Delayed Neutron Activation Analysis

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Introduction to NAA

- NAA is a quantitative chemical method based on nuclear activation of a sample
- It focuses on radioactivity of the nuclides formed
- Used in two main cases
  - Radioactive nuclei emitting radiation (delayed time measurements are used)
  - Stable elements possessing undesired radiation, which is emitted immediately (prompt measurements are used)

Overview of Delayed Neutrons

- Interactions of fissionable nuclei may produce radioactive products
- Consequently, more than one neutron may be emitted by these products
- Timing of a delayed neutron reaction is governed by rate of β-decay

Delayed Neutron Emission in Fission

- A material is irradiated
  - May give way to one or more radioactive components
  - These radioactive components may have the capability to emit neutrons
  - If they do, they are referred to as delayed neutron precursors (DNPs)

More on DNPs

- DNPs are radionuclides that have the capability to emit neutrons
  - Generally have few neutrons in excess of a fully-occupied, closed neutron shell
  - Due to low binding energy of the loose neutrons, greater probability that those neutrons will be emitted
  - Those nuclides that cannot emit neutrons undergo subsequent β-decay instead

Emission of Delayed Neutrons

- DNPs emit ‘late’ neutrons which are referred to as *delayed* neutrons
- The β-decay of the radionuclide with high decay energy fills excited states
  - These states possess greater energy than the neutron binding energy of the nuclide
- Excited states “de-excite” themselves by emitting neutrons

Examples of DNPs

- Some of the more common examples of DNPs
  - ^{85}As
  - ^{87}Br
  - ^{135}Sb
  - ^{138}I

Delayed Neutrons on a Larger Scale

- In a given nuclear reaction, delayed neutrons make up less than 1% of total neutron emission
- 30% of delayed neutrons are emitted less than 1 second after fission reaction
- This type of emission is rarely used for non-fissionable materials
- Most common fissionable materials are Uranium, Thorium, Plutonium

Experimental Setup

- Irradiation source
  - Provides light, or energy, to induce a nuclear reaction
- Detection System
  - Moderators (paraffin, polyethylene, water)
  - Shielding from gamma rays
  - Neutron detectors

Neutron Detectors

- Common ones are ^{3}B-BF_3 or ^{3}He detectors
- Substances have been chosen based on their sensitivity to impulses generated by neutron emission
- Are tubes placed in a cylinder filled with moderator

Experimental Setup (cont.)

- Sample chamber is at the center of a cylinder
- Cylinder surrounded by shielding to protect sample from interference of gamma rays
- Discriminator (single-channel analyzer) may be placed on the outside

Use of Delayed Neutrons in Detecting Trace Elements

- Method may be used to determine concentration of fissionable isotopic mixtures of one element
- May also be used for multi-element mixtures of two fissionable elements

Methodology

- Irradiation of the material
- Reaction produces DNPs
- Amount of radioactive atoms present is detected by the system
  - Amount of radiation depends on number of atoms activated
  - Number of atoms activated is proportional to number of atoms in the target sample
- Can analyze the elemental contents of sample

Basic Steps

- Nuclear activation of the material by irradiation
- Count the neutrons emitted
- Identify the type of radiation emitted
- Determine its energy or half-life
- This may allow researcher to identify the element in the sample and its quantity

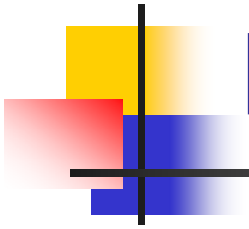
Common Sources of Error

- Sampling errors
- Measuring the weight of the sample
- Timing of irradiation
- Counting system
- Data reduction
- Low efficiency of the detectors

Importance of Delayed Neutrons in Nuclear Reactors

- Time delay is controlled by the half life of the β-decay precursors (DNPs)
- In nuclear reactor, nuclear reaction must be controlled
- Time delay in delayed neutron emission provides ample time for control
- Substantially increases average time between generations of neutrons

Importance of Delayed Neutrons in Nuclear Reactors



- Consequently, delayed neutrons can control the reactor's period
  - Even true in fast reactors, where reactors deal mainly with fast neutrons
- Also, amount of decay heat after reactor shutdown is determined by the delay time

Other Applications

- Nuclear physics
  - Delayed neutron emission used as a tool for studying the fission process and molecular interactions
- Astrophysics
  - Used in rapid-neutron capture, which is frequently used to estimate the age of the galaxy or universe

Concluding Remarks

- NAA has long been known as a reliable method for detecting major, minor, trace or bulk elements in samples
- Delayed neutron emission provides one more option
  - Allows for control in nuclear reactors
- More research should be done on its application in other fields

Main References

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