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Mass Attenuation Coefficients Of Rare Earth Oxides And Rare Earth Elements At Energies 42.0 Kev And 59.54 KeV.

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Abstract:
The mass attenuation coefficients were measured using gamma ray spectrometry based on NaI(Tl) scintillation detector at various energies with good collimated geometrical setup, in the gamma ray spectrometer with multi-channel analyzer experiment. In the present study fourteen rare earth oxides of Yttrium, Lanthanum, Cerium, Praseodymium, Neodymium, Samarium, Europium, Gadolinium, Terbium, Dysprosium, Holmium, Erbium, Thulium and Ytterbium and also rare earth elements were chosen. The cross sections for rare earth elements were extracted at two photon energies 42.0 KeV and 59.54 KeV. The results are compared with theoretical values of Strom & Isreal and Veigele by using XCOM programme. The cross sections at 42.0 KeV for Lanthanum is very large compared to other rare earth elements. This is due to the K-edge absorption energy of Lanthanum is nearly to the incident photon energy 42.0 KeV. From these measured attenuation coefficients total photon cross sections (σ_{comp}) in rare earth oxides were obtained. From the computed values of the total photon cross sections of rare earth oxides and the total photon cross sections of rare earth elements at 42.0 KeV & 59.54 KeV photon energies were determined. For this study 99.99% pure oxides were used. The variation in attenuation coefficient attributed to rare earth oxides and elements used.

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I. INTRODUCTION:

The present study of the interaction of photons with matter is serving a lot to the modern society. Day by day the importance of interaction of photons with matter is increasing in the fields of medicine, agriculture, biotechnology, radiography, space, industries and in modern diagnosis like CT scanning etc., the study of photon atom interaction in different materials has gained importance in recent years. Since these interactions involve various compounds with different compositions, that the effective atomic number of a material composed of several elements cannot be expressed by a single number, it can be concluded that it is an energy dependent parameter due to the different partial photon interaction processes with matter for which the various atomic numbers in the material have to be weighted differently. The effective atomic number Z_{eff} for the total and partial gamma ray interactions in alloys is equally important. A number of investigations on effective atomic numbers for total and partial photon interactions have been reported in the literature. Including both theoretical and experimental studies covering energies 42.0 KeV and 59.54 KeV. There was a study on few compounds in which the effective atomic number has been determined using the ratio of elastic-to-inelastic scattering. In the present work, wrought rare earth Oxides and Elements is subjected to mass attenuation coefficient and total photon cross sections of studies at 42.0 KeV and 59.54 KeV photon energies to estimate the corresponding effective atomic number values for total photon interactions. The mass attenuation coefficient values are measured from experiment and compared with theoretical values of Strom-Israel, and Veigele by the using XCOM program and these are in good agreement with experimental values.

II. ANALYSIS OF DATA:

The relations used in the present work are summarized in this section. The mass attenuation coefficients for wrought Nickel based alloys at different energies are determined by performing transmission experiments. This process is described by the following equation.

$$I = I_0 \exp(-\mu_m t) \quad (1)$$

Where I_0 and I are the un- attenuated and attenuated photon intensities $\mu_m = \mu/\rho$ (cm^2/g) is

the linear mass attenuation coefficient, t (g/cm^2) is sample mass thickness (the mass per unit area)

The total mass attenuation coefficient μm for any chemical compound or mixture of elements is given by mixture rule.

$$\mu_m = \sum_i w_i \left(\mu_m\right)_i \qquad (2)$$

Where w_i is the weight fraction (the proportion by weight) $(\mu m)_i$ is the mass attenuation coefficient of i^{th} element. For a material composed of multi elements the fraction by weight is given by

$$w_i = \frac{n_i A_i}{\sum_i n_i A_i} \qquad (3)$$

Where A_i is the atomic weight of the i^{th} element and n_i is the number of formula units.

The total atomic cross-section (σ_t) for materials can be obtained from the measured values of μm using the following relation

$$\sigma_t = \frac{\mu_m N}{N_A} \qquad (4)$$

Where $N = \sum_i n_i A_i$ atomic mass of materials, N_A is the Avagadro's number.

The total electronic cross-section (σ_e) for the element is expressed by the following equation

$$\sigma_e = \frac{1}{N_A} \sum \frac{f_i N_i}{Z_i} (\mu_m)_i = \frac{\sigma_i}{Z_{eff}} \qquad (5)$$

Where f_i denotes the fractional abundance of the element I with respect to the number of atoms such that $f_1+f_2+f_3+f_4+\ldots.f_i = 1$ Z_i is the atomic number of i^{th} element

The total atomic cross-section (σ_t) and total electronic cross-section (σ_e) are related to the effective atomic number (Z_{eff}) of the material through the following relation

$$Z_{eff} = \frac{\sigma_t}{\sigma_e} \qquad (6)$$

Finally, the average distance between two successive interactions, called the photon mean free path (λ), is given by

$$\lambda = \frac{\int_0^\infty x \ \exp(-\mu x) dz}{\int_0^\infty \exp(-\mu x) dx} = \frac{1}{\mu} \qquad (7)$$

Where (μ) is the linear attenuation coefficient and x is the absorber thickness.

III. EXPERIMENTAL PROCEDURE (Methods and Materials):

The present investigation are taken up with a view to estimate total photon cross sections in the energy region 30 to 662 KeV, in most of the rare earth elements and Oxides by conducting transmission experiments on a good geometry setup. In the present study 14 rare earth Oxides and Elements are chosen and the cross sections for rare earth elements were extracted at two photon energies 42.0 KeV and 59.54 KeV because very meagre experimental results are available at the energies. Two NaI(Tl) detectors were employed for the present measurements. The thin crystal detectors were used for the detection of X- and gamma photons in the energy range 30 KeV to 100 KeV. The other NaI(Tl) detectors with thick crystal was used for the detection of gamma photons of energy 145.4 KeV and 661.6 KeV.

a. Calibration of the Spectrometer:

The scintillation spectrometers assembled using the instruments described and thoroughly tested for stability, linearity and resolution characteristics to fix the best possible operation conditions, to carry out the present experimental investigations.

The percentage of resolution of the spectrometer, which is defined as the ratio of the full width at half maximum of the photo peak multiplied by 100 to the pulse height corresponding to the photo peak. It was determined as a function of high tension voltage and decay constant of the pulse amplifier. The spectrometer and detector with PC based 8K MCA used in the laboratory is shown in the Fig.1. The spectra obtained with different radioactive sources with thin and thick NaI(Tl) crystal at the best possible operating conditions have been shown in Fig 2. Whereas with the thin NaI(Tl) crystal detector, it was observed that, the spectrometer has an optimum resolution of about 12% at the same gamma photon energy with an optimum high tension voltage of +650 volts.

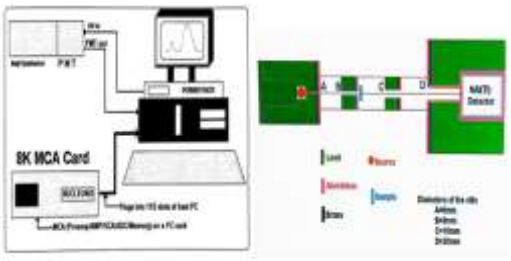


Figure 1: A PC based 8K MCA bloc diagram of Nuclear Electronic System

Figure 2: Schematic diagram of geometrical setup

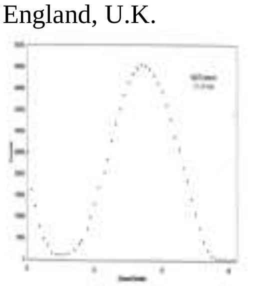
The linearity of the spectrometer was studied separately with thick and thin NaI (Tls)

crystal detectors, the spectral distribution between the pulse height and the photon energy using the standard sources are shown in Fig 4. The results plotted in figure 4 shown an excellent linearity over the photon energy region of interest.

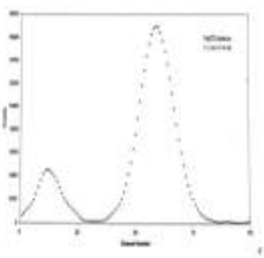
Experiments were also conducted to study the problems associated with the electronic drift in the instruments. To minimise these drifts, the line voltage is stabilized with an A.C. voltage stabilizer. Moreover the experiments were conducted in an air-conditioned room under conditions of constant temperature and humidity to minimise thermal drift in electronic instruments. The laboratory temperature is maintained at 22 ± 1^0 C thorough out the period of the present investigations. Normally a warm-up period of 3 hours was allowed for the spectrometer to attain the conditions of stability. The stability of the spectrometer was checked periodically. Repeated check on energy calibration showed that the linearity was being maintained at all times during the experiment.

b. Radioactive Source:

The radioactive isotopes used in the present investigation are Europium ($^{152+154}$Eu) and Americium (^{241}Am), their energies and half-lives are 42.0 KeV , 59.54 KeV and 16 years, 433 years respectively. Here Europium has obtained from the BRIT, Bhabha Atomic Research Centre, Trombay, Mumbai, India and Americium of strength 30 mCi source obtained from isotope division, Americium laboratories, Americium, Buckinghamshire, England, U.K.



Typical gamma ray spectrum of $^{152+154}$Eu (42.0 KeV)



Typical gamma ray spectrum of ^{241}Am (59.54 KeV)

Two types of sources were used in the present investigation. Sources in the form of radiographic capsule each of strength approximately 1mCi to 30mCi was used as a source of gamma energies. For X-energies the sources were prepared by drop deposition and evaporation of a liquid source of high specific activity,. In the method a small cylindrical grove drilled in Perspex container. The source is covered on the top with a thin Mylar foil to avoid contamination.

c. Samples:

The sample yttrium oxide, lanthanum oxide, cerium oxide, terbium oxide and Dysprosium oxide were obtained from Indian Rare Earth limited, India. And europium oxide, holmium oxide, erbium oxide, thulium oxide and yttrium oxide were obtained from Rare Earth products limited, United Kingdom.

The rare earth oxides were in powder from and the absorbers are prepared by filling the fine powder in Perspex cylindrical containers of different depths with inner diameter ranging from 1 to 1.5 cm. The empty containers are thoroughly cleaned. These containers are uniformly filled and were closed with a cover slip. The mass of the Perspex container with and without sample powder is determined in a electrical microbalance and is corrected to third decimal place. The inner diameter of the Perspex containers was determined with the help of travelling microscope. Using the value of the mass of sample powder and diameter of the container, the mass per unit area was determined.

Various thicknesses of the samples were prepared so that the statistical variation is minimum. During the transmission experiment an empty equivalent Perspex container is used to measure the incident photon intensity I0 without absorber. The uniformity of the thickness is tested by exposing the incident beam on the sample at various points on the surface of the sample. It is found that the absorbers are sufficiently uniform for the exposed areas of the samples.

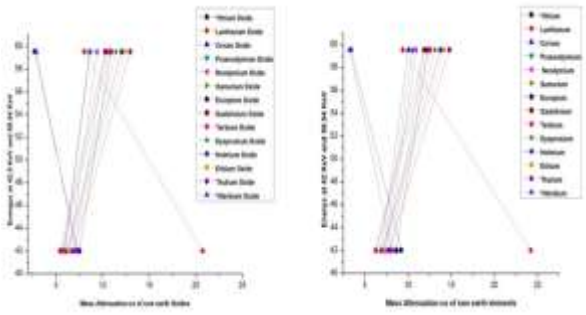
IV. RESULTS AND DISCUSSION

Utilizing the good geometry setup and employing the methods already discussed, the mass attenuation coefficients are measures in fourteen rare earth oxides at two photon energies 42.0 KeV and 59.54 KeV. The measured mass attenuation coefficients of rare earth oxides and elements at the energy 42.0 KeV are tabulated and shown in Table 2 and 3.

Sl.No	Name of the Rare Earth Oxides	Mass Attenuation		
		Strom &Isreal	Veigele	Experimental
1	Yttrium Oxide	7.337	7.313	7.297
2	Lanthanum Oxide	19.458	20.687	20.742
3	Cerium Oxide	5.883	5.955	5.824
4	Praseodymium Oxide	5.212	6.823	5.958
5	Neodymium Oxide	6.255	6.537	6.489
6	Samarium Oxide	6.909	7.181	6.978
7	Europium Oxide	7.256	7.549	7.486
8	Gadolinium Oxide	5.246	5.395	5.466
9	Terbium Oxide	5.481	5.301	5.874
10	Dysprosium Oxide	5.809	5.921	6.356
11	Holmium Oxide	6.098	6.218	6.287
12	Erbium Oxide	6.398	6.474	6.414
13	Thulium Oxide	6.701	6.798	6.824
14	Ytterbium Oxide	6.979	7.801	7.356

Sl.No	Name of the Rare Earth Elements	Mass Attenuation		
		Strom &Isreal	Veigele	Experimental
1	Yttrium	9.381	9.220	9.228
2	Lanthanum	23.715	24.216	24.729
3	Cerium	6.614	6.932	6.897
4	Praseodymium	6.364	7.11	7.213
5	Neodymium	7.254	7.583	7.522
6	Samarium	7.925	8.287	8.015
7	Europium	8.329	8.702	8.478
8	Gadolinium	6.089	6.181	6.364
9	Terbium	6.485	6.521	6.269
10	Dysprosium	6.631	6.759	7.001
11	Holmium	6.949	7.087	7.831
12	Erbium	7.206	7.379	7.904
13	Thulium	7.408	7.728	7.718
14	Ytterbium	7.903	7.999	8.149

Table 2: Mass attenuation coefficients of rare earth oxides (gm/cm^2) at energy (42.0 KeV).
Table 3: Mass attenuation coefficients of rare earth elements (gm/cm^2) at energy (42.0 KeV).



And the calculated mass attenuation coefficients of rare earth oxides and rare earth elements at the energy 59.54 KeV are tabulated in Table 4 and Table 5.

Sl.No	Name of the Rare Earth Oxides	Mass Attenuation		
		Strom &Israel	Veigele	Experimental
1	Yttrium Oxides	2.842	2.787	2.698
2	Lanthanum Oxide	7.788	8.082	8.046
3	Cerium Oxide	8.227	8.325	8.617
4	Praseodymium Oxide	8.318	8.682	8.831
5	Neodymium Oxide	8.011	8.468	8.384
6	Samarium Oxide	9.752	10.332	10.392
7	Europium Oxide	10.167	10.885	10.862
8	Gadolinium Oxide	10.391	10.523	10.325
9	Terbium Oxide	9.991	10.289	10.894
10	Dysprosium Oxide	10.538	11.400	12.421
11	Holmium Oxide	10.915	11.929	12.828
12	Erbium Oxide	11.417	12.435	12.398
13	Thulium Oxide	11.864	13.007	12.813
14	Ytterbium Oxide	2.814	2.874	2.982

Sl.No	Name of the Rare Earth Elements	Mass Attenuation		
		Strom &Israel	Veigele	Experimental
1	Yttrium	3.158	3.487	3.374
2	Lanthanum	9.112	9.388	9.403
3	Cerium	9.864	10.813	10.860
4	Praseodymium	10.160	10.811	10.748
5	Neodymium	10.479	11.003	10.923
6	Samarium	11.278	11.956	11.983
7	Europium	11.765	12.551	12.274
8	Gadolinium	11.948	11.858	11.667
9	Terbium	11.718	12.651	12.544
10	Dysprosium	12.066	13.090	13.108
11	Holmium	12.522	13.656	13.748
12	Erbium	13.036	14.291	14.156
13	Thulium	13.533	14.858	14.788
14	Ytterbium	3.178	3.246	3.233

Table 4: Mass attenuation coefficients of rare earth oxides (gm/cm^2) at energy (59.54KeV)

Table 5: Mass attenuation coefficients of rare earth elements (gm/cm2) at energy (59.54 KeV)

In the present measurements the statistical error is limited to less than 1% by collecting a sufficient number of counts under the photo peak for the selected region of interest (ROI). The percentage deviation due to the non-uniformity of the absorbers was estimated using the fundamental relation. This has been minimized by following the counting sequence of the Conner *et al. (1970).* The errors due to this method will be almost of the order of 0.5%. The extrapolation technique described earlier eliminates the error due to multiple scattering. The overall errors introduced on the total photon mass attenuation coefficients are thus around 0.9%.

i) The measurement of mass attenuation coefficients in fourteen rare earth oxides on good geometry setup and evaluation of total photon cross sections.

ii) Extraction of the total photon cross sections of rare earth elements using mixture rule and comparison with theoretical values of strom and Israel, compiled data of veigele.

iii) Discussion of the present experimental results in the light of available experimental values.

iv) Extraction of total atomic photoelectric cross section and comparison of the results with the theoretical and earlier experimental values.

The present investigation forms a comprehensive study on the total photon and effective atomic numbers in some nickel based alloys and special alloys leading to the following useful information.

The total mass attenuation cross sections measured in fourteen rare earth oxides at two photon energies in the present investigation are in good agreement with the theoretical compilations of Storm and Israel proving the validity of mixture rule for compounds or alloys. The references related work done by the previous researches are listed below.

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