

## DETERMINATION OF MINIMUM DETECTABLE CONCENTRATION OF IRON (Fe), MANGANESE (Mn), FERRIC OXIDE (Fe<sub>2</sub>O<sub>3</sub>) AND MANGANESE (IV) OXIDE (MnO<sub>2</sub>) FROM THALLIUM ACTIVATED SODIUM IODIDE [NaI (Tl)] DETECTOR

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### ABSTRACT

*A dual irradiation procedure with and without cadmium (Cd) cover was adopted with a 5Ci Am-Be Isotopic Neutron source (Thermalised with paraffin wax). The 76cm × 76cm NaI (Tl) detector coupled to a computer based Multi channel analyzer (MCA) via electronic module has detectable concentrations of Fe, Mn, Fe<sub>2</sub>O<sub>3</sub> and MnO<sub>2</sub> with NaI (Tl) detector. Standard samples of manganese (IV) oxide [MnO<sub>2</sub>, 100% pure] and ferric oxide [Fe<sub>2</sub>O<sub>3</sub> 85% pure] were used. A time of 20 hours irradiation, 1800 seconds counting time for the background, 1200 seconds counting time after irradiation 22 minute decay time were adopted. A region of interest (ROI) of 846.7 KeV gamma ray line of the reaction <sup>55</sup>Mn(n,γ)<sup>56</sup>Mn and <sup>56</sup>Fe (n,p) <sup>56</sup>Mn in combination with neutron flux parameter at the irradiation site and Nuclear data were used in the analysis.*

**KEYWORDS:** Irradiation, detector, minimum detection limit, nuclear data.

### INTRODUCTION

The NaI (Tl) detector is a type of detector within a class known as scintillation detectors. It has been a universal one in a very wide range of high energy physics experiments. It makes use of the fact that when gamma rays (γ-rays) penetrate into the NaI crystal, it interact with the atoms inside the crystal and the interaction causes emission of electrons from the atom interacted and travel short distance within the crystal (Bartle, 1994).

The level of interaction of a radiation with matter is expressed as the interaction cross section. If there is a neutron flux  $I$  incident on a target of  $n$  nuclei per unit area, then the number of interaction per unit time is proportional to both  $\phi$  and  $n$

$$\frac{dn}{dt} = n\phi\sigma \dots\dots\dots(1)$$

Where  $\sigma$  (cross section) is a constant having dimension of area called barn; 1 barn = 10<sup>-24</sup>cm<sup>2</sup>

In the NaI (Tl) detector, Thallium (Tl) is used as a dopant for NaI because it helps to increase the number of visible photons (Leo, 1994; Nakamura et al., 2002).

The visible photons are detected by a photocathode to produce an electric signal, which are amplified (by a photo multiplier tube, PMT) and processed to create a γ-ray spectrum by MCA (Leo, 1994). The first consideration for a detector is its sensitivity. According to Leo(1994) no detector can be sensitive to all types of radiation at all energies. They are designed to be sensitive to certain types of radiations in a given energy range.

In physics research, scintillators are used to detect electromagnetic waves or particles. It converts the energy of the particles to light of wavelength which can be detected by detectors such as PMT. Research of trace elements in

materials is now a universal phenomenon in the field of science and technology. According to (Jonah et al., 2004, Elegba et al., 1998) the trace elements of any sample from chemical method is often susceptible to errors due to closeness of atomic numbers in most elements.

The decision "detected" or "not detected" is made by comparing the estimated quantity ( $Q$ ) with critical value ( $Q_c$ ) of the respective contribution such that the probability of exceeding  $Q_c$  is no more than  $\beta$  if analyte is absent ( $Q = 0$ , null hypothesis). The critical value is thus the minimum significant value of an estimated signal or concentration, applied as a discriminator against background noise. According to (Currie, 1999) least detectable signal is expressed as:

$$L.D = 2.71 + 4.65\sqrt{B} \dots\dots\dots(2)$$

$B$  is the gross counts of the background. (Wada, 2007; Currie, 1999) gave the expression for minimum detectable signal, by definition, as

$$M = \frac{L.D_m}{N_p t_m} \times \% \text{ element or compound} \dots\dots\dots(3)$$

where  $t_m$  is live time of the gross count,  $t_m$  is the counting regimes of the irradiated samples,  $N_p$  is the net count of the irradiated samples,  $L.D$  is the least detectable signal and  $M$  the minimum detectable signal. In nuclear reaction, most trace elements in a sample are due to contribution of both thermal and threshold reactions known as interference. Cadmium (Cd) cover as a good thermal neutron absorber is normally employed to eliminate possible reactions (interference) due to the thermal reactions.

### MATERIALS AND METHODS

The standard samples of MnO<sub>2</sub> (100% pure) and Fe<sub>2</sub>O<sub>3</sub>, (85% pure) in powder form were respectively packed in a vial (plastic sample holder) of diameter 2.5cm and height 4.8cm for the experiment (for irradiation without Cd cover). The mass of each sample in the vial was found as recorded in table 1 A cylindrical Cd cover of diameter 3.0cm and height 7.0cm were constructed from a sheet of 1mm thick Cd. It covered both sides and bottom of the vial for irradiation with Cd cover. Both the vial and the Cd cover are identical in dimension with the neutron source. A detail description of the irradiation facility and NaI (TI) detector has been given by (Isa, 2002), Jonah et al, 1998).

The electronic components connected via the NaI (TI) detector were pre- set the spectra of the detector with no sample inside it was collected for a set live time of 1800 seconds and the gross count (B) of the background for the set

time using region of interest (ROI) of 846.7 KeV Gamma ray line of energy of the high purity MnO<sub>2</sub> irradiated with Cd cover was found as 9105.

Dual irradiation procedures for the standard samples were carried out with and without Cd cover respectively. Irradiation without Cd cover in the facility used produced <sup>56</sup>Mn due to <sup>55</sup>Mn (n, γ) <sup>56</sup>Mn with thermal neutrons and <sup>56</sup>Fe (n,p)<sup>56</sup>Mn with fast neutrons reactions. Irradiation Cd cover produced <sup>56</sup>Mn due to <sup>56</sup>Fe(n, γ) <sup>56</sup>Mn reaction due to fast neutrons. After irradiation with and without Cd cover for 20 hours for each sample. It was then put in the NaI (TI) detector and under the detection arrangement the respective peak count (I) for a set live time of 1200 seconds after 22 minutes decay time was collected. The net count (N<sub>p</sub>) for each sample was found under buffer when peak count (I) was merged with the spectra of the created ROI. The results are shown in table 1.

**Table 1:** The (n, γ) measured and calculated data of the 20 hours irradiation, 20 minutes counting time after decay time of 22 minutes each from the NaI (TI) detector.

Sample	Sample weight w(g)	Net count (N <sub>p</sub> ) without Cd cover	Net count (N <sub>p</sub> ) with Cd cover
MnO <sub>2</sub>	45.657	1182263 ±2149	109116 ±742
Fe <sub>2</sub> O <sub>3</sub>	6.485	735 ±329	880 ±314

The result of the measured net-count (N<sub>p</sub>) counts of the standard samples MnO<sub>2</sub> (100% pure) and Fe<sub>2</sub>O<sub>3</sub> (85%) due to irradiation with and without cadmium cover are presented in table1. The minimum detectable concentrations of Fe, Mn MnO<sub>2</sub> and Fe<sub>2</sub>O<sub>3</sub> the NaI (TI) detector detected from the sample in respect to thermal, epithermal to fast neutrons were found using equations (2) and (3) and the results are presented in table 2. Fast neutrons reactions, irradiation with Cd cover produced <sup>56</sup>Mn due to

<sup>56</sup>Fe(n,y)<sup>56</sup>Mn reaction due to fast neutrons. After irradiation with and without Cd cover for 20 hours for each sample, it was then put in the NaI (TI) detector and under the detection arrangement the respective peak count (I) for a set live time of 1200 seconds after 22 minutes decay time was collected. The net count (N<sub>p</sub>) for each sample was found under buffer when peak count (I) was merged with the spectra of the created ROL. The result are shown in table1.

**Table 2:** The NaI (TI) detector detection limit from <sup>55</sup>Mn(n, γ)<sup>56</sup>Mn and <sup>56</sup>Fe(n,p)<sup>56</sup>Mn reactions.

Detection Element and their oxides	Detection limit		Calculated concentration from standard sample %
	Thermal neutrons%	Epithermal to fast neutrons%	
MnO <sub>2</sub>	0.028	0.273	100.000
Mn	0.018	0.175	63.636
Fe <sub>2</sub> O <sub>3</sub>	**	28.746	85.000
Fe	**	20.088	59.398

\*\* Thermal neutrons are absent in fast neutrons reaction.

### RESULTS AND DISCUSSION

Using the result in table 1, and after computing the elements concentration in their oxides of the standard samples couple with the use of equations (2) and (3), the minimum detectable concentrations of the concerned element from

the NaI (TI) detector were found as recorded in table 2. The gross count (B) of the background of the NaI (TI) detector with no sample for 1800 seconds set live time using 846.7Kev line of energy was found to be 9105.

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#### CONCLUSION

The minimum detectable elements and compounds concentration the NaI (TI) detector detected in this work were 0.018wt%Mn by thermal neutrons; 0.175wt%Mn by epithermal to

fast neutrons; 28.746wt%Fe<sub>2</sub>O<sub>3</sub> by epithermal to fast neutrons and 20.088wt%Fe by epithermal to fast neutrons as presented in table 2. It also showed that in nuclear reactions, most trace elements in a sample are due to the contributions of both thermal and epithermal to fast (threshold) reactions known as interference and the use of cadmium cover as a good thermal neutrons absorber yield the reaction due to threshold.

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