

## Activation Analysis Facilities at Washington State University

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Neutron activation analysis (NAA) has been practiced at Washington State University (WSU) since the early 1960s, and a significant fraction of research projects at the university that require measurement of trace elements continue to use NAA despite the availability of other trace element techniques. The neutron source is a 1-MW TRIGA III-fueled research reactor with a rectangular fuel box, unlike a conventional TRIGA reactor. The reactor is fueled with a mixture of 25% enriched and 70% enriched  $^{235}\text{U}$  in a zirconium hydride matrix. Available thermal neutron fluxes range from  $1 \times 10^{12}$  to  $8 \times 10^{12} \text{ cm}^{-2} \cdot \text{S}^{-1}$  in water-cooled positions and  $\sim 10^{13} \text{ cm}^{-2} \cdot \text{S}^{-1}$  in a thimble position. Cadmium ratios (Au) values range from 2 to 12. All irradiation positions, except the thimble position, have rotator assemblies for sample rotation during irradiation to correct for lateral flux inhomogeneity. In addition to the normal irradiation positions that are used primarily for thermal NAA, a Cd-lined tube can be inserted into any of the in-core irradiation positions for epithermal NAA (typically this tube is used in conjunction with boron nitride capsules to further filter neutrons that have been thermalized by the small water volume inside the Cd tube). A pneumatic transfer facility is used for measurement of radionuclides of short half-life ( $<10\text{s}$ ), and the reactor can be pulsed up to  $\sim 2000 \text{ MV}$  with a pulse full-width at half-maximum of 11 ms for enhancement of saturation activity of very short half-life radionuclides.

Most NAAA at WSU utilizes gamma-ray spectrometry using Ge or Ge (Li) detectors and low-energy photon detectors coupled to personal computer-based Genie 2000 (Canberra) data acquisition and analysis spectrometers. Fission-track analysis (FTA) is also used as a method for the determination of ultra low levels of U and Pu using Lexan track detectors.

The Nuclear Radiation Center is university-wide research facility, and NAA is used in many different projects from a wide variety of departments. Table I shows some specific WSU projects that have utilized NAA in the past few years

Neutron activation analysis has also been used to extend the measurement capability for actinide elements in human tissues as part of the United States Transuranium and Uranium Registries at WSU. Thorium is normally measured in human tissues by dissolution of the tissue; separation of Th by ion exchange; and determination of  $^{228}\text{Th}$ ,  $^{230}\text{Th}$ , and  $^{232}\text{Th}$  by alpha spectrometry. However, the detection limits for  $^{232}\text{Th}$  can be greatly improved by combined NAA –alpha spectrometry in which  $^{232}\text{Th}$  is determined on the electrodeposited disk used for alpha spectrometry, using the  $^{232}\text{Th}(\text{n}, \text{A})^{233}\text{Th} \rightarrow ^{233}\text{Pa}$  reaction. Both  $^{228}\text{Th}$  and  $^{230}\text{Th}$  are determined by alpha spectrometry, and  $^{229}\text{Th}$  is used as a chemical yield tracer. A similar combined NAA –alpha spectrometry method has been developed for U isotopes. Another application of a combined technique is the method developed for the determination of the  $^{240}\text{Pu}/^{239}\text{Pu}$  in human tissues from occupationally exposed workers. In this method,  $^{239}\text{Pu} + ^{240}\text{Pu}$  is determined by alpha spectrometry, and  $^{239}\text{Pu}$  is determined by FTA ( $^{240}\text{Pu}$  has a low fission cross section), using  $^{238}\text{Pu}$  as a chemical yield tracer.