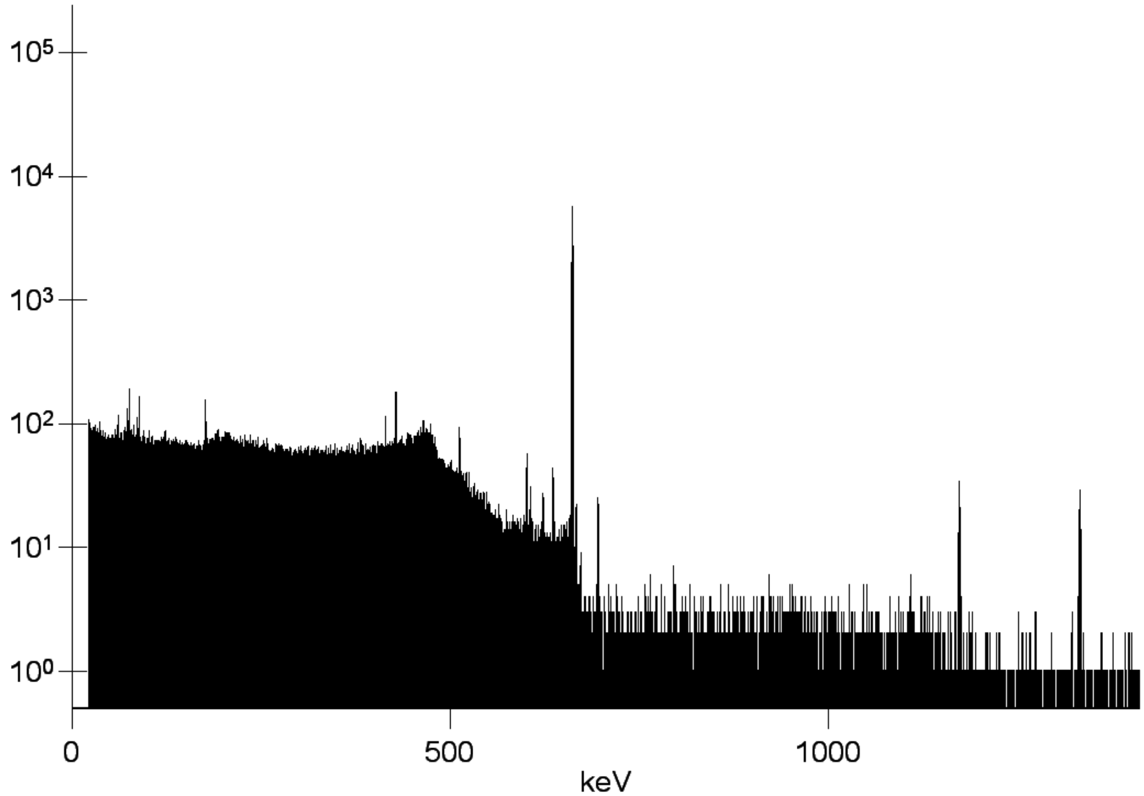
600 seconds Sample 7 measurement



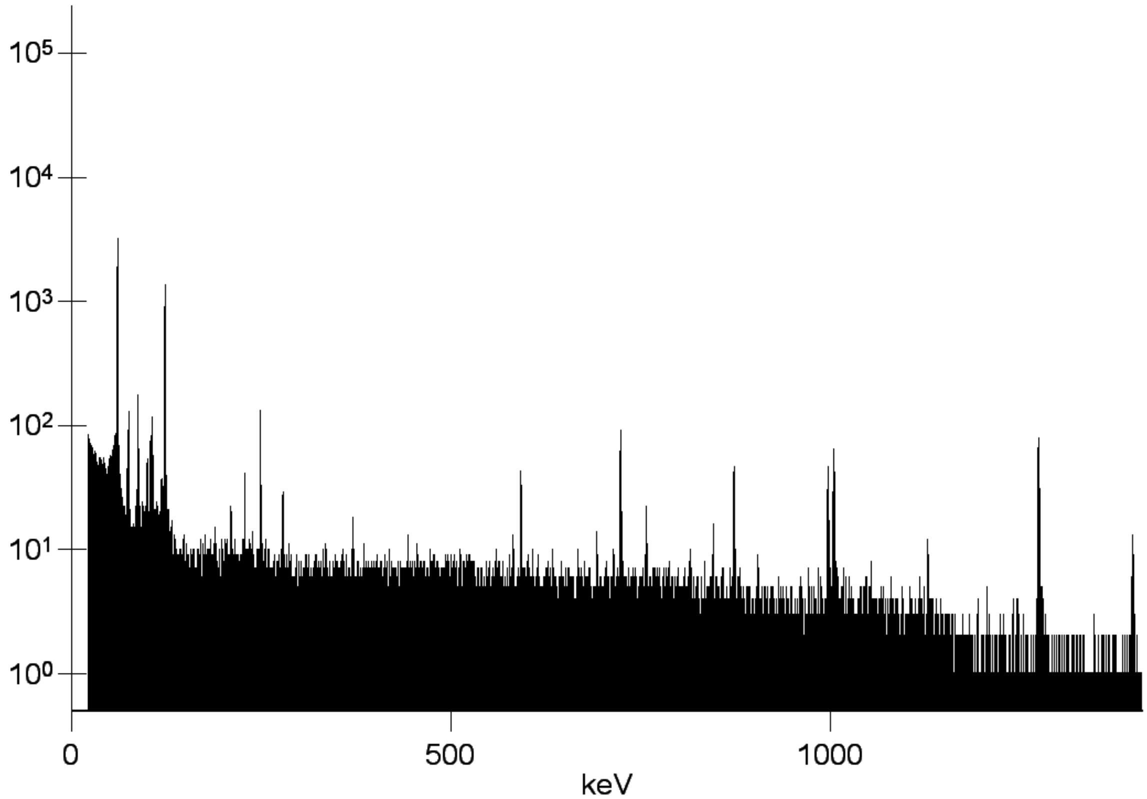
10 seconds Sample 8 measurement



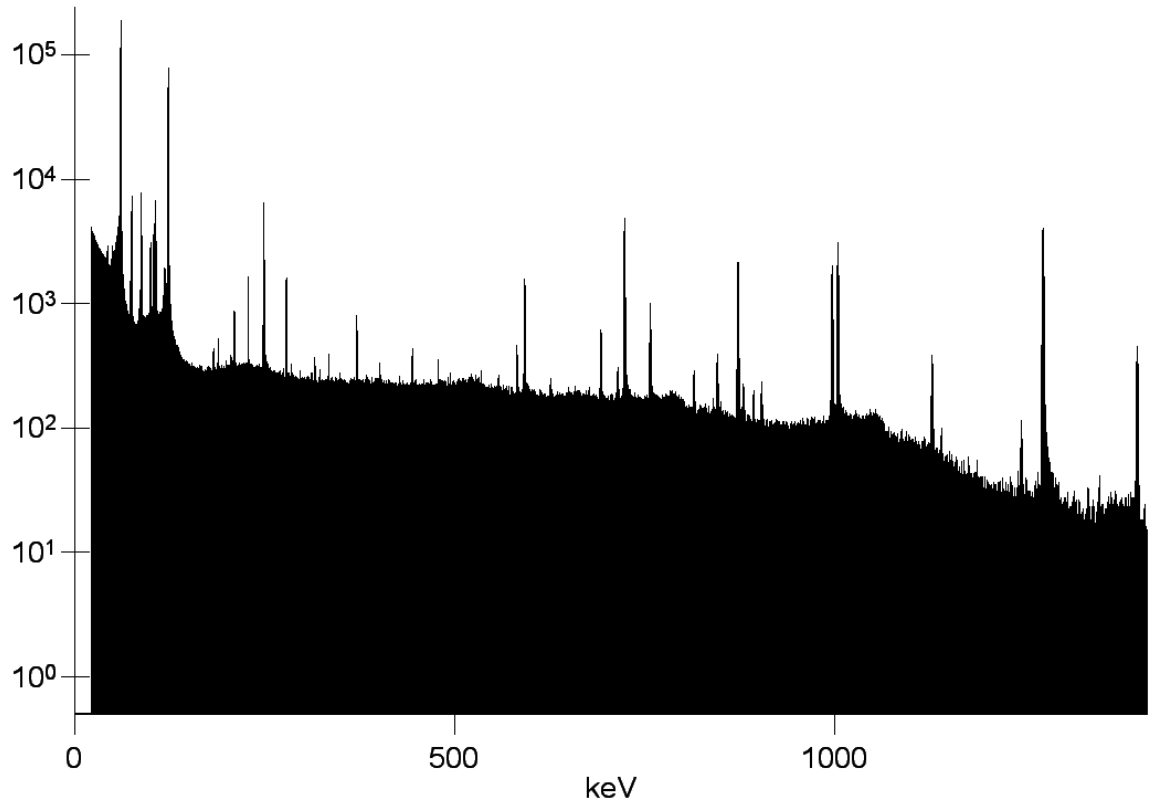
600 seconds Sample 8 measurement



10 seconds Sample 9 measurement



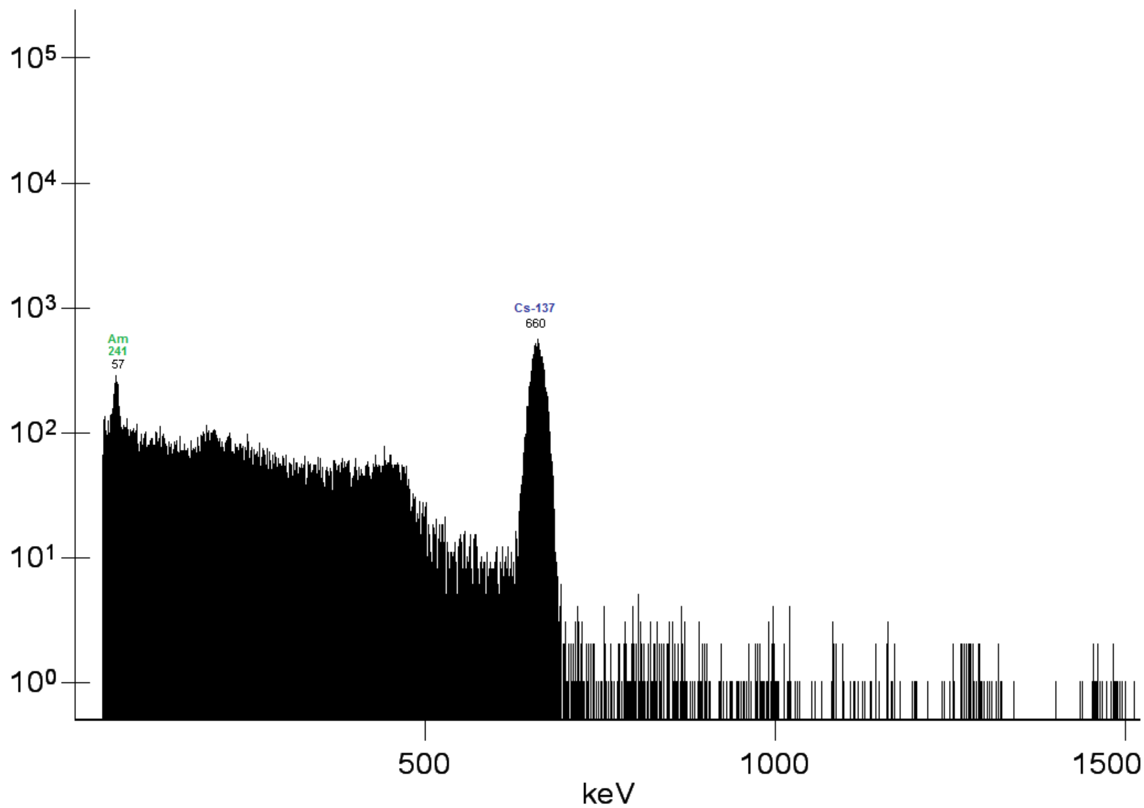
600 seconds Sample 9 measurement



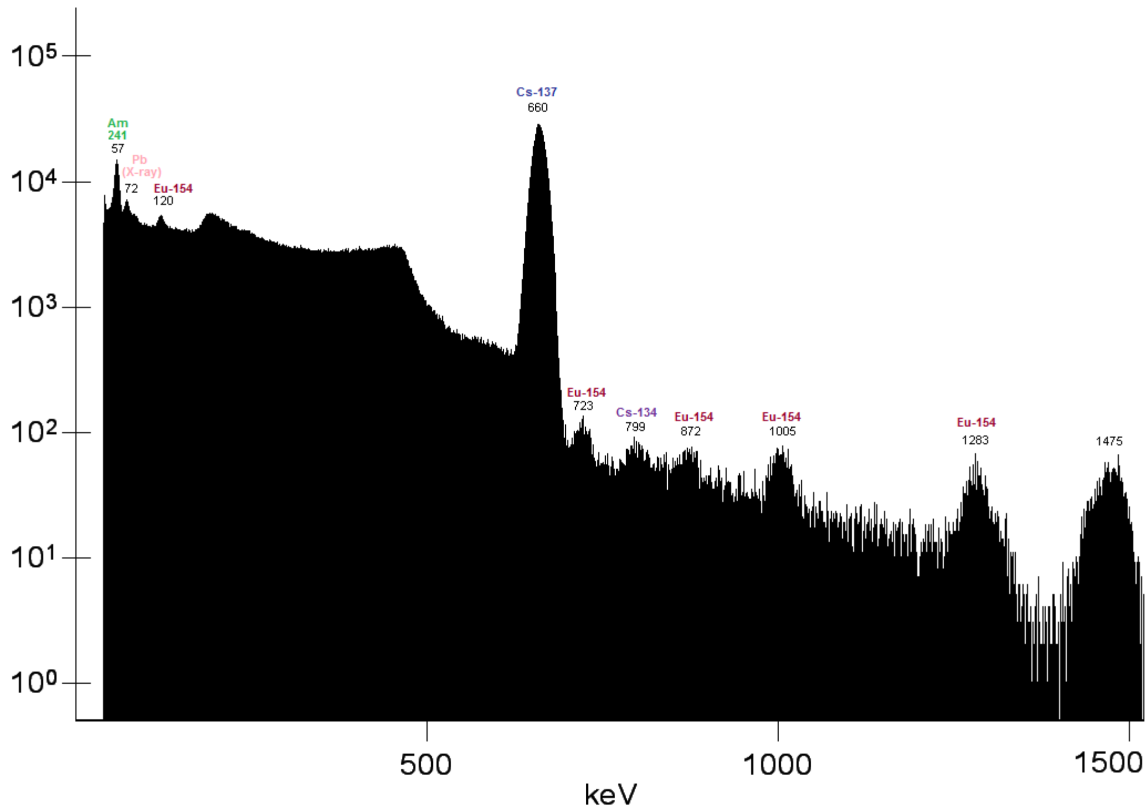
APPENDIX C

LaBr gamma ray spectra. Units of the ordinate are in counts.

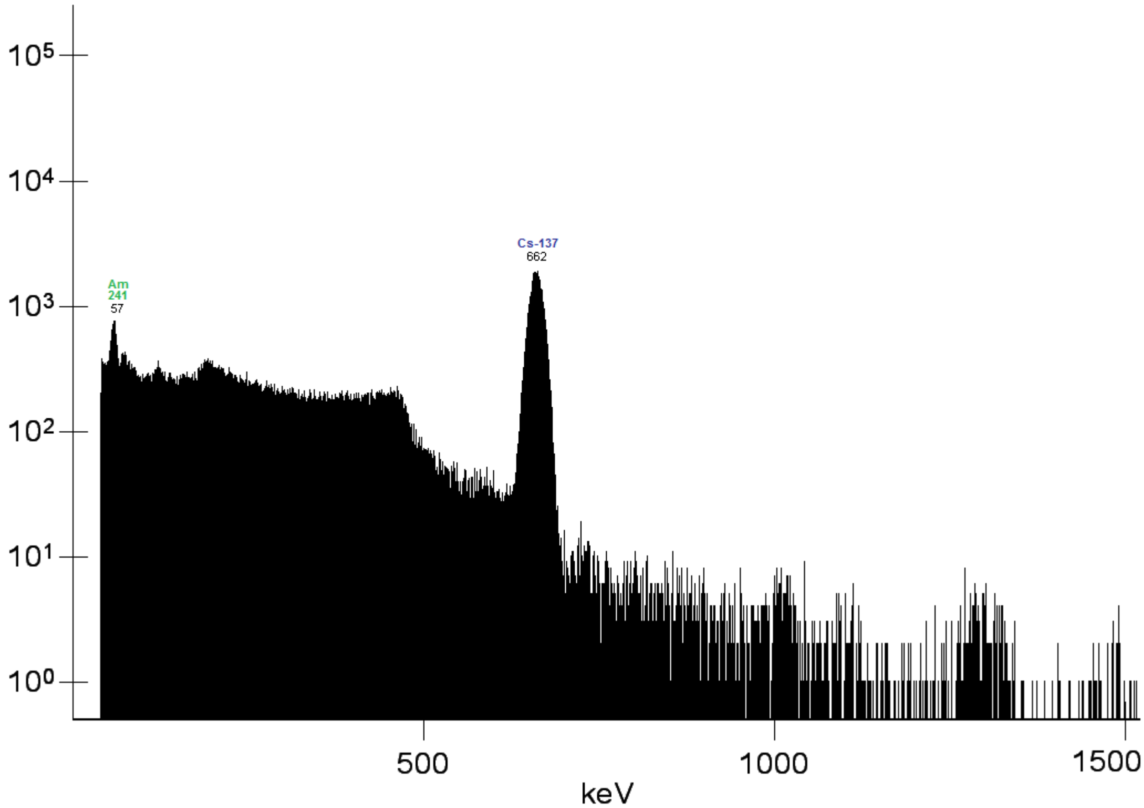
10 seconds Sample 1 measurement



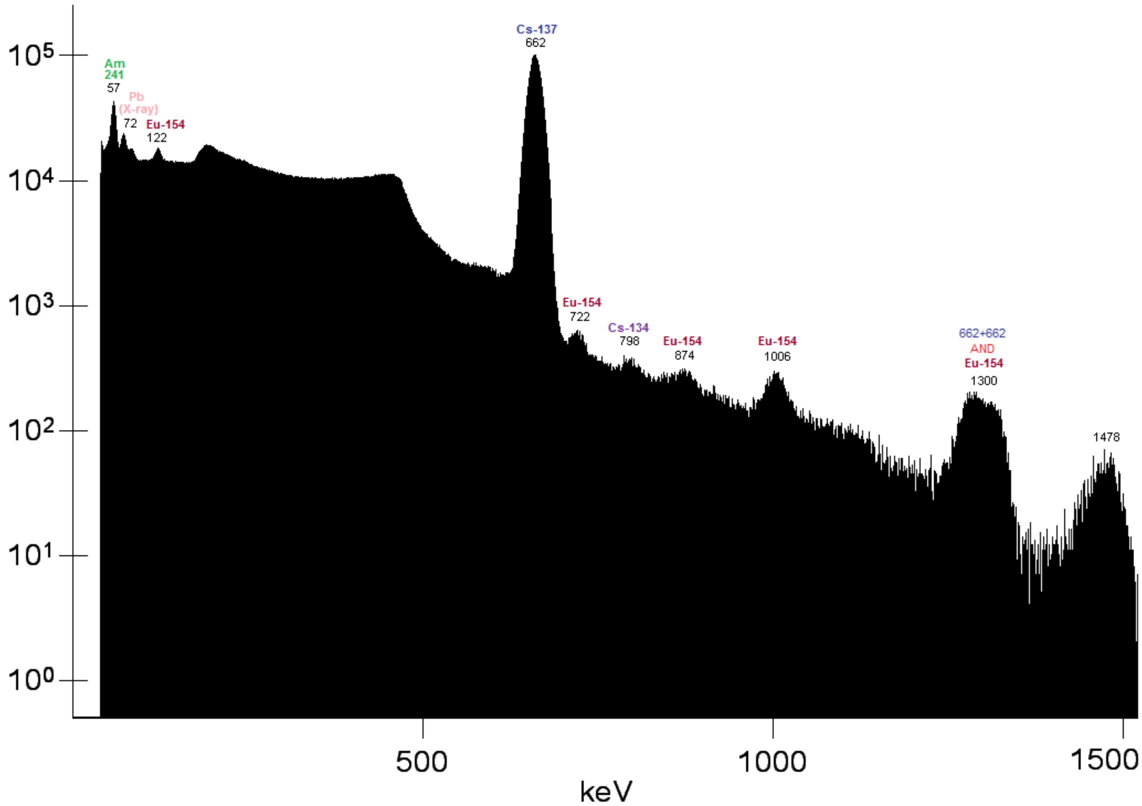
600 seconds Sample 1 measurement



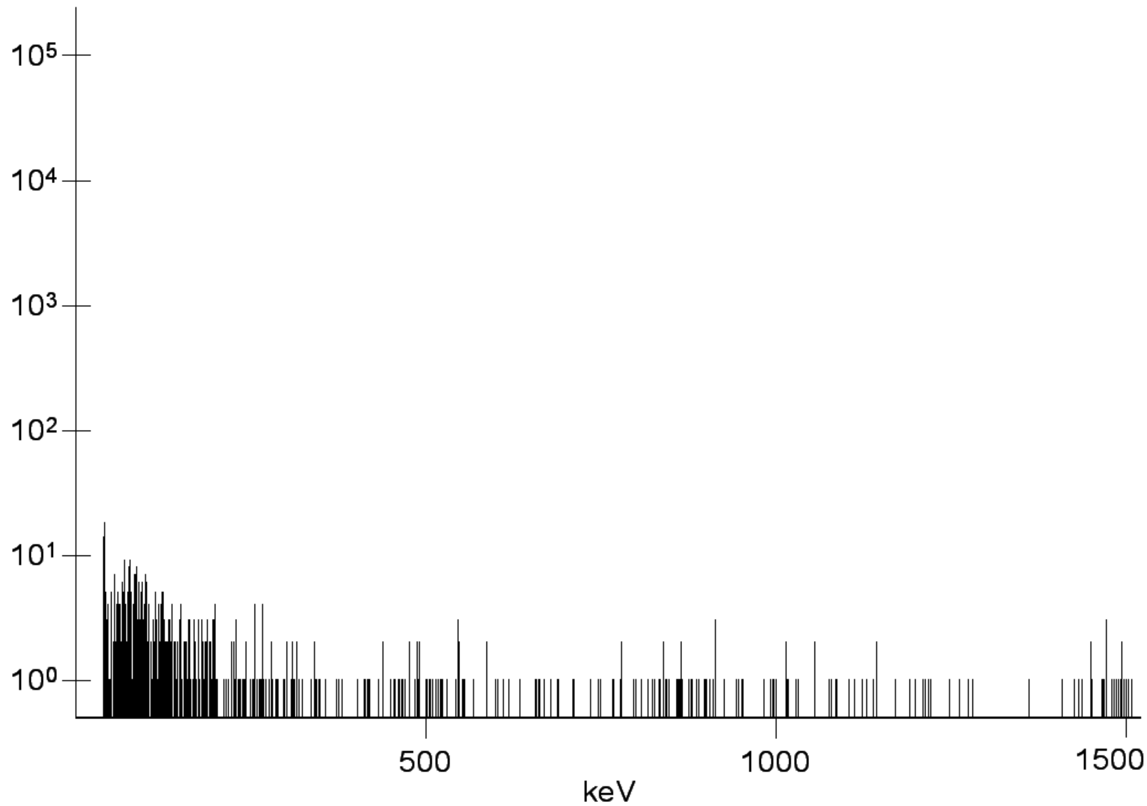
10 seconds Sample 2 measurement



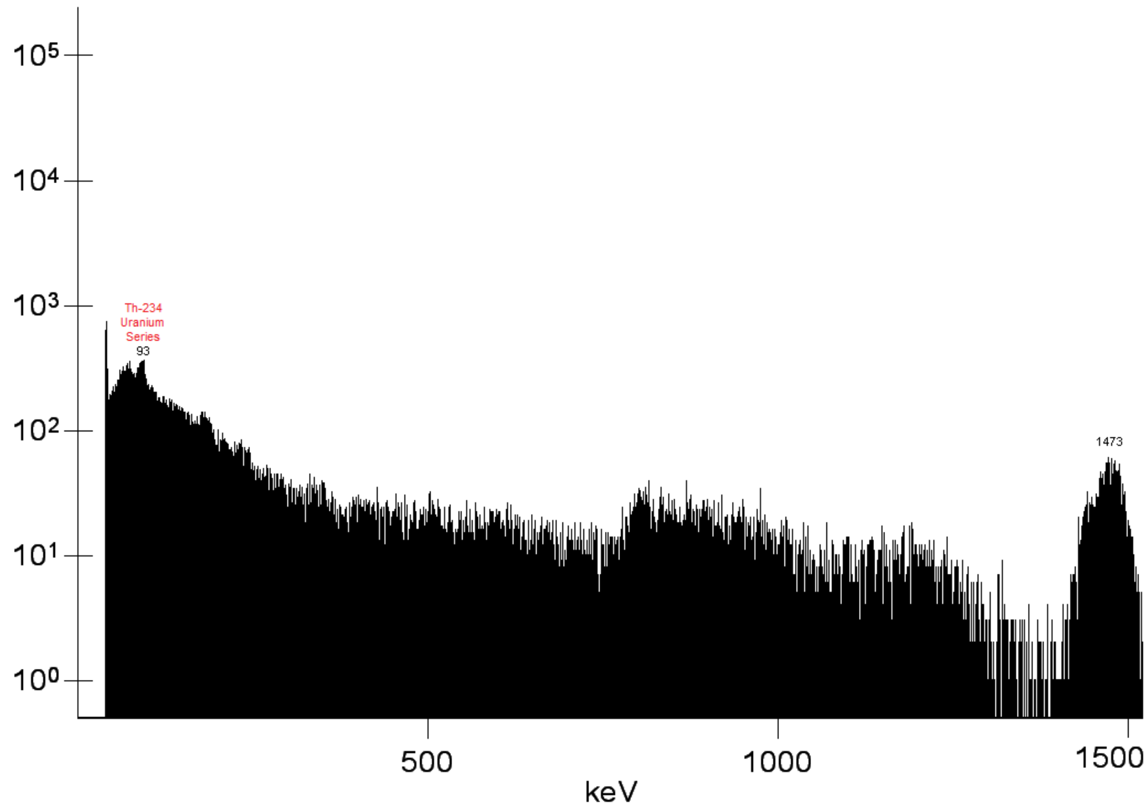
600 seconds Sample 2 measurement



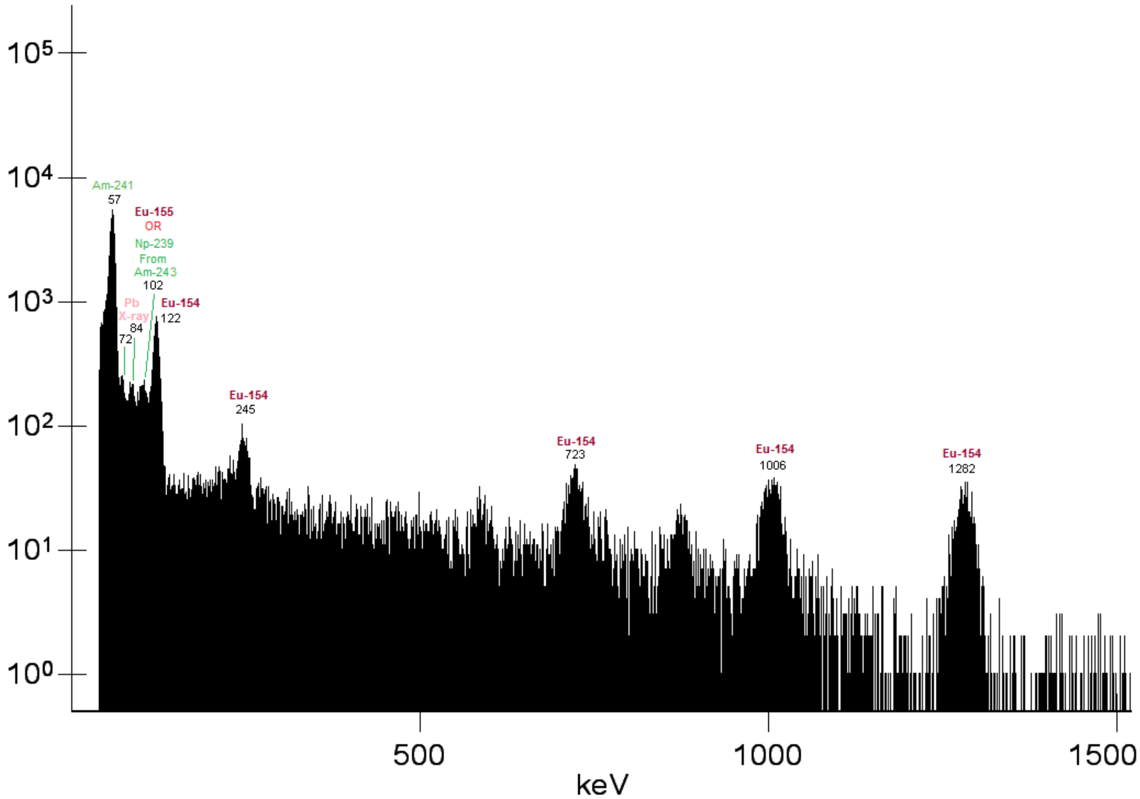
10 seconds Sample 3 measurement



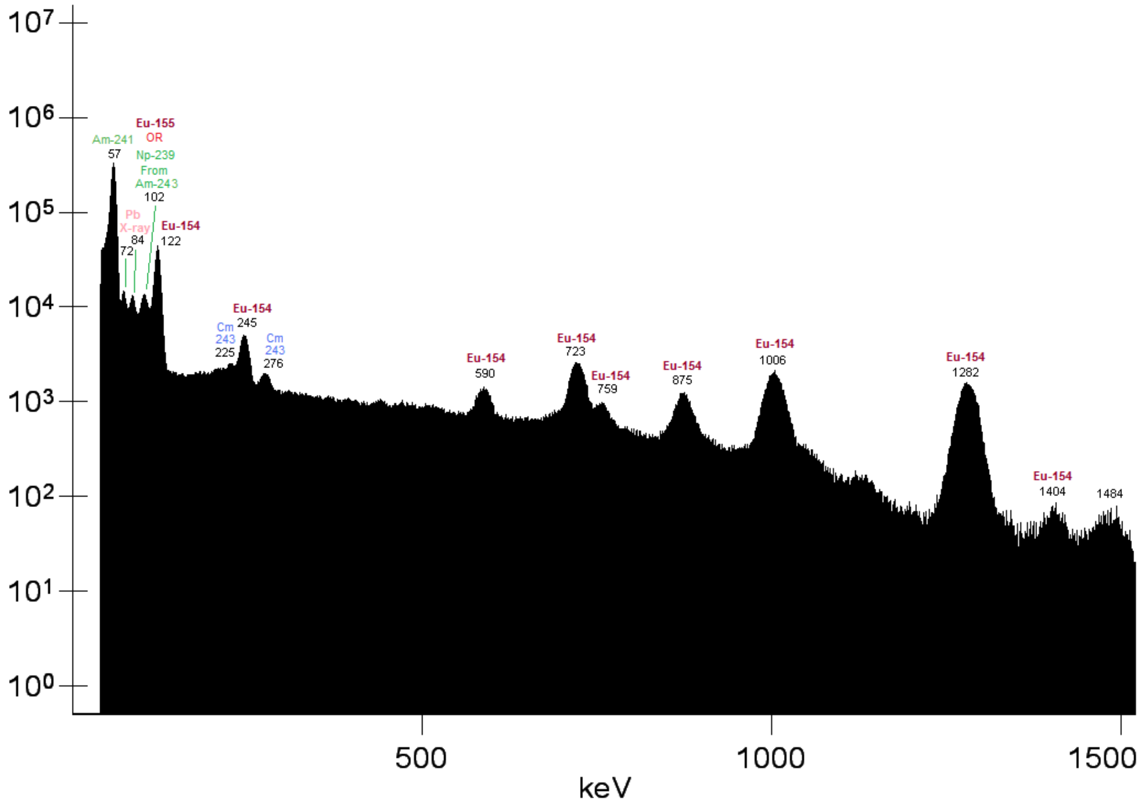
600 seconds Sample 3 measurement



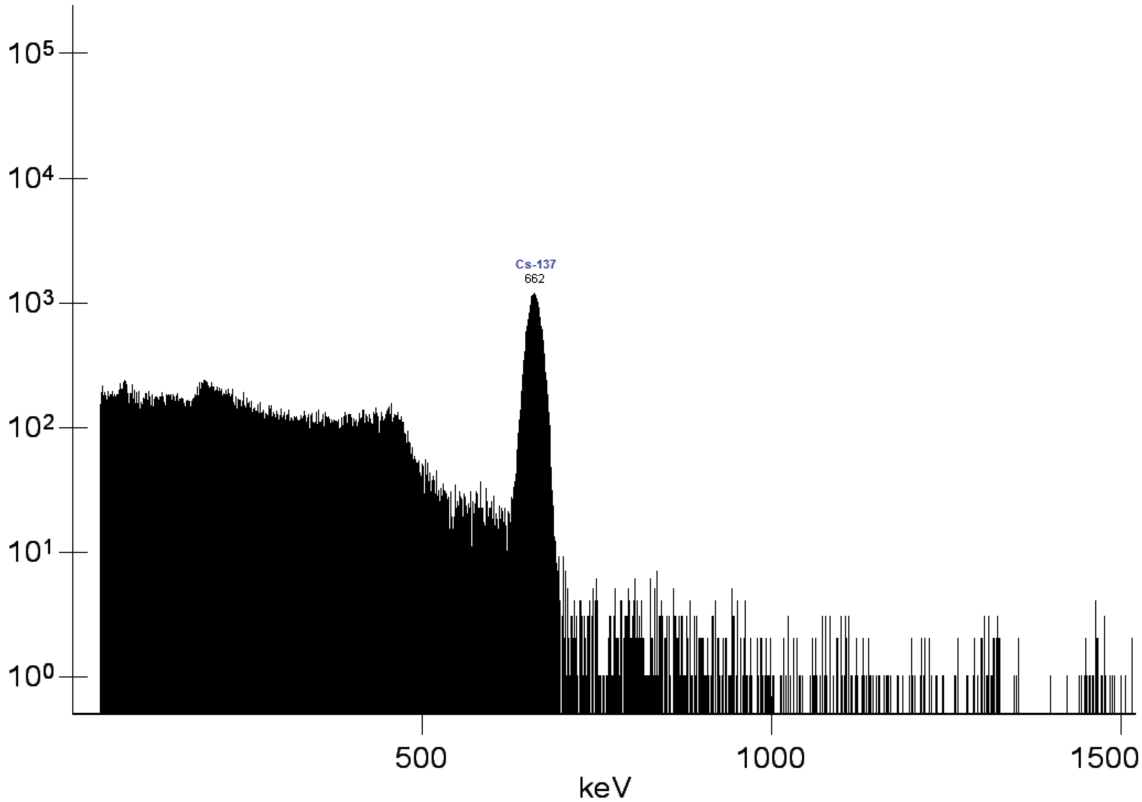
10 seconds Sample 4 measurement



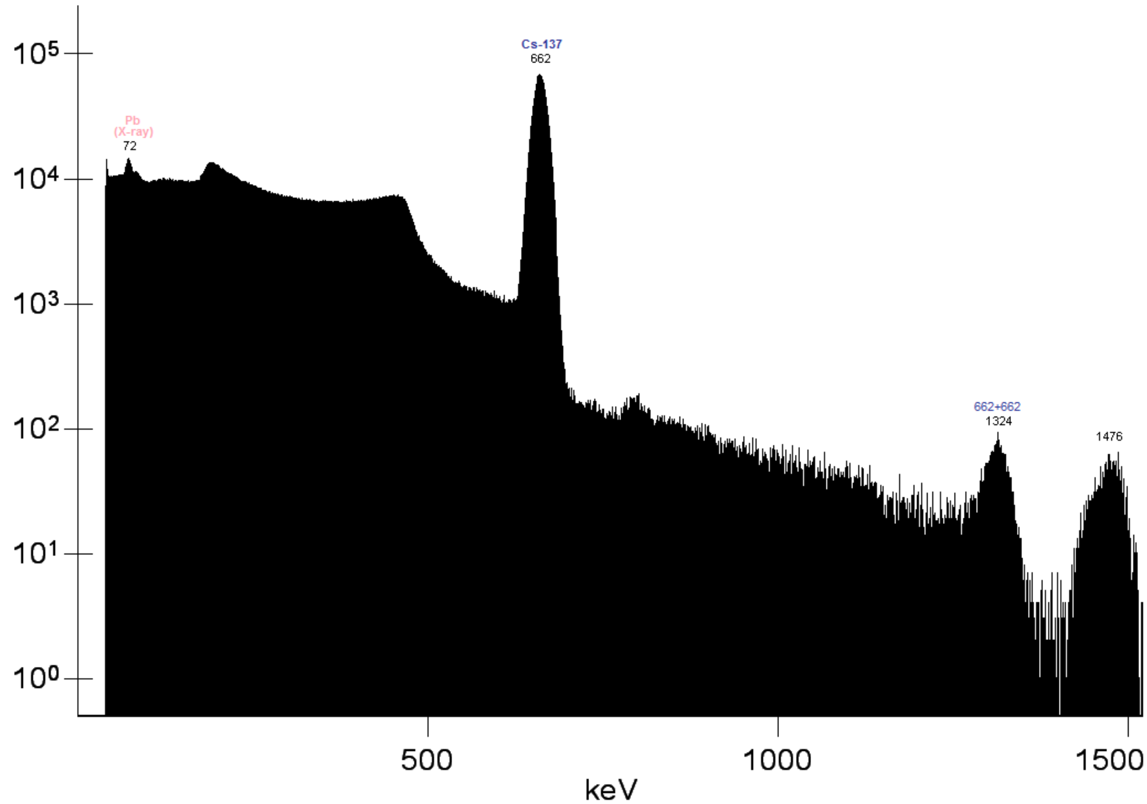
600 seconds Sample 4 measurement



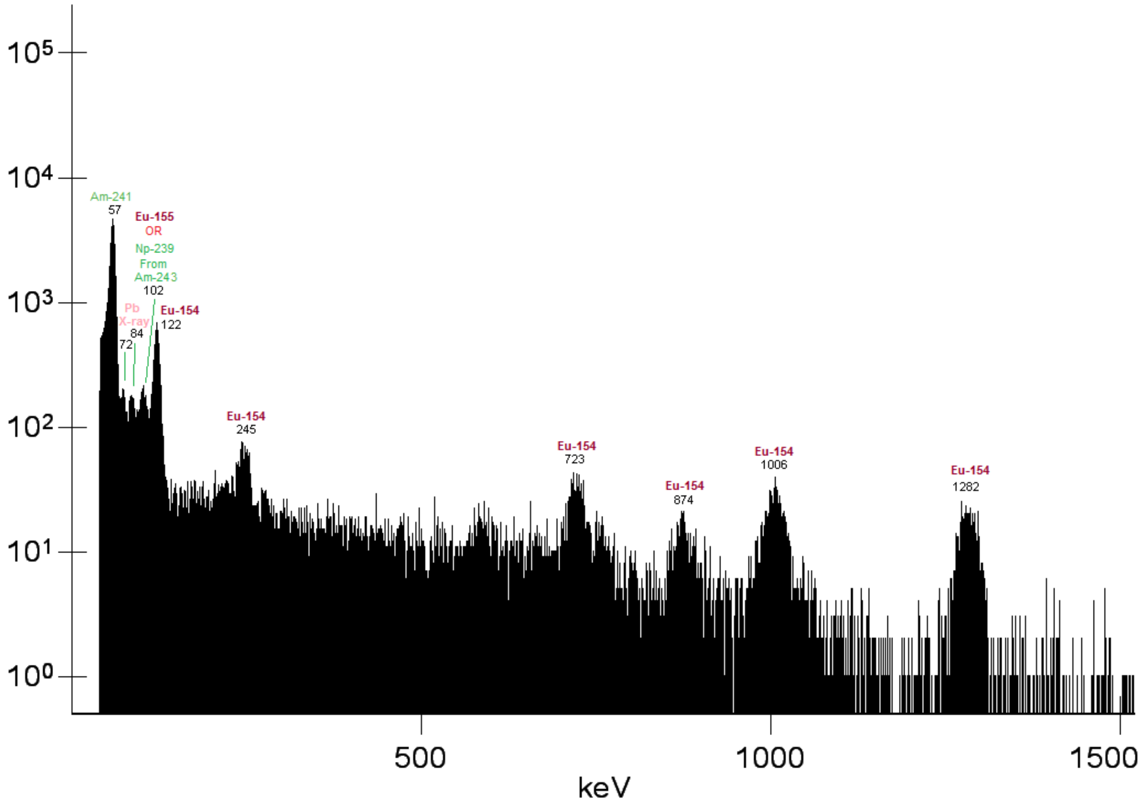
10 seconds Sample 5 measurement



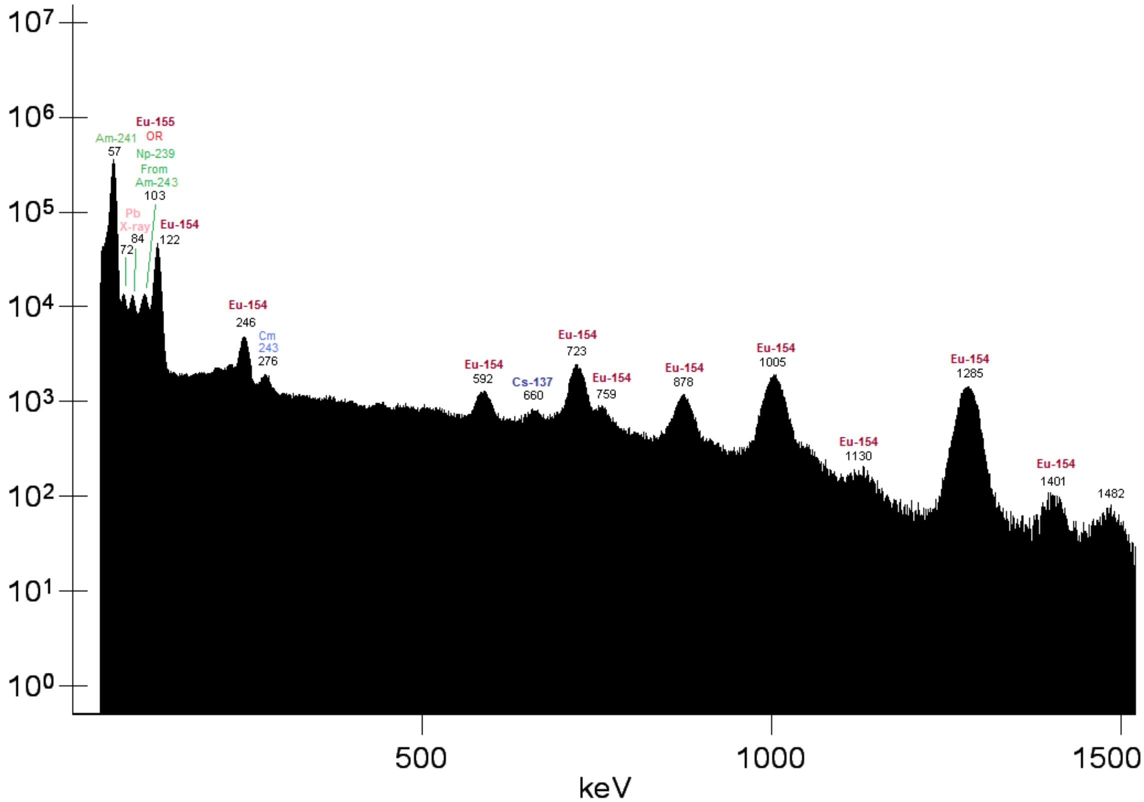
600 seconds Sample 5 measurement



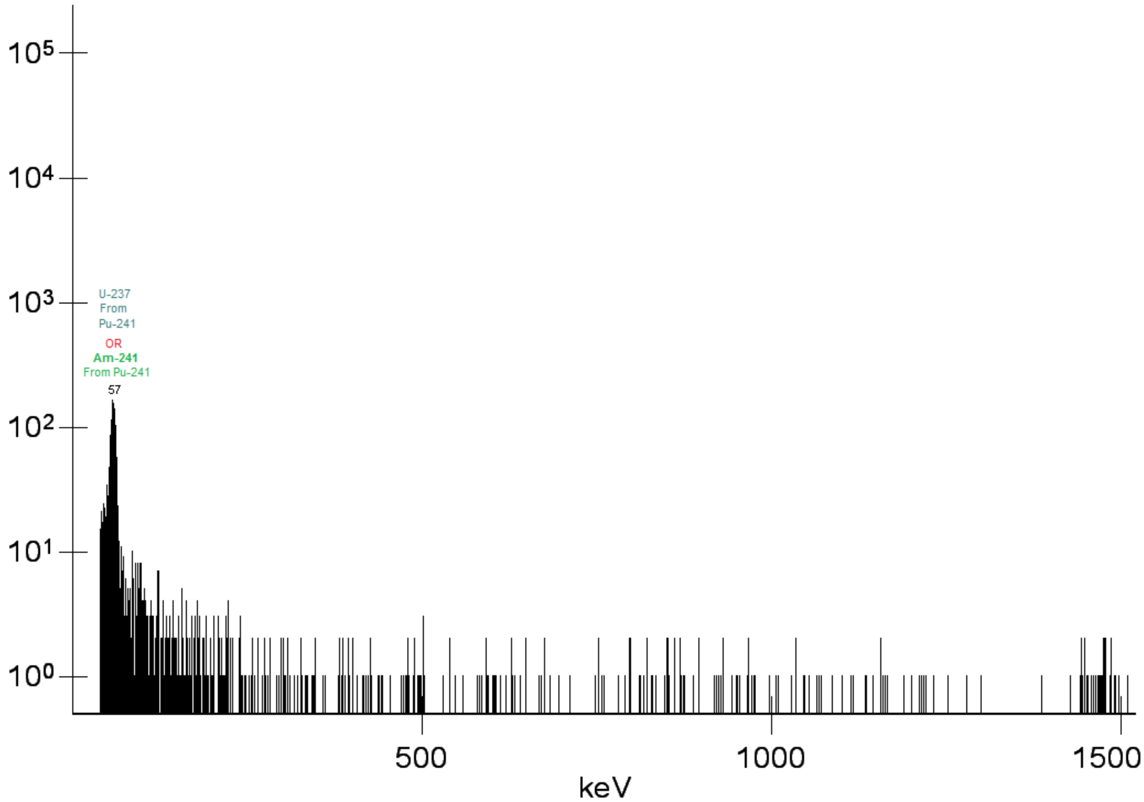
10 seconds Sample 6 measurement



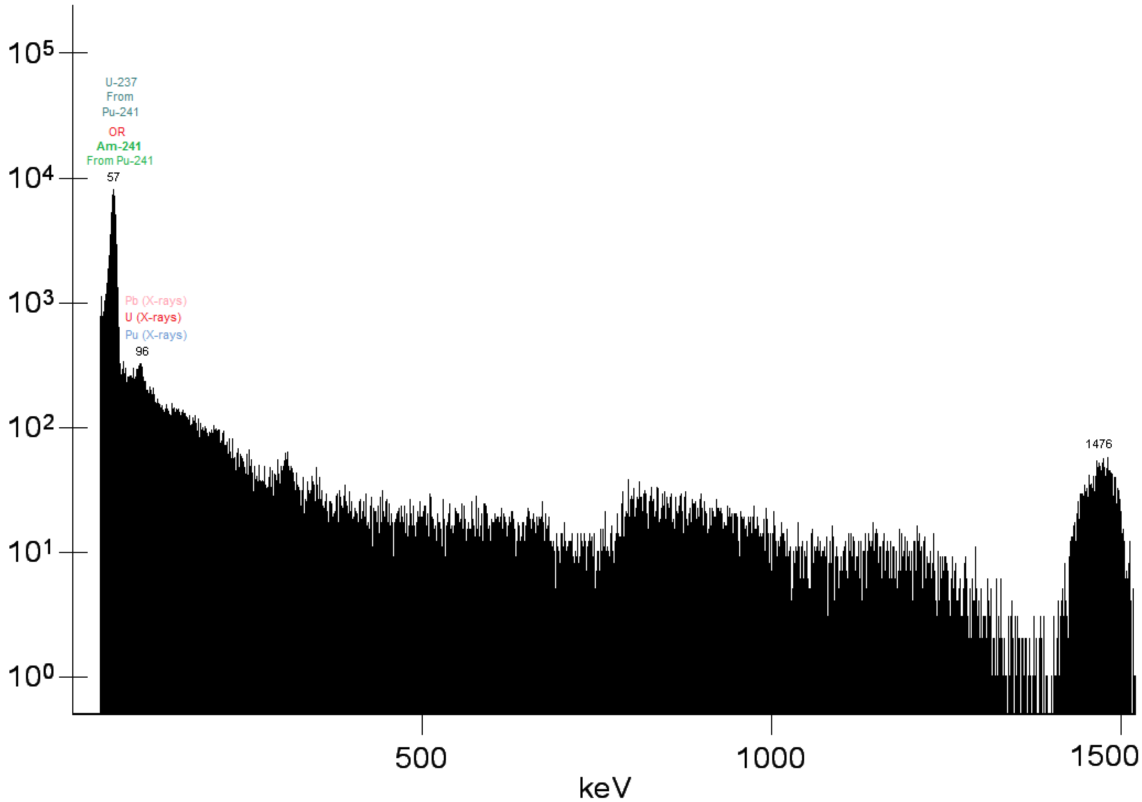
600 seconds Sample 6 measurement



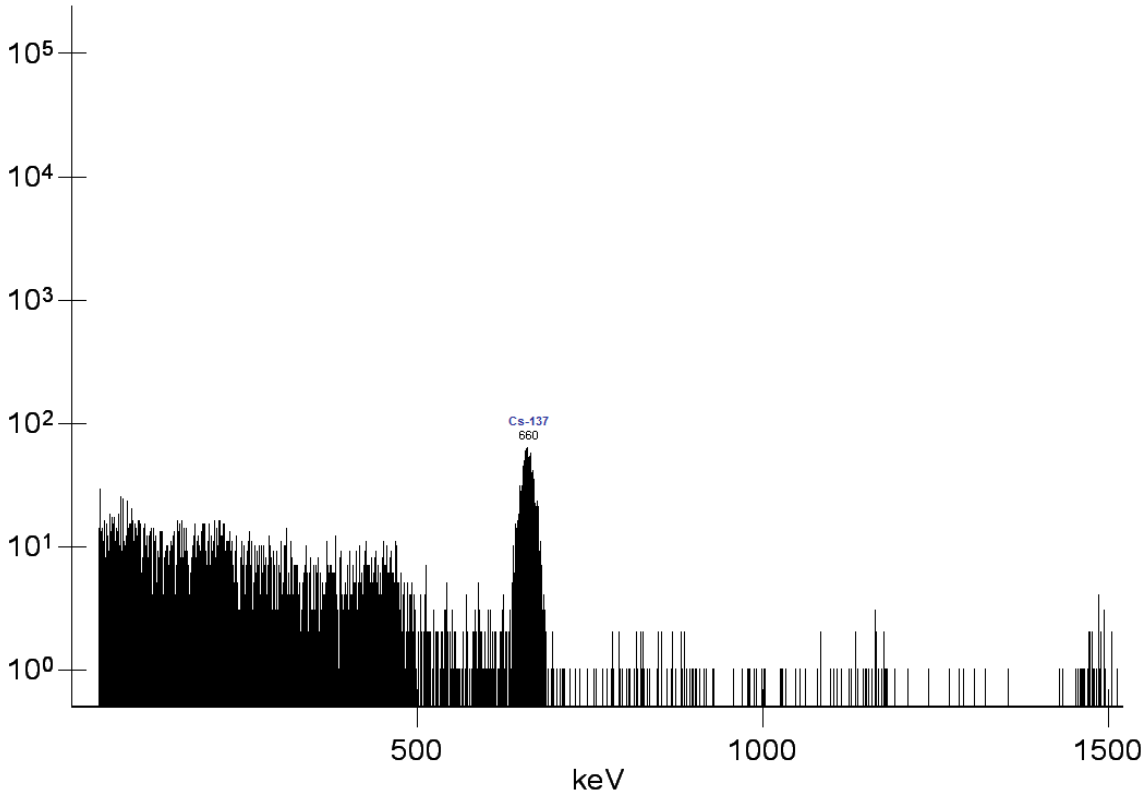
10 seconds Sample 7 measurement



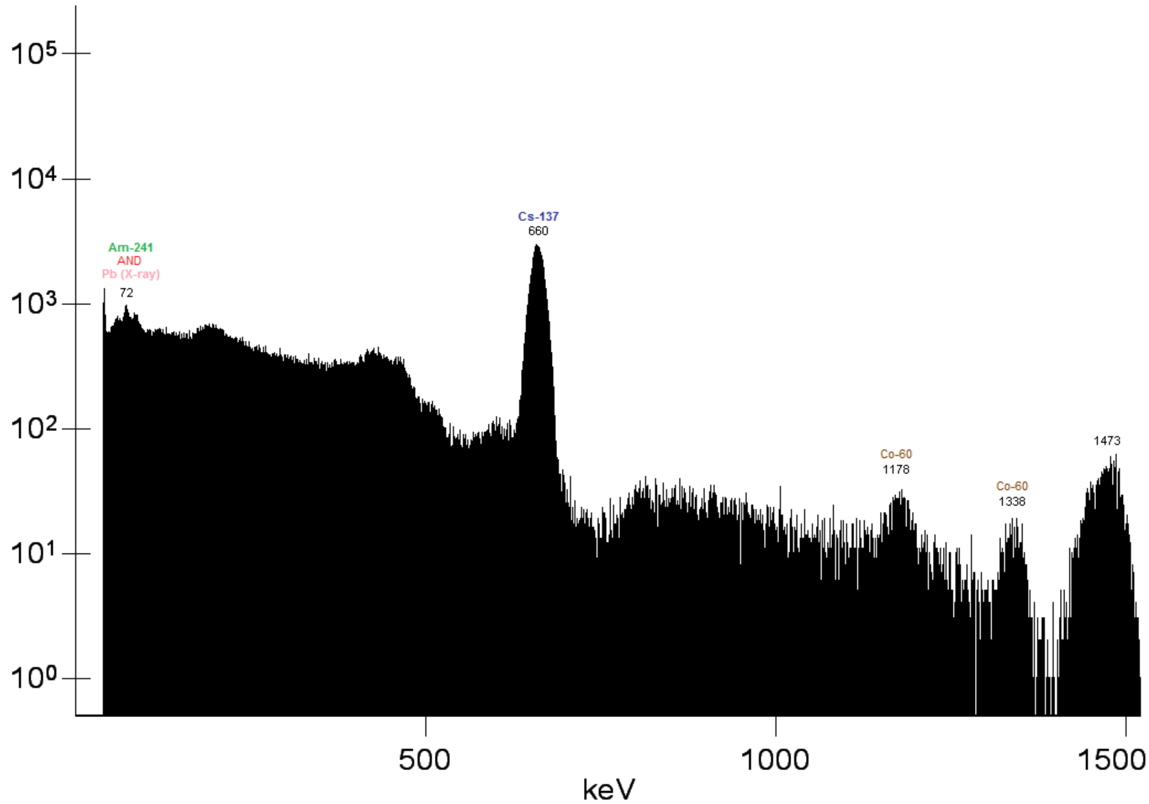
600 seconds Sample 7 measurement



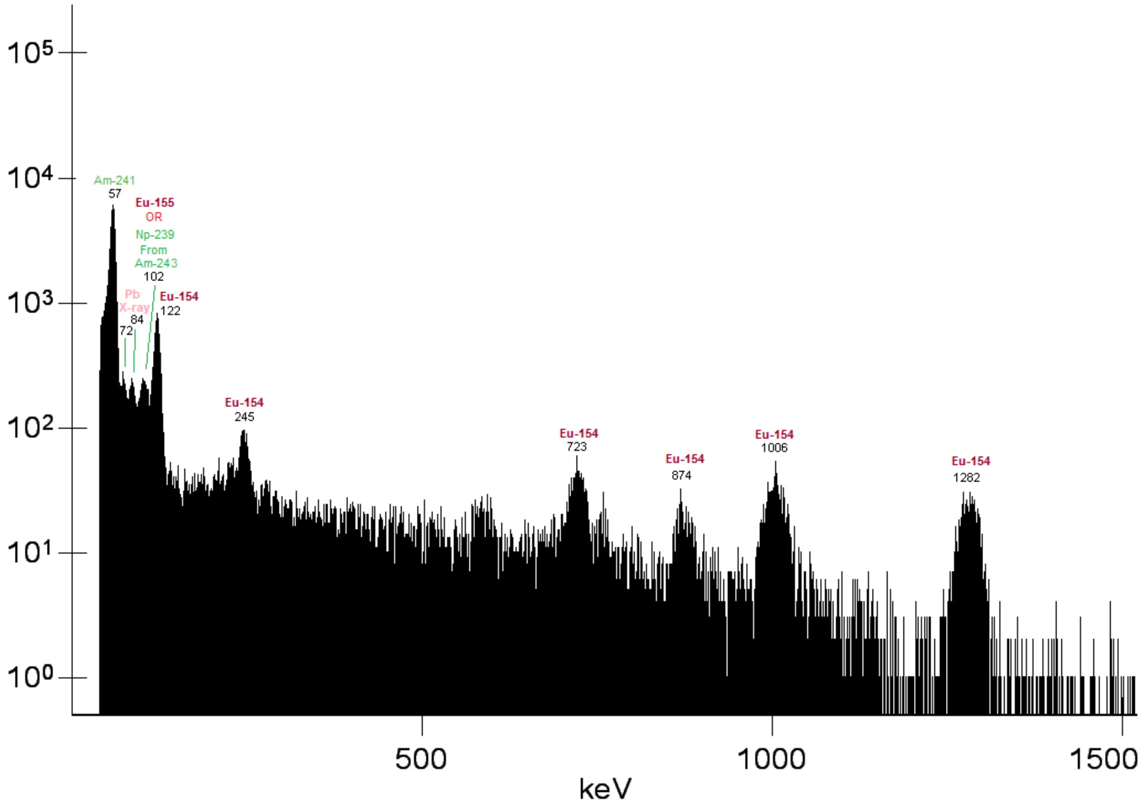
10 seconds Sample 8 measurement



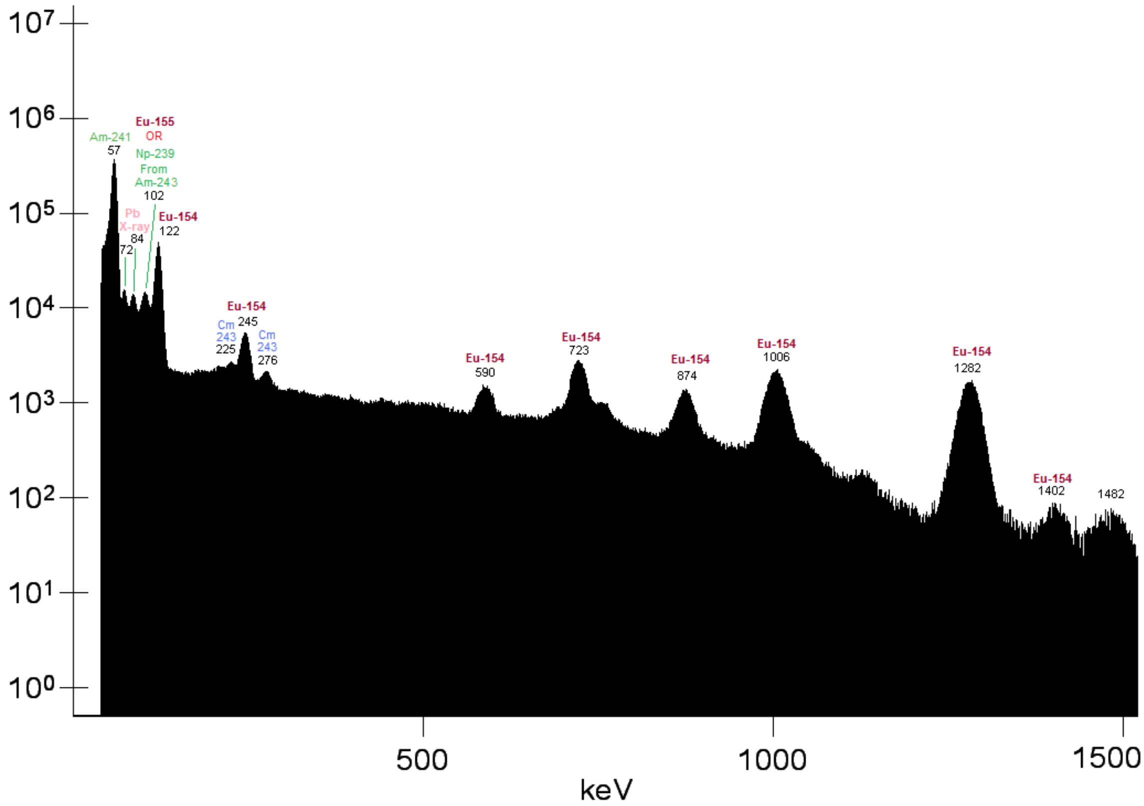
600 seconds Sample 8 measurement



10 seconds Sample 9 measurement



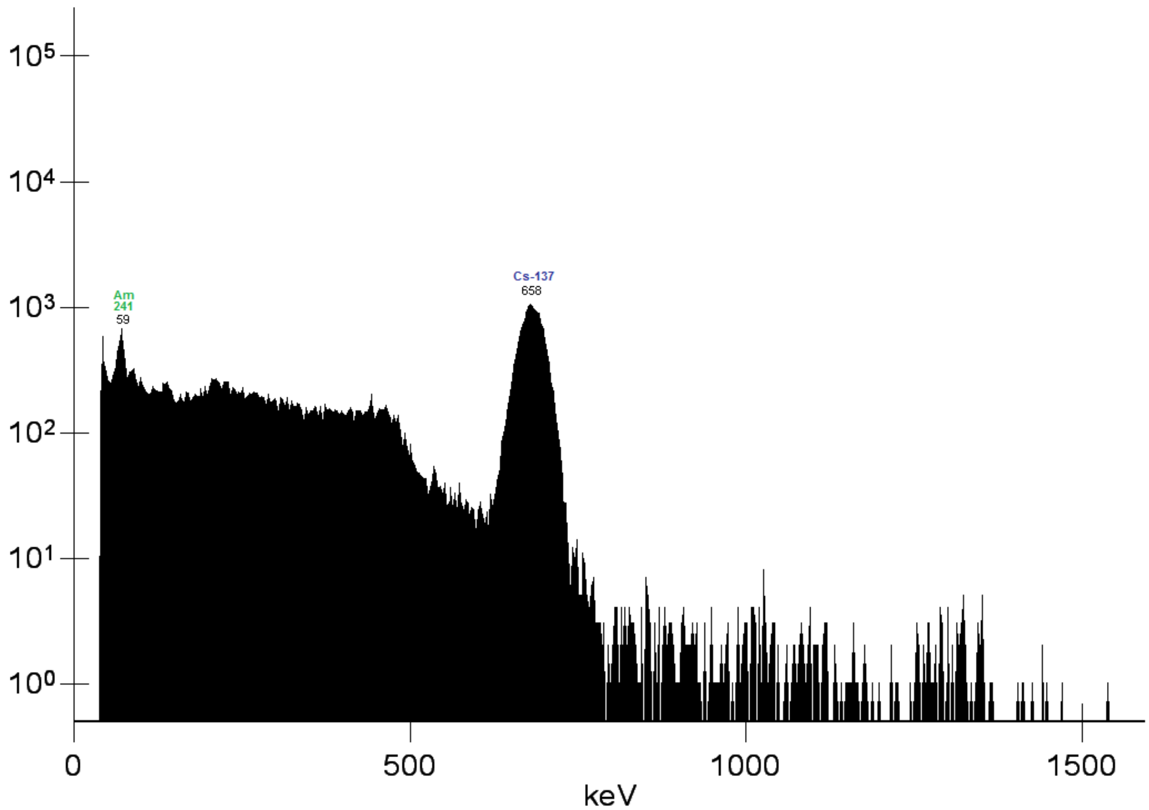
600 seconds Sample 9 measurement



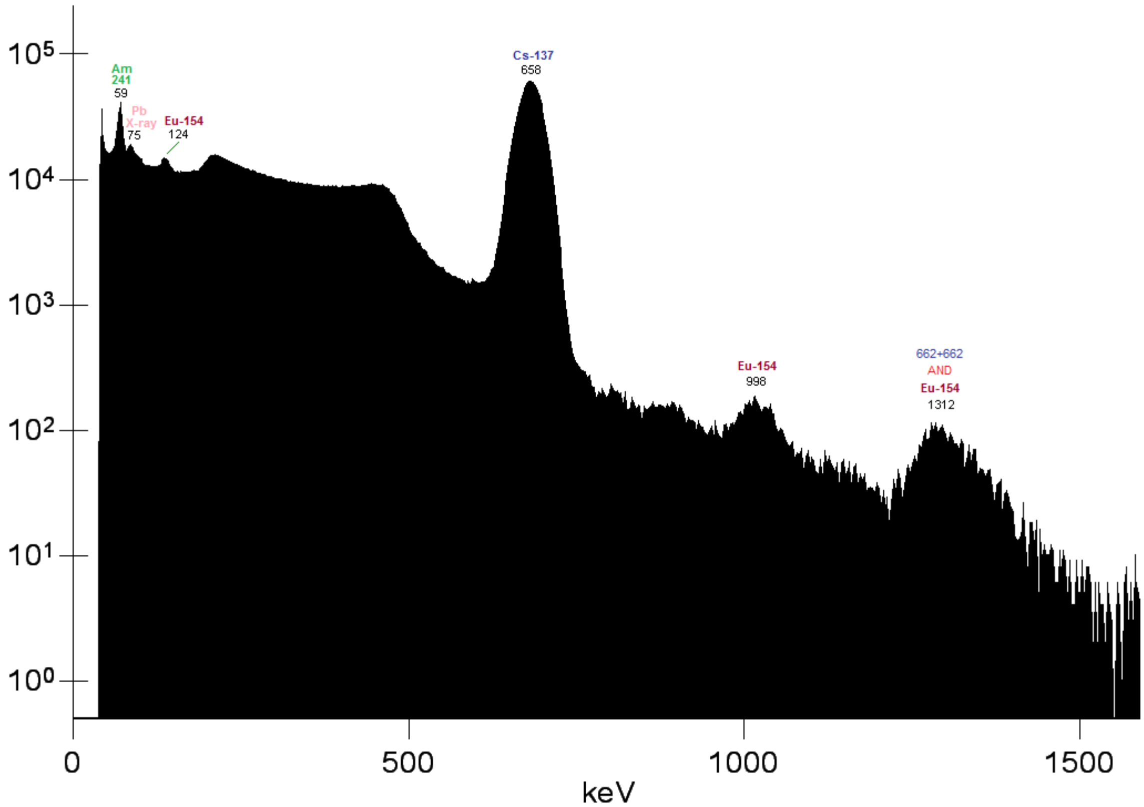
APPENDIX D

NaI gamma ray spectra. Units of the ordinate are in counts.

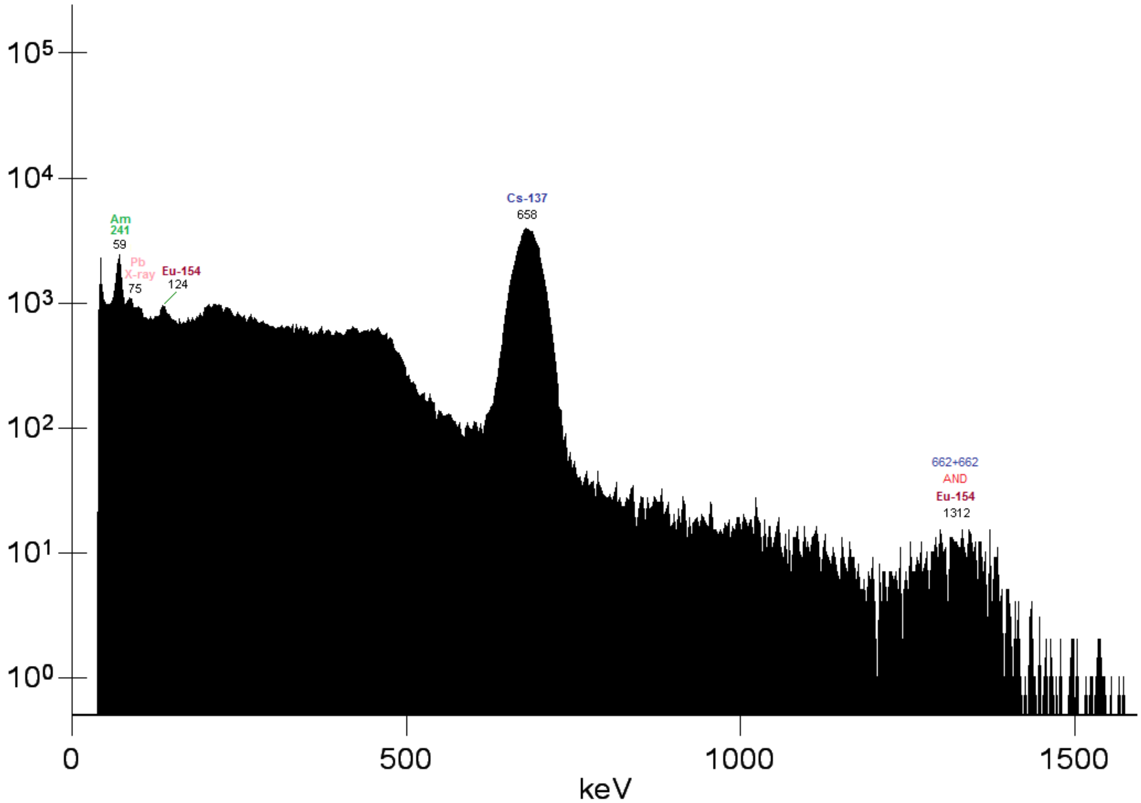
10 seconds Sample 1 measurement



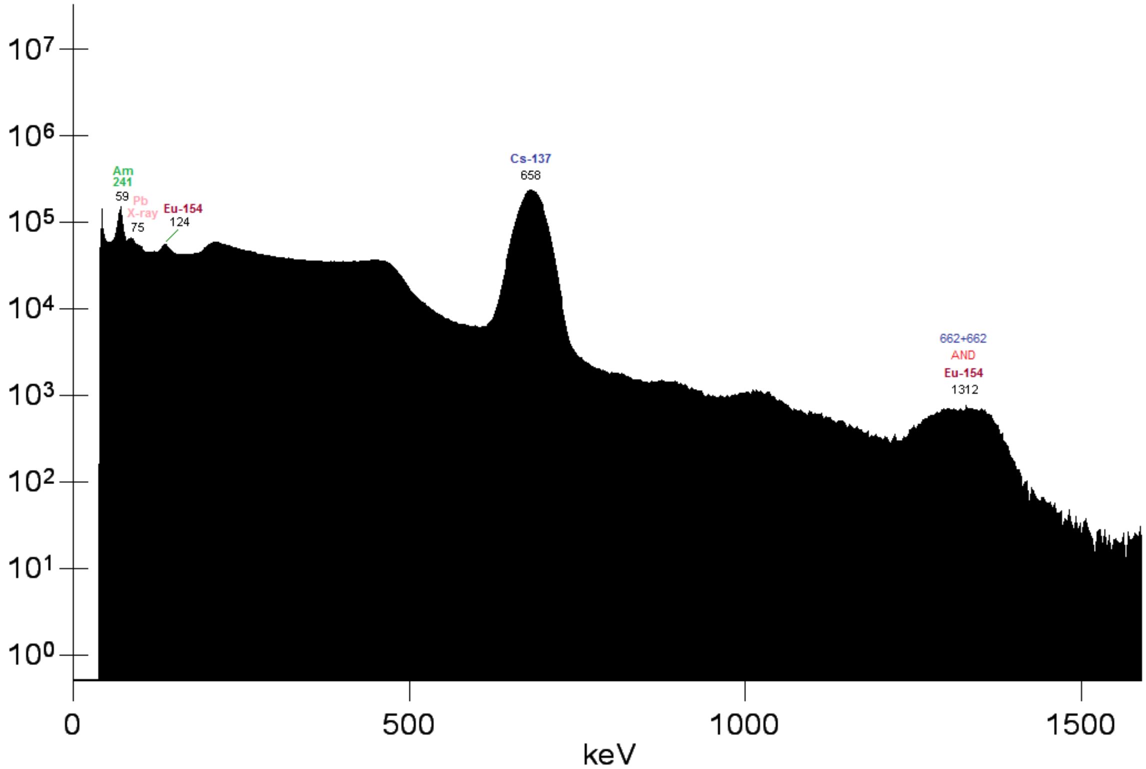
600 seconds Sample 1 measurement



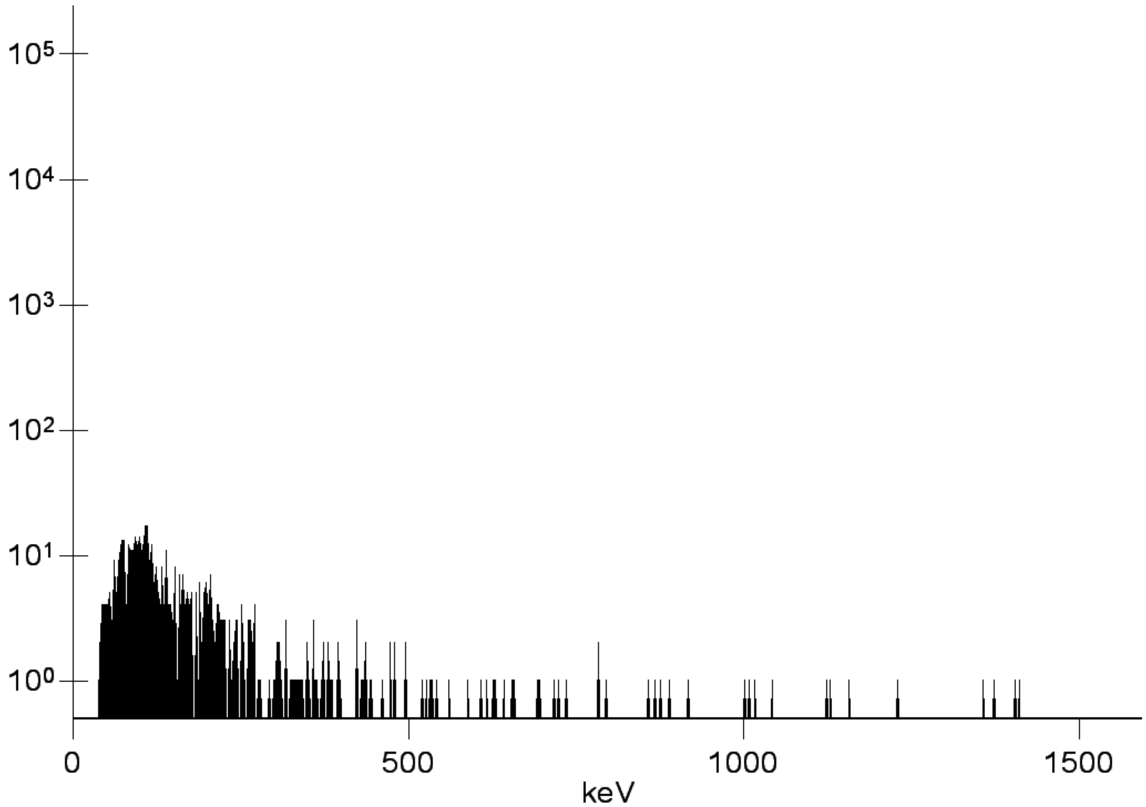
10 seconds Sample 2 measurement



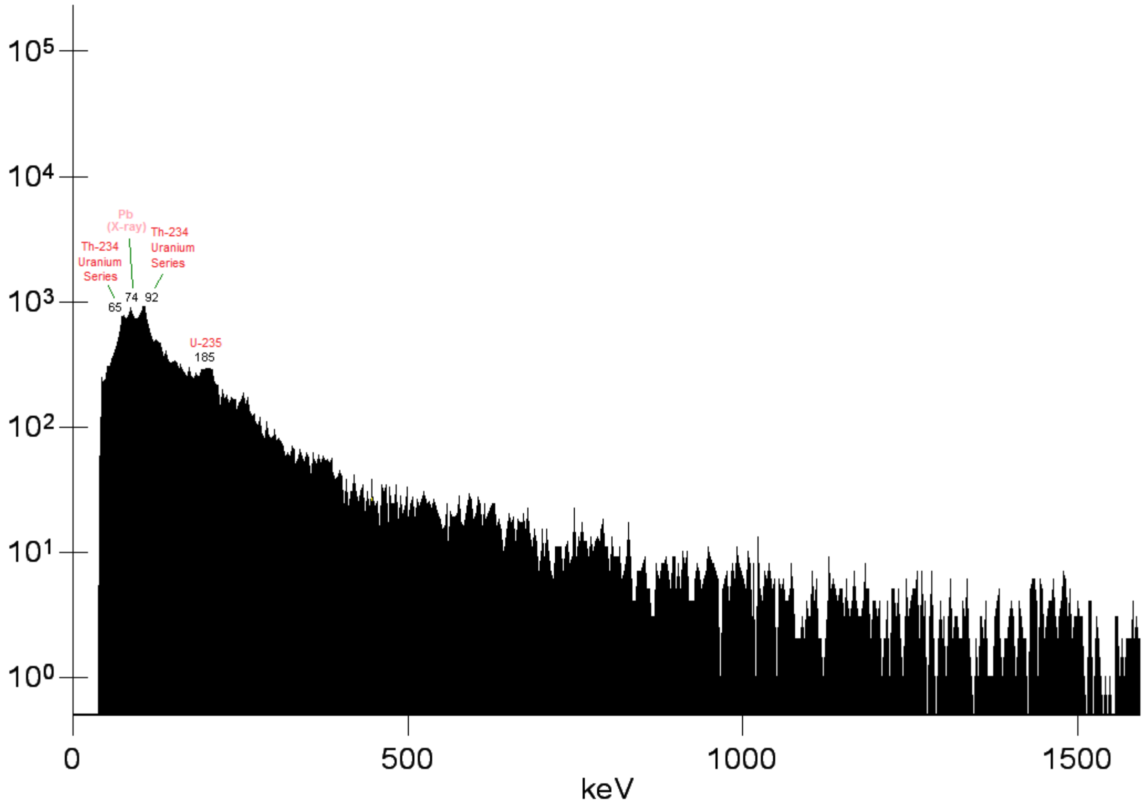
600 seconds Sample 2 measurement



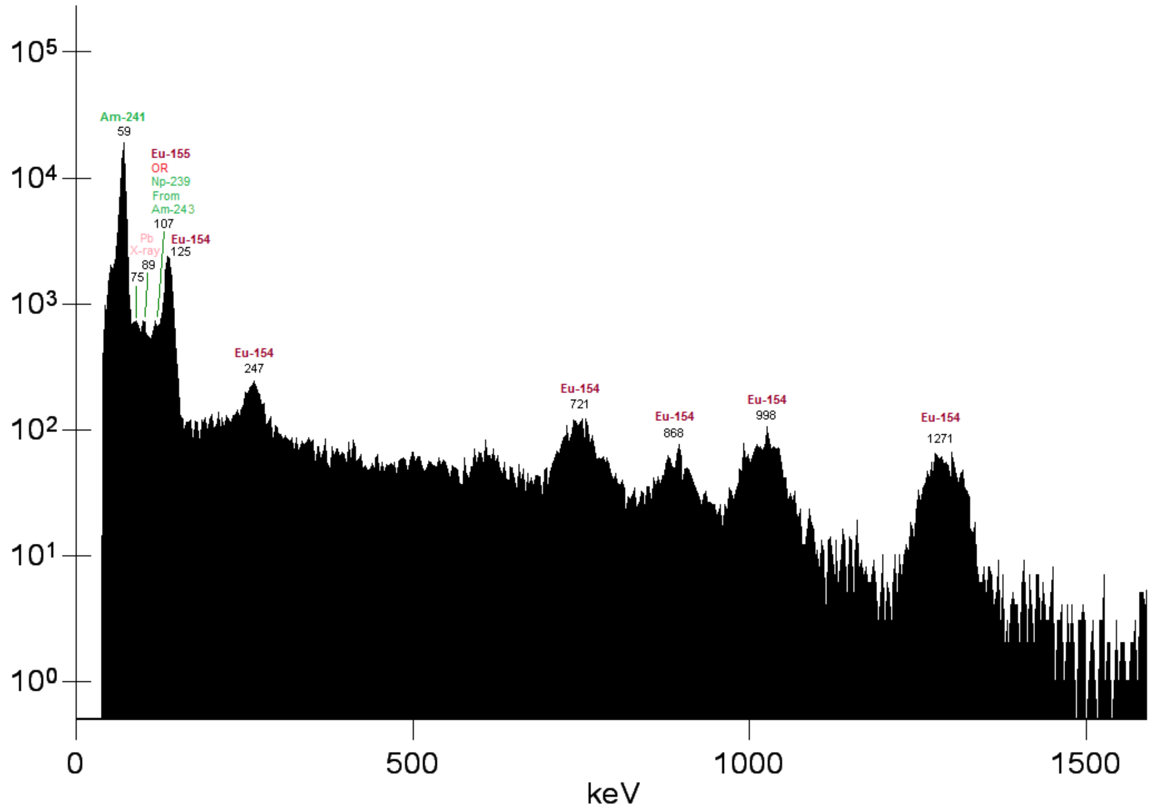
10 seconds Sample 3 measurement



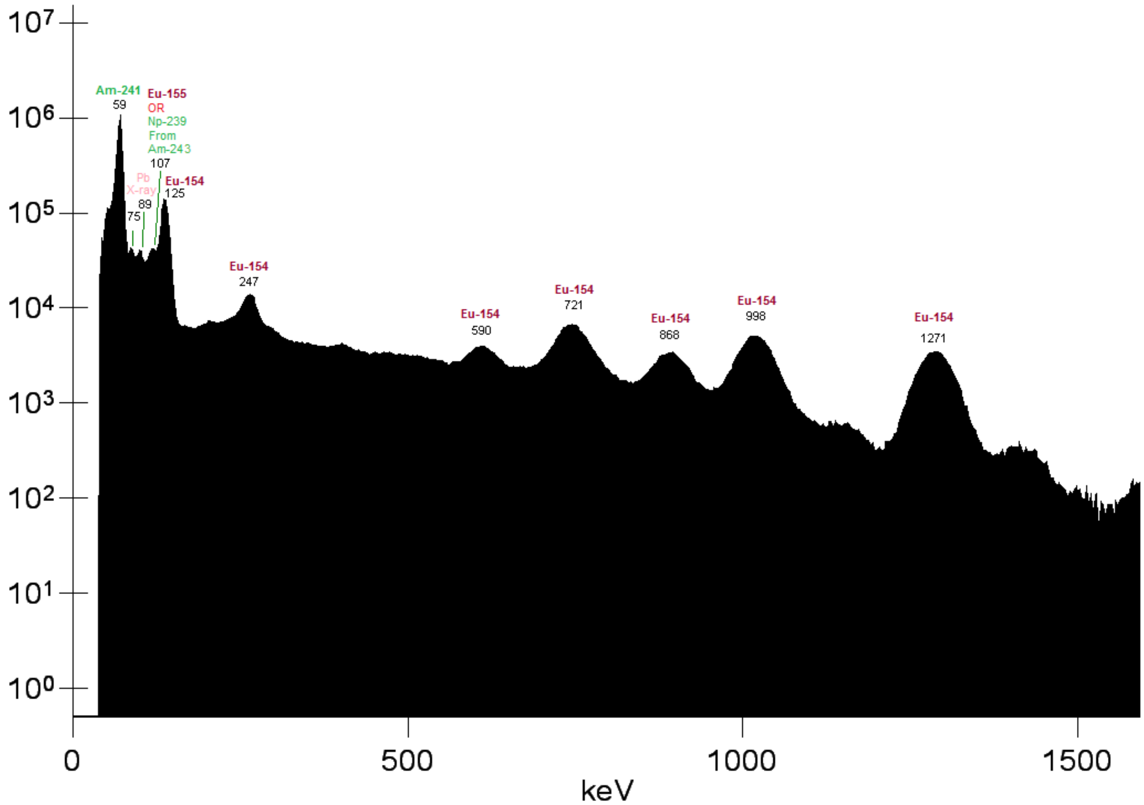
600 seconds Sample 3 measurement



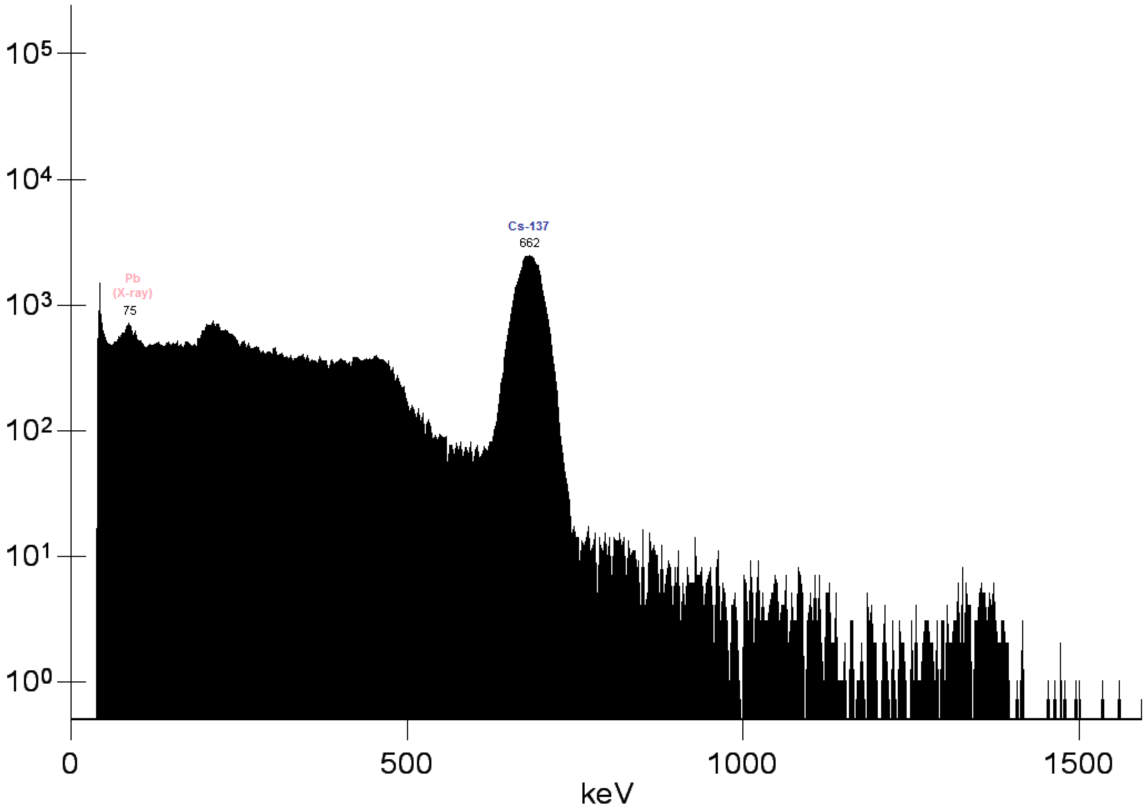
10 seconds Sample 4 measurement



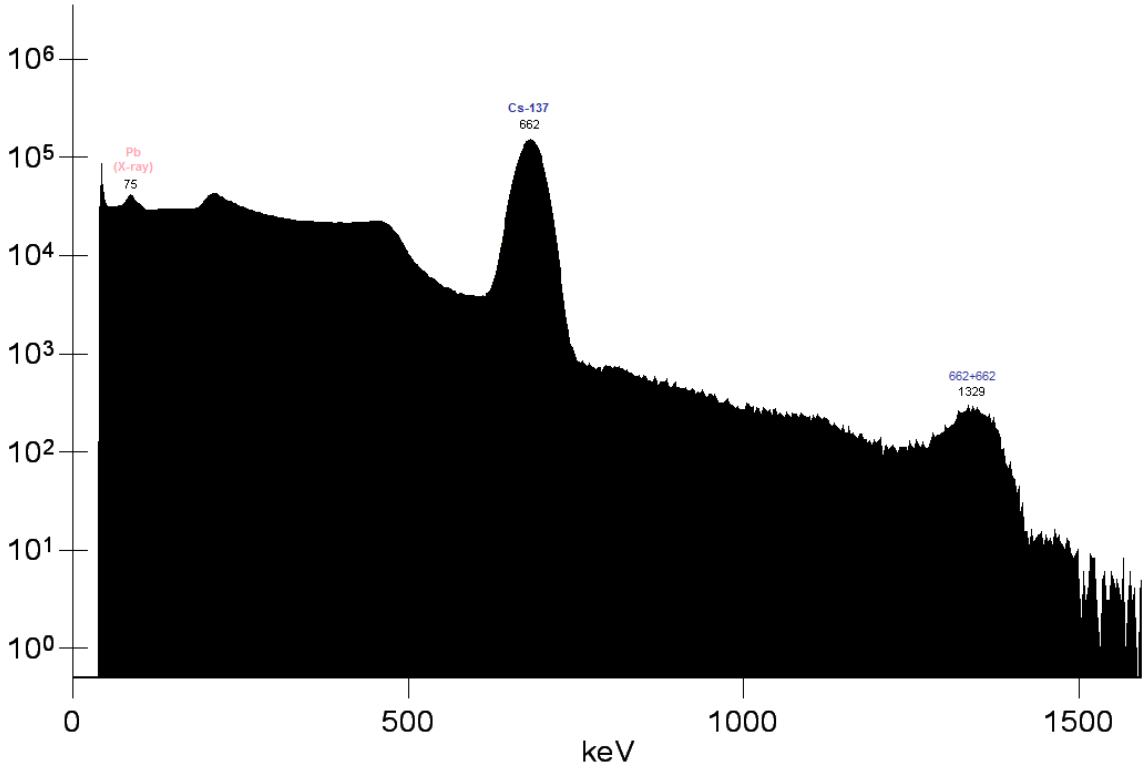
600 seconds Sample 4 measurement



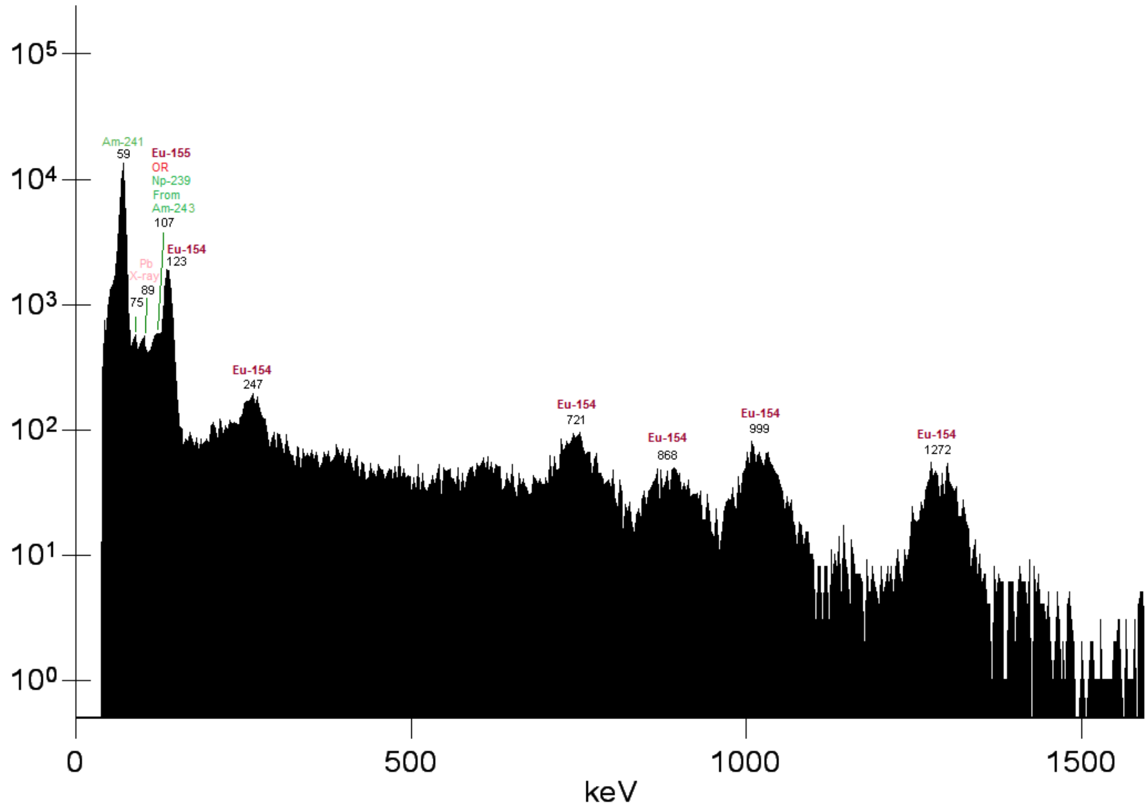
10 seconds Sample 5 measurement



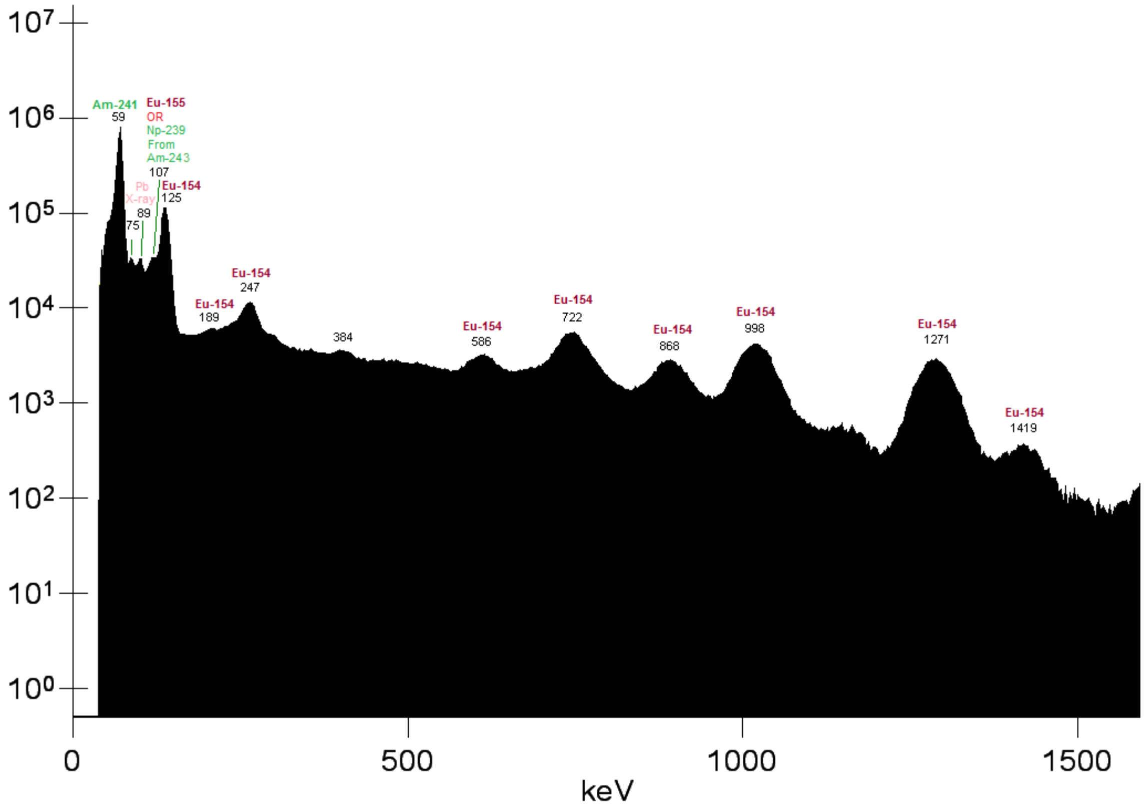
600 seconds Sample 5 measurement



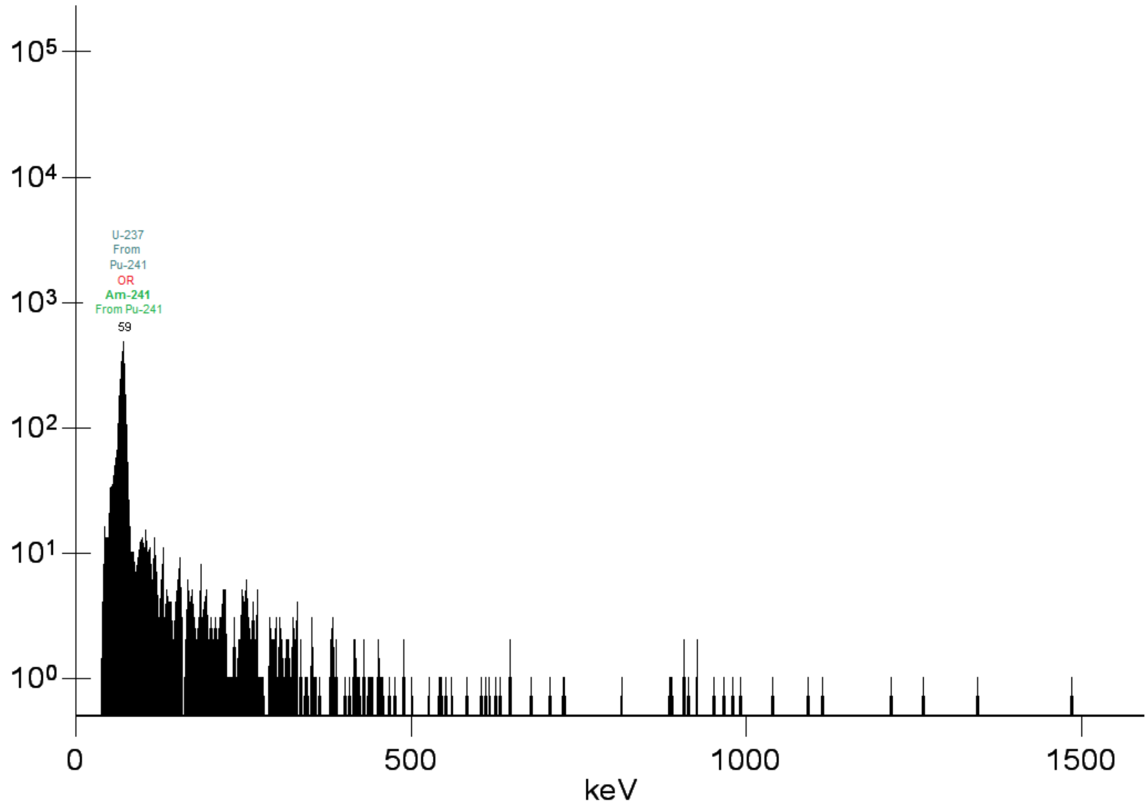
10 seconds Sample 6 measurement



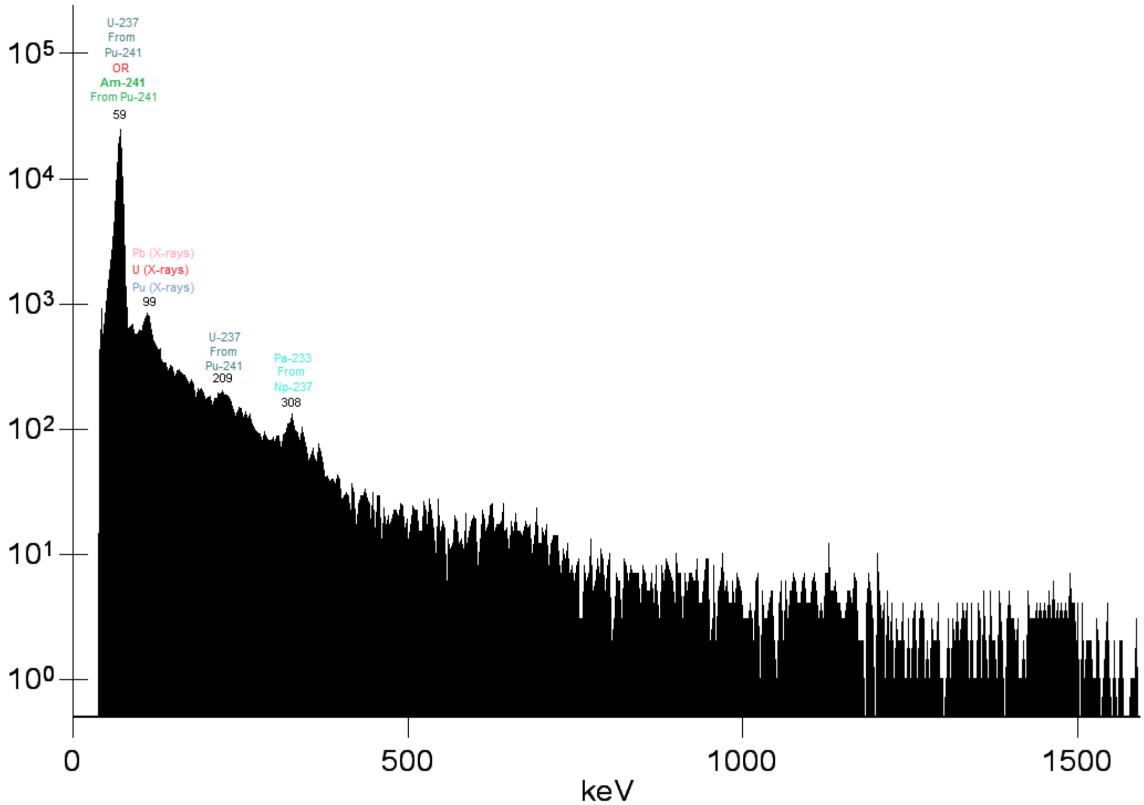
600 seconds Sample 6 measurement



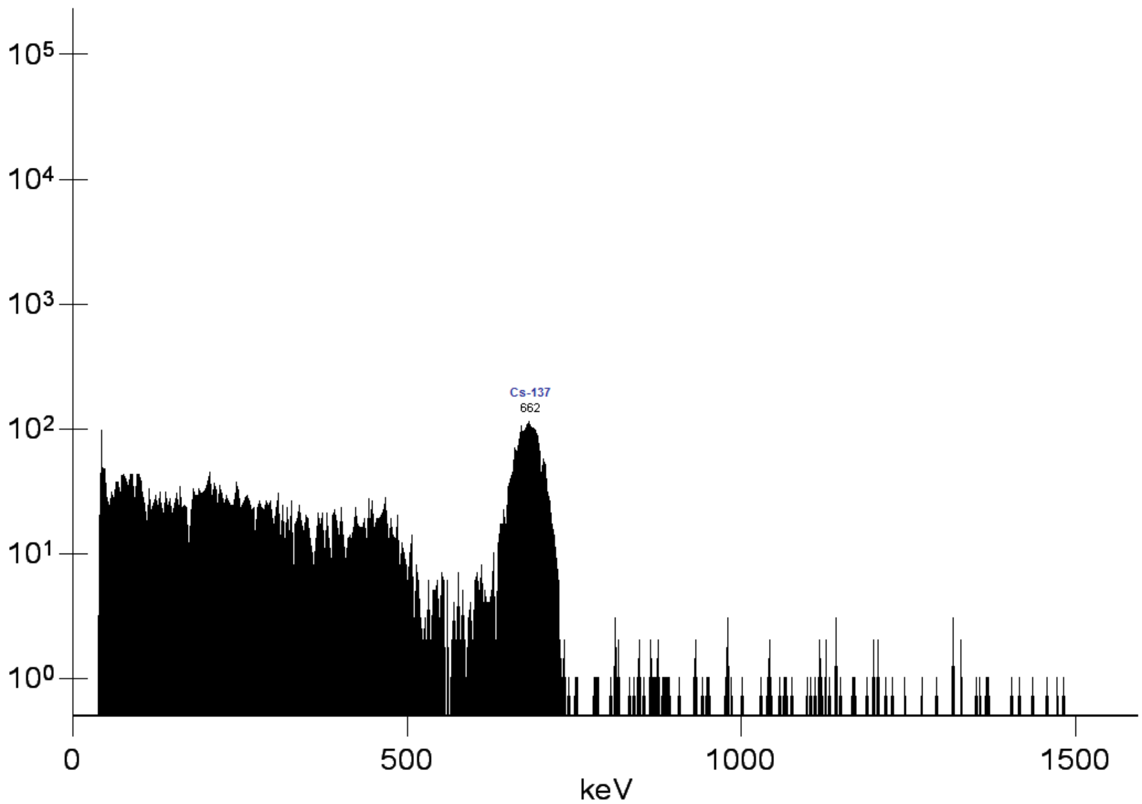
10 seconds Sample 7 measurement



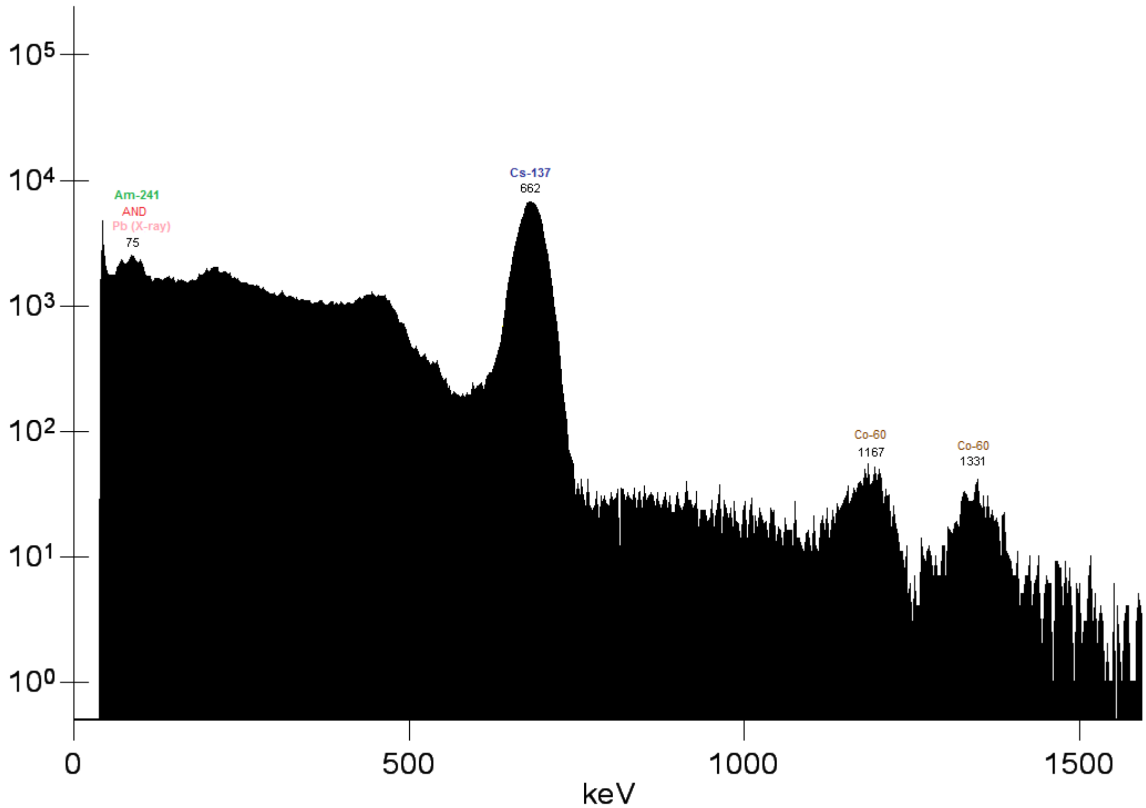
600 seconds Sample 7 measurement



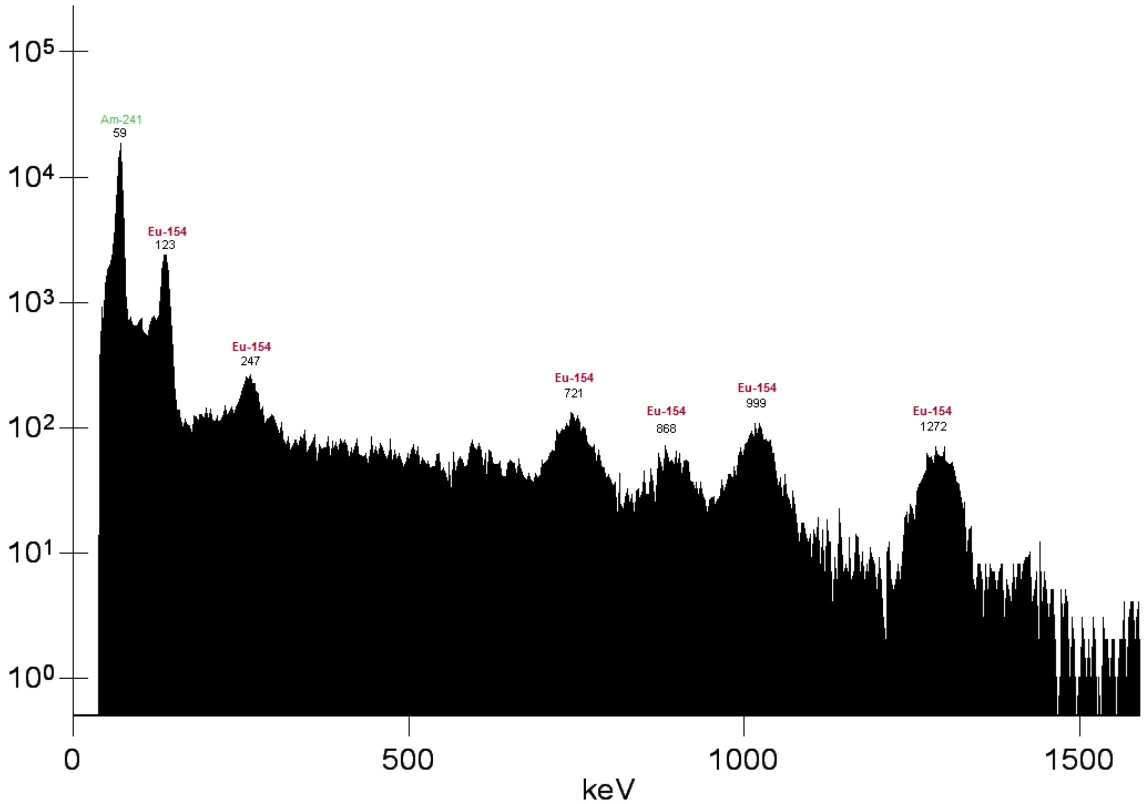
10 seconds Sample 8 measurement



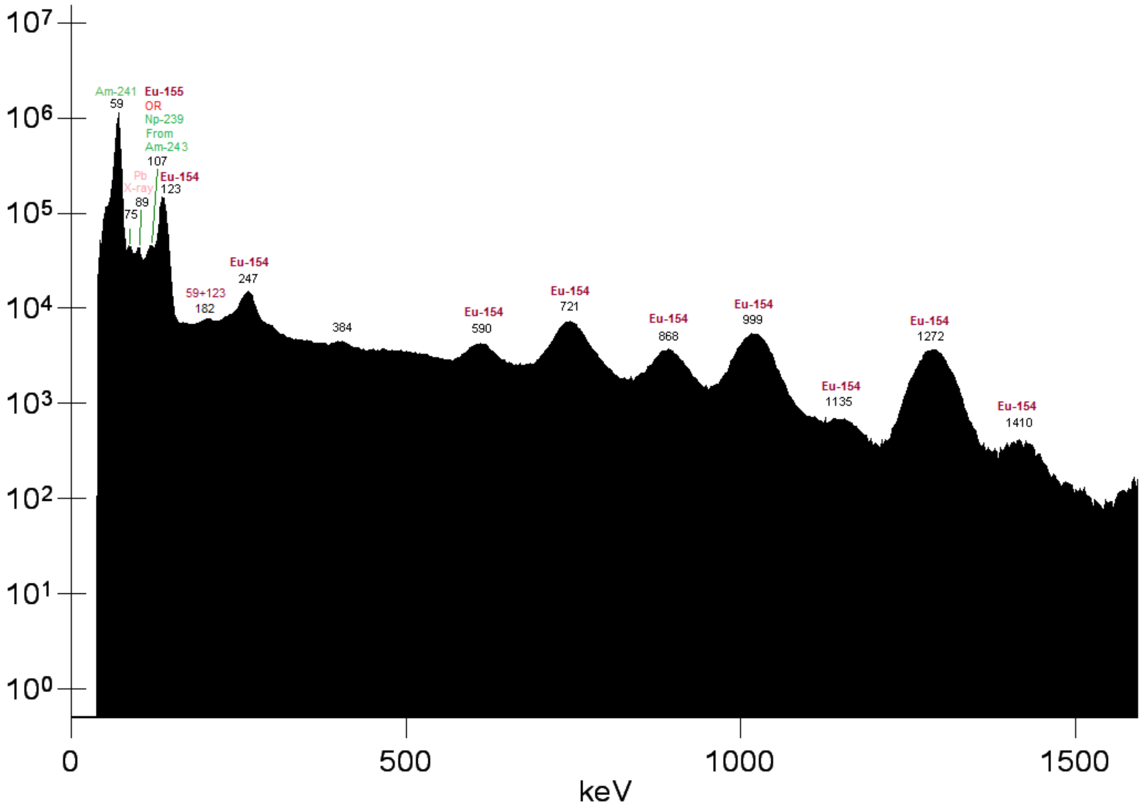
600 seconds Sample 8 measurement



10 seconds Sample 9 measurement



600 seconds Sample 9 measurement



APPENDIX E

Dead-time and identified isotopes for gamma ray measurements.

	Everything	No U, Tc	U, Tc	No U, Tc Cs, Sr	Cs, Sr	FP, Ln, Cm, Am	U, Np, Pu	FP	Ln, Cm, Am
	Fuel Dissolved	UREX Raf	Urex Prod	FPEX Raf	FPEX Prod	NPEX Raf	NPEX Prod	TRUEX Raf	TRUEX Prod
Sample #	1	2	3	4	5	6	7	8	9
NaI (2x2) 10 sec life									
Isotopes identified	Cs-137, Am-241	Cs-137, Eu-154, Am-241	none	Eu-154, Am-241	Cs-137	Eu-154, Am-241	U-237	Cs-137	Eu-154, Am-241
Dead-time	3.29%	11.27%	0.10%	7.06%	7.32%	5.39%	0.20%	0.50%	7.15%
NaI (2x2) 600 sec life									
Isotopes identified	Cs-137, Eu-154, Am-241	Cs-137, Eu-154, Am-241	U-235, Th-234	Eu-154, Am-241	Cs-137	Eu-154, Am-241	Pa-233, U-237	Co-60, Cs-137	Eu-154, Am-241
Dead-time	3.35%	11.29%	0.14%	6.85%	7.37%	5.47%	0.24%	0.52%	7.15%
LaBr (2x1.5) 10 sec life									
Isotopes identified	Cs-137, Am-241	Cs-137, Am-241	none	Eu-154, Am-241	Cs-137	Eu-154, Am-241	U-237	Cs-137	Eu-154, Am-241
Dead-time	2.72%	8.51%	0.20%	3.94%	5.39%	3.38%	0.20%	0.50%	4.31%
LaBr (2x1.5) 600 sec life									
Isotopes identified	Cs-134, Cs-137, Eu-154, Am-241	Cs-134, Cs-137, Eu-154, Am-241	Th-234	Eu-154, Am-241, Cm-243	Cs-137	Cs-137, Eu-154, Am-241, Cm-243	U-237	Co-60, Cs-137	Eu-154, Am-241, Cm-243
Dead-time	2.49%	7.69%	0.23%	3.99%	5.26%	4.04%	0.27%	0.47%	4.31%
HPGe (P-Type) 10 sec life									
Isotopes identified	Cs-137, Eu-154, Am-241	Cs-137, Eu-154, Am-241	Nothing	Eu-154, Am-241, Cm-243	Cs-137	Eu-154, Am-241, Cm-243	U-237	Cs-137	Eu-154, Am-241, Cm-243
Dead-time	12.36%	38.54%	0.00%	18.03%	23.61%	13.79%	0.20%	1.38%	19.29%
HPGe (P-Type) 600 sec life									

Isotopes identified	Cs-134, Cs-137, Eu-154, Am-241	Cs-134, Cs-137, Eu-154, Am-241	Pb-212, Th-234, U-235	Eu-154, Np-239, Am-241, Cm-243	Cs-134, Cs-137	Cs-137, Eu-154, Am-241, Cm-243	Cs-137, Pa-233, U-237, Pu-241	Co-60, Rh-106, Sb-125, Sb-126, Cs-137	Eu-154, Am-241, Cm-243
Dead-time	12.12%	38.26%	0.06%	18.08%	23.74%	13.86%	0.25%	1.41%	18.95%
HPGe (N-Type) 10 sec life									
Isotopes identified	Cs-137, Eu-154, Am-241	Cs-137, Eu-154, Am-241	Nothing	Eu-154, Am-241, Cm-243	Cs-137	Eu-154, Am-241, Cm-243	U-237	Cs-137	Eu-154, Am-241, Cm-243
Dead-time	9.67%	32.57%	0.00%	26.47%	17.90%	22.54%	1.38%	1.19%	28.83%
HPGe (N-Type) 600 sec life									
Isotopes identified	Cs-134, Cs-137, Eu-154, Am-241	Cs-134, Cs-137, Eu-154, Am-241	Pb-212, Th-234, U-235	Eu-154, Np-239, Am-241, Cm-243	Cs-134, Cs-137	Cs-137, Eu-154, Am-241, Cm-243	Cs-137, Pa-233, U-237, Pu-241	Co-60, Rh-106, Sb-125, Sb-126, Cs-137	Eu-154, Am-241, Cm-243
Dead-time	9.01%	31.06%	0.06%	26.33%	17.90%	20.41%	1.41%	1.12%	28.80%
HPGe (N-Type) 3600 sec life									
Isotopes identified	Cs-134, Cs-137, Eu-154, Am-241	Cs-134, Cs-137, Eu-154, Am-241	Cs-137,Tl-208, Pb-212, Pb-214, Bi-214, Pa-234m, Th-234, U-235, U-238	Cs-137, Eu-154, Np-239, Am-241, Cm-243	Cs-134, Cs-137	Cs-137, Eu-154, Np-239, Am-241, Cm-243	Cs-137, Pb-212, Pb-214, Bi-214, Pa-233, U-237, Pu-241	Co-60, Rh-106, Sb-125, Sb-126, Cs-134, Cs-137	Eu-154, Np-239, Am-241, Cm-243
Commercial Facility	Cs-134, Cs-137, Eu-154, Am-241	Cs-134, Cs-137, Eu-154, Am-241	Cs-137,U-235, U-237, U-238	Cs-137, Eu-154, Np-239, Am-241, Cm-243	Cs-134, Cs-137	Cs-137, Eu-154, Np-239, Am-241, Cm-243	Cs-137, U-237, Np-239, Pu-241	Co-60, Rh-106, Sb-125, Sb-126, Cs-134, Cs-137	Eu-154, Am-241, Cm-243
Dead-time	9.65%	31.39%	0.07%	25.53%	18.06%	20.13%	1.42%	1.13%	28.93%
HPGe (N-Type) 3600 sec life Zoomed									
Isotopes identified							Pb-214, Pa-233, U-237, Pu-241		
Dead-time							1.43%		
HPGe (N-Type) 7200 sec life Zoomed									
Isotopes identified							Pb-212, Pb-214, Pa-233, U-237, Pu-239, Pu-241		

Dead-time							1.43%		
HPGe (N-Type) 21600 sec life Zoomed									
Isotopes identified							Pb-212, Pb-214, Pa-233, U-237, Pu-238, Pu-239, Pu-240, Pu-241		
Commercial Facility							U-237, Pu-238, Pu-239, Pu-240, Pu-241		
Dead-time							1.39%		

APPENDIX F

List of counts and corresponding error for isotopes of interest for measurements of interest.

From sample 3 600 seconds, HPGe N-type

Energy [keV]	Isotope	ROI start	ROI end	Area [counts]	Error [%]	
186	U-235	1053	1076	427	±	5.76%

From sample 3 3600 seconds, HPGe N-type

Energy [keV]	Isotope	ROI start	ROI end	Area [counts]	Error [%]	
113	U-238	619	665	1436	±	7.13%
144	U-235	815	833	649	±	7.14%
163	U-235	928	946	275	±	13.83%
186	U-235	1053	1076	2750	±	2.27%
205	U-235	1170	1197	206	±	14.48%
662	Cs-137	3782	3803	186	±	9.77%

From sample 5 10 seconds, HPGe N-type

Energy [keV]	Isotope	ROI start	ROI end	Area [counts]	Error [%]	
662	Cs-137	3772	3810	20957	±	0.70%

From sample 5 600 seconds, HPGe N-type

Energy [keV]	Isotope	ROI start	ROI end	Area [counts]	Error [%]	
605	Cs-134	3457	3475	1335	±	8.27%
662	Cs-137	3772	3810	1254860	±	0.09%
796	Cs-134	4552	4572	964	±	6.84%

From sample 5 600 seconds, HPGe N-type

Energy [keV]	Isotope	ROI start	ROI end	Area [counts]	Error [%]	
605	Cs-134	3457	3475	8093	±	3.36%
662	Cs-137	3772	3810	7650170	±	0.04%
796	Cs-134	4552	4572	5550	±	2.92%
1365	Cs-134	7818	7839	213	±	10.83%

From sample 7 600 seconds, HPGe N-type

Energy [keV]	Isotope	ROI start	ROI end	Area [counts]	Error [%]	
148	Pu-241	844	861	97	±	16.36%
208	U-237	1182	1206	169	±	10.19%
662	Cs-137	3777	3804	89	±	11.35%

From sample 7 3600 seconds, HPGe N-type

Energy [keV]	Isotope	ROI start	ROI end	Area [counts]	Error [%]	
148	Pu-241	844	861	376	±	10.65%
208	U-237	1182	1206	1011	±	4.20%
662	Cs-137	3777	3804	519	±	4.96%

From sample 7 21600 seconds zoomed in, HPGe N-type

Energy [keV]	Isotope	ROI start	ROI end	Area [counts]	Error [%]	
129	Pu-239	1877	1918	1137	±	9.73%
148	Pu-241	2161	2201	3027	±	3.59%
153	Pu-238	2223	2256	898	±	9.86%
161	Pu-240	2337	2379	699	±	13.93%
164	Pu-241	2389	2431	595	±	15.35%
186	U-235	2704	2757	569	±	16.24%
208	U-237	3026	3081	5668	±	1.97%
268	U-237	3908	3945	507	±	10.08%
332	U-237	4859	4899	235	±	17.08%

From sample 8 10 seconds, HPGe N-type

Energy [keV]	Isotope	ROI start	ROI end	Area [counts]	Error [%]	
662	Cs-137	3777	3806	1043	±	3.15%

From sample 8 600 seconds, HPGe N-type

Energy [keV]	Isotope	ROI start	ROI end	Area [counts]	Error [%]	
177	Sb-125	998	1021	777	±	8.84%
428	Sb-125	2441	2461	863	±	7.87%
601	Sb-125	3429	3454	415	±	8.46%
622	Rh-106	3558	3575	162	±	16.35%
636	Sb-125	3635	3651	193	±	13.71%
662	Cs-137	3777	3806	60078	±	0.41%
696	Sb-126	3976	3995	202	±	10.89%

1175	Co-60	6709	6747	429	±	5.35%
1334	Co-60	7621	7661	367	±	6.00%

From sample 8 3600 seconds, HPGe N-type

Energy [keV]	Isotope	ROI start	ROI end	Area [counts]	Error [%]	
177	Sb-125	1001	1024	3829	±	4.37%
415	Sb-126	2369	2389	2525	±	6.11%
428	Sb-125	2444	2464	5084	±	3.30%
463	Sb-125	2650	2666	1652	±	9.12%
601	Sb-125	3432	3457	2041	±	4.25%
622	Rh-106	3561	3578	945	±	6.83%
636	Sb-125	3638	3654	1014	±	6.38%
662	Cs-137	3780	3809	361841	±	0.17%
696	Sb-126	3979	3998	1384	±	3.95%
797	Cs-134	4548	4584	374	±	14.85%
1175	Co-60	6712	6750	2659	±	2.22%
1334	Co-60	7624	7664	2339	±	2.23%

From sample 9 10 seconds, HPGe N-type

Energy [keV]	Isotope	ROI start	ROI end	Area [counts]	Error [%]	
228	Cm-243	1297	1323	134	±	16.25%
278	Cm-243	1576	1607	166	±	13.17%

From sample 9 600 seconds, HPGe N-type

Energy [keV]	Isotope	ROI start	ROI end	Area [counts]	Error [%]	
210	Cm-242	1192	1214	3765	±	3.71%
228	Cm-243	1297	1323	9010	±	1.87%
278	Cm-243	1576	1607	9128	±	1.88%

From sample 9 3600 seconds, HPGe N-type

Energy [keV]	Isotope	ROI start	ROI end	Area [counts]	Error [%]	
210	Cm-243	1192	1214	24531	±	1.41%
228	Cm-243	1297	1323	54218	±	0.76%
278	Cm-243	1576	1607	75122	±	0.74%
286	Cm-243	1630	1646	2639	±	8.66%

APPENDIX G

Sample MCNP deck for the gamma spectrum simulation of sample 1.

```
N-type HPGe detector with a UREX+3a sample 1
c
c  ****************************************************************************
c
c       Originally written by:
c
c            William S. Charlton, Ph.D.
c            Nuclear Engineering Teaching Laboratory
c            10100 Burnet Rd. Bldg. 159
c            University of Texas at Austin
c            Austin, TX 78758
c            charlton@mail.utexas.edu
c
c       modified by:
c
c            Braden Goddard
c            Texas A&M University
c            Nuclear Engineering Department
c            129 Zachry Engineering Center
c            3133 TAMU
c            College Station, TX 77843-3133
c            goddard.braden@gmail.com
c
c  ****************************************************************************
c
c       Date:
c
c            Initial construction= May 18, 2003
c            Initially remodified= September 23, 2008
c            Last remodified= March 25, 2009
c
c  ****************************************************************************
c
c       Overview:
c
c            This deck simulates the counting of a UREX+3a sample 1 source
c            with a N-type HPGe detector, located in ZACH 133C.
c
c            Pulse height tallies for the germanium detector are used.  The
c            tallies are separated into 11,000 evenly spaced energy bins.  This
c            is used to allow for a complete simulation of the actual detector
c            and electronics.  Gaussian energy broadening is used via the "ft8"
c            card and the "GEB" parameter.  The FWHM data used in the GEB
c            parameter was measured in (September 2008).
c
c  ****************************************************************************
c
c       Cell Cards:
c
c          -- sample vial --
500    3  -0.0012 -501 -503 +504                     imp:p=1 $air space inside vial
501    2  -2.15   -500 -705 +505 #500                imp:p=1 $vial container (Teflon)
c
c          -- lead shielding --
600    12 -11.34  +601 -705 +604 -605 +608 -611      imp:p=1 $sample stand Pb 1/2 brick
601    3  -0.0012 +600 -601 +603 -606 +609 -610      imp:p=1 $front corner air spot
602    3  -0.0012 +601 -602 +604 -605 +608 -610
                  #700 #701 #702 #703 #704 #705
                  #706 #707 #708 #709 #710 #711
                  #500 #501 #600                     imp:p=1 $air space between the detector and the
c                                                             shielding
603    12 -11.34  +600 -602 +603 -606 +607 -610
                  #700 #701 #702 #703 #704 #705
                  #706 #707 #708 #709 #710 #711
                  #500 #501 #600 #601 #602           imp:p=1 $Pb shielding
c
c          -- HPGe detector --
700    1  -2.7    +703 -704 +705 -710                imp:p=1 $can
701    6  -1.848  -703 +705 -713                     imp:p=1 $Be window
702    0          -711 -712                          imp:p=1 $annulus head
703    0          -700 +712 -708                     imp:p=1 $annulus cylinder
```

```
704    7  -5.323  -701 +707 -708 #702 #703           imp:p=1 $crystal
705    1  -2.7    +701 -702 +706 -709                imp:p=1 $clad
706    0          -701 +706 -707                     imp:p=1 $Al Mylar window
707    0          -703 +713 -706                     imp:p=1 $front gap
708    0          +702 -703 +706 -710                imp:p=1 $side gap
709    1  -2.7    +700 -702 +709 -710                imp:p=1 $Al backing
710    0          +700 -701 +708 -709                imp:p=1 $inner gap
711    0          -700 +709 -710                     imp:p=1 $backing gap
c
c         -- void --
901    0          -600:+602:-603:+606:-607:+610      imp:p=0 $universe

c  ****************************************************************************
c
c       Surface Cards:
c
c       Note: the detector geometry was taken from a different N-type detector and
c             then modified.  Some of the less critical dimensions may be slightly
c             different.
c
c         -- sample vial --
500   c/x  -0.0 -0.04 1.54                         $vial OD If problems try "-0.0 -0.03 1.54"
501   c/x  -0.0 -0.04 1.41                         $vial ID If problems try "-0.0 -0.03 1.41"
c     px   -0.00                                   $vial bottom outside see surface 705 (right up against
c                                                   detector face)
503   px   -0.13                                   $vial bottom inside (right up against detector face)
504   px   -7.35                                   $vial top inside
505   px   -7.48                                   $vial top outside
c
c         -- lead shielding -- 2.56cm=1in
600   px  -15.24                                   $Pb front outside
601   px  -10.12                                   $Pb front inside
602   px  +20.32                                   $Pb end of shielding
603   py  -10.16                                   $Pb left side outside (looking at detector)
604   py   -5.08                                   $Pb left side inside (looking at detector)
605   py   +5.08                                   $Pb right side inside (looking at detector)
606   py  +10.16                                   $Pb right side outside (looking at detector)
607   pz  -11.76                                   $Pb bottom outside
608   pz   -6.66                                   $Pb bottom inside
611   pz   -1.58                                   $pb top sample Pb 1/2 brick
609   pz   +8.58                                   $Pb top inside
610   pz  +13.66                                   $Pb top outside
c
c         -- detector surfaces --
700   cx   0.420                                   $crystal annulus
701   cx   2.375                                   $crystal OD
702   cx   2.425                                   $Al clad OD
703   cx   3.690                                   $can ID
704   cx   3.820                                   $can OD
705   px   0.0                                     $front of Be window
706   px  +0.350                                   $front of Al Mylar
707   px  +0.850                                   $front of crystal
708   px  +5.500                                   $back of crystal
709   px  +7.640                                   $front of Al back plate
710   px  +7.894                                   $back of Al back plate
711   sx  +2.54 0.420                              $rounded annulus end
712   px  +2.54                                    $end of annulus cylinder
713   px  +0.05                                    $back of Be window

c  ****************************************************************************
c
c       Data Cards:
c
mode  p                               $only considers photons
rand  seed=1                          $must use odd numbers
c
sdef   par=2 erg=d2 ext=d3 pos=-0.04 0 0 axs=1 0 0 rad=d4   $source is cell 1 with energy according to d2
c                                                             with sampling cylinder of height d3 centered at
c                                                             (0,0,0) extending in the Z-axis direction with a
c                                                             radius according to d4
c
C      ---------------------------------------------------------------
C      Photon Source Definition - generated from ORIGEN F71 file
C         total strength:  4.5881E04 gammas/second
C         discrete lines:  4.5881E04 gammas/second in 3417 lines
C                          100.00% of energy
C         multigroup bins: 0.0000E00 gammas/second in 1 bins
C                          0.00% of energy
C         not counted:     0.0000E00 gammas/second
C      ---------------------------------------------------------------
C
C      discrete lines (in MeV) and their probabilities
si2    l 2.0400E-03 2.2573E-03 2.6833E-03 3.8435E-03 3.8435E-03  $ Y-90 Nb-93m Tc-99 Sn-126 Sb-126m
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4.0295E-03 4.0295E-03 4.4187E-03 4.4300E-03 4.8275E-03  $ Sb-126 Sb-126m Cs-134 Ra-223 Cs-134
4.8275E-03 6.0000E-03 6.2058E-03 6.2058E-03 6.2058E-03  $ Ba-137m Sn-126 Pm-147 Eu-152 Eu-154
6.3000E-03 6.4565E-03 6.7131E-03 6.7131E-03 6.7131E-03  $ Th-227 Sm-151 Eu-152 Eu-154 Eu-155
7.8600E-03 7.8610E-03 8.0000E-03 9.3000E-03 1.0010E-02  $ Cm-243 Np-239 Th-227 Ac-227 Ra-223
1.0400E-02 1.0423E-02 1.1119E-02 1.1618E-02 1.1618E-02  $ Eu-155 Eu-155 U-234 Pu-238 Pu-239
1.1618E-02 1.1618E-02 1.1890E-02 1.1890E-02 1.2213E-02  $ Pu-240 Pu-242 U-237 Am-241 Bi-210
1.2213E-02 1.2213E-02 1.2614E-02 1.2614E-02 1.2614E-02  $ Bi-211 Bi-212 Tl-206 Tl-207 Tl-208
1.2614E-02 1.2614E-02 1.2614E-02 1.2614E-02 1.2614E-02  $ Tl-209 Po-210 Po-211 Po-214 Po-216
1.2700E-02 1.2760E-02 1.2969E-02 1.3024E-02 1.3024E-02  $ Eu-155 Ra-228 U-234 Pb-210 Pb-211
1.3024E-02 1.3024E-02 1.3446E-02 1.3446E-02 1.3446E-02  $ Pb-212 Pb-214 Bi-212 Bi-213 Bi-214
1.3446E-02 1.3446E-02 1.3446E-02 1.3520E-02 1.3615E-02  $ Rn-219 Rn-220 Rn-222 Ra-228 Pu-238
1.3615E-02 1.3615E-02 1.3615E-02 1.3800E-02 1.3810E-02  $ Pu-239 Pu-240 Pu-242 Eu-155 U-237
1.3876E-02 1.3944E-02 1.3944E-02 1.4316E-02 1.4316E-02  $ Fr-221 U-237 Am-241 Ra-223 Ra-224
1.4316E-02 1.4420E-02 1.4770E-02 1.4770E-02 1.5200E-02  $ Ra-226 Ra-223 Ac-225 Ac-227 Ac-227
1.5236E-02 1.5236E-02 1.5236E-02 1.5236E-02 1.5236E-02  $ Fr-223 Th-227 Th-228 Th-229 Th-230
1.5236E-02 1.5500E-02 1.5691E-02 1.5713E-02 1.5713E-02  $ Th-232 Ra-228 Y-90 Ra-225 Pa-231
1.5775E-02 1.6000E-02 1.6180E-02 1.6202E-02 1.6202E-02  $ Y-90 Sn-126 Ra-228 Ac-227 Ac-228
1.6202E-02 1.6202E-02 1.6202E-02 1.6202E-02 1.6202E-02  $ U-232 U-233 U-234 U-235 U-236
1.6202E-02 1.6390E-02 1.6521E-02 1.6615E-02 1.6702E-02  $ U-238 Pa-231 Nb-93m Nb-93m Th-231
1.6702E-02 1.6702E-02 1.6702E-02 1.7200E-02 1.7220E-02  $ Th-234 Pa-234m Np-237 Th-231 Pa-233
1.7220E-02 1.7220E-02 1.7220E-02 1.7220E-02 1.7220E-02  $ Pa-234 Pa-234m Pu-238 Pu-239 Pu-240
1.7220E-02 1.7220E-02 1.7260E-02 1.7360E-02 1.7660E-02  $ Pu-241 Pu-242 Pa-233 Th-229 Y-90
1.7700E-02 1.7750E-02 1.7750E-02 1.7750E-02 1.7750E-02  $ Sb-126m U-237 U-240 Am-241 Am-242m
1.7750E-02 1.8070E-02 1.8294E-02 1.8294E-02 1.8294E-02  $ Am-243 Th-231 Np-238 Np-239 Np-240
1.8294E-02 1.8294E-02 1.8294E-02 1.8294E-02 1.8294E-02  $ Np-240m Am-242 Cm-242 Cm-243 Cm-244
1.8294E-02 1.8294E-02 1.8615E-02 1.8780E-02 1.8800E-02  $ Cm-245 Cm-246 Nb-93m Eu-155 Ra-228
1.8852E-02 1.8950E-02 1.8983E-02 1.9150E-02 1.9279E-02  $ Am-242m Pa-231 U-234 Tc-99 Tc-99
1.9400E-02 1.9552E-02 2.0020E-02 2.0167E-02 2.0167E-02  $ Ra-228 Am-242 Th-234 Pu-238 Pu-239
2.0167E-02 2.0167E-02 2.0270E-02 2.0270E-02 2.0785E-02  $ Pu-240 Pu-242 Fr-223 Th-227 U-237
2.0785E-02 2.1020E-02 2.1540E-02 2.1578E-02 2.1645E-02  $ Am-241 Eu-155 Sm-151 Th-229 Tc-99
2.1650E-02 2.3280E-02 2.3600E-02 2.3600E-02 2.4500E-02  $ Sn-126 Sn-126 Th-229 Pa-231 Ac-227
2.4500E-02 2.4560E-02 2.5318E-02 2.5390E-02 2.5440E-02  $ Pa-231 Eu-155 U-233 Th-229 Pa-231
2.5509E-02 2.6000E-02 2.6000E-02 2.6111E-02 2.6345E-02  $ Th-231 Sn-126 Ac-225 Sn-126 U-237
2.6345E-02 2.6359E-02 2.6513E-02 2.6550E-02 2.7202E-02  $ Am-241 Sn-126 Eu-155 Th-231 Sb-126
2.7202E-02 2.7360E-02 2.7472E-02 2.7472E-02 2.7500E-02  $ Sb-126m Pa-231 Sb-126 Sb-126m Th-229
2.8540E-02 2.9192E-02 2.9300E-02 2.9374E-02 2.9458E-02  $ Pa-233 U-233 Th-231 Np-237 Cs-134
2.9490E-02 2.9580E-02 2.9580E-02 2.9702E-02 2.9779E-02  $ Th-234 Fr-223 Th-227 Sn-126 Cs-134
2.9910E-02 2.9910E-02 2.9950E-02 3.0037E-02 3.0300E-02  $ Fr-223 Th-227 Pa-231 Pu-239 Th-229
3.0770E-02 3.0970E-02 3.0970E-02 3.1100E-02 3.1100E-02  $ Nb-93m Sb-126 Sb-126m Th-229 Am-243
3.1430E-02 3.1450E-02 3.1520E-02 3.1540E-02 3.1570E-02  $ Eu-155 Th-229 U-233 Pa-231 Th-229
3.1600E-02 3.1600E-02 3.1620E-02 3.1817E-02 3.1817E-02  $ Ra-223 U-235 Th-227 Cs-134 Ba-137m
3.2183E-02 3.2194E-02 3.2194E-02 3.2300E-02 3.2730E-02  $ Am-241 Cs-134 Ba-137m U-233 Th-231
3.3195E-02 3.3195E-02 3.3320E-02 3.3500E-02 3.3593E-02  $ U-237 Am-241 Th-231 Th-227 Cs-134
3.4300E-02 3.4700E-02 3.5820E-02 3.6000E-02 3.6341E-02  $ Pa-234 U-235 Pa-231 Sn-126 Cs-134
3.6341E-02 3.6600E-02 3.7800E-02 3.7980E-02 3.8200E-02  $ Ba-137m Ac-225 Th-229 U-233 Pa-231
3.8500E-02 3.8661E-02 3.8900E-02 3.9522E-02 3.9522E-02  $ Ac-225 Pu-239 Th-231 Pm-147 Eu-152
3.9522E-02 3.9570E-02 3.9858E-02 3.9970E-02 4.0100E-02  $ Eu-154 Pa-231 Bi-212 Pa-231 Ra-225
4.0118E-02 4.0118E-02 4.0118E-02 4.0200E-02 4.0350E-02  $ Pm-147 Eu-152 Eu-154 Th-227 Pa-233
4.0410E-02 4.0750E-02 4.1400E-02 4.1550E-02 4.1650E-02  $ Pu-239 Eu-155 U-235 Th-231 Pa-233
4.1950E-02 4.1960E-02 4.2088E-02 4.2100E-02 4.2130E-02  $ Cm-245 U-235 Pu-239 Th-227 Am-242
4.2220E-02 4.2250E-02 4.2309E-02 4.2309E-02 4.2309E-02  $ Th-231 Th-229 Eu-152 Eu-154 Eu-155
4.2460E-02 4.2468E-02 4.2480E-02 4.2640E-02 4.2730E-02  $ Ac-228 U-233 Pa-231 Sn-126 Am-241
4.2820E-02 4.2824E-02 4.2824E-02 4.2824E-02 4.2860E-02  $ Th-229 Np-240 Np-240m Cm-244 Th-231
4.2996E-02 4.2996E-02 4.2996E-02 4.3050E-02 4.3100E-02  $ Eu-152 Eu-154 Eu-155 Pa-231 Am-243
4.3423E-02 4.3423E-02 4.3498E-02 4.3498E-02 4.3498E-02  $ U-237 Am-241 Pa-234 Pa-234m Pu-238
4.3530E-02 4.3800E-02 4.3990E-02 4.4080E-02 4.4080E-02  $ Am-243 Th-227 Th-229 Th-231 Np-238
4.4080E-02 4.4100E-02 4.4120E-02 4.4160E-02 4.4200E-02  $ Cm-242 U-240 Th-227 Pa-231 Pu-241
4.4430E-02 4.4540E-02 4.4545E-02 4.4663E-02 4.4665E-02  $ Th-227 Am-242 Cm-246 Cm-243 Np-239
4.4860E-02 4.4915E-02 4.5190E-02 4.5242E-02 4.5298E-02  $ Pu-241 Pu-242 Pa-234 Pu-240 Eu-155
4.5340E-02 4.5354E-02 4.5354E-02 4.5354E-02 4.6000E-02  $ Th-231 Pm-147 Eu-152 Eu-154 Sn-126
4.6204E-02 4.6370E-02 4.6500E-02 4.6520E-02 4.6520E-02  $ Pu-239 Pa-231 Ac-227 Pb-210 Th-229
4.6530E-02 4.6625E-02 4.7560E-02 4.8300E-02 4.8623E-02  $ Np-237 Pu-239 Pu-239 Th-227 Eu-152
4.8623E-02 4.8623E-02 4.8630E-02 4.9000E-02 4.9100E-02  $ Eu-154 Eu-155 Am-242m Ac-225 U-240
4.9367E-02 4.9369E-02 4.9412E-02 4.9415E-02 4.9550E-02  $ Am-242m U-236 Cm-243 Np-239 U-238
4.9750E-02 4.9863E-02 4.9863E-02 4.9863E-02 4.9880E-02  $ Th-229 Eu-152 Eu-154 Eu-155 Fr-223
4.9880E-02 5.0200E-02 5.0200E-02 5.0300E-02 5.0600E-02  $ Th-227 Fr-223 Th-227 U-240 Am-243
5.0880E-02 5.0980E-02 5.0990E-02 5.1010E-02 5.1010E-02  $ Th-227 Pa-231 Th-229 U-237 Am-241
5.1200E-02 5.1220E-02 5.1624E-02 5.2620E-02 5.2740E-02  $ Th-227 U-235 Pu-239 U-233 Pa-231
5.3200E-02 5.3200E-02 5.3226E-02 5.3608E-02 5.3740E-02  $ Th-229 U-234 Pb-214 U-233 Cm-245
5.3750E-02 5.3800E-02 5.4030E-02 5.4200E-02 5.4250E-02  $ Th-229 Ac-225 Pu-239 Th-227 U-235
5.4610E-02 5.4699E-02 5.5110E-02 5.5400E-02 5.5560E-02  $ Pa-231 U-233 Th-229 Am-243 Am-241
5.6000E-02 5.6050E-02 5.6320E-02 5.6518E-02 5.6550E-02  $ Sn-126 Th-227 Pu-241 Th-229 Th-227
5.6760E-02 5.6760E-02 5.6810E-02 5.6828E-02 5.6960E-02  $ Pa-231 Pu-241 Cm-245 Pu-239 Ac-228
5.7104E-02 5.7190E-02 5.7273E-02 5.7276E-02 5.7300E-02  $ Np-237 Pa-231 Cm-243 Np-239 Np-239
5.7300E-02 5.7750E-02 5.7759E-02 5.7762E-02 5.7800E-02  $ Cm-243 Th-234 U-232 Ac-228 Ac-225
5.7850E-02 5.7900E-02 5.7980E-02 5.8200E-02 5.8400E-02  $ Am-241 Pa-233 Eu-155 Pa-234 Eu-154
5.8570E-02 5.9537E-02 5.9537E-02 5.9600E-02 6.0010E-02  $ Th-231 U-237 Am-241 Th-227 Eu-155
6.0500E-02 6.1460E-02 6.1461E-02 6.1510E-02 6.2000E-02  $ Pa-231 Cm-243 Np-239 Th-227 Th-227
6.2500E-02 6.2590E-02 6.2700E-02 6.2860E-02 6.2900E-02  $ Th-227 Np-237 Th-227 Th-234 Ac-225
6.3000E-02 6.3000E-02 6.3000E-02 6.3290E-02 6.3670E-02  $ Pa-234 Pa-234m Pu-238 Th-234 Pa-231
6.3700E-02 6.3700E-02 6.3820E-02 6.3860E-02 6.3900E-02  $ Th-229 U-233 Th-232 Th-231 Np-237
6.4100E-02 6.4280E-02 6.4370E-02 6.4400E-02 6.4830E-02  $ Ac-225 Sn-126 U-235 Th-227 U-237
6.4830E-02 6.5360E-02 6.5502E-02 6.5723E-02 6.6000E-02  $ Am-241 Cm-245 Pb-211 Pu-239 Sn-126
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6.6122E-02 6.6200E-02 6.6400E-02 6.6500E-02 6.6898E-02  $ U-233 Th-227 Th-227 U-240 Am-242m
6.7100E-02 6.7450E-02 6.7672E-02 6.7673E-02 6.7846E-02  $ Pa-234 Am-241 Th-230 Pu-239 Np-239
6.7900E-02 6.7943E-02 6.8090E-02 6.8500E-02 6.8699E-02  $ Am-242m U-233 Th-229 Th-231 Pu-239
6.8700E-02 6.8730E-02 6.8800E-02 6.8830E-02 6.8870E-02  $ Th-227 Pu-239 Th-227 Th-229 U-233
6.9170E-02 6.9500E-02 6.9760E-02 6.9760E-02 6.9800E-02  $ Cm-245 Ac-227 U-237 Am-241 Ac-225
6.9800E-02 6.9900E-02 7.0200E-02 7.0280E-02 7.0490E-02  $ Th-227 Pa-234 Ac-227 U-233 Np-237
7.0500E-02 7.0832E-02 7.0832E-02 7.0832E-02 7.0900E-02  $ Pa-231 Bi-210 Bi-211 Bi-212 Ac-225
7.1600E-02 7.1700E-02 7.1819E-02 7.1900E-02 7.2500E-02  $ Pu-241 Ac-225 U-233 Pa-231 Pa-231
7.2700E-02 7.2739E-02 7.2751E-02 7.2805E-02 7.2805E-02  $ U-235 Th-229 Th-231 Tl-206 Tl-207
7.2805E-02 7.2805E-02 7.2805E-02 7.2805E-02 7.2805E-02  $ Tl-208 Tl-209 Po-210 Po-211 Po-214
7.2805E-02 7.2873E-02 7.2873E-02 7.2873E-02 7.2880E-02  $ Po-216 Bi-210 Bi-211 Bi-212 U-233
7.2900E-02 7.3300E-02 7.3600E-02 7.3700E-02 7.3720E-02  $ Th-227 Am-242m Ac-225 Th-227 U-235
7.3830E-02 7.3920E-02 7.4180E-02 7.4400E-02 7.4540E-02  $ Ac-225 Pa-234m Pa-231 Th-228 Np-237
7.4550E-02 7.4670E-02 7.4800E-02 7.4815E-02 7.4815E-02  $ U-233 Am-243 U-235 Pb-211 Pb-212
7.4815E-02 7.4900E-02 7.4960E-02 7.4969E-02 7.4969E-02  $ Pb-214 Ac-225 Pu-239 Tl-206 Tl-207
7.4969E-02 7.4969E-02 7.4969E-02 7.4969E-02 7.4969E-02  $ Tl-208 Tl-209 Po-210 Po-211 Po-214
7.4969E-02 7.5065E-02 7.5150E-02 7.5280E-02 7.5800E-02  $ Po-216 Th-229 Th-227 Pa-233 Am-241
7.6000E-02 7.6150E-02 7.6380E-02 7.6861E-02 7.6861E-02  $ Sn-126 Pm-147 U-233 Bi-212 Bi-213
7.6861E-02 7.6861E-02 7.6861E-02 7.6861E-02 7.7100E-02  $ Bi-214 Rn-219 Rn-220 Rn-222 Pu-241
7.7107E-02 7.7107E-02 7.7107E-02 7.7130E-02 7.7340E-02  $ Pb-211 Pb-212 Pb-214 U-233 Ac-228
7.7360E-02 7.7598E-02 7.7630E-02 7.8090E-02 7.8100E-02  $ Pa-231 Pu-239 Th-229 U-233 U-240
7.8300E-02 7.8422E-02 7.8945E-02 7.9250E-02 7.9291E-02  $ Th-229 Pu-239 Fr-221 Cm-245 Bi-212
7.9291E-02 7.9291E-02 7.9291E-02 7.9291E-02 7.9291E-02  $ Bi-213 Bi-214 Rn-219 Rn-220 Rn-222
7.9690E-02 7.9770E-02 7.9770E-02 8.0400E-02 8.1000E-02  $ Pa-234 Fr-223 Th-227 Eu-154 Pb-211
8.1067E-02 8.1067E-02 8.1067E-02 8.1228E-02 8.1516E-02  $ Ra-223 Ra-224 Ra-226 Th-231 Fr-221
8.1990E-02 8.2087E-02 8.2344E-02 8.2344E-02 8.2344E-02  $ Eu-154 Th-231 Bi-210 Bi-211 Bi-212
8.2600E-02 8.2900E-02 8.2957E-02 8.3231E-02 8.3300E-02  $ U-240 Ac-225 U-233 Ac-225 Th-234
8.3785E-02 8.3785E-02 8.3785E-02 8.3800E-02 8.4214E-02  $ Ra-223 Ra-224 Ra-226 Pb-211 Th-231
8.4300E-02 8.4373E-02 8.4685E-02 8.4685E-02 8.4685E-02  $ U-233 Th-228 Bi-210 Bi-211 Bi-212
8.4694E-02 8.4694E-02 8.4694E-02 8.4694E-02 8.4694E-02  $ Tl-206 Tl-207 Tl-208 Tl-209 Po-210
8.4694E-02 8.4694E-02 8.4694E-02 8.5430E-02 8.5438E-02  $ Po-211 Po-214 Po-216 U-233 Fr-223
8.5438E-02 8.5438E-02 8.5438E-02 8.5438E-02 8.5438E-02  $ Th-227 Th-228 Th-229 Th-230 Th-232
8.5800E-02 8.6000E-02 8.6062E-02 8.6106E-02 8.6250E-02  $ Th-231 Sn-126 Eu-155 Ac-225 Th-229
8.6400E-02 8.6477E-02 8.6543E-02 8.6590E-02 8.6680E-02  $ Th-229 Np-237 Eu-155 Pa-233 Am-242m
8.6770E-02 8.6790E-02 8.6940E-02 8.7020E-02 8.7089E-02  $ U-233 Am-243 Sn-126 Th-234 Pb-211
8.7089E-02 8.7089E-02 8.7111E-02 8.7111E-02 8.7111E-02  $ Pb-212 Pb-214 Tl-206 Tl-207 Tl-208
8.7111E-02 8.7111E-02 8.7111E-02 8.7111E-02 8.7111E-02  $ Tl-209 Po-210 Po-211 Po-214 Po-216
8.7270E-02 8.7380E-02 8.7570E-02 8.7672E-02 8.7990E-02  $ U-233 Ac-225 Sn-126 Pa-231 Np-237
8.8050E-02 8.8200E-02 8.8430E-02 8.8460E-02 8.8477E-02  $ Np-239 Pb-211 Th-229 U-233 Fr-223
8.8477E-02 8.8477E-02 8.8477E-02 8.8477E-02 8.8477E-02  $ Th-227 Th-228 Th-229 Th-230 Th-232
8.9527E-02 8.9527E-02 8.9527E-02 8.9527E-02 8.9527E-02  $ Bi-212 Bi-213 Bi-214 Rn-219 Rn-220
8.9527E-02 8.9580E-02 8.9588E-02 8.9588E-02 8.9588E-02  $ Rn-222 Cm-245 Pb-211 Pb-212 Pb-214
8.9648E-02 8.9650E-02 8.9950E-02 8.9958E-02 8.9958E-02  $ Pu-239 Tc-99 Th-231 Ac-228 U-232
8.9958E-02 8.9958E-02 8.9958E-02 8.9958E-02 8.9958E-02  $ U-233 U-234 U-235 U-236 U-238
9.0000E-02 9.0884E-02 9.1030E-02 9.2000E-02 9.2013E-02  $ Th-227 Pa-231 U-233 Pa-233 Fr-221
9.2110E-02 9.2110E-02 9.2110E-02 9.2110E-02 9.2110E-02  $ Bi-212 Bi-213 Bi-214 Rn-219 Rn-220
9.2110E-02 9.2288E-02 9.2288E-02 9.2380E-02 9.2500E-02  $ Rn-222 Th-231 Np-237 Th-234 Am-242m
9.2800E-02 9.3020E-02 9.3351E-02 9.3351E-02 9.3351E-02  $ Th-234 Th-231 Ac-228 U-232 U-233
9.3351E-02 9.3351E-02 9.3351E-02 9.3351E-02 9.3820E-02  $ U-234 U-235 U-236 U-238 Cm-245
9.4000E-02 9.4300E-02 9.4555E-02 9.4555E-02 9.4555E-02  $ Th-227 Pb-211 Ra-223 Ra-224 Ra-226
9.4640E-02 9.4659E-02 9.4659E-02 9.4659E-02 9.4659E-02  $ Np-237 Pa-233 Pa-234 Pa-234m Pu-238
9.4659E-02 9.4659E-02 9.4659E-02 9.4659E-02 9.4688E-02  $ Pu-239 Pu-240 Pu-241 Pu-242 Fr-221
9.4729E-02 9.4900E-02 9.4920E-02 9.5000E-02 9.5000E-02  $ Th-229 Ac-225 Th-229 Pb-211 Th-227
9.5868E-02 9.5868E-02 9.6000E-02 9.6090E-02 9.6100E-02  $ Th-231 Np-237 Sn-126 U-235 Th-227
9.6118E-02 9.6244E-02 9.6300E-02 9.6800E-02 9.6880E-02  $ Pu-239 U-233 Ac-225 Am-241 Pa-231
9.7077E-02 9.7077E-02 9.7077E-02 9.7077E-02 9.7077E-02  $ U-237 U-240 Am-241 Am-242m Am-243
9.7134E-02 9.7142E-02 9.7300E-02 9.7307E-02 9.7307E-02  $ U-233 Ac-225 Pb-211 Ra-223 Ra-224
9.7307E-02 9.7550E-02 9.8440E-02 9.8440E-02 9.8440E-02  $ Ra-226 Th-231 Pa-233 Pa-234 Pa-234m
9.8440E-02 9.8440E-02 9.8440E-02 9.8440E-02 9.8440E-02  $ Pu-238 Pu-239 Pu-240 Pu-241 Pu-242
9.8500E-02 9.8780E-02 9.8860E-02 9.8860E-02 9.8860E-02  $ Am-243 Pu-239 Np-240 Np-240m Cm-244
9.8970E-02 9.9278E-02 9.9497E-02 9.9500E-02 9.9500E-02  $ Am-241 Th-231 Ac-228 Fr-221 Th-227
9.9550E-02 9.9552E-02 9.9552E-02 9.9552E-02 9.9552E-02  $ Ac-225 Np-238 Np-239 Np-240 Np-240m
9.9552E-02 9.9552E-02 9.9552E-02 9.9552E-02 9.9552E-02  $ Am-242 Cm-242 Cm-243 Cm-244 Cm-245
9.9700E-02 9.9781E-02 9.9781E-02 9.9781E-02 9.9781E-02  $ Th-227 Fr-223 Th-227 Th-228 Th-229
9.9781E-02 9.9781E-02 9.9800E-02 9.9853E-02 9.9853E-02  $ Th-230 Th-232 Ac-225 Pa-234 Pa-234m
9.9853E-02 9.9984E-02 1.0000E-01 1.0003E-01 1.0030E-01  $ Pu-238 Ac-225 Ac-227 U-233 Fr-223
1.0030E-01 1.0041E-01 1.0080E-01 1.0092E-01 1.0107E-01  $ Th-227 Ac-228 Ac-225 Pa-231 U-237
1.0107E-01 1.0107E-01 1.0107E-01 1.0107E-01 1.0120E-01  $ U-240 Am-241 Am-242m Am-243 Th-229
1.0177E-01 1.0190E-01 1.0193E-01 1.0196E-01 1.0227E-01  $ U-233 Np-238 Cm-242 Cm-243 Th-231
1.0247E-01 1.0250E-01 1.0260E-01 1.0271E-01 1.0271E-01  $ Pa-231 Th-227 Pa-231 Fr-223 Th-227
1.0271E-01 1.0271E-01 1.0271E-01 1.0271E-01 1.0298E-01  $ Th-228 Th-229 Th-230 Th-232 U-237
1.0298E-01 1.0303E-01 1.0335E-01 1.0341E-01 1.0350E-01  $ Am-241 Pu-239 Th-234 Pa-234 Pu-242
1.0360E-01 1.0368E-01 1.0370E-01 1.0376E-01 1.0376E-01  $ U-233 Pu-241 Ra-223 Np-238 Np-239
1.0376E-01 1.0376E-01 1.0376E-01 1.0376E-01 1.0376E-01  $ Np-240 Np-240m Am-242 Cm-242 Cm-243
1.0376E-01 1.0376E-01 1.0380E-01 1.0386E-01 1.0423E-01  $ Cm-244 Cm-245 Ac-225 Pa-233 Pu-240
1.0454E-01 1.0500E-01 1.0521E-01 1.0521E-01 1.0521E-01  $ Th-229 Th-227 Ac-228 U-232 U-233
1.0521E-01 1.0521E-01 1.0521E-01 1.0521E-01 1.0531E-01  $ U-234 U-235 U-236 U-238 Eu-155
1.0549E-01 1.0581E-01 1.0600E-01 1.0612E-01 1.0612E-01  $ Pa-231 Th-231 Sn-126 Np-239 Cm-243
1.0615E-01 1.0648E-01 1.0650E-01 1.0661E-01 1.0672E-01  $ Np-237 Np-239 Ac-227 Th-231 Ra-223
1.0711E-01 1.0760E-01 1.0800E-01 1.0800E-01 1.0801E-01  $ Th-229 Eu-155 Th-227 Th-234 Th-231
1.0801E-01 1.0832E-01 1.0832E-01 1.0832E-01 1.0832E-01  $ Np-237 Ac-228 U-232 U-233 U-234
1.0832E-01 1.0832E-01 1.0832E-01 1.0840E-01 1.0870E-01  $ U-235 U-236 U-238 Ac-225 Np-237
1.0916E-01 1.0920E-01 1.0950E-01 1.0960E-01 1.0960E-01  $ U-235 Th-229 U-233 Th-227 Am-242m
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1.0970E-01 1.1000E-01 1.1033E-01 1.1060E-01 1.1082E-01  $ Am-241 Th-230 Th-229 Th-227 Ra-223
1.1086E-01 1.1086E-01 1.1086E-01 1.1086E-01 1.1086E-01  $ Pa-233 Pa-234 Pa-234m Pu-238 Pu-239
1.1086E-01 1.1086E-01 1.1086E-01 1.1110E-01 1.1121E-01  $ Pu-240 Pu-241 Pu-242 Am-242m Th-231
1.1121E-01 1.1150E-01 1.1200E-01 1.1260E-01 1.1275E-01  $ Np-237 Ac-225 U-233 Th-227 U-236
1.1281E-01 1.1320E-01 1.1350E-01 1.1378E-01 1.1378E-01  $ Th-234 Th-227 U-238 U-237 U-240
1.1378E-01 1.1378E-01 1.1378E-01 1.1400E-01 1.1417E-01  $ Am-241 Am-242m Am-243 Pu-241 Pa-233
1.1417E-01 1.1417E-01 1.1417E-01 1.1417E-01 1.1417E-01  $ Pa-234 Pa-234m Pu-238 Pu-239 Pu-240
1.1417E-01 1.1417E-01 1.1440E-01 1.1440E-01 1.1450E-01  $ Pu-241 Pu-242 U-233 Np-238 Ra-223
1.1456E-01 1.1518E-01 1.1530E-01 1.1537E-01 1.1540E-01  $ Ac-228 Pb-212 Th-229 Pu-239 Rn-219
1.1540E-01 1.1545E-01 1.1563E-01 1.1598E-01 1.1600E-01  $ Np-237 U-235 Th-231 Th-229 Sn-126
1.1626E-01 1.1641E-01 1.1677E-01 1.1677E-01 1.1677E-01  $ Pu-239 U-233 Np-238 Np-239 Np-240
1.1677E-01 1.1677E-01 1.1677E-01 1.1677E-01 1.1677E-01  $ Np-240m Am-242 Cm-242 Cm-243 Cm-244
1.1677E-01 1.1682E-01 1.1700E-01 1.1716E-01 1.1718E-01  $ Cm-245 Th-231 Tl-209 U-233 U-237
1.1718E-01 1.1718E-01 1.1718E-01 1.1718E-01 1.1720E-01  $ U-240 Am-241 Am-242m Am-243 Th-227
1.1730E-01 1.1760E-01 1.1770E-01 1.1799E-01 1.1820E-01  $ Th-227 Am-243 Np-237 Th-229 Fr-221
1.1897E-01 1.1969E-01 1.1990E-01 1.1990E-01 1.1998E-01  $ U-233 Pu-239 Ac-225 Np-238 Th-229
1.2026E-01 1.2026E-01 1.2026E-01 1.2026E-01 1.2026E-01  $ Np-238 Np-239 Np-240 Np-240m Am-242
1.2026E-01 1.2026E-01 1.2026E-01 1.2026E-01 1.2035E-01  $ Cm-242 Cm-243 Cm-244 Cm-245 U-235
1.2036E-01 1.2082E-01 1.2090E-01 1.2120E-01 1.2125E-01  $ Am-241 U-233 U-234 Pu-241 Pm-147
1.2150E-01 1.2178E-01 1.2180E-01 1.2231E-01 1.2235E-01  $ Ac-227 Eu-152 Am-242m Ra-223 Pu-239
1.2301E-01 1.2307E-01 1.2319E-01 1.2323E-01 1.2360E-01  $ Am-241 Eu-154 Th-229 Pu-239 Th-227
1.2363E-01 1.2380E-01 1.2389E-01 1.2443E-01 1.2450E-01  $ Pu-239 Ac-225 U-233 Np-239 Th-227
1.2450E-01 1.2455E-01 1.2460E-01 1.2465E-01 1.2470E-01  $ Pu-239 Th-229 Pa-231 Th-229 Th-227
1.2480E-01 1.2491E-01 1.2518E-01 1.2530E-01 1.2539E-01  $ Ac-225 Th-231 Pu-239 Am-241 Eu-154
1.2540E-01 1.2541E-01 1.2570E-01 1.2600E-01 1.2625E-01  $ Pa-234 U-233 Eu-152 Sn-126 Ac-225
1.2640E-01 1.2650E-01 1.2830E-01 1.2840E-01 1.2904E-01  $ Th-229 Th-229 U-240 Eu-154 Th-229
1.2907E-01 1.2907E-01 1.2920E-01 1.2930E-01 1.2950E-01  $ Ac-228 U-232 U-233 Pu-239 Eu-154
1.3067E-01 1.3110E-01 1.3120E-01 1.3120E-01 1.3120E-01  $ Rn-219 Np-237 Ra-223 Pa-234 U-233
1.3157E-01 1.3161E-01 1.3193E-01 1.3249E-01 1.3299E-01  $ Eu-154 Th-228 Th-229 Np-238 Cm-245
1.3403E-01 1.3410E-01 1.3420E-01 1.3429E-01 1.3437E-01  $ Th-231 Ac-227 Th-229 Np-237 Pa-234
1.3450E-01 1.3450E-01 1.3480E-01 1.3484E-01 1.3517E-01  $ Fr-223 Th-227 Ac-225 Eu-154 Am-242m
1.3537E-01 1.3554E-01 1.3566E-01 1.3580E-01 1.3600E-01  $ U-233 Ac-228 Th-231 Eu-154 Sn-126
1.3606E-01 1.3610E-01 1.3655E-01 1.3675E-01 1.3699E-01  $ Cm-245 Am-242m U-235 Th-231 Th-229
1.3745E-01 1.3770E-01 1.3791E-01 1.3820E-01 1.3839E-01  $ Pb-214 Pa-234 Ac-228 Ac-225 Eu-154
1.3850E-01 1.3944E-01 1.3979E-01 1.3981E-01 1.3990E-01  $ U-233 Am-241 U-233 Cm-245 Np-237
1.3990E-01 1.4010E-01 1.4030E-01 1.4030E-01 1.4050E-01  $ Np-240 Pa-234m Pa-234 Pu-238 Th-227
1.4054E-01 1.4076E-01 1.4086E-01 1.4102E-01 1.4102E-01  $ Th-231 U-235 Th-232 Ac-228 U-232
1.4130E-01 1.4130E-01 1.4165E-01 1.4200E-01 1.4200E-01  $ Pb-214 Th-227 Pu-239 Th-228 Th-229
1.4218E-01 1.4240E-01 1.4296E-01 1.4300E-01 1.4325E-01  $ Am-243 U-235 Th-229 Eu-154 Np-237
1.4368E-01 1.4377E-01 1.4387E-01 1.4400E-01 1.4400E-01  $ Pu-239 U-235 Th-230 Bi-212 Pa-234
1.4420E-01 1.4420E-01 1.4440E-01 1.4450E-01 1.4500E-01  $ Ra-223 Pu-239 U-233 Pa-231 Ac-225
1.4506E-01 1.4534E-01 1.4540E-01 1.4585E-01 1.4594E-01  $ Th-231 U-233 U-240 Ac-228 Th-231
1.4600E-01 1.4603E-01 1.4606E-01 1.4609E-01 1.4635E-01  $ Sn-126 Eu-154 Eu-155 Pu-239 U-233
1.4655E-01 1.4680E-01 1.4720E-01 1.4750E-01 1.4764E-01  $ Am-241 Th-229 Np-240 Ac-227 Th-229
1.4801E-01 1.4815E-01 1.4816E-01 1.4857E-01 1.4930E-01  $ Eu-152 Th-229 U-233 Pu-241 Sb-126
1.4983E-01 1.5000E-01 1.5000E-01 1.5004E-01 1.5004E-01  $ U-233 Fr-221 Th-227 Th-229 Am-241
1.5009E-01 1.5020E-01 1.5093E-01 1.5141E-01 1.5260E-01  $ Ac-225 Pa-234 U-235 Np-237 Ac-225
1.5263E-01 1.5263E-01 1.5272E-01 1.5272E-01 1.5275E-01  $ Np-240 Cm-244 Pa-234 Pu-238 Am-242m
1.5320E-01 1.5337E-01 1.5384E-01 1.5398E-01 1.5400E-01  $ U-233 Np-237 Am-242m Ac-228 Ac-225
1.5419E-01 1.5427E-01 1.5434E-01 1.5470E-01 1.5494E-01  $ Ra-223 Am-241 Th-229 U-233 Eu-154
1.5524E-01 1.5600E-01 1.5614E-01 1.5631E-01 1.5641E-01  $ Np-237 Sn-126 U-233 Eu-154 Th-229
1.5725E-01 1.5742E-01 1.5742E-01 1.5835E-01 1.5842E-01  $ Ac-225 Np-238 Cm-242 Pu-239 Th-229
1.5862E-01 1.5880E-01 1.5910E-01 1.5926E-01 1.5990E-01  $ Ra-223 Pu-242 Pa-234 Am-241 Eu-154
1.5995E-01 1.6019E-01 1.6031E-01 1.6040E-01 1.6145E-01  $ Pu-241 Pu-239 Pu-240 Ac-227 Pu-239
1.6154E-01 1.6160E-01 1.6209E-01 1.6220E-01 1.6241E-01  $ Am-241 Cm-245 Eu-154 Th-227 Np-237
1.6250E-01 1.6310E-01 1.6324E-01 1.6334E-01 1.6336E-01  $ U-233 Th-231 Am-242m Th-229 U-235
1.6400E-01 1.6420E-01 1.6452E-01 1.6461E-01 1.6469E-01  $ Bi-212 Pb-212 U-233 U-237 Am-241
1.6500E-01 1.6530E-01 1.6550E-01 1.6572E-01 1.6580E-01  $ Th-231 Cm-245 Ra-223 U-233 Pa-234
1.6581E-01 1.6591E-01 1.6600E-01 1.6637E-01 1.6639E-01  $ Am-241 Eu-154 Sn-126 Np-239 Cm-243
1.6641E-01 1.6698E-01 1.6745E-01 1.6781E-01 1.6830E-01  $ Th-228 Th-229 Th-229 Pu-239 Th-227
1.6865E-01 1.6900E-01 1.6905E-01 1.6916E-01 1.6920E-01  $ Ac-228 Am-243 U-233 Np-237 U-240
1.6956E-01 1.6966E-01 1.7010E-01 1.7059E-01 1.7060E-01  $ Am-241 Th-231 Th-227 Np-237 Ac-225
1.7077E-01 1.7084E-01 1.7130E-01 1.7139E-01 1.7140E-01  $ Pa-234 U-233 Fr-221 Pu-239 Th-227
1.7150E-01 1.7175E-01 1.7180E-01 1.7210E-01 1.7230E-01  $ Th-229 Th-229 Ac-227 Eu-152 U-233
1.7256E-01 1.7293E-01 1.7330E-01 1.7345E-01 1.7345E-01  $ Pu-239 Th-229 U-235 Fr-223 Th-227
1.7371E-01 1.7396E-01 1.7400E-01 1.7415E-01 1.7421E-01  $ Pu-239 Ac-228 Np-238 Th-231 U-233
1.7422E-01 1.7460E-01 1.7460E-01 1.7482E-01 1.7494E-01  $ Th-229 Pa-234 Pu-238 Th-229 Cm-245
1.7507E-01 1.7540E-01 1.7575E-01 1.7580E-01 1.7600E-01  $ Am-241 Np-240 Ra-223 Th-227 Sn-126
1.7612E-01 1.7613E-01 1.7666E-01 1.7710E-01 1.7740E-01  $ Np-237 U-233 Pb-212 Ra-223 Ra-223
1.7781E-01 1.7860E-01 1.7921E-01 1.7950E-01 1.7967E-01  $ U-233 Ac-225 Pu-239 Th-227 Ra-223
1.7976E-01 1.8073E-01 1.8081E-01 1.8171E-01 1.8230E-01  $ Th-229 Eu-154 Np-237 Np-239 Th-228
1.8261E-01 1.8350E-01 1.8393E-01 1.8430E-01 1.8454E-01  $ U-235 Th-231 Th-229 U-233 Ac-228
1.8455E-01 1.8468E-01 1.8470E-01 1.8470E-01 1.8470E-01  $ Pu-239 Eu-154 Fr-223 Th-227 Pa-234m
1.8480E-01 1.8572E-01 1.8580E-01 1.8581E-01 1.8600E-01  $ Th-234 U-235 Cm-245 U-233 Sn-126
1.8600E-01 1.8605E-01 1.8610E-01 1.8610E-01 1.8686E-01  $ Pa-234 Th-230 Ra-226 Ac-225 Np-237
1.8797E-01 1.8800E-01 1.8810E-01 1.8825E-01 1.8876E-01  $ U-233 Ac-225 Pu-239 Eu-154 Th-231
1.8935E-01 1.8970E-01 1.8982E-01 1.9040E-01 1.9135E-01  $ Pu-239 U-240 Cm-245 Am-241 Ac-228
1.9135E-01 1.9146E-01 1.9196E-01 1.9213E-01 1.9260E-01  $ U-232 Np-237 Am-241 U-233 Eu-152
1.9313E-01 1.9326E-01 1.9330E-01 1.9340E-01 1.9351E-01  $ Pu-239 Np-237 Np-240 Pa-234m Th-229
1.9360E-01 1.9430E-01 1.9494E-01 1.9495E-01 1.9500E-01  $ Pa-234 Th-229 U-235 Np-237 Am-243
1.9550E-01 1.9568E-01 1.9569E-01 1.9600E-01 1.9630E-01  $ Eu-154 Pu-239 Ac-225 Sn-126 Pb-214
1.9640E-01 1.9686E-01 1.9687E-01 1.9700E-01 1.9735E-01  $ Pa-234 Np-237 Pu-239 Am-241 Pm-147
1.9770E-01 1.9870E-01 1.9890E-01 1.9890E-01 1.9940E-01  $ Th-227 Ac-225 Pa-231 U-235 Ra-223
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1.9941E-01 1.9970E-01 1.9990E-01 1.9995E-01 2.0050E-01  $ Ac-228 Pa-234 Pa-234m Np-237 Th-227
2.0070E-01 2.0081E-01 2.0090E-01 2.0098E-01 2.0160E-01  $ U-233 Th-229 Pa-234 Pu-238 Th-227
2.0162E-01 2.0170E-01 2.0211E-01 2.0250E-01 2.0288E-01  $ Np-237 Am-241 U-235 Th-227 Eu-152
2.0290E-01 2.0290E-01 2.0290E-01 2.0330E-01 2.0355E-01  $ Pa-234 Np-237 Pu-238 Pa-234m Pu-239
2.0403E-01 2.0406E-01 2.0430E-01 2.0469E-01 2.0500E-01  $ Ac-228 Am-241 Th-227 Th-229 Fr-223
2.0500E-01 2.0510E-01 2.0532E-01 2.0593E-01 2.0598E-01  $ Th-227 Th-230 U-235 Th-228 U-233
2.0600E-01 2.0610E-01 2.0771E-01 2.0800E-01 2.0801E-01  $ Sn-126 Th-227 Eu-152 U-237 Am-241
2.0817E-01 2.0860E-01 2.0919E-01 2.0925E-01 2.0925E-01  $ U-233 Sb-126 Np-237 Ac-228 U-232
2.0940E-01 2.0949E-01 2.0975E-01 2.0975E-01 2.0990E-01  $ Eu-154 Eu-152 Np-239 Cm-243 Pa-234m
2.1000E-01 2.1015E-01 2.1060E-01 2.1065E-01 2.1070E-01  $ Cm-242 Th-229 Cm-245 Th-227 Pa-234
2.1085E-01 2.1140E-01 2.1229E-01 2.1230E-01 2.1232E-01  $ Th-229 Tl-208 Np-237 U-240 U-233
2.1246E-01 2.1257E-01 2.1260E-01 2.1270E-01 2.1401E-01  $ Pu-240 Eu-152 Th-227 Th-227 Np-237
2.1485E-01 2.1510E-01 2.1528E-01 2.1599E-01 2.1600E-01  $ Ac-228 Th-229 U-235 Th-228 Sn-126
2.1620E-01 2.1620E-01 2.1716E-01 2.1770E-01 2.1794E-01  $ Ac-225 U-233 U-233 U-233 Th-231
2.1799E-01 2.1800E-01 2.1815E-01 2.1880E-01 2.1900E-01  $ Fr-221 Pu-239 Th-229 Th-227 Th-227
2.1937E-01 2.1940E-01 2.1980E-01 2.2060E-01 2.2087E-01  $ U-233 Eu-154 Pa-234 Ra-223 Np-238
2.2122E-01 2.2138E-01 2.2146E-01 2.2156E-01 2.2180E-01  $ Th-229 U-235 Am-241 Rn-219 U-237
2.2250E-01 2.2260E-01 2.2330E-01 2.2380E-01 2.2385E-01  $ Np-240 Np-237 U-233 Sb-126 Ac-228
2.2410E-01 2.2456E-01 2.2470E-01 2.2500E-01 2.2515E-01  $ Th-231 Ac-225 Th-227 U-233 Th-229
2.2542E-01 2.2600E-01 2.2638E-01 2.2640E-01 2.2670E-01  $ Pu-239 Sn-126 Np-239 Pa-234 U-233
2.2720E-01 2.2810E-01 2.2818E-01 2.2818E-01 2.2850E-01  $ Pa-234 U-233 Np-239 Cm-243 Th-228
2.2878E-01 2.2900E-01 2.2994E-01 2.3000E-01 2.3011E-01  $ U-235 Eu-154 Np-237 Pa-231 U-233
2.3040E-01 2.3142E-01 2.3201E-01 2.3270E-01 2.3281E-01  $ Th-227 Ac-228 Eu-154 Cm-245 Am-241
2.3336E-01 2.3350E-01 2.3433E-01 2.3440E-01 2.3490E-01  $ Tl-208 U-235 Am-241 U-237 Fr-223
2.3490E-01 2.3500E-01 2.3590E-01 2.3590E-01 2.3600E-01  $ Th-227 Th-230 Pa-234m Pu-238 Sn-126
2.3600E-01 2.3601E-01 2.3625E-01 2.3642E-01 2.3700E-01  $ Th-227 Th-231 Th-229 U-233 Eu-154
2.3728E-01 2.3777E-01 2.3786E-01 2.3863E-01 2.3930E-01  $ Eu-152 Pu-239 Np-237 Pb-212 Np-240
2.3940E-01 2.4027E-01 2.4039E-01 2.4070E-01 2.4085E-01  $ Eu-152 Th-231 U-233 Ac-225 U-235
2.4099E-01 2.4191E-01 2.4208E-01 2.4220E-01 2.4227E-01  $ Ra-224 Pb-214 Pu-239 Pa-231 Th-229
2.4250E-01 2.4269E-01 2.4315E-01 2.4338E-01 2.4350E-01  $ Th-231 Cs-134 Pa-231 Pu-239 Pa-234m
2.4470E-01 2.4493E-01 2.4520E-01 2.4520E-01 2.4534E-01  $ Eu-152 Pu-239 Ra-223 Pa-234 U-233
2.4545E-01 2.4590E-01 2.4600E-01 2.4600E-01 2.4630E-01  $ Pa-231 Pa-231 Sn-126 Fr-223 Th-227
2.4673E-01 2.4684E-01 2.4770E-01 2.4794E-01 2.4850E-01  $ Am-241 U-235 Pa-234m Eu-154 Pa-233
2.4870E-01 2.4873E-01 2.4888E-01 2.4890E-01 2.4895E-01  $ Ac-225 U-233 Pu-239 Pa-234 Np-237
2.4900E-01 2.4940E-01 2.4960E-01 2.4960E-01 2.5020E-01  $ Am-241 Ra-223 Th-227 Th-231 Fr-223
2.5020E-01 2.5040E-01 2.5045E-01 2.5110E-01 2.5120E-01  $ Th-227 Th-227 Th-231 Ra-223 Cm-244
2.5147E-01 2.5150E-01 2.5163E-01 2.5180E-01 2.5243E-01  $ Np-240m U-235 Eu-152 Ra-223 Th-229
2.5253E-01 2.5255E-01 2.5261E-01 2.5350E-01 2.5373E-01  $ U-233 Th-227 Tl-208 Ac-225 Th-230
2.5380E-01 2.5441E-01 2.5442E-01 2.5470E-01 2.5500E-01  $ Th-230 Cm-243 Np-239 Th-227 Ra-223
2.5537E-01 2.5560E-01 2.5560E-01 2.5576E-01 2.5595E-01  $ Pu-239 Ra-223 U-240 Pa-231 U-233
2.5600E-01 2.5625E-01 2.5625E-01 2.5709E-01 2.5752E-01  $ Sn-126 Fr-223 Th-227 Np-237 Ac-228
2.5790E-01 2.5820E-01 2.5830E-01 2.5840E-01 2.5879E-01  $ Pa-234m Pa-233 Pu-238 Pa-231 Pb-214
2.5908E-01 2.5933E-01 2.6023E-01 2.6050E-01 2.6065E-01  $ Th-229 U-233 Pa-231 Ra-223 U-233
2.6080E-01 2.6090E-01 2.6191E-01 2.6227E-01 2.6244E-01  $ Am-241 Eu-154 U-233 Ra-226 Np-237
2.6280E-01 2.6334E-01 2.6337E-01 2.6358E-01 2.6391E-01  $ Th-227 Cm-244 Np-240m Ac-228 Pu-239
2.6489E-01 2.6540E-01 2.6560E-01 2.6572E-01 2.6600E-01  $ Am-241 Eu-154 Bi-210 Pu-239 Sn-126
2.6645E-01 2.6710E-01 2.6730E-01 2.6744E-01 2.6754E-01  $ U-235 Pa-234 Th-227 Eu-154 U-237
2.6758E-01 2.6762E-01 2.6800E-01 2.6866E-01 2.6941E-01  $ Am-241 Th-231 Th-227 U-233 Ra-223
2.6980E-01 2.6986E-01 2.7024E-01 2.7024E-01 2.7060E-01  $ Eu-154 Eu-152 Ac-228 U-232 Th-227
2.7063E-01 2.7070E-01 2.7114E-01 2.7123E-01 2.7130E-01  $ Am-241 Th-227 Eu-152 Rn-219 Np-240
2.7148E-01 2.7210E-01 2.7231E-01 2.7285E-01 2.7287E-01  $ Pa-233 Pa-234 U-233 Np-239 Cm-243
2.7300E-01 2.7324E-01 2.7370E-01 2.7400E-01 2.7410E-01  $ Th-227 Pa-231 Bi-214 Eu-154 Th-231
2.7453E-01 2.7473E-01 2.7500E-01 2.7540E-01 2.7545E-01  $ Pb-214 U-233 Th-227 Eu-154 Eu-152
2.7545E-01 2.7550E-01 2.7550E-01 2.7577E-01 2.7600E-01  $ U-235 Pa-234 Pa-234m Am-241 Sn-126
2.7732E-01 2.7736E-01 2.7760E-01 2.7760E-01 2.7790E-01  $ Pa-231 Tl-208 Np-239 Cm-243 Pa-234
2.7804E-01 2.7811E-01 2.7860E-01 2.7895E-01 2.7950E-01  $ Am-241 U-233 Sb-126 Ac-228 U-235
2.7965E-01 2.7975E-01 2.7990E-01 2.7990E-01 2.8010E-01  $ Np-237 Th-227 Eu-154 Ac-225 U-240
2.8094E-01 2.8100E-01 2.8114E-01 2.8140E-01 2.8142E-01  $ Bi-214 Th-227 Pu-239 Th-227 U-235
2.8192E-01 2.8280E-01 2.8292E-01 2.8369E-01 2.8425E-01  $ Ac-228 Fr-221 U-235 Pa-231 U-233
2.8430E-01 2.8533E-01 2.8546E-01 2.8546E-01 2.8550E-01  $ Th-227 Pu-239 Np-239 Cm-243 Ac-225
2.8550E-01 2.8598E-01 2.8600E-01 2.8610E-01 2.8615E-01  $ Th-227 Eu-152 Sn-126 Pa-234 Fr-223
2.8615E-01 2.8666E-01 2.8690E-01 2.8803E-01 2.8807E-01  $ Th-227 Pa-231 Bi-214 U-233 Bi-212
2.8817E-01 2.8921E-01 2.8921E-01 2.8950E-01 2.8950E-01  $ Ra-223 Np-240m Cm-244 Fr-223 Th-227
2.8950E-01 2.8956E-01 2.8960E-01 2.9000E-01 2.9130E-01  $ Th-229 U-235 Pa-234 Eu-154 Am-241
2.9135E-01 2.9165E-01 2.9230E-01 2.9270E-01 2.9277E-01  $ U-233 U-235 Th-227 Ra-224 U-237
2.9277E-01 2.9286E-01 2.9370E-01 2.9376E-01 2.9389E-01  $ Am-241 Bi-213 Pa-234 Rn-219 U-233
2.9430E-01 2.9480E-01 2.9510E-01 2.9517E-01 2.9520E-01  $ U-235 U-240 Bi-212 Pb-214 U-233
2.9520E-01 2.9570E-01 2.9594E-01 2.9600E-01 2.9600E-01  $ Np-240 Eu-154 Eu-152 Sn-126 Eu-154
2.9620E-01 2.9660E-01 2.9730E-01 2.9745E-01 2.9800E-01  $ Th-229 Th-227 Sb-126 Pu-239 Po-214
2.9850E-01 2.9900E-01 2.9920E-01 2.9980E-01 2.9990E-01  $ Pa-233 Pa-234m Pu-238 U-240 Th-227
3.0000E-01 3.0007E-01 3.0009E-01 3.0012E-01 3.0030E-01  $ Fr-223 Pa-231 Pb-212 Pa-233 Th-227
3.0125E-01 3.0140E-01 3.0170E-01 3.0267E-01 3.0281E-01  $ Eu-154 Np-238 U-235 Pa-231 U-233
3.0291E-01 3.0298E-01 3.0299E-01 3.0421E-01 3.0443E-01  $ Pu-239 Np-240m Cm-244 Am-241 Bi-214
3.0444E-01 3.0444E-01 3.0460E-01 3.0512E-01 3.0560E-01  $ Fr-223 Th-227 Bi-210 Eu-154 Pb-214
3.0600E-01 3.0680E-01 3.0730E-01 3.0781E-01 3.0820E-01  $ Sn-126 Np-240 Fr-223 Pu-239 Eu-154
3.0840E-01 3.0878E-01 3.0910E-01 3.0910E-01 3.0950E-01  $ Th-227 Th-231 U-237 Am-241 U-233
3.0960E-01 3.0999E-01 3.1015E-01 3.1069E-01 3.1100E-01  $ Pa-234 Np-240m Pa-231 U-235 Th-231
3.1100E-01 3.1170E-01 3.1173E-01 3.1198E-01 3.1200E-01  $ Pa-234m Cm-243 Pu-239 Pa-233 U-233
3.1228E-01 3.1250E-01 3.1266E-01 3.1266E-01 3.1294E-01  $ Eu-154 Pa-234 Fr-223 Th-227 Pa-231
3.1380E-01 3.1420E-01 3.1480E-01 3.1486E-01 3.1517E-01  $ Pb-211 Pb-214 Th-227 Th-227 Eu-152
3.1542E-01 3.1588E-01 3.1588E-01 3.1600E-01 3.1620E-01  $ Eu-154 Np-239 Cm-243 Sn-126 Eu-152
3.1630E-01 3.1630E-01 3.1644E-01 3.1680E-01 3.1710E-01  $ Pa-234 Pa-234m Pu-239 Am-241 U-235
3.1716E-01 3.1787E-01 3.1810E-01 3.1870E-01 3.1926E-01  $ U-233 Th-231 Pa-231 Th-227 Fr-223
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3.1926E-01 3.1929E-01 3.1980E-01 3.2000E-01 3.2003E-01  $ Th-227 Np-238 Pu-239 Eu-154 Eu-152
3.2015E-01 3.2054E-01 3.2070E-01 3.2087E-01 3.2165E-01  $ Th-231 U-233 Pa-234 Pu-239 Ac-228
3.2175E-01 3.2201E-01 3.2230E-01 3.2252E-01 3.2340E-01  $ Np-238 Eu-154 Cm-243 Am-241 U-233
3.2381E-01 3.2385E-01 3.2389E-01 3.2398E-01 3.2410E-01  $ Bi-213 Pu-239 Ra-223 Np-238 Fr-221
3.2430E-01 3.2479E-01 3.2500E-01 3.2580E-01 3.2600E-01  $ Pb-214 Eu-152 Th-227 U-235 Sn-126
3.2604E-01 3.2620E-01 3.2651E-01 3.2713E-01 3.2764E-01  $ Ac-228 Th-227 Cs-134 Pa-231 Ac-228
3.2796E-01 3.2800E-01 3.2800E-01 3.2800E-01 3.2804E-01  $ Bi-212 Ac-228 Pa-234 U-232 Po-211
3.2850E-01 3.2870E-01 3.2943E-01 3.2948E-01 3.2982E-01  $ Ra-223 U-233 Eu-152 Eu-154 Th-227
3.2990E-01 3.3006E-01 3.3054E-01 3.3060E-01 3.3235E-01  $ Fr-223 Pa-231 Eu-152 Pa-234 Am-241
3.3236E-01 3.3237E-01 3.3237E-01 3.3284E-01 3.3361E-01  $ U-237 Ac-228 U-232 Pu-239 Bi-214
3.3391E-01 3.3431E-01 3.3431E-01 3.3440E-01 3.3440E-01  $ Ra-223 Np-239 Cm-243 Fr-223 Th-227
3.3490E-01 3.3537E-01 3.3538E-01 3.3600E-01 3.3611E-01  $ Bi-214 Am-241 U-237 Sn-126 Pu-239
3.3638E-01 3.3638E-01 3.3662E-01 3.3770E-01 3.3770E-01  $ Np-238 Cm-242 U-233 U-237 Am-241
3.3810E-01 3.3832E-01 3.3832E-01 3.3832E-01 3.3850E-01  $ Pa-234m Ra-223 Ac-228 U-232 Bi-214
3.3870E-01 3.3890E-01 3.3980E-01 3.4045E-01 3.4048E-01  $ Fr-223 U-233 Th-227 U-237 Eu-152
3.4050E-01 3.4056E-01 3.4070E-01 3.4070E-01 3.4077E-01  $ Pa-233 Am-241 Np-240m Cm-244 Pa-231
3.4097E-01 3.4151E-01 3.4246E-01 3.4246E-01 3.4270E-01  $ Ac-228 Pu-239 Fr-223 Th-227 Pb-211
3.4290E-01 3.4350E-01 3.4428E-01 3.4501E-01 3.4550E-01  $ Ra-223 U-235 Eu-152 Pu-239 Sn-126
3.4590E-01 3.4650E-01 3.4672E-01 3.4710E-01 3.4850E-01  $ U-235 Th-227 Eu-154 Bi-214 Th-227
3.4980E-01 3.5050E-01 3.5080E-01 3.5100E-01 3.5160E-01  $ Fr-223 Th-227 Pu-239 Bi-211 Pa-231
3.5167E-01 3.5180E-01 3.5181E-01 3.5190E-01 3.5190E-01  $ Eu-152 Th-231 U-233 Pb-214 Pa-234
3.5200E-01 3.5260E-01 3.5401E-01 3.5403E-01 3.5447E-01  $ Eu-154 Th-227 U-233 Pu-239 Pa-231
3.5603E-01 3.5694E-01 3.5721E-01 3.5726E-01 3.5750E-01  $ U-235 Ac-228 Pa-231 Eu-152 Pa-234m
3.5762E-01 3.5800E-01 3.5825E-01 3.5910E-01 3.5947E-01  $ Np-238 Cm-242 Am-241 Fr-221 Pa-231
3.6100E-01 3.6145E-01 3.6155E-01 3.6184E-01 3.6250E-01  $ Fr-223 Ra-223 Np-240m Pu-239 Th-227
3.6280E-01 3.6396E-01 3.6420E-01 3.6579E-01 3.6707E-01  $ Pa-234m Pa-231 Bi-214 U-233 Pu-239
3.6779E-01 3.6821E-01 3.6856E-01 3.6859E-01 3.6865E-01  $ Eu-152 Eu-154 Pu-239 U-237 Am-241
3.6880E-01 3.6940E-01 3.6940E-01 3.6950E-01 3.6980E-01  $ Ra-223 Fr-223 Th-227 Ra-223 Pa-234
3.7071E-01 3.7090E-01 3.7094E-01 3.7094E-01 3.7184E-01  $ Eu-154 Th-227 U-237 Am-241 Ra-223
3.7240E-01 3.7257E-01 3.7450E-01 3.7505E-01 3.7513E-01  $ Pa-234 Ac-228 Th-227 Pu-239 Pa-231
3.7520E-01 3.7545E-01 3.7600E-01 3.7660E-01 3.7665E-01  $ Eu-154 Pa-233 Th-227 Bi-214 Am-241
3.7700E-01 3.7799E-01 3.7805E-01 3.7936E-01 3.7941E-01  $ Rn-219 Ac-228 Np-238 Eu-152 Pa-231
3.8000E-01 3.8017E-01 3.8029E-01 3.8180E-01 3.8200E-01  $ Rn-219 Pu-239 Np-238 Fr-221 Eu-154
3.8230E-01 3.8274E-01 3.8300E-01 3.8350E-01 3.8350E-01  $ Th-227 Pu-239 Ra-223 Th-227 U-233
3.8381E-01 3.8400E-01 3.8463E-01 3.8494E-01 3.8552E-01  $ Am-241 U-233 Ac-228 Pa-231 Eu-152
3.8700E-01 3.8725E-01 3.8760E-01 3.8782E-01 3.8790E-01  $ Bi-214 Pa-231 Pa-234m U-235 Eu-152
3.8800E-01 3.8800E-01 3.8870E-01 3.8900E-01 3.8910E-01  $ Rn-219 Ra-223 Np-240 Am-241 Bi-214
3.8912E-01 3.9030E-01 3.9062E-01 3.9100E-01 3.9132E-01  $ Ac-228 U-235 Am-241 Ra-223 Eu-152
3.9175E-01 3.9240E-01 3.9240E-01 3.9256E-01 3.9314E-01  $ Pa-231 Th-227 Np-239 Pu-239 Pu-239
3.9370E-01 3.9400E-01 3.9575E-01 3.9601E-01 3.9670E-01  $ U-233 Bi-214 Pa-231 Bi-214 U-233
3.9714E-01 3.9794E-01 3.9835E-01 3.9862E-01 3.9864E-01  $ Eu-154 Ac-228 Pa-231 Pa-233 Am-241
3.9890E-01 3.9954E-01 3.9962E-01 4.0130E-01 4.0130E-01  $ Th-227 Pu-239 Ac-228 Eu-154 Am-241
4.0174E-01 4.0240E-01 4.0260E-01 4.0355E-01 4.0420E-01  $ Rn-219 U-233 Th-227 Eu-154 Ra-224
4.0484E-01 4.0574E-01 4.0635E-01 4.0670E-01 4.0674E-01  $ Pb-211 Bi-214 Am-241 U-233 Eu-152
4.0688E-01 4.0783E-01 4.0910E-01 4.0946E-01 4.0980E-01  $ Pu-239 Pa-231 Fr-221 Ac-228 Pa-234
4.1029E-01 4.1076E-01 4.1102E-01 4.1112E-01 4.1244E-01  $ U-235 Pa-231 Pu-239 Eu-152 Pu-239
4.1371E-01 4.1430E-01 4.1450E-01 4.1460E-01 4.1480E-01  $ Pu-239 Eu-154 Sb-126m Ra-226 Sb-126
4.1520E-01 4.1520E-01 4.1576E-01 4.1588E-01 4.1605E-01  $ Pb-212 Th-227 Pa-233 Am-241 Eu-152
4.1630E-01 4.1630E-01 4.1640E-01 4.1920E-01 4.1933E-01  $ Ac-228 Pa-234 U-233 Np-240 Am-241
4.1940E-01 4.1942E-01 4.2114E-01 4.2204E-01 4.2208E-01  $ Eu-154 Ac-228 Np-238 Ra-224 Eu-154
4.2260E-01 4.2345E-01 4.2647E-01 4.2650E-01 4.2667E-01  $ Pu-239 Eu-152 Am-241 Bi-214 Pu-239
4.2680E-01 4.2699E-01 4.2810E-01 4.2980E-01 4.2994E-01  $ Pa-234 Pb-211 Pu-239 Np-239 Am-241
4.3000E-01 4.3019E-01 4.3050E-01 4.3178E-01 4.3240E-01  $ Pb-211 Pu-239 Ra-223 Eu-154 Th-227
4.3260E-01 4.3280E-01 4.3300E-01 4.3350E-01 4.3490E-01  $ Ra-223 Pa-234 U-235 Bi-212 Np-239
4.3538E-01 4.3590E-01 4.3660E-01 4.3817E-01 4.3820E-01  $ Pa-231 Eu-154 U-233 Pa-231 Rn-219
4.3880E-01 4.3897E-01 4.4040E-01 4.4042E-01 4.4045E-01  $ Po-215 Pa-231 Bi-214 Bi-213 Ac-228
4.4086E-01 4.4281E-01 4.4398E-01 4.4444E-01 4.4494E-01  $ Eu-152 Am-241 Eu-152 Eu-154 Ra-223
4.4574E-01 4.4643E-01 4.4650E-01 4.4682E-01 4.4800E-01  $ Pu-239 Am-241 Pa-234 Pu-239 Th-227
4.4801E-01 4.4820E-01 4.4840E-01 4.4915E-01 4.4937E-01  $ Np-240 Np-239 U-235 Ac-228 Ra-226
4.4960E-01 4.5120E-01 4.5148E-01 4.5240E-01 4.5247E-01  $ U-233 Pa-234m Pu-239 Ac-225 Ac-228
4.5260E-01 4.5270E-01 4.5283E-01 4.5360E-01 4.5466E-01  $ Am-241 Th-227 Bi-212 Pa-234m Am-241
4.5477E-01 4.5495E-01 4.5510E-01 4.5670E-01 4.5717E-01  $ Bi-214 U-234 U-235 Pa-234m Ac-228
4.5750E-01 4.5765E-01 4.5880E-01 4.5968E-01 4.5980E-01  $ Th-227 Pu-239 Pa-234 Am-241 U-233
4.5980E-01 4.5980E-01 4.6020E-01 4.6126E-01 4.6180E-01  $ Np-238 Cm-242 Eu-154 Pu-239 Pa-234
4.6190E-01 4.6200E-01 4.6210E-01 4.6301E-01 4.6322E-01  $ Np-239 Th-227 Pb-214 Ac-228 Am-241
4.6371E-01 4.6390E-01 4.6640E-01 4.6650E-01 4.6670E-01  $ Pu-239 Eu-154 Ac-228 Th-227 Np-240
4.6700E-01 4.6750E-01 4.6792E-01 4.6810E-01 4.6812E-01  $ Tl-209 Pa-234 Eu-154 Pa-234m Am-241
4.6969E-01 4.6980E-01 4.7025E-01 4.7060E-01 4.7130E-01  $ Bi-214 Np-239 Ac-228 Pb-214 U-233
4.7176E-01 4.7210E-01 4.7350E-01 4.7350E-01 4.7430E-01  $ Ac-228 Pa-234 Bi-212 Pa-234 Pu-239
4.7438E-01 4.7475E-01 4.7500E-01 4.7535E-01 4.7550E-01  $ Bi-214 Ac-228 Np-240m Cs-134 Pa-234m
4.7800E-01 4.7826E-01 4.7830E-01 4.7830E-01 4.7870E-01  $ Pb-211 Eu-154 Ac-228 U-232 Pa-234
4.7870E-01 4.8000E-01 4.8040E-01 4.8042E-01 4.8050E-01  $ U-233 Th-227 Pa-234 Pb-214 Ac-225
4.8061E-01 4.8094E-01 4.8110E-01 4.8152E-01 4.8200E-01  $ Eu-154 Ac-228 Pb-211 Pu-239 Th-227
4.8230E-01 4.8250E-01 4.8374E-01 4.8410E-01 4.8430E-01  $ Eu-152 Pa-234 Eu-154 U-233 Np-239
4.8464E-01 4.8591E-01 4.8595E-01 4.8636E-01 4.8683E-01  $ Eu-154 Am-241 Tl-208 Eu-154 Pa-231
4.8702E-01 4.8708E-01 4.8730E-01 4.8760E-01 4.8826E-01  $ Pu-239 Pb-214 Am-241 Ra-223 Eu-154
4.8866E-01 4.9033E-01 4.9090E-01 4.9200E-01 4.9210E-01  $ Eu-152 Ac-228 Pa-231 Pb-211 Np-239
4.9237E-01 4.9270E-01 4.9310E-01 4.9314E-01 4.9350E-01  $ Ac-228 Bi-212 Th-227 Pu-239 Eu-152
4.9460E-01 4.9639E-01 4.9670E-01 4.9700E-01 4.9749E-01  $ Bi-214 Eu-152 Np-240m Pu-239 Ac-228
4.9780E-01 4.9880E-01 4.9890E-01 5.0040E-01 5.0140E-01  $ Np-239 Np-239 Pa-234 Pb-211 Pa-231
5.0220E-01 5.0330E-01 5.0339E-01 5.0350E-01 5.0382E-01  $ Bi-214 Pb-211 Eu-152 U-234 Ac-228
5.0382E-01 5.0640E-01 5.0680E-01 5.0690E-01 5.0720E-01  $ U-232 Eu-154 Pa-234 Cm-244 Np-240
5.0720E-01 5.0740E-01 5.0750E-01 5.0820E-01 5.0896E-01  $ Np-240m Th-227 Pa-234m U-234 Ac-228
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5.0920E-01 5.0988E-01 5.1000E-01 5.1000E-01 5.1077E-01  $ Pa-234m Eu-154 Rn-222 Pa-231 Tl-208
5.1100E-01 5.1100E-01 5.1203E-01 5.1250E-01 5.1360E-01  $ Eu-152 Pb-214 Eu-154 Am-241 Pa-234
5.1370E-01 5.1400E-01 5.1500E-01 5.1506E-01 5.1525E-01  $ Pa-234 Am-241 Ac-225 Ac-228 Cm-242
5.1550E-01 5.1620E-01 5.1640E-01 5.1720E-01 5.1720E-01  $ Np-238 Pa-231 Th-227 Rn-219 Pa-234m
5.1720E-01 5.1800E-01 5.1820E-01 5.2015E-01 5.2020E-01  $ U-235 Eu-154 Np-240m Ac-228 Pa-234
5.2023E-01 5.2040E-01 5.2100E-01 5.2206E-01 5.2313E-01  $ Eu-152 Bi-214 Pa-234 Am-241 Eu-152
5.2313E-01 5.2430E-01 5.2500E-01 5.2590E-01 5.2639E-01  $ Ac-228 Th-227 Bi-214 Pa-234m Pu-239
5.2660E-01 5.2689E-01 5.2730E-01 5.2800E-01 5.2917E-01  $ Ac-225 Eu-152 Ra-223 Pa-234 Am-241
5.3284E-01 5.3305E-01 5.3320E-01 5.3369E-01 5.3425E-01  $ Eu-154 Eu-154 Pa-234 Pb-214 Eu-152
5.3500E-01 5.3506E-01 5.3540E-01 5.3560E-01 5.3694E-01  $ Th-227 Eu-154 Eu-152 Pa-231 Bi-214
5.3700E-01 5.3710E-01 5.3811E-01 5.3820E-01 5.3829E-01  $ Th-227 Pa-234 Pu-240 Rn-219 Eu-152
5.3870E-01 5.3880E-01 5.4030E-01 5.4076E-01 5.4340E-01  $ Pb-214 Pu-239 U-233 Ac-228 Bi-214
5.4410E-01 5.4410E-01 5.4510E-01 5.4540E-01 5.4560E-01  $ Pb-214 Pa-234m U-233 Am-241 Eu-154
5.4645E-01 5.4645E-01 5.4690E-01 5.4710E-01 5.4873E-01  $ Ac-228 U-232 Pa-231 Bi-214 Ac-228
5.4973E-01 5.5053E-01 5.5180E-01 5.5240E-01 5.5450E-01  $ Rn-220 Pu-239 Th-230 Th-227 Cm-244
5.5460E-01 5.5512E-01 5.5520E-01 5.5600E-01 5.5650E-01  $ Np-240m Ac-228 Sb-126 Pa-234m Th-227
5.5656E-01 5.5700E-01 5.5730E-01 5.5730E-01 5.5756E-01  $ Eu-152 Pa-234 Pa-234m Pu-239 Eu-154
5.5810E-01 5.6102E-01 5.6111E-01 5.6120E-01 5.6250E-01  $ Eu-152 Cm-242 Np-238 Eu-152 Ac-228
5.6305E-01 5.6323E-01 5.6370E-01 5.6402E-01 5.6590E-01  $ Am-241 Cs-134 Rn-219 Eu-152 Pa-234
5.6634E-01 5.6642E-01 5.6870E-01 5.6900E-01 5.6923E-01  $ Np-240 Eu-152 Pa-234 Th-227 Eu-154
5.6931E-01 5.6940E-01 5.6950E-01 5.6970E-01 5.7050E-01  $ Cs-134 U-233 Pa-234 Po-211 Th-230
5.7091E-01 5.7183E-01 5.7200E-01 5.7229E-01 5.7240E-01  $ Ac-228 Eu-152 Pa-234m Ac-228 Pa-231
5.7283E-01 5.7300E-01 5.7340E-01 5.7394E-01 5.7400E-01  $ Bi-214 Sb-126 Np-240m Am-241 Pa-234
5.7570E-01 5.7600E-01 5.7850E-01 5.7850E-01 5.7940E-01  $ Th-227 Bi-212 Th-227 U-233 Pu-239
5.8015E-01 5.8070E-01 5.8170E-01 5.8200E-01 5.8260E-01  $ Pb-214 Np-240m U-234 Eu-154 Am-241
5.8280E-01 5.8300E-01 5.8319E-01 5.8341E-01 5.8390E-01  $ Pu-239 Pa-231 Tl-208 Ac-228 Np-240
5.8580E-01 5.8609E-01 5.8629E-01 5.8659E-01 5.8770E-01  $ Pa-234 Pu-239 Eu-152 Am-241 Tl-208
5.8900E-01 5.9028E-01 5.9181E-01 5.9300E-01 5.9583E-01  $ Th-227 Am-241 Eu-154 Sb-126 Pu-239
5.9600E-01 5.9600E-01 5.9720E-01 5.9740E-01 5.9748E-01  $ Bi-214 Th-227 Cm-244 Np-240m Am-241
5.9750E-01 5.9798E-01 5.9831E-01 5.9860E-01 5.9960E-01  $ Eu-154 Pu-239 Eu-154 Ra-223 Pu-239
6.0000E-01 6.0057E-01 6.0066E-01 6.0280E-01 6.0281E-01  $ Eu-154 Np-240 Ra-226 Pa-234 Eu-154
6.0470E-01 6.0504E-01 6.0513E-01 6.0580E-01 6.0610E-01  $ Cs-134 Cm-242 Np-238 Cm-244 Np-240
6.0610E-01 6.0690E-01 6.0750E-01 6.0830E-01 6.0890E-01  $ Np-240m Pu-239 Th-227 Rn-219 Pu-239
6.0900E-01 6.0910E-01 6.0932E-01 6.0950E-01 6.1064E-01  $ Pa-231 Ra-223 Bi-214 Pb-211 Ac-228
6.1150E-01 6.1200E-01 6.1283E-01 6.1326E-01 6.1578E-01  $ Pa-234 Eu-154 Pu-239 Eu-154 Bi-214
6.1605E-01 6.1620E-01 6.1622E-01 6.1710E-01 6.1710E-01  $ Eu-152 Pa-234 Ac-228 Bi-214 Pu-239
6.1722E-01 6.1736E-01 6.1833E-01 6.1901E-01 6.1928E-01  $ Cm-242 Np-238 Pu-239 Am-241 Pu-239
6.2000E-01 6.2000E-01 6.2020E-01 6.2037E-01 6.2040E-01  $ Sb-126m Th-230 Sb-126 Ac-228 Bi-212
6.2052E-01 6.2090E-01 6.2140E-01 6.2327E-01 6.2340E-01  $ Eu-154 U-233 Th-227 Ac-228 Ra-223
6.2360E-01 6.2380E-01 6.2440E-01 6.2460E-01 6.2475E-01  $ Pa-234 Th-227 U-234 Pa-234m Pu-239
6.2522E-01 6.2640E-01 6.2718E-01 6.2723E-01 6.2750E-01  $ Eu-154 Bi-214 Am-241 Ac-228 Pa-234
6.2940E-01 6.3060E-01 6.3109E-01 6.3120E-01 6.3230E-01  $ Ac-228 Pa-234 Am-243 Bi-214 Th-227
6.3293E-01 6.3309E-01 6.3314E-01 6.3350E-01 6.3418E-01  $ Am-241 Pu-239 Bi-214 Np-240 Ac-228
6.3450E-01 6.3779E-01 6.3937E-01 6.3970E-01 6.3970E-01  $ Pa-234 Pu-239 Bi-214 Sb-126 Pa-234
6.3997E-01 6.4034E-01 6.4100E-01 6.4147E-01 6.4235E-01  $ Pu-239 Ac-228 Th-227 Am-241 Pu-240
6.4240E-01 6.4320E-01 6.4420E-01 6.4438E-01 6.4550E-01  $ Eu-154 Pa-234 Th-227 Eu-152 Ra-224
6.4590E-01 6.4600E-01 6.4770E-01 6.4850E-01 6.4884E-01  $ Pu-239 Pa-234 Pa-234m Th-227 Ac-228
6.4900E-01 6.4918E-01 6.4931E-01 6.4944E-01 6.5010E-01  $ Pa-234m Bi-214 Pu-239 Eu-154 Tl-208
6.5053E-01 6.5060E-01 6.5149E-01 6.5205E-01 6.5302E-01  $ Pu-239 Eu-154 Ac-228 Pu-239 Am-241
6.5370E-01 6.5481E-01 6.5500E-01 6.5530E-01 6.5630E-01  $ Pa-234 Pu-239 Pa-234 Pa-234m Sb-126
6.5648E-01 6.5700E-01 6.5800E-01 6.5886E-01 6.5981E-01  $ Eu-152 U-233 Pa-234 Pu-239 Bi-213
6.6010E-01 6.6060E-01 6.6070E-01 6.6140E-01 6.6166E-01  $ Ac-228 Pa-234 Eu-154 Bi-214 Ba-137m
6.6224E-01 6.6240E-01 6.6310E-01 6.6382E-01 6.6454E-01  $ Am-243 Am-241 Th-227 Ac-228 Pu-239
6.6468E-01 6.6478E-01 6.6480E-01 6.6545E-01 6.6610E-01  $ Eu-154 Eu-152 Pa-234 Bi-214 Sb-126m
6.6630E-01 6.6645E-01 6.6650E-01 6.6670E-01 6.6820E-01  $ Sb-126 Ac-228 Am-241 Pa-234 Pu-239
6.6890E-01 6.6983E-01 6.6990E-01 6.7080E-01 6.7080E-01  $ Eu-154 Am-241 Pa-234 Pa-234m Pu-239
6.7115E-01 6.7200E-01 6.7390E-01 6.7400E-01 6.7463E-01  $ Eu-152 Ac-228 Pa-234m Pu-239 Ac-228
6.7468E-01 6.7500E-01 6.7500E-01 6.7603E-01 6.7659E-01  $ Eu-152 Sb-126 Pb-211 Am-241 Eu-154
6.7700E-01 6.7711E-01 6.7760E-01 6.7858E-01 6.8010E-01  $ Rn-219 Ac-228 U-234 Eu-152 Am-241
6.8322E-01 6.8330E-01 6.8332E-01 6.8340E-01 6.8597E-01  $ Bi-214 Pa-234 Eu-152 Pa-234m Pu-239
6.8661E-01 6.8700E-01 6.8759E-01 6.8770E-01 6.8810E-01  $ Eu-152 Pa-234 Pu-240 Bi-214 Ac-228
6.8810E-01 6.8868E-01 6.8872E-01 6.9072E-01 6.9100E-01  $ Pu-239 Eu-152 Am-241 Pu-239 Pa-234m
6.9200E-01 6.9241E-01 6.9270E-01 6.9320E-01 6.9330E-01  $ Th-227 Eu-154 Pa-234 Pu-239 Bi-214
6.9362E-01 6.9480E-01 6.9500E-01 6.9550E-01 6.9660E-01  $ Am-241 Sb-126m Sb-126 Pa-234m Am-241
6.9700E-01 6.9777E-01 6.9790E-01 6.9900E-01 6.9900E-01  $ Sb-126 Pu-239 Bi-214 Pa-234 Pa-234m
6.9908E-01 6.9960E-01 7.0050E-01 7.0101E-01 7.0160E-01  $ Ac-228 Pu-239 Th-228 Pu-239 Pa-234m
7.0170E-01 7.0175E-01 7.0311E-01 7.0323E-01 7.0368E-01  $ Eu-154 Ac-228 Bi-214 Eu-152 Pu-239
7.0430E-01 7.0450E-01 7.0520E-01 7.0610E-01 7.0610E-01  $ Th-227 Pb-211 Tl-208 Pa-234 Pu-238
7.0630E-01 7.0720E-01 7.0741E-01 7.0750E-01 7.0820E-01  $ Pa-234m Th-227 Ac-228 U-233 Pa-234m
7.0842E-01 7.0842E-01 7.0945E-01 7.1080E-01 7.1120E-01  $ Pa-234 Pu-238 Am-241 Bi-214 Ra-223
7.1250E-01 7.1285E-01 7.1296E-01 7.1456E-01 7.1576E-01  $ Pa-234 Eu-152 Pu-239 Pu-239 Eu-154
7.1776E-01 7.1848E-01 7.1850E-01 7.1935E-01 7.1986E-01  $ Pu-239 Ac-228 Th-227 Eu-152 Bi-214
7.2030E-01 7.2050E-01 7.2050E-01 7.2201E-01 7.2204E-01  $ Pu-239 Sb-126 Pa-234m Am-241 Tl-208
7.2210E-01 7.2330E-01 7.2340E-01 7.2360E-01 7.2360E-01  $ Th-227 Eu-154 Bi-214 Fr-223 Th-227
7.2686E-01 7.2718E-01 7.2730E-01 7.2780E-01 7.2781E-01  $ Ac-228 Bi-212 Eu-154 Bi-214 Pu-239
7.2803E-01 7.2972E-01 7.3150E-01 7.3250E-01 7.3300E-01  $ Eu-152 Am-241 Am-241 Pa-234m Pa-234
7.3365E-01 7.3440E-01 7.3540E-01 7.3550E-01 7.3591E-01  $ Bi-214 Th-227 Eu-152 Th-227 Pu-239
7.3734E-01 7.3765E-01 7.3772E-01 7.3800E-01 7.3840E-01  $ Am-241 Eu-154 Ac-228 Pa-234 Th-227
7.4010E-01 7.4150E-01 7.4180E-01 7.4250E-01 7.4270E-01  $ Pa-234m Bi-214 Th-228 U-235 Pu-239
7.4281E-01 7.4281E-01 7.4281E-01 7.4290E-01 7.4640E-01  $ Pa-234 Pa-234m Pu-238 Am-241 Fr-223
7.4640E-01 7.4650E-01 7.4797E-01 7.4850E-01 7.4870E-01  $ Th-227 Pa-234 Pu-239 Th-227 Tl-208
7.5070E-01 7.5284E-01 7.5400E-01 7.5400E-01 7.5532E-01  $ Pa-234m Bi-214 Fr-223 Th-227 Ac-228
7.5560E-01 7.5590E-01 7.5612E-01 7.5622E-01 7.5687E-01  $ Pa-234 Am-241 Eu-152 Pu-239 Eu-154
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7.5690E-01 7.5690E-01 7.5860E-01 7.5861E-01 7.5938E-01  $ Fr-223 Th-227 Cm-244 Np-240m Am-241
7.6000E-01 7.6030E-01 7.6220E-01 7.6313E-01 7.6361E-01  $ Pa-234 Pa-234m Th-227 Tl-208 Pu-239
7.6390E-01 7.6490E-01 7.6550E-01 7.6600E-01 7.6630E-01  $ Am-241 Eu-152 Pa-234 Pb-214 Fr-223
7.6630E-01 7.6634E-01 7.6636E-01 7.6641E-01 7.6641E-01  $ Th-227 Pb-211 Pa-234m Pa-234 Pu-238
7.6647E-01 7.6700E-01 7.6836E-01 7.6870E-01 7.6895E-01  $ Pu-239 Am-241 Bi-214 Pa-234 Eu-152
7.6919E-01 7.7057E-01 7.7229E-01 7.7240E-01 7.7300E-01  $ Pu-239 Am-241 Ac-228 Am-241 Th-227
7.7410E-01 7.7410E-01 7.7440E-01 7.7530E-01 7.7530E-01  $ Ac-228 U-232 Eu-154 Fr-223 Th-227
7.7656E-01 7.7710E-01 7.7720E-01 7.7790E-01 7.7892E-01  $ Ac-228 Pu-239 Am-241 Pa-234 Eu-152
7.7943E-01 7.8050E-01 7.8070E-01 7.8070E-01 7.8214E-01  $ Pu-239 Th-227 Pa-234 Am-241 Ac-228
7.8220E-01 7.8230E-01 7.8310E-01 7.8310E-01 7.8310E-01  $ Am-241 Pa-234m Pa-234 Pa-234m Pu-238
7.8420E-01 7.8420E-01 7.8542E-01 7.8591E-01 7.8600E-01  $ Fr-223 Th-227 Bi-212 Pb-214 Am-241
7.8610E-01 7.8627E-01 7.8627E-01 7.8627E-01 7.8690E-01  $ Bi-214 Pa-234 Pa-234m Pu-238 Pu-239
7.8740E-01 7.8740E-01 7.8850E-01 7.8917E-01 7.8959E-01  $ Fr-223 Th-227 Pu-239 Am-241 Np-240m
7.9012E-01 7.9149E-01 7.9260E-01 7.9260E-01 7.9261E-01  $ Eu-154 Ac-228 Fr-223 Th-227 Pu-239
7.9350E-01 7.9360E-01 7.9470E-01 7.9478E-01 7.9492E-01  $ Pa-234m Pa-234 U-235 Eu-152 Am-241
7.9495E-01 7.9585E-01 7.9630E-01 7.9680E-01 7.9680E-01  $ Ac-228 Cs-134 Pa-234 Fr-223 Th-227
7.9690E-01 7.9970E-01 7.9976E-01 8.0020E-01 8.0193E-01  $ Pu-239 Po-214 Bi-214 Eu-154 Cs-134
8.0194E-01 8.0310E-01 8.0310E-01 8.0320E-01 8.0350E-01  $ Am-241 Tl-206 Po-210 Pu-239 Fr-223
8.0350E-01 8.0430E-01 8.0490E-01 8.0565E-01 8.0572E-01  $ Th-227 Pa-234 Po-216 Pu-239 Eu-152
8.0580E-01 8.0580E-01 8.0600E-01 8.0617E-01 8.0626E-01  $ Pa-234 Pu-238 Pa-234m Bi-214 Am-241
8.0735E-01 8.0750E-01 8.0820E-01 8.0821E-01 8.0825E-01  $ Bi-213 Th-227 Pa-234m Pu-239 Pa-234
8.0825E-01 8.1046E-01 8.1201E-01 8.1220E-01 8.1220E-01  $ Pu-238 Eu-152 Am-241 Fr-223 Th-227
8.1250E-01 8.1341E-01 8.1350E-01 8.1377E-01 8.1508E-01  $ Pa-234 Np-240m Pu-239 Ac-228 Bi-214
8.1555E-01 8.1600E-01 8.1671E-01 8.1671E-01 8.1780E-01  $ Eu-154 Pu-239 Ac-228 U-232 Cm-244
8.1789E-01 8.1800E-01 8.1820E-01 8.1900E-01 8.1960E-01  $ Np-240m Th-227 Pa-234m Am-241 Pa-234
8.2118E-01 8.2120E-01 8.2120E-01 8.2130E-01 8.2260E-01  $ Bi-214 Tl-208 Np-240 Pu-239 Am-241
8.2310E-01 8.2310E-01 8.2494E-01 8.2560E-01 8.2600E-01  $ Fr-223 Th-227 Ac-228 Pa-234m Fr-223
8.2600E-01 8.2620E-01 8.2630E-01 8.2680E-01 8.2850E-01  $ Th-227 Bi-214 Pa-234 Pu-239 Th-227
8.2850E-01 8.2890E-01 8.3038E-01 8.3049E-01 8.3150E-01  $ Am-241 Pu-239 Eu-154 Ac-228 Pa-234m
8.3160E-01 8.3183E-01 8.3200E-01 8.3235E-01 8.3250E-01  $ Pa-234 Pb-211 Th-228 Bi-214 Pu-239
8.3300E-01 8.3560E-01 8.3571E-01 8.3701E-01 8.3711E-01  $ Rn-219 Am-241 Ac-228 Cm-242 Np-238
8.3730E-01 8.3730E-01 8.3730E-01 8.3760E-01 8.3903E-01  $ Fr-223 Th-227 Pu-239 Np-240m Pb-214
8.3937E-01 8.4025E-01 8.4038E-01 8.4111E-01 8.4150E-01  $ Eu-152 Pu-239 Ac-228 Np-240m Am-241
8.4159E-01 8.4190E-01 8.4220E-01 8.4220E-01 8.4379E-01  $ Eu-152 Pa-234 Fr-223 Th-227 Pu-239
8.4410E-01 8.4440E-01 8.4539E-01 8.4670E-01 8.4670E-01  $ Pa-234m Pa-234 Eu-154 Fr-223 Th-227
8.4702E-01 8.4720E-01 8.4740E-01 8.4870E-01 8.4870E-01  $ Cs-134 Bi-214 Am-241 Fr-223 Th-227
8.5064E-01 8.5160E-01 8.5170E-01 8.5170E-01 8.5190E-01  $ Eu-154 Am-241 Pa-234 Pu-238 Pa-234m
8.5317E-01 8.5430E-01 8.5470E-01 8.5670E-01 8.5730E-01  $ Ac-228 Th-227 Am-241 Sb-126 Th-227
8.5748E-01 8.5750E-01 8.5830E-01 8.5880E-01 8.6056E-01  $ Np-240m Cm-244 Th-227 Fr-223 Tl-208
8.6070E-01 8.6270E-01 8.6300E-01 8.6300E-01 8.6560E-01  $ Am-241 Am-241 Fr-223 Th-227 Pb-211
8.6680E-01 8.6720E-01 8.6720E-01 8.6739E-01 8.6750E-01  $ Pa-234m Np-240 Np-240m Eu-152 Fr-223
8.6750E-01 8.6790E-01 8.7046E-01 8.7070E-01 8.7290E-01  $ Th-227 U-233 Ac-228 Am-241 Pa-234
8.7317E-01 8.7319E-01 8.7392E-01 8.7444E-01 8.7444E-01  $ Ac-228 Eu-154 Pu-240 Ac-228 U-232
8.7620E-01 8.7620E-01 8.7640E-01 8.7746E-01 8.7820E-01  $ Fr-223 Th-227 Pa-234 Ac-228 Fr-223
8.7820E-01 8.7920E-01 8.8051E-01 8.8051E-01 8.8061E-01  $ Th-227 Pu-239 Pa-234 Pu-238 Eu-154
8.8076E-01 8.8090E-01 8.8260E-01 8.8263E-01 8.8320E-01  $ Ac-228 Pa-234m Cm-242 Np-238 Pa-234m
8.8324E-01 8.8324E-01 8.8330E-01 8.8730E-01 8.8733E-01  $ Pa-234 Pu-238 Tl-208 Am-241 Ac-228
8.8750E-01 8.8880E-01 8.8900E-01 8.9060E-01 8.9100E-01  $ Pa-234m Np-240 Rn-219 Np-240m Fr-223
8.9100E-01 8.9100E-01 8.9273E-01 8.9300E-01 8.9300E-01  $ Th-227 Pu-239 Eu-154 Fr-223 Th-227
8.9339E-01 8.9470E-01 8.9530E-01 8.9540E-01 8.9580E-01  $ Bi-212 Cm-244 Np-240m Pu-239 Np-240
8.9610E-01 8.9610E-01 8.9733E-01 8.9733E-01 8.9770E-01  $ Fr-223 Th-227 Np-238 Cm-242 Tl-207
8.9774E-01 8.9810E-01 8.9837E-01 8.9840E-01 8.9900E-01  $ Po-211 Pu-239 Eu-154 Am-241 Pa-234
9.0010E-01 9.0037E-01 9.0119E-01 9.0123E-01 9.0250E-01  $ Cm-244 Np-240m Eu-152 Ac-228 Am-241
9.0405E-01 9.0420E-01 9.0425E-01 9.0437E-01 9.0437E-01  $ Eu-154 Ac-228 Bi-214 Pa-234 Pu-238
9.0550E-01 9.0602E-01 9.0610E-01 9.0810E-01 9.0820E-01  $ Pu-239 Eu-152 Eu-154 Th-228 Fr-223
9.0820E-01 9.1000E-01 9.1010E-01 9.1120E-01 9.1170E-01  $ Th-227 Th-227 Np-240m Ac-228 Pu-239
9.1240E-01 9.1580E-01 9.1598E-01 9.1598E-01 9.1869E-01  $ Am-241 Bi-214 Np-240 Np-240m Np-238
9.1870E-01 9.1870E-01 9.1897E-01 9.1924E-01 9.1940E-01  $ Pu-239 Cm-242 Ac-228 Eu-154 Eu-152
9.2000E-01 9.2000E-01 9.2150E-01 9.2198E-01 9.2230E-01  $ Th-227 Pa-234 Am-241 Ac-228 Pa-234m
9.2398E-01 9.2400E-01 9.2449E-01 9.2500E-01 9.2600E-01  $ Np-238 Np-238 Eu-154 Pa-234 Pa-234
9.2632E-01 9.2672E-01 9.2672E-01 9.2680E-01 9.2700E-01  $ Eu-152 Pa-234 Pu-238 Pa-234m Th-227
9.2760E-01 9.2820E-01 9.2840E-01 9.2855E-01 9.2880E-01  $ Tl-208 Sb-126m Eu-154 Np-240m Am-241
9.3058E-01 9.3093E-01 9.3190E-01 9.3405E-01 9.3450E-01  $ Eu-152 Ac-228 Pu-239 Bi-214 Np-240
9.3630E-01 9.3661E-01 9.3700E-01 9.3800E-01 9.3802E-01  $ Pa-234m Np-238 Eu-152 Th-227 Np-240m
9.3820E-01 9.3891E-01 9.3895E-01 9.3987E-01 9.4030E-01  $ Np-240 Cm-242 Np-238 Ac-228 Pu-239
9.4138E-01 9.4160E-01 9.4190E-01 9.4239E-01 9.4250E-01  $ Np-238 Th-227 Pu-238 Np-240m Pa-234m
9.4330E-01 9.4420E-01 9.4570E-01 9.4600E-01 9.4600E-01  $ Bi-214 Ac-228 Am-241 Pa-234 Pu-238
9.4630E-01 9.4798E-01 9.4900E-01 9.5100E-01 9.5210E-01  $ Pa-234m Ac-228 Pa-234 Pb-211 Bi-212
9.5400E-01 9.5560E-01 9.5570E-01 9.5760E-01 9.5861E-01  $ Sb-126 Pu-239 Am-241 Pu-239 Ac-228
9.5863E-01 9.5870E-01 9.5900E-01 9.5910E-01 9.5960E-01  $ Eu-152 Th-227 Np-240m Np-240 Sb-126
9.6000E-01 9.6000E-01 9.6162E-01 9.6277E-01 9.6280E-01  $ Pa-234 Pa-234m Np-240m Np-238 Cm-242
9.6408E-01 9.6413E-01 9.6477E-01 9.6600E-01 9.6800E-01  $ Bi-214 Eu-152 Ac-228 Pa-234 Eu-152
9.6837E-01 9.6890E-01 9.6897E-01 9.7000E-01 9.7170E-01  $ Pu-239 Np-238 Ac-228 Th-227 Th-227
9.7390E-01 9.7409E-01 9.7450E-01 9.7595E-01 9.7620E-01  $ Np-240 Eu-152 Cm-242 Ac-228 Bi-214
9.7880E-01 9.7948E-01 9.7970E-01 9.7980E-01 9.8050E-01  $ Pa-234 Ac-228 Pu-239 Cm-242 Pa-234
9.8050E-01 9.8130E-01 9.8270E-01 9.8270E-01 9.8300E-01  $ Pu-238 Eu-154 Tl-208 Pu-239 Cm-242
9.8400E-01 9.8445E-01 9.8450E-01 9.8450E-01 9.8570E-01  $ Pa-234 Np-238 Eu-154 Cm-242 Np-240m
9.8690E-01 9.8741E-01 9.8776E-01 9.8843E-01 9.8920E-01  $ Pu-239 Ac-228 Np-240 Ac-228 Bi-214
9.8920E-01 9.8930E-01 9.9000E-01 9.9020E-01 9.9270E-01  $ Np-240m Sb-126 Th-227 Eu-152 Pu-239
9.9290E-01 9.9500E-01 9.9610E-01 9.9632E-01 9.9980E-01  $ Th-228 Th-227 Pa-234m Eu-154 Th-227
1.0010E00 1.0010E00 1.0011E00 1.0030E00 1.0048E00  $ Pa-234m Pu-238 Eu-152 U-233 Eu-154
1.0053E00 1.0057E00 1.0094E00 1.0100E00 1.0128E00  $ Eu-152 Pu-239 Pu-239 Cm-242 Eu-154
1.0134E00 1.0136E00 1.0144E00 1.0147E00 1.0147E00  $ Bi-214 Ac-228 Np-240 Pb-211 Am-241
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1.0152E00 1.0164E00 1.0179E00 1.0199E00 1.0200E00  $ Th-227 Ac-228 Ac-228 Ac-228 Th-227
1.0205E00 1.0226E00 1.0230E00 1.0250E00 1.0259E00  $ Bi-214 Pa-234 Eu-154 Th-227 Np-238
1.0283E00 1.0283E00 1.0285E00 1.0285E00 1.0324E00  $ Pa-234 Np-240m Np-238 Cm-242 Bi-214
1.0332E00 1.0334E00 1.0335E00 1.0348E00 1.0349E00  $ Ac-228 Eu-154 Np-240 Sb-126 Sb-126m
1.0365E00 1.0380E00 1.0386E00 1.0396E00 1.0409E00  $ Np-240m Bi-214 Cs-134 Ac-228 Ac-228
1.0419E00 1.0423E00 1.0449E00 1.0454E00 1.0466E00  $ Pu-238 Pa-234m Pa-234 Bi-214 Np-240m
1.0474E00 1.0494E00 1.0520E00 1.0531E00 1.0541E00  $ Eu-154 Eu-154 Bi-214 Ac-228 Ac-228
1.0550E00 1.0573E00 1.0594E00 1.0616E00 1.0616E00  $ Rn-219 Pu-239 Pa-234m Sb-126m Np-240m
1.0621E00 1.0625E00 1.0639E00 1.0652E00 1.0669E00  $ Pa-234m Ac-228 Sb-126 Ac-228 Bi-214
1.0700E00 1.0722E00 1.0722E00 1.0740E00 1.0747E00  $ Bi-214 Eu-154 Np-240m Bi-212 Ac-228
1.0786E00 1.0802E00 1.0817E00 1.0819E00 1.0825E00  $ Bi-212 Pb-211 Cm-242 Pa-234m Pa-234
1.0840E00 1.0854E00 1.0857E00 1.0859E00 1.0882E00  $ Eu-152 Pu-238 Pa-234m Eu-152 Ac-228
1.0883E00 1.0897E00 1.0905E00 1.0905E00 1.0939E00  $ Np-240m Eu-152 Pb-211 Np-240 Tl-208
1.0942E00 1.0957E00 1.1001E00 1.1034E00 1.1034E00  $ Np-240m Ac-228 Bi-213 Pb-211 Ac-228
1.1037E00 1.1048E00 1.1092E00 1.1095E00 1.1100E00  $ Bi-214 Bi-214 Eu-152 Pb-211 Eu-154
1.1106E00 1.1121E00 1.1132E00 1.1176E00 1.1183E00  $ Ac-228 Eu-152 Np-240m Ac-228 Cm-242
1.1185E00 1.1190E00 1.1203E00 1.1206E00 1.1223E00  $ Eu-154 U-233 Bi-214 Pa-234m Pa-234
1.1242E00 1.1257E00 1.1257E00 1.1260E00 1.1284E00  $ Eu-154 Tl-208 Pa-234m Pa-234 Eu-154
1.1308E00 1.1310E00 1.1337E00 1.1352E00 1.1361E00  $ Bi-214 Np-240m Bi-214 Ac-228 Eu-154
1.1370E00 1.1390E00 1.1409E00 1.1429E00 1.1481E00  $ Np-240m Eu-152 Eu-154 Ac-228 Ac-228
1.1531E00 1.1531E00 1.1535E00 1.1552E00 1.1571E00  $ Eu-154 Pa-234 Ac-228 Bi-214 Ac-228
1.1592E00 1.1606E00 1.1608E00 1.1645E00 1.1671E00  $ Np-240m Eu-154 Tl-208 Ac-228 Np-240
1.1674E00 1.1679E00 1.1700E00 1.1710E00 1.1713E00  $ Np-240m Cs-134 Eu-154 Eu-152 Pa-234
1.1731E00 1.1742E00 1.1753E00 1.1801E00 1.1821E00  $ Bi-214 Pa-234m Ac-228 Np-240m Np-240m
1.1846E00 1.1852E00 1.1886E00 1.1908E00 1.1938E00  $ Cm-242 Tl-208 Eu-154 Ac-228 Pa-234m
1.1966E00 1.1980E00 1.2061E00 1.2077E00 1.2105E00  $ Pb-211 Np-240m Eu-152 Bi-214 Np-240m
1.2129E00 1.2130E00 1.2168E00 1.2170E00 1.2175E00  $ Eu-152 Sb-126 Eu-154 Ac-228 Pa-234
1.2200E00 1.2202E00 1.2230E00 1.2268E00 1.2290E00  $ Pa-234m Cm-242 Np-240m Bi-214 Pa-234
1.2294E00 1.2305E00 1.2321E00 1.2343E00 1.2374E00  $ Ac-228 Bi-214 Eu-154 Pb-211 Pa-234m
1.2381E00 1.2405E00 1.2416E00 1.2450E00 1.2462E00  $ Bi-214 Pa-234 Eu-154 Ac-228 Eu-154
1.2471E00 1.2499E00 1.2500E00 1.2510E00 1.2613E00  $ Ac-228 Eu-152 Ac-228 Pa-234 Eu-152
1.2708E00 1.2744E00 1.2767E00 1.2774E00 1.2810E00  $ Pb-211 Eu-154 Ac-228 Pa-234 Bi-214
1.2828E00 1.2863E00 1.2877E00 1.2900E00 1.2920E00  $ Tl-208 Ac-228 Ac-228 Eu-154 Eu-154
1.2927E00 1.2928E00 1.2955E00 1.2991E00 1.3038E00  $ Pa-234 Eu-152 Eu-154 Eu-152 Bi-214
1.3058E00 1.3090E00 1.3108E00 1.3153E00 1.3170E00  $ Np-240m Ac-228 Ac-228 Ac-228 Bi-214
1.3211E00 1.3270E00 1.3289E00 1.3300E00 1.3373E00  $ Np-240m Eu-154 Np-240m Bi-214 Ac-228
1.3400E00 1.3415E00 1.3446E00 1.3475E00 1.3481E00  $ Np-240m Bi-214 Ac-228 Ac-228 Eu-152
1.3530E00 1.3530E00 1.3533E00 1.3572E00 1.3578E00  $ Bi-214 Pa-234m Pa-234 Np-240m Ac-228
1.3585E00 1.3638E00 1.3652E00 1.3657E00 1.3742E00  $ Pa-234 Eu-152 Cs-134 Ac-228 Ac-228
1.3777E00 1.3811E00 1.3853E00 1.3854E00 1.3870E00  $ Bi-214 Tl-208 Bi-214 Ac-228 Eu-154
1.3904E00 1.3925E00 1.3927E00 1.3941E00 1.3985E00  $ Eu-152 Bi-214 Pa-234m Pa-234 Np-240m
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1.4080E00 1.4085E00 1.4142E00 1.4150E00 1.4156E00  $ Bi-214 Eu-154 Pa-234m Eu-154 Ac-228
1.4172E00 1.4185E00 1.4192E00 1.4197E00 1.4259E00  $ Np-240m Eu-154 Eu-154 Bi-214 Eu-154
1.4275E00 1.4283E00 1.4310E00 1.4342E00 1.4343E00  $ Pa-234 Np-240m Ac-228 Ac-228 Pa-234m
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1.4697E00 1.4711E00 1.4761E00 1.4762E00 1.4792E00  $ Ac-228 Bi-214 Sb-126m Sb-126 Bi-214
1.4804E00 1.4830E00 1.4882E00 1.4896E00 1.4937E00  $ Ac-228 Np-240m Np-240m Eu-154 Pa-234
1.4944E00 1.4959E00 1.4969E00 1.5010E00 1.5016E00  $ Eu-154 Ac-228 Np-240m Pa-234m Ac-228
1.5092E00 1.5100E00 1.5105E00 1.5128E00 1.5159E00  $ Bi-214 Eu-154 Pa-234m Bi-212 Np-240m
1.5160E00 1.5220E00 1.5272E00 1.5281E00 1.5290E00  $ Pa-234 Eu-154 Pa-234m Eu-152 Ac-228
1.5314E00 1.5378E00 1.5379E00 1.5385E00 1.5396E00  $ Eu-154 Eu-154 Ac-228 Bi-214 Np-240m
1.5433E00 1.5486E00 1.5494E00 1.5500E00 1.5540E00  $ Bi-214 Ac-228 Pa-234 Pa-234m Eu-154
1.5541E00 1.5571E00 1.5584E00 1.5588E00 1.5598E00  $ Pa-234m Ac-228 Pa-234m Np-240m Ac-228
1.5660E00 1.5686E00 1.5708E00 1.5715E00 1.5732E00  $ Tl-209 Np-240m Pa-234m Ac-228 Ac-228
1.5797E00 1.5805E00 1.5832E00 1.5841E00 1.5854E00  $ Pa-234 Ac-228 Bi-214 Np-240m Pa-234
1.5882E00 1.5905E00 1.5930E00 1.5937E00 1.5938E00  $ Ac-228 Np-240m Eu-154 Pa-234m Pa-234
1.5947E00 1.5965E00 1.5993E00 1.6018E00 1.6048E00  $ Bi-214 Eu-154 Bi-214 Pa-234m Np-240m
1.6056E00 1.6076E00 1.6084E00 1.6206E00 1.6250E00  $ Eu-152 Np-240m Eu-152 Bi-212 Ac-228
1.6266E00 1.6279E00 1.6306E00 1.6333E00 1.6352E00  $ Np-240m Pa-234 Ac-228 Np-240m Eu-152
1.6366E00 1.6380E00 1.6383E00 1.6473E00 1.6475E00  $ Bi-214 Pa-234 Ac-228 Eu-152 Tl-208
1.6560E00 1.6574E00 1.6613E00 1.6665E00 1.6673E00  $ Pa-234 Bi-214 Bi-214 Ac-228 Eu-154
1.6676E00 1.6676E00 1.6685E00 1.6716E00 1.6736E00  $ Pa-234m Np-240m Pa-234 Ac-228 Eu-154
1.6777E00 1.6795E00 1.6840E00 1.6840E00 1.6862E00  $ Ac-228 Bi-212 Bi-214 Ac-228 Ac-228
1.6862E00 1.6941E00 1.6946E00 1.6998E00 1.7006E00  $ Pa-234 Pa-234m Pa-234 Pa-234 Ac-228
1.7024E00 1.7062E00 1.7110E00 1.7135E00 1.7169E00  $ Ac-228 Ac-228 Np-240m Ac-228 Eu-154
1.7195E00 1.7205E00 1.7214E00 1.7242E00 1.7296E00  $ Pa-234 Pa-234m Ac-228 Ac-228 Bi-214
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1.7453E00 1.7501E00 1.7505E00 1.7529E00 1.7560E00  $ Ac-228 Pa-234 Ac-228 Np-240m Pa-234
1.7581E00 1.7591E00 1.7645E00 1.7652E00 1.7654E00  $ Ac-228 Pa-234m Bi-214 Np-240m Pa-234m
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1.7753E00 1.7821E00 1.7844E00 1.7873E00 1.7951E00  $ Np-240m Bi-214 Ac-228 Ac-228 Ac-228
1.7962E00 1.7962E00 1.7973E00 1.7975E00 1.8009E00  $ Pa-234m Np-240m Pa-234 Ac-228 Ac-228
1.8060E00 1.8079E00 1.8090E00 1.8128E00 1.8137E00  $ Bi-212 Np-240m Pa-234m Np-240m Bi-214
1.8204E00 1.8232E00 1.8267E00 1.8280E00 1.8315E00  $ Pa-234m Ac-228 Ac-228 Pa-234 Pa-234m
1.8354E00 1.8380E00 1.8381E00 1.8384E00 1.8421E00  $ Ac-228 Eu-154 Pa-234 Bi-214 Ac-228
1.8445E00 1.8474E00 1.8500E00 1.8501E00 1.8611E00  $ Np-240m Bi-214 Pa-234 Ac-228 Np-240m
1.8638E00 1.8682E00 1.8708E00 1.8728E00 1.8732E00  $ Pa-234m Pa-234m Ac-228 Pa-234 Bi-214
1.8749E00 1.8755E00 1.8796E00 1.8871E00 1.8903E00  $ Np-240m Pa-234m Ac-228 Ac-228 Bi-214
1.8906E00 1.8944E00 1.8950E00 1.8963E00 1.8971E00  $ Pa-234 Pa-234m Eu-154 Bi-214 Pa-234
1.8987E00 1.9001E00 1.9050E00 1.9072E00 1.9114E00  $ Bi-214 Ac-228 Pa-234 Ac-228 Np-240m
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          1.9118E00 1.9159E00 1.9180E00 1.9195E00 1.9260E00  $ Pa-234m Ac-228 Np-240m Ac-228 Pa-234
          1.9265E00 1.9298E00 1.9358E00 1.9363E00 1.9377E00  $ Pa-234m Ac-228 Bi-214 Ac-228 Pa-234
          1.9377E00 1.9442E00 1.9523E00 1.9536E00 1.9559E00  $ Pa-234m Ac-228 Ac-228 Np-240m Ac-228
          1.9584E00 1.9590E00 1.9652E00 1.9700E00 1.9719E00  $ Ac-228 Pa-234 Ac-228 Pa-234m Ac-228
          1.9780E00 1.9793E00 1.9880E00 1.9947E00 1.9967E00  $ Np-240m Ac-228 Pa-234 Bi-214 Np-240m
          1.9980E00 2.0009E00 2.0045E00 2.0107E00 2.0218E00  $ Pa-234 Ac-228 Bi-214 Bi-214 Bi-214
          2.0294E00 2.0417E00 2.0529E00 2.0748E00 2.0850E00  $ Ac-228 Np-240m Bi-214 Np-240m Bi-214
          2.0867E00 2.0895E00 2.1099E00 2.1175E00 2.1185E00  $ Np-240m Bi-214 Bi-214 Np-240m Bi-214
          2.1478E00 2.1768E00 2.1863E00 2.1926E00 2.2041E00  $ Bi-214 Bi-214 Y-90 Bi-214 Bi-214
          2.2512E00 2.2597E00 2.2666E00 2.2700E00 2.2844E00  $ Bi-214 Bi-214 Bi-214 Bi-214 Bi-214
          2.2934E00 2.3122E00 2.3248E00 2.3313E00 2.3609E00  $ Bi-214 Bi-214 Bi-214 Bi-214 Bi-214
          2.3693E00 2.3770E00 2.3909E00 2.4235E00 2.4477E00  $ Bi-214 Bi-214 Bi-214 Bi-214 Bi-214
          2.4828E00 2.5056E00 2.5510E00 2.6045E00 2.6145E00  $ Bi-214 Bi-214 Bi-214 Bi-214 Tl-208
          2.6309E00 2.6620E00 2.6948E00 2.6994E00 2.7194E00  $ Bi-214 Bi-214 Bi-214 Bi-214 Bi-214
          2.7700E00 2.7861E00 2.8270E00 2.8609E00 2.8804E00  $ Bi-214 Bi-214 Bi-214 Bi-214 Bi-214
          2.8936E00 2.9221E00 2.9287E00 2.9349E00 2.9400E00  $ Bi-214 Bi-214 Bi-214 Bi-214 Bi-214
          2.9788E00 2.9887E00 3.0000E00 3.0539E00 3.0817E00  $ Bi-214 Bi-214 Bi-214 Bi-214 Bi-214
          3.0939E00 3.1363E00 3.1426E00 3.1605E00 3.1836E00  $ Bi-214 Bi-214 Bi-214 Bi-214 Bi-214
          3.2333E00 3.2697E00                                $ Bi-214 Bi-214
sp2     d 7.5562E-06 4.9053E-08 8.9360E-11 2.5818E-06 3.7480E-07  $ Y-90 Nb-93m Tc-99 Sn-126 Sb-126m
          1.1081E-08 6.1218E-08 6.7666E-12 1.8768E-17 2.9929E-08  $ Sb-126 Sb-126m Cs-134 Ra-223 Cs-134
          9.1829E-03 5.0616E-07 1.3263E-09 3.8610E-06 7.4803E-07  $ Ba-137m Sn-126 Pm-147 Eu-152 Eu-154
          7.8247E-18 1.9780E-05 4.7752E-08 1.0868E-03 1.4550E-04  $ Th-227 Sm-151 Eu-152 Eu-154 Eu-155
          5.5498E-08 5.3059E-08 1.0955E-16 2.3172E-19 1.5905E-17  $ Cm-243 Np-239 Th-227 Ac-227 Ra-223
          1.4317E-06 5.5677E-07 4.5589E-08 1.3094E-04 6.7845E-06  $ Eu-155 Eu-155 U-234 Pu-238 Pu-239
          2.7332E-05 1.1919E-07 1.8457E-07 9.9199E-04 1.2984E-22  $ Pu-240 Pu-242 U-237 Am-241 Bi-210
          1.6223E-15 9.3794E-09 1.1610E-24 3.0138E-18 1.2168E-09  $ Bi-211 Bi-212 Tl-206 Tl-207 Tl-208
          6.1564E-14 2.1335E-23 3.6303E-20 3.4753E-20 7.3205E-15  $ Tl-209 Po-210 Po-211 Po-214 Po-216
          1.2726E-07 8.7214E-20 7.5844E-07 3.3919E-16 8.4137E-16  $ Eu-155 Ra-228 U-234 Pb-210 Pb-211
          1.7501E-08 1.2724E-14 6.1996E-11 5.8699E-13 5.0895E-16  $ Pb-212 Pb-214 Bi-212 Bi-213 Bi-214
          1.6064E-15 1.1095E-12 7.3223E-19 4.5902E-19 2.0447E-03  $ Rn-219 Rn-220 Rn-222 Ra-228 Pu-238
          1.0927E-04 4.3049E-04 1.7595E-06 2.5452E-07 1.3338E-08  $ Pu-239 Pu-240 Pu-242 Eu-155 U-237
          7.5813E-13 3.2738E-06 1.5226E-02 3.8967E-14 4.5524E-10  $ Fr-221 U-237 Am-241 Ra-223 Ra-224
          7.9125E-16 3.9762E-17 6.5414E-12 5.1772E-18 6.2757E-17  $ Ra-226 Ra-223 Ac-225 Ac-227 Ac-227
          5.7688E-16 6.5727E-14 1.1060E-08 2.5820E-11 2.4170E-11  $ Fr-223 Th-227 Th-228 Th-229 Th-230
          2.6929E-17 4.5902E-20 2.0834E-05 5.0976E-12 3.3237E-12  $ Th-232 Ra-228 Y-90 Ra-225 Pa-231
          3.9832E-05 5.0616E-07 2.0656E-19 8.2206E-16 1.0386E-17  $ Y-90 Sn-126 Ra-228 Ac-227 Ac-228
          3.2139E-08 1.5505E-08 1.0092E-06 7.1871E-08 4.5033E-07  $ U-232 U-233 U-234 U-235 U-236
          5.1836E-07 1.6322E-14 5.8040E-08 1.1046E-07 2.2257E-07  $ U-238 Pa-231 Nb-93m Nb-93m Th-231
          6.4796E-07 3.1750E-09 3.6475E-06 5.3324E-10 3.8806E-06  $ Th-234 Pa-234m Np-237 Th-231 Pa-233
          9.4342E-09 2.7214E-08 2.9462E-03 1.2969E-04 5.5120E-04  $ Pa-234 Pa-234m Pu-238 Pu-239 Pu-240
          7.8816E-06 2.3555E-06 2.4810E-10 6.0358E-14 1.0255E-05  $ Pu-241 Pu-242 Pa-233 Th-229 Y-90
          1.7907E-11 3.4758E-06 2.1844E-12 2.2262E-02 7.5210E-07  $ Sb-126m U-237 U-240 Am-241 Am-242m
          1.1275E-04 3.8254E-10 3.3747E-07 3.0101E-04 9.7657E-15  $ Am-243 Th-231 Np-238 Np-239 Np-240
          2.2130E-12 2.7885E-05 2.2805E-05 2.4275E-04 3.1125E-03  $ Np-240m Am-242 Cm-242 Cm-243 Cm-244
          5.8692E-06 1.8638E-06 3.2765E-08 6.7607E-07 5.9673E-20  $ Cm-245 Cm-246 Nb-93m Eu-155 Ra-228
          6.5946E-05 2.6263E-14 2.1758E-07 3.2693E-10 6.3206E-10  $ Am-242m Pa-231 U-234 Tc-99 Tc-99
          4.1312E-21 4.5890E-05 5.9288E-10 6.9500E-04 3.1821E-05  $ Ra-228 Am-242 Th-234 Pu-238 Pu-239
          1.3666E-04 6.1300E-07 1.8875E-17 3.1299E-16 9.4306E-07  $ Pu-240 Pu-242 Fr-223 Th-227 U-237
          5.5944E-03 5.5677E-08 4.9451E-06 2.3473E-14 1.9616E-10  $ Am-241 Eu-155 Sm-151 Th-229 Tc-99
          5.1616E-07 2.6655E-06 4.3592E-16 3.2644E-16 6.0343E-18  $ Sn-126 Sn-126 Th-229 Pa-231 Ac-227
          2.5967E-16 9.9422E-08 3.0756E-12 2.4479E-15 7.0481E-15  $ Pa-231 Eu-155 U-233 Th-229 Pa-231
          3.3849E-08 5.0616E-07 5.0319E-16 3.4980E-06 3.2738E-07  $ Th-231 Sn-126 Ac-225 Sn-126 U-237
          2.7683E-03 6.4962E-06 4.0962E-06 1.2520E-09 2.9219E-08  $ Am-241 Sn-126 Eu-155 Th-231 Sb-126
          1.6242E-07 8.2351E-13 5.4239E-08 2.9984E-07 1.2072E-14  $ Sb-126m Pa-231 Sb-126 Sb-126m Th-229
          9.5425E-09 3.0502E-11 8.1145E-11 9.7394E-07 1.5615E-11  $ Pa-233 U-233 Th-231 Np-237 Cs-134
          9.4861E-11 6.3191E-19 9.3896E-18 2.2070E-06 3.1231E-11  $ Th-234 Fr-223 Th-227 Sn-126 Cs-134
          6.7294E-19 1.5649E-16 7.0481E-15 1.3029E-08 1.3413E-14  $ Fr-223 Th-227 Pa-231 Pu-239 Th-229
          1.0297E-11 1.8838E-08 1.0370E-07 3.2862E-13 3.8264E-07  $ Nb-93m Sb-126 Sb-126m Th-229 Am-243
          9.1469E-08 4.6610E-13 6.8630E-13 5.6385E-16 2.6826E-14  $ Eu-155 Th-229 U-233 Pa-231 Th-229
          1.5905E-19 3.7095E-11 1.2519E-16 6.2201E-08 1.8277E-02  $ Ra-223 U-235 Th-227 Cs-134 Ba-137m
          2.0071E-05 1.1425E-07 3.3729E-02 2.5164E-12 1.6925E-10  $ Am-241 Cs-134 Ba-137m U-233 Th-231
          1.7514E-08 1.3842E-04 6.9553E-11 2.1909E-17 1.0931E-11  $ U-237 Am-241 Th-231 Th-227 Cs-134
          3.0324E-13 8.5782E-11 1.1870E-15 5.0616E-07 4.1901E-08  $ Pa-234 U-235 Pa-231 Sn-126 Cs-134
          1.2362E-02 5.0319E-15 7.3771E-16 9.1506E-13 1.0609E-14  $ Ba-137m Ac-225 Th-229 U-233 Pa-231
          3.1868E-15 6.3042E-07 2.5503E-10 1.9863E-09 5.3625E-06  $ Ac-225 Pu-239 Th-231 Pm-147 Eu-152
          9.0328E-07 1.0387E-16 1.2580E-09 8.9028E-16 1.0061E-11  $ Eu-154 Pa-231 Bi-212 Pa-231 Ra-225
          3.6202E-09 9.7036E-06 1.6231E-06 3.1299E-17 2.4810E-09  $ Pm-147 Eu-152 Eu-154 Th-227 Pa-233
          9.7265E-09 3.4201E-07 6.9553E-11 3.7095E-11 8.9063E-10  $ Pu-239 Eu-155 U-235 Th-231 Pa-233
          3.3637E-08 1.3911E-10 9.9066E-09 6.2597E-17 8.4094E-08  $ Cm-245 U-235 Pu-239 Th-227 Am-242
          1.2056E-10 2.2131E-14 6.2818E-08 1.0444E-03 8.4873E-05  $ Th-231 Th-229 Eu-152 Eu-154 Eu-155
          2.6711E-21 2.1911E-10 4.0063E-16 2.0800E-07 6.3441E-06  $ Ac-228 U-233 Pa-231 Sn-126 Am-241
          4.4598E-14 9.2517E-18 5.2826E-15 7.7190E-06 1.3447E-10  $ Th-229 Np-240 Np-240m Cm-244 Th-231
          1.1287E-07 1.8630E-03 1.5156E-04 5.1933E-16 3.3672E-07  $ Eu-152 Eu-154 Eu-155 Pa-231 Am-243
          3.2333E-09 8.1897E-05 1.0108E-11 8.7474E-11 1.9893E-05  $ U-237 Am-241 Pa-234 Pa-234m Pu-238
          3.0254E-05 7.8247E-17 2.5552E-13 1.6229E-12 8.9329E-10  $ Am-243 Th-227 Th-229 Th-231 Np-238
          6.5015E-08 7.4956E-14 1.0955E-17 4.1547E-15 2.3645E-08  $ Cm-242 U-240 Th-227 Pa-231 Pu-241
          2.0344E-17 3.0520E-08 5.5899E-09 6.0540E-07 4.6427E-07  $ Th-227 Am-242 Cm-246 Cm-243 Np-239
          4.7289E-09 2.1171E-08 9.2658E-13 5.0907E-06 1.6464E-05  $ Pu-241 Pu-242 Pa-234 Pu-240 Eu-155
          7.8827E-11 1.4096E-09 3.7640E-06 6.3512E-07 5.0616E-07  $ Th-231 Pm-147 Eu-152 Eu-154 Sn-126
          4.4249E-08 1.6544E-14 2.4137E-18 5.6531E-17 7.0418E-15  $ Pu-239 Pa-231 Ac-227 Pb-210 Th-229
          6.7476E-09 3.4823E-09 3.3622E-09 1.5649E-17 3.4218E-08  $ Np-237 Pu-239 Pu-239 Th-227 Eu-152
          5.6455E-04 4.6074E-05 3.1264E-10 1.6773E-15 4.9970E-16  $ Eu-154 Eu-155 Am-242m Ac-225 U-240
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4.0693E-07 3.5480E-09 4.0360E-07 5.1018E-07 4.1469E-09  $ Am-242m U-236 Cm-243 Np-239 U-238
7.3771E-15 1.0470E-08 1.7360E-04 1.4065E-05 1.7808E-17  $ Th-229 Eu-152 Eu-154 Eu-155 Fr-223
3.1299E-16 8.2066E-16 1.3302E-14 3.5693E-16 1.5305E-08  $ Th-227 Fr-223 Th-227 U-240 Am-243
2.5039E-17 1.0387E-16 6.0358E-15 4.5806E-08 2.9990E-08  $ Th-227 Pa-231 Th-229 U-237 Am-241
4.6948E-18 4.6369E-11 1.6271E-06 6.3546E-13 6.6771E-15  $ Th-227 U-235 Pu-239 U-233 Pa-231
6.0358E-15 2.5489E-08 1.0151E-15 1.0930E-11 6.3984E-09  $ Th-229 U-234 Pb-214 U-233 Cm-245
4.0239E-15 6.3737E-15 1.1828E-08 1.2519E-17 3.4776E-11  $ Th-229 Ac-225 Pu-239 Th-227 U-235
5.7126E-15 4.6261E-11 9.3891E-16 5.3569E-08 2.0878E-05  $ Pa-231 U-233 Th-229 Am-243 Am-241
5.0616E-07 7.8247E-18 1.4130E-08 1.0462E-13 1.0955E-17  $ Sn-126 Th-227 Pu-241 Th-229 Th-227
3.5611E-16 5.5171E-09 3.4734E-09 6.7845E-08 5.7237E-21  $ Pa-231 Pu-241 Cm-245 Pu-239 Ac-228
2.4317E-08 2.9676E-15 4.5405E-07 5.3059E-07 3.0611E-08  $ Np-237 Pa-231 Cm-243 Np-239 Np-239
2.5225E-07 3.9525E-10 5.4016E-10 1.3966E-19 1.6773E-15  $ Cm-243 Th-234 U-232 Ac-228 Ac-225
5.9981E-06 2.4810E-10 8.5503E-07 7.2442E-13 5.5114E-07  $ Am-241 Pa-233 Eu-155 Pa-234 Eu-154
1.1592E-09 4.6479E-06 4.1410E-02 1.4084E-17 1.4715E-05  $ Th-231 U-237 Am-241 Th-227 Eu-155
4.0805E-16 5.5498E-08 6.5813E-06 1.2519E-16 3.1299E-18  $ Pa-231 Cm-243 Np-239 Th-227 Th-227
3.7558E-16 3.8194E-10 1.4084E-17 1.2648E-09 1.8450E-13  $ Th-227 Np-237 Th-227 Th-234 Ac-225
2.6955E-10 1.2311E-10 1.7627E-11 2.8972E-07 3.4127E-15  $ Pa-234 Pa-234m Pu-238 Th-234 Pa-231
1.6766E-15 8.1339E-14 8.9875E-19 5.3324E-11 7.6388E-10  $ Th-229 U-233 Th-232 Th-231 Np-237
2.0127E-14 3.9906E-06 4.1732E-11 4.3818E-17 1.7649E-07  $ Ac-225 Sn-126 U-235 Th-227 U-237
1.6725E-07 1.0969E-09 1.2186E-16 2.7378E-09 5.0616E-07  $ Am-241 Cm-245 Pb-211 Pu-239 Sn-126
2.1351E-12 9.3896E-18 1.0955E-17 1.0993E-14 4.5655E-08  $ U-233 Th-227 Th-227 U-240 Am-242m
4.8856E-12 4.8446E-07 1.0680E-12 9.8465E-09 4.6427E-07  $ Pa-234 Am-241 Th-230 Pu-239 Np-239
1.5880E-08 8.1339E-13 2.3808E-14 1.3215E-11 1.8012E-08  $ Am-242m U-233 Th-229 Th-231 Pu-239
8.9201E-18 6.6044E-09 6.2597E-17 4.7281E-14 2.7960E-13  $ Th-227 Pu-239 Th-227 Th-229 U-233
6.3984E-10 9.6549E-18 1.2799E-10 3.3451E-06 1.6773E-15  $ Cm-245 Ac-227 U-237 Am-241 Ac-225
1.4084E-17 1.9374E-11 2.8965E-17 1.5251E-12 7.6388E-10  $ Th-227 Pa-234 Ac-227 U-233 Np-237
4.3030E-16 8.6558E-23 1.1770E-15 6.1767E-11 3.3546E-15  $ Pa-231 Bi-210 Bi-211 Bi-212 Ac-225
1.6045E-08 3.3546E-15 6.8630E-12 1.1129E-16 2.5967E-16  $ Pu-241 Ac-225 U-233 Pa-231 Pa-231
2.5503E-10 5.0299E-14 6.0279E-10 4.0303E-25 2.2207E-18  $ U-235 Th-229 Th-231 Tl-206 Tl-207
8.3452E-10 4.1559E-14 1.4243E-23 2.4493E-20 2.2861E-20  $ Tl-208 Tl-209 Po-210 Po-211 Po-214
4.9185E-15 1.4659E-22 1.9881E-15 1.0409E-10 1.4997E-12  $ Po-216 Bi-210 Bi-211 Bi-212 U-233
4.3818E-17 1.2903E-08 5.7028E-15 2.9734E-17 2.3184E-11  $ Th-227 Am-242m Ac-225 Th-227 U-235
1.0735E-13 6.9331E-10 1.6322E-15 4.7888E-13 7.0022E-10  $ Ac-225 Pa-234m Pa-231 Th-228 Np-237
4.0669E-12 3.4794E-04 1.3911E-10 3.4832E-16 1.2010E-08  $ U-233 Am-243 U-235 Pb-211 Pb-212
5.9101E-15 1.3418E-14 2.2815E-09 6.7337E-25 3.6482E-18  $ Pb-214 Ac-225 Pu-239 Tl-206 Tl-207
1.4100E-09 6.9735E-14 2.4053E-23 4.1114E-20 3.8717E-20  $ Tl-208 Tl-209 Po-210 Po-211 Po-214
8.3500E-15 2.0790E-13 1.4084E-17 8.3974E-08 6.8055E-07  $ Po-216 Th-229 Th-227 Pa-233 Am-241
5.0616E-07 3.2870E-14 9.9132E-13 4.0263E-11 3.9580E-13  $ Sn-126 Pm-147 U-233 Bi-212 Bi-213
3.2363E-16 8.1115E-16 6.5198E-13 4.2513E-19 1.1653E-07  $ Bi-214 Rn-219 Rn-220 Rn-222 Pu-241
5.8689E-16 2.0131E-08 9.9578E-15 1.8301E-12 7.5553E-21  $ Pb-211 Pb-212 Pb-214 U-233 Ac-228
4.2288E-15 2.4616E-08 1.5760E-14 1.5251E-13 2.8555E-16  $ Pa-231 Pu-239 Th-229 U-233 U-240
2.6826E-15 8.4656E-09 3.1868E-13 1.4442E-08 6.7372E-11  $ Th-229 Pu-239 Fr-221 Cm-245 Bi-212
6.6078E-13 5.4215E-16 1.3678E-15 1.0981E-12 7.1009E-19  $ Bi-213 Bi-214 Rn-219 Rn-220 Rn-222
1.0950E-11 2.2158E-16 3.2864E-15 4.0083E-07 7.1087E-17  $ Pa-234 Fr-223 Th-227 Eu-154 Pb-211
2.3857E-14 1.4412E-10 1.7706E-16 1.9707E-09 5.3673E-13  $ Ra-223 Ra-224 Ra-226 Th-231 Fr-221
4.7599E-07 8.5782E-10 5.0259E-23 6.8709E-16 3.5459E-11  $ Eu-154 Th-231 Bi-210 Bi-211 Bi-212
9.9941E-16 5.0319E-14 4.5753E-13 3.9248E-13 4.7430E-09  $ U-240 Ac-225 U-233 Ac-225 Th-234
3.9603E-14 2.3906E-10 2.9418E-16 9.1397E-17 1.5557E-08  $ Ra-223 Ra-224 Ra-226 Pb-211 Th-231
1.9064E-13 1.3910E-09 1.4380E-23 1.9563E-16 1.0180E-11  $ U-233 Th-228 Bi-210 Bi-211 Bi-212
2.4215E-25 1.2531E-18 4.8509E-10 2.4161E-14 8.2738E-24  $ Tl-206 Tl-207 Tl-208 Tl-209 Po-210
1.4171E-20 1.3274E-20 2.8596E-15 4.8295E-13 4.0792E-17  $ Po-211 Po-214 Po-216 U-233 Fr-223
2.9108E-15 2.1664E-11 4.9963E-12 1.2227E-14 7.4054E-21  $ Th-227 Th-228 Th-229 Th-230 Th-232
1.3447E-11 5.0616E-07 1.9487E-06 6.4743E-13 4.6945E-13  $ Th-231 Sn-126 Eu-155 Ac-225 Th-229
8.7184E-13 7.8298E-07 3.9769E-04 1.2532E-07 7.9400E-08  $ Th-229 Np-237 Eu-155 Pa-233 Am-242m
3.5586E-13 1.7244E-06 3.7132E-06 1.1462E-09 2.0199E-16  $ U-233 Am-243 Sn-126 Th-234 Pb-211
6.9774E-09 3.4207E-15 5.8049E-26 3.6482E-19 1.4306E-10  $ Pb-212 Pb-214 Tl-206 Tl-207 Tl-208
7.1143E-15 2.4349E-24 4.1551E-21 3.8717E-21 8.4643E-16  $ Tl-209 Po-210 Po-211 Po-214 Po-216
4.8295E-13 9.7283E-14 1.5408E-05 3.5092E-14 8.7846E-09  $ U-233 Ac-225 Sn-126 Pa-231 Np-237
3.0611E-08 2.6404E-17 9.3891E-15 1.1184E-12 6.7584E-17  $ Np-239 Pb-211 Th-229 U-233 Fr-223
4.7887E-15 3.5688E-11 8.2154E-12 1.9904E-14 1.2118E-20  $ Th-227 Th-228 Th-229 Th-230 Th-232
2.3220E-11 2.2809E-13 1.8717E-16 4.7714E-16 3.7746E-13  $ Bi-212 Bi-213 Bi-214 Rn-219 Rn-220
2.4531E-19 2.1023E-09 6.1075E-17 2.1046E-09 1.0327E-15  $ Rn-222 Cm-245 Pb-211 Pb-212 Pb-214
1.8012E-09 1.2423E-09 2.1793E-09 2.9264E-19 1.4422E-11  $ Pu-239 Tc-99 Th-231 Ac-228 U-232
2.0309E-11 5.3464E-10 8.2536E-09 5.9134E-11 4.5357E-11  $ U-233 U-234 U-235 U-236 U-238
5.3208E-18 5.7423E-14 8.3881E-13 1.2723E-10 1.8450E-13  $ Th-227 Pa-231 U-233 Pa-233 Fr-221
7.2290E-12 7.1110E-14 5.8179E-17 1.4632E-16 1.1781E-13  $ Bi-212 Bi-213 Bi-214 Rn-219 Rn-220
7.6543E-20 9.5056E-10 1.2095E-07 1.6838E-07 8.9326E-09  $ Rn-222 Th-231 Np-237 Th-234 Am-242m
1.6601E-07 1.0433E-10 4.7626E-19 2.3497E-11 3.3044E-11  $ Th-234 Th-231 Ac-228 U-232 U-233
8.7034E-10 1.3470E-08 9.5524E-11 7.3867E-11 3.4734E-09  $ U-234 U-235 U-236 U-238 Cm-245
2.1909E-15 1.8279E-17 1.3662E-14 8.2356E-11 1.0144E-16  $ Th-227 Pb-211 Ra-223 Ra-224 Ra-226
3.8194E-08 5.6746E-07 1.3056E-09 4.2765E-10 3.0419E-08  $ Np-237 Pa-233 Pa-234 Pa-234m Pu-238
1.2488E-07 7.2886E-09 1.8071E-06 1.0557E-11 5.7028E-14  $ Pu-239 Pu-240 Pu-241 Pu-242 Fr-221
9.3891E-14 5.3673E-14 4.6945E-15 2.8435E-17 1.8779E-17  $ Th-229 Ac-225 Th-229 Pb-211 Th-227
1.5302E-09 1.9097E-07 5.0616E-07 1.9939E-10 9.3896E-17  $ Th-231 Np-237 Sn-126 U-235 Th-227
1.3389E-09 3.5586E-12 1.0064E-14 5.4213E-08 6.0836E-15  $ Pu-239 U-233 Ac-225 Am-241 Pa-231
2.1690E-06 5.8537E-14 1.4303E-06 7.9400E-08 3.1121E-08  $ U-237 U-240 Am-241 Am-242m Am-243
5.5920E-11 2.2476E-13 1.8279E-17 4.4534E-15 2.6994E-11  $ U-233 Ac-225 Pb-211 Ra-223 Ra-224
3.3107E-17 5.3324E-11 9.2371E-07 2.1059E-09 6.9331E-10  $ Ra-226 Th-231 Pa-233 Pa-234 Pa-234m
4.9355E-08 2.0173E-07 1.1616E-08 2.9162E-06 1.7028E-11  $ Pu-238 Pu-239 Pu-240 Pu-241 Pu-242
4.8467E-08 7.3249E-08 4.1119E-16 1.2136E-14 3.4237E-07  $ Am-243 Pu-239 Np-240 Np-240m Cm-244
2.3070E-05 2.7821E-10 3.6632E-19 3.6900E-14 3.1299E-18  $ Am-241 Th-231 Ac-228 Fr-221 Th-227
2.1469E-13 1.9057E-09 7.8568E-05 1.1650E-15 1.2207E-14  $ Ac-225 Np-238 Np-239 Np-240 Np-240m
8.0581E-06 1.6404E-10 7.2824E-05 1.8613E-08 1.6357E-06  $ Am-242 Cm-242 Cm-243 Cm-244 Cm-245
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2.0344E-17 2.3172E-17 1.6588E-15 1.2314E-11 2.8435E-12  $ Th-227 Fr-223 Th-227 Th-228 Th-229
6.9097E-15 4.2413E-21 5.7028E-13 4.0432E-10 2.3974E-11  $ Th-230 Th-232 Ac-225 Pa-234 Pa-234m
3.7016E-06 7.3801E-14 5.5515E-17 1.5251E-13 1.2310E-17  $ Pu-238 Ac-225 Ac-227 U-233 Fr-223
1.3458E-16 2.7474E-20 1.6773E-14 1.7064E-15 3.4893E-06  $ Th-227 Ac-228 Ac-225 Pa-231 U-237
9.4230E-14 2.2954E-06 1.2792E-07 5.0508E-08 6.3712E-15  $ U-240 Am-241 Am-242m Am-243 Th-229
2.2877E-13 2.6799E-09 5.0011E-09 4.0360E-08 9.2737E-10  $ U-233 Np-238 Cm-242 Cm-243 Th-231
1.9883E-14 1.8779E-18 1.1129E-15 7.7239E-18 5.5399E-16  $ Pa-231 Th-227 Pa-231 Fr-223 Th-227
4.1275E-12 9.4897E-13 2.3032E-15 1.4138E-21 8.6223E-10  $ Th-228 Th-229 Th-230 Th-232 U-237
2.2608E-05 1.3809E-08 2.3715E-10 1.0108E-11 1.4473E-09  $ Am-241 Pu-239 Th-234 Pa-234 Pu-242
2.5418E-13 5.7423E-07 2.7038E-17 3.0471E-09 1.2550E-04  $ U-233 Pu-241 Ra-223 Np-238 Np-239
1.8846E-15 1.9560E-14 1.2889E-05 2.6206E-10 1.1632E-04  $ Np-240 Np-240m Am-242 Cm-242 Cm-243
2.9880E-08 2.5978E-06 3.3546E-15 5.5346E-08 8.1314E-07  $ Cm-244 Cm-245 Ac-225 Pa-233 Pu-240
3.0179E-15 6.2597E-17 1.6497E-19 8.1564E-12 1.1489E-11  $ Th-229 Th-227 Ac-228 U-232 U-233
3.0255E-10 4.6600E-09 3.2751E-11 2.5270E-11 2.6486E-04  $ U-234 U-235 U-236 U-238 Eu-155
6.6994E-15 1.6461E-11 5.0616E-07 1.3877E-04 1.3622E-06  $ Pa-231 Th-231 Sn-126 Np-239 Cm-243
3.3738E-09 2.4489E-07 2.4137E-18 3.9413E-11 3.4991E-17  $ Np-237 Np-239 Ac-227 Th-231 Ra-223
2.7128E-13 5.1700E-08 1.0955E-17 6.3241E-10 5.3324E-10  $ Th-229 Eu-155 Th-227 Th-234 Th-231
6.5566E-08 5.5946E-20 2.7818E-12 3.8890E-12 1.0237E-10  $ Np-237 Ac-228 U-232 U-233 U-234
1.5835E-09 1.1372E-11 8.4234E-12 9.3928E-14 4.3286E-09  $ U-235 U-236 U-238 Ac-225 Np-237
3.5704E-09 1.5425E-14 7.8797E-13 9.3896E-18 5.2603E-08  $ U-235 Th-229 U-233 Th-227 Am-242m
5.6520E-09 1.6894E-16 4.2922E-14 7.8247E-18 7.6343E-17  $ Am-241 Th-230 Th-229 Th-227 Ra-223
3.3399E-07 7.3284E-10 2.3974E-10 1.7123E-08 7.0247E-08  $ Pa-233 Pa-234 Pa-234m Pu-238 Pu-239
3.9860E-09 1.0133E-06 5.9029E-12 5.9550E-09 1.8316E-10  $ Pu-240 Pu-241 Pu-242 Am-242m Th-231
2.2280E-08 1.0735E-13 1.1947E-12 1.2519E-17 8.6426E-10  $ Np-237 Ac-225 U-233 Th-227 U-236
1.6601E-08 8.7636E-16 6.6091E-10 1.2125E-06 3.2838E-14  $ Th-234 Th-227 U-238 U-237 U-240
8.0051E-07 4.4552E-08 1.7346E-08 3.4904E-08 1.1069E-07  $ Am-241 Am-242m Am-243 Pu-241 Pa-233
2.5270E-10 8.2938E-11 5.8924E-09 2.4196E-08 1.0591E-09  $ Pa-234 Pa-234m Pu-238 Pu-239 Pu-240
3.4960E-07 2.0433E-12 6.3546E-13 5.9553E-11 1.4314E-17  $ Pu-241 Pu-242 U-233 Np-238 Ra-223
2.9000E-21 6.7642E-10 9.7244E-15 2.7738E-08 5.2486E-18  $ Ac-228 Pb-212 Th-229 Pu-239 Rn-219
1.6551E-10 1.6229E-10 2.3184E-12 6.0358E-15 5.0616E-07  $ Np-237 U-235 Th-231 Th-229 Sn-126
3.5844E-08 5.3379E-13 1.0720E-09 4.3927E-05 6.5104E-16  $ Pu-239 U-233 Np-238 Np-239 Np-240
6.8531E-15 4.5231E-06 9.2021E-11 4.0963E-05 1.0427E-08  $ Np-240m Am-242 Cm-242 Cm-243 Cm-244
9.6216E-07 4.7992E-11 5.4238E-13 6.3546E-12 4.2303E-07  $ Cm-245 Th-231 Tl-209 U-233 U-237
1.1422E-14 2.7799E-07 1.5439E-08 6.0712E-09 2.6604E-16  $ U-240 Am-241 Am-242m Am-243 Th-227
1.8779E-17 2.9080E-06 1.1013E-08 4.6945E-15 1.3418E-14  $ Th-227 Am-243 Np-237 Th-229 Fr-221
1.0320E-11 1.9213E-09 2.0127E-14 1.0720E-09 1.6766E-14  $ U-233 Pu-239 Ac-225 Np-238 Th-229
3.7320E-10 1.5356E-05 2.3129E-16 2.3986E-15 1.5787E-06  $ Np-238 Np-239 Np-240 Np-240m Am-242
3.2007E-11 1.4261E-05 3.6416E-09 3.2714E-07 6.0279E-11  $ Cm-242 Cm-243 Cm-244 Cm-245 U-235
5.1907E-09 8.4389E-12 7.0870E-09 3.8845E-09 9.1306E-09  $ Am-241 U-233 U-234 Pu-241 Pm-147
9.6549E-18 7.2463E-06 1.2903E-08 1.8927E-15 1.8012E-10  $ Ac-227 Eu-152 Am-242m Ra-223 Pu-239
1.1535E-06 5.7118E-03 5.2311E-14 9.6064E-14 1.2519E-17  $ Am-241 Eu-154 Th-229 Pu-239 Th-227
1.1828E-09 6.3737E-14 1.6522E-12 5.6120E-08 7.8247E-18  $ Pu-239 Ac-225 U-233 Np-239 Th-227
3.6804E-09 2.3473E-13 2.8934E-16 2.5149E-13 4.6948E-18  $ Pu-239 Th-229 Pa-231 Th-229 Th-227
1.6773E-14 1.3911E-10 4.2688E-09 4.7293E-06 1.0021E-06  $ Ac-225 Th-231 Pu-239 Am-241 Eu-154
8.4234E-11 1.6522E-13 3.0349E-09 5.0616E-07 4.6964E-15  $ Pa-234 U-233 Eu-152 Sn-126 Ac-225
6.7065E-15 4.0239E-15 6.2106E-15 1.4029E-06 5.7005E-15  $ Th-229 Th-229 U-240 Eu-154 Th-229
7.0211E-19 1.8419E-10 1.7793E-13 3.7885E-07 1.9541E-06  $ Ac-228 U-232 U-233 Pu-239 Eu-154
2.0040E-16 5.4745E-09 7.9524E-18 1.6847E-09 8.1339E-14  $ Rn-219 Np-237 Ra-223 Pa-234 U-233
2.9060E-06 1.4480E-10 1.0965E-13 2.7791E-11 2.6690E-07  $ Eu-154 Th-228 Th-229 Np-238 Cm-245
5.7961E-11 4.8274E-18 4.3592E-15 4.5196E-09 1.7689E-11  $ Th-231 Ac-227 Th-229 Np-237 Pa-234
1.3131E-17 4.2253E-17 1.3418E-14 1.4029E-06 2.2828E-08  $ Fr-223 Th-227 Ac-225 Eu-154 Am-242m
5.8971E-12 5.1895E-21 1.9475E-10 1.5532E-06 5.0616E-07  $ U-233 Ac-228 Th-231 Eu-154 Sn-126
1.0786E-08 2.0843E-08 2.7821E-11 9.7374E-12 3.9266E-13  $ Cm-245 Am-242m U-235 Th-231 Th-229
5.4381E-17 1.2635E-11 6.9448E-21 6.7091E-15 1.4029E-07  $ Pb-214 Pa-234 Ac-228 Ac-225 Eu-154
3.8128E-14 6.1134E-09 2.5418E-13 5.4843E-10 3.1828E-10  $ U-233 Am-241 U-233 Cm-245 Np-237
2.2273E-17 5.8316E-11 7.5811E-11 5.0362E-12 5.0078E-17  $ Np-240 Pa-234m Pa-234 Pu-238 Th-227
1.6461E-12 5.1006E-10 9.0885E-20 1.4882E-20 8.3725E-15  $ Th-231 U-235 Th-232 Ac-228 U-232
3.6254E-17 2.0344E-16 1.9213E-09 1.5963E-15 4.0239E-15  $ Pb-214 Th-227 Pu-239 Th-228 Th-229
6.1222E-07 1.1592E-11 1.3447E-13 1.0021E-07 2.7500E-08  $ Am-243 U-235 Th-229 Eu-154 Np-237
1.0447E-09 2.5410E-08 1.3830E-13 1.1510E-11 2.9482E-11  $ Pu-239 U-235 Th-230 Bi-212 Pa-234
5.1850E-15 1.7171E-08 7.6255E-13 8.1609E-16 4.3609E-14  $ Ra-223 Pu-239 U-233 Pa-231 Ac-225
1.3447E-11 4.0669E-12 5.7823E-15 4.6553E-20 7.4190E-11  $ Th-231 U-233 U-240 Ac-228 Th-231
5.0616E-07 3.6576E-06 6.8005E-07 7.4449E-09 1.6700E-11  $ Sn-126 Eu-154 Eu-155 Pu-239 U-233
5.3060E-07 5.7005E-15 1.0965E-16 1.4482E-17 6.9077E-14  $ Am-241 Th-229 Np-240 Ac-227 Th-229
1.0116E-08 2.9676E-13 9.1506E-13 1.0466E-06 2.3259E-08  $ Eu-152 Th-229 U-233 Pu-241 Sb-126
3.3044E-13 2.3482E-14 1.5649E-17 1.4084E-14 8.5357E-08  $ U-233 Fr-221 Th-227 Th-229 Am-241
2.6702E-13 1.6847E-11 1.8547E-10 1.4896E-08 1.3418E-14  $ Ac-225 Pa-234 U-235 Np-237 Ac-225
6.2534E-16 3.0814E-07 5.6437E-10 4.7189E-07 2.9775E-09  $ Np-240 Cm-244 Pa-234 Pu-238 Am-242m
1.3980E-13 3.1828E-10 9.9251E-09 2.1140E-19 6.3737E-14  $ U-233 Np-237 Am-242m Ac-228 Ac-225
8.8908E-15 6.2288E-10 2.6826E-13 3.8128E-13 7.0145E-08  $ Ra-223 Am-241 Th-229 U-233 Eu-154
5.8564E-09 5.0616E-07 1.4743E-13 1.4029E-06 4.1480E-13  $ Np-237 Sn-126 U-233 Eu-154 Th-229
1.0399E-13 9.9255E-12 2.8006E-09 6.0040E-11 1.6766E-14  $ Ac-225 Np-238 Cm-242 Pu-239 Th-229
1.0943E-15 1.7028E-10 5.8964E-11 1.6149E-09 1.4029E-07  $ Ra-223 Pu-242 Pa-234 Am-241 Eu-154
3.7043E-08 3.7225E-10 4.5782E-08 3.3792E-17 7.3849E-09  $ Pu-241 Pu-239 Pu-240 Ac-227 Pu-239
1.7302E-09 8.2265E-10 1.4029E-07 1.0955E-17 2.0370E-09  $ Am-241 Cm-245 Eu-154 Th-227 Np-237
1.9064E-13 3.5936E-10 5.1610E-08 7.0418E-15 1.1778E-08  $ U-233 Th-231 Am-242m Th-229 U-235
5.3442E-12 5.2342E-12 1.5836E-11 2.5193E-07 8.3050E-08  $ Bi-212 Pb-212 U-233 U-237 Am-241
9.0419E-12 8.2265E-10 7.9524E-18 9.6590E-13 7.5811E-12  $ Th-231 Cm-245 Ra-223 U-233 Pa-234
2.6761E-08 3.2568E-07 5.0616E-07 8.6731E-08 9.5854E-08  $ Am-241 Eu-154 Sn-126 Np-239 Cm-243
1.2200E-10 7.1089E-14 1.6766E-14 1.7412E-10 2.1909E-17  $ Th-228 Th-229 Th-229 Pu-239 Th-227
3.8158E-21 7.1425E-09 1.7284E-13 4.5196E-09 8.2094E-15  $ Ac-228 Am-243 U-233 Np-237 U-240
1.9840E-07 2.7821E-12 4.6948E-18 1.2731E-09 3.3546E-15  $ Am-241 Th-231 Th-227 Np-237 Ac-225
4.2117E-11 3.5586E-13 2.3482E-14 6.6044E-09 1.5649E-18  $ Pa-234 U-233 Fr-221 Pu-239 Th-227
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6.3712E-15 6.7065E-15 7.2411E-18 1.0648E-10 8.8964E-14  $ Th-229 Th-229 Ac-227 Eu-152 U-233
1.8012E-13 4.0239E-14 2.3184E-11 3.2827E-18 2.0344E-17  $ Pu-239 Th-229 U-235 Fr-223 Th-227
1.8612E-10 1.0303E-20 2.5806E-10 4.1964E-11 5.8462E-13  $ Pu-239 Ac-228 Np-238 Th-231 U-233
3.0179E-15 1.6847E-11 2.5181E-12 6.7065E-15 9.1406E-07  $ Th-229 Pa-234 Pu-238 Th-229 Cm-245
2.0993E-08 4.3688E-16 2.7038E-17 2.8169E-17 5.0616E-07  $ Am-241 Np-240 Ra-223 Th-227 Sn-126
1.1458E-09 1.0676E-13 5.8381E-11 6.3619E-18 7.4753E-17  $ Np-237 U-233 Pb-212 Ra-223 Ra-223
5.0837E-14 6.7091E-15 3.9626E-09 3.1299E-18 2.4334E-16  $ U-233 Ac-225 Pu-239 Th-227 Ra-223
7.2095E-14 6.5135E-07 1.2731E-09 4.1325E-07 6.1570E-15  $ Th-229 Eu-154 Np-237 Np-239 Th-228
7.8827E-10 7.6276E-11 4.8957E-14 6.3546E-14 2.0605E-20  $ U-235 Th-231 Th-229 U-233 Ac-228
1.2608E-10 5.7619E-07 7.3860E-18 5.1643E-17 7.7755E-11  $ Pu-239 Eu-154 Fr-223 Th-227 Pa-234m
7.9051E-10 1.3261E-07 1.0055E-09 1.0167E-13 5.0616E-07  $ Th-234 U-235 Cm-245 U-233 Sn-126
1.6847E-10 2.4911E-14 3.2277E-15 6.7091E-15 1.9097E-10  $ Pa-234 Th-230 Ra-226 Ac-225 Np-237
5.0837E-12 1.5431E-13 6.5443E-10 3.2066E-05 7.4190E-12  $ U-233 Ac-225 Pu-239 Eu-154 Th-231
4.9833E-09 1.7133E-14 1.8555E-08 2.5377E-09 3.6632E-20  $ Pu-239 U-240 Cm-245 Am-241 Ac-228
8.3725E-14 1.5914E-09 2.4915E-08 1.0167E-13 1.7570E-09  $ U-232 Np-237 Am-241 U-233 Eu-152
5.3435E-10 3.1192E-09 5.2255E-16 2.8510E-11 1.4788E-12  $ Pu-239 Np-237 Np-240 Pa-234m Th-229
5.0541E-11 1.0060E-14 1.4606E-09 1.1776E-08 4.8467E-09  $ Pa-234 Th-229 U-235 Np-237 Am-243
2.8058E-07 6.4243E-09 4.6964E-14 5.0616E-07 4.5317E-17  $ Eu-154 Pu-239 Ac-225 Sn-126 Pb-214
5.8964E-12 1.2731E-09 2.2215E-10 5.6520E-10 1.0957E-12  $ Pa-234 Np-237 Pu-239 Am-241 Pm-147
1.8779E-17 6.7091E-15 3.1902E-16 9.7374E-11 4.7714E-18  $ Th-227 Ac-225 Pa-231 U-235 Ra-223
9.3106E-20 4.0432E-11 2.5918E-11 2.5463E-10 3.1299E-17  $ Ac-228 Pa-234 Pa-234m Np-237 Th-227
2.5418E-15 2.3808E-14 8.4234E-11 2.0648E-09 3.1299E-17  $ U-233 Th-229 Pa-234 Pu-238 Th-227
2.8009E-09 9.2278E-10 2.5039E-09 9.3896E-18 9.5836E-10  $ Np-237 Am-241 U-235 Th-227 Eu-152
1.0108E-10 3.0555E-10 6.5471E-12 4.6653E-11 3.4163E-08  $ Pa-234 Np-237 Pu-238 Pa-234m Pu-239
3.4342E-20 3.3451E-09 3.5994E-16 1.9952E-13 2.2979E-17  $ Ac-228 Am-241 Th-227 Th-229 Fr-223
2.3474E-16 1.4603E-17 1.1615E-08 2.3260E-11 1.6522E-13  $ Th-227 Th-230 U-235 Th-228 U-233
5.0616E-07 3.5994E-16 1.1181E-09 2.9100E-06 9.1125E-07  $ Sn-126 Th-227 Eu-152 U-237 Am-241
5.8208E-12 2.9073E-08 1.0185E-09 1.1142E-18 2.9709E-14  $ U-233 Sb-126 Np-237 Ac-228 U-232
3.4071E-07 1.1181E-09 1.7448E-05 1.6649E-05 5.9612E-11  $ Eu-154 Eu-152 Np-239 Cm-243 Pa-234m
3.0007E-11 7.0418E-14 6.3984E-10 1.7684E-15 4.2117E-12  $ Cm-242 Th-229 Cm-245 Th-227 Pa-234
9.9591E-13 7.3376E-11 9.6121E-09 1.0708E-16 3.5586E-13  $ Th-229 Tl-208 Np-237 U-240 U-233
3.3027E-09 5.0048E-09 1.0955E-16 2.6604E-17 2.8645E-09  $ Pu-240 Eu-152 Th-227 Th-227 Np-237
8.7001E-21 4.7616E-14 6.2598E-11 2.9645E-10 5.0616E-07  $ Ac-228 Th-229 U-235 Th-228 Sn-126
1.1406E-13 1.6776E-12 8.8964E-12 1.2709E-13 8.5782E-11  $ Ac-225 U-233 U-233 U-233 Th-231
3.8812E-12 7.2048E-11 6.3712E-14 9.3896E-17 6.2597E-17  $ Fr-221 Pu-239 Th-229 Th-227 Th-227
3.8128E-13 3.2568E-07 1.6847E-11 5.2486E-17 3.3747E-11  $ U-233 Eu-154 Pa-234 Ra-223 Np-238
7.7125E-15 2.7821E-10 4.8907E-08 4.7714E-17 2.7618E-09  $ Th-229 U-235 Am-241 Rn-219 U-237
3.4265E-17 1.2731E-10 8.1339E-14 8.1406E-08 1.6026E-20  $ Np-240 Np-237 U-233 Sb-126 Ac-228
2.0634E-11 2.6837E-14 2.3474E-17 2.5418E-14 2.4814E-14  $ Th-231 Ac-225 Th-227 U-233 Th-229
9.0660E-10 5.0616E-07 1.4285E-06 4.9698E-10 2.5418E-14  $ Pu-239 Sn-126 Np-239 Pa-234 U-233
4.6329E-10 5.0837E-14 5.7498E-05 5.3480E-05 2.1664E-14  $ Pa-234 U-233 Np-239 Cm-243 Th-228
1.8547E-11 2.8058E-07 8.9119E-10 1.1870E-16 1.7284E-13  $ U-235 Eu-154 Np-237 Pa-231 U-233
1.0955E-18 7.3264E-21 3.1565E-06 1.4625E-09 5.3060E-09  $ Th-227 Ac-228 Eu-154 Cm-245 Am-241
1.2637E-10 6.7235E-11 7.6130E-10 2.7618E-09 8.2066E-17  $ Tl-208 U-235 Am-241 U-237 Fr-223
7.0422E-16 2.3766E-17 2.0735E-12 5.0362E-12 5.0616E-07  $ Th-227 Th-230 Pa-234m Pu-238 Sn-126
1.7527E-14 2.1330E-11 6.0358E-14 1.2709E-13 8.5177E-07  $ Th-227 Th-231 Th-229 U-233 Eu-154
2.3959E-09 8.6457E-10 3.7557E-09 4.9926E-08 3.8549E-17  $ Eu-152 Pu-239 Np-237 Pb-212 Np-240
1.0648E-09 6.4916E-13 9.6590E-13 6.7091E-15 1.7388E-10  $ Eu-152 Th-231 U-233 Ac-225 U-235
4.5410E-09 6.8792E-15 4.3829E-10 8.1609E-16 3.2862E-14  $ Ra-224 Pb-214 Pu-239 Pa-231 Th-229
1.9475E-12 5.4654E-09 2.3741E-15 1.5190E-09 2.2678E-11  $ Th-231 Cs-134 Pa-231 Pu-239 Pa-234m
1.9167E-06 3.0620E-10 1.4314E-17 7.5811E-11 9.2014E-12  $ Eu-152 Pu-239 Ra-223 Pa-234 U-233
5.0449E-16 5.1933E-16 5.0616E-07 1.0669E-18 1.7214E-17  $ Pa-231 Pa-231 Sn-126 Fr-223 Th-227
2.7683E-09 1.2288E-10 4.3413E-11 9.3193E-04 3.7534E-09  $ Am-241 U-235 Pa-234m Eu-154 Pa-233
6.7091E-15 3.9653E-12 4.3229E-10 2.3586E-10 3.1828E-10  $ Ac-225 U-233 Pu-239 Pa-234 Np-237
6.2288E-10 5.8848E-17 1.0955E-17 1.8084E-12 1.0669E-18  $ Am-241 Ra-223 Th-227 Th-231 Fr-223
5.7903E-16 2.0344E-16 1.5070E-12 5.5667E-17 3.0502E-09  $ Th-227 Th-227 Th-231 Ra-223 Cm-244
6.1392E-14 4.6369E-11 1.5973E-08 4.9305E-17 3.2862E-14  $ Np-240m U-235 Eu-152 Ra-223 Th-229
9.6590E-14 1.7214E-16 2.8535E-10 3.3546E-14 3.1497E-14  $ U-233 Th-227 Tl-208 Ac-225 Th-230
2.4052E-15 5.5498E-07 5.6120E-07 1.2519E-15 5.0895E-17  $ Th-230 Cm-243 Np-239 Th-227 Ra-223
4.8032E-09 7.9524E-18 2.8555E-16 7.9384E-15 1.0676E-13  $ Pu-239 Ra-223 U-240 Pa-231 U-233
5.0616E-07 1.0669E-18 1.0642E-14 4.0740E-10 8.7764E-21  $ Sn-126 Fr-223 Th-227 Np-237 Ac-228
3.6934E-09 2.4810E-10 5.5398E-11 7.3448E-17 5.0755E-16  $ Pa-234m Pa-233 Pu-238 Pa-231 Pb-214
1.1736E-14 4.5753E-13 1.3503E-14 9.5429E-18 2.7960E-13  $ Th-229 U-233 Pa-231 Ra-223 U-233
1.3957E-09 2.8058E-07 7.8797E-13 4.5188E-18 4.3286E-10  $ Am-241 Eu-154 U-233 Ra-226 Np-237
1.5649E-16 1.6776E-08 8.1380E-14 1.1829E-20 1.5911E-09  $ Th-227 Cm-244 Np-240m Ac-228 Pu-239
1.0381E-08 2.2547E-07 6.2657E-22 9.6064E-11 5.0616E-07  $ Am-241 Eu-154 Bi-210 Pu-239 Sn-126
1.3911E-11 1.4320E-11 3.9123E-18 1.9541E-06 9.8348E-08  $ U-235 Pa-234 Th-227 Eu-154 U-237
3.0336E-08 2.6894E-12 1.5649E-17 6.6088E-13 2.1631E-14  $ Am-241 Th-231 Th-227 U-233 Ra-223
1.0021E-06 2.0764E-09 9.8448E-19 8.5345E-12 1.2519E-17  $ Eu-154 Eu-152 Ac-228 U-232 Th-227
7.3823E-10 5.0078E-17 1.8635E-08 1.5746E-14 5.3111E-16  $ Am-241 Th-227 Eu-152 Rn-219 Np-240
2.0357E-08 8.4234E-11 1.5251E-13 3.9284E-07 4.0360E-07  $ Pa-233 Pa-234 U-233 Np-239 Cm-243
7.6682E-16 4.3772E-15 1.6310E-16 5.5114E-07 6.9553E-14  $ Th-227 Pa-231 Bi-214 Eu-154 Th-231
2.9909E-16 1.1184E-12 2.3474E-18 5.0104E-09 8.5721E-09  $ Pb-214 U-233 Th-227 Eu-154 Eu-152
1.1360E-10 2.5270E-11 1.4255E-11 7.6130E-09 5.0616E-07  $ U-235 Pa-234 Pa-234m Am-241 Sn-126
5.1191E-15 2.5926E-09 7.3364E-05 7.0629E-05 5.8964E-12  $ Pa-231 Tl-208 Np-239 Cm-243 Pa-234
5.0753E-10 2.9994E-12 1.3955E-07 5.6474E-20 6.2598E-10  $ Am-241 U-233 Sb-126 Ac-228 U-235
1.2731E-10 1.0955E-16 4.2588E-07 1.0064E-14 1.1422E-15  $ Np-237 Th-227 Eu-154 Ac-225 U-240
7.4305E-17 1.0955E-17 1.2608E-10 2.5039E-16 1.3911E-11  $ Bi-214 Th-227 Pu-239 Th-227 U-235
1.8316E-20 3.3546E-15 1.1592E-11 1.2241E-13 2.5418E-14  $ Ac-228 Fr-221 U-235 Pa-231 U-233
7.8247E-17 1.1408E-10 4.0304E-06 3.6829E-06 3.3546E-15  $ Th-227 Pu-239 Np-239 Cm-243 Ac-225
8.6071E-17 2.8220E-09 5.0616E-07 1.1793E-11 4.2675E-19  $ Th-227 Eu-152 Sn-126 Pa-234 Fr-223
2.4726E-15 7.7158E-16 2.9903E-17 2.6943E-12 3.5354E-10  $ Th-227 Pa-231 Bi-214 U-233 Bi-212
2.4493E-16 1.2136E-15 1.4629E-10 6.5653E-18 1.4084E-17  $ Ra-223 Np-240m Cm-244 Fr-223 Th-227
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2.0119E-15 1.6229E-11 9.2658E-12 4.8100E-07 3.5758E-09  $ Th-229 U-235 Pa-234 Eu-154 Am-241
1.3650E-11 6.9553E-12 9.3896E-17 6.8630E-12 3.3681E-10  $ U-233 U-235 Th-227 Ra-224 U-237
1.6379E-08 1.4390E-13 3.2851E-10 1.0338E-16 3.5586E-13  $ Am-241 Bi-213 Pa-234 Rn-219 U-233
7.6508E-11 1.3563E-16 2.7543E-11 1.7673E-14 5.5920E-14  $ U-235 U-240 Bi-212 Pb-214 U-233
4.1119E-17 3.4071E-07 1.1234E-07 5.0616E-07 1.9541E-07  $ Np-240 Eu-154 Eu-152 Sn-126 Eu-154
4.3592E-15 6.7292E-16 2.9073E-08 2.9900E-09 4.6092E-20  $ Th-229 Th-227 Sb-126 Pu-239 Po-214
2.2266E-09 2.9158E-11 3.5253E-11 9.2802E-16 3.1299E-15  $ Pa-233 Pa-234m Pu-238 U-240 Th-227
1.0669E-18 1.7880E-13 3.8250E-09 4.2178E-07 3.1299E-16  $ Fr-223 Pa-231 Pb-212 Pa-233 Th-227
1.4029E-06 1.1911E-10 1.1592E-11 1.8325E-13 1.7793E-13  $ Eu-154 Np-238 U-235 Pa-231 U-233
3.0620E-10 7.1386E-14 5.1667E-09 1.1650E-09 3.1716E-17  $ Pu-239 Np-240m Cm-244 Am-241 Bi-214
5.4984E-19 1.6432E-15 7.9242E-22 2.5052E-06 2.0846E-17  $ Fr-223 Th-227 Bi-210 Eu-154 Pb-214
5.0616E-07 3.6835E-17 7.3860E-19 3.3022E-10 2.2547E-07  $ Sn-126 Np-240 Fr-223 Pu-239 Eu-154
2.3474E-17 9.0419E-13 3.6375E-11 1.6149E-09 1.8301E-13  $ Th-227 Th-231 U-237 Am-241 U-233
8.4234E-12 3.1410E-15 7.4190E-17 9.2737E-12 6.7235E-12  $ Pa-234 Np-240m Pa-231 U-235 Th-231
2.3326E-11 8.5765E-08 1.5490E-09 2.4575E-06 7.1171E-14  $ Pa-234m Cm-243 Pu-239 Pa-233 U-233
2.0543E-06 2.5270E-11 6.1550E-19 7.5117E-16 7.3448E-15  $ Eu-154 Pa-234 Fr-223 Th-227 Pa-231
4.8745E-17 7.2507E-17 4.6948E-17 7.1987E-16 1.2938E-08  $ Pb-211 Pb-214 Th-227 Th-227 Eu-152
6.5135E-07 8.1629E-06 9.0812E-08 5.0616E-07 5.3242E-10  $ Eu-154 Np-239 Cm-243 Sn-126 Eu-152
1.0108E-11 6.4796E-12 7.9253E-10 2.8837E-11 2.3184E-12  $ Pa-234 Pa-234m Pu-239 Am-241 U-235
1.9725E-11 1.8547E-13 1.4838E-16 9.3896E-18 1.3787E-17  $ U-233 Th-231 Pa-231 Th-227 Fr-223
3.4429E-17 8.9329E-11 2.8819E-10 1.5031E-07 4.2594E-10  $ Th-227 Np-238 Pu-239 Eu-154 Eu-152
2.5503E-13 7.3713E-12 1.0108E-11 3.2542E-09 6.7158E-20  $ Th-231 U-233 Pa-234 Pu-239 Ac-228
1.2903E-11 9.5197E-06 3.5315E-08 1.7302E-07 2.1351E-12  $ Np-238 Eu-154 Cm-243 Am-241 U-233
5.3668E-14 3.2361E-09 6.2029E-15 1.5881E-10 6.7091E-15  $ Bi-213 Pu-239 Ra-223 Np-238 Fr-221
1.8127E-17 1.9167E-08 9.3896E-18 9.2737E-13 5.0616E-07  $ Pb-214 Eu-152 Th-227 U-235 Sn-126
9.8448E-21 7.8247E-18 3.7477E-09 2.5967E-15 3.2053E-20  $ Ac-228 Th-227 Cs-134 Pa-231 Ac-228
1.6033E-10 8.4711E-19 2.5270E-11 7.6433E-12 1.4014E-20  $ Bi-212 Ac-228 Pa-234 U-232 Po-211
3.1492E-16 1.6522E-13 3.1412E-08 1.7035E-06 4.3036E-15  $ Ra-223 U-233 Eu-152 Eu-154 Th-227
8.2066E-19 1.0090E-13 1.9167E-09 5.0541E-11 1.7302E-07  $ Fr-223 Pa-231 Eu-152 Pa-234 Am-241
1.6301E-07 1.0684E-19 1.3234E-13 2.9660E-08 8.7898E-17  $ U-237 Ac-228 U-232 Pu-239 Bi-214
1.5746E-16 1.0561E-05 1.2108E-07 3.6930E-19 1.5649E-15  $ Ra-223 Np-239 Cm-243 Fr-223 Th-227
5.2557E-17 5.7097E-07 1.3068E-08 5.0616E-07 6.7245E-09  $ Bi-214 Am-241 U-237 Sn-126 Pu-239
2.4814E-12 1.2003E-12 1.4997E-12 1.1990E-09 4.9600E-09  $ Np-238 Cm-242 U-233 U-237 Am-241
5.1189E-11 4.4215E-15 3.2282E-18 9.9929E-14 3.6246E-17  $ Pa-234m Ra-223 Ac-228 U-232 Bi-214
1.6413E-18 2.0335E-14 2.1909E-18 2.2229E-10 6.9215E-09  $ Fr-223 U-233 Th-227 U-237 Eu-152
2.8627E-07 4.9600E-09 4.2832E-15 5.2912E-10 1.3206E-14  $ Pa-233 Am-241 Np-240m Cm-244 Pa-231
1.0837E-19 3.9746E-09 7.3860E-19 5.4773E-16 5.4838E-17  $ Ac-228 Pu-239 Fr-223 Th-227 Pb-211
3.1810E-16 6.9553E-12 6.7884E-06 3.3382E-08 4.5557E-07  $ Ra-223 U-235 Eu-152 Pu-239 Sn-126
8.8100E-11 1.1737E-17 4.2588E-06 5.4369E-17 9.3896E-18  $ U-235 Th-227 Eu-154 Bi-214 Th-227
2.2486E-18 1.7214E-16 1.0807E-10 2.0303E-14 1.1870E-16  $ Fr-223 Th-227 Pu-239 Bi-211 Pa-231
2.2894E-09 1.6229E-13 1.1438E-13 3.4169E-14 5.0541E-11  $ Eu-152 Th-231 U-233 Pb-214 Pa-234
1.2526E-07 1.5649E-17 1.4743E-13 4.3829E-11 7.1964E-15  $ Eu-154 Th-227 U-233 Pu-239 Pa-231
1.1592E-11 5.0369E-21 1.2538E-14 1.2246E-09 3.6286E-11  $ U-235 Ac-228 Pa-231 Eu-152 Pa-234m
5.2605E-10 1.2003E-12 1.3842E-09 1.3418E-14 6.3804E-16  $ Np-238 Cm-242 Am-241 Fr-221 Pa-231
1.4772E-19 6.8391E-17 2.5699E-15 7.3249E-10 7.8247E-18  $ Fr-223 Ra-223 Np-240m Pu-239 Th-227
3.1102E-11 5.9352E-16 5.7994E-18 2.0843E-12 5.3435E-09  $ Pa-234m Pa-231 Bi-214 U-233 Pu-239
2.1936E-07 4.2588E-07 5.2835E-09 5.6584E-09 2.5377E-07  $ Eu-152 Eu-154 Pu-239 U-237 Am-241
1.2724E-17 2.6261E-18 7.8247E-18 3.1810E-17 2.4428E-10  $ Ra-223 Fr-223 Th-227 Ra-223 Pa-234
7.5156E-07 1.0955E-17 1.4820E-08 6.0327E-08 7.7934E-16  $ Eu-154 Th-227 U-237 Am-241 Ra-223
1.0950E-10 1.9842E-21 2.1909E-18 9.3302E-08 3.4869E-16  $ Pa-234 Ac-228 Th-227 Pu-239 Pa-231
2.5052E-07 4.3259E-08 9.3896E-18 4.5308E-18 1.5953E-07  $ Eu-154 Pa-233 Th-227 Bi-214 Am-241
1.1133E-17 7.2501E-21 3.2754E-11 2.1297E-10 3.7095E-15  $ Rn-219 Ac-228 Np-238 Eu-152 Pa-231
4.7714E-19 1.8312E-08 1.1911E-10 1.3418E-14 1.4029E-06  $ Rn-219 Pu-239 Np-238 Fr-221 Eu-154
9.3896E-18 1.5550E-08 6.3619E-18 7.5117E-17 2.5418E-13  $ Th-227 Pu-239 Ra-223 Th-227 U-233
3.2528E-08 3.8128E-14 1.9842E-21 2.8934E-16 1.2778E-09  $ Am-241 U-233 Ac-228 Pa-231 Eu-152
3.3528E-16 2.5225E-17 1.9439E-11 8.8100E-11 7.4539E-10  $ Bi-214 Pa-231 Pa-234m U-235 Eu-152
6.3619E-19 2.2267E-17 8.3094E-17 5.6520E-10 3.8059E-16  $ Rn-219 Ra-223 Np-240 Am-241 Bi-214
3.0527E-21 9.2737E-11 6.8055E-09 4.7714E-18 3.1945E-10  $ Ac-228 U-235 Am-241 Ra-223 Eu-152
5.0449E-16 1.4084E-17 8.1629E-09 1.2308E-08 2.0894E-08  $ Pa-231 Th-227 Np-239 Pu-239 Pu-239
2.0335E-14 8.1554E-18 1.8548E-16 2.8091E-17 2.0843E-14  $ U-233 Bi-214 Pa-231 Bi-214 U-233
4.2588E-06 8.0895E-21 7.1223E-16 8.9699E-08 2.3070E-09  $ Eu-154 Ac-228 Pa-231 Pa-233 Am-241
1.4084E-17 3.5424E-10 8.7001E-21 2.9561E-05 5.6520E-10  $ Th-227 Pu-239 Ac-228 Eu-154 Am-241
1.0561E-14 2.0843E-14 1.8779E-17 3.8079E-06 2.4020E-12  $ Rn-219 U-233 Th-227 Eu-154 Ra-224
6.0931E-15 1.5405E-16 1.6725E-09 1.3218E-14 2.1297E-10  $ Pb-211 Bi-214 Am-241 U-233 Eu-152
1.5010E-10 2.6708E-15 4.6964E-14 5.5559E-19 3.3694E-11  $ Pu-239 Pa-231 Fr-221 Ac-228 Pa-234
6.9553E-12 1.2612E-16 4.0827E-10 5.7021E-07 1.0807E-12  $ U-235 Pa-231 Pu-239 Eu-152 Pu-239
8.8018E-08 7.0145E-07 3.5815E-05 2.7666E-19 5.8147E-08  $ Pu-239 Eu-154 Sb-126m Ra-226 Sb-126
3.2210E-11 2.6604E-18 1.1069E-07 3.5758E-09 2.8217E-08  $ Pb-212 Th-227 Pa-233 Am-241 Eu-152
3.8921E-21 8.4234E-12 2.5418E-14 7.3671E-17 3.3105E-08  $ Ac-228 Pa-234 U-233 Np-240 Am-241
5.5114E-07 6.1053E-21 2.2829E-10 3.3171E-12 1.7035E-07  $ Eu-154 Ac-228 Np-238 Ra-224 Eu-154
7.3249E-09 6.9215E-10 2.8376E-08 9.9679E-17 1.3989E-09  $ Pu-239 Eu-152 Am-241 Bi-214 Pu-239
5.0541E-11 2.7418E-15 6.0040E-11 1.9387E-08 1.3265E-09  $ Pa-234 Pb-211 Pu-239 Np-239 Am-241
1.0155E-17 2.5817E-10 3.0219E-17 3.9582E-07 7.8247E-18  $ Pb-211 Pu-239 Ra-223 Eu-154 Th-227
5.2486E-17 5.0541E-12 9.2737E-12 1.4388E-11 6.3263E-08  $ Ra-223 Pa-234 U-235 Bi-212 Np-239
2.2257E-16 3.6576E-07 1.2709E-14 3.4127E-16 2.2267E-17  $ Pa-231 Eu-154 U-233 Pa-231 Rn-219
6.3619E-17 9.6447E-17 2.7185E-17 8.7546E-12 3.5869E-20  $ Po-215 Pa-231 Bi-214 Bi-213 Ac-228
2.7686E-09 4.0372E-09 8.1993E-08 7.1148E-05 2.0199E-15  $ Eu-152 Am-241 Eu-152 Eu-154 Ra-223
5.2835E-10 5.6520E-10 1.0108E-11 5.0434E-11 2.3474E-19  $ Pu-239 Am-241 Pa-234 Pu-239 Th-227
1.1479E-15 1.3265E-09 2.3184E-12 1.4119E-20 1.7522E-19  $ Np-240 Np-239 U-235 Ac-228 Ra-226
2.5418E-14 1.3607E-10 1.1372E-08 3.6900E-14 4.5790E-21  $ U-233 Pa-234m Pu-239 Ac-225 Ac-228
2.7683E-09 1.5649E-19 3.6176E-10 1.1015E-10 1.1189E-08  $ Am-241 Th-227 Bi-212 Pa-234m Am-241
2.9360E-16 5.1806E-12 1.8547E-11 3.2398E-11 4.4264E-21  $ Bi-214 U-234 U-235 Pa-234m Ac-228
1.0955E-19 8.9459E-11 1.2635E-10 4.1525E-09 2.0843E-14  $ Th-227 Pu-239 Pa-234 Am-241 U-233
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2.9776E-11 1.2003E-13 3.9582E-07 1.3629E-10 1.3477E-11  $ Np-238 Cm-242 Eu-154 Pu-239 Pa-234
8.1629E-09 7.8247E-20 1.5408E-16 1.2745E-18 1.1535E-09  $ Np-239 Th-227 Pb-214 Ac-228 Am-241
1.6811E-11 6.0125E-07 8.4711E-21 7.8247E-20 1.0023E-16  $ Pu-239 Eu-154 Ac-228 Th-227 Np-240
6.7621E-13 3.3694E-11 8.0166E-06 1.0691E-10 3.3220E-09  $ Tl-209 Pa-234 Eu-154 Pa-234m Am-241
1.2233E-16 5.4079E-09 3.8158E-21 9.0634E-18 3.8128E-14  $ Bi-214 Np-239 Ac-228 Pb-214 U-233
9.6159E-21 2.0216E-11 5.3442E-11 1.5162E-11 3.2422E-12  $ Ac-228 Pa-234 Bi-212 Pa-234 Pu-239
1.0874E-16 6.4869E-21 7.8525E-16 3.7997E-07 1.2959E-10  $ Bi-214 Ac-228 Np-240m Cs-134 Pa-234m
2.0310E-17 3.0563E-05 6.1816E-20 3.7811E-15 2.5270E-11  $ Pb-211 Eu-154 Ac-228 U-232 Pa-234
3.8128E-14 4.6948E-19 3.3694E-11 3.1178E-16 1.0064E-14  $ U-233 Th-227 Pa-234 Pb-214 Ac-225
7.0145E-07 6.8685E-21 4.0621E-17 2.7618E-10 2.1909E-19  $ Eu-154 Ac-228 Pb-211 Pu-239 Th-227
6.9215E-09 2.5270E-11 7.0145E-07 1.0676E-14 5.3059E-09  $ Eu-152 Pa-234 Eu-154 U-233 Np-239
5.5114E-07 1.1535E-09 2.0382E-11 3.1064E-07 1.1129E-16  $ Eu-154 Am-241 Tl-208 Eu-154 Pa-231
1.5911E-11 4.0513E-16 5.0753E-10 1.5905E-17 1.0021E-06  $ Pu-239 Pb-214 Am-241 Ra-223 Eu-154
1.0382E-07 3.2816E-21 2.8192E-17 2.2342E-17 3.0611E-08  $ Eu-152 Ac-228 Pa-231 Pb-211 Np-239
6.9448E-21 6.9886E-12 8.6071E-19 5.2235E-11 2.3959E-09  $ Ac-228 Bi-212 Th-227 Pu-239 Eu-152
8.1554E-18 1.1713E-09 7.1386E-16 2.7618E-12 1.7553E-21  $ Bi-214 Eu-152 Np-240m Pu-239 Ac-228
1.5816E-08 1.5816E-08 8.4234E-12 1.8279E-17 5.1933E-17  $ Np-239 Np-239 Pa-234 Pb-211 Pa-231
1.6310E-17 2.4373E-17 3.8868E-08 1.9686E-13 5.3422E-20  $ Bi-214 Pb-211 Eu-152 U-234 Ac-228
3.9162E-14 8.5177E-07 1.3477E-10 2.4900E-09 1.5591E-16  $ U-232 Eu-154 Pa-234 Cm-244 Np-240
4.9970E-14 6.2597E-19 7.1275E-11 3.1084E-12 1.3432E-19  $ Np-240m Th-227 Pa-234m U-234 Ac-228
9.7193E-11 5.1607E-06 7.0087E-17 2.2257E-17 9.2940E-09  $ Pa-234m Eu-154 Rn-222 Pa-231 Tl-208
1.3534E-08 2.7190E-17 4.6096E-06 1.3265E-09 7.9180E-11  $ Eu-152 Pb-214 Eu-154 Am-241 Pa-234
3.0324E-11 2.9990E-09 3.3546E-15 1.4347E-20 9.0020E-12  $ Pa-234 Am-241 Ac-225 Ac-228 Cm-242
4.2679E-10 1.1129E-16 2.8169E-19 6.3619E-17 7.7755E-13  $ Np-238 Pa-231 Th-227 Rn-219 Pa-234m
9.2737E-13 6.5135E-06 4.2832E-16 1.9842E-20 5.0541E-11  $ U-235 Eu-154 Np-240m Ac-228 Pa-234
1.3683E-08 5.2557E-18 7.5811E-11 1.0381E-09 3.7803E-09  $ Eu-152 Bi-214 Pa-234 Am-241 Eu-152
3.0527E-20 2.3474E-19 1.4499E-17 1.4255E-12 3.4223E-12  $ Ac-228 Th-227 Bi-214 Pa-234m Pu-239
3.3546E-15 3.3544E-09 1.1292E-16 5.0541E-11 5.3060E-10  $ Ac-225 Eu-152 Ra-223 Pa-234 Am-241
1.5532E-06 3.2568E-06 1.6847E-11 1.7492E-16 1.0968E-08  $ Eu-154 Eu-154 Pa-234 Pb-214 Eu-152
1.5649E-19 3.2568E-06 2.0232E-09 4.4514E-17 6.5244E-17  $ Th-227 Eu-154 Eu-152 Pa-231 Bi-214
1.7214E-18 1.3477E-11 1.6741E-11 9.5429E-18 1.0648E-09  $ Th-227 Pa-234 Pu-240 Rn-219 Eu-152
4.5317E-18 1.8012E-11 1.3218E-14 7.7080E-21 7.7930E-17  $ Pb-214 Pu-239 U-233 Ac-228 Bi-214
2.0846E-17 1.6847E-10 6.1004E-15 8.5357E-10 1.5031E-06  $ Pb-214 Pa-234m U-233 Am-241 Eu-154
5.9527E-20 2.7008E-15 5.9352E-17 2.9903E-17 6.7922E-21  $ Ac-228 U-232 Pa-231 Bi-214 Ac-228
1.2582E-10 2.5217E-11 1.5462E-18 3.5994E-19 2.4589E-08  $ Rn-220 Pu-239 Th-230 Th-227 Cm-244
1.4920E-12 1.3584E-20 9.8850E-08 9.0714E-13 3.4429E-19  $ Np-240m Ac-228 Sb-126 Pa-234m Th-227
4.8452E-09 2.1901E-11 3.2398E-11 2.2815E-12 3.6075E-05  $ Eu-152 Pa-234 Pa-234m Pu-239 Eu-154
1.0116E-09 3.0007E-10 1.1315E-09 2.6621E-10 2.4955E-19  $ Eu-152 Cm-242 Np-238 Eu-152 Ac-228
8.5357E-10 2.1809E-06 3.1810E-18 6.3891E-09 1.1793E-10  $ Am-241 Cs-134 Rn-219 Eu-152 Pa-234
2.3643E-15 3.3010E-08 2.7797E-10 9.3896E-19 1.4029E-06  $ Np-240 Eu-152 Pa-234 Th-227 Eu-154
4.0157E-06 9.6590E-15 8.5919E-10 2.3356E-18 9.4492E-18  $ Cs-134 U-233 Pa-234 Po-211 Th-230
4.8079E-20 1.2246E-09 3.9525E-11 4.4264E-20 2.2257E-17  $ Ac-228 Eu-152 Pa-234m Ac-228 Pa-231
7.5211E-17 3.8958E-07 5.7109E-16 1.4418E-09 1.6847E-10  $ Bi-214 Sb-126 Np-240m Am-241 Pa-234
2.0344E-19 9.0440E-13 2.0344E-19 1.2709E-14 5.1634E-12  $ Th-227 Bi-212 Th-227 U-233 Pu-239
3.3535E-16 4.9970E-16 2.4867E-12 1.1875E-04 2.6530E-10  $ Pb-214 Np-240m U-234 Eu-154 Am-241
3.6925E-11 2.2257E-17 3.4731E-08 3.2816E-20 3.4265E-17  $ Pu-239 Pa-231 Tl-208 Ac-228 Np-240
1.2635E-11 9.1861E-12 1.1767E-07 1.5111E-09 1.6306E-11  $ Pa-234 Pu-239 Eu-152 Am-241 Tl-208
9.3896E-20 3.2989E-09 6.8141E-04 4.3610E-07 2.3416E-12  $ Th-227 Am-241 Eu-154 Sb-126 Pu-239
1.0874E-17 1.5649E-20 1.5251E-08 8.3522E-13 8.5473E-09  $ Bi-214 Th-227 Cm-244 Np-240m Am-241
8.0166E-07 1.0027E-10 8.5177E-07 1.4314E-16 1.2008E-11  $ Eu-154 Pu-239 Eu-154 Ra-223 Pu-239
8.5177E-07 1.7133E-15 4.5188E-19 7.5811E-11 4.8100E-06  $ Eu-154 Np-240 Ra-226 Pa-234 Eu-154
2.5401E-05 2.2005E-10 8.0396E-10 2.3032E-09 1.5162E-16  $ Cs-134 Cm-242 Np-238 Cm-244 Np-240
4.7829E-14 7.2048E-12 2.8169E-19 6.3619E-18 6.9646E-12  $ Np-240m Pu-239 Th-227 Rn-219 Pu-239
3.7095E-17 1.0020E-16 4.2499E-14 3.6559E-17 6.7922E-21  $ Pa-231 Ra-223 Bi-214 Pb-211 Ac-228
6.7387E-11 8.5177E-07 5.7038E-11 1.3027E-05 6.3431E-17  $ Pa-234 Eu-154 Pu-239 Eu-154 Bi-214
2.2894E-09 1.6847E-11 2.3658E-20 3.1716E-17 8.0453E-11  $ Eu-152 Pa-234 Ac-228 Bi-214 Pu-239
3.2007E-13 8.9329E-11 1.2248E-10 6.8517E-08 7.2648E-11  $ Cm-242 Np-238 Pu-239 Am-241 Pu-239
6.4466E-07 2.2621E-18 5.2332E-08 2.3658E-20 4.1109E-12  $ Sb-126m Th-230 Sb-126 Ac-228 Bi-212
1.3027E-06 5.8462E-15 9.3896E-20 3.2816E-20 1.2724E-17  $ Eu-154 U-233 Th-227 Ac-228 Ra-223
5.0541E-11 2.5039E-19 1.6992E-13 6.4796E-11 2.7438E-11  $ Pa-234 Th-227 U-234 Pa-234m Pu-239
4.3590E-05 4.5308E-18 6.4595E-10 4.1211E-21 6.7387E-11  $ Eu-154 Bi-214 Am-241 Ac-228 Pa-234
1.3279E-20 3.3694E-11 1.5305E-09 1.5405E-17 2.1909E-19  $ Ac-228 Pa-234 Am-243 Bi-214 Th-227
1.4534E-09 1.5190E-10 5.5276E-17 1.8846E-17 3.1290E-21  $ Am-241 Pu-239 Bi-214 Np-240 Ac-228
2.5270E-11 1.5370E-10 2.8997E-17 5.2332E-08 1.6847E-11  $ Pa-234 Pu-239 Bi-214 Sb-126 Pa-234
5.2235E-10 1.6026E-20 3.1299E-20 8.1897E-09 1.4805E-09  $ Pu-239 Ac-228 Th-227 Am-241 Pu-240
5.5114E-07 1.6847E-11 7.8247E-20 1.4908E-09 5.9479E-12  $ Eu-154 Pa-234 Th-227 Eu-152 Ra-224
9.1261E-10 1.6847E-11 7.1275E-11 3.1299E-20 1.1829E-20  $ Pu-239 Pa-234 Pa-234m Th-227 Ac-228
4.8597E-11 5.4369E-17 4.2628E-11 1.0522E-05 1.4675E-11  $ Pa-234m Bi-214 Pu-239 Eu-154 Tl-208
1.6211E-11 1.4029E-06 2.6711E-20 3.9626E-10 4.3486E-08  $ Pu-239 Eu-154 Ac-228 Pu-239 Am-241
5.8964E-11 1.3509E-10 5.0541E-11 6.2852E-11 1.2792E-07  $ Pa-234 Pu-239 Pa-234 Pa-234m Sb-126
3.6738E-08 7.6255E-15 7.5811E-11 5.8239E-10 2.9182E-14  $ Eu-152 U-233 Pa-234 Pu-239 Bi-213
6.8685E-21 2.5270E-11 4.1085E-07 3.9871E-17 7.9556E-01  $ Ac-228 Pa-234 Eu-154 Bi-214 Ba-137m
6.1222E-09 4.1525E-07 9.3896E-20 8.3185E-21 9.9666E-11  $ Am-243 Am-241 Th-227 Ac-228 Pu-239
4.1085E-06 4.7918E-09 1.0950E-10 1.4408E-15 3.5815E-05  $ Eu-154 Eu-152 Pa-234 Bi-214 Sb-126m
5.8147E-06 1.8316E-20 5.6520E-10 1.3477E-10 2.3416E-12  $ Sb-126 Ac-228 Am-241 Pa-234 Pu-239
1.7035E-06 4.3832E-10 1.1793E-10 1.6847E-11 5.4036E-13  $ Eu-154 Am-241 Pa-234 Pa-234m Pu-239
5.8566E-09 7.6316E-21 2.9158E-11 3.0921E-11 2.9763E-20  $ Eu-152 Ac-228 Pa-234m Pu-239 Ac-228
4.8452E-09 2.1514E-07 1.0155E-17 7.3823E-10 1.9741E-05  $ Eu-152 Sb-126 Pb-211 Am-241 Eu-154
9.5429E-18 1.8316E-20 2.0722E-13 1.1980E-07 3.6104E-09  $ Rn-219 Ac-228 U-234 Eu-152 Am-241
7.2493E-17 2.0216E-11 7.9863E-10 2.5918E-11 5.2235E-11  $ Bi-214 Pa-234 Eu-152 Pa-234m Pu-239
4.8983E-09 2.3586E-11 3.9860E-10 5.4369E-18 1.9842E-20  $ Eu-152 Pa-234 Pu-240 Bi-214 Ac-228
6.6644E-12 2.1723E-07 3.7488E-08 5.4036E-11 3.5638E-10  $ Pu-239 Eu-152 Am-241 Pu-239 Pa-234m
6.2597E-20 2.3900E-04 1.2635E-10 1.8012E-12 5.4369E-18  $ Th-227 Eu-154 Pa-234 Pu-239 Bi-214
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4.2448E-09 3.4382E-05 5.8147E-06 7.1275E-11 6.1596E-09  $ Am-241 Sb-126m Sb-126 Pa-234m Am-241
1.6863E-06 4.4430E-12 3.4434E-17 3.8748E-10 3.6286E-11  $ Sb-126 Pu-239 Bi-214 Pa-234 Pa-234m
1.0837E-20 4.7432E-12 3.6486E-15 3.0740E-11 3.4990E-10  $ Ac-228 Pu-239 Th-228 Pu-239 Pa-234m
6.5135E-07 5.1132E-20 4.3495E-16 9.0512E-10 2.3716E-10  $ Eu-154 Ac-228 Bi-214 Eu-152 Pu-239
1.2519E-19 7.6571E-16 8.9680E-12 2.6113E-10 7.0507E-11  $ Th-227 Pb-211 Tl-208 Pa-234 Pu-238
1.8143E-10 6.2597E-20 4.5790E-20 7.1171E-15 3.2398E-11  $ Pa-234m Th-227 Ac-228 U-233 Pa-234m
2.0216E-12 1.9138E-10 7.3938E-09 6.8868E-17 5.5667E-18  $ Pa-234 Pu-238 Am-241 Bi-214 Ra-223
1.5162E-11 2.4491E-08 3.1221E-12 4.7432E-12 2.4551E-05  $ Pa-234 Eu-152 Pu-239 Pu-239 Eu-154
1.6811E-10 5.4948E-21 4.6948E-20 1.4908E-08 3.7153E-16  $ Pu-239 Ac-228 Th-227 Eu-152 Bi-214
2.9119E-12 3.1399E-06 1.4903E-12 2.2608E-07 8.2749E-11  $ Pu-239 Sb-126 Pa-234m Am-241 Tl-208
5.9468E-19 2.7808E-03 4.1683E-17 1.2310E-18 4.2253E-19  $ Th-227 Eu-154 Bi-214 Fr-223 Th-227
1.8316E-19 7.6052E-09 1.0522E-05 1.4499E-17 7.4449E-12  $ Ac-228 Bi-212 Eu-154 Bi-214 Pu-239
2.8751E-09 1.5341E-09 5.4213E-10 5.8964E-11 7.2442E-10  $ Eu-152 Am-241 Am-241 Pa-234m Pa-234
4.3495E-17 1.5649E-19 1.4908E-09 2.5039E-19 1.8012E-12  $ Bi-214 Th-227 Eu-152 Th-227 Pu-239
9.2278E-09 1.0522E-06 1.0913E-20 8.4234E-11 1.0955E-19  $ Am-241 Eu-154 Ac-228 Pa-234 Th-227
4.6005E-10 3.6246E-17 1.7103E-15 9.2737E-13 2.2815E-12  $ Pa-234m Bi-214 Th-228 U-235 Pu-239
2.0216E-10 3.6674E-09 3.8275E-09 4.0372E-10 5.7446E-19  $ Pa-234 Pa-234m Pu-238 Am-241 Fr-223
1.5649E-19 1.0950E-11 4.8632E-12 4.6948E-19 1.7529E-11  $ Th-227 Pa-234 Pu-239 Th-227 Tl-208
9.0714E-13 1.2233E-16 3.2827E-19 1.5649E-19 2.8848E-19  $ Pa-234m Bi-214 Fr-223 Th-227 Ac-228
1.1793E-10 8.7664E-09 1.3843E-09 2.0834E-10 6.1127E-04  $ Pa-234 Am-241 Eu-152 Pu-239 Eu-154
6.5653E-19 1.2519E-18 4.0462E-09 8.4236E-14 1.9263E-09  $ Fr-223 Th-227 Cm-244 Np-240m Am-241
1.3477E-11 7.1275E-11 4.0688E-19 7.4597E-10 1.9213E-12  $ Pa-234 Pa-234m Th-227 Tl-208 Pu-239
2.3070E-10 4.4723E-08 2.5270E-11 7.2507E-17 6.5653E-19  $ Am-241 Eu-152 Pa-234 Pb-214 Fr-223
4.6948E-19 1.1272E-15 1.3413E-08 6.7387E-12 1.6619E-08  $ Th-227 Pb-211 Pa-234m Pa-234 Pu-238
1.6511E-11 5.7674E-09 4.5036E-15 4.7171E-11 2.2894E-08  $ Pu-239 Am-241 Bi-214 Pa-234 Eu-152
7.1447E-10 5.4675E-09 4.3119E-19 3.0683E-09 2.0344E-19  $ Pu-239 Am-241 Ac-228 Am-241 Th-227
2.2895E-20 1.2694E-14 1.4029E-06 1.0094E-17 2.3474E-18  $ Ac-228 U-232 Eu-154 Fr-223 Th-227
5.5711E-21 1.6811E-12 7.0362E-11 1.6847E-11 3.3094E-06  $ Ac-228 Pu-239 Am-241 Pa-234 Eu-152
8.1654E-12 5.0078E-19 9.2658E-11 2.8837E-10 1.4347E-19  $ Pu-239 Th-227 Pa-234 Am-241 Ac-228
1.7302E-10 3.4342E-10 4.2117E-11 2.5918E-12 1.5109E-11  $ Am-241 Pa-234m Pa-234 Pa-234m Pu-238
1.6413E-19 1.5649E-19 1.2662E-09 1.0060E-15 7.1516E-10  $ Fr-223 Th-227 Bi-212 Pb-214 Am-241
2.8997E-16 1.1793E-10 2.2160E-09 2.4174E-09 5.1634E-12  $ Bi-214 Pa-234 Pa-234m Pu-238 Pu-239
4.1033E-19 1.4084E-19 2.1014E-12 4.4986E-10 1.2850E-14  $ Fr-223 Th-227 Pu-239 Am-241 Np-240m
1.5532E-06 6.7922E-21 3.2827E-19 4.6948E-20 1.2008E-12  $ Eu-154 Ac-228 Fr-223 Th-227 Pu-239
3.8877E-12 1.2635E-10 1.3911E-12 6.2826E-09 1.0843E-09  $ Pa-234m Pa-234 U-235 Eu-152 Am-241
1.2440E-18 2.2226E-05 3.2009E-10 2.4620E-19 1.2519E-18  $ Ac-228 Cs-134 Pa-234 Fr-223 Th-227
9.0060E-13 9.5871E-18 3.8059E-17 4.6096E-06 2.2720E-06  $ Pu-239 Po-214 Bi-214 Eu-154 Cs-134
1.5687E-09 1.0136E-25 6.2645E-21 3.8426E-12 1.3951E-18  $ Am-241 Tl-206 Po-210 Pu-239 Fr-223
1.5180E-18 3.3694E-11 2.1733E-12 1.6211E-12 3.2479E-09  $ Th-227 Pa-234 Po-216 Pu-239 Eu-152
2.7797E-10 9.0652E-11 1.9439E-10 1.1327E-15 3.5758E-10  $ Pa-234 Pu-238 Pa-234m Bi-214 Am-241
9.7944E-14 7.8247E-20 1.3607E-10 7.2648E-12 5.8964E-12  $ Bi-213 Th-227 Pa-234m Pu-239 Pa-234
5.5398E-10 8.0928E-08 7.0362E-10 4.9240E-19 4.2253E-18  $ Pu-238 Eu-152 Am-241 Fr-223 Th-227
4.2117E-11 1.2850E-14 2.7018E-12 2.0605E-21 3.7153E-17  $ Pa-234 Np-240m Pu-239 Ac-228 Bi-214
6.5636E-05 1.4410E-12 8.8527E-21 2.1606E-15 1.9827E-08  $ Eu-154 Pu-239 Ac-228 U-232 Cm-244
9.1375E-14 4.6948E-20 4.5357E-11 4.6139E-10 2.1901E-10  $ Np-240m Th-227 Pa-234m Am-241 Pa-234
1.3864E-16 1.6306E-11 9.9370E-17 3.0020E-12 2.5377E-10  $ Bi-214 Tl-208 Np-240 Pu-239 Am-241
2.4620E-19 3.9123E-18 1.4882E-20 6.4148E-11 1.0997E-18  $ Fr-223 Th-227 Ac-228 Pa-234m Fr-223
3.1299E-19 8.5179E-17 3.3694E-10 1.0807E-12 1.5649E-20  $ Th-227 Bi-214 Pa-234 Pu-239 Th-227
2.7683E-10 7.9853E-12 7.0145E-07 1.5874E-19 1.6199E-10  $ Am-241 Pu-239 Eu-154 Ac-228 Pa-234m
4.6329E-10 6.0526E-15 1.7103E-14 2.0841E-17 1.7772E-12  $ Pa-234 Pb-211 Th-228 Bi-214 Pu-239
1.5905E-18 2.4223E-10 4.8079E-19 3.8009E-13 2.7791E-10  $ Rn-219 Am-241 Ac-228 Cm-242 Np-238
1.6413E-19 6.2597E-19 1.1408E-12 5.7109E-16 5.4109E-16  $ Fr-223 Th-227 Pu-239 Np-240m Pb-214
4.2063E-09 2.8819E-12 2.6940E-19 1.0708E-14 4.6139E-11  $ Eu-152 Pu-239 Ac-228 Np-240m Am-241
4.1529E-08 1.1793E-11 1.6413E-19 9.3896E-19 8.0453E-12  $ Eu-152 Pa-234 Fr-223 Th-227 Pu-239
4.9245E-11 4.2117E-11 7.7661E-05 1.0669E-18 2.3474E-19  $ Pa-234m Pa-234 Eu-154 Fr-223 Th-227
7.8077E-11 1.5405E-17 3.1144E-10 8.2066E-20 9.3896E-20  $ Cs-134 Bi-214 Am-241 Fr-223 Th-227
3.2568E-05 4.3832E-10 1.0108E-11 9.5688E-10 2.8510E-10  $ Eu-154 Am-241 Pa-234 Pu-238 Pa-234m
3.5106E-21 1.0955E-19 2.3070E-10 1.0292E-06 9.3896E-20  $ Ac-228 Th-227 Am-241 Sb-126 Th-227
3.4979E-14 1.6807E-09 3.7558E-19 8.2066E-20 5.1078E-09  $ Np-240m Cm-244 Th-227 Fr-223 Tl-208
9.4585E-11 6.1134E-10 4.9240E-20 3.1299E-20 1.0155E-17  $ Am-241 Am-241 Fr-223 Th-227 Pb-211
4.8597E-11 7.5384E-16 6.4248E-16 1.0755E-06 3.2827E-20  $ Pa-234m Np-240 Np-240m Eu-152 Fr-223
1.0955E-19 5.3379E-15 1.2974E-20 5.3060E-10 1.0108E-11  $ Th-227 U-233 Ac-228 Am-241 Pa-234
9.1580E-21 1.6234E-03 6.6053E-11 1.4042E-20 8.6425E-16  $ Ac-228 Eu-154 Pu-240 Ac-228 U-232
1.0669E-18 2.5039E-19 3.3694E-10 4.0448E-21 1.6413E-20  $ Fr-223 Th-227 Pa-234 Ac-228 Fr-223
1.8779E-19 2.1614E-12 7.5811E-10 1.1583E-10 1.1524E-05  $ Th-227 Pu-239 Pa-234 Pu-238 Eu-154
1.8316E-21 1.7495E-10 1.2403E-13 8.6352E-09 8.4234E-11  $ Ac-228 Pa-234m Cm-242 Np-238 Pa-234m
1.2635E-09 5.5398E-10 1.2637E-11 2.5377E-10 8.0895E-21  $ Pa-234 Pu-238 Tl-208 Am-241 Ac-228
3.3694E-10 2.1416E-16 2.3857E-18 1.2136E-15 4.9240E-20  $ Pa-234m Np-240 Rn-219 Np-240m Fr-223
3.1299E-20 4.5030E-12 6.5135E-05 3.2827E-20 2.0344E-20  $ Th-227 Pu-239 Eu-154 Fr-223 Th-227
4.1932E-10 5.2912E-10 4.3546E-15 4.5030E-13 1.2678E-15  $ Bi-212 Cm-244 Np-240m Pu-239 Np-240
4.1033E-19 1.7214E-19 7.9404E-11 4.4010E-11 3.8069E-16  $ Fr-223 Th-227 Np-238 Cm-242 Tl-207
2.2656E-18 1.0807E-12 2.8058E-07 8.0743E-11 3.4536E-10  $ Po-211 Pu-239 Eu-154 Am-241 Pa-234
3.7350E-10 1.1422E-14 2.3427E-08 4.8079E-21 3.4604E-10  $ Cm-244 Np-240m Eu-152 Ac-228 Am-241
1.1624E-04 2.2437E-19 9.6959E-17 4.2117E-11 5.0362E-11  $ Eu-154 Ac-228 Bi-214 Pa-234 Pu-238
4.5030E-13 3.8334E-09 1.7035E-06 2.0523E-15 3.2827E-19  $ Pu-239 Eu-152 Eu-154 Th-228 Fr-223
3.2864E-18 2.3474E-20 9.9941E-15 7.6316E-18 8.4056E-13  $ Th-227 Th-227 Np-240m Ac-228 Pu-239
2.8837E-10 2.0841E-17 1.1393E-16 7.2814E-14 5.8560E-09  $ Am-241 Bi-214 Np-240 Np-240m Np-238
5.0434E-13 1.0802E-12 8.0132E-21 1.7536E-06 1.1127E-07  $ Pu-239 Cm-242 Ac-228 Eu-154 Eu-152
1.8779E-20 3.3694E-11 2.1916E-10 4.3500E-21 5.3780E-10  $ Th-227 Pa-234 Am-241 Ac-228 Pa-234m
2.8387E-08 4.9627E-10 8.5177E-06 2.4428E-10 9.2658E-10  $ Np-238 Np-238 Eu-154 Pa-234 Pa-234
6.7619E-08 9.2658E-10 4.1801E-10 5.6372E-11 1.0955E-20  $ Eu-152 Pa-234 Pu-238 Pa-234m Th-227
5.3808E-11 5.3722E-07 7.0145E-07 1.0708E-14 6.3441E-11  $ Tl-208 Sb-126m Eu-154 Np-240m Am-241
1.8635E-08 3.6632E-21 7.8052E-13 2.9178E-15 3.0839E-17  $ Eu-152 Ac-228 Pu-239 Bi-214 Np-240
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8.4234E-11 3.9702E-09 7.9863E-10 1.5649E-20 8.6377E-14  $ Pa-234m Np-238 Eu-152 Th-227 Np-240m
1.5419E-17 3.6008E-13 2.5806E-10 2.5948E-21 3.0020E-12  $ Np-240 Cm-242 Np-238 Ac-228 Pu-239
5.3598E-09 1.1268E-19 3.3743E-10 6.8531E-15 1.3607E-10  $ Np-238 Th-227 Pu-238 Np-240m Pa-234m
1.5405E-17 2.8237E-20 6.4595E-11 1.0108E-09 6.5471E-11  $ Bi-214 Ac-228 Am-241 Pa-234 Pu-238
4.5357E-10 3.1290E-20 6.7387E-10 3.4528E-17 2.0144E-10  $ Pa-234m Ac-228 Pa-234 Pb-211 Bi-212
6.9776E-08 1.8612E-12 6.6902E-10 1.9213E-12 8.3948E-20  $ Sb-126 Pu-239 Am-241 Pu-239 Ac-228
5.8566E-09 9.7026E-20 5.2112E-16 1.5762E-16 2.9073E-08  $ Eu-152 Th-227 Np-240m Np-240 Sb-126
8.4234E-12 3.8877E-11 9.2802E-15 6.9478E-09 1.0602E-12  $ Pa-234 Pa-234m Np-240m Np-238 Cm-242
3.5340E-16 3.4182E-08 1.4653E-18 5.0541E-11 6.9215E-10  $ Bi-214 Eu-152 Ac-228 Pa-234 Eu-152
1.6811E-12 1.6873E-10 4.6401E-18 4.6948E-20 1.5649E-20  $ Pu-239 Np-238 Ac-228 Th-227 Th-227
2.2187E-15 3.6736E-09 1.8004E-14 1.4653E-20 2.0841E-17  $ Np-240 Eu-152 Cm-242 Ac-228 Bi-214
1.1793E-10 7.7843E-21 1.6811E-12 5.2012E-13 1.6847E-10  $ Pa-234 Ac-228 Pu-239 Cm-242 Pa-234
4.0290E-11 1.1524E-06 8.3567E-11 6.6044E-13 1.0002E-12  $ Pu-238 Eu-154 Tl-208 Pu-239 Cm-242
1.6005E-10 2.7593E-07 9.0187E-07 4.0009E-12 1.0708E-15  $ Pa-234 Np-238 Eu-154 Cm-242 Np-240m
1.2608E-12 1.4500E-20 6.2534E-16 3.8158E-20 1.0874E-17  $ Pu-239 Ac-228 Np-240 Ac-228 Bi-214
5.9251E-15 3.9540E-07 5.4773E-20 7.8798E-09 1.6211E-12  $ Np-240m Sb-126 Th-227 Eu-152 Pu-239
1.7103E-15 1.0955E-20 1.8791E-10 1.4530E-03 4.6948E-20  $ Th-228 Th-227 Pa-234m Eu-154 Th-227
3.8229E-08 7.0507E-10 1.0116E-09 2.0843E-14 2.5252E-03  $ Pa-234m Pu-238 Eu-152 U-233 Eu-154
1.6505E-07 1.0807E-12 8.4056E-13 8.0018E-12 4.1085E-07  $ Eu-152 Pu-239 Pu-239 Cm-242 Eu-154
9.0616E-18 1.3737E-21 1.9703E-17 2.8435E-17 7.3823E-11  $ Bi-214 Ac-228 Np-240 Pb-211 Am-241
2.3474E-20 5.4948E-21 1.6790E-21 6.1816E-21 3.1299E-20  $ Th-227 Ac-228 Ac-228 Ac-228 Th-227
1.0874E-17 5.0541E-11 1.0021E-06 2.3474E-20 9.5284E-08  $ Bi-214 Pa-234 Eu-154 Th-227 Np-238
6.7387E-11 4.9970E-16 2.0149E-07 3.2007E-12 8.8803E-17  $ Pa-234 Np-240m Np-238 Cm-242 Bi-214
5.9527E-20 1.7035E-06 1.2850E-17 5.8147E-08 7.5211E-07  $ Ac-228 Eu-154 Np-240 Sb-126 Sb-126m
2.1416E-16 1.5405E-17 2.6026E-07 1.3203E-20 1.3203E-20  $ Np-240m Bi-214 Cs-134 Ac-228 Ac-228
1.4101E-10 6.4796E-11 4.2117E-11 2.6278E-17 6.9245E-15  $ Pu-238 Pa-234m Pa-234 Bi-214 Np-240m
2.0042E-05 2.4551E-06 2.9088E-16 3.9685E-21 5.3422E-21  $ Eu-154 Eu-154 Bi-214 Ac-228 Ac-228
9.5429E-19 2.7018E-12 4.9893E-11 2.1489E-07 2.0702E-15  $ Rn-219 Pu-239 Pa-234m Sb-126m Np-240m
9.0714E-11 3.0527E-21 5.2332E-08 3.8921E-20 2.6278E-17  $ Pa-234m Ac-228 Sb-126 Ac-228 Bi-214
2.6278E-16 5.5114E-07 1.7847E-15 1.8089E-11 2.9763E-21  $ Bi-214 Eu-154 Np-240m Bi-212 Ac-228
6.1253E-10 2.4373E-17 1.0002E-13 4.0821E-11 6.3176E-11  $ Bi-212 Pb-211 Cm-242 Pa-234m Pa-234
6.2295E-08 5.5398E-11 2.2031E-11 2.5322E-06 1.7553E-21  $ Eu-152 Pu-238 Pa-234m Eu-152 Ac-228
2.2844E-15 4.3659E-07 4.0621E-18 6.8531E-18 1.6306E-10  $ Np-240m Eu-152 Pb-211 Np-240 Tl-208
1.4277E-15 3.8158E-20 9.4589E-14 8.1242E-18 4.4264E-21  $ Np-240m Ac-228 Bi-213 Pb-211 Ac-228
9.0616E-17 7.3399E-17 4.6853E-08 2.3356E-16 4.2588E-07  $ Bi-214 Bi-214 Eu-152 Pb-211 Eu-154
9.0053E-20 3.4629E-06 1.2850E-15 1.6026E-20 3.4008E-13  $ Ac-228 Eu-152 Np-240m Ac-228 Cm-242
1.4530E-05 2.0843E-14 1.3864E-14 7.7755E-11 4.2117E-11  $ Eu-154 U-233 Bi-214 Pa-234m Pa-234
1.0021E-06 2.0382E-12 4.3413E-11 6.7387E-11 3.7578E-05  $ Eu-154 Tl-208 Pa-234m Pa-234 Eu-154
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1.0002E-12 6.9298E-12 1.1524E-05 1.8316E-21 5.8316E-10  $ Cm-242 Tl-208 Eu-154 Ac-228 Pa-234m
2.0310E-17 6.4248E-16 3.8334E-09 4.2408E-16 1.0708E-15  $ Pb-211 Np-240m Eu-152 Bi-214 Np-240m
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2.1197E-11 1.4729E-20 2.3658E-20 1.6033E-06 1.8538E-06  $ Tl-208 Ac-228 Ac-228 Eu-154 Eu-154
5.0541E-11 2.6090E-08 5.5114E-07 4.1529E-07 1.1145E-16  $ Pa-234 Eu-152 Eu-154 Eu-152 Bi-214
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1.6419E-15 3.0062E-07 9.5197E-07 4.7121E-18 1.8538E-07  $ Np-240m Eu-154 Eu-154 Bi-214 Eu-154
1.6847E-11 1.9988E-15 1.0379E-20 2.3658E-21 3.7581E-10  $ Pa-234 Np-240m Ac-228 Ac-228 Pa-234m
1.7553E-21 2.7127E-14 3.3694E-11 3.1290E-21 8.4234E-11  $ Ac-228 Np-240m Pa-234 Ac-228 Pa-234
1.2672E-07 8.4234E-11 2.2895E-19 2.5270E-11 3.5073E-07  $ Eu-152 Pa-234m Ac-228 Pa-234 Eu-154
5.9527E-21 1.0874E-17 1.4326E-07 1.6281E-08 6.3431E-17  $ Ac-228 Bi-214 Sb-126m Sb-126 Bi-214
4.8079E-21 1.9274E-15 1.4277E-14 4.2588E-07 1.6847E-11  $ Ac-228 Np-240m Np-240m Eu-154 Pa-234
9.1690E-05 2.5642E-19 9.4944E-14 5.8316E-11 1.3508E-19  $ Eu-154 Ac-228 Np-240m Pa-234m Ac-228
2.0207E-15 7.0145E-07 5.8964E-10 3.5765E-10 1.0708E-15  $ Bi-214 Eu-154 Pa-234m Bi-212 Np-240m
3.3694E-11 8.5177E-08 9.7193E-11 6.7619E-08 1.6790E-20  $ Pa-234 Eu-154 Pa-234m Eu-152 Ac-228
8.5177E-07 7.0145E-06 1.3813E-20 3.8059E-16 5.9965E-14  $ Eu-154 Eu-154 Ac-228 Bi-214 Np-240m
3.2622E-16 1.1219E-20 8.4234E-12 8.4234E-11 2.0042E-07  $ Bi-214 Ac-228 Pa-234 Pa-234m Eu-154
4.0821E-10 5.2658E-20 3.4342E-11 4.2832E-16 6.0290E-21  $ Pa-234m Ac-228 Pa-234m Np-240m Ac-228
7.0439E-13 4.2832E-16 5.5724E-11 1.6790E-21 9.6922E-21  $ Tl-209 Np-240m Pa-234m Ac-228 Ac-228
1.4320E-11 1.7400E-19 6.6149E-16 1.2136E-15 2.1059E-11  $ Pa-234 Ac-228 Bi-214 Np-240m Pa-234
9.3869E-19 6.9245E-15 1.4530E-04 1.7495E-10 5.0541E-11  $ Ac-228 Np-240m Eu-154 Pa-234m Pa-234
2.4467E-16 2.5804E-04 3.0809E-16 2.1383E-11 2.6413E-15  $ Bi-214 Eu-154 Bi-214 Pa-234m Np-240m
1.9167E-09 3.9262E-15 1.2778E-09 1.7266E-09 7.5553E-20  $ Eu-152 Np-240m Eu-152 Bi-212 Ac-228
3.5693E-16 1.2635E-11 4.5790E-19 1.0993E-14 3.7269E-11  $ Np-240m Pa-234 Ac-228 Np-240m Eu-152
1.7217E-17 3.3694E-11 1.3584E-19 1.5440E-09 8.1528E-13  $ Bi-214 Pa-234 Ac-228 Eu-152 Tl-208
1.2635E-11 6.7962E-17 1.0602E-15 5.2658E-20 2.8058E-07  $ Pa-234 Bi-214 Bi-214 Ac-228 Eu-154
```

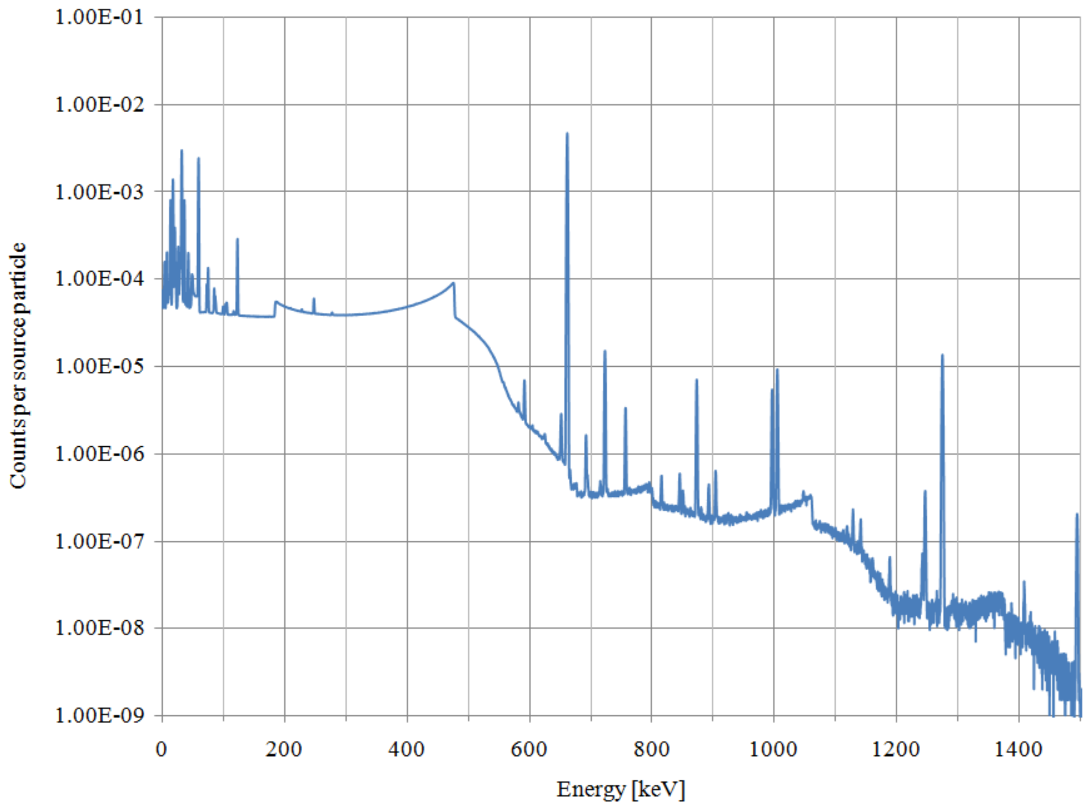
```
         3.7581E-11 1.3563E-15 1.0108E-10 1.2211E-21 1.9541E-07  $ Pa-234m Np-240m Pa-234 Ac-228 Eu-154
         1.6026E-20 7.8108E-11 2.1748E-16 4.3500E-21 2.8237E-20  $ Ac-228 Bi-212 Bi-214 Ac-228 Ac-228
         4.2117E-11 2.0735E-11 1.0108E-10 1.2635E-11 2.9763E-21  $ Pa-234 Pa-234m Pa-234 Pa-234 Ac-228
         1.4195E-20 2.5184E-21 1.4277E-16 1.6026E-21 8.5177E-08  $ Ac-228 Ac-228 Np-240m Ac-228 Eu-154
         1.6847E-12 1.4903E-11 1.6790E-21 8.5474E-21 2.8091E-15  $ Pa-234 Pa-234m Ac-228 Ac-228 Bi-214
         8.4234E-11 1.4277E-16 2.8555E-16 8.4234E-12 5.1895E-21  $ Pa-234m Np-240m Np-240m Pa-234 Ac-228
         9.2010E-10 3.2053E-21 8.4234E-12 2.3658E-21 8.1528E-13  $ Pa-234m Ac-228 Pa-234 Ac-228 Tl-208
         1.9079E-21 4.2117E-12 2.3658E-21 3.8549E-16 2.1059E-11  $ Ac-228 Pa-234 Ac-228 Np-240m Pa-234
         1.0226E-20 1.0367E-10 1.4679E-14 4.9970E-16 3.9525E-10  $ Ac-228 Pa-234m Bi-214 Np-240m Pa-234m
         5.0541E-12 2.2362E-09 5.3422E-22 8.4234E-12 4.0083E-08  $ Pa-234 Eu-152 Ac-228 Pa-234 Eu-154
         2.1416E-16 1.4499E-17 1.7553E-21 3.8158E-22 6.1053E-22  $ Np-240m Bi-214 Ac-228 Ac-228 Ac-228
         1.4255E-11 2.1416E-16 2.5270E-11 6.1053E-22 1.2974E-21  $ Pa-234m Np-240m Pa-234 Ac-228 Ac-228
         1.2743E-10 1.4277E-16 1.9439E-10 3.5693E-16 1.0874E-17  $ Bi-212 Np-240m Pa-234m Np-240m Bi-214
         5.3780E-11 1.2974E-20 6.1053E-22 2.5270E-12 7.2571E-10  $ Pa-234m Ac-228 Ac-228 Pa-234 Pa-234m
         1.1142E-20 1.1524E-07 5.0541E-12 3.5340E-16 1.2363E-20  $ Ac-228 Eu-154 Pa-234 Bi-214 Ac-228
         1.4277E-16 1.9573E-15 5.8964E-12 1.2974E-21 2.8555E-16  $ Np-240m Bi-214 Pa-234 Ac-228 Np-240m
         5.5076E-11 3.4342E-10 7.1737E-21 5.8964E-12 2.0841E-16  $ Pa-234m Pa-234m Ac-228 Pa-234 Bi-214
         8.5664E-16 3.5638E-10 3.8158E-22 2.6711E-20 8.2461E-17  $ Np-240m Pa-234m Ac-228 Ac-228 Bi-214
         1.6005E-11 9.7193E-11 8.5177E-08 1.6310E-16 1.2635E-11  $ Pa-234 Pa-234m Eu-154 Bi-214 Pa-234
         5.7994E-17 8.3948E-22 2.3586E-11 3.5106E-21 9.9941E-16  $ Bi-214 Ac-228 Pa-234 Ac-228 Np-240m
         2.3974E-10 2.2895E-22 5.7109E-17 6.1053E-22 4.2117E-11  $ Pa-234m Ac-228 Np-240m Ac-228 Pa-234
         2.0087E-11 5.8764E-21 4.7121E-17 6.1053E-22 4.2117E-12  $ Pa-234m Ac-228 Bi-214 Ac-228 Pa-234
         1.3607E-10 6.1053E-22 1.7553E-20 1.6419E-16 2.2895E-22  $ Pa-234m Ac-228 Ac-228 Np-240m Ac-228
         4.5790E-22 8.4234E-14 6.0290E-21 2.5270E-11 1.0684E-21  $ Ac-228 Pa-234 Ac-228 Pa-234m Ac-228
         2.8555E-17 5.3422E-22 1.6847E-13 4.9839E-18 7.1386E-17  $ Np-240m Ac-228 Pa-234 Bi-214 Np-240m
         8.4234E-14 3.0527E-22 2.7185E-18 4.5308E-17 1.7217E-17  $ Pa-234 Ac-228 Bi-214 Bi-214 Bi-214
         5.3422E-22 4.2832E-16 6.4337E-17 2.2130E-16 9.0616E-18  $ Ac-228 Np-240m Bi-214 Np-240m Bi-214
         5.7109E-17 5.1651E-17 8.0648E-17 4.9970E-17 1.1145E-15  $ Np-240m Bi-214 Bi-214 Np-240m Bi-214
         1.4499E-17 3.6246E-18 9.4453E-09 5.6182E-17 4.6033E-15  $ Bi-214 Bi-214 Y-90 Bi-214 Bi-214
         6.3431E-18 8.1554E-18 1.6310E-17 2.7185E-18 4.7121E-18  $ Bi-214 Bi-214 Bi-214 Bi-214 Bi-214
         2.9903E-16 1.0874E-17 1.7217E-18 1.9936E-17 1.7217E-18  $ Bi-214 Bi-214 Bi-214 Bi-214 Bi-214
         2.7185E-18 1.0874E-17 1.8123E-18 5.4369E-18 1.4317E-15  $ Bi-214 Bi-214 Bi-214 Bi-214 Bi-214
         1.9029E-18 5.4369E-18 3.6246E-19 4.1683E-19 4.0764E-08  $ Bi-214 Bi-214 Bi-214 Bi-214 Tl-208
         8.1554E-19 2.7185E-19 2.9903E-17 2.5372E-18 1.6310E-18  $ Bi-214 Bi-214 Bi-214 Bi-214 Bi-214
         2.3560E-17 5.4369E-18 2.2654E-18 3.1716E-19 8.5179E-18  $ Bi-214 Bi-214 Bi-214 Bi-214 Bi-214
         5.8900E-18 1.4499E-17 1.0874E-18 5.2557E-19 1.5405E-18  $ Bi-214 Bi-214 Bi-214 Bi-214 Bi-214
         1.3592E-17 9.9679E-19 8.1554E-18 2.0841E-17 3.9871E-18  $ Bi-214 Bi-214 Bi-214 Bi-214 Bi-214
         4.7121E-19 3.1716E-19 1.4499E-18 4.7121E-19 1.3592E-18  $ Bi-214 Bi-214 Bi-214 Bi-214 Bi-214
         1.8123E-19 9.0616E-20                                   $ Bi-214 Bi-214
c
c
si3     -0.01 0.01                    $the lower and upper height from pos location
si4      0.0 1.54                     $r1 r2, inner radius and outer radius
sp4     -21 1                         $distribute the source radially with the correct probability
c
c
c          -- tally cards (pulse height tally in HPGe detector) --
f8:p  704                             $give the photon counts per cm^3 for cell 704
sd8   1                               $give the result in counts instead of counts per cm^3
e8    0.0 7999I 2.00                  $gives the energy bins for cell 704, 8000 bins at 0.25 Kev per bin
ft8   GEB 0.000853482 0.000962040 0.000733352 $broadens the results resolution to simulate a read detector
c                                              for parameters a, b, c.  FWHM=a+b*SQRT (E+c*E^2), E is in
c                                              MeV. Values based on (E, FWHM), (1.27433, 0.00194), (0.38436,
c                                              0.00145), (0.27715, 0.00136)
c
c
c          -- material cards --
m1    13027.92c  1.00000              $aluminum (density=2.7 g/cc)
c
m2     6000.62c  1.00000
       9019.62c  2.00000              $Teflon (density=2.15 g/cc)
c
m3     7014.62c   0.72
       8016.62c   0.28                $air (density=0.0012 g/cc)
c
m6     4009.62c  1.0                  $beryllium (density=1.848 g/cc)
c
m7    32070.00c  0.2123
      32072.00c  0.2766
      32073.00c  0.0773
      32074.00c  0.3594
      32076.00c  0.0744               $germanium (density=5.323 g/cc)
c
m10   74182.62c  0.00120
      74183.62c  0.26498
      74184.62c  0.30642
      74186.62c  0.28426              $pure tungsten (density=19.3 g/cc)
c
m11   26054.62c  0.05845
      26056.62c  0.91754
      26057.62c  0.02119
      26058.62c  0.00282              $pure iron (density=7.87 g/cc)
c
```

```
m12   82206.66c  0.241
      82207.66c  0.221
      82208.66c  0.524                $lead neglecting Pb-204 (density=11.34 g/cc)
c
c
nps 500000000                         $run this many particles, 500 million particles (do this 4 times and
c                                      correctly sum the results)
```

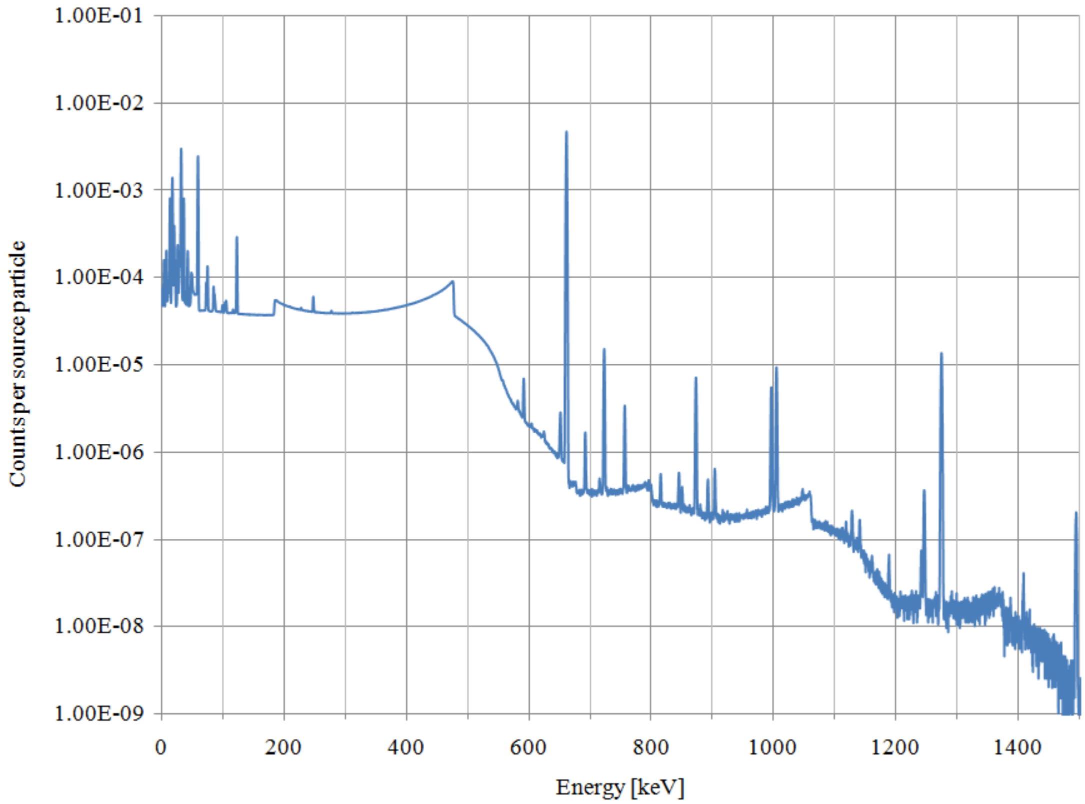
APPENDIX H

Gamma ray spectra simulated in MCNP for the UREX+3a samples.

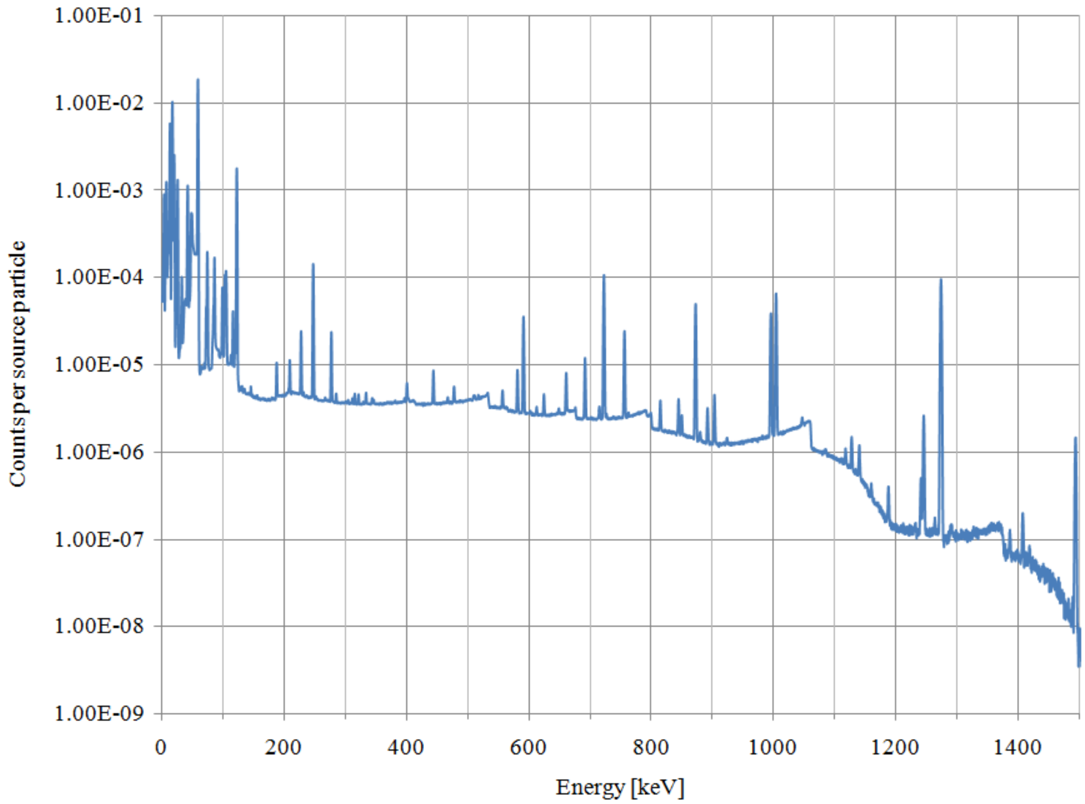
Sample 1



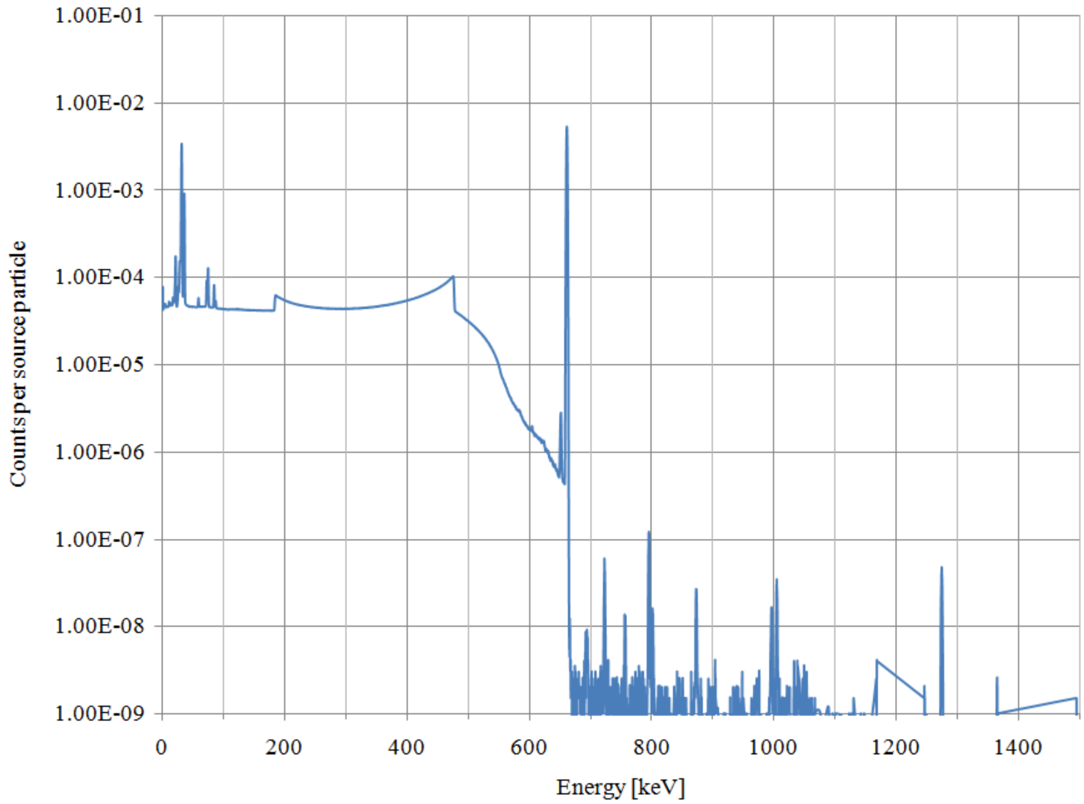
Sample 2


1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
200
400
600
800
1000
1200
1400
Energy [keV]

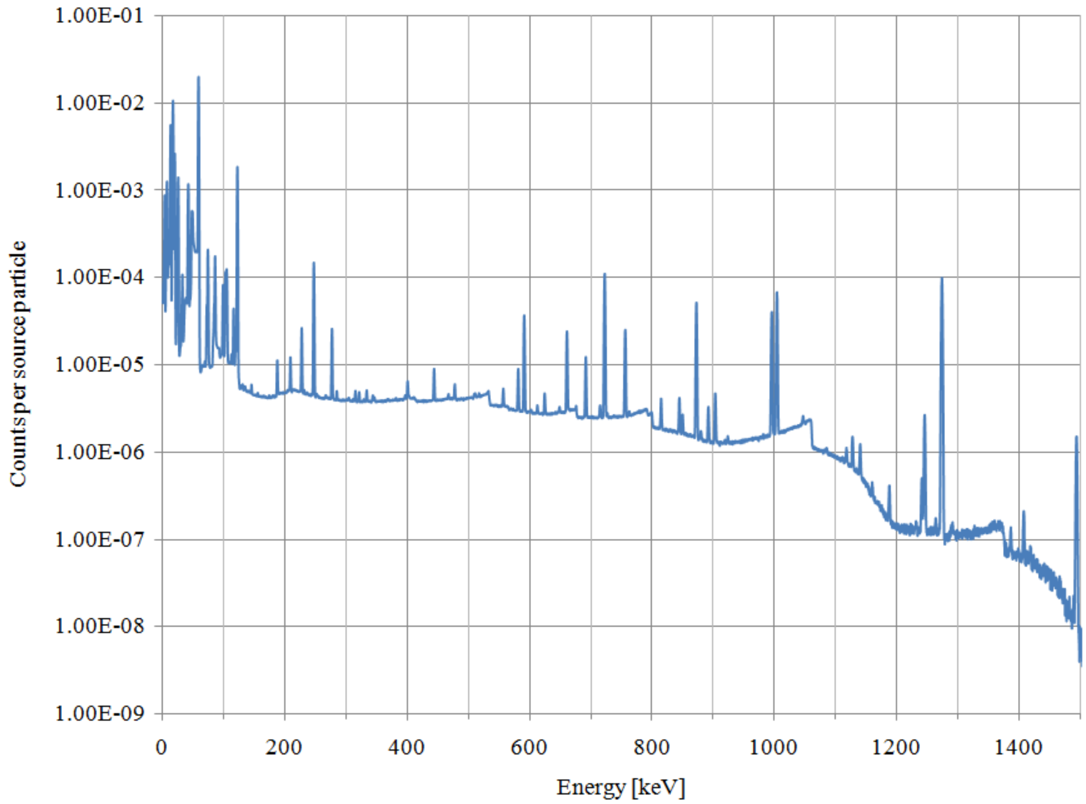
Sample 4


1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
200
400
600
800
1000
1200
1400
Energy [keV]

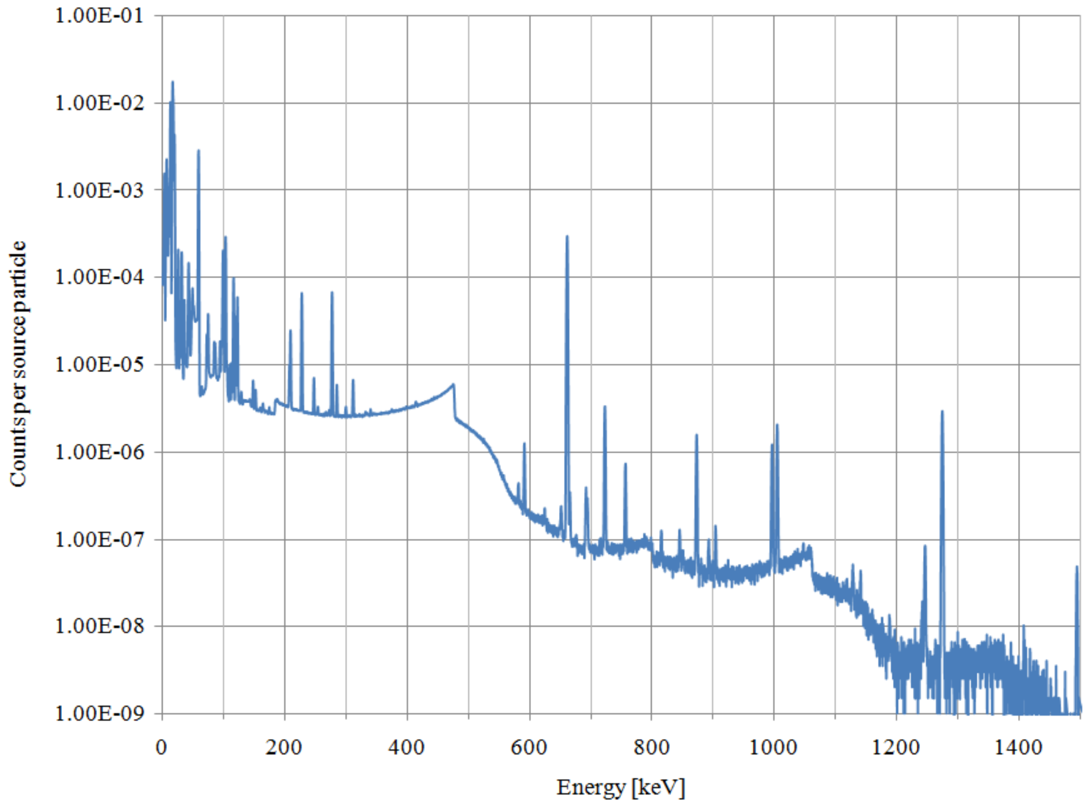
Sample 5


1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
200
400
600
800
1000
1200
1400
Energy [keV]

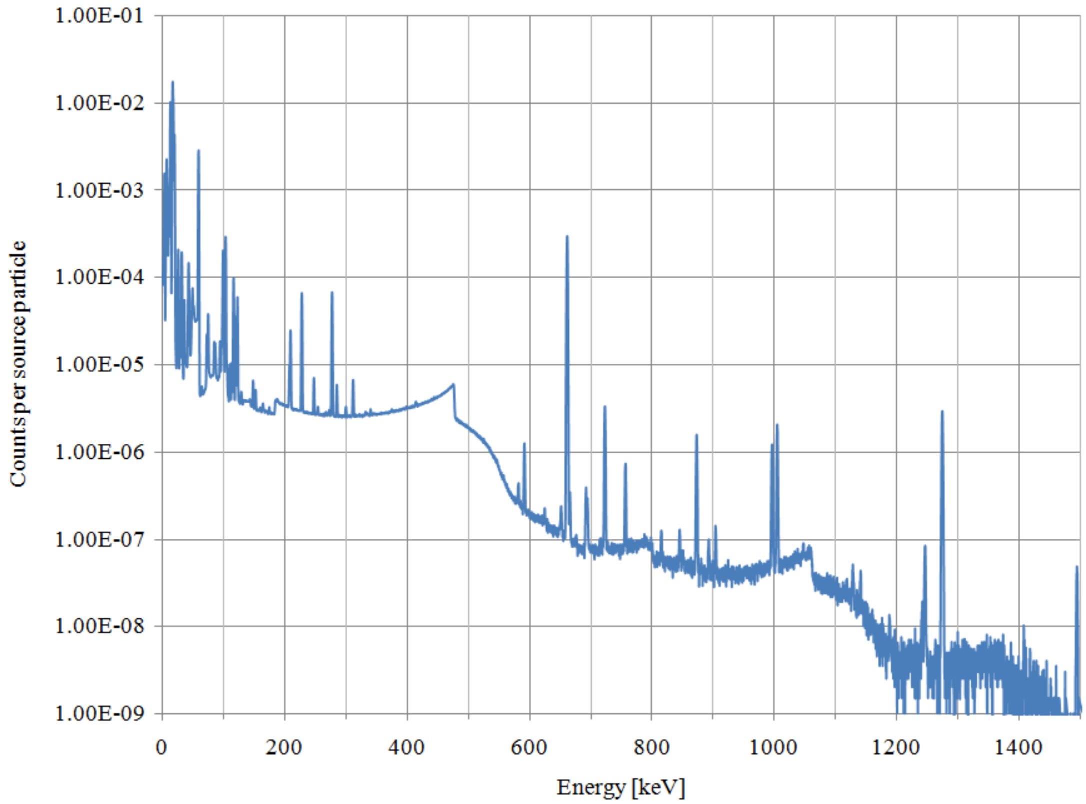
Sample 6


1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
200
400
600
800
1000
1200
1400
Energy [keV]

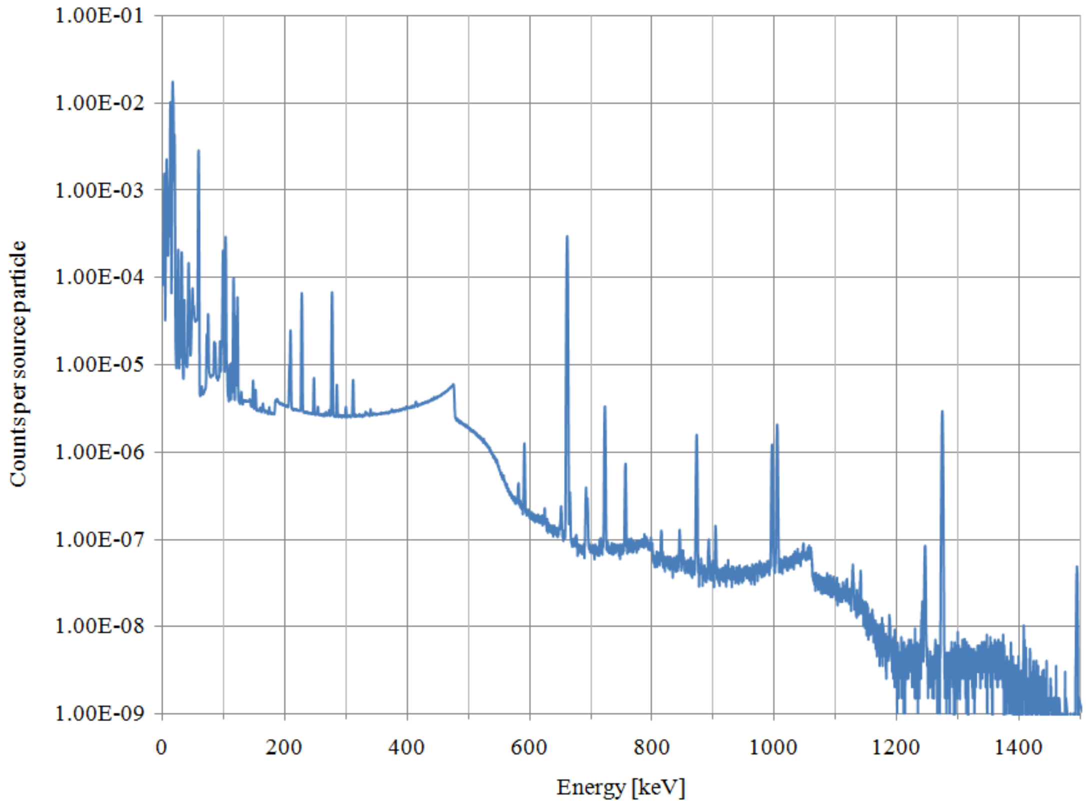
Sample 7


1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
200
400
600
800
1000
1200
1400
Energy [keV]

Sample 8


1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
200
400
600
800
1000
1200
1400
Energy [keV]

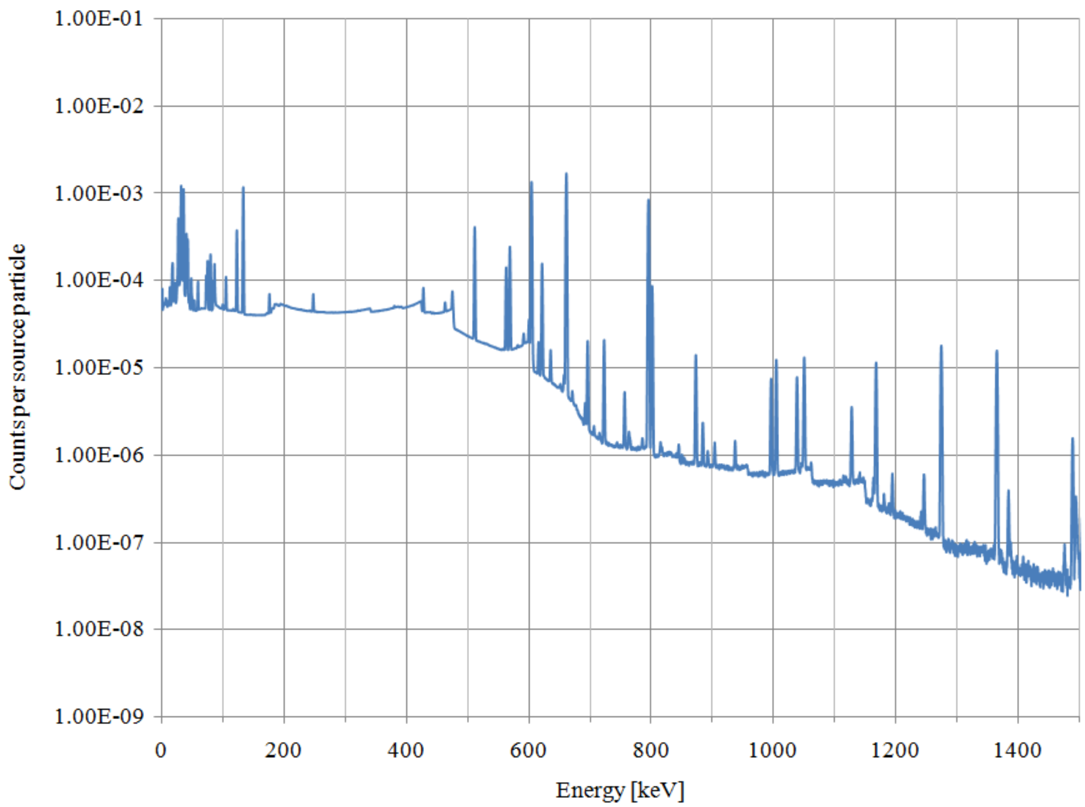
Sample 9


1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
200
400
600
800
1000
1200
1400
Energy [keV]

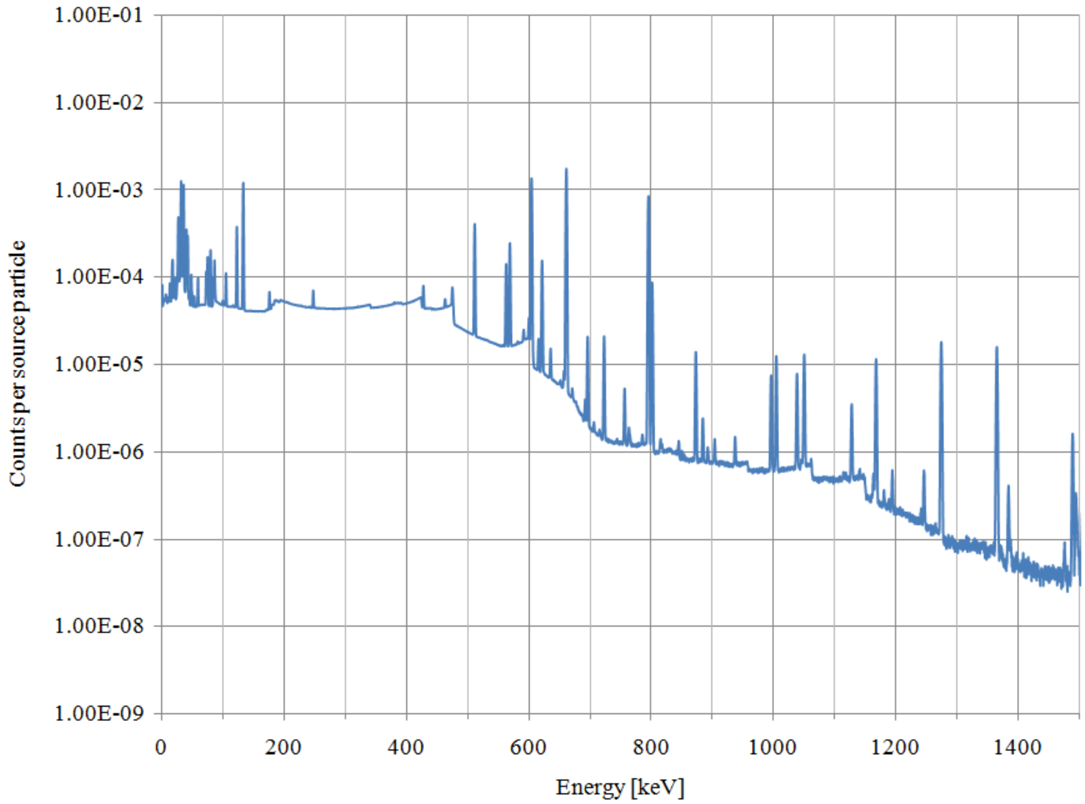
APPENDIX I

Gamma ray spectra simulated in MCNP for the "Simulated Fuel".

Sample 1



Sample 2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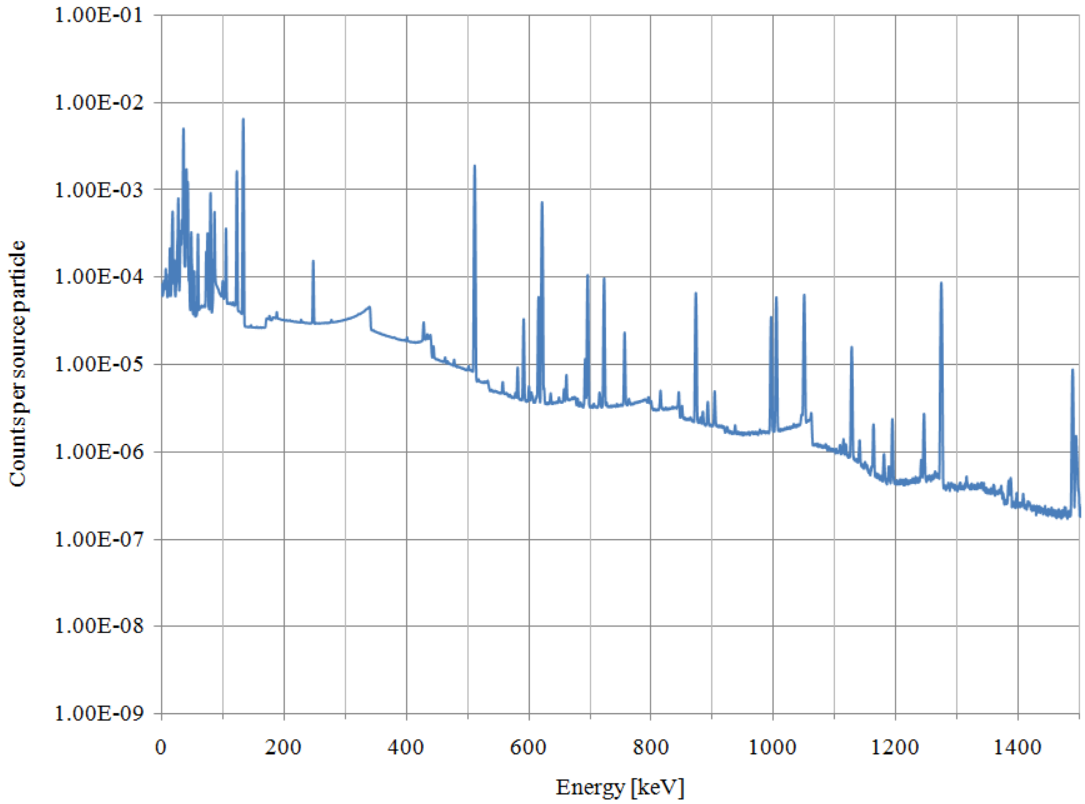
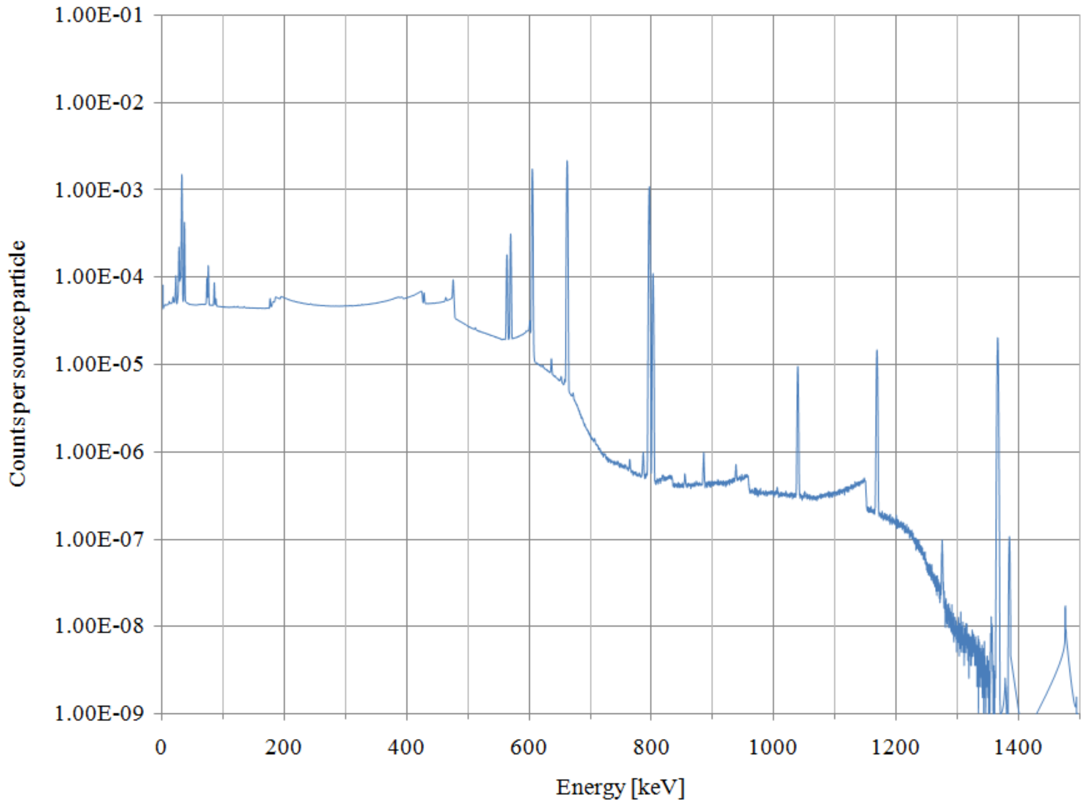
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
200
400
600
800
1000
1200
1400
Energy [keV]

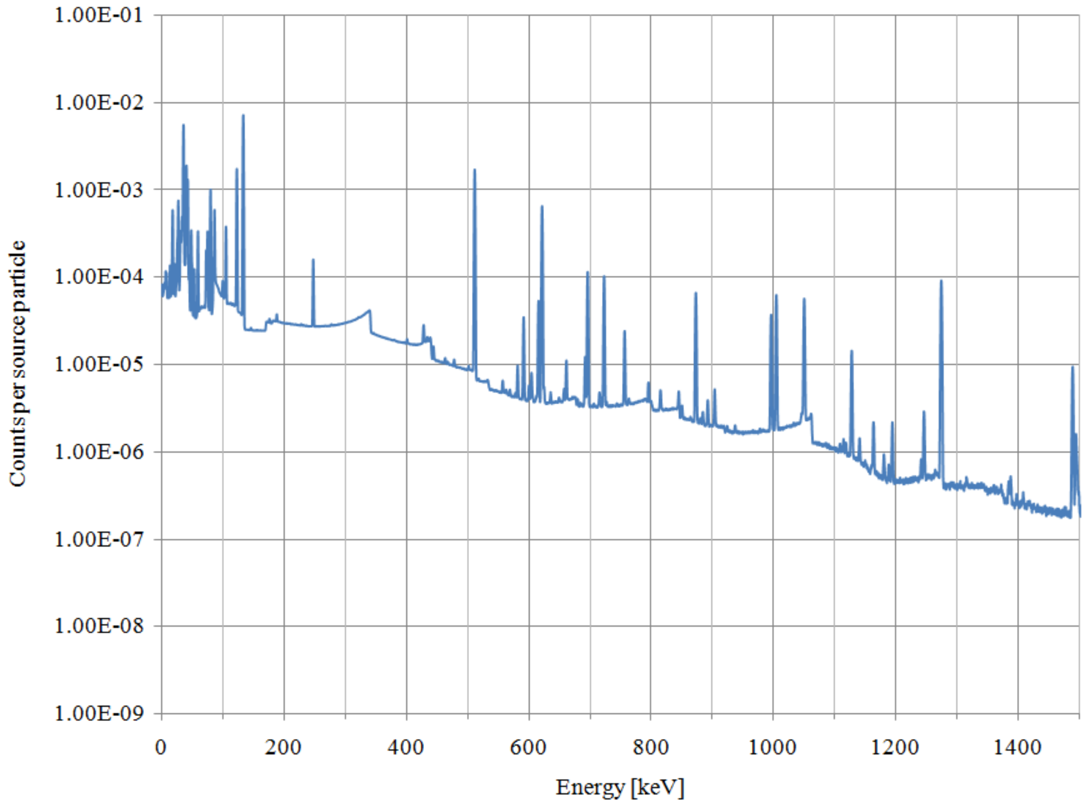
Sample 4


1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
200
400
600
800
1000
1200
1400
Energy [keV]

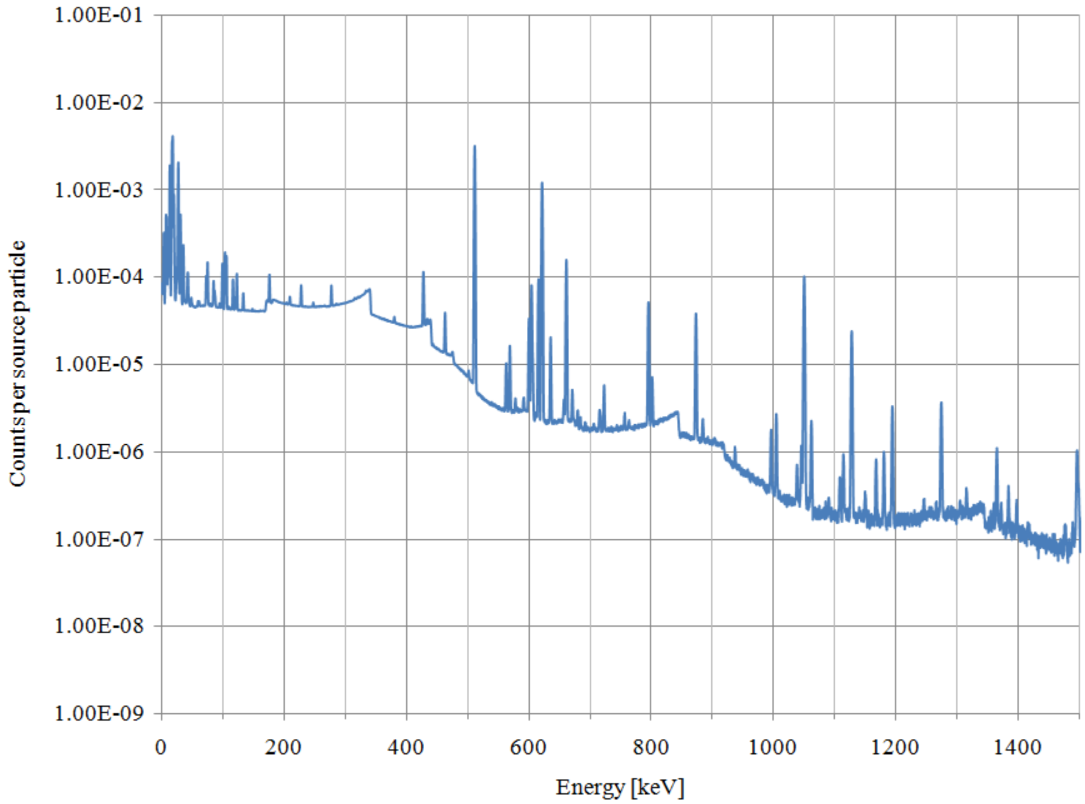
Sample 5


1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
0
200
400
600
800
1000
1200
1400
Counts per source particle
Energy [keV]

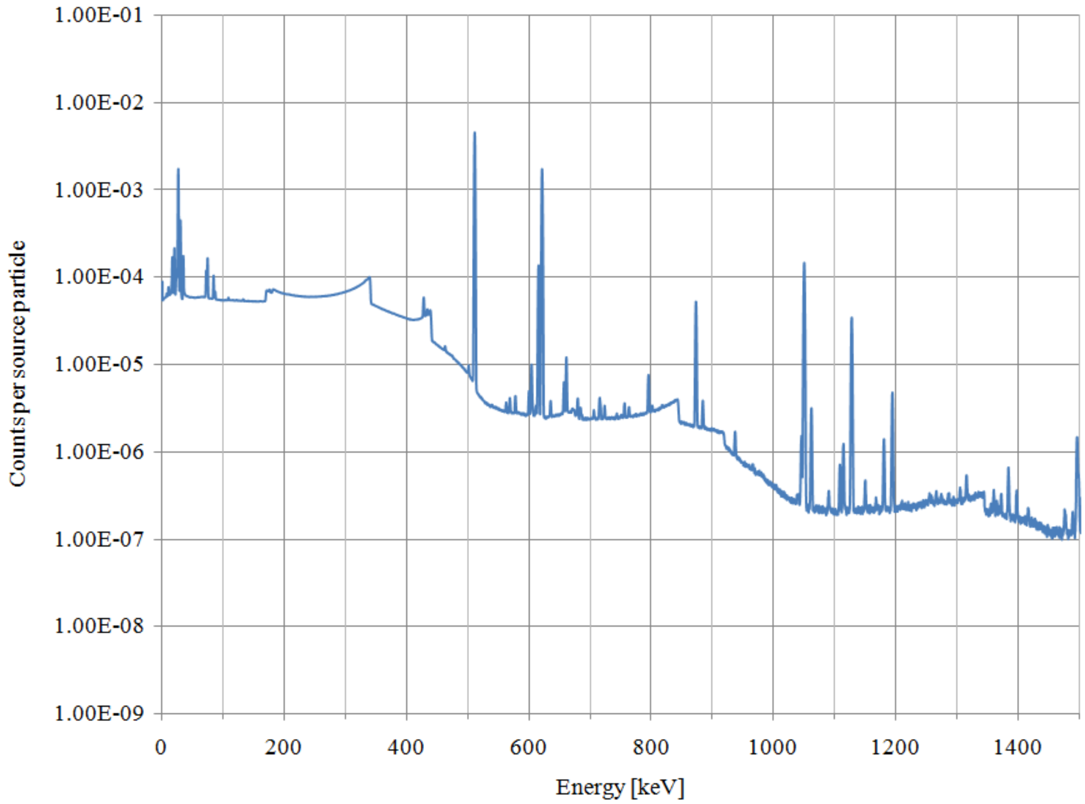
Sample 6


1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
200
400
600
800
1000
1200
1400
Energy [keV]

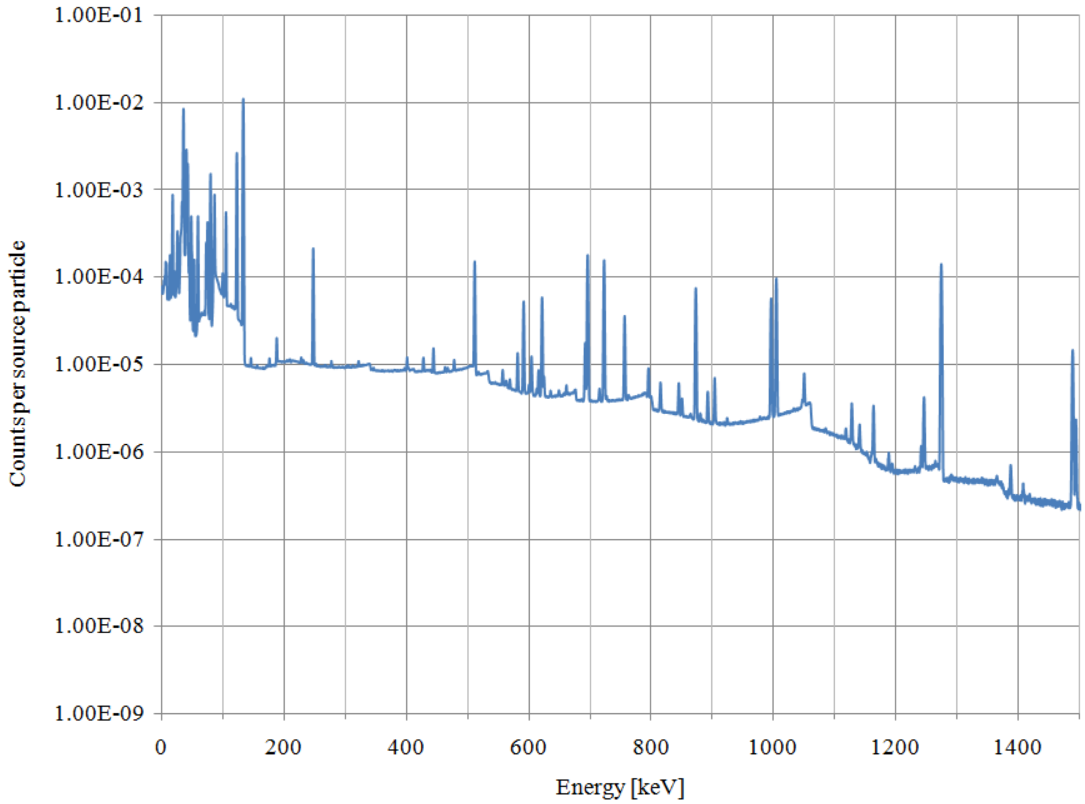
Sample 7


1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
200
400
600
800
1000
1200
1400
Energy [keV]

Sample 8


Counts per source particle
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
0
200
400
600
800
1000
1200
1400
Energy [keV]

Sample 9


1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
200
400
600
800
1000
1200
1400
Energy [keV]

APPENDIX J

Sample MCNP deck for the self shielding calculations of the FPEX product.

```
This deck checks the affects of self shielding.
C “Simulated Fuel” Cs/Sr stream = 8.94*10^11 Gammas/(cm^3*sec) = 3.2 Ci/cm^3
C    CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C    Cell cards
99   1 -.0012    -99     7  -11                     imp:p=1     $air inside of source tube
1    8 -1.000    -1   99 7  -11                     imp:p=1     $source film
2    2 -7.950     1  -2  7  -11                     imp:p=1     $source tubing, 0.125 in
3    4 -5.323    -3                                 imp:p=1     $detector
4    1 -.0012     4  -8  12 -16 20 -24 2 3          imp:p=1     $air inside shielding
5    5 -8.65      5  -9  13 -17 21 -25 2 3 #4       imp:p=1     $shielding Cd 0.5 in
6    6 -8.96      6  -10 14 -18 22 -26 2 3 #4 #5    imp:p=1     $shielding Cu 0.5 in
7    3 -11.34     7  -11 15 -19 23 -27 2 3 #4 #5 #6 imp:p=1     $shielding Pb 6.0 in
8    0           -7:11:-15:19:-23:27                imp:p=0     $void

C    Surface cards
99   cz    2.04        $source, 0.50 cm thick surface
1    cz    2.54        $source, 2.0 inch inside diameter
2    cz    2.93116     $source tubing, SS-316 0.154 in (0.39116 cm), for Schedule 40 pipe [in]: id=1 =>
C                       t=0.133, id=2 => t=0.154, id=3 => t=0.216, id=4 => t=0.237, id=6 => t=0.280, id=6 =>
C                       t=0.322
3    sx    40 1.3      $detector, 9 cm^3
4    pz   -2.5         $shielding, bot     Cd/air
5    pz   -3.75        $shielding, bot     Cu/Cd
6    pz   -5           $shielding, bot     Pb/Cu
7    pz   -20.25       $shielding, bot   void/Pb
8    pz    2.5         $shielding, top     Cd/air
9    pz    3.75        $shielding, top     Cu/Cd
10   pz    5           $shielding, top     Pb/Cu
11   pz    20.25       $shielding, top   void/Pb
12   py   -2.5         $shielding, left    Cd/air
13   py   -3.75        $shielding, left    Cu/Cd
14   py   -5           $shielding, left    Pb/Cu
15   py   -20.25       $shielding, left  void/Pb
16   py    2.5         $shielding, right   Cd/air
17   py    3.75        $shielding, right   Cu/Cd
18   py    5           $shielding, right   Pb/Cu
19   py    20.25       $shielding, right void/Pb
20   px   -3.5         $shielding, back    Cd/air
21   px   -4.75        $shielding, back    Cu/Cd
22   px   -6           $shielding, back    Pb/Cu
23   px   -21.25       $shielding, back  void/Pb
24   px    202.5       $shielding, front   Cd/air
25   px    203.75      $shielding, front   Cu/Cd
26   px    205         $shielding, front   Pb/Cu
27   px    220.25      $shielding, front void/Pb

C    Materials Cards
mode p                                                      $consider photons only
m1   007014 .72 008016 .28                                  $air, density 0.0012 g/cm^3
m2   26000 0.68 24000 0.17 28000 0.12 42000 0.02 25055 0.01 $stainless steel 316, density 7.950 g/cm^3
m3   82000 1                                                $lead, density 11.34 g/cm^3
m4   32074 1                                                $germanium, density 5.323 g/cm^3
m5   48000 1                                                $cadmium, density 8.65 g/cm^3
m6   29063 .6917 29065 .3083                                $copper, density 8.96 g/cm^3
m7   11023 0.5 53127 0.5                                    $NaI, density 3.67 g/cm^3
m8   07014 0.2142 08016 0.6426 37085 0.0039 37087 0.0091    $N-14, O-16, Rb-85, Rb-87 (FPEX product (source)
C                                                            60%-NO3, 40%-Cs-Ba-Rb-Sr, density 1.0 g/cm^3)
     38088 0.0124 38090 0.0178 55133 0.0273 55135 0.0032    $Sr-88,  Sr-90,  Cs-133, Cs-135
     55137 0.0089 56134 0.0270 56137 0.0030 56138 0.0306    $Cs-137, Ba-134, Ba-137, Ba-138
C
C    Data cards
C      ---------------------------------------------------------------
C      Photon Source Definition - generated from ORIGEN F71 file
C         total strength:  1.1349E16 gammas/second
C         discrete lines:  1.1349E16 gammas/second in 192 lines
C                          100.00% of energy
C         multigroup bins: 0.0000E00 gammas/second in 44 bins
C                          0.00% of energy
C         not counted:     0.0000E00 gammas/second
C      ---------------------------------------------------------------
C
```

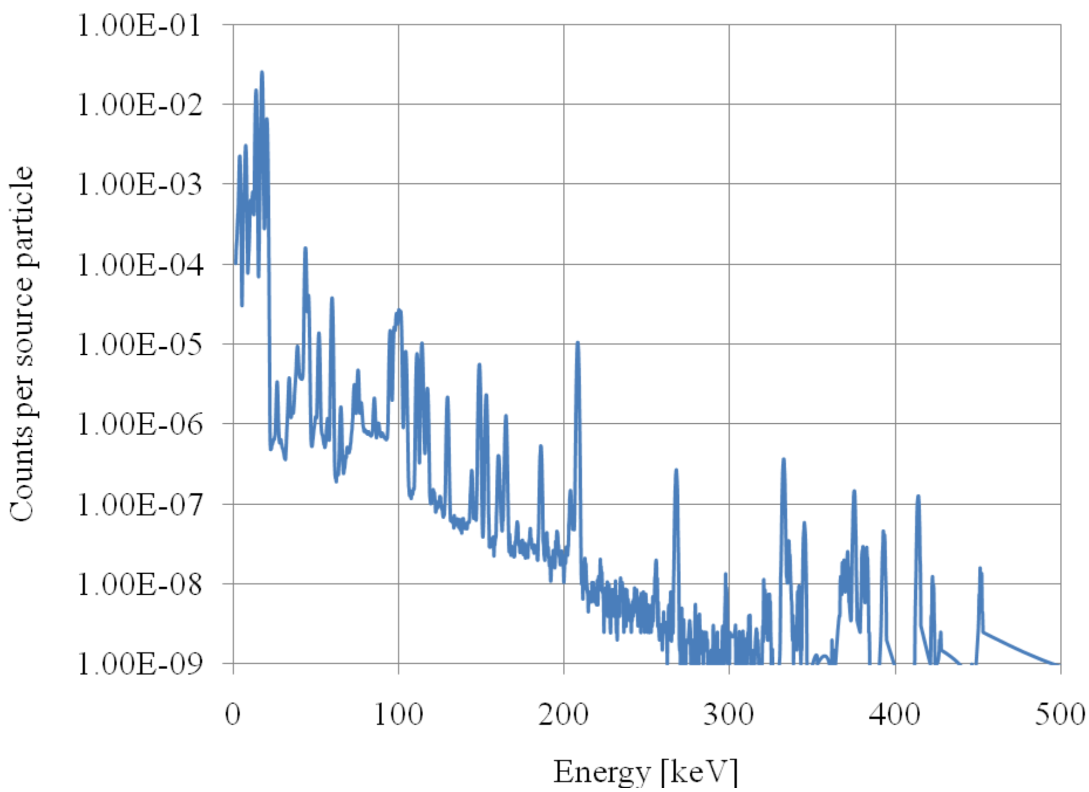
```
sdef   cel=1   par=2   erg=d2   ext=d3   pos=0 0 0   axs=0 0 1   rad=d4
C              $source is cell 1 with energy according to d2 with sampling cylinder of height d3 centered
C               at (0,0,0) extending in the Z-axis direction with a radius according to d4
C      discrete lines (in MeV) and their probabilities
si2    l 1.5900E-03 1.6383E-03 1.6383E-03 1.7521E-03 1.8718E-03  $ Rb-83 Rb-84 Rb-86 Sr-85 Rb-86
         4.1100E-03 4.2900E-03 4.4187E-03 4.6199E-03 4.8275E-03  $ Cs-131 Ba-131 Cs-134 Ba-133 Cs-134
         4.8275E-03 4.8275E-03 4.8275E-03 5.0421E-03 1.2598E-02  $ Cs-136 Ba-136m Ba-137m Ba-140 Rb-83
         1.2598E-02 1.2598E-02 1.2649E-02 1.2651E-02 1.2651E-02  $ Rb-84 Rb-86 Rb-83 Rb-84 Rb-86
         1.3336E-02 1.3395E-02 1.3850E-02 1.4098E-02 1.4100E-02  $ Sr-85 Sr-85 Ba-140 Rb-86 Rb-83
         1.4107E-02 1.4107E-02 1.4165E-02 1.4957E-02 1.5830E-02  $ Rb-84 Rb-86 Rb-86 Sr-85 Rb-86
         2.9458E-02 2.9458E-02 2.9779E-02 2.9779E-02 2.9955E-02  $ Cs-131 Cs-134 Cs-131 Cs-134 Ba-140
         3.0625E-02 3.0625E-02 3.0973E-02 3.0973E-02 3.1817E-02  $ Ba-131 Ba-133 Ba-131 Ba-133 Cs-134
         3.1817E-02 3.1817E-02 3.1817E-02 3.2194E-02 3.2194E-02  $ Cs-136 Ba-136m Ba-137m Cs-134 Cs-136
         3.2194E-02 3.2194E-02 3.3034E-02 3.3442E-02 3.3593E-02  $ Ba-136m Ba-137m Ba-140 Ba-140 Cs-134
         3.3600E-02 3.4953E-02 3.5000E-02 3.6341E-02 3.6341E-02  $ Cs-131 Ba-133 Ba-131 Cs-134 Cs-136
         3.6341E-02 3.6341E-02 3.7761E-02 5.3161E-02 5.4889E-02  $ Ba-136m Ba-137m Ba-140 Ba-133 Ba-131
         6.6881E-02 7.8733E-02 7.9623E-02 8.0997E-02 8.2580E-02  $ Cs-136 Ba-131 Ba-133 Ba-133 Ba-131
         8.6360E-02 9.2284E-02 1.0968E-01 1.1355E-01 1.1890E-01  $ Cs-136 Ba-131 Cs-136 Ba-140 Ba-140
         1.1932E-01 1.2381E-01 1.2809E-01 1.2855E-01 1.3272E-01  $ Rb-83 Ba-131 Ba-131 Rb-83 Ba-140
         1.3361E-01 1.3736E-01 1.5325E-01 1.5715E-01 1.6061E-01  $ Ba-131 Ba-131 Cs-136 Ba-131 Ba-133
         1.6267E-01 1.6392E-01 1.6658E-01 1.7660E-01 1.8728E-01  $ Ba-140 Ba-136m Cs-136 Cs-136 Cs-136
         2.1608E-01 2.2323E-01 2.3350E-01 2.3963E-01 2.4269E-01  $ Ba-131 Ba-133 Cs-136 Ba-131 Cs-134
         2.4689E-01 2.4943E-01 2.7365E-01 2.7640E-01 2.9452E-01  $ Ba-131 Ba-131 Cs-136 Ba-133 Ba-131
         3.0240E-01 3.0285E-01 3.0487E-01 3.1550E-01 3.1550E-01  $ Cs-136 Ba-133 Ba-140 Cs-136 Ba-136m
         3.1991E-01 3.2651E-01 3.4055E-01 3.5120E-01 3.5602E-01  $ Cs-136 Cs-134 Cs-136 Ba-131 Ba-133
         3.6912E-01 3.7325E-01 3.8385E-01 3.9005E-01 4.0405E-01  $ Ba-131 Ba-131 Ba-133 Ba-131 Ba-131
         4.2373E-01 4.2757E-01 4.3759E-01 4.5142E-01 4.6126E-01  $ Ba-140 Ba-131 Ba-140 Ba-131 Ba-131
         4.6268E-01 4.6750E-01 4.7420E-01 4.7535E-01 4.8041E-01  $ Ba-131 Ba-140 Ba-131 Cs-134 Ba-131
         4.8652E-01 4.9000E-01 4.9633E-01 5.0610E-01 5.0719E-01  $ Ba-131 Cs-136 Ba-131 Ba-131 Cs-136
         5.1100E-01 5.1401E-01 5.1750E-01 5.2040E-01 5.2960E-01  $ Rb-84 Sr-85 Ba-131 Rb-83 Rb-83
         5.3370E-01 5.3731E-01 5.4628E-01 5.5039E-01 5.5120E-01  $ Ba-131 Ba-140 Ba-131 Ba-131 Ba-140
         5.5260E-01 5.6217E-01 5.6287E-01 5.6323E-01 5.6931E-01  $ Rb-83 Rb-83 Ba-131 Cs-134 Cs-134
         5.7269E-01 5.8504E-01 5.9650E-01 6.0470E-01 6.2011E-01  $ Ba-131 Ba-131 Ba-131 Cs-134 Ba-131
         6.4897E-01 6.5760E-01 6.6166E-01 6.7443E-01 6.8118E-01  $ Rb-83 Ba-131 Ba-137m Ba-131 Rb-83
         6.9649E-01 7.0344E-01 7.3300E-01 7.3300E-01 7.4550E-01  $ Ba-131 Ba-131 Cs-136 Ba-136m Ba-131
         7.8592E-01 7.9015E-01 7.9585E-01 7.9745E-01 7.9937E-01  $ Ba-131 Rb-83 Cs-134 Ba-131 Rb-83
         8.0193E-01 8.1851E-01 8.1851E-01 8.3162E-01 8.4090E-01  $ Cs-134 Cs-136 Ba-136m Ba-131 Ba-131
         8.4702E-01 8.6835E-01 8.8146E-01 9.1407E-01 9.1960E-01  $ Cs-134 Sr-85 Rb-84 Ba-131 Ba-131
         9.2387E-01 9.5461E-01 9.6894E-01 1.0159E00 1.0386E00    $ Ba-131 Ba-131 Ba-131 Rb-84 Cs-134
         1.0464E00 1.0476E00 1.0481E00 1.0481E00 1.0770E00       $ Ba-131 Ba-131 Cs-136 Ba-136m Rb-86
         1.1679E00 1.1705E00 1.2084E00 1.2183E00 1.2354E00       $ Cs-134 Ba-131 Ba-131 Ba-131 Cs-136
         1.3216E00 1.3419E00 1.3652E00 1.5381E00 1.5513E00       $ Cs-136 Ba-131 Cs-134 Cs-136 Cs-136
         1.5513E00 1.8970E00                                     $ Ba-136m Rb-84
sp2    d 8.1469E-14 4.4210E-18 1.2339E-26 7.9234E-16 1.0776E-26  $ Rb-83 Rb-84 Rb-86 Sr-85 Rb-86
         6.8211E-41 1.5270E-41 6.9742E-08 2.8274E-08 3.0847E-04  $ Cs-131 Ba-131 Cs-134 Ba-133 Cs-134
         2.1227E-28 1.4924E-28 4.2220E-03 1.1666E-26 5.6689E-13  $ Cs-136 Ba-136m Ba-137m Ba-140 Rb-83
         5.0338E-17 1.3985E-25 1.0863E-12 9.7613E-17 2.7147E-25  $ Rb-84 Rb-86 Rb-83 Rb-84 Rb-86
         8.5116E-15 1.6416E-14 9.6154E-28 1.2339E-25 2.8854E-13  $ Sr-85 Sr-85 Ba-140 Rb-86 Rb-83
         2.5388E-17 7.0746E-26 2.3527E-25 4.3872E-15 6.4494E-26  $ Rb-84 Rb-86 Rb-86 Sr-85 Rb-86
         1.6702E-40 1.6094E-07 3.0934E-40 3.2189E-07 1.1342E-26  $ Cs-131 Cs-134 Cs-131 Cs-134 Ba-140
         3.4573E-41 5.7375E-08 6.3927E-41 1.0599E-07 6.4109E-04  $ Ba-131 Ba-133 Ba-131 Ba-133 Cs-134
         4.2453E-28 1.8931E-28 8.4034E-03 1.1776E-03 7.8224E-28  $ Cs-136 Ba-136m Ba-137m Cs-134 Cs-136
         3.5000E-28 1.5508E-02 4.4734E-28 8.2066E-28 1.1266E-07  $ Ba-136m Ba-137m Ba-140 Ba-140 Cs-134
         1.1082E-40 3.8360E-08 2.3211E-41 4.3186E-04 2.8499E-28  $ Cs-131 Ba-133 Ba-131 Cs-134 Cs-136
         1.2767E-28 5.6835E-03 3.0413E-28 3.6359E-09 1.2797E-43  $ Ba-136m Ba-137m Ba-140 Ba-133 Ba-131
         9.4062E-28 9.1741E-43 4.3320E-09 5.6316E-08 1.7530E-44  $ Cs-136 Ba-131 Ba-133 Ba-133 Ba-131
         1.0190E-27 7.3042E-43 4.1152E-29 1.5110E-29 5.2983E-29  $ Cs-136 Ba-131 Cs-136 Ba-140 Ba-140
         4.8556E-16 3.6170E-41 1.7530E-44 4.5521E-17 1.7661E-28  $ Rb-83 Ba-131 Ba-131 Rb-83 Ba-140
         2.6529E-42 4.6747E-44 1.1307E-27 2.1913E-43 1.0665E-09  $ Ba-131 Ba-131 Cs-136 Ba-131 Ba-133
         4.9961E-27 6.7578E-28 7.2505E-29 1.9596E-27 7.0545E-29  $ Ba-140 Ba-136m Cs-136 Cs-136 Cs-136
         2.4542E-41 7.4405E-10 1.5677E-29 3.0093E-42 5.6330E-05  $ Ba-131 Ba-133 Cs-136 Ba-131 Cs-134
         7.8885E-43 3.5119E-42 2.1751E-27 1.1845E-08 2.0685E-43  $ Ba-131 Ba-131 Cs-136 Ba-133 Ba-131
         5.8788E-30 3.0308E-08 3.4596E-27 3.9193E-30 4.7305E-31  $ Cs-136 Ba-133 Ba-140 Cs-136 Ba-136m
         9.7981E-29 3.8626E-05 8.2892E-27 1.1395E-43 1.0260E-07  $ Cs-136 Cs-134 Cs-136 Ba-131 Ba-133
         1.6946E-44 1.7530E-41 1.4782E-08 2.3373E-45 1.6361E-42  $ Ba-131 Ba-131 Ba-133 Ba-131 Ba-131
         2.5118E-27 1.1920E-43 1.5306E-27 5.0837E-44 7.0120E-44  $ Ba-140 Ba-131 Ba-140 Ba-131 Ba-131
         5.8434E-44 7.8493E-31 2.9217E-45 3.9163E-03 4.0904E-43  $ Ba-131 Ba-140 Ba-131 Cs-134 Ba-131
         2.6062E-42 1.5677E-29 5.8434E-41 2.3373E-45 1.9008E-28  $ Ba-131 Cs-136 Ba-131 Ba-131 Cs-136
         2.2762E-16 4.9572E-14 1.7530E-45 1.5174E-12 1.0015E-12  $ Rb-84 Sr-85 Ba-131 Rb-83 Rb-83
         1.7530E-45 1.9623E-26 4.3825E-45 2.6879E-45 5.2983E-30  $ Ba-131 Ba-140 Ba-131 Ba-131 Ba-140
         5.4170E-13 2.8830E-16 4.4994E-45 2.2478E-02 4.1389E-02  $ Rb-83 Rb-83 Ba-131 Cs-134 Cs-134
         1.9517E-43 1.4901E-42 2.0452E-45 2.6180E-01 1.7940E-42  $ Ba-131 Ba-131 Ba-131 Cs-134 Ba-131
         2.8830E-15 4.3241E-45 3.6577E-01 1.6479E-43 1.0622E-15  $ Rb-83 Ba-131 Ba-137m Ba-131 Rb-83
         1.8114E-43 8.0054E-45 3.9193E-30 2.7031E-31 1.7530E-45  $ Ba-131 Ba-131 Cs-136 Ba-136m Ba-131
         2.9217E-45 2.2305E-14 2.2908E-01 4.4994E-44 8.0420E-15  $ Ba-131 Rb-83 Cs-134 Ba-131 Rb-83
         2.3417E-02 1.7441E-26 2.1963E-27 2.8458E-43 2.3373E-45  $ Cs-134 Cs-136 Ba-136m Ba-131 Ba-131
         8.0471E-07 5.9484E-18 2.9722E-16 5.7849E-44 1.1102E-44  $ Cs-134 Sr-85 Rb-84 Ba-131 Ba-131
         8.9988E-43 4.0904E-44 4.5578E-44 1.8130E-18 2.6824E-03  $ Ba-131 Ba-131 Ba-131 Rb-84 Cs-134
         1.1278E-43 1.6536E-42 1.3521E-26 2.2030E-27 1.4215E-21  $ Ba-131 Ba-131 Cs-136 Ba-136m Rb-86
         4.8417E-03 1.9867E-45 2.1620E-45 5.8434E-46 3.9389E-27  $ Cs-134 Ba-131 Ba-131 Ba-131 Cs-136
         9.7981E-30 1.3440E-45 8.1544E-03 1.9596E-29 2.9395E-30  $ Cs-136 Ba-131 Cs-134 Cs-136 Cs-136
         2.0273E-31 3.2694E-18                                   $ Ba-136m Rb-84
si3      20.25                      $H/2, half the total height
```

```
si4      2.04 2.54                    $r1 r2, inner radius and outer radius
sp4      -21 1                        $distribute the source radially with the correct probability
C
f4:p 3                                $give the photon flux for cell 3
nps 250000000                         $run this many particles, 1/4 billion particles
```

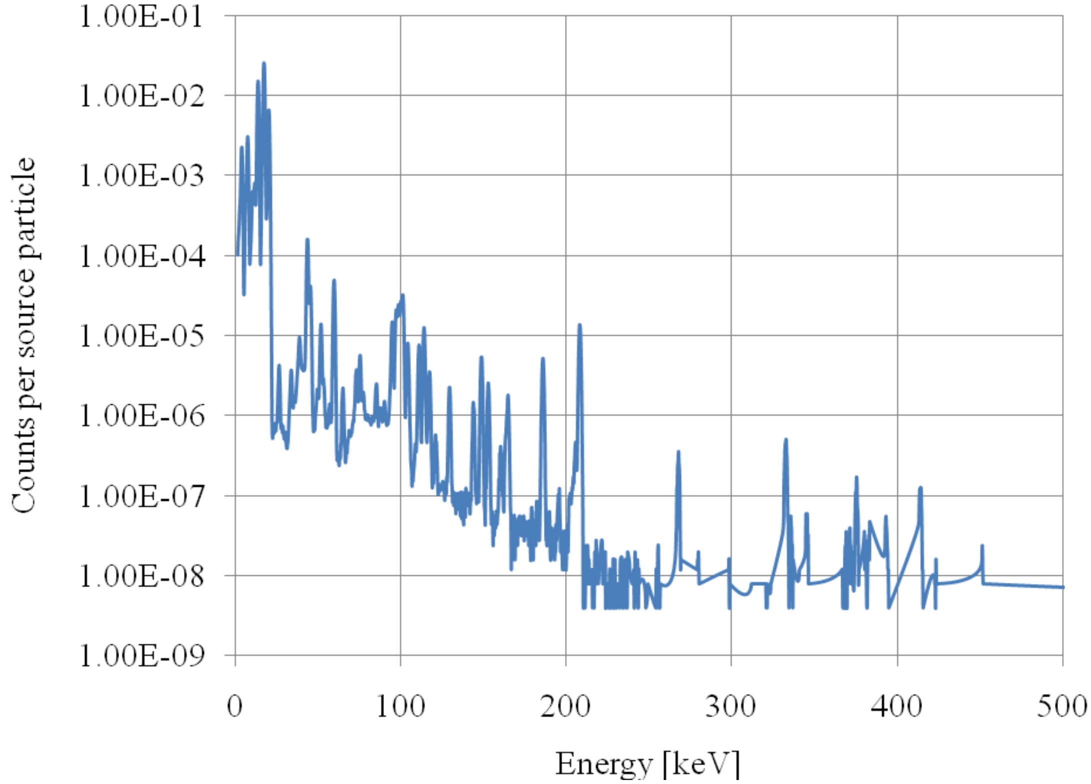
APPENDIX K

MCNP gamma spectra simulations for the UREX extraction stream with the ANL sample isotopics for various Pu extraction fractions.

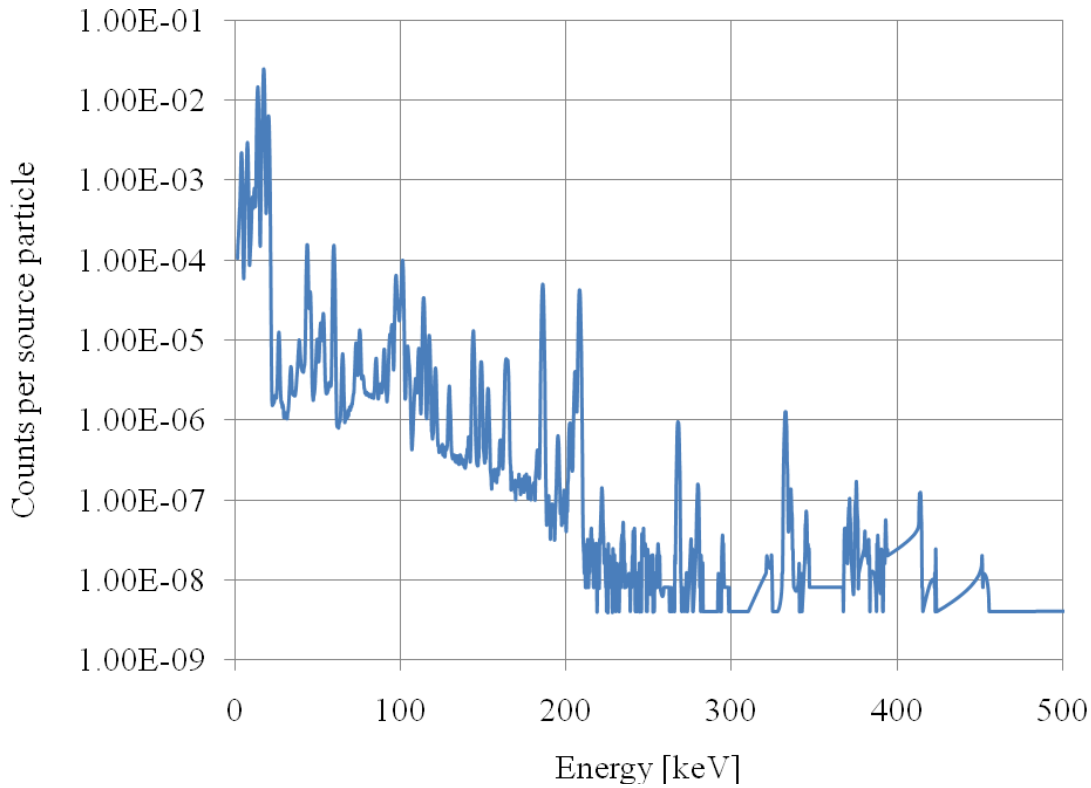
100% Pu



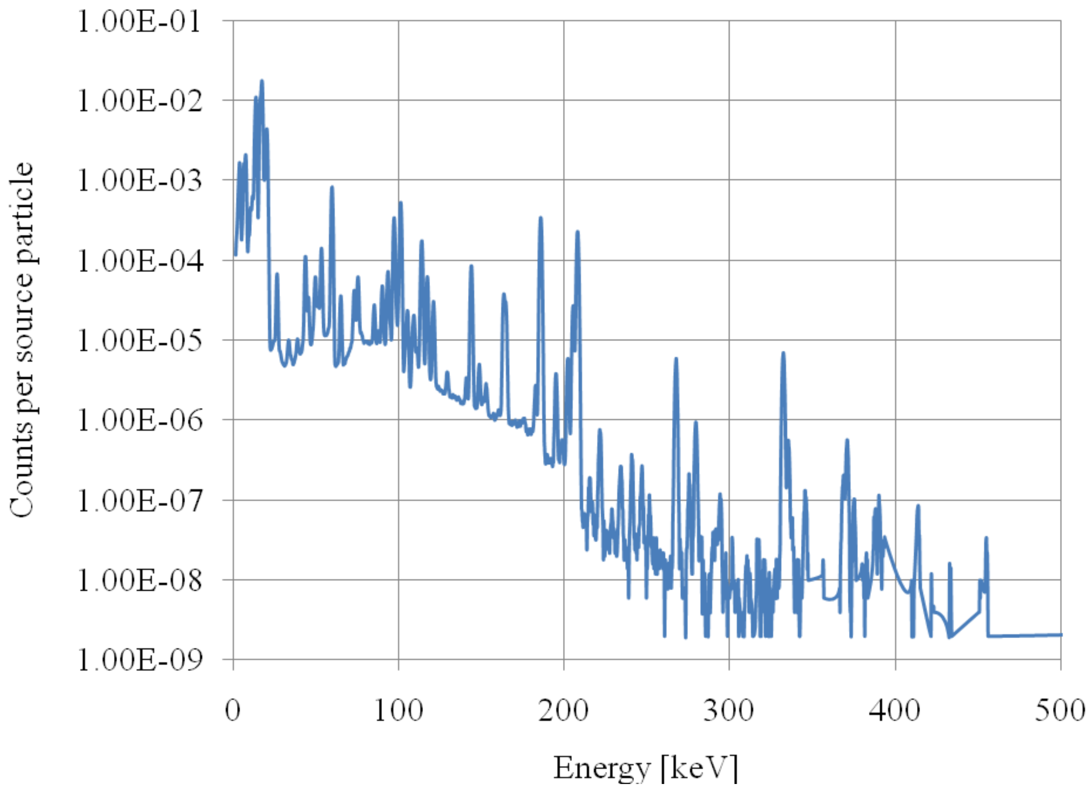
10% Pu


1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
100
200
300
400
500
Energy [keV]

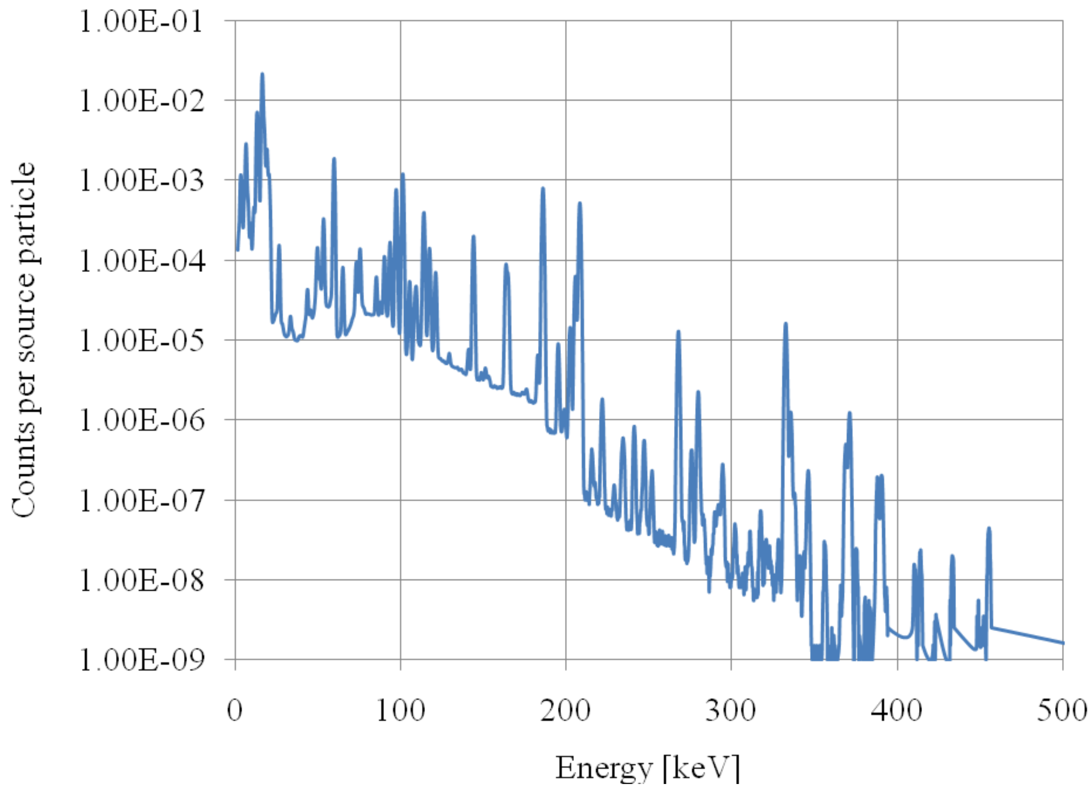
1% Pu


1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
100
200
300
400
500
Energy [keV]

0.1% Pu

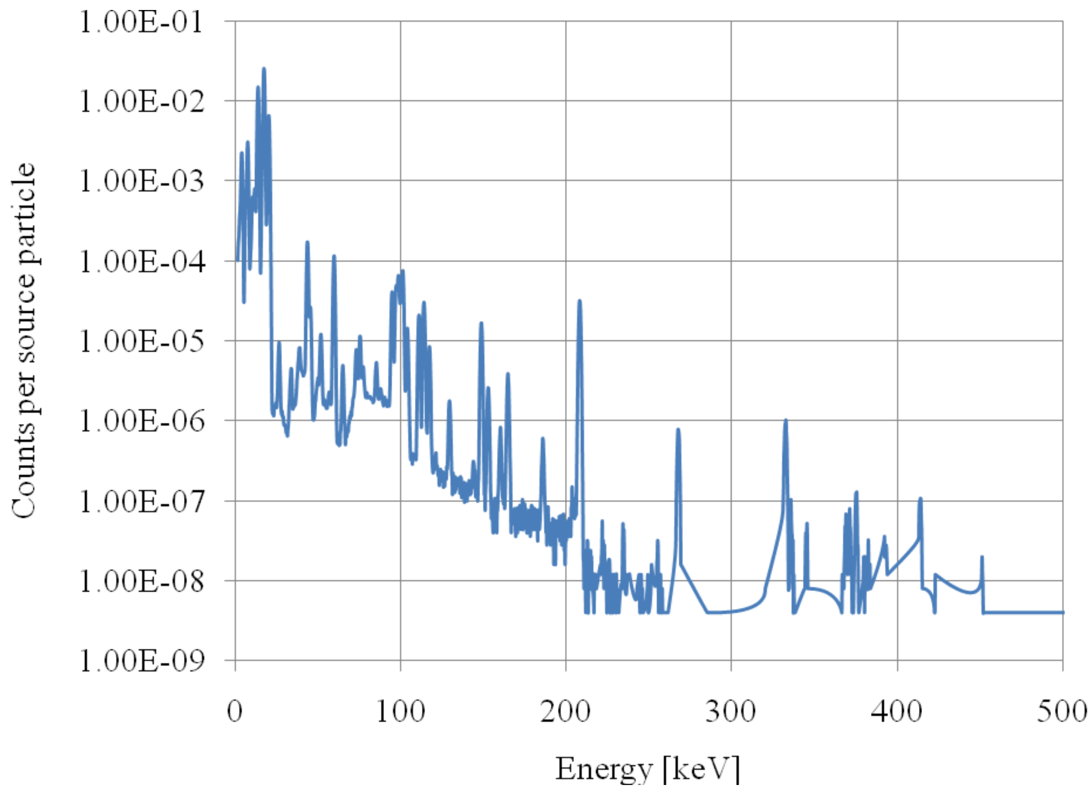

1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
100
200
300
400
500
Energy [keV]

0.01% Pu

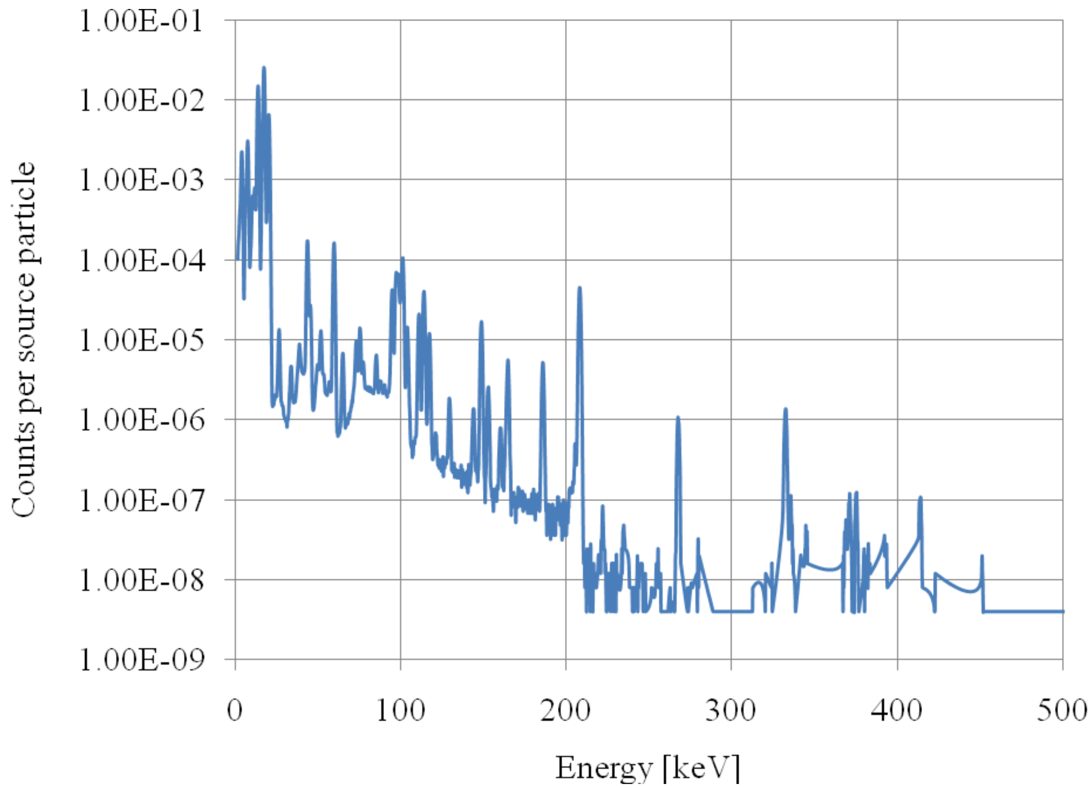

1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
100
200
300
400
500
Energy [keV]

MCNP gamma spectra simulations for the UREX extraction stream with the Simulated Fuel isotopics for various Pu extraction fractions.

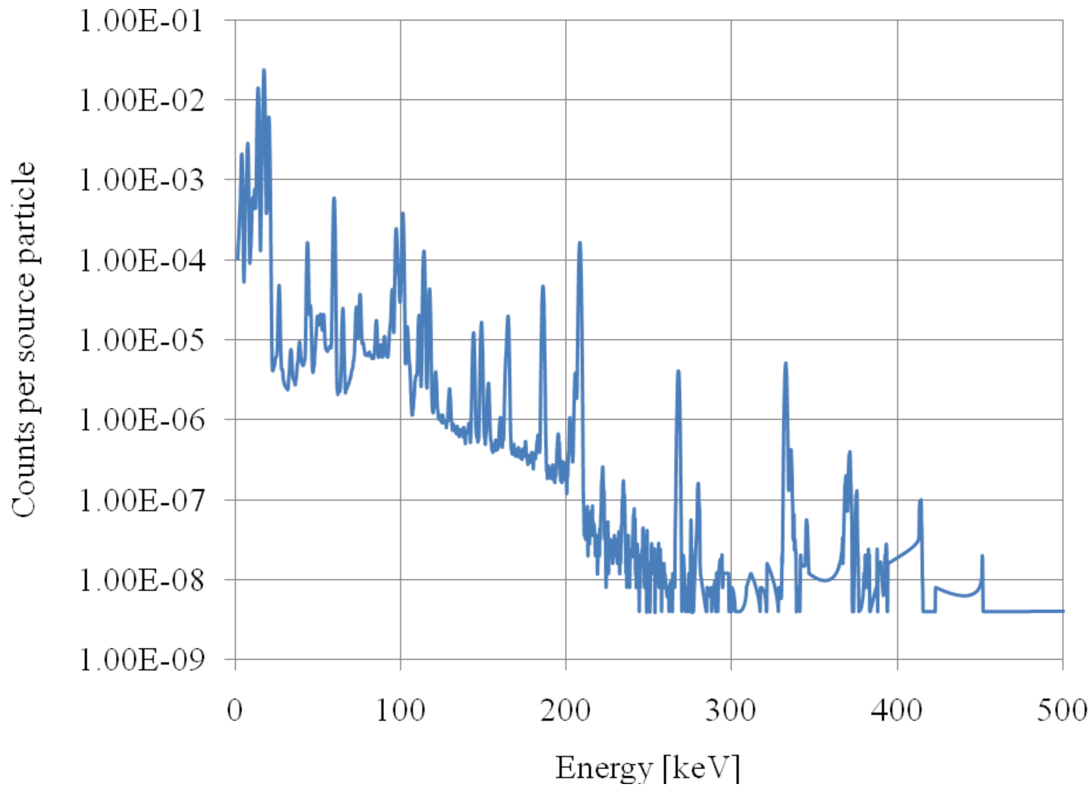
100% Pu



10% Pu


1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
100
200
300
400
500
Energy [keV]

1% Pu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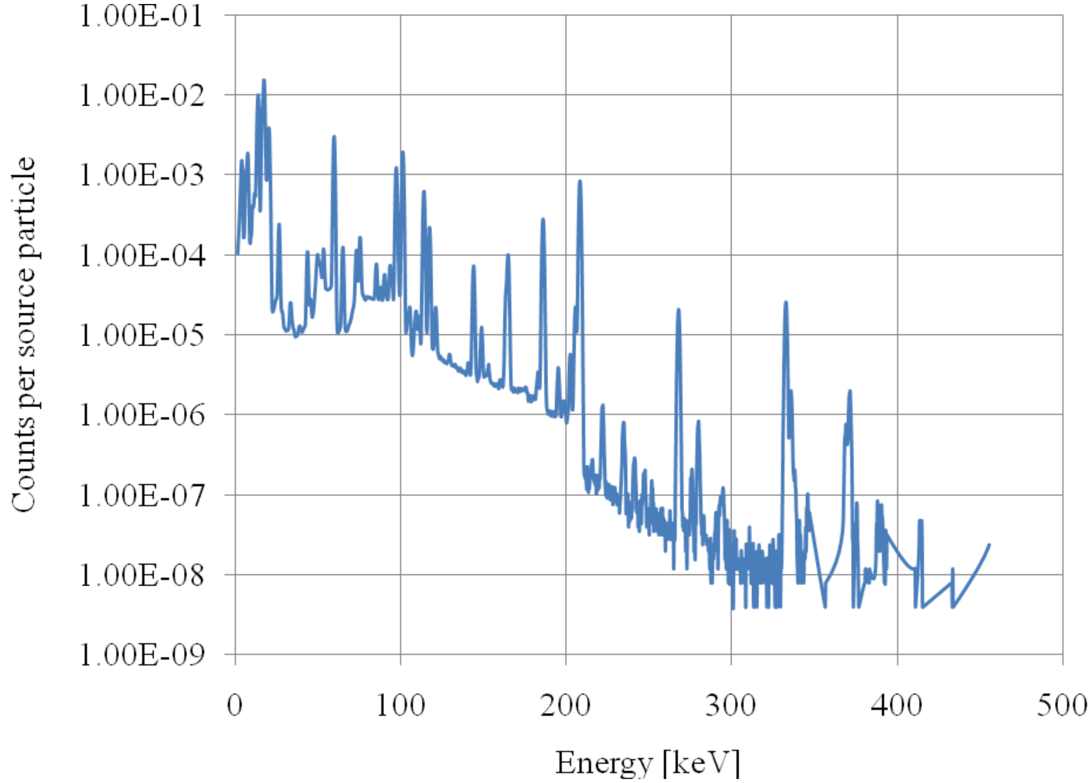
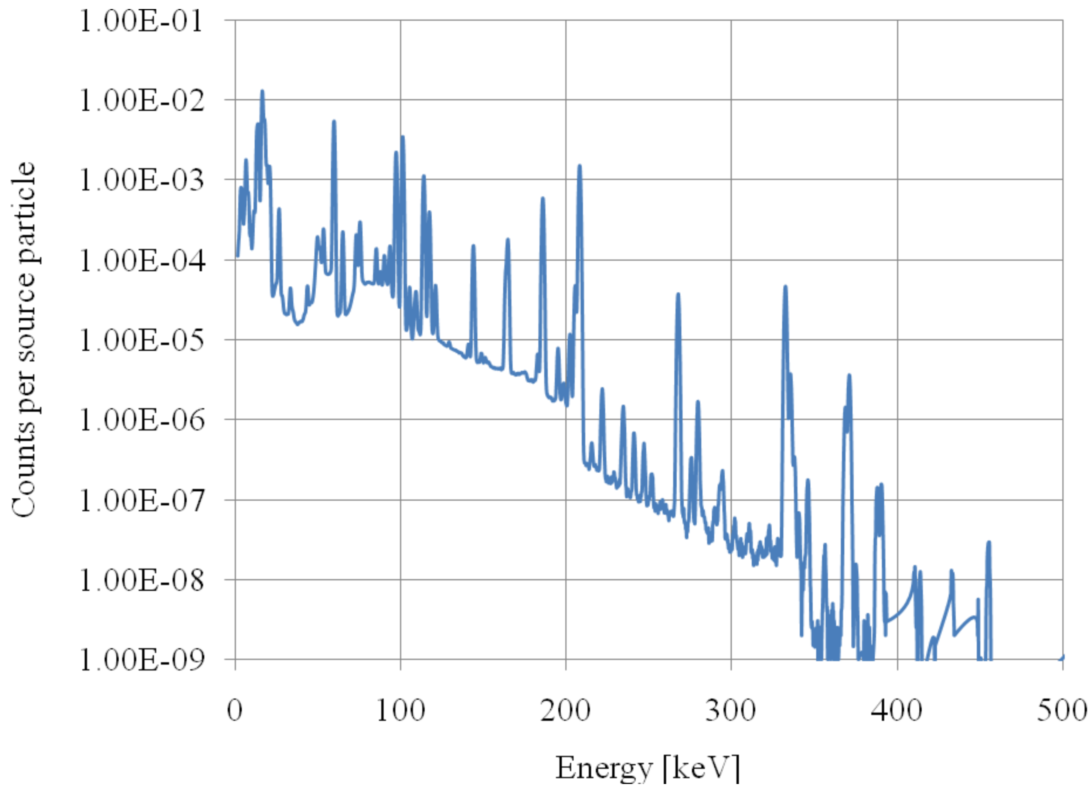
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
100
200
300
400
500
Energy [keV]

0.1% Pu


1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
100
200
300
400
500
Energy [keV]

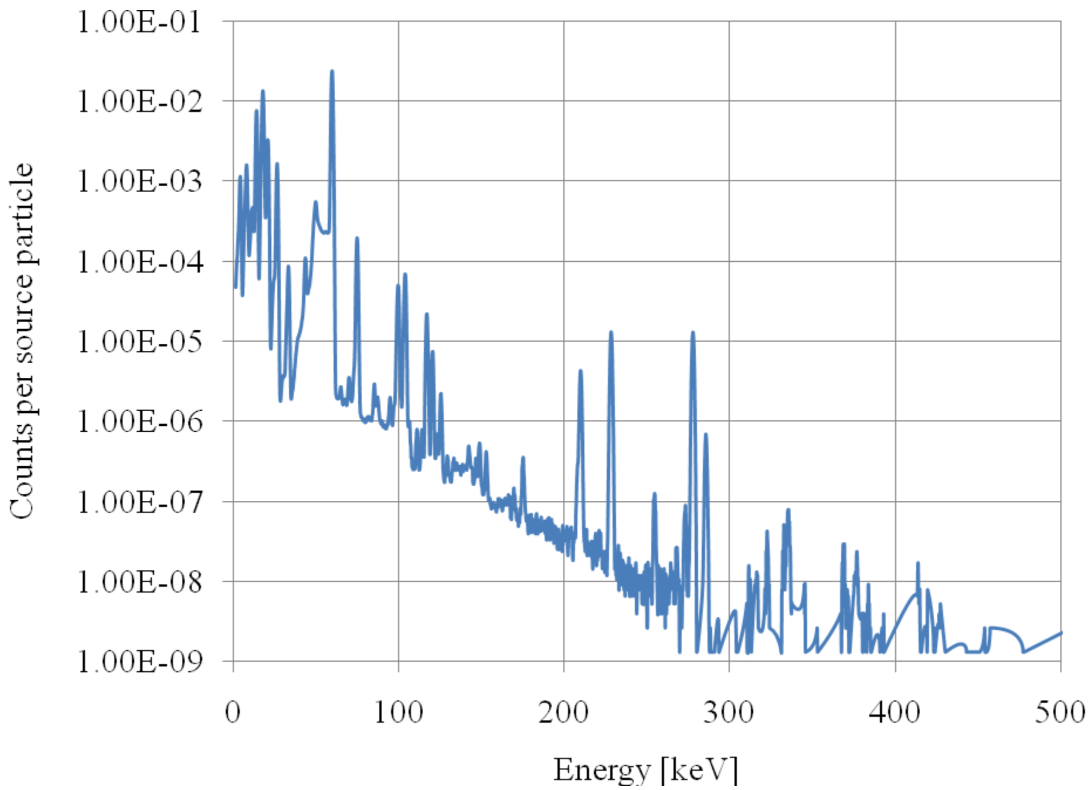
0.01% Pu


1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
100
200
300
400
500
Energy [keV]

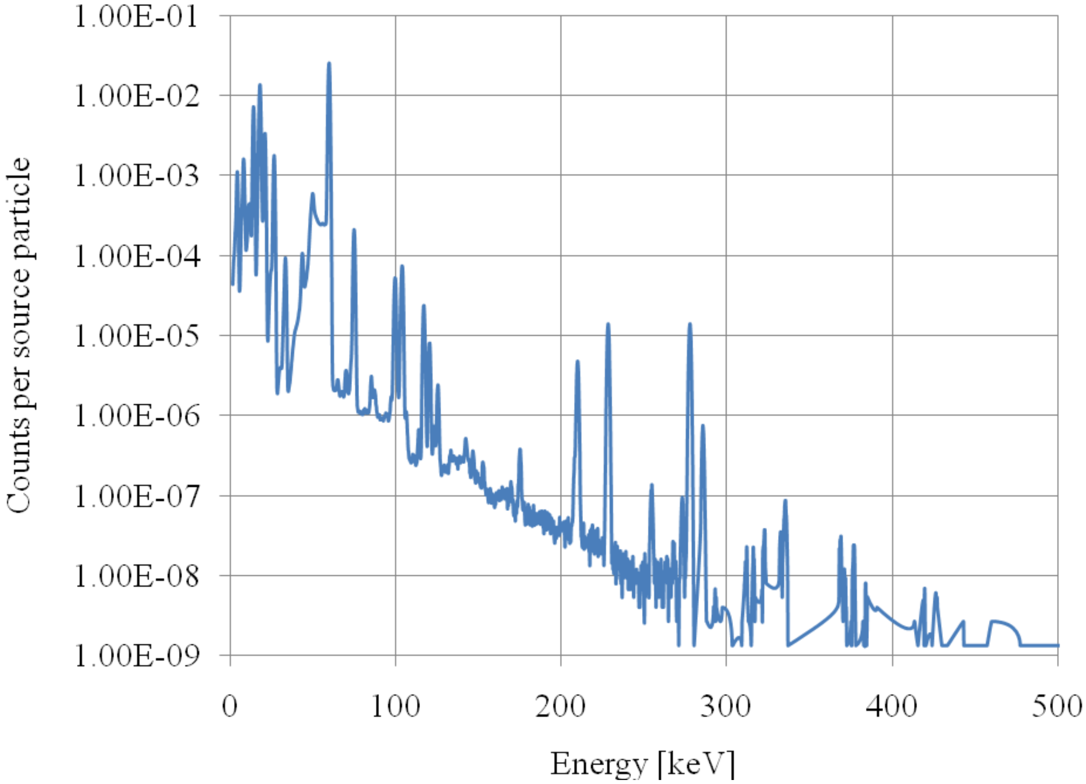
APPENDIX L

MCNP gamma spectra simulations for the TALSPEAK extraction stream with the ANL sample isotopics for various Pu extraction fractions.

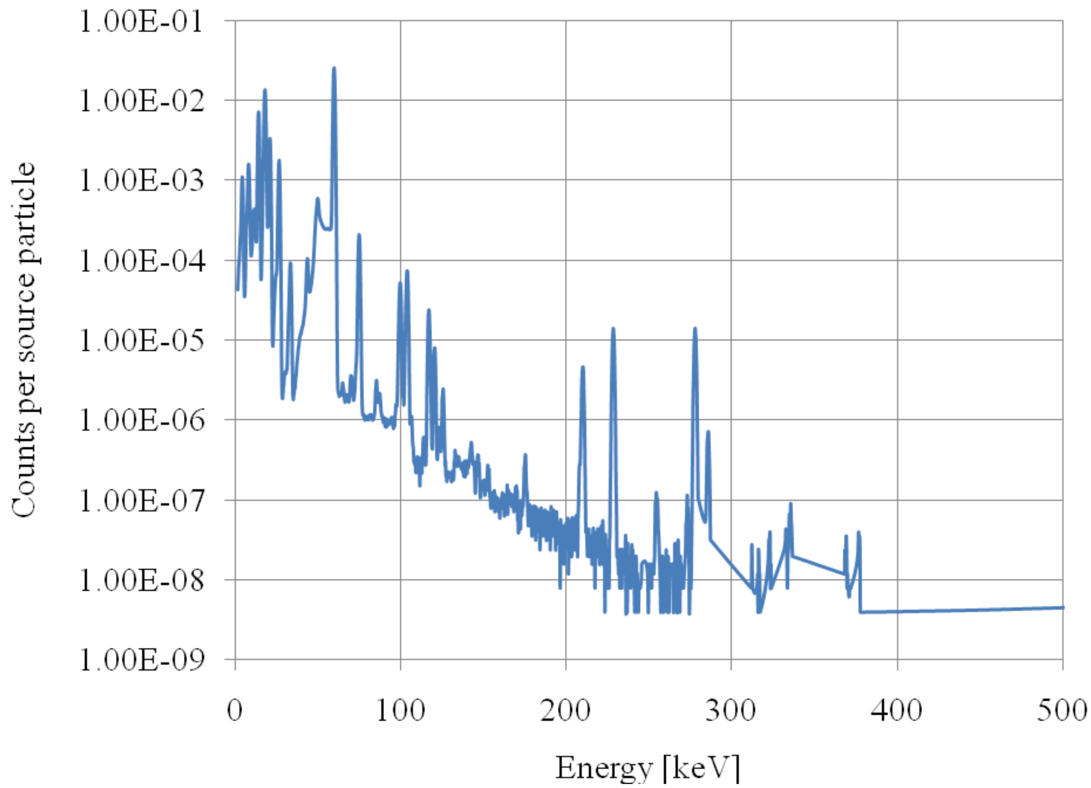
100% Pu



10% Pu

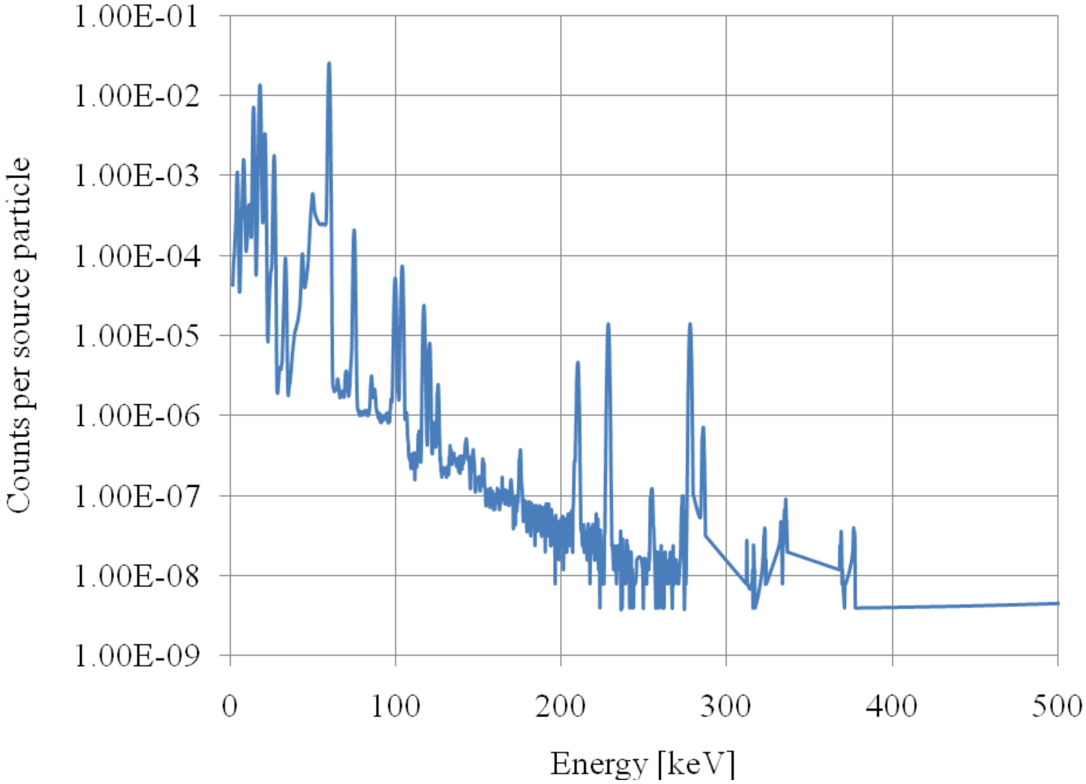

1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
100
200
300
400
500
Energy [keV]

1% Pu

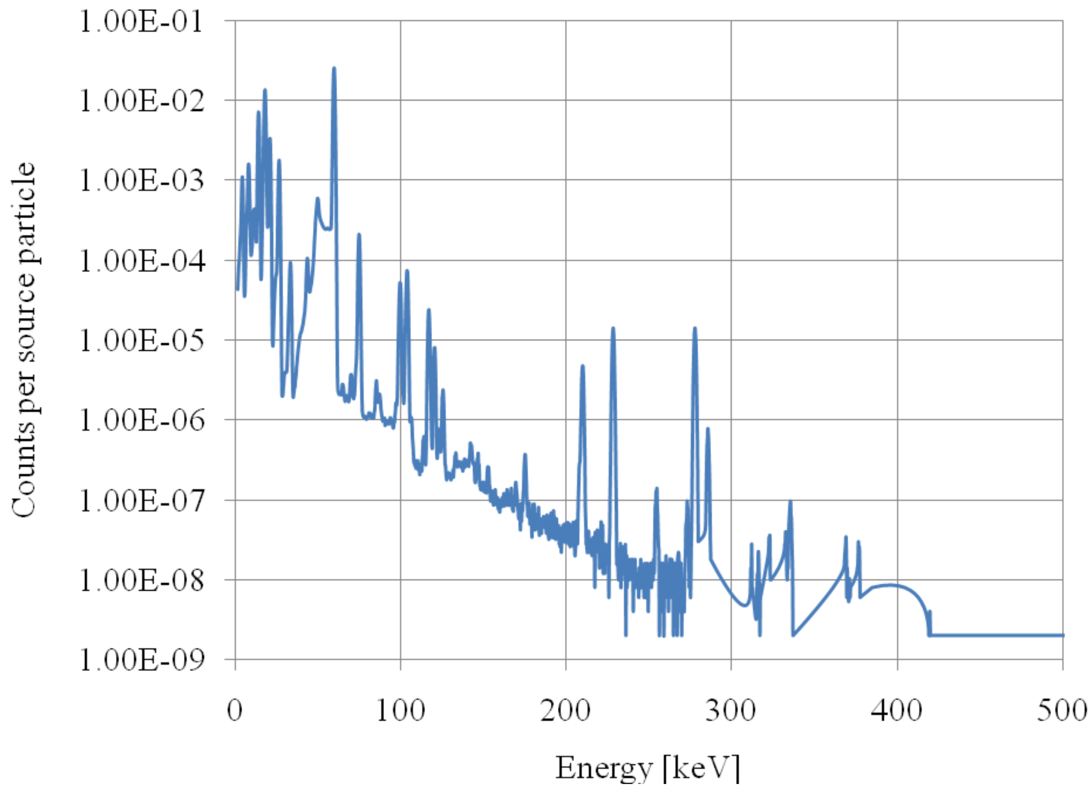


1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
100
200
300
400
500
Energy [keV]

0.1% Pu

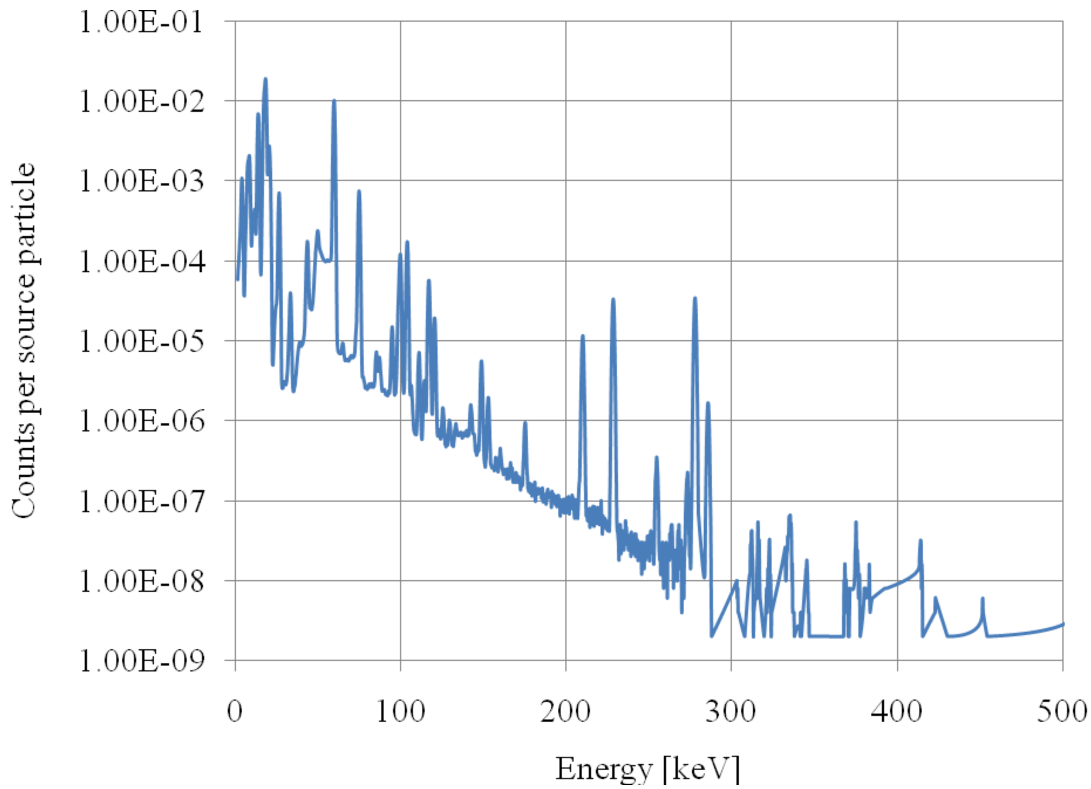

1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
100
200
300
400
500
Energy [keV]

0.01% Pu

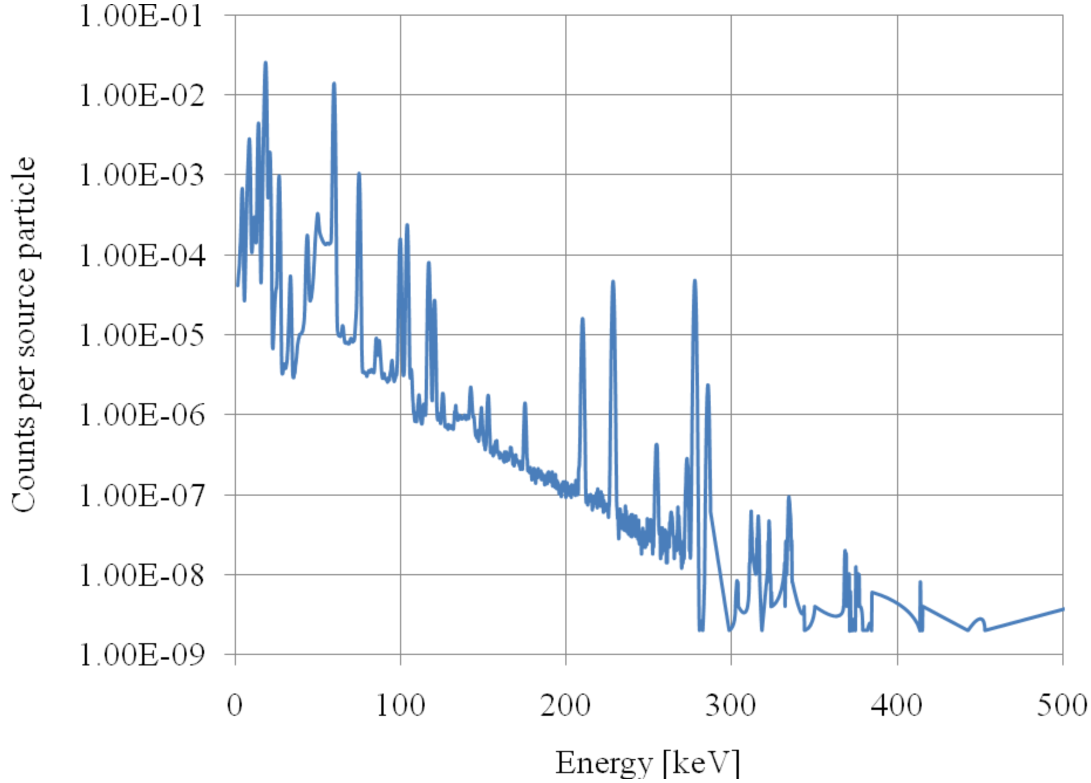

1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
100
200
300
400
500
Energy [keV]

MCNP gamma spectra simulations for the TALSPEAK extraction stream with the Simulated Fuel isotopics for various Pu extraction fractions.

100% Pu



10% Pu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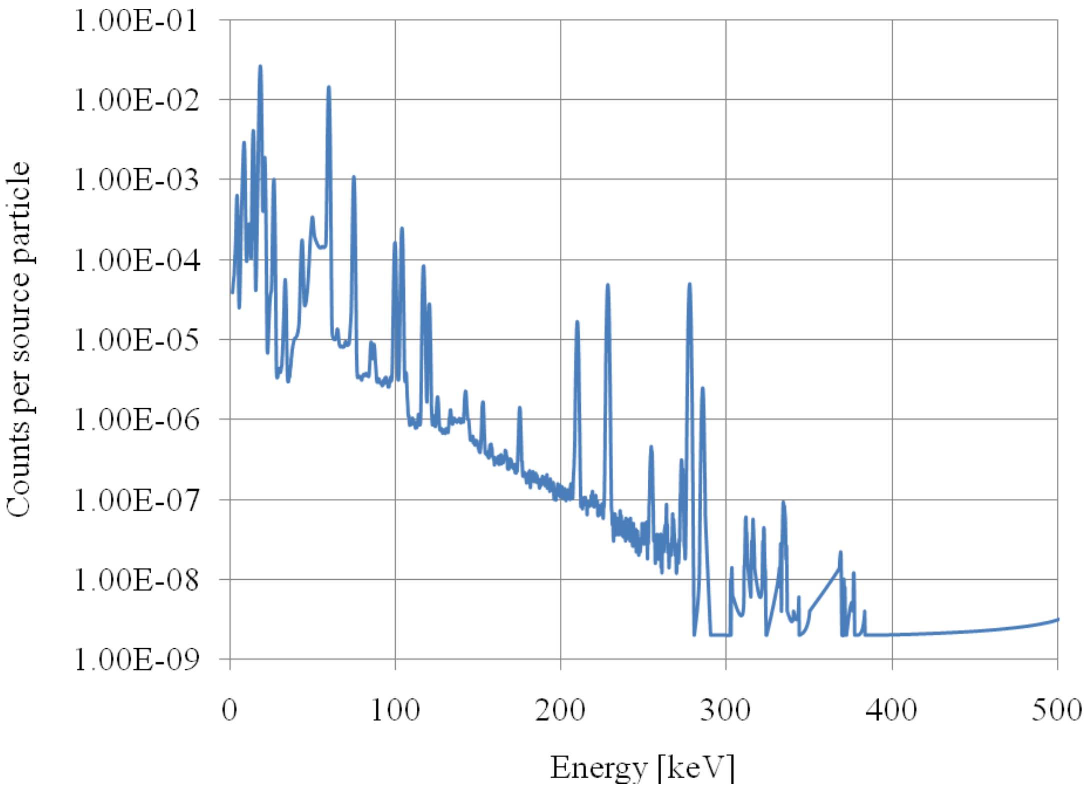
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
100
200
300
400
500
Energy [keV]

1% Pu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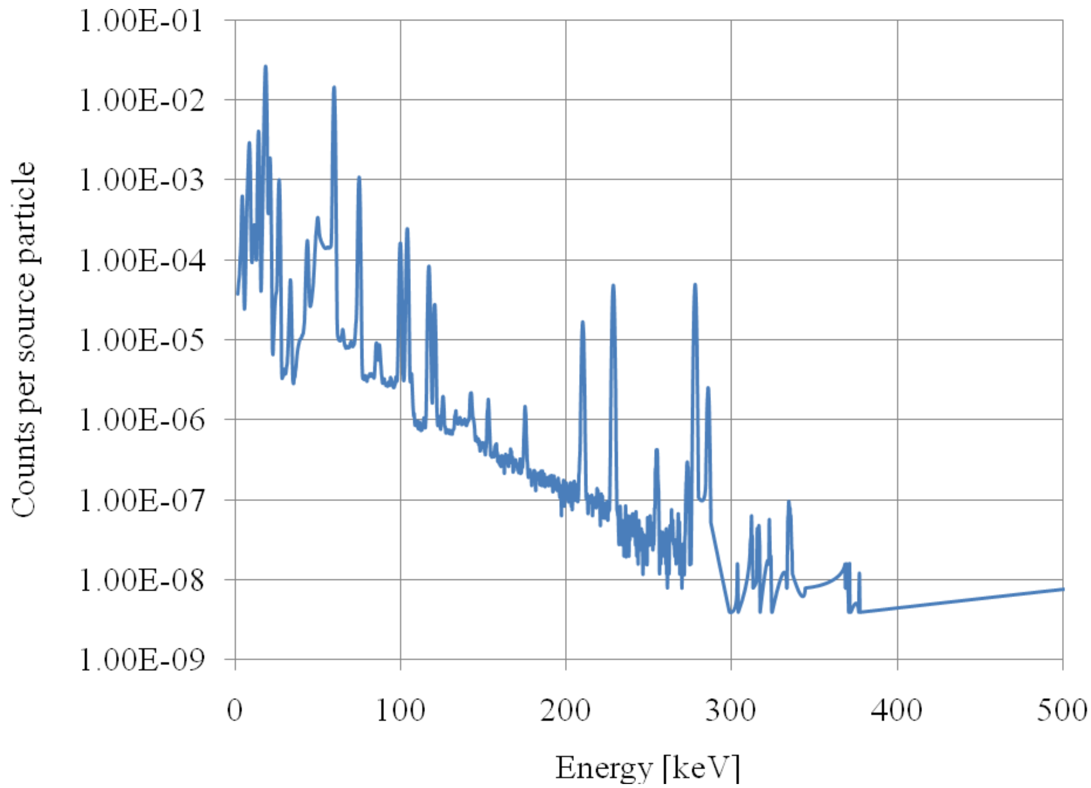
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
100
200
300
400
500
Energy [keV]

0.1% Pu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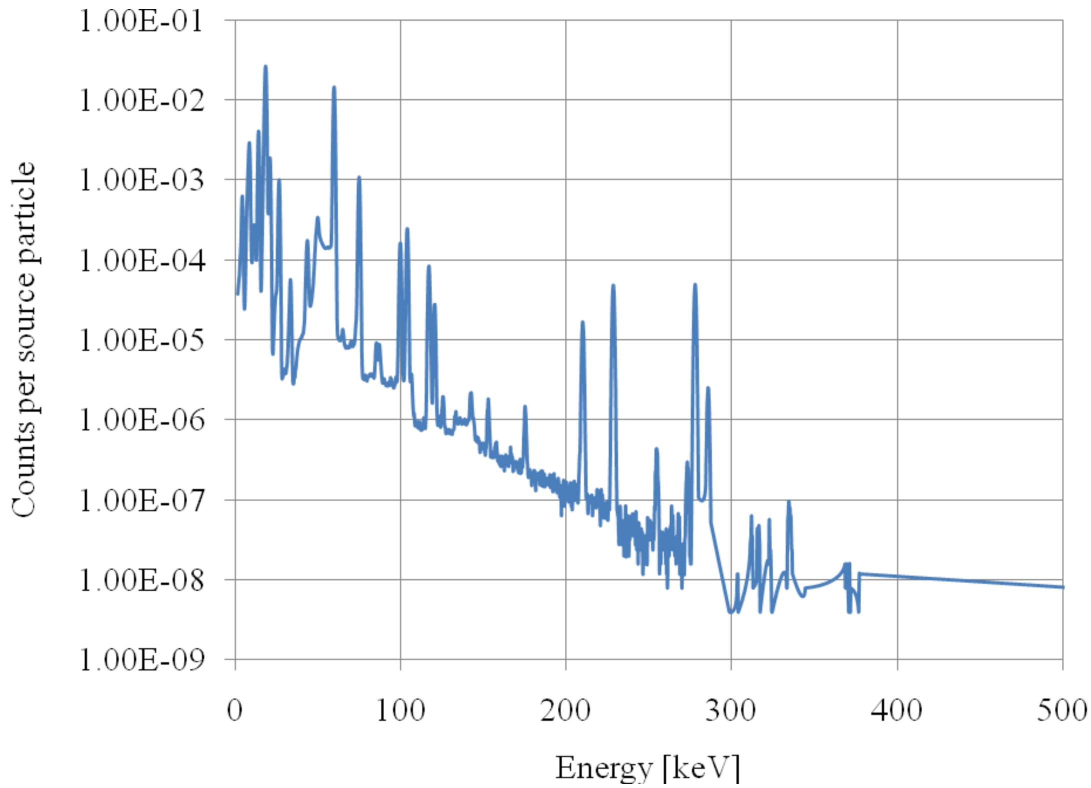
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
100
200
300
400
500
Energy [keV]

0.01% Pu


1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
Counts per source particle
0
100
200
300
400
500
Energy [keV]

VITA

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