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Neutron Activation Analysis Of Heavy Elements in the Environment

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ABSTRACT

The main focus of the research is an application of neutron activation analysis (NAA) to determine concentrations and distribution of heavy metals in environmental samples. Due to human activity and industrialization, heavy metal pollutants have been accumulating in the environment.
The principle of NAA is that traces of various elements can be identified and measured by analyzing the gamma rays they give off after being irradiated with neutrons.

The project is conducted online by using, summarizing, analyzing, and organizing relevant literature, articles, and data that are available via open sources, and the world wide web. This project will focus on the application of NAA to the detection of high atomic number elements or heavy elements in the environment which could cause health problems for plants, animals, and human beings.

PRINCIPLE AND METHOD

Figure 1. illustrates the principle of NAA technique of analyzing the gamma rays given off after the target nucleus element was irradiated.[1]

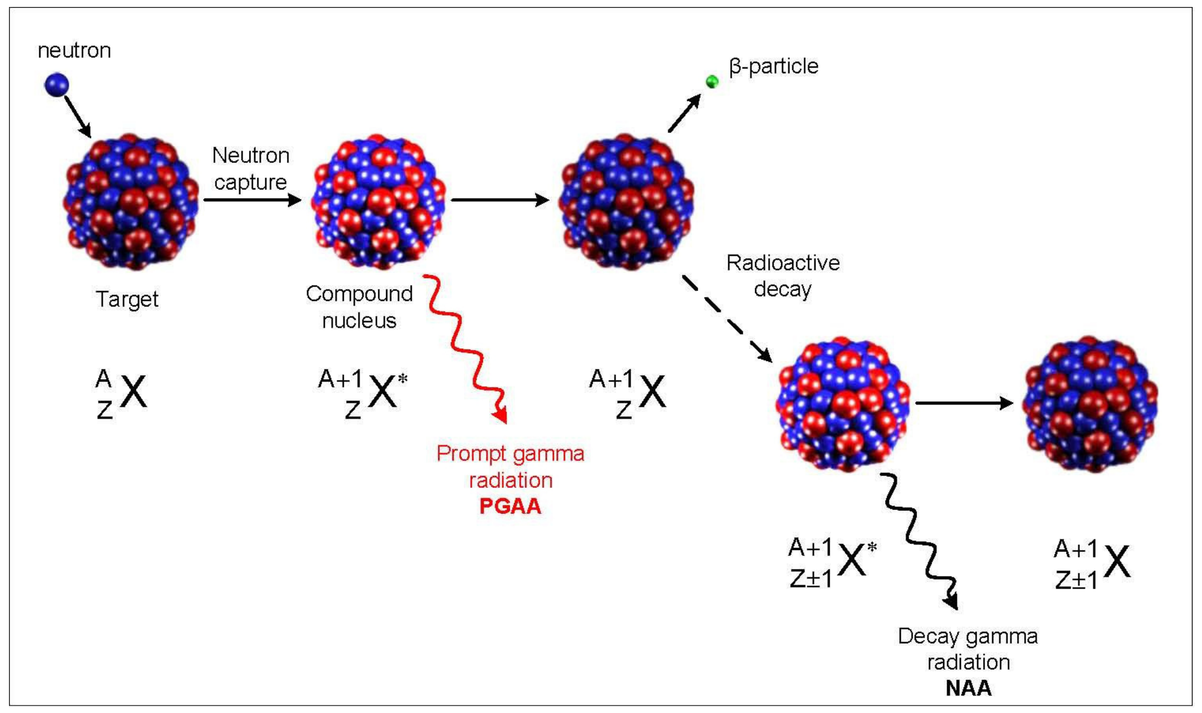

Figure 2. Neutron Activation of heavy metals from a research article shows distinctive gamma-radiation and the decay times of each specific radionuclide produced [Reference 4, Table 1].

Table 1

NEUTRON ACTIVATION OF As, Se, Cd, Hg

(e.g.) ^{75}As + neutron ⟶ ^{76}As (27 h)

Natural Element	Nuclide Produced	γ-Radiations (MeV)	Sensitivity* (g)
As-75	As-76 (27 h)	0.56, 1.2	3×10^{-11}
Se-74	Se-75 (120 d)	0.26	2×10^{-9}
Cd-114	Cd-115m (54 h)	0.54, 1.1	6×10^{-10}
Hg-196	Hg-197 (65 h)	0.777	5×10^{-11}
Hg-202	Hg-203 (45 d)	0.28	2×10^{-10}

* Sensitivity based on 50 h activation at 10^{13} neutron flux minimum detectable radioactivity of 1000 disint/min.

INTRODUCTION AND BACKGROUND

Neutron activation analysis (NAA) is one of the nuclear techniques that has many useful applications, such as bio-monitoring, biological analysis, environmental research, and materials science. One advantage of this technique is that: it is a non-destructive analytical method that is suitable for tracing low concentrations, especially rare elements, and heavy metal elements. The heavy metal elements (such as mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), thallium (Tl), and lead (Pb)) tend to be toxic and their presence in the environment is problematic for the plant, animal, and human health. Using NAA, we can find both the identity and quantity of a specific element. In other words, this technique helps identify the elements in samples, and their concentrations at the same time.

Background:
In May 1932, the neutron was first discovered by James Chadwick as an uncharged particle of the atomic nucleus. After the discovery of the neutron, neutron activation analysis was first suggested by G. Hevesy and H. Levi in 1936. At that time, they were using a neutron source: radium-226 mixed with beryllium (Ra-226 + Be) to measure activated Dy (dysprosium) atoms.[1],[2]

PRINCIPLE AND METHOD

The principle of NAA is quite simple. To analyze samples by NAA, the process involves irradiating them with a neutron source. The neutrons are captured by elements in the sample (**Figure 1**) to produce **radionuclides**, which are unstable radioactive isotopes (isotopes are different types of atoms that have the same atomic number with a different number of neutrons in their nuclei, in short, a radioactive form of an element). Beta particles (**β**-particle), and in most cases gamma rays (γ-rays), are emitted from the radionuclides as they decay[1],[3].
According to research conducted by R.E. Jervis and others, the analysis process of applying the radioactivation nuclear method depends on:
(i) the activation probability factor for the particular element of interest
(ii) the half-life of the **radionuclide** that can be created in it
(iii) the existence of suitable beta(**β**-) or gamma(γ-) radiations for measurement. [4]

Figure 2 (table 1 from reference 4) shows each radionuclide of a specific heavy element gives off distinct energy of the gamma radiation (γ-radiation), which is distinctive for a specific nuclide and the rate at which these photons are emitted with particular energy can be measured using special radiation detectors.

To **determine the element:** using the distinctive γ-rays that are emitted from the sample in relatively high abundance, the elements of interest can be distinguished in the spectrum of γ-rays from the activated sample.[4] Since the production and decay rate of γ-radiation are dependent on the half-life of the nuclide, elemental measurements can be optimized by varying the irradiation and the decay times (i.e., how long the sample is near a neutron source and when the sample is analyzed). [3]

To **determine the element concentration:** The rate at which gamma(γ-) rays are emitted from an element in a sample is directly proportional to the concentration of that element.[3]

AN EXAMPLE OF NAA APPLICATION

One specific example of NAA application was shown in research[4] published in 1970 conducted by R.E. Jervis and others. Non-destructive or Instrumental NAA (INAA) for determining Mercury (Hg) concentration in fish: The mercury content in the fish samples taken from various water bodies in Ontario and elsewhere were determined in the concentration range from 0.01 to 2 ppm.[4] The result of this research was shown in **Figure 3**.

Figure 3. Typical mercury (Hg) content in Ontario Fish [in reference 4]. Note *Reference (4) is stated [in references 5]

Typical Hg Content in Fish

	Species	Hg Content* (ppm, wet wt. basis) Lower Range	Maximum Observed
Piscivorous (predatory) Species	Pike, Walleye, etc.	0.3	1.6
Deep-water Feeders	Whitefish, Perch, etc.	0.07	0.7
Bottom-Feeders	Sucker, Carp, etc.	0.05	0.5
Ocean	Salmon	----	0.4

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* Reference (4)

TYPES OF NAA

NAA can be categorized into two broad types:
-Destructive or Radiochemical NAA (RNAA):
A method of NAA in which chemical separations are applied after the irradiation to separate activities of interest from interfering activities.[2]
-Non-destructive or Instrumental NAA (INAA):
The most widely applied method of NAA, in which no chemical procedures are applied before or after the irradiation. The selectivity of activities of interest is accomplished by the measurement after different decay times and by the use of special radiation detectors.[2]

CONCLUSION

NAA is a significant and powerful technique complementary with other assay methods for tracing and measuring low concentration heavy elements in specific samples.

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