Comparative Analysis of Kimberlite Rock Using Activation Technique

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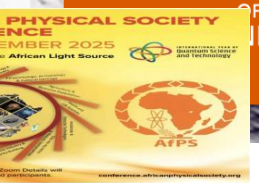

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Introduction

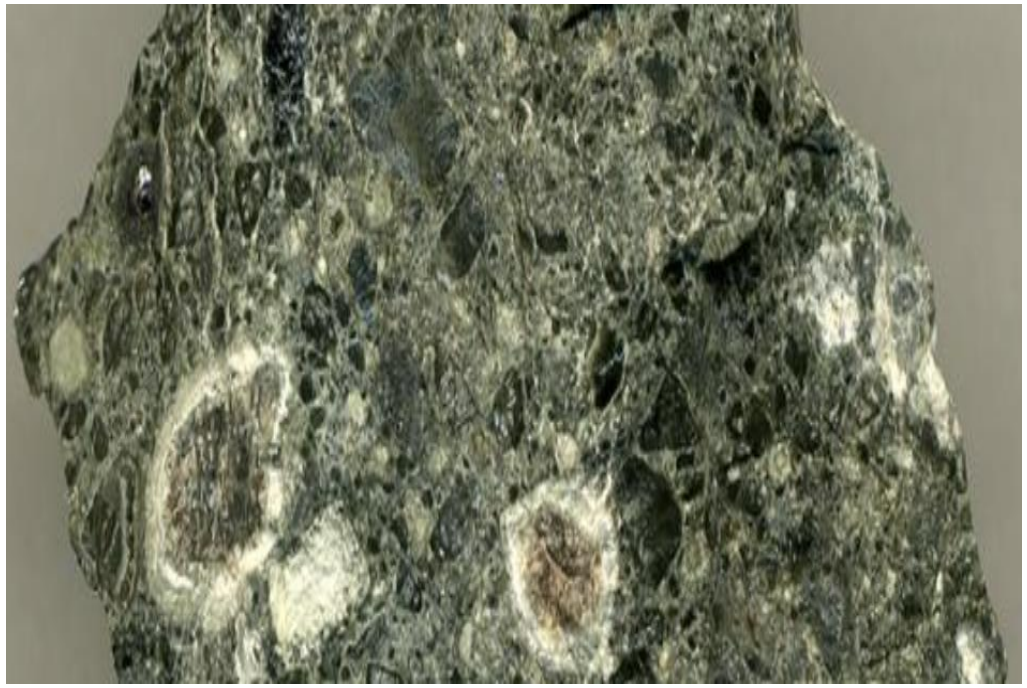
Activation technique is the process where a high-energy beam (photon, electron, ion, neutron) is used to irradiate sample to become radioactive for further analysis. This tecniques has been used to analyse mineral-rich sample, leading to the right selection technique for extraction.

Kimberlite rocks are the primary source of diamonds, and detecting such diamonds and the background radioisotopes requires special analysis.

These rocks exhibit spectral lines of long-lived radioisotopes when gamma spectroscopy analysis is performed on them when they are not irradiated, and selecting the kimberlite with the diamond content in it becomes impossible.

When similar kimberlite is irradiated, it produces spectral lines of radionuclides that fall within short-lived, medium-lived, and long-loved radioisotopes and selecting the right kimberlite with diamond content within a time frame is possible

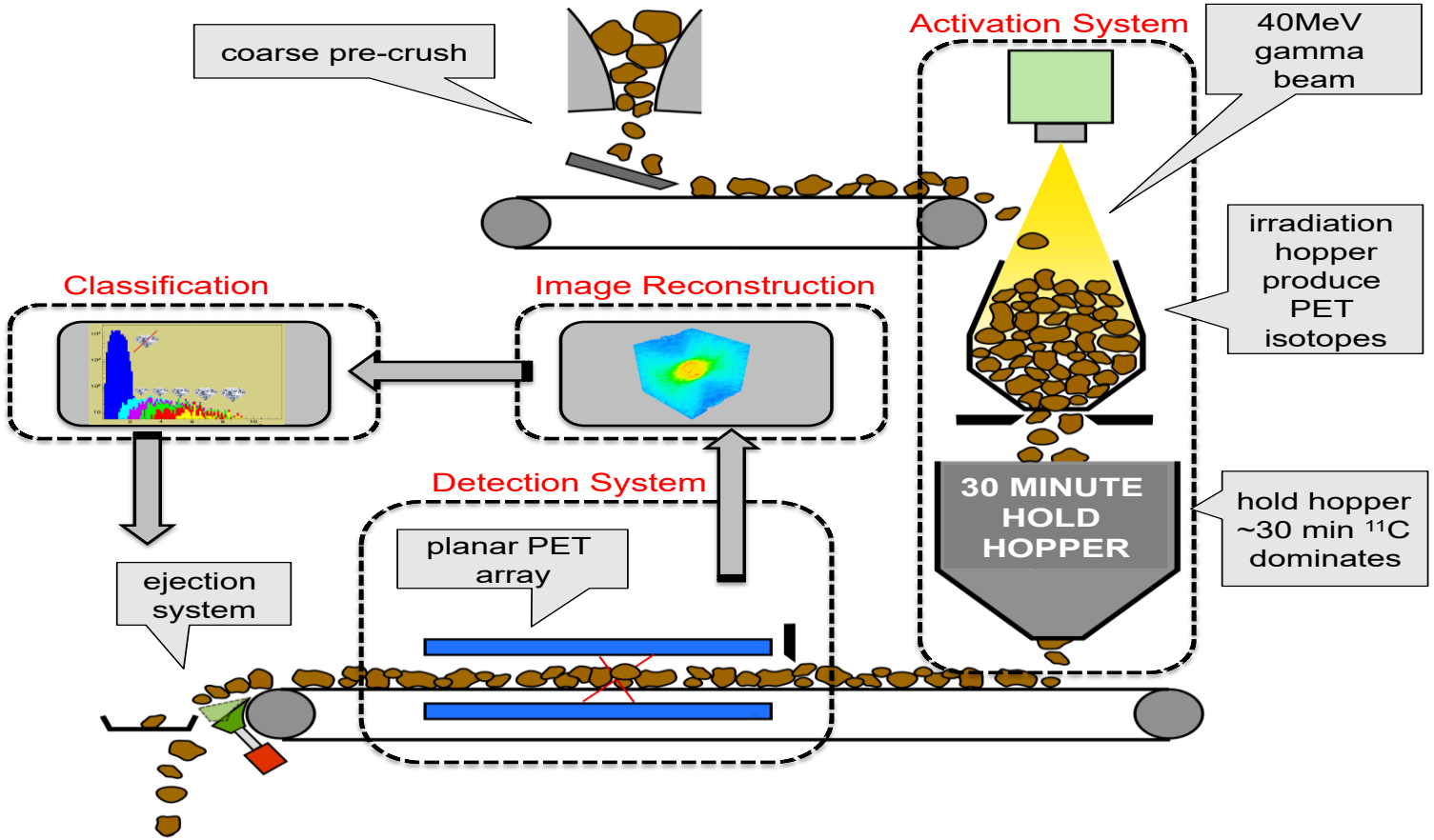
In this work, unirradiated kimberlite and radiated kimberlite will be compared using activation technique



Loose diamonds being sparkled in kimberlite rock

DESCRIPTION OF MINERAL POSITRON EMISSION TOMOGRAPHY TECHNIQUE

- Crush kimberlite to 10 cm top size
- Irradiated the sample with high-energy photon beams to transmute stable elements into PET isotopes
- Hold for 30 minutes for ^{11}C become dominate
- 511 keV photons are counted with a photon detector(HPGe)



MINPET DIAMONDS | SORTED

NeT INSTRUMENTS

research instruments

GEM DIAMONDS

LETŠENG DIAMONDS

COSYLAB

ISA

AFRICAN PHYSICAL SOCIETY CONFERENCE
17–21 NOVEMBER 2025
Held Jointly With the African Light Source
AfPS

LETSENG DIAMOND PIT AND KIMBERLITE SELECTION

- Letseng diamond is located in Lesotho
- It shared a border with South Africa
- It is situated at an average elevation of approximately 3,100 to 3,200 meters above sea level
- It is the one of the highest diamond mine in the world in terms of elevation
- The average temperature during winter at the mine is -17 degree

Letseng Diamond Pit

MinPET Team members

LETSENG DIAMOND PIT AND KIMBERLITE SELECTION

S11 kimberlite

K6 kimberlite

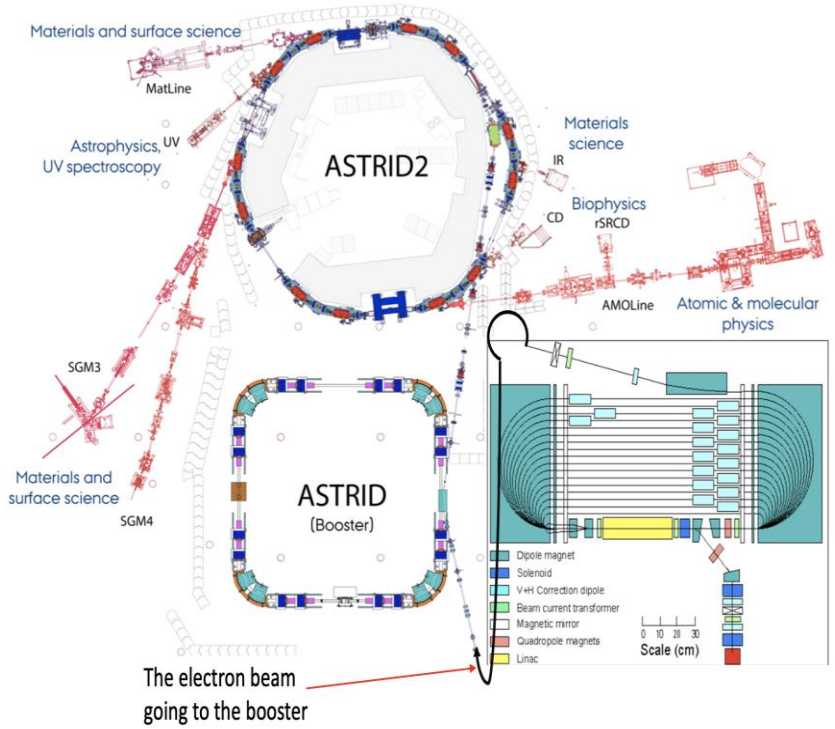
	Grey	Altered	Black	Spectrau	Average	Tappe	Final
SiO_2	43.50	39.10	40.96	45.44	42.25		42.56
TiO_2	0.74	0.83	2.21	3.36	1.97		1.80
Al_2O_3	3.66	3.77	2.87	7.25		**2.50**	2.52
Fe_2O_3	4.90	4.05	5.03	12.94	6.73		4.69
FeO	2.70	2.89	4.28	0.00	2.47		3.31
MnO	0.16	0.25	0.10	0.24	0.19		0.19
MgO	27.85	36.00	27.25	16.18		**28.40**	28.61
CaO	3.64	0.42	6.02	11.06	5.29		5.32
Na_2O	0.20	0.05	0.71	0.97		**0.13**	0.13
K_2O	0.67	0.20	1.22	0.61	0.68		0.68
P_2O_5	0.15	0.13	0.19	0.29	0.19		0.19
H_2O							*5.00*
CO_2							*5.00*

Elemental Composition of kimberlite rock by X-ray Fluorescence

- CO_2 concentration in the kimberlite is 5%
- S11 is Mantle xenolith

DESCRIPTION OF AARHUS 100 MeV ELECTRON BEAM

Aarhus microtron injector showing the electron gun

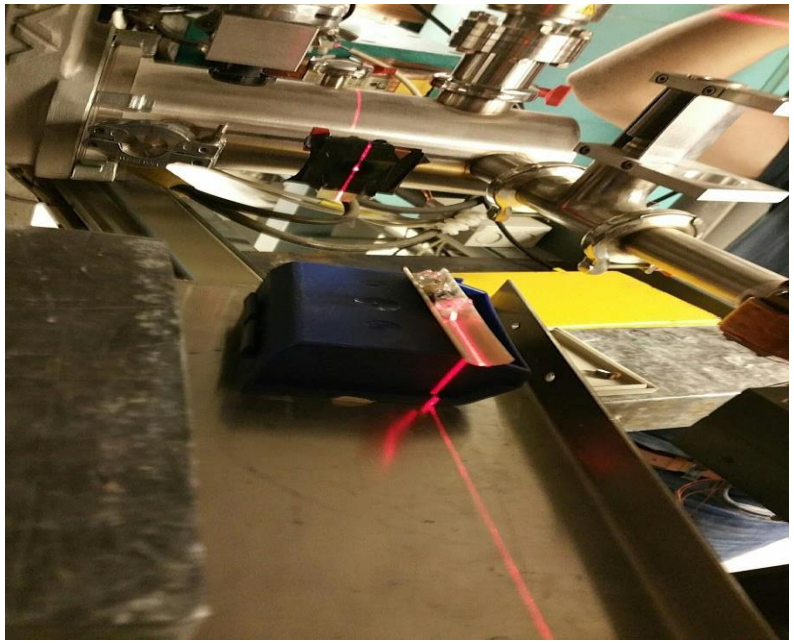


An overview of ASTRID/ASTRID2 facility

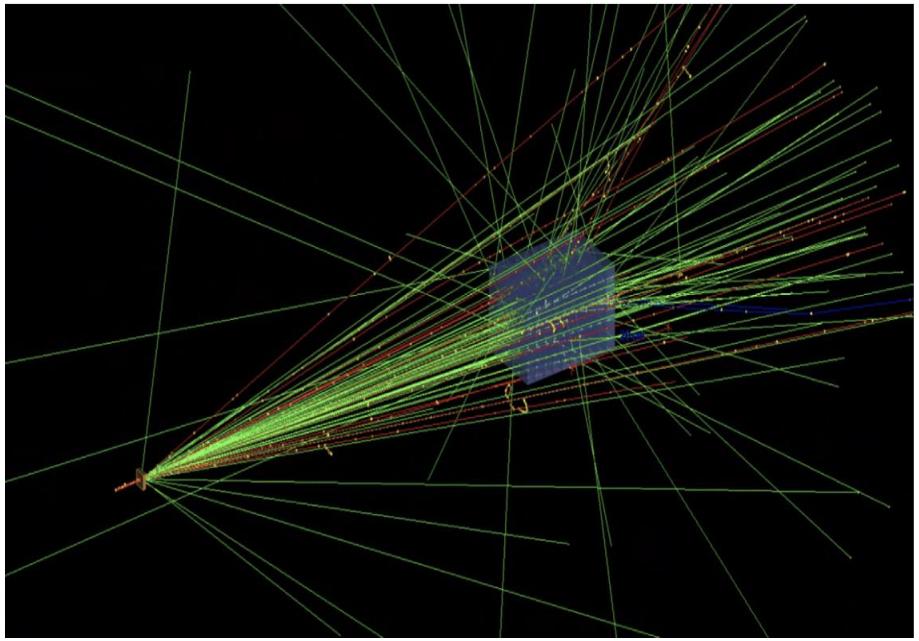
- Accelerator capacity 100 MeV
- The energy circulating in ASTRID and ASTRID2 is 580 MeV with current of 200 mA.
- ASTRID2 and ASTRID have a circumference of 45.7m and 40 m..
- Beam degraded to 40 MeV using 5mm copper and 2.5 mm stainless steel plate flange
- Our interest is in injector on the right

ACTIVATION TECHNIQUE

Rock ID	Irradiation Time [min]	Irradiation Distance [mm]	Cooling Time [min]	Count Time
S11	10	750	10	23.51
K6	-	-	-	1:49



The incoming 100 MeV electron beam from the microtron injector



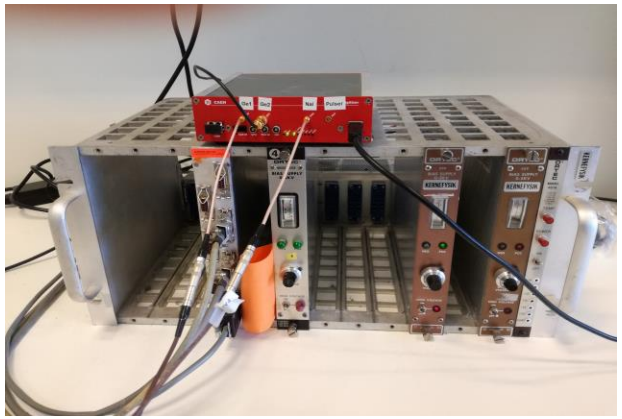
Geant4 sim showing 1M events of 100 MeV passing through a 2.5 mm stainless steel and 5mm copper plate flange to create bremsstrahlung distribution (photons) to irradiate the kimberlite

- Irradiation time =10 min
- Irradiation distance from beam exit point =750 mm
- Cooling time (waited period) = 10 min
- The colours are charges: red-negative, blue-positrons, and green-photons

HIGH PURITY GERMANIUM DETECTORS AND DATA ACQUISITION

Activated kimberlite was placed between HPGe detectors (000, 001, 002) for time-differential detection after 10 minutes of irradiation.

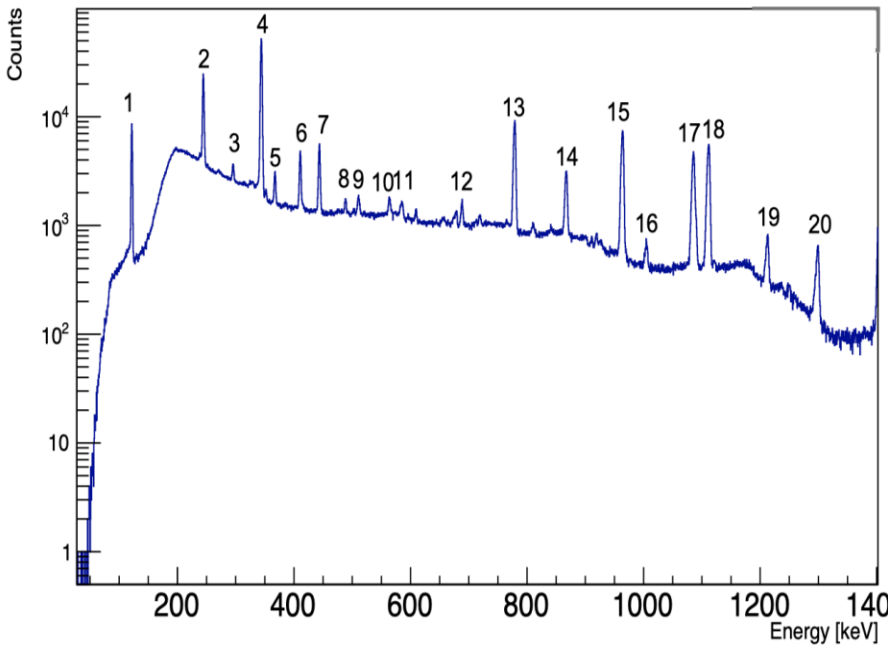
K6 rock in between HPGe detectors



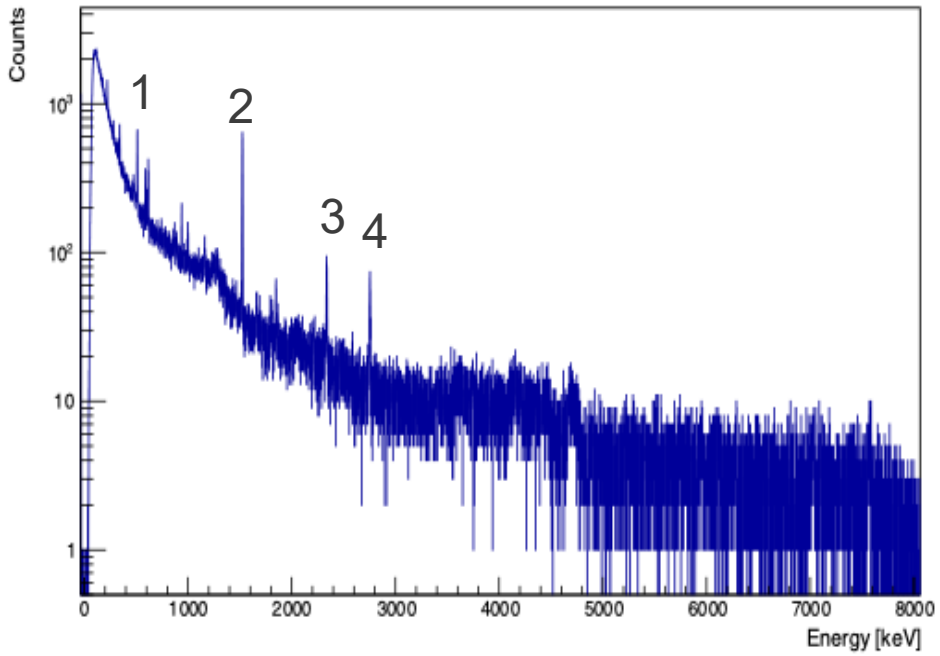
CAEN digitizer/module

- The HPGe dead time of 0.4% and efficiency of 0.159%
- HPGe detector produces analog signal
- CAEN converts the analog pulse signal to digital signals
- CAEN CoMPASS (graphical DAQ software)
- This is a list mode data, so every detector has both time and energy value
- Europium-152 source used to calibrate the detectors

DETECTORS CALIBRATION



S11 kimberlite

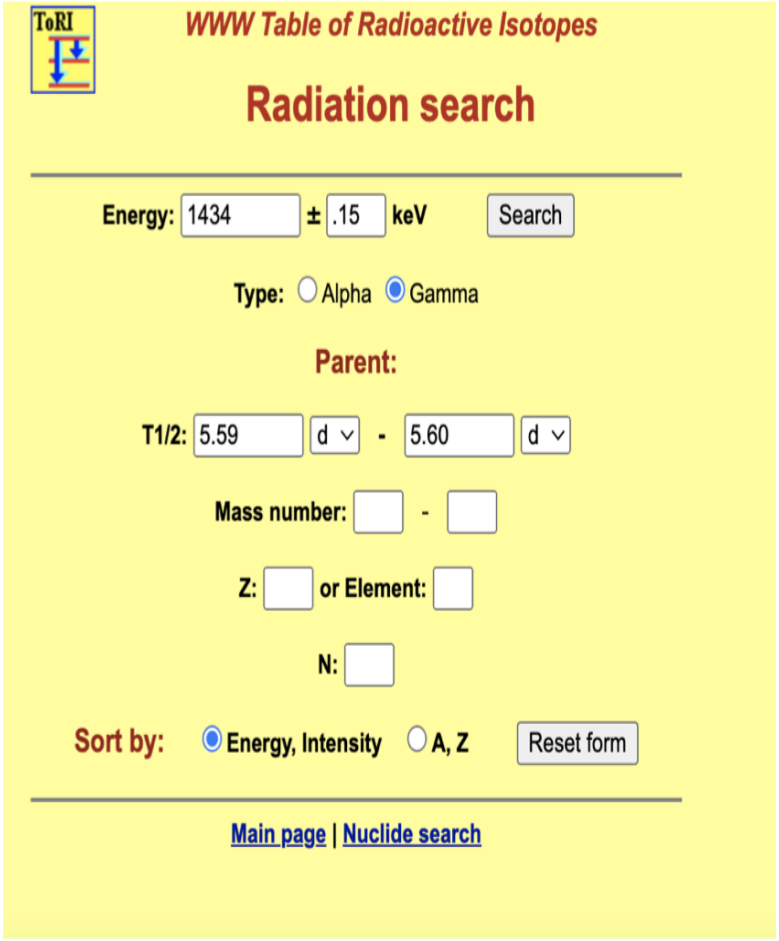


S6 kimberlite

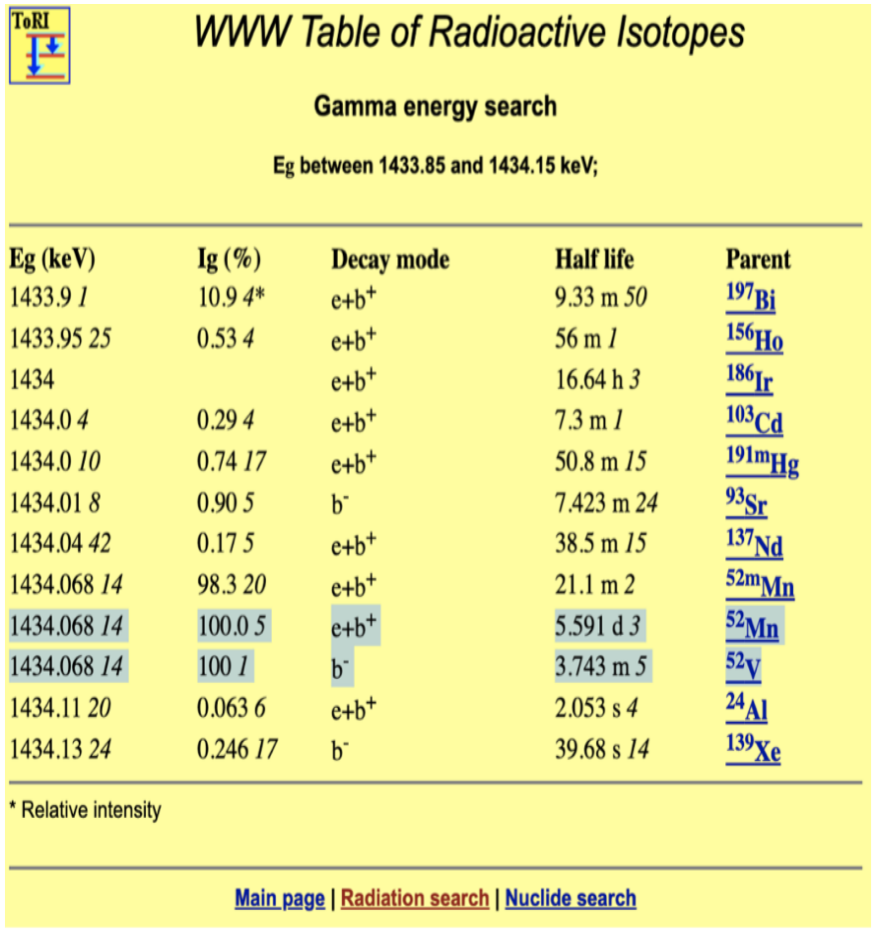
- Europium-152 emits many well-defined gamma lines
- Allows both energy and efficiency calibration with a single source, unlike cobalt-60 and others that needs other isotopes to achieve that.
- It has a longer half-life of 13.5 years

Europium-152 calibration spectrum showing the various energy peaks for different channels for S11 and K6 kimberlite

PEAK IDENTIFICATION



Energy input data



WWW Table of Radioactive Isotopes

Gamma energy search

Eg between 1433.85 and 1434.15 keV;

Eg (keV)	Ig (%)	Decay mode	Half life	Parent
1433.9 *1*	10.9 *4**	e+b+	9.33 m *50*	^{197}Bi
1433.95 *25*	0.53 *4*	e+b+	56 m *1*	^{156}Ho
1434		e+b+	16.64 h *3*	^{186}Ir
1434.0 *4*	0.29 *4*	e+b+	7.3 m *1*	^{103}Cd
1434.0 *10*	0.74 *17*	e+b+	50.8 m *15*	^{191m}Hg
1434.01 *8*	0.90 *5*	b-	7.423 m *24*	^{93}Sr
1434.04 *42*	0.17 *5*	e+b+	38.5 m *15*	^{137}Nd
1434.068 *14*	98.3 *20*	e+b+	21.1 m *2*	^{52m}Mn
1434.068 *14*	100.0 *5*	e+b+	5.591 d *3*	^{52}Mn
1434.068 *14*	100 *1*	b-	3.743 m *5*	^{52}V
1434.11 *20*	0.063 *6*	e+b+	2.053 s *4*	^{24}Al
1434.13 *24*	0.246 *17*	b-	39.68 s *14*	^{139}Xe

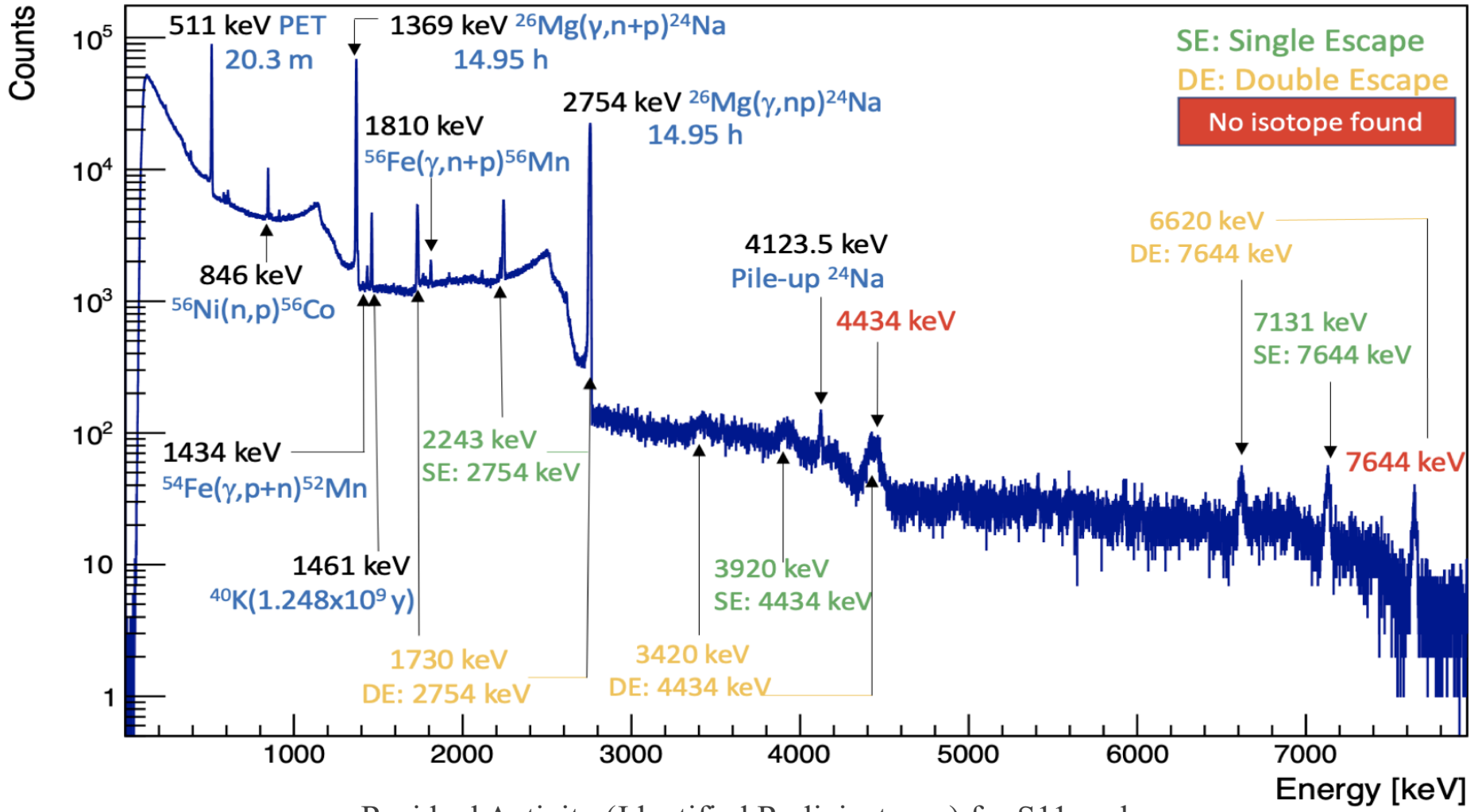
* Relative intensity

Main page | Radiation search | Nuclide search

Nuclide found with high branching ratio (BR%)

- Lund University nuclear database
- Both ^{52}Mn and ^{52}V have higher Ig of 100%
- They have energy of 1434 keV
- The 511 keV PET photon is the signature of positron annihilation, not a nuclear gamma ray. Therefore, it is not listed in the nuclear database nuclear database

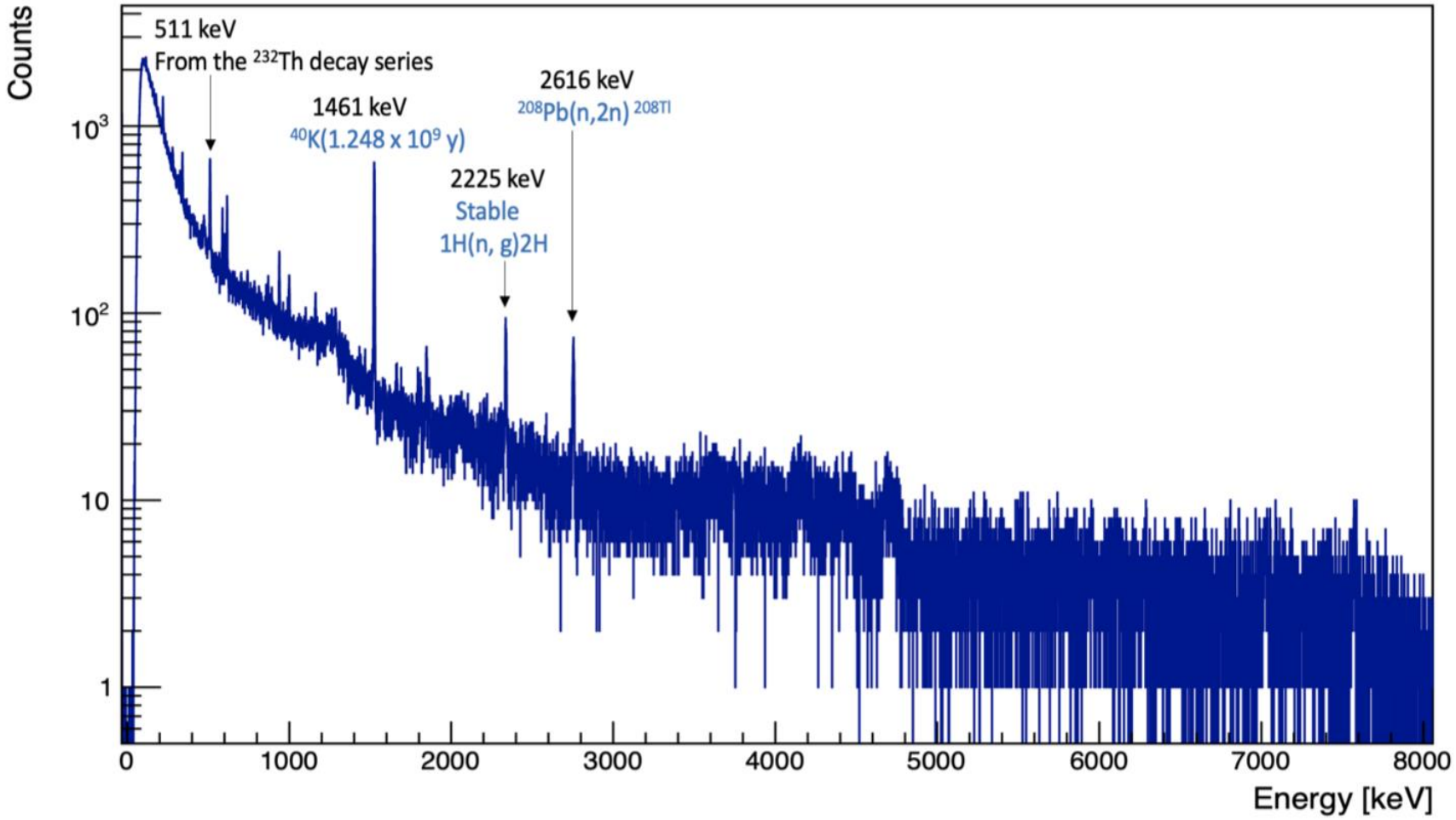
RESULTS: RESIDUAL ACTIVITY



Residual Activity (Identified Radioisotopes) for S11 rock

- 511 keV PET has a half-life of 20.3 min
- The remaining radioisotopes are of radiological concern.
- Short-lived isotopes (^{56}Mn, ^{52}Mn, ^{24}Na, and ^{56}Co-56 which are occupational hazard
- Long-lived isotopes (^{40}K) which is environmental hazard

RESULTS: RESIDUAL ACTIVITY



Residual Activity (Identified Radioisotopes) for K6 rock

- The 511 keV is coming from Thorium decay series
- ^{2}H is stable element

DISCUSSION

S11 kimberlite

- 511 keV PET ,^{56}Mn, ^{52}Mn, ^{24}Na, ^{56}Co, and ^{40}K with half-lives of 20.3 m 2.578 h, 5.591 d, 77.24 d and 1.248 x 10^{9} years respectively.
- 511 keV PET, ^{56}Mn, and ^{24}Na are short-lived radioisotopes.
- ^{40}K is belongs to the long-lived radioisotopes.
- Apart from ^{40}K radioisotope which environmental hazard, the rest of the nuclides are occupational hazard.

K6 kimberlite

- 511 keV observed with shorter peak as compared with S11 rock.
- stable ^{2}H element was seen
- 208TI and ^{40}K were observed in the spectrum.
- 208TI was from the background source from the Aarhus lab

Conclusion

Two kimberlite samples, S11 and K6, have been compared. 40K was observed in both spectra with a half-life of 1.248×10^9 years, which is an environmental hazard, with hydrogen being the only stable isotope in both spectra. The height of the 511 keV PET in the S11 rock was seen to be longer than that of the 511 keV in the K6 rock. This observation shows that the 511 keV, which is the main event for image reconstruction, can only occur in the activated sample at a time of 20.3 minutes, though it is present in unirradiated kimberlite because of supernova processes during the rock formation and constructing an image from it will not give the desired result. Also, radioisotopes of half-lives of minutes, hours and days are of hazardous concern

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Thank you


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