A Method to improve Experimental Facilities for Teaching Nuclear Physics at the Universities

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Nuclear physics experiments are included in the M.Sc. physics syllabus of many Indian universities. However, the required experimental facilities are scarce due to the high cost of the equipment and difficulties in obtaining radioactive sources. Recently the applications of radioactivity in the industry and medical fields are on the rise but the education in this area has not shown any progress. This report looks into some of the reasons and proposes a plan to introduce the study of radioactivity from natural sources using the low cost radiation detection equipment developed for this purpose.

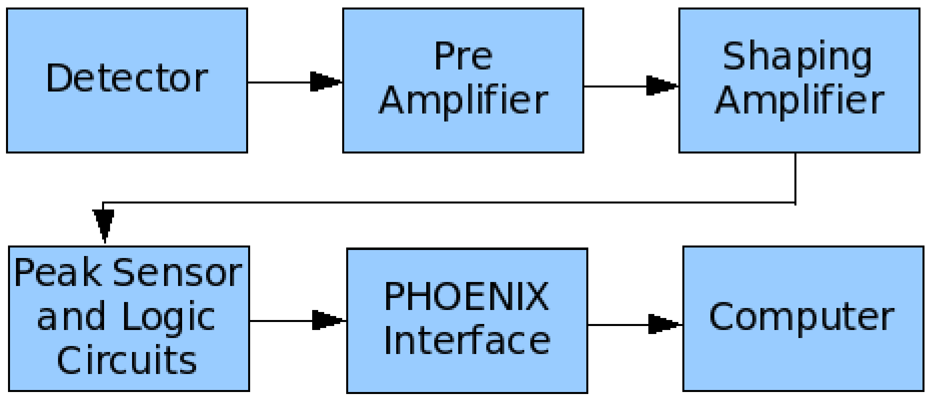
Introduction

The major reason preventing most of the university laboratories from acquiring radiation detection equipment is the cost. A typical setup of detector and signal processing electronics to measure the energy spectrum of alpha particles costs several lakhs. Getting an enriched source costs less money but more paper work due to the safety regulations. Considering all these factors most of the teaching labs now prefer to avoid including the study of radio activity in the syllabus.

When teaching is the major objective, and not research, one does not require the state of the art equipment. What is required a reliable, easy to maintain and inexpensive equipment. One such setup developed at Inter University Accelerator Centre is described in the next section. The other hurdle is the radioactive source. There is no need to have a strong source or enriched material to understand the measurement techniques used for studying radioactivity. The amount of activity required is less than that of some commonly available items like a gas light mantle, smoke detector or light bulb filament.

The Equipment

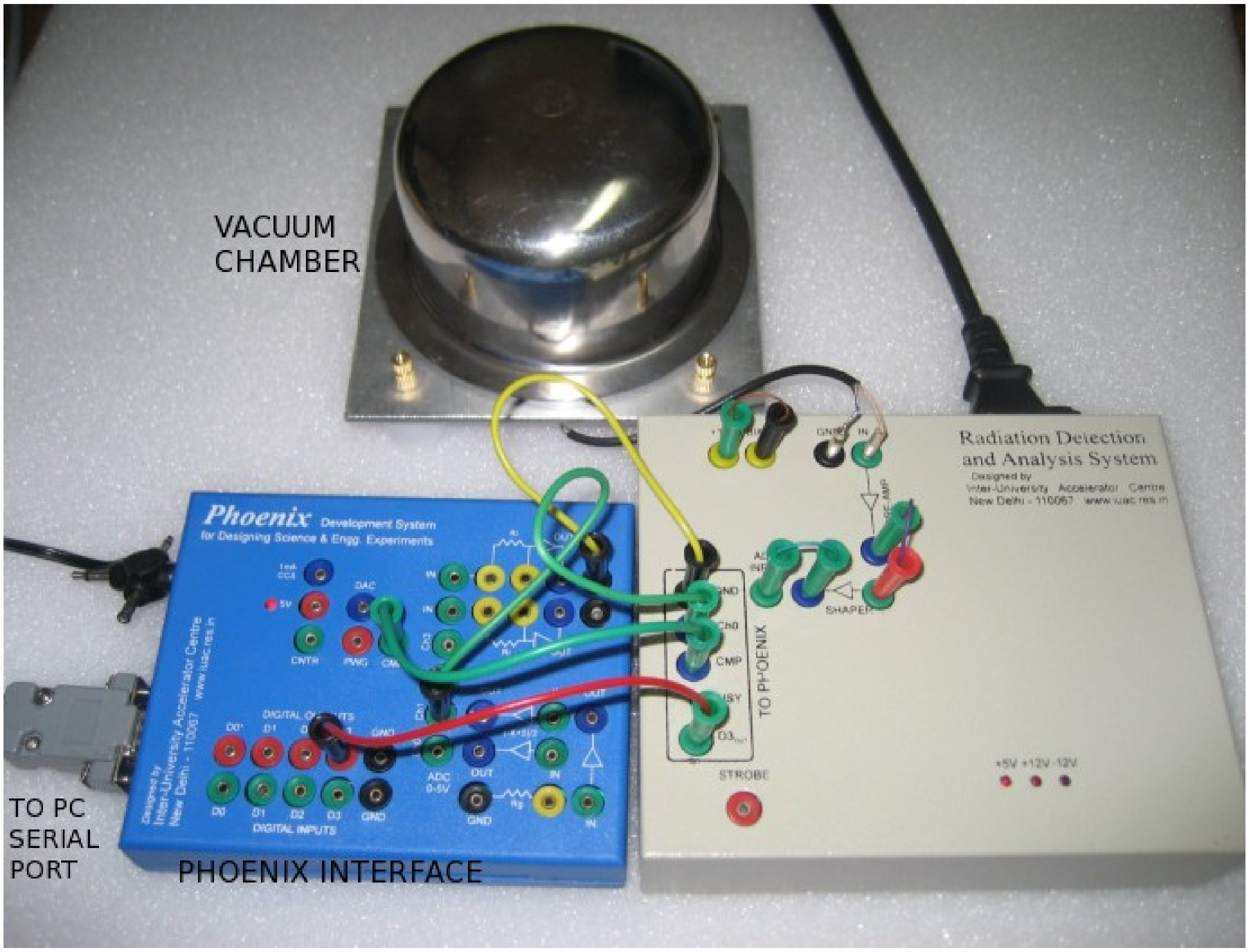
The focus is on measuring the energy spectrum of the observed radiation. An inexpensive PN junction is used for alpha particle detection. Gamma radiation can be studied using scintillation or HPGe detectors. The required signal processing electronics (Pre-Amplifier, Shaping amplifier, discriminator etc.) has been packaged in to a a 6”x5”x1.5” box. The digitization and the PC interfacing is provided by PHOENIX (Appendix B). The required electronics have been already developed, packaged and arrangements for commercial production established. A block diagram and photograph of the setup is shown below.

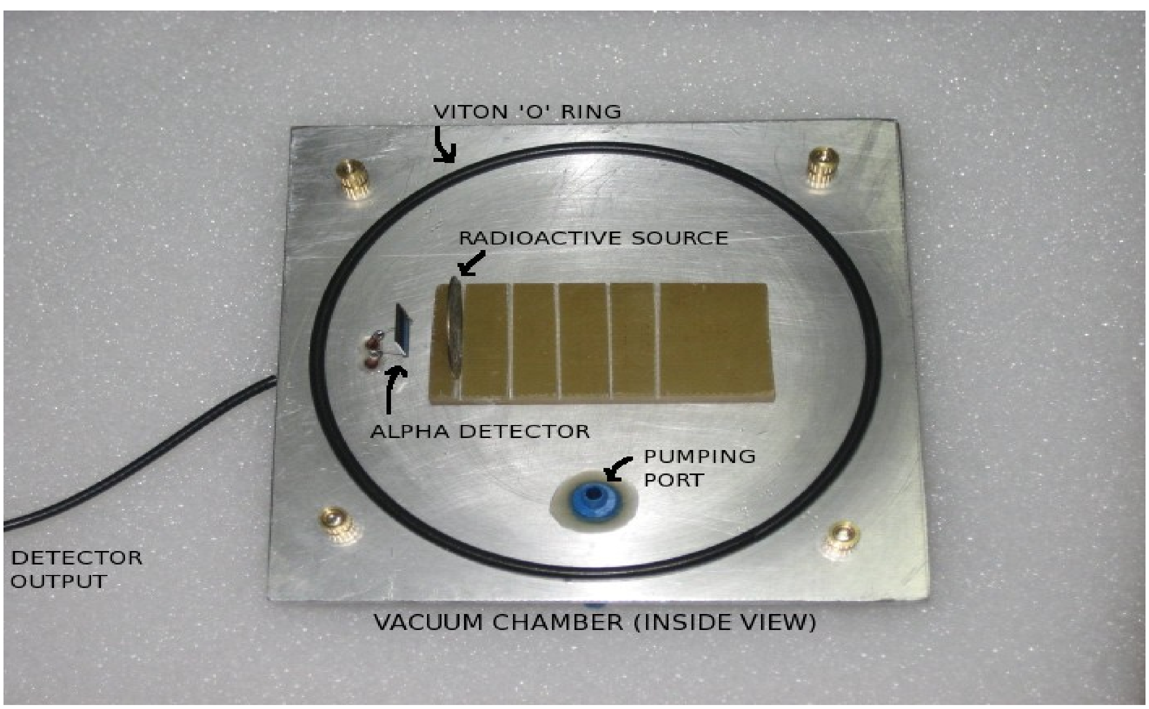


Block diagram of the radiation detection system

The radiation detection system has been designed as an accessory of the Phoenix Interface. Phoenix (Appendix B) provides several other experiments and is presently available from several vendors. A PN junction available for US$20/- is used for detecting alpha particles. The total setup including a small vacuum chamber can be made commercially available at around Rs.5000/-, excluding the rotary pump required to study under vacuum. Study in air also is possible if the loss of energy resolution is acceptable.

Several experiments conducted using this equipment to study the activity from natural thorium, uranium and other radioactive sources are discussed later.

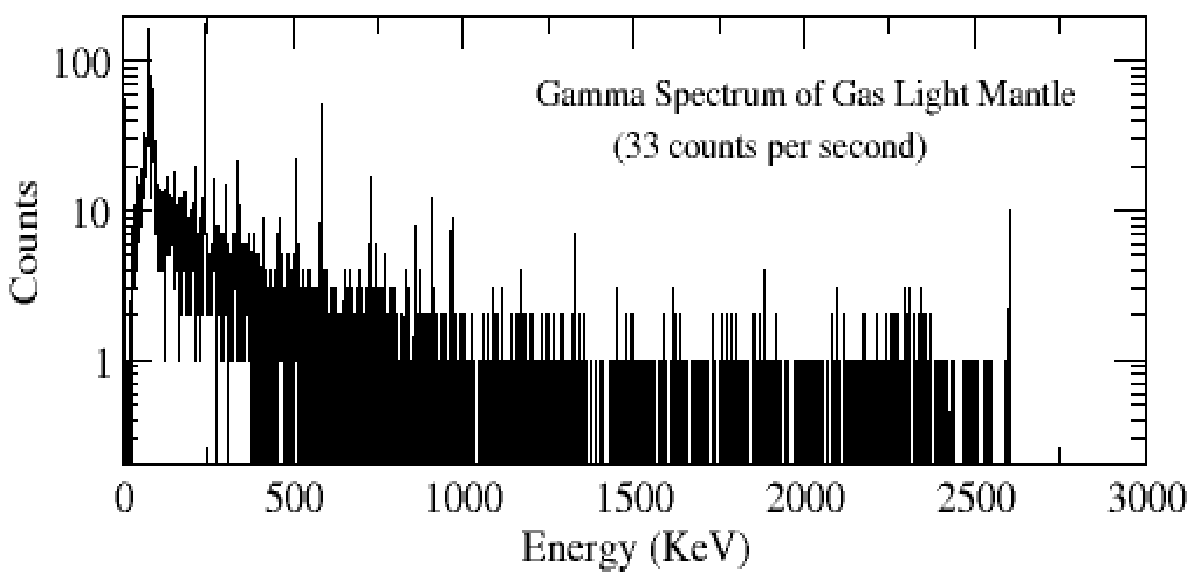

VACUUM
CHAMBER
Radiation Detection
and Analysis System
Phoenix Development System
for Designing Science & Engg. Experiments
TO PHOENIX
TO PC
SERIAL
PORT
PHOENIX INTERFACE


VITON 'O' RING
RADIOACTIVE SOURCE
ALPHA DETECTOR
PUMPING
PORT
DETECTOR
OUTPUT
VACUUM CHAMBER (INSIDE VIEW)

The Radioactive Source

Since the inexpensive PN junction can detect alpha, we started looking for commercially available items containing alpha emitting materials. The activity from the gas light mantle, containing thorium, was measured. The gamma radiation from the mantle is big enough to build an energy spectrum within minutes but the alphas are unable to come out due to the self absorption. After that we tried a small amount of thorium powder smeared on a cello-tape and were able obtain the alpha spectrum of thorium series. To minimize self absorption we used a very thin layer of thorium powder and the count rate recorded is about 0.3 counts per second.

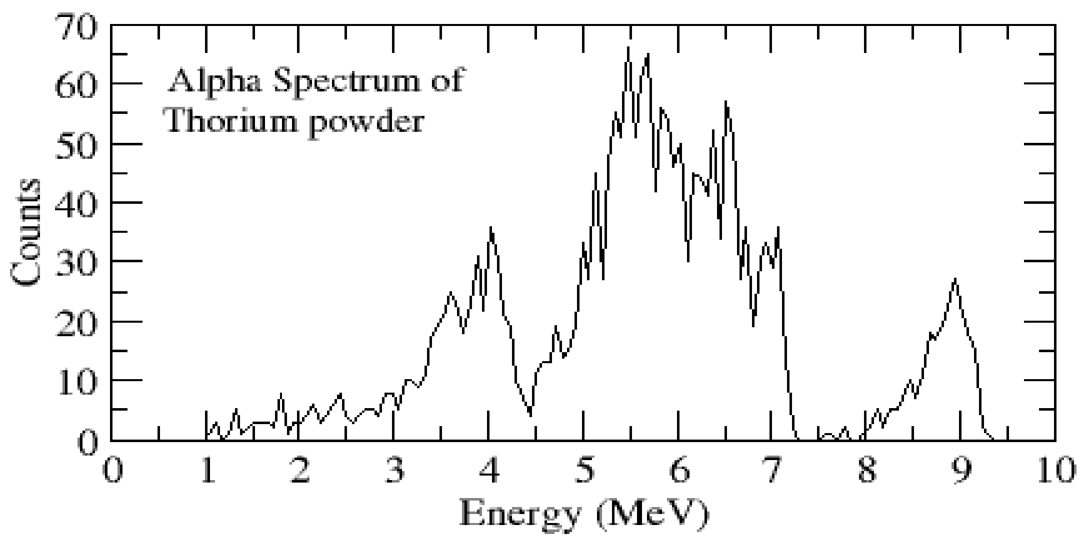
The gamma radiation from one mantle and the thorium powder used for generating the alpha spectrum are compared using a HPGe detector and associated electronics. The mantle gave 33 counts per second and the gamma peaks corresponding to the thorium series can be identified. What we require is the amount of thorium inside a gas mantle, but in the form of a metallic foil. It would make things simple if such a thing can be made available, without the lengthy paperwork involved in getting a radio active source.

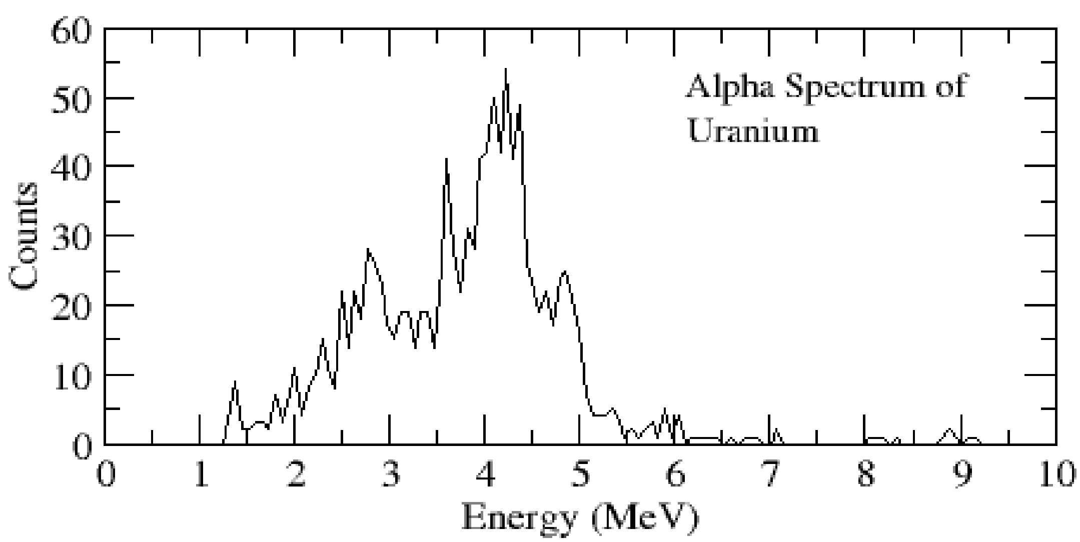


The following sections explain some of the experiments done using natural thorium, uranium and some other radio active sources.

Energy Spectrum of Alphas from Natural Thorium and Uranium

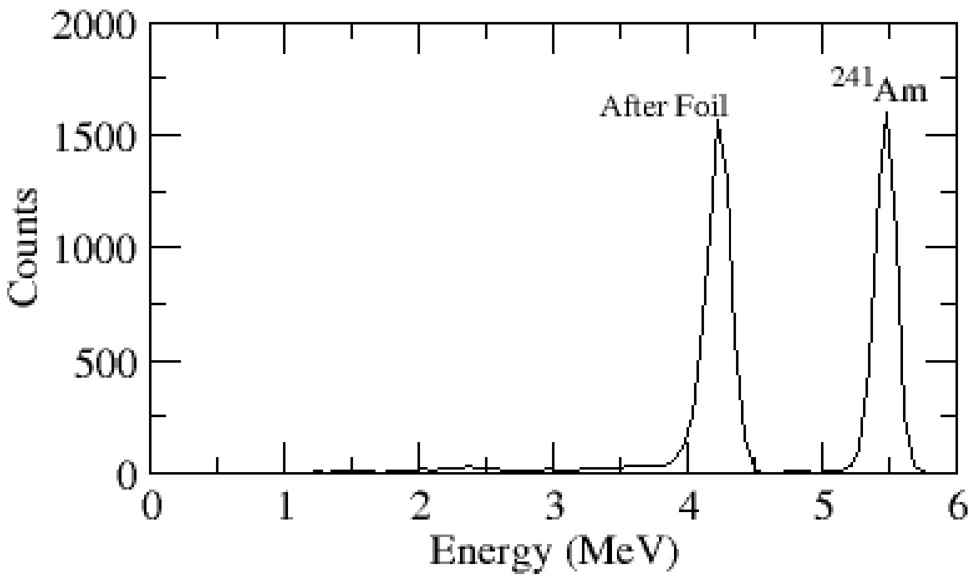
The spectra shown below are taken using thorium powder and uranil acetate powder. The alpha energies above 4.9 MeV are missing from the uranium spectrum, even though they are present in the decay chain. A possible explanation is the different half lives of the Radon isotopes, which is a gas, formed in both cases. In the Thorium series the ^{220}Rn isotope is having a half life of only 55.6 seconds and most of it may be decaying in to daughter products, again in the solid form, before it can diffuse out from the source material. On the other hand the ^{222}Rn in the Uranium series has a half life of 3.8 days, sufficient enough to escape from the material so that the high energy alphas emitted by the decay of the radon's daughter products are missing.





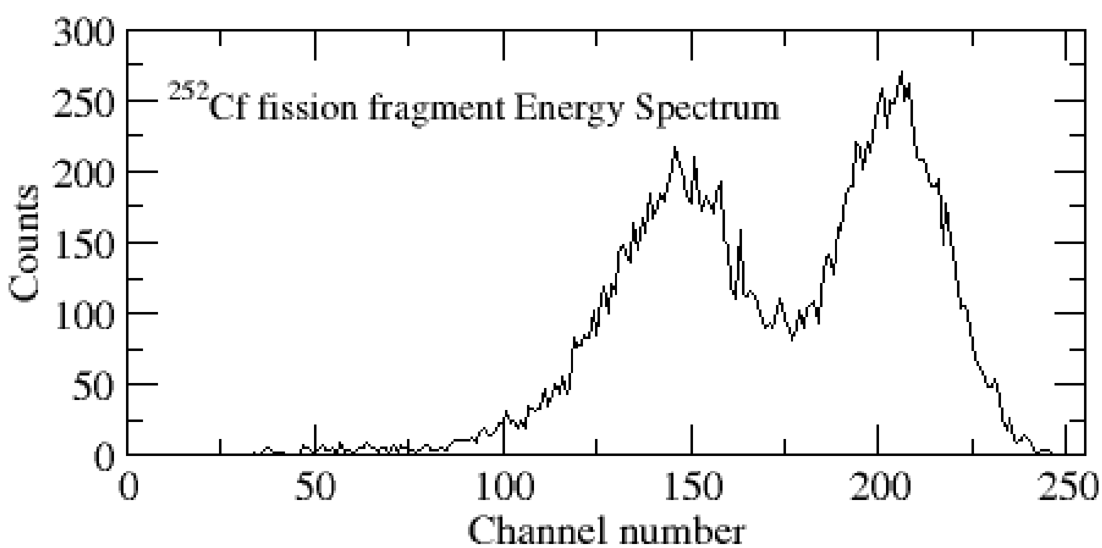
Alpha Attenuation in thin foil using ^{241}Am source

The foil is placed in between the source and the detector kept inside the vacuum chamber. The spectrum shows the attenuation and energy straggling due to the foil. The energy resolution is around three percent.



Fission Fragments from ^{252}Cf

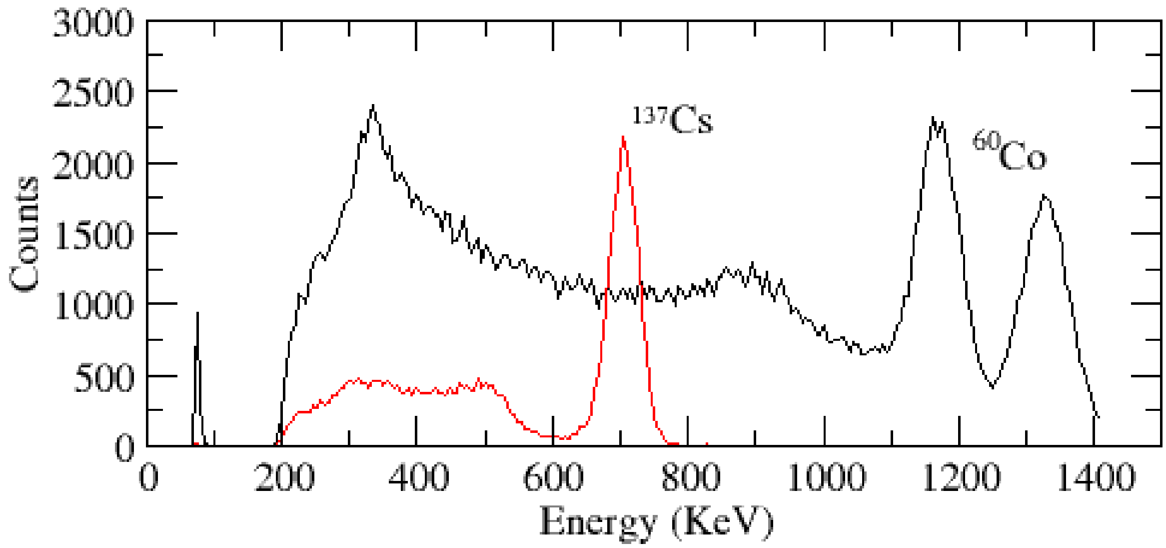
The fission fragment spectrum is taken using the same setup by selecting a lower gain for the shaping amplifier, using the jumper setting provided.

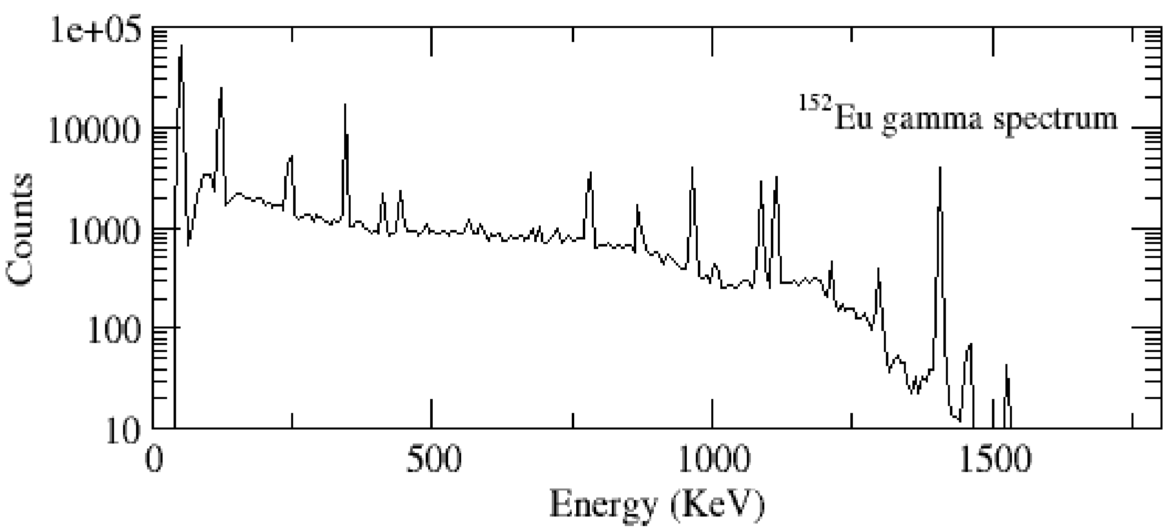


Study of Gamma Spectrum

The PN junction cannot detect light particles or gamma rays. However, the setup can accept the pulse output from an external shaping amplifier and generate the histogram. The gamma spectrum of ^{60}Co and ^{137}Cs were taken using scintillation detector . This data was recorded at dept. of physics, university of Calicut, using their scintillation detector and feeding the output to the ADC of the setup described above.

Energy spectrum of ^{152}Eu was taken by using an HPGe detector. The 256 channel resolution of this setup is cannot match the resolution of HPGe detector but all the energy peaks could be identified.





Conclusion

Study of several radioactive materials using the low cost equipment developed has been presented. The objective of this report is to initiate some action to improve the present state of experimental nuclear physics at Indian universities. The lack of experimental facilities have arisen mainly due to two reasons; the high cost of equipment and the difficulties in maintaining them. An equally important reason is the paper work involved in getting and maintaining radioactive sources.

The equipment developed at IUAC is inexpensive and capable of supporting experiments at M.Sc. level. It can be made available to interested departments. The kind of radioactive material suitable for teaching lab need to be worked out. There are several daily life articles which contains lightly radioactive materials. We have measured the activity from a gas light mantle and found that it is much more than from the thorium powder used in this study. Making such a low activity source for education purposes and making it freely available is one solution. What is required is a thin foil of thorium giving 4 to 5 counts per second (or whatever amount of activity that is permissible to be distributed freely without violating the safety norms) to make this system widely available.

This action has to be initiated by not only those who are concerned about the present state of experimental nuclear physics education but also by the regulating authorities who control the production and distribution of radioactive material. In my view, a PG student can be more careful about radioactivity than a normal user of gas light mantle and it may not be wise to make it difficult for them to study it. This report is circulated with the hope that it will help in initiating some actions to make the experimental nuclear physics studies more popular at the university level.

17-Sep-07

Appendix A :

Thorium series : The 4n chain of Th-232

nuclide	decay mode	half life	energy released, MeV	product of decay
^{252}Cf	α	2.645 a	6.1181	^{248}Cm
^{248}Cm	α	3.4×10^5 a	6.260	^{244}Pu
^{244}Pu	α	8×10^8 a	4.589	^{240}U
^{240}U	β^-	14.1 h	.39	^{240}Np
^{240}Np	β^-	1.032 h	2.2	^{240}Pu
^{244}Cm	α	18 a	5.8048	^{240}Pu
^{240}Pu	α	6561 a	5.1683	^{236}U
^{236}U	α	$2.3 \cdot 10^7$ a	4.494	^{232}Th
^{232}Th	α	$1.405 \cdot 10^{10}$ a	4.081	^{228}Ra
^{228}Ra	β^-	5.75 a	0.046	^{228}Ac
^{228}Ac	β^-	6.25 h	2.124	^{228}Th
^{228}Th	α	1.9116 a	5.520	^{224}Ra
^{224}Ra	α	3.6319 d	5.789	^{220}Rn
^{220}Rn	α	55.6 s	6.404	^{216}Po
^{216}Po	α	0.145 s	6.906	^{212}Pb
^{212}Pb	β^-	10.64 h	0.570	^{212}Bi
^{212}Bi	β^- 64.06% α 35.94%	60.55 min	2.252 6.208	^{212}Po ^{208}Tl
^{212}Po	α	299 ns	8.955	^{208}Pb
^{208}Tl	β^-	3.053 min	4.999	^{208}Pb
^{208}Pb	.	stable	.	.

Radium series The 4n+2 chain of U-238

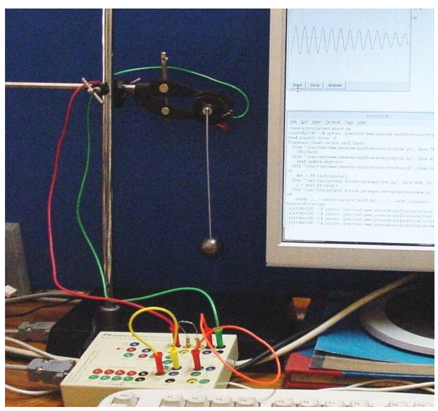
nuclide	decay mode	half life	MeV	product of decay
^{238}U	α	$4.468 \cdot 10^{9}$ a	4.270	^{234}Th
^{234}Th	β^-	24.10 d	0.273	^{234}Pa
^{234}Pa	β^-	6.70 h	2.197	^{234}U
^{234}U	α	245500 a	4.859	^{230}Th
^{230}Th	α	75380 a	4.770	^{226}Ra
^{226}Ra	α	1602 a	4.871	^{222}Rn
^{222}Rn	α	3.8235 d	5.590	^{218}Po
^{218}Po	A 99.98 % β^- 0.02 %	3.10 min	6.115 0.265	^{214}Pb ^{218}At
^{218}At	A 99.90 % β^- 0.10 %	1.5 s	6.874 2.883	^{214}Bi ^{218}Rn
^{218}Rn	α	35 ms	7.263	^{214}Po
^{214}Pb	β^-	26.8 min	1.024	^{214}Bi
^{214}Bi	β^- 99.98 % α 0.02 %	19.9 min	3.272 5.617	^{214}Po ^{210}Tl
^{214}Po	α	0.1643 ms	7.883	^{210}Pb
^{210}Tl	β^-	1.30 min	5.484	^{210}Pb
^{210}Pb	β^-	22.3 a	0.064	^{210}Bi
^{210}Bi	β^-- 99.99987% α 0.00013%	5.013 d	1.426 5.982	^{210}Po ^{206}Tl
^{210}Po	α	138.376 d	5.407	^{206}Pb
^{206}Tl	β^-	4.199 min	1.533	^{206}Pb
^{206}Pb	-	stable	-	-

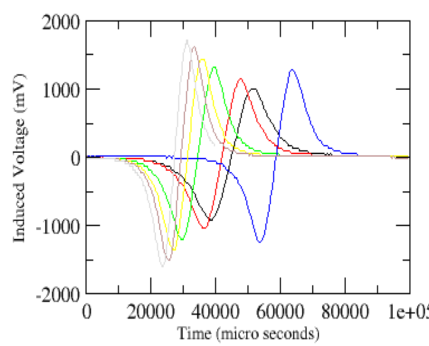
Appendix B: PHOENIX

Physics with Homemade Equipment & Innovative Experiments

Phoenix is a framework that can be used for developing computer interfaced science experiments without getting into the details of electronics or computer programming. The objective is to make teachers and students familiar with computerized experimental systems and also to enable them to develop new experiments and science demonstrations. Phoenix utilizes the power of personal computers for experiment control, data acquisition and processing. The instrument is designed using locally available low cost components and the design is freely available for commercial production. Phoenix is developed using Free Software tools. The Phoenix Live CD contains all the required phoenix software plus a collection of programs for science and engineering education. Phoenix is capable of measuring time intervals with microsecond accuracy and sampling analog data with precise timing. Velocity of sound, Acceleration due to gravity, Compound Pendulum, diode characteristics, RC circuits, temperature measurements etc. are some of the studies done.

- 10 bit 4 channel ADC
- 8 bit PWM DAC
- Digital Inputs/Outputs
- Waveform Generator
- Constant Current Source
- Op-Amp Gain Blocks
- Expansion Modules
- Serial / USB Interface





Magnet droped into a coil from different heights

Phoenix was introduced as a part of a program by IUAC to improve the lab facilities at Universities and has grown due to the interest and contribution from the academic community. One day workshops to introduce Phoenix are conducted at various places. Those who are interested in organizing such workshops may contact us for details of available support. We also conduct training programs for physics teachers from colleges.

For details please visit www.iuac.res.in.

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