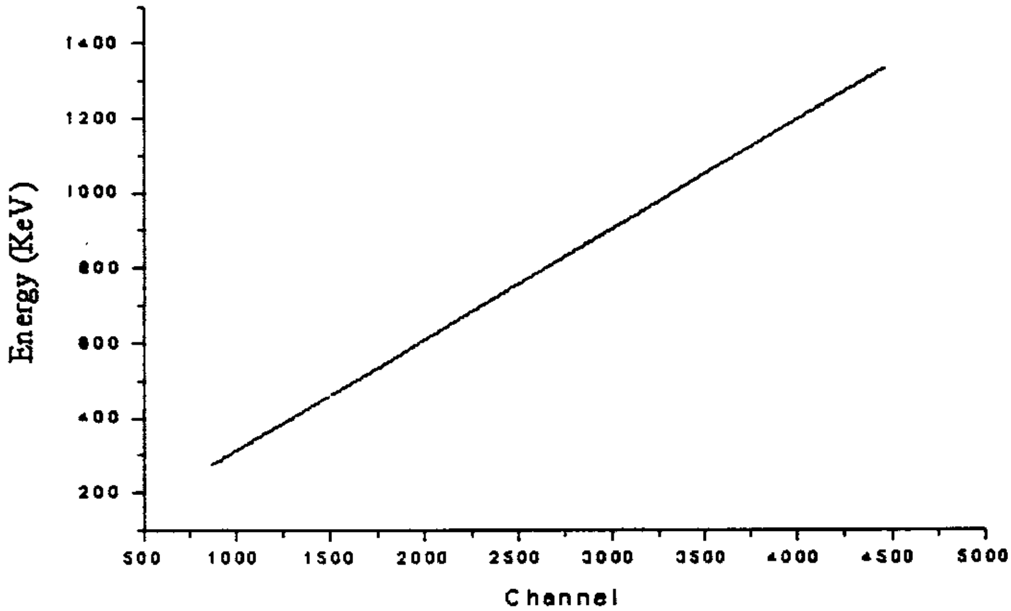

Fig (4-1) Energy calibration curve for HPGe detector

The used reference materials are:

1. IAEA-SOIL-7[41], Trace Elements in Soil, supplied by: Analytical Quality Control Services (AQCS)-Agency's Laboratories, Seibersdorf - International Atomic Energy Agency.
2. Reference Samples NIM[42](National Institute of Metallurgy-South Africa): NIM-D,NIM-G,NIM-L, NIM-N, NIM-P, NIM-M.

Energy of the peaks of the isotopes Co 60, Cs 137 and Ba 133 are used for the energy calibration of the gamma spectra (where the source is located 7 cm far from the surface of the detector). Fig (4-5) shows energy calibration peaks by using Co 60 (2 lines at 173.2 and1332.5), Cs 137 at (661.62) and Ba 133 at (302.84, 356, 383.85 and 276.4) KeV.

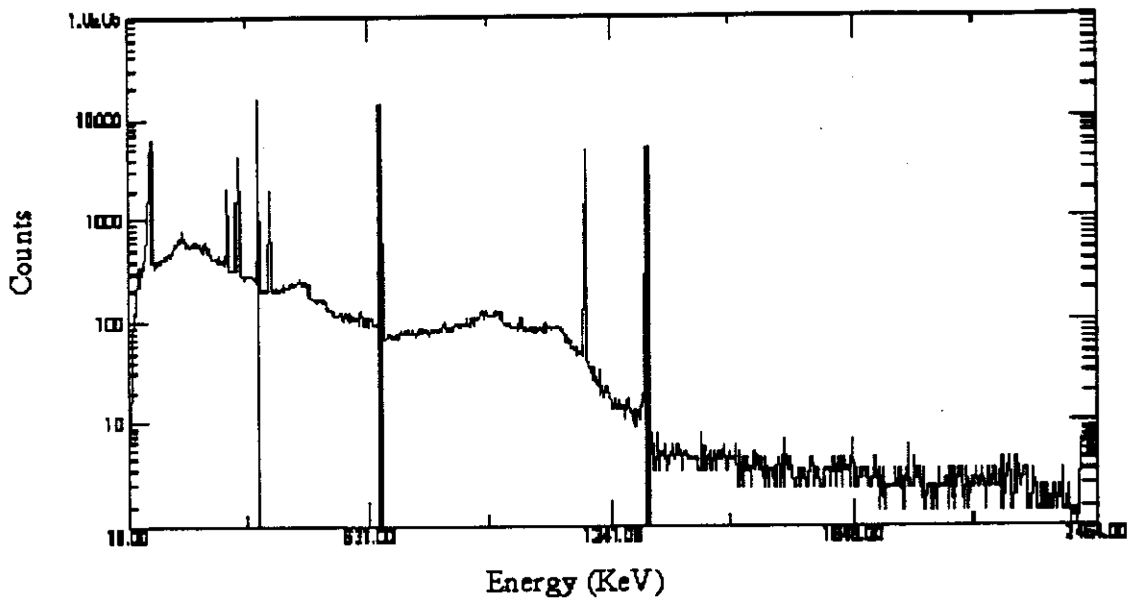

Fig (4-2) Energy Calibration (using Co 60-Cs 137 and Ba 133 isotopes)

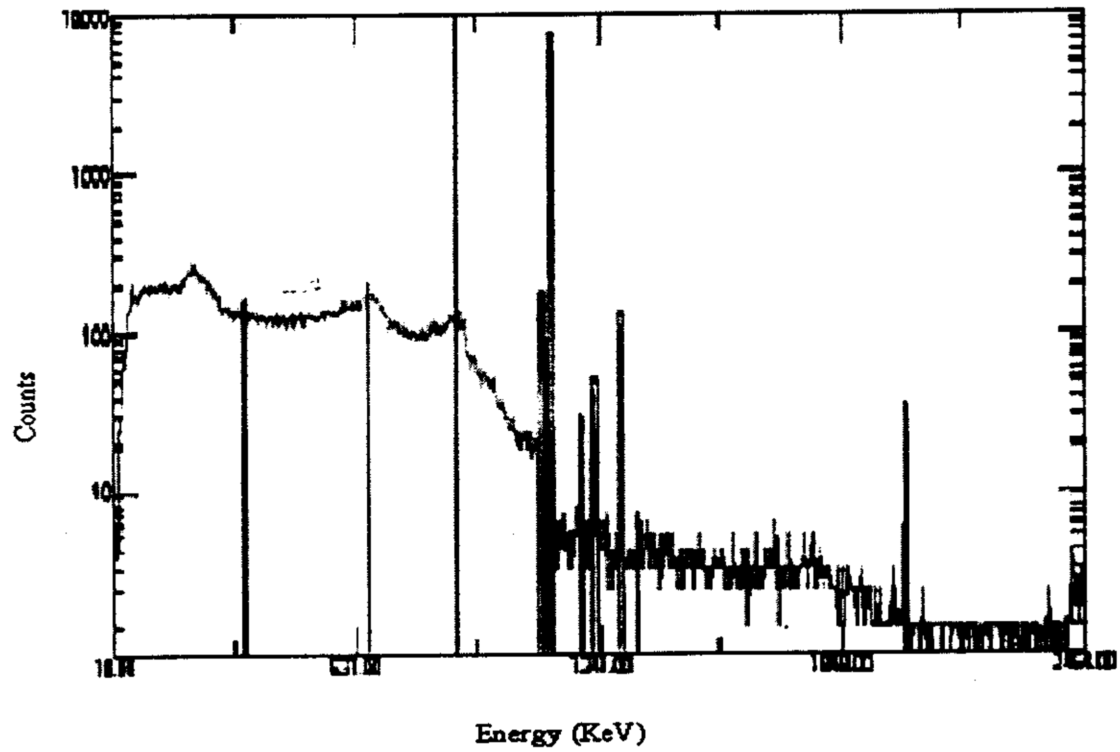

Fig (4-3) Gamma spectrum of neutron long irradiated topaz (Sc-46, Mn-54, Co-60, Cs-134 and Ta-182)

Fig (4-6) Shows gamma spectrum of long irradiated topaz where the sample at 7 cm far from the detector surface. Fig (4-6) shows that neutron irradiated topaz consist of Sc-46(889.25), Mn-54(834.83), Co-60(1332.5and1173.2),Cs-134(604.7and 795.8)and Ta- 182(1121.3,1189.1 and 1221.4) as isotopes producing to residual radioactivity.

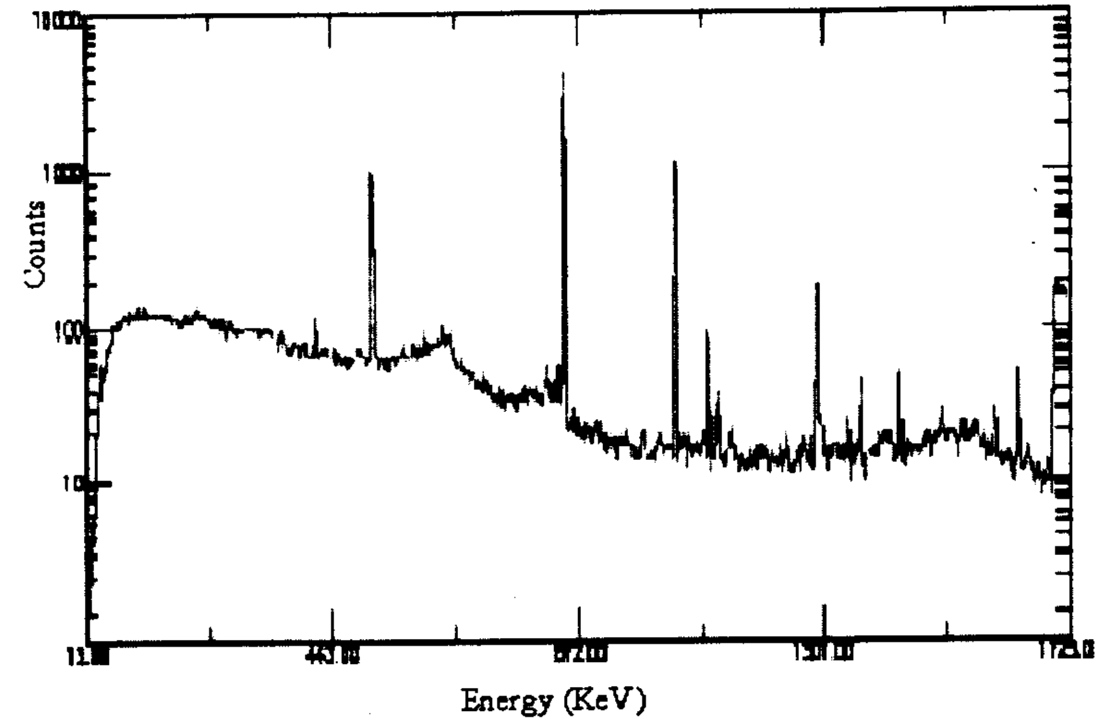

Fig (4-4) Topaz spectrum by Rabbit (pneumatic transport) system

Fig (4-7) Shows gamma spectrum of short irradiated topaz where the detector at 7 cm from the sample surface. Fig(4-7) shows that neutron irradiated topaz contains many isotopes with short half-life as trace element by short irradiation using pneumatic system.

Qualitative and quantitative studies by NAA technique for topaz samples removed from irradiation box during the same day, showed the following short life isotopes:

Al-28, CL-38, Rh-106M, Kr-88, Bi-214, Rb-89, Ac-228 and As-76.

And their specific activities are:

736345.91, 1.5, 10.6, 22.4, 91.4, 11.4, 153.5 and 41.7 (Bq/g) for each isotope, respectively. Activities of these isotopes vanish during days as presented in table (4-4).

Table (4-4) NAA for short irradiation of topaz for 30 sec (Pneumatic Rabbit Transport System)

Isotope	Element Name	T ½ (Half-Life)	Energy (KeV)	Intensity /100 Decay (Branching Ratio)
Al-28	Aluminium	2.24 m	1778.9	100%
Na-24	Sodium	15.03 hr.	1368.55	100%
CL-38	Chlorine	37.30m	2167.50 . 1642.40	44% 32.8%
Rh-106M	Rhodium	2.200 hr.	511.80 1045.7	86.4% 29.76%
Kr-87	Krypton	76.3m	402.58 845.43	49.50% 7.28%
Ti-208	Thallium	3.053m	583.14 860.37	84.23% 12.46%
Sb-122	Antimony	2.7 d	563.93 692.80	70.65% 03.74%
Na-24	Sodium	15.03 hr.	1368.55 2754.10	100% 99.85%

Table (4-4) shows that the isotopes with short half-life as Al-28(2.24m) and Na-24(15.03 hr) could be detected by the pneumatic transport - rabbit system. Inspection of table (4-4) shows that the major elements in topaz have short life time. Therefore, topaz is preferred in the gem stone industry to be used as an industrial product from the reactor.

Table (4-5)-Detected Elements in topaz after long irradiation using NAA technique

Isotope	Element Name	T ½ (Half-Life)	Energy (KeV)	Intensity /100 Decay (Branching Ratio)
Sc-46	Scandium	83.85 d	889.26 1120.52	99.9800% 99.9900%
Mn-54	Manganese	312.7 d	834.83	99.97%
Co-60	Cobalt	5.271 y	1332.5 1173.2	100% 100%
Co-58	Cobalt	70.8 d	810.76 511.00	99.43% 29.86%
Cs-134	Cesium	2.062 y	604.7 795.84	97.6% 85.4%
Ta-182	Tantalum	114.740d	67.75 1121.28	41.3% 35%
Fe-59	Iron	44.630d	1099.22 1291.56	56.5% 43.2%
Ag-110 m	Silver	249.85 d	657.75 884.67	94.39% 72.58%

Table (4-5) shows the complementary part of the previous short irradiation gamma spectrum where the previous isotopes with short half-life times disappeared and the isotopes with long half-life times such as Sc-46 (83.85d) and Ta-182 (114.74 d) started to appear.

From qualitative and quantitative studies after 22 days from irradiation, it is found that neutron irradiated topaz produce the following radioactive isotopes: Sc-46, Mn-54, Co-60, Cs-134 and Ta-182. They have radioactivity between 0.07 and 71.7 nCi/gram for each element.

Their are different methods of calculations of the elemental concentrations as obtained from NAA technique as in the following:

4.2.1. Comparator method [43, 44]

The basic formula is $m = A.\{\kappa\, e^{-\lambda t_d} (1- e^{-\lambda t_i}) (1- e^{-\lambda t_c})\}^{-1}$ (4-1)

Where:

$K = z\, \theta\, N_A\, \sigma\, \Phi\, M / \lambda$,

A = Net peak area,

a = Abundance of the activated nuclide,

m = sample weight,

M=Atomic weight of the irradiated element,

$\lambda = \ln 2/ t_{1/2} = 0.693/ t_{1/2}$,

Z=Detector efficiency,

θ =Branching ratio=inensity/100 decay,

σ = Isotopic activation cross section,

N_A= Avogadro's number= 6.023×10^{23},

And t_i ,t_d and t_c are the times of irradiation ,decay and counting respectively.