JOINT INSTITUTE FOR NUCLEAR RESEARCH

Frank laboratory of Neutron Physics

Sector of Neutron Activation Analysis and Applied Research

FINAL REPORT ON THE

SUMMER STUDENT PROGRAM

Air Pollution studies by the Moss biomonitoring, Neutron Activation Analysis and Related Analytical Techniques

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Contents:

Air Pollution studies by the Moss biomonitoring, Neutron Activation Analysis and Related Analytical Techniques

Abstract:

Concerning of levels of public health, monitoring of atmospheric deposition has become necessary. Biomonitoring provides information about the pollutants and their concentrations in the atmosphere when biological samples are analyzed using a specific technique.

Neutron Activation Analysis is a powerful nuclear technique for determination of elements and elemental composition of the material. In this overview, it can be used for analyzing organisms and biological samples like moss to obtain information about the concentrations of some elements in the sample, which in turn will give an indication of pollution level and ecological situation assessment of the environment.

This present report gives an overview on biomonitoring of atmospheric deposition using mosses and a discussion of the main steps in the process.

1. Introduction:

Neutron Activation Analysis was first developed by G. Hevesy and H. Levi in 1936. They used Ra-226 and Be as a neutron source and an ionization chamber. They promptly noticed that the element Dy (dysprosium) in the sample became highly radioactive after exposure to the neutron source. So, They suggested using this nuclear reaction to determine the elemental composition of unknown samples by measuring the induced radioactivity.

Although many analytical techniques are developed , NAA is maintained as a powerful technique because it’s fast, simple, selective, sensitive, and accurate. It’s a useful technique for performing both qualitative and quantitative multi-elemental analysis. NAA can be used as a reference for other analytical techniques. It’s now possible to measure a vast amount of elemental constituents in any environmental sample by Instrumental Neutron Activation Analysis (INAA) which isa nondestructive multi-element analysis technique.

Neutron Activation Analysis depends on activating the nucleus and converting it from a stable nucleus into a radioactive one by bombarding it with a neutron and then detecting and identifying the radiation emitted by the radioactive nucleus. This allows precise identification of elements as the radioactive decay paths are well known for each element.. NAA can detect up to 74 elements. The report is an attempt to, go deeper and discuss NAA and biomonitoring in details. .

2. Theoretical concepts

2.1. Physical concepts of Neutron Activation Analysis :

Neutrons were first discovered by J. Chadwick in 1932 and the Neutron Activation was discovered by G. Hevsey and H. Levi in 1936 as mentioned in the introduction.. It's based on measuring the characteristic gamma energies from the formed radionuclides as a result of bombarding stable ones with neutrons.

To perform analysis of a sample, the sample is bombarded (irradiated) by neutrons from neutron source,in the present report it is a IBR-2 reactor, FLNP –JINR -Dubna. The neutron is captured in a nucleus, which has a good cross section to neutrons, a compound nucleus is formed. This compound nucleus de-excites emitting one or more prompt gamma rays that can be used in PGNAA technique and the nucleus becomes radioactive. This radioactive nucleus decays emitting a negative beta and delayed gamma emission (one or more gamma rays). This delayed gamma ray is the radiation of interest in our study DGNAA. This happens through the nuclear reaction (n,γ).

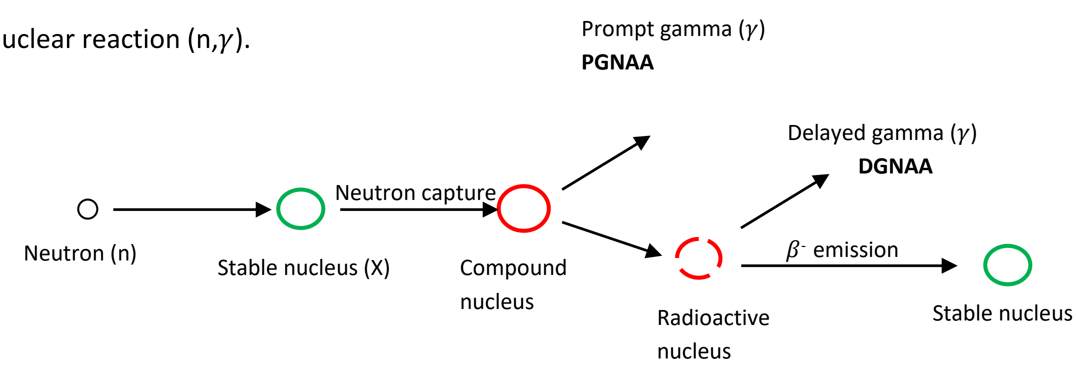

Fig.(2.1.) scheme of neutron activation analysis principle

The energy of gamma is specific for the nucleus and it can be measured by high resolution semiconductor detector.

$${}^{1}_{0}n + {}^{A}_{Z}X \longrightarrow ({}^{A+1}_{Z}X)^{*}$$

$$({}^{A+1}_{Z}X)^{*} \longrightarrow {}^{0}_{0}\gamma + {}^{A+1}_{Z}X$$

If the productive nucleus is radioactive, the nuclear transformation follows first order kinetic reaction:

$$A_t = A_0\, e^{-\lambda t}$$

where

A_t =Activity after time t

A_0 = initial activity

λ= Decay constant and it's equal to ln(2) / T , where T is the half life time.

2.1.1. Prompt and delayed Gamma neutron Activation Analysis (PGNAA and DGNAA)

Prompt gamma neutron activation analysis(PGNAA) employs the prompt gamma emitted after irradiation. The PGNAA technique is most applicable to elements with extremely high neutron capture cross-sections (B, Cd, Sm, and Gd); elements which decay too rapidly to be measured by DGNAA.

Delayed gamma neutron activation analysis (DGNAA) employs with the majority of elements that produce radioactive nuclides. The technique is flexible with respect to time such that the sensitivity for a long-lived radionuclide that interferes with a shorter-lived radionuclide can be improved by waiting for the short-lived radionuclide to decay. This selectivity is a key advantage of DGNAA over other analytical methods. DGNAA is our interest in this study.

2.1.2. Instrumental Neutron Activation Analysis:

. With the use of automated sample changer, HPGe detectors, and computerized data processing, it is generally possible to simultaneously measure more than thirty elements in most sample types without chemical processing. The application of purely instrumental procedures is commonly called instrumental neutron activation analysis (INAA). INAA using Ge-detector is a useful tool in determining large number of elements in water, soil, and vegetation. INAA is a non-destructive method although under certain conditions some material damage may occur.The technique used here in REGATA is INAA using epithermal neutrons. Using epithermal neutrons in the technique improve detection limits by INAA, e.g., for As, Br, Rb, Sr, Cd, Sb, I, Tb, Hf, Ta, Th, and U , reduce high matrix activity , and reduce fission product interference from ^{235}U fission

2.2. Biomonitoring:

2.2.1. What's Biomonitoring?

Biomonitoring is a simple method to estimate the atmospheric pollution at a certain area using living organisms. It's based on the capability of some living organisms to detect toxic substances in the atmosphere. The main purpose of using biomonitoring is to detect elements that can be detected by more expensive techniques. We can use plants to monitor atmosphere. When plants are exposed to air pollution, they will exhibit different symptoms. Damage symptoms give an indication to types, concentrations, and contacting time of pollutants. Compared with traditional monitoring method, monitoring using plants is an economic, simple and reliable method.

Living organisms that are used in biomonitoring air pollution can be bioindicator, bioaccumulator, or both. First, bioaccumulator can accumulate substances from the atmosphere with a possibly linear correlation between concentrations of contaminants in environment and the living organism. Second , Bioindicator is sensitive to contamination that can produce an estimate of air quality in the area concerned. The good bioindicator should have long life cycle, known sensitivity to specific pollutants, and broad distribution in area concerned. Thetwo strategies may be regarded as complementary, can generate data on pollution and ensure effective integrated biomonitoring.

Bryophytes, which include mosses, are among the organisms most frequently used as bioaccumulators.

2.2.2. Biomonitoring using Moss:

The biomonitoring using moss allows simultaneous monitoring of large number of contaminants within the same sample. Biomonitoring using moss is simple, reliable, cost effective, doesn't need electricity, inexpensive, and can promote a good performing. Moss is a type of bryophyte, which is a group of non-vascular. That's why They grow low and flat along the ground. Unlike other plants, mosses can grow in rocks and areas with poor quality soil. moss has very shallow roots, just enough to hold on to the bare rock it lives on. Mosses grow in moist shady places.

The reason why mosses are used in biomonitoring is that it has high capacity to intercept and accumulate most of the airborne elements compared to other living organisms. They obtain nutrients from both wet and dry depositions. Mosses have a large surface to weight ratio that impresses absorption. Moss has no real roots and it receives the nutrient from the atmosphere. Contaminants are therefore absorbed through the surface of their leaves. Therefore, there is a close correlation between the concentration of these substances in the plant and atmospheric deposition.

There're 2 types of Moss biomonitoring: active moss biomonitoring and passive moss biomonitoring.

1- Passive Moss Biomonitoring:
   It's where the native species of moss are used in the area under study. The process of study involves 2 major steps: collecting moss and analysis. Moss samples are collected from the site of interest. In the laboratory, the samples should be carefully cleaned from all dead material and attached litter, then only green and green-brown moss upper parts from the two–three last years were analyzed by Instrumental Neutron Activation Analysis (INAA) to obtain results about the level of pollution in the sampling site.
2- Active Moss Biomonitoring:
   In the areas where there's no moss like urban areas. The active moss biomonitoring is also called "moss bag technique". The process involves many steps: collection of moss species from unpolluted area then cleaned and packed in nylon net bags then

transplanted in the area of study to be exposed to atmosphere. Then after time of exposure the moss bags should be analyzed using INAA to know the accumulation of atmospheric pollutants in the moss. The moss bag technique can be performed by dry or wet moss bags. The detailed sample preparation steps will be discussed later in the experimental work section.

There're several moss species. in this research , we're interested in *Sphagnum girensohnii* moss.

3. Experimental work

3.1. Experimental Setup:

Neutron Activation Analysis is not a "Push – button" device, therefore, , there are some essentials should be compiled neutron source which is the IBR-2 reactor and gamma detection system. The full description of the used station of REGATA is given elsewhere[1]

3.1.1. Neutron Source (IBR-2 reactor)

The used neutron source is the IBR-2 reactor because of its high fluxes of neutrons from fission givesthe highest available sensitivities for most elements. The pulsed fast reactor IBR-2 provides thermal, epithermal, and fast neutrons for activation. As shown in Figure (3.1.), the IBR-2 provides wide neutron spectrum for activation.

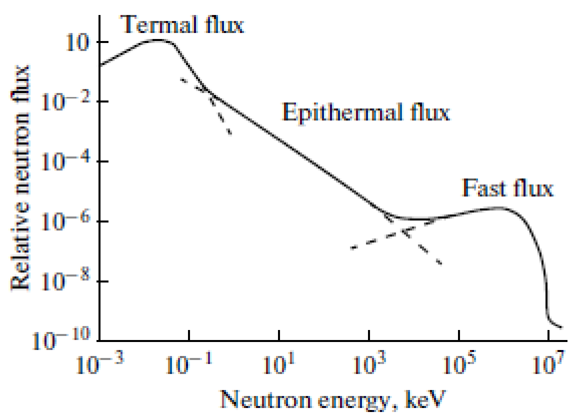

Fig. (3.1.) neutron spectrum of the nuclear reactor

The neutron spectrum contains Thermal, epithermal, and fast neutrons. Thermal neutrons (90-95% of the total flux) are low energy neutrons (below 0.5 eV). The energy spectrum of thermal neutrons at room temperature is described well by Maxwell Boltzman with a mean energy 0.025 eV.

Epithermal neutrons (2% of the total flux)have energies from 0.5 eV to 0.5 MeV. A cadmium foil of 1mm thick can absorb thermal neutrons and allow only epithermal and fast neutrons above 0.5 eVto pass (energies above the cut-off of Cd can pass). Both thermal and epithermal neutrons undergo (n,γ) reactions with target nuclei. NAA technique employs only epithermal neutrons to induce (n,γ) reactions by irradiating the samples being analyzed inside either cadmium shield is called epithermal neutron activation analysis (ENAA). ENAA is the used here in REGATA setup (FLNP, JINR).Fast Neutrons (5% of the total flux) are neurons of energy above 0.5 MeV. Fast neutrons contribute very little in (n,γ) reactions. But instead they undergo other reactions like (n,n) and (n,p). NAA technique that employ fast neutrons releasing nuclear particles is called Fast Neutron Activation Analysis (FNAA).

3.1.2. The Experimental setup for INAA (REGATA):

The Experimental setup Consists of four irradiation channels, the pneumatic transport system (PTS) which transports containers by compressed air (at 3-6 atm. pressure), and four gamma detectors. Ch1 and Ch2 are connected to the pneumatic system and cooled by air. Ch3 and ch4 are cooled by water so, their temperature is less than ch1 and ch2. Ch1 is coated by Cadmium to prevent thermal neutrons and allow only epithermal and fast neutrons

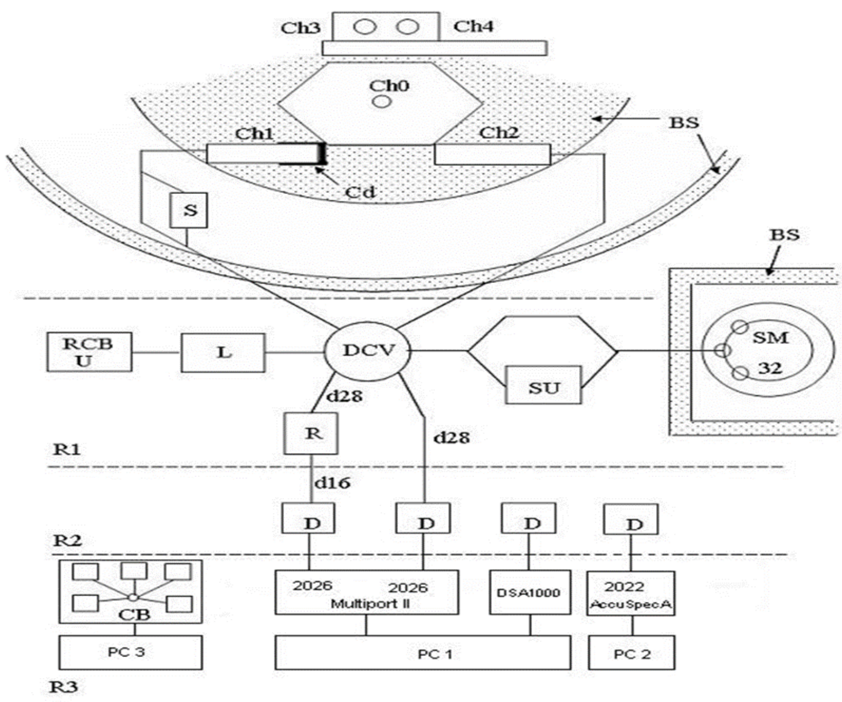

Fig.(3.2.) The REGATA setup : Ch1-Ch4 -irradiation channels, S- intermediate storage, DCV- directional control valves, L-loading unit, U- unloading unit, SU- separate unit, SM- storage magazine, R- repacking unit, D- HPGe detector, AA- amplitude analyzer, CB- control board

PTS has loading (L) and unloading (U) units to load and to extract containers from the system. To provide safety, the unloading unit is placed into a glove box. All devices of the pneumatic system are equipped with photosensors and end-switches to indicate the container position in the system and to correct operation of all mechanisms.

3.2. Moss Sampling and Sample Preparation:

3.2.1. Passive biomonitoring:

Samples are collected from the site of study then cleaned from soil and only green parts are taken then washed and dried in the laboratory. The moss samples are prepared to be sent to the reactor for irradiation. From each sampling site, 2 samples were made into bills and put in polyethylene bag for short lived measurements and in Aluminum cups for long lived isotopes and then labeled with a number. Now, the samples are ready for irradiation.

3.2.2. Active biomonitoring:

Moss samples should be collected from non-polluted place and should be at least 300 meters away from the nearest high way or industrial settlement and at least 100 meters away from any road or single house. At each sampling site 5 to 10 samples should be taken. Theses collected samples are taken to the laboratory and the green parts of the plant are separated and carefully cleaned. These parts are washed with distilled water and left to be air-dried.

Some grams of moss should be packed in nylon mesh bags (fig.3.3)of fixed dimensions to be exposed to the atmosphere. Some bags are kept in the laboratory to be irradiated and analyzed to determine initial concentrations of elements in our sample and be used to determine the relative accumulation factor.

Fig. (3.3.) Dry Moss bag

4. Irradiation and sample analysis

4.1. Sample preparation for irradiation:

First, we have some unexposed moss samples that are used as references to determine only the elements coming from atmospheric deposition. It will enable us to determine the Relative Accumulation Factor (RAF). After being exposed to the atmosphere, moss bags are collected and taken to the chemistry laboratory to be mainly homogenized and dried in oven at 40°Cand then about 3 grams of treated moss are made into a bill, weighted with and without the cover and the weight is recorded on the computer. The bill is wrapped by polyethylene bag in case of short-lived measurements and in Aluminum cup in case of long lived measurements.

Fig.(4.1)samples ready for irradiation

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4.2. Irradiation atIBR-2 FLNP, JINR:

The wrapped bills are put in capsules (Transport containers) that will be sent by the pneumatic transport system to the reactor core for irradiation. Pneumatic transport system (PTS) which tubes are about 50–60 m long take 3-20 s to deliver the capsules to the reactor core. Transport containers of polyethylene and aluminum are used to deliver samples to the irradiation position and back. Polyethylene transport capsules are used in case of short lived measurements, while aluminum capsules are used for long lived measurements. A total of3 or 4 samples are put together in the same capsule to be irradiated simultaneously. Loading and unloading of capsules are done automatically.

For long-lived measurements, Channel Ch1 is used for determination of long-lived isotopes. Samples are irradiated for 3–5 days, repacked, and measured two times after delay for 4 and 15–20 days. The measurement time varies from 1.5 to 10 h.
for short-lived isotopes (Mg, Al, Cl, Ca, V, Mn, I), Ch2 is used for the determination. Samples are irradiated for 3 min and measured two times for 5–8 min after three to five delays and for 20 min after 20 min delay. To handle highly active samples, the REGATA PTS is equipped with three

hot chambers, one of which is connected through the lock with the unit for unloading of irradiated samples. Elements with a short (seconds) half-life are determined by cyclic NAA with the possibility of automatic transportation of the irradiated sample to the detector through a pneumatic transport system.

If the sample after irradiation is too hot, we can remotely control it through lead shielded glass

Fig.(4.2.) The Control room in the irradiation unit

Fig.(4.3) treating with the irradiated sample

4.3. Analysis using Genie2K:

4.3.1. Spectrum from Genie 2k

Fig. (4.1. A) Screenshot of the Spectrum

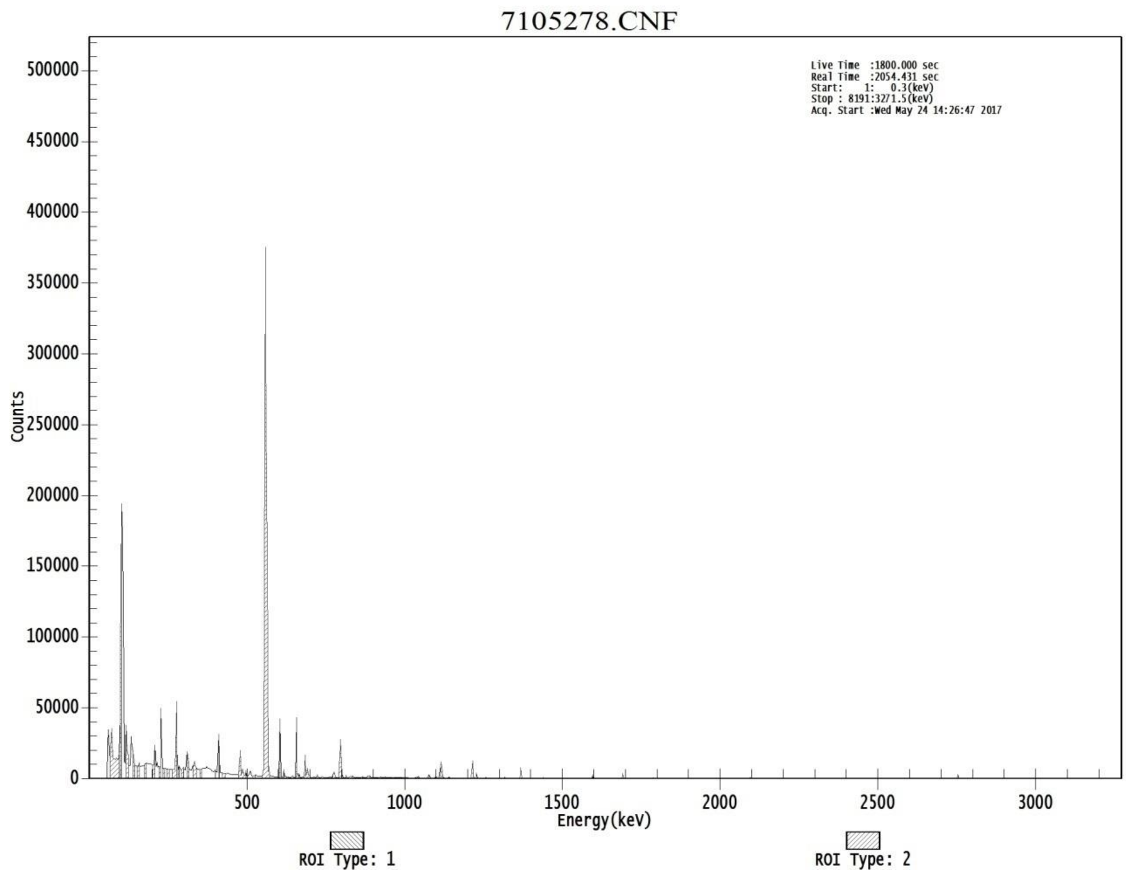


Fig. (4.1. B) The spectrum data plot

4.3.2. Calibration:

Energy calibration:

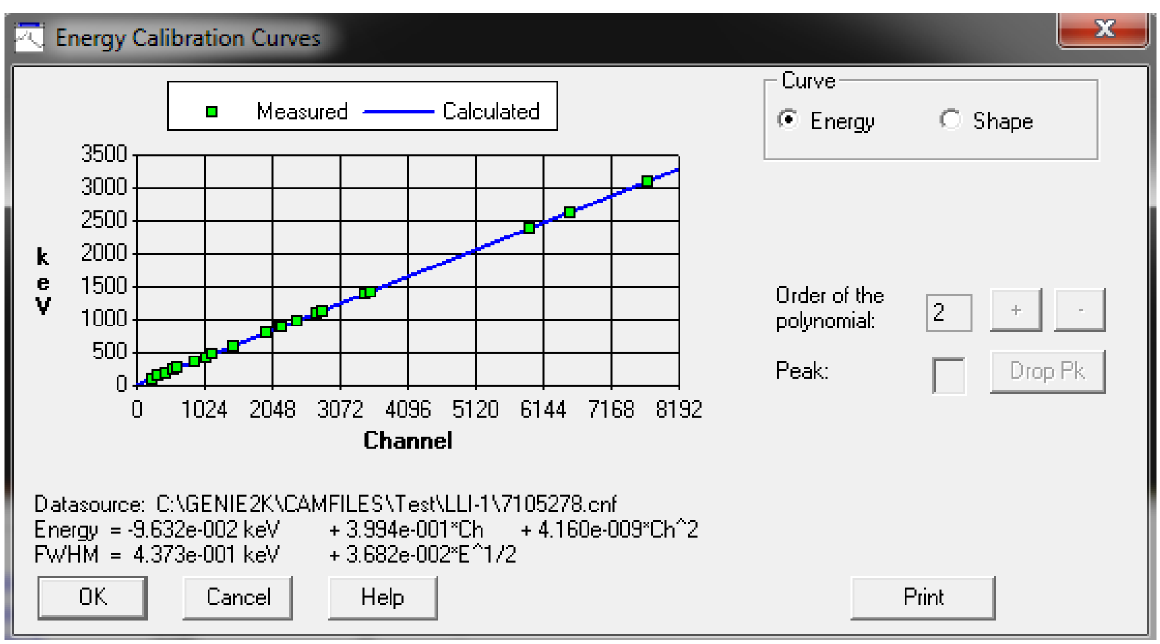


Fig. (4.2. A) Energy calibration

Efficiency calibration curve :

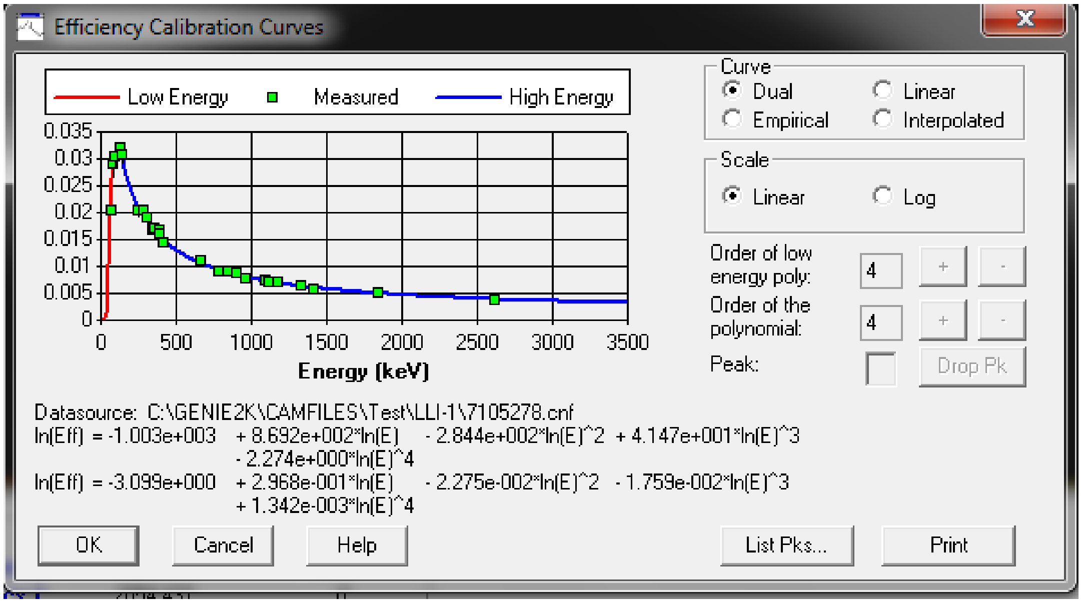


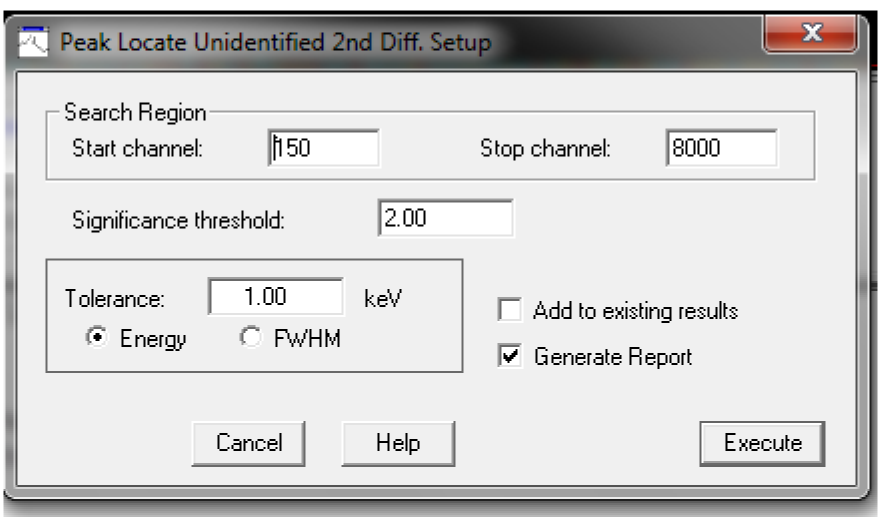
Fig. (4.2. B) Efficiency calibration

4.3.3. Analyzing The Spectrum:

```
*************************************************************************
*****        G A M M A   S P E C T R U M   A N A L Y S I S        *****
*************************************************************************

Filename: C:\GENIE2K\CAMFILES\Test\LLI-1\7105278.cnf

Report Generated On             : 05/11/2017 06:02:59 ,

Sample Title                    : 2710-4
Sample Description              : Vergel_K.N.
Sample Identification           : s-2710-03-29
Sample Type                     : LLI-1
Sample Geometry                 : 5

Peak Locate Threshold           :  3.00
Peak Locate Range (in channels) :   150 -  8000
Peak Area Range (in channels)   :   150 -  8000
Identification Energy Tolerance :    2.000 keV

Sample Size                     :  8.210E-002 gram

Sample Taken On                 : 19/05/2017 11:22:00 ص
Acquisition Started             : 24/05/2017 02:26:47 ,

Live Time                       :      1800.0 seconds
Real Time                       :      2054.4 seconds

Dead Time                       :  12.38 %

              Energy Calibration Used Done On       : 16/05/2017
              Efficiency Calibration Used Done On   : 05/10/2016
              Efficiency ID                         : D7-H5

♀Interference Corrected Activity Report    05/11/2017 06:02:59 ,    Page  2
```

A. Peak Locate

In this section we choose the taken part from the whole spectrum by adjusting Start channel and stop channel and it will calculate all peaks between the 2 channels.

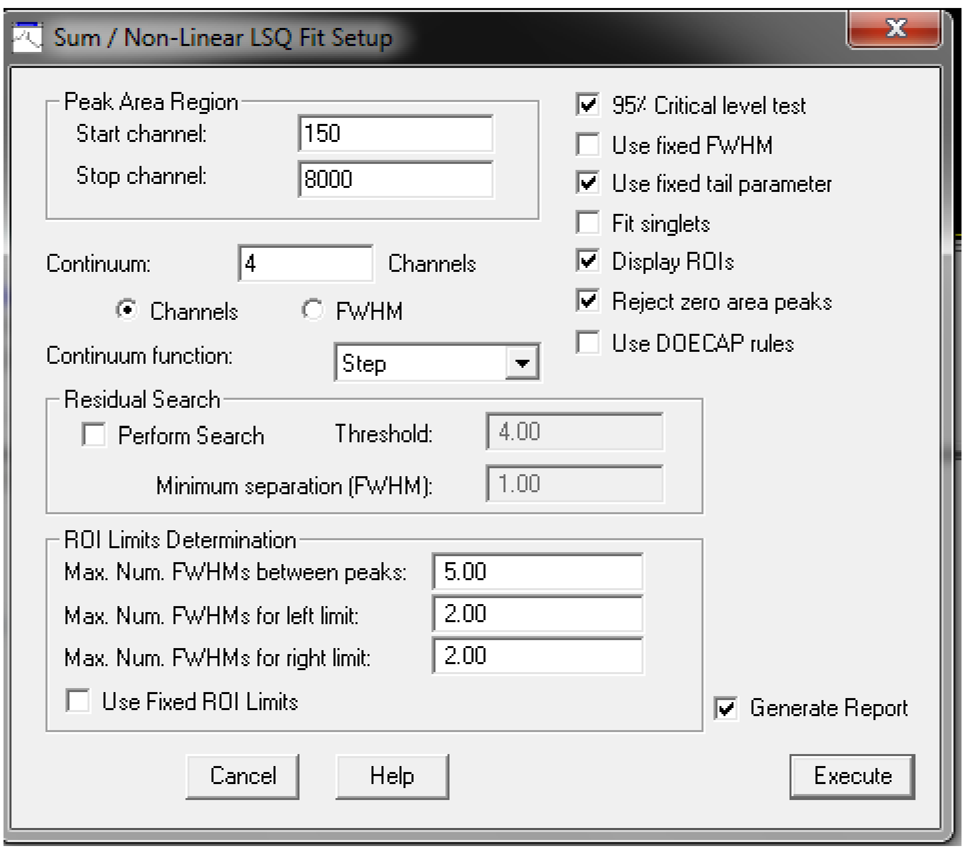


The output report:

```
***************************************************************************
*****             P E A K   L O C A T E   R E P O R T                *****
***************************************************************************

     Detector Name:   D7
     Sample Title:    2710-4
               Peak Locate Performed on:   05/11/2017 10:31:33
               Peak Locate From Channel:     150
               Peak Locate To Channel:      8000
               Peak Search Sensitivity:      2.00

     Peak    Centroid     Centroid      Energy       Peak
      No.     Channel    Uncertainty     (keV)     Significance

       1      153.62       0.1144        61.26        47.08
       2      169.93       0.2838        67.77        11.53
       3      174.56       0.1294        69.62        33.15
       4      180.61       0.1123        72.04        48.47
```

B. Peak area

The area under the peak



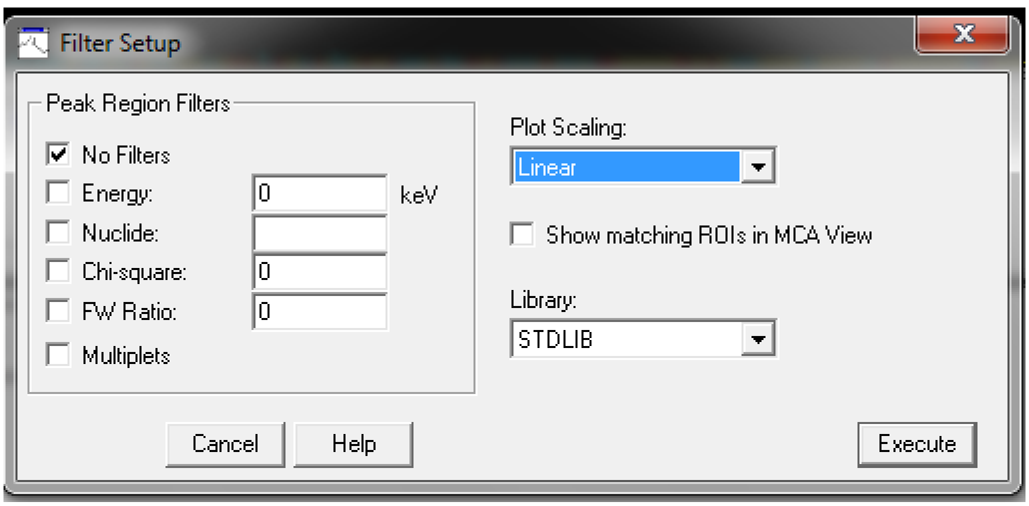
The output report :

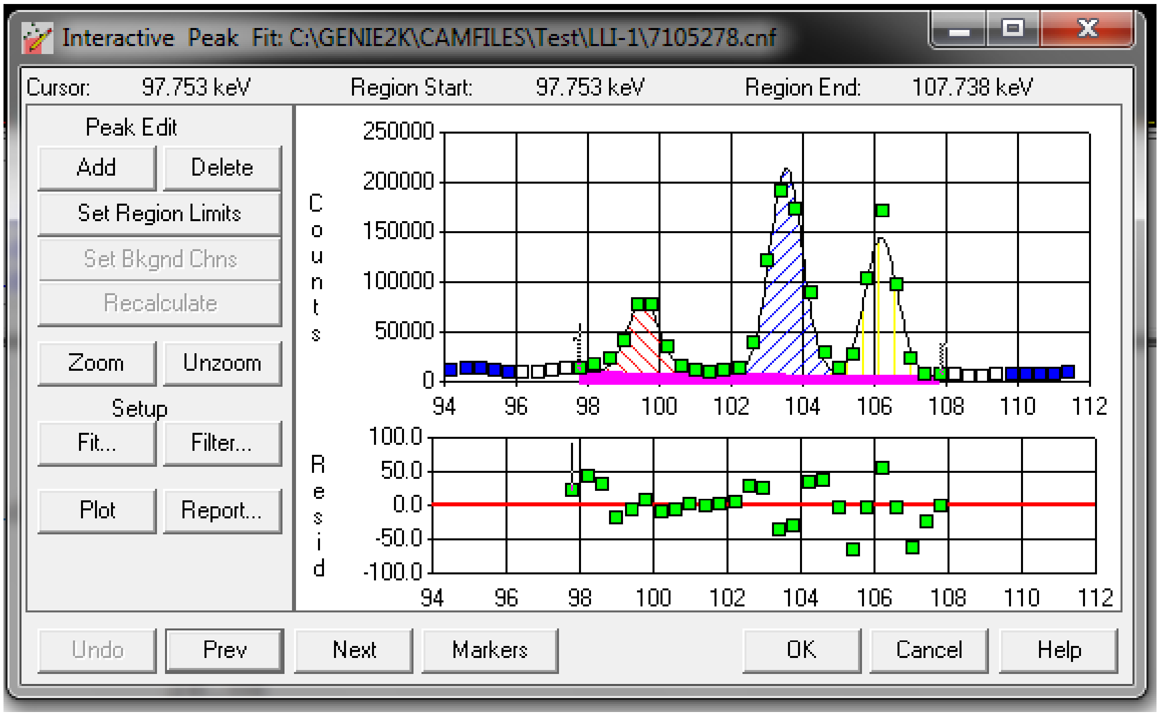
```
*****************************************************************************
*****           P E A K   A N A L Y S I S   R E P O R T               *****
*****************************************************************************

     Detector Name:   D7
     Sample Title:    2710-4
     Peak Analysis Performed on:   05/11/2017 10:36:43 م
               Peak Analysis From Channel:    150
               Peak Analysis To Channel:      8000
```

	Peak No.	ROI start	ROI end	Peak centroid	Energy (keV)	FWHM (keV)	Net Peak Area	Net Area Uncert.	Continuum Counts
	1	149-	157	153.62	61.26	1.07	1.08E+005	544.29	8.35E+004
M	2	166-	241	170.07	67.83	0.98	6.48E+003	260.59	9.11E+004
m	3	166-	241	174.42	69.57	0.99	3.19E+004	1275.23	1.05E+005
m	4	166-	241	180.56	72.02	0.99	3.71E+004	1481.33	1.10E+005
m	5	166-	241	188.40	75.15	1.00	4.47E+003	180.98	1.15E+005

C. Interactive peak fit

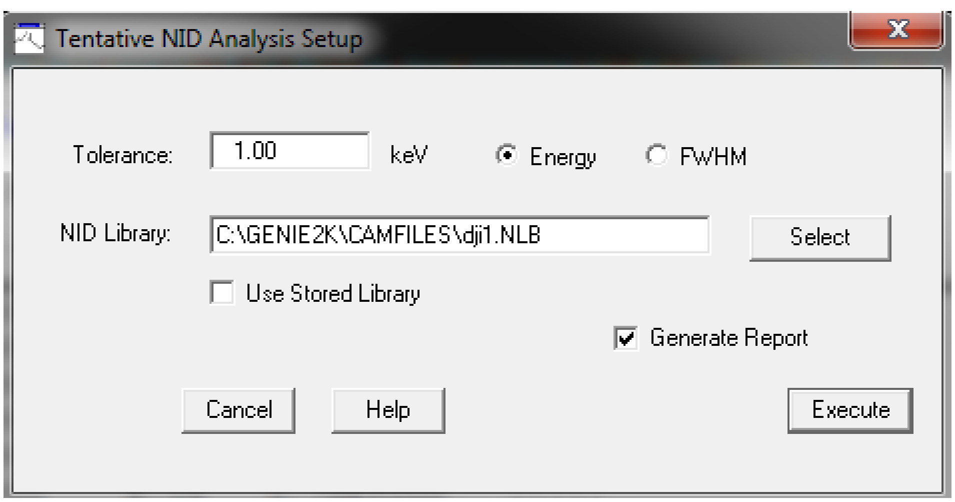
This choice allows us to edit our peaks by adding or deleting some row that we suspect





D. Nuclide Identification :

- **NID Nuclide Identification**



Nuclide identification report:

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*****************************************************************************
*****   N U C L I D E   I D E N T I F I C A T I O N   R E P O R T   *****
*****************************************************************************
     Sample Title:          2710-4
     Nuclide Library Used: C:\GENIE2K\CAMFILES\dji1.NLB
   ....................     IDENTIFIED NUCLIDES     ....................
```

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/gram)	Activity Uncertainty
NA-24	0.705	1368.55*	100.00	3.41127E+002	6.87465E+000
		2754.05*	99.94	2.97689E+002	1.45824E+001
K-42	0.593	312.35* @	0.35	1.11527E+005	8.02971E+003
		1524.58*	18.80	1.31142E+002	1.03917E+001
MN-54	0.996	834.83*	99.98	1.52104E+001	3.76071E-001
FE-59	0.881	142.65 @	1.02		
		192.35 @	3.08		
		334.80* @	0.27	1.51341E+003	6.58406E+001
		1099.25*	56.50	4.63519E+000	1.63381E-001
		1291.60* @	43.20	4.74975E+000	1.77194E-001
ZN-65	1.000	1115.55*	50.70	2.49012E+002	3.94141E+000
ZN-69m	0.670	438.63*	94.77	1.78659E+001	1.21235E+000
GA-72	0.315	336.63* @	0.11	3.10955E+004	1.34864E+003
		600.95 @	5.54		
		629.96	24.80		
		786.44 @	3.20		
		810.20* @	2.01	2.06121E+002	3.07650E+001
		834.03* @	95.63	5.65075E+001	1.41862E+000
		894.25 @	9.88		
		924.22* @	0.14	1.15430E+004	7.17158E+002
		999.86 @	0.80		
		1050.69 @	6.91		
		1215.15 @	0.79		
		1230.86 @	1.45		
		1260.10 @	1.13		
		1276.76 @	1.57		
		1464.00 @	3.55		
		1596.68* @	4.24	5.10971E+003	1.65994E+002
		1861.09* @	5.25	2.62409E+001	8.04150E+000
		2201.70*	25.80	1.63953E+001	2.00884E+000
		2507.79* @	12.78	1.66574E+001	4.43675E+000
AS-76	0.894	559.10*	45.00	1.02271E+003	5.05386E+001
		563.23* @	1.20	1.09421E+004	8.54300E+002
		571.50* @	0.14	1.62524E+003	1.40532E+002
		657.05* @	6.20	1.29428E+003	1.08022E+002
		665.34* @	0.36	1.33755E+003	1.52447E+002
		740.10* @	0.12	1.63757E+003	1.63978E+002
		1212.92* @	1.44	1.22369E+003	9.65709E+001
		1216.08* @	3.42	1.35284E+003	9.83620E+001
		1228.52* @	1.22	1.18229E+003	1.09279E+002
BR-82	0.935	137.41 @	0.16		

```
NP-239     0.973     106.12* @  22.90    6.63490E+001  6.65906E+000
                     117.00* @  10.50    2.83516E+001  2.12167E+000
                     209.75* @   3.27    6.71444E+001  5.38067E+000
                     228.18*    10.80    6.60469E+001  4.16511E+000
                     277.60*    14.20    6.30864E+001  1.77386E+000
                     315.88* @   1.60    6.34192E+001  4.64530E+000
                     334.31* @   2.04    7.11063E+001  6.48348E+000

     * = Energy line found in the spectrum.
     @ = Energy line not used for Weighted Mean Activity
     Energy Tolerance :    2.000 keV
     Nuclide confidence index threshold =   0.30
     Errors quoted at  1.000 sigma
```

Interference Corrected report :

```
*****************************************************************************
*****   I N T E R F E R E N C E   C O R R E C T E D   R E P O R T   *****
*****************************************************************************


                 Nuclide        Wt mean          Wt mean
      Nuclide       Id          Activity         Activity
      Name      Confidence     (uCi/gram)       Uncertainty

      NA-24        0.705      3.243526E+002   6.235832E+000
      K-42      @  0.593      1.311415E+002   1.039175E+001
      MN-54        0.996      1.079717E+001   6.583750E-001
      FE-59     @  0.881      4.635193E+000   1.633793E-001
      ZN-65        1.000      2.486351E+002   3.888069E+000
      ZN-69m       0.670      1.786592E+001   1.212345E+000
      GA-72     @  0.315      1.639529E+001   2.008845E+000
      AS-76     @  0.894      1.022714E+003   2.208251E+001
      BR-82     @  0.935      5.860860E+000   1.044882E-001
      RB-86        0.992      2.771378E+001   3.249591E+000
      RU-97     @  0.818      1.834947E-002   2.354568E-002
      MO-99     @  0.719      1.250125E+000   1.184604E-001
   X  RU-103       0.909
      CD-115    @  0.973      1.079814E+000   5.842355E-002
      SN-117m   @  0.899      3.933202E-001   1.951052E-002
      SB-122    @  0.975      3.665697E+001   8.275475E-001
      SB-124    @  0.975      3.491282E+001   8.618782E-001
      BA-131    @  0.963      2.341468E+000   5.655027E-002
      LA-140    @  0.953      5.526382E+000   1.343579E-001
      SM-153    @  0.914      3.337965E+001   8.435934E+000
      TB-160    @  0.636      3.534607E+000   1.681631E-001
      W-187     @  0.872      1.745961E+002   2.916051E+000
   X  IR-194       0.579
   X  HG-197m      0.630
      AU-198       0.982      6.697566E+000   1.203591E-001
      NP-239    @  0.973      6.420144E+001   1.215707E+000

      ? = Nuclide is part of an undetermined solution
      X = Nuclide rejected by the interference analysis
      @ = Nuclide contains energy lines not used in Weighted Mean Activity

      Errors quoted at  1.000 sigma
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4.4. Statistical analysis :

As we put many samples in the same site, we have to obtain information about the site.First, all samples from each site are collected, analyzed, then concentrations of elements are determined. Then we calculate the Minimumdetectable concentration for each element, maximum, mean, median, and standard deviation (SD). Then RAF Factor for each element should be calculated.

RAF (Relative Accumulation Factor) : it's used to assess the accumulation level of each element in the sample.[RAF = [$C_{exposed} – C_{initial}$] / $C_{initial}$] where $C_{exposed}$ is the concentration of element in the sample exposed to the atmosphere($C_{exposed}$: the concentration of the median of the concentrations of samples). $C_{initial}$ is the concentration of the element in the non polluted sample (sample with no exposure to the polluted atmosphere).

Now we have calculated the accumulation factor

if we want to test the sensitivity, MDC(Minimum Detectable Concentration) should be calculated [MDC = $X*C_{initial}$ + 1.96* SD* $C_{initial}$]Where (1.96 Suggesting that the initial values are normally distributed)

Conclusion and Future plans:

NAA is a super powerful nuclear technique that can be used to determine the elemental composition of material. Mosses are good accumulators and biomonitors for airborne elements. Therefore, using NAA to determine the elements accumulated in mosses is a powerful application for determining the level of atmospheric pollution.

Furthermore, NAA is widely used to analyze another biomonitors. it is used to measure the accumulated elements in different tree species as such as leaves that are exposed to air pollutants, accumulate the elements by two ways (roots and air). So, it is used as a biomonitor. When the nutrition coming from the soil is corrected, the atmospheric deposition in the leaves is known.

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