The Process of Epithermal Neutron Activation Analysis

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ENAA

- NAA most commonly uses thermal neutrons (0.0253 eV)
- Fast neutrons (>1MeV)
- Epithermal neutrons (1Mev – 1eV)
- Thermal neutrons (<1eV)
- Vast majority of neutrons in fission reactor are thermalized.

Reaction Rate

- The formula can be used to calculate the rate of neutron capture for thermal and epithermal neutrons.
- $R = \Phi th*\delta + \Phi epi*(I + 0.44*\delta)$
- Φth = thermal neutron flux
- δ = thermal neutron cross-section (probability of thermal neutron capture in cm^2)
- Φepi = epithermal neutron flux
- I = resonance integral (equivalent of epithermal neutron cross-section)
- $0.44*\delta$ takes the 1/v characteristic into account

Cadmium Ratio

To compare ability to activate nuclide by epithermal activation compared to thermal activation.

$$Rcd = \frac{(\Phi th*\delta + \Phi epi*(I + 0.44*\delta))}{(\Phi epi*(I + 0.44*\delta))}$$

- In comparison to Au, only need to have the thermal cross-section and resonance integral of isotope.

$$Rcd=1+\frac{\delta*(0.44*\delta(Au) + I(Au)}{\delta(Au)*(0.44*\delta + I)}*(Rcd(Au)-1)$$

Cadmium

- Common thickness for ENAA is 0.7 mm
- Cadmium cutoff is 0.4 eV, absorbs nearly all neutrons below this energy level.
- Nuclides with resonances below 1 eV: Eu-158, Yb-368, Lu-176, and Ir-191
- 1/2,000 thermal neutrons pass Cd barrier
- Rcd >20, there should be 1/10^5 thermal neutrons that make it past Cd barrier, 1.5 mm thick
- Foil more efficient than lined ports because foils will absorb thermal neutrons scattered at all angles

Advantage Factor

- Effectiveness of ENAA
- Fa = (Rcd)d / (Rcd)D
- d is for interference nuclide, for silicate nuclides: Na-23 (Fa < 2)
- D is for the nuclide experimenter is searching for: Ag-109 (Fa = 26)
- More than 20 trace elements in silicate rocks have Fa > 20
- A table of advantage factors for various isotopes can be found in Steinnes, Epithermal Neutron Activation Analysis of Geological Material

Silicate Rocks

- ENAA good for finding elements with high I / δ, excellent epithermal neutron capture properties compared to thermal neutron capture properties.
- Examples: Sc, Hf, Ta, U, Th, Rb, Sr, Cs, Ga , In, Cd, Au, and Pd
- ENAA helps to reduce interference of major and minor elements that usually have low I / δ.

Advantages of ENAA

- Provides improvement in the precision and sensitivity in instrumental activation analysis
- Reduction of high activity levels caused by more numerous major and minor elements
- Thermal fission interference of U-235 reduced, would have produced radioactive daughter products, gamma rays, and fast neutrons.
- An example of INNA compared to ENAA can be found in Fig. 3 of Steinnes, <u>Epithermal neutron actiavation analysis of Geological Material</u>

Unpopular analytical process

- Not as routinely applicable as instrumental neutron activation analysis (INAA) with thermal neutrons
- 1982 - NAA made up 35% of analytical analysis
- 1983 - 36% NAA
- 1996-98 - 18% NAA

Disadvantages

- May cause fast fission interference with Thorium-232
- Highly active Cadmium which gives off gamma rays.
- Needs to be near the core for epithermal flux, Cd lower the neutron flux which nuclear reactor operators may not want
- Cd can melt
- Cd burnup, becomes less effective over long periods of use
- Time needed to take off Cd foil prevents the detection of short-lived nuclids (half-lives < 20 s)

Boron and Cadmium

- Boron not as activated as Cd. Alpha decay (n,α) instead of gamma rays. Generates a lot of heat.
- Heat may lead to decomposition of biological samples. Airtight capsules may explode due to high pressure generated.
- Generation of He may lead to structural damage
- Cd sheets are more easily attainable than B
- Using both B and Cd together can be used to avoid activation problems generated by B powder's Al-28, Mn-56, and Cl-38 impurities

Errors

- (n,p) and (n,α) reactions may occur
- Beta decay of daughter nuclide
- Thermalizing property of light elements: H and C, would undo the advantage of having ENAA. Polyethylene of pneumatic system capsule can cause thermalization.
- Heavy element shielding of gamma rays by large electron clouds
- Non-homogenous sample. Samples must have a homogenous concentration of elements throughout its body. NAA cannot detect concentrations in different parts of the sample but can tell the overall concentration

Spirulina platensis

- Algae produces chemicals that can by used to treat cancer and AIDS patients
- ENAA used to test biomass of algae for poisonous elements.
- Insignificant amount of arsenic and lead found
- OK for consumption in food and pharmaceuticals.
- Concentrations found are on Table 1 of Mosulishvili, Epithermal neutron activation analysis of spirulina platensis biomass and extracted C-phycocianin and DNA pg. 43
- High concentration of K and Na due to nutrient media algae was placed and not the actual algae.

Halogens in the soil

- Trying to find origin of halogens in the soil
- NAA was accurate and sensitive enough for experiment
- ENAA prevents interference from Mn-56 and Na-24, which are major elements in the soil.
- Ideal $Q=I/\delta$ and half-life values for experiment. Q values of significant isotopes are found in Table 1 of Steinnes, <u>Marine gradients of halogens in soil studied by epithermal neutron activation analysis</u> pg. 174
- Used Cd to prevent thermal neutrons from getting to sample
- Exponential decrease in distance with coastline proves halogens in soil come from Ocean as seen in Figure 2, pg. 175. Figure 1 pg. 174 gives the locations of where samples were taken from

World of Tomorrow?

- Indium filters would raise cutoff from 0.4 eV to 4.0 eV. Would be more efficient in filtering out thermal neutrons.
- Have materials with large resonances, Ag-199's 5.2 eV, overlaps interference nuclide's resonance, Au-197's 4.9 eV resonance peak.
- Mono-energetic epithermal beam. However, large range of epithermal neutrons (1eV-1MeV) prevents this from being obtained.

Work Cited

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