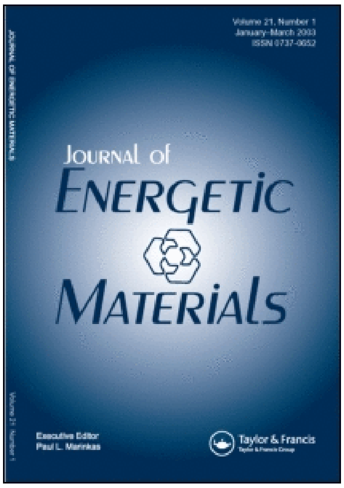

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FAST NEUTRON ACTIVATION ANALYSIS OF HIGH ENERGY MATERIALS AND POLYMERS

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ABSTRACT

Fast neutron activation analysis (FNAA) technique using 14 MeV neutrons has been applied to estimate nitrogen, chlorine, oxygen and aluminium in explosives and propellants. FNAA also has been employed to determine nitrogen, oxygen, chlorine and fluorine in various polymers. The technique is fast, accurate, non-destructive and non-hazardous in analysing elements in explosives and propellants compared to a number of chemical methods which are time consuming, less accurate, suitable for single elemental analysis and do not measure oxygen directly. In this paper FNAA technique, its theory and application for estimation of elements in high energy materials carried out in the laboratories of the authors have been reviewed. The method also helped to determine the differential distribution of aluminium and ammonium perchlorate in aluminized explosives and rocket propellants. Modification of polyepichlorohydrin to polyglycidylazide was followed by FNAA more accurately than IR spectral analysis.

1. INTRODUCTION

Fast neutron activation analysis (FNAA) uses neutrons of 14 MeV of energy to bombard the test specimens to convert different elements in them into radioactive isotopes which decay either by positron (β^+), electron (β^-) or α-emissions and during their nuclear de-excitation process they emit characteristic γ- rays with half life periods around 5-10 minutes having different energies. The γ-rays spectra are recorded from which the percentage of elements to be estimated can be calculated using a monitor of known elemental composition. The method is fast, fairly accurate and capable of estimating several elements simultaneously.

FNAA has not been widely used to analyse polymers. Bhoraskar et al[1] used it to analyse fluorine in polytetrafluoroethylene. Panda and Kulkarni employed the method for the analysis of nitrogen in cellulose nitrate, amine cured epoxy resins, Schiff-base oligomers and nylon-6[2]. The same workers also estimated chlorine content of PVC by FNAA. However, the method has been used by Bhoraskar et al and Panda and Kulkarni to analyse various other materials including aluminium in aluminized explosives and rocket propellants and nitrogen in various explosives[3-7]

Glycidyl azide polymers which are used as energetic plasticizers in double base rocket propellants, fuel binder in composite propellants[8] and as fuel rich propellants in integrated ram rocket engines[9-10] are interesting low molecular weight polymers which have nitrogen, chlorine and oxygen to be simultaneously determined by FNAA. Such analysis by other chemical methods are laborious, time consuming and not very accurate.

2. PRINCIPLES OF FAST NEUTRON ACTIVATION ANALYSIS AND NUCLEAR REACTION

Fast neutrons are generated by bombarding a tritium target with accelerated deuterium ions according to the following nuclear reaction.

$$^{2}H + \ ^{3}T \longrightarrow \ ^{4}He + \ ^{1}n + 17.6 \text{ MeV}$$

(Neutron shares 14 Mev of energy)

The reaction cross-section (σ) for the above reaction is 5 barns. These 14 MeV neutrons are focussed on the sample materials to convert the elements in them into their radioactive isotopes which subsequently decay by γ-emission.

2.1 Determination of the amount of a given element in a particular sample[11]

Let x gram of sample containing N atoms of the element be placed in a uniform flux of thermal neutrons for time t to produce measurable activity, say A_t. It is presumed that the activity A_t is solely due to isotope under study. The activity produced is given by

$$A_t = N\Phi\sigma(1-e^{-\lambda t}) \qquad (1)$$

Where N = no of atoms of the target element

Φ = neutron flux

σ = neutron capture cross section

λ = decay constant (sec^{-1})

t = time of radiation

A_t = activity produced if measured immediately at the end of irradiation.

At time = t', activity will be

$$A'_t = A_t.e^{-\lambda t'}$$

$$\text{or } A'_t = N\Phi\sigma(1-e^{-\lambda t})e^{-\lambda t'} \qquad (2)$$

From eqn(2) the weight w gram of the particular element present in the x gram of the sample is known from

$$W = MN/L = (M/L)(A_t/\Phi\sigma(1-e^{-\lambda t})e^{-\lambda t'}) \qquad (3)$$

where M = atomic weight of the test element,

$L = 6.022 \times 10^{23}$

In analysis of an unknown sample, a monitor material with known elemental composition is used. If w is the weight of the element present in the test sample to be determined, w' is the weight of the same element in the monitor, A_t^* is the γ-activity induced due to the test element and $A_t^{*'}$ is the γ-activity induced due to the same element in the monitor, then

$$w/w' = A_t^* / A_t^{*'} \qquad (4)$$

However, the monitor can have an element other than the element to be determined in the test sample provided the radioactive isotope formed by the monitor element on neutron irradiation has comparable half life period ($t_{1/2}$) for decay with that of the test sample but different energy for γ-emission. Such elements can sometimes monitor neutron analysis of more than one elements in the test samples. Therefore if x_1 gram of an unknown sample is taken with x_2 gram of monitor where w_1 and w_2 are the weights of the elements to be determined in the test sample and monitor respectively, we get

$$W_1/W_2 = K(A_{t1}/A_{t2})$$

where A_{t1} = activity induced due to test element,

A_{t2} = activity induced due to monitor element

K = activation constant

$$= \frac{M_1}{M_2}\left[\frac{x_1\ \sigma_1\ (1-e^{-\lambda_1 t})\ e^{-\lambda_1 t'}}{x_2\ \sigma_2\ (1-e^{-\lambda_2 t})\ e^{-\lambda_2 t'}}\right]$$

The term in the above expression have their significance already defined earlier

3. EXPERIMENTAL

3.1 Method

The FNAA facilities available at the department of physics University of Poona were utilised. The details of the fast neutron generator have been described by Bhoraskar et al elsewhere[12].

3.2 Estimation of Nitrogen

The estimation of nitrogen was carried out by irradiating for 5 minutes a mixture of known quantities of the test sample and aluminium powder (aluminium in the mixture acts as a monitor) packed in a polyethylene vial with 14 MeV neutrons having neutrons flux of 10^8 neutrons/cm^2/sec. Nitrogen undergoes the following nuclear reaction.

$$^{14}N(n,2n)^{13}N$$

The reaction cross-section σ, for the above reaction is 5.7 millibarns. The half life period ($t_{1/2}$) of ^{13}N is 9.96 min and the γ-energy, E_γ is 0.511 MeV. Aluminium undergoes the following nuclear reactions with fast neutrons,

$^{27}Al(n,p)^{27}Mg$; σ , 81 mb; $t_{1/2}$, 10 min;

E_{γ}, 0.84 MeV (70%) and 1.01 MeV (30%)

A pneumatic transfer system was used to transfer the sample from irradiation head to γ-ray detector. The induced γ-ray activity was measured with a HPGe detector coupled to a 4096 multi channel analyser. The concentration of the test element in the sample was estimated by measuring the activity under the photo peak using computer software . The nitrogen content was determined by using the following formula

$$W_N/W_{Al} = K \ (A_N/A_{Al})$$

where W_N is the weight of nitrogen in the test sample (to be determined), W_{Al} is the weight of aluminium as monitor, A_N is the activity or counts induced due to nitrogen under the photopeak of 0.511 MeV and A_{Al} is the activity or counts induced due to aluminium under the photopeak of 0.84 MeV. K is the activation constant which was determined using an authentic sample of sodium nitrate with known nitrogen content following the similar procedure discussed above. It is more convenient to use the activity of aluminium under the photopeak at 0.84 MeV both for calculation of K and determination of W_N than that at 1.01 MeV which is a smaller peak.

3.3 Estimation of Chlorine

Chlorine in the test sample was determined by using manganese (in the form of MnO_2) as the monitor element adopting the same procedure as discussed for the estimation of nitrogen. The irradiation time was kept five minutes. The relevant nuclear reactions of chlorine and manganese with 14 MeV neutrons are represented below

$^{37}Cl(n,p)^{37}S$; σ, 40 ± 3 mb; $t_{1/2}$, 5.06 min; E_γ, 3.09 MeV

$^{55}Mn(n,\alpha)^{52}V$; σ, 52 mb; $t_{1/2}$, 3.76 min; E_γ, 1.434 MeV

The chlorine content was determined using the following formula,

$$W_{Cl}/W_{Mn} = K(A_{Cl}/A_{Mn})$$

where W_{Cl} is the weight of chlorine in the test sample, W_{Mn} is the weight of manganese in the monitor, A_{Cl} is the activity or counts induced due to chlorine under the photopeak of 3.09 MeV and A_{Mn} is the activity or counts induced due to manganese under the photopeak of 1.434 MeV. The activation constant was predetermined by using sodium chloride as the authentic sample for chlorine by adopting the similar procedure as discussed earlier.

3.4 Estimation of Oxygen

The oxygen content in the test samples was determined using sodium as the monitor (in the form of NaCl) and following exactly the similar procedure given for nitrogen except for the irradiation time which was kept 30 sec in this case instead of 5 minutes. The nuclear reactions of oxygen and sodium with 14 MeV. neutrons are given below

$^{16}O(n,p)^{16}N$; σ ,42 ± 3mb ; $t_{1/2}$, 7.35 sec ; E_{γ}, 6.13 MeV

$^{23}Na(n,\alpha)^{20}F$; σ ,150 ± 14 mb; $t_{1/2}$,11.5 sec; E_{γ},1.63 MeV

The oxygen content was determined by using the following formula,

$$W_O/W_{Na} = K(A_O/A_{Na})$$

where W_O is the weight of oxygen in the test sample, W_{Na} is the weight of sodium in NaCl, $A_O$is the activity or counts induced due to oxygen under the photopeak of 6.13 MeV and A_{Na} is the activity or counts induced due to sodium under the photopeak of 1.63 MeV. K is the activation constant predetermined using sodium as the monitor.

3.5 Estimation of Aluminium in the Samples Containing Nitrogen

The aluminium content in the test sample was determined by slightly modifying the procedure to determine the nitrogen content in the sample. Thus the test sample was irradiated for five minutes by 14 MeV neutrons without and with addition of a known quantity of aluminium powder. In both the cases the activity induced due to nitrogen and aluminium were measured. The following formula was used for the determination of aluminium content in the test sample.

$$(W_{Al}+W'_{Al})/W_{Al}=(C_N/C'_N)[(C_{Al}+C_{Al})/C'_{Al}]$$

where W_{Al} is the weight of aluminium initially present in the propellant sample (to be determined), W'_{Al} is the weight of the extra quantity of aluminium added to the sample, C_{Al} is the activity or counts induced due to aluminium (i.e. by ^{27}Mg present initially and C'_{Al} is the activity or counts induced due to aluminium (i.e. by ^{27}Mg), after adding an extra quantity of aluminium to the sample. C_N and C'_N are the counts or activity induced due to nitrogen without and with extra aluminium added respectively.

3.6 Simultaneous Estimation of Nitrogen, Aluminium and Chlorine

To simplify the procedure to determine nitrogen and aluminium described so far, a common monitor for nitrogen, aluminium and chlorine was searched, so that all these elements could be determined simultaneously. Manganese was found to be suitable as the monitor for the purpose. Thus a known quantity of a mixture of test sample and manganese (in the form of manganese dioxide) was irradiated for five minutes by 14 MeV neutrons. Nitrogen, aluminium and manganese undergo the same nuclear reactions, as mentioned earlier with 14 MeV neutrons.

After cooling the sample for one minute, the activities induced due to nitrogen, aluminium and manganese were measured for five minutes under their respective photo peaks in the γ-ray spectrum using detector and multi channel analyser. The following formula was used for nitrogen estimation

$$W_N/W_{Mn} = K(C_N/C_{Mn})$$

where W_N is the weight of nitrogen in the test sample, W_{Mn} is the weight of manganese (as the monitor), C_N is the counts due to ^{13}N under the photo peak of 0.511 MeV and C_{Mn} is the counts induced due to manganese (i.e. by ^{52}V) under the photo peak of 1.43 MeV. K is the activation constant, predetermined using 99% sodium nitrate as the standard and manganese as the monitor. Its average value was found to be, 0.6.

The formula used for aluminium determination can be expressed as

$$W_{Al}/W_{Mn} = K(C_{Al}/C_{Mn})$$

where W_{Al} is the weight of aluminium in the test sample, W_{Mn} is the weight of manganese as the monitor, C_{Al} the counts induced due to aluminium (i.e. by ^{27}Mg) under the photo peak of 0.84 MeV and C_{Mn} the counts induced due to Mn (i.e. by ^{52}V) under the photo peak of 1.43 MeV. K is the activation constant predetermined using aluminium powder as standard and manganese as the monitor (average value, 0.6).

The method for estimation of chlorine using manganese as the monitor has already been discussed under para 3.3

3.7 Materials

Various high explosives such as TNT, RDX, tetryl, picric acid and PETN which were used for the estimation of their total nitrogen content were synthesized in our laboratory. However various double base and composite propellants and aluminized explosives were supplied by HEMRL, Pune with detailed compositions for analysis by FNAA.

Most of the polymeric samples which were analysed for their nitrogen or chlorine content were procured from trade. Kevlar-49, however, was obtained from DMSRDE, Kanpur.

Polyepichlorohydrin (PECH) was prepared by polymerizing epichlorohydrin using BF_3-ethylene glycol complex as the catalyst with methylene chloride as solvent for different specified period at 20°C. Glycidyl azide polymers (GAP) were synthesized by reacting polyepichlorohydrin with sodium azide in dimethylsulphoxide for 11 hours at 100°C. The conversion of PECH to GAP was studied by FNAA by estimating total chlorine, nitrogen and oxygen content of different GAP samples collected after different reaction times.

4. RESULTS AND DISCUSSION

Table 1 gives the calculated and experimentally determined values of total nitrogen content of different explosives. It can be seen from the Table 1 that experimentally determined values are reasonably in close agreement with those calculated from the respective molecular formulae. However, there is some variation in the values which may be partly due to the impurities present in the samples and partly due to the experimental errors.

Table 2 includes the details of the different ingredients with their compositions present in five aluminized explosives along with their incorporated and experimentally determined values of aluminium content. It also contains the experimental and calculated values of total nitrogen and oxygen content. Low variations between the calculated and experimental values testifies the importance of the method of analysis.

Fig.1 gives the representative γ-ray spectrum of a typical aluminized explosive AX_3 showing the photopeak due to ^{27}Mg (E_γ= 0.84 MeV) which was formed as a result of a nuclear reaction of aluminium present in the sample with fast neutrons. Fig.2 is a γ-ray spectrum of the same sample showing the photopeak due to ^{52}V (E_γ= 1.43 MeV) which was formed as a result of a nuclear reaction of manganese (used as a common monitor for nitrogen and chlorine) with fast neutrons. It can be seen from the Table 2 that in the majority of cases, the experimentally determined aluminium content is not in close agreement with that incorporated while formulating the explosive grains, though similar values for nitrogen and oxygen match well. This is ascribed to the non-uniform mixing of aluminium powder with other ingredients leading to a non-homogeneous mixture. Similar variation in aluminium content was also noticed in case of some composite propellants analysed by this method using manganese as the monitor (Table 4). Thus it is argued that the method is not only suitable for non-destructive estimation of aluminium but also useful for finding out its distribution in explosives and propellants. This is achieved by determining the total aluminium content of various random samples cut from different sections of main explosive or propellant grain. Simultaneous estimation of nitrogen, oxygen and aluminium is an interesting feature of the method as well.

Table 3 gives the details of the compositions of two double base and one triple base propellants along with their calculated and experimentally determined values of total nitrogen and oxygen content. It was noticed that the two sets of values were in very close agreement with each other, thus indicating the accuracy of the technique. Table 4 contains similar analytical data of three composite and one CMDB propellants. The calculated and experimental values of total nitrogen content in these samples are in good agreement. However, there is some variation in the experimental and calculated values of aluminium and chlorine contents which may be attributed to non-uniform mixing of aluminium and ammonium perchlorate with other ingredients. Fig.3 presents the γ-ray spectrum of propellant CP-3 showing the photo peak induced due to nitrogen (E_γ =0.511 MeV). Fig.4 is the γ-ray spectrum of the same sample showing the photo peak induced due to oxygen (E_γ= 6.13 MeV). The peaks obtained are sharp and clear and thus contributed to the ease of experimental calculations.

Nitrogen and chlorine estimation by FNAA technique for different polymers were carried out by Panda and Kulkarni[2] and results are tabulated in Table 5. The polymers included amine cured epoxy resins, nylon-6, urea-formaldehyde resin, Kevlar 49 and Polyvinyl chloride. Fluorine content of some polytetrafluoroethylene (teflon) samples was determined by Bhoraskar et al[1] by using the same technique. Sodium was used as the monitor for fluorine and following nuclear reactions and formula were used for the estimation of fluorine.

$^{19}F(n,p)^{19}O$; $t_{1/2}$, 29.1 sec; E_γ , 0.197 MeV

$^{23}Na(n,p)^{23}Ne$; $t_{1/2}$, 37.6 sec; E_γ 0.439MeV

$$W_F = K(C_F/C_{Na})W_{Na}$$

where W_F and W_{Na} are the weights of fluorine and sodium respectively and C_F and C_{Na} are the activities induced due to fluorine and sodium respectively. K is the activation constant predetermined using NaF as the standard. Table 6 includes the calculated and experimental values of total fluorine content of some teflon samples as reported by Bhoraskar[1]. From a comparison of values reported in Table 5 and 6 it can be seen that FNAA is a handy method for elemental analysis of various polymers.

The conversion of polyepichlorohydrin (PECH) to glycidyl azide polymer (GAP) was recently studied by Panda et al[13] using FNAA technique. The elemental composition of GAP depend upon the extent of conversion of $-CH_2Cl$ group of PECH to $-CH_2N_3$ group of GAP. The conversion of PECH to GAP was also followed by recording the IR spectra of different aliquots by withdrawing them at different time intervals from the reaction mixture. It is interesting to note that after around seven hours of reaction, the IR absorption peak at 745 cm^{-1} due to $-CH_2Cl$ group in PECH becomes completely flat. This is accompanied by appearance of a very strong absorption at 2100 cm^{-1} due to $-CH_2N_3$ group. It is misleading to believe that in 7 hours of reaction, the complete conversion of PECH to GAP has taken place as IR absorption at 745 cm^{-1} is absent in GAP. In the patent literature[14], 11 hours of reaction for complete conversion of PECH to GAP in DMSO has been recommended where chlorine content of GAP is reported to be 0.2%. This necessitated finding out the chlorine content in different samples of GAP prepared with different duration of conversions beyond 7 hours of reaction of PECH with sodium azide in DMSO at 100°C using FNAA. It is very interesting to note that a very substantial amount of $-CH_2Cl$ remains in GAP after 7 hours of reaction which demanded prolonging the reaction time. Table 7 gives the nitrogen, chlorine and oxygen content of different PECH and GAP samples measured by FNAA.

After 11 hours of conversion, the decrease in chlorine content with reaction peiod became asymptotic with time axis. However, in the present analysis, the chlorine content of (3.3%) was left out with GAP with the nitrogen content of 40.15% after 11 hours of reaction (Table 6).

Fig. 5 gives the γ-ray spectrum of GAP showing the photo-peaks induced due to nitrogen and chlorine. It also shows the photopeak induced due to aluminium and manganease which were used as the monitors for nitrogen and chlorine respectively. It is interesting to note that we have successfully used FNAA to estimate nitrogen, chlorine and oxygen in GAP simultaneously.

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TABLE 1 Nitrogen Content of High Explosives Measured by FNAA

Srl No	Compound	Molecular Formula	Percentage of nitrogen	
			Calculated	Experimental
1.	TNT	$C_7H_5N_3O_6$	18.5	19.5
2.	RDX	$C_3H_6N_6O_6$	37.8	38.9
3.	Picric acid	$C_6H_3N_3O_7$	18.3	19.1
4.	Tetryl	$C_7H_5N_5O_8$	24.3	23.2
5.	PETN	$C_5H_8N_4O_{12}$	17.7	16.9

TABLE 2 Nitrogen, Oxygen and Aluminium Content of Some Aluminized Explosives

Srl No.	Explosive Code No	Composition of Explosive						%N		%O		% Al	
		% RDX	% HMX	% TNT	% Al	% Wax	% Additive	Calc.	Expt.	Calc.	Expt.	Incorporated	Expt
1.	AX-1	74	-	-	20	6	-	27.9	27.1	31.9	29.5	20	20.6
2.	AX-2	19.04	-	52.3	23.8	5	-	16.8	16.9	30.3	29.6	23.8	26.6
3.	AX-3	-	74	-	20	6	-	28	27.1	32.0	31.4	20	22.5
4.	AX-4	48.5	-	33.5	18	0.05	-	24.5	25.7	35.1	36.1	18	21.3
5.	AX-5 (cast explosive)	58.82	-	-	21.56	2	17.64 (EP-4)	22.2	20.2	26.9	27.1	21.5	20.5

TABLE 3 Nitrogen and Oxygen Content of Double Base/Triple Base Propellants

Propellant*	Total nitrogen content(%)		Total oxygen content(%)	
	Calculated	Experimental	Calculated	Experimental
WM cordite	13.58	13.59	56.07	55.63
SC (Solventless cordite)	15.61	15.55	56.18	57.14
Triple base	32.96	32.78	49.00	48.64

* Composition :

WM-cordite, NC, 65% (12.2% N); NG, 29.5%; Carbamite, 2% and mineral jelly, 3.5%.

SC-Solventless cordite, NC, 49.5% (12.2% N); NG, 41.5% and carbamite, 9%

Triple base, NC, 27% (13.2% N); NG, 32%; picrite, 40%; Carbamite, 1% and K_2SO_4, 1%.

TABLE 4 Aluminium, Nitrogen and Chlorine Content of Some Composite and CMDB Propellants

Propellant Code No.	Total Aluminium Content % Incorp.	Expt.	Total Nitrogen Content % Cal.	Expt.	Total Chlorine Content % Cal.	Expt.
CP-1	5.0	5.1	9.04	9.9	22.6	21
CP-2	17.0	19.4	8.14	8.9	20.2	20
CP-3	17.0	16.92	8.31	8.98	20.6	21
CMDBP	3.0	3.4	13.57	13.52	1.8	2

* COMPOSITION

CP-1: AP, 75%; Al, 5%; Binder, 20% (HTPB: DOA, 60:40).

CP-2; AP, 67%; Binder, 15% (HTPB: DOA, 60:40); Additives, 1% (Undisclosed); Al, 17% .

CP-3; AP, 68.5%; Al, 17%; Binder, 13.5% (HTPB: DOA, 55.45); Additives, 1% (Undisclosed).

CMDBP; AP, 6%, Al 3%, Binder; 38% (casting liquid with known composition); RDX 14%, NC 39%.

(HTPB=Hydroxy Terminated Polybutadiene, Mn=2600, DOA = Dioctyl adipate, AP=Ammonium perchlorate .

TABLE 5 Nitrogen and Chlorine Content of Some Polymers

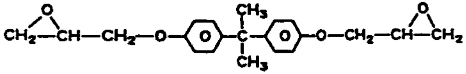
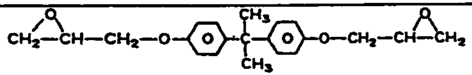
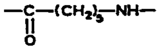
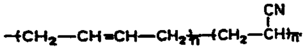
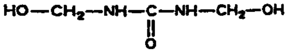
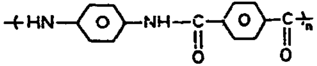
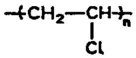
S.No.	Name of the Polymer	Polymer system	% N		% Cl	
			Calculated	Experimental	Calculated	Experimental
1.	Diglycidyl ether of bisphenol-A cured with ethylenediamine	 + $H_2N-CH_2-CH_2-NH_2$	3.23	3.413	-	-
2.	Diglycidyl ether of bisphenol-A cured with diethylenetriamine	 + $NH_2-CH_2-CH_2-NH-CH_2-CH_2-NH_2$	3.988	4.1	-	-
3.	Nylon-6	 $-\underset{\underset{O}{\|}}{C}-(CH_2)_5-NH-$	12.3	11.1	-	-
4.	Nilrile rubber	 $-(CH_2-CH=CH-CH_2)_n-(CH_2-\overset{\overset{CN}{\mid}}{CH})_m-$	12.27	13.5	-	-
5.	Urea formaldehyde resin	 $HO-CH_2-NH-\underset{\underset{O}{\|}}{C}-NH-CH_2-OH$	23.3	24.94	-	-
6.	Kevlar - 49		11.7	9.98	-	-
7.	Polyvinylchloride	 $-(CH_2-\underset{\underset{Cl}{\mid}}{CH})_n-$	-	-	56.8	55.9

TABLE 6 Fluorine Estimation of Some Teflon Samples by FNAA[1]

Sample No	Weight of fluorine, mg	
	Calculated	Estimated
1	76	72
2	104	110
3	152	160
4	228	218
5	304	315

TABLE 7 Elemental Analysis of Nitrogen, Chlorine and Oxygen in GAP by FNAA

Sample	No. of hours of reaction with sodium azide	Nitrogen %	Chlorine %	Oxygen %
PECH 1	-	0.00	40	21
GAP 1A	7	13	28	18
GAP 1B	8	25	16	20
GAP IC	9	28	13	18
PECH 2	-	0.00	42	17
GAP 2A	10	39	05	16
GAP 2B	11	40.15	3.3	16

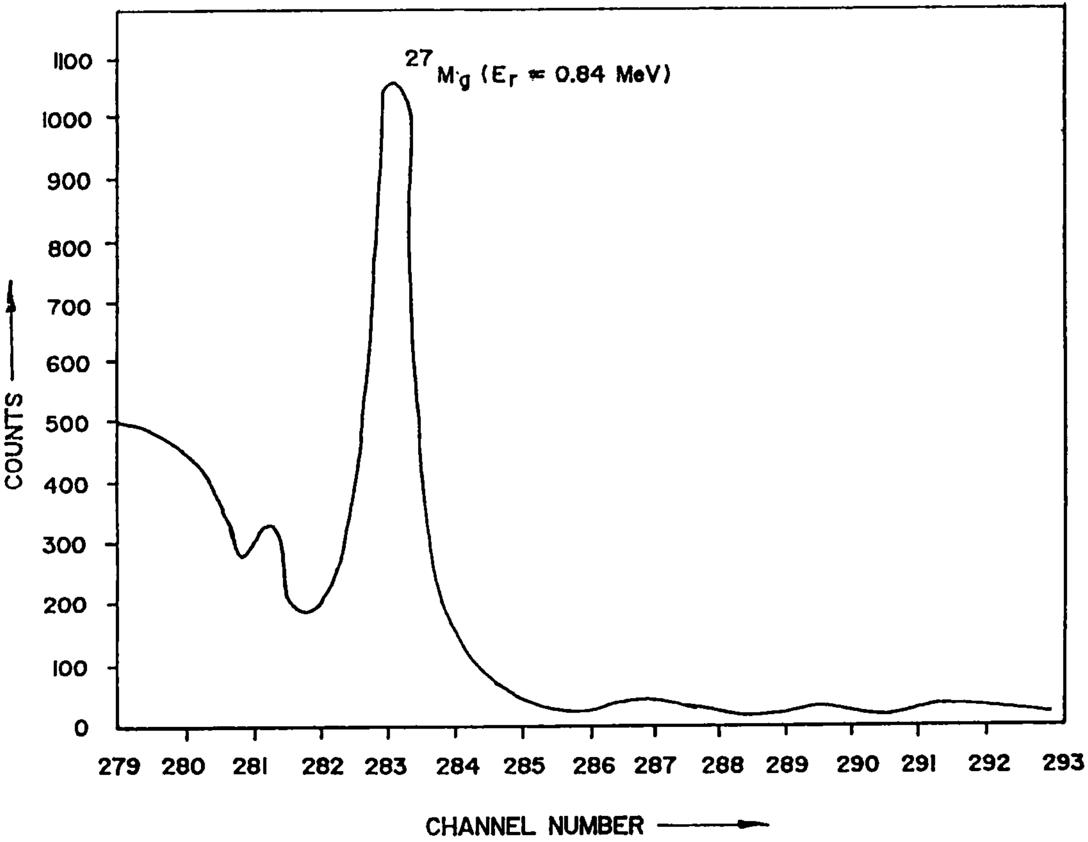


FIGURE 1

1. γ-Ray spectrum of AX_3 showing the photo peak due to ^{27} Mg.

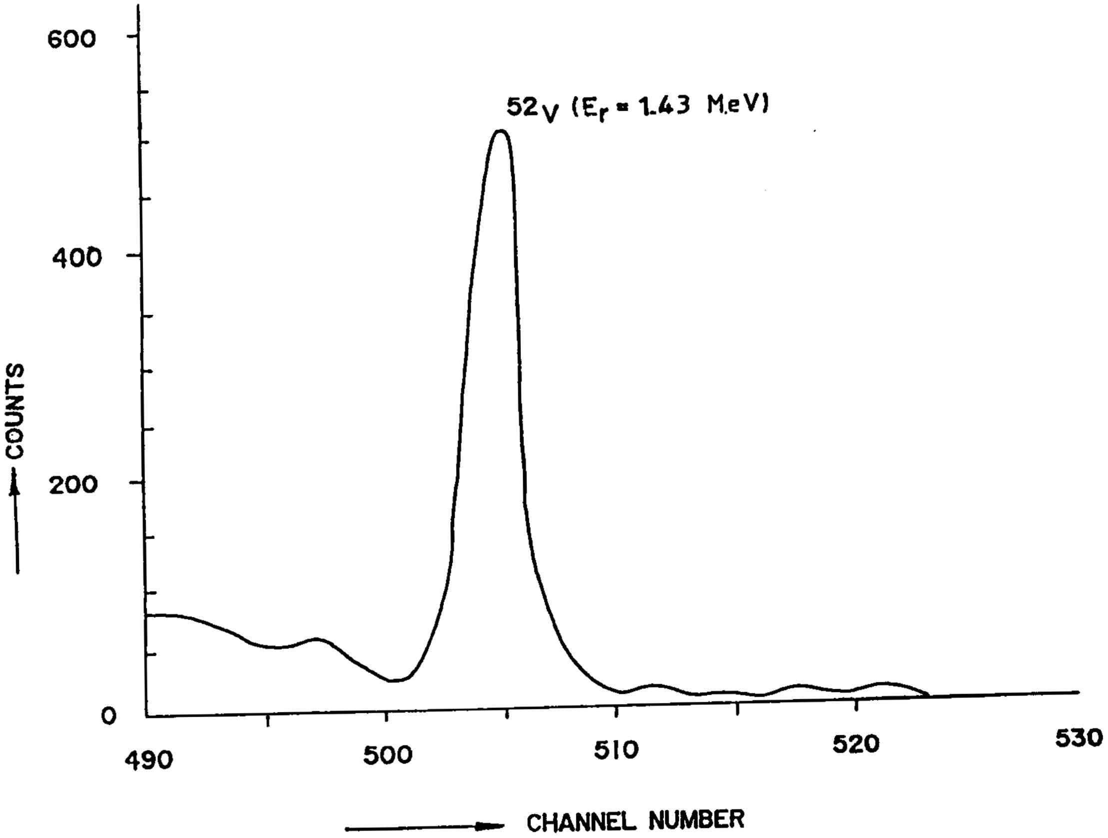


FIGURE 2

2. γ-Ray spectrum of AX_3 showing the photo peak due to ^{52}V.

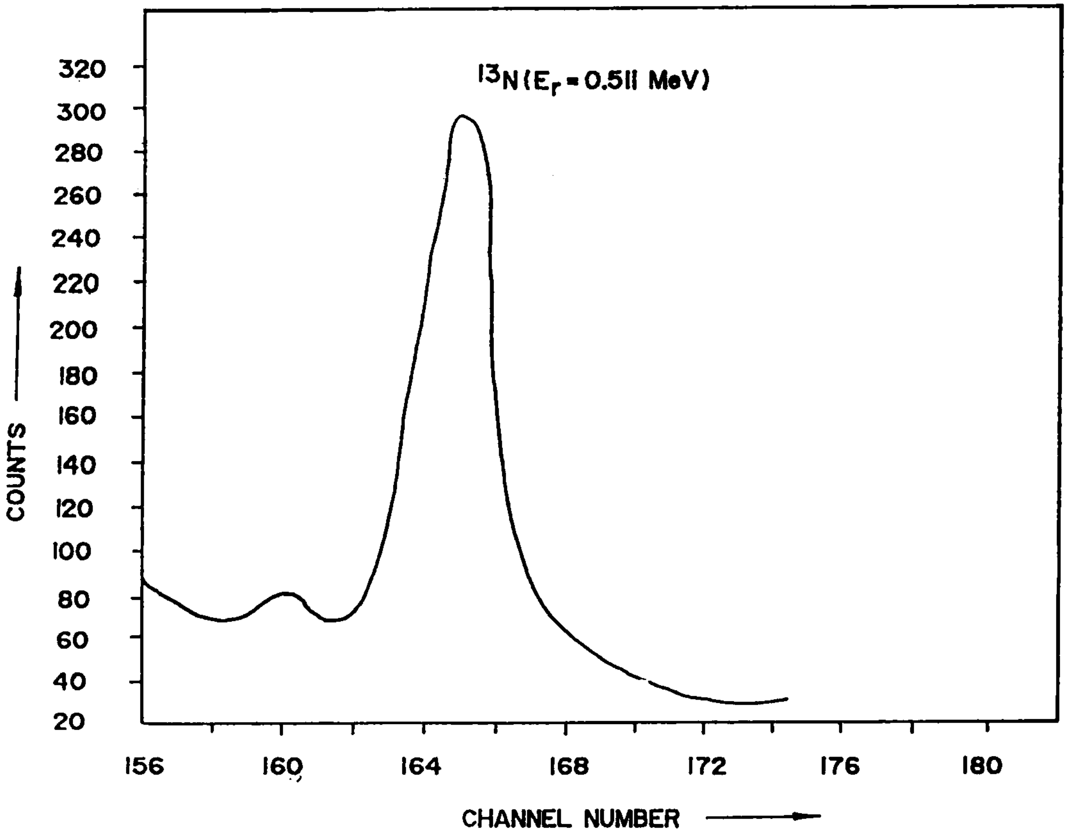


FIGURE 3

3. γ -Ray spectrum of CP-3 showing the photo peak due to ^{13}N.

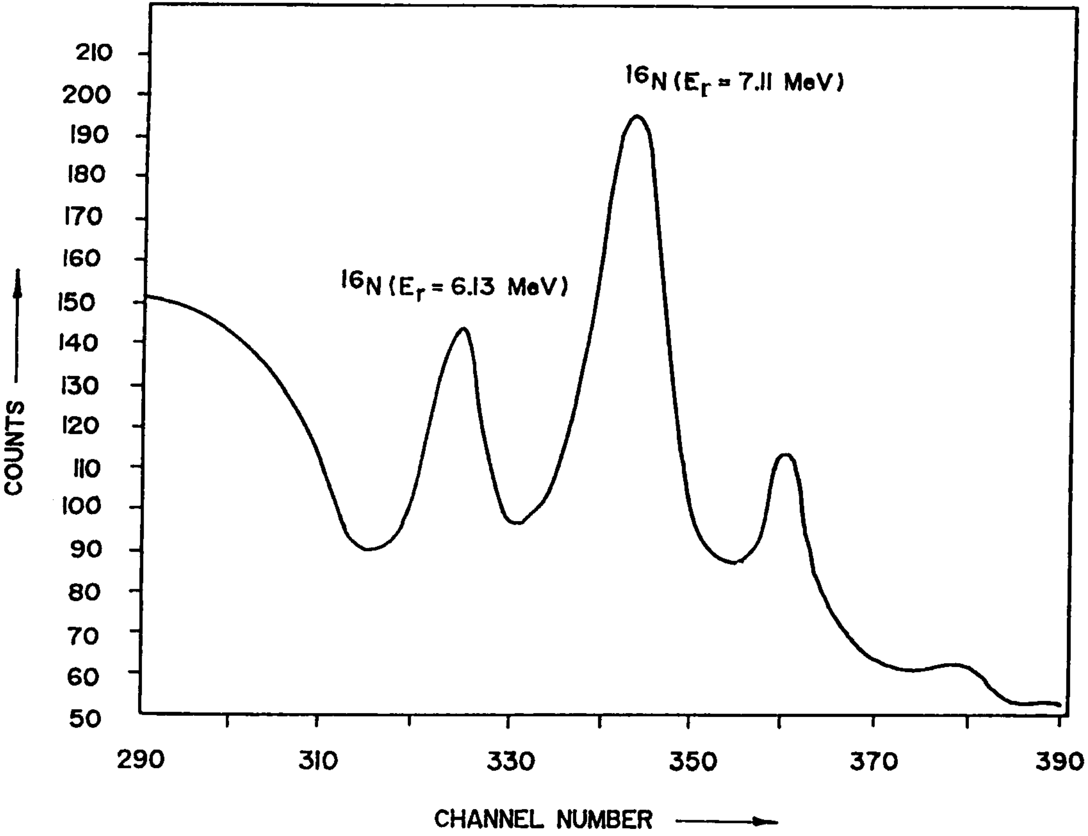


FIGURE 4

4. γ-Ray spectrum of CP-3 showing the photo peak due to ^{16}N.

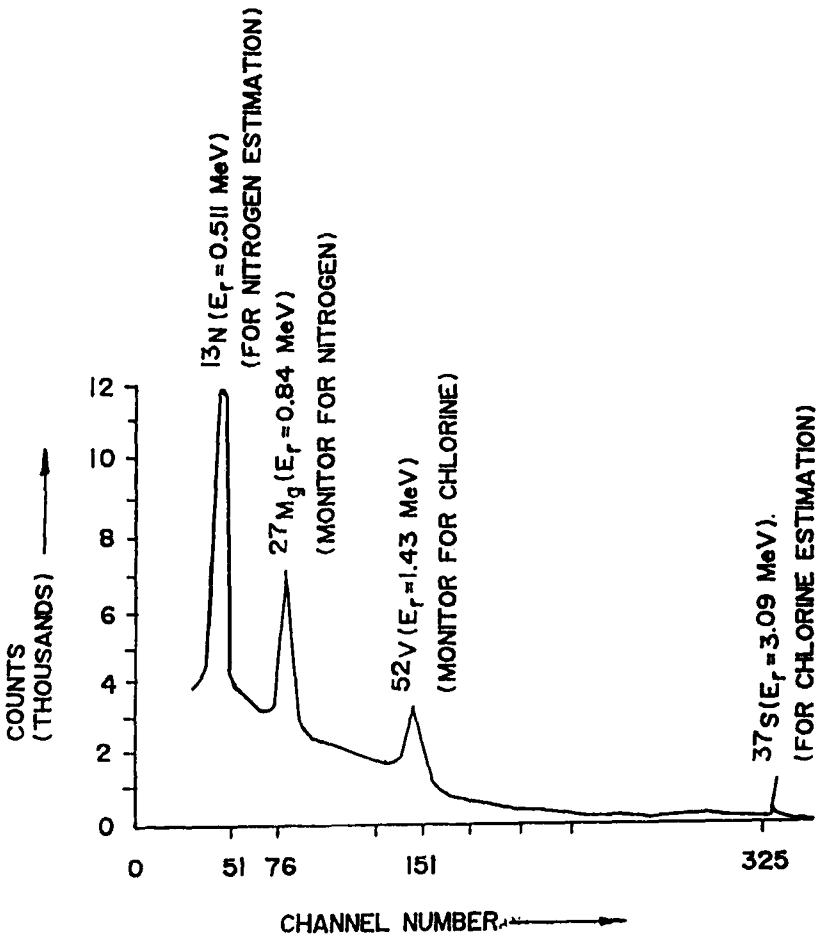


FIGURE 5

5. γ-Ray spectrum of GAP.