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.
The formula can be used to calculate the rate of neutron capture for thermal and epithermal neutrons.

\[ R = \Phi_{th} \delta + \Phi_{epi} (I + 0.44 \delta) \]

- \( \Phi_{th} \) = thermal neutron flux
- \( \delta \) = thermal neutron cross-section (probability of thermal neutron capture in cm^2)
- \( \Phi_{epi} \) = 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.

\[ R_{cd} = \frac{(\Phi_{th} \cdot \delta + \Phi_{epi} \cdot (I + 0.44 \cdot \delta)) \cdot (\Phi_{epi} \cdot (I + 0.44 \cdot \delta))}{\Phi_{epi} \cdot (I + 0.44 \cdot \delta)} \]

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

\[ R_{cd} = 1 + \delta \cdot (0.44 \cdot \delta(Au) + I(Au) \cdot (R_{cd}(Au) - 1)) \cdot \delta(Au) \cdot (0.44 \cdot \delta + I) \]
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
- \( Fa = \frac{(Rcd)d}{(Rcd)D} \)
- \( d \) 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, Epithermal neutron activation analysis of Geological Material
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 $(n,\alpha)$ 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 be 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-phycocyanin and DNA pg. 43*
- High concentration of K and Na due to nutrient media algae was placed and not the actual algae.
Halogen 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, Marine gradients of halogens in soil studied by epithermal neutron activation analysis 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
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