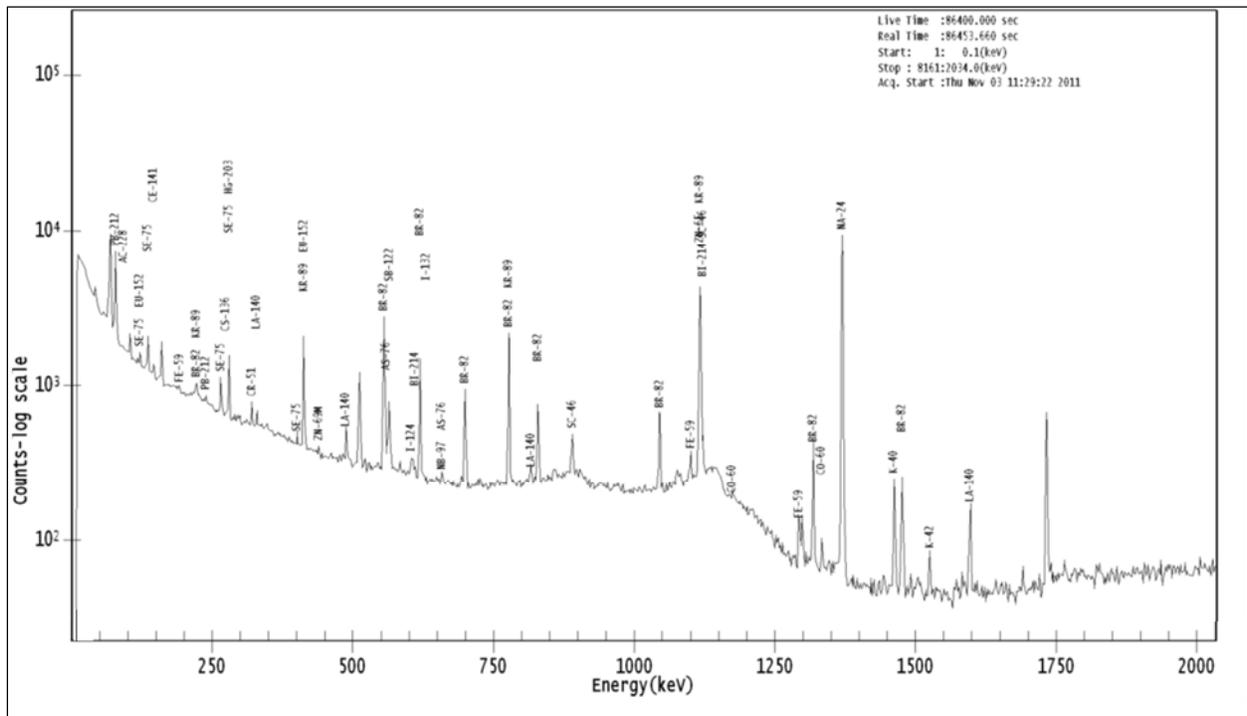


Details about NAA at NRL

The MIT-NRL has extensive capabilities for performing element analysis on a wide range of materials using Neutron Activation Analysis (NAA). These capabilities also enable the reactor's research staff to produce small amounts of radioactive tracers, and to detect, identify, and measure the radioactivity of natural or man-made materials.

NAA Basics

Neutron Activation Analysis is based on two simple physical procedures. The first entails the neutron irradiation of the sample material which causes a small fraction of some stable isotopes to be transformed into radioactive isotopes. The second is the measurement of the gamma rays emitted during the radioactive decay of these newly created radioisotopes.



NAA gamma ray spectrum of biological sample for nutrition study.

A typical full analysis involves two irradiations of different durations and the collection of three or four gamma spectra of the activated materials so that elements with activation products with half-lives from a few minutes to a few years can be accurately measured. Up to 48 elements from sodium through uranium can be measured by standard NAA. Elements that have activation products with half-lives that are too short or too long, or that do not emit gamma rays as part of their decay, cannot be measured using NAA.

| | | | | | | | | | | | | | | | | | | |
|--------------------------------|---------------------------------|--------------------------------|---------------------------------|-------------------------------|------------------------------------|---------------------------------|----------------------------------|--------------------------------|---------------------------------|----------------------------------|--------------------------------|----------------------------------|----------------------------------|---------------------------------|-----------------------------------|---------------------------------|-------------------------------|----------------------------|
| hydrogen 1 H 1.0079 | | | | | | | | | | | | | | | | | helium 2 He 4.0026 | |
| lithium 3 Li 6.941 | beryllium 4 Be 9.0122 | | | | | | | | | | | boron 5 B 10.811 | carbon 6 C 12.011 | nitrogen 7 N 14.007 | oxygen 8 O 15.999 | fluorine 9 F 18.998 | neon 10 Ne 20.180 | |
| sodium 11 Na 22.990 | magnesium 12 Mg 24.305 | | | | | | | | | | | aluminum 13 Al 26.982 | silicon 14 Si 28.086 | phosphorus 15 P 30.974 | sulfur 16 S 32.065 | chlorine 17 Cl 35.453 | argon 18 Ar 39.948 | |
| potassium 19 K 39.098 | calcium 20 Ca 40.078 | scandium 21 Sc 44.956 | titanium 22 Ti 47.867 | vanadium 23 V 50.942 | chromium 24 Cr 51.996 | manganese 25 Mn 54.938 | iron 26 Fe 55.845 | cobalt 27 Co 58.933 | nickel 28 Ni 58.693 | copper 29 Cu 63.546 | zinc 30 Zn 65.39 | gallium 31 Ga 69.723 | germanium 32 Ge 72.61 | arsenic 33 As 74.922 | selecnium 34 Se 78.96 | bromine 35 Br 79.904 | krypton 36 Kr 83.80 | |
| rubidium 37 Rb 85.468 | strontium 38 Sr 87.62 | yttrium 39 Y 88.906 | zirconium 40 Zr 91.224 | niobium 41 Nb 92.906 | molybdenum 42 Mo 95.94 | technetium 43 Tc [98] | ruthenium 44 Ru 101.07 | rhodium 45 Rh 102.91 | palladium 46 Pd 106.42 | silver 47 Ag 107.87 | cadmium 48 Cd 112.41 | indium 49 In 114.82 | tin 50 Sn 118.71 | antimony 51 Sb 121.76 | tellurium 52 Te 127.60 | iodine 53 I 126.90 | xenon 54 Xe 131.29 | |
| cesium 55 Cs 132.91 | barium 56 Ba 137.33 | 57-70 * | lutetium 71 Lu 174.967 | hafnium 72 Hf 178.49 | tantalum 73 Ta 180.948 | wolfram 74 W 183.84 | rhenium 75 Re 186.21 | osmium 76 Os 190.23 | iridium 77 Ir 192.22 | platinum 78 Pt 195.08 | gold 79 Au 196.967 | mercury 80 Hg 200.59 | thallium 81 Tl 204.38 | lead 82 Pb 207.2 | bismuth 83 Bi 208.98 | polonium 84 Po [209] | astatine 85 At [210] | radon 86 Rn [222] |
| francium 87 Fr [223] | radium 88 Ra [226] | 89-102 ** | lanthanum 103 La [227] | cerium 104 Ce [226] | praseodymium 105 Pr [227] | neodymium 106 Nd [227] | promethium 107 Pm [227] | samarium 108 Sm [227] | europlum 109 Eu [227] | gadolinium 110 Gd [227] | terbium 111 Tb [227] | dysprosium 112 Dy [227] | holmium 113 Ho [227] | erbium 114 Er [227] | thulium 115 Tm [227] | ytterbium 116 Yb [227] | | |
| | | | * Lanthanide series | | | | | | | | | | | | | | | |
| | | | ** Actinide series | | | | | | | | | | | | | | | |
| | | | actinium 89 Ac [227] | thorium 90 Th 232.04 | protactinium 91 Pa 231.04 | uranium 92 U 238.03 | neptunium 93 Np [237] | plutonium 94 Pu [244] | americium 95 Am [243] | curium 96 Cm [247] | berkelium 97 Bk [247] | californium 98 Cf [251] | einsteinium 99 Es [252] | fermium 100 Fm [257] | mendelevium 101 Md [258] | nobelium 102 No [259] | | |



Short irradiation



Long irradiation

Elements that can be measured using NAA.

Elemental concentrations the unknown samples can be calculated either based on the parameters of the irradiation and counting and the physical properties of the elements of interest; or, more usually, by comparing the decay rates in the unknowns to decay rates in a set reference materials of known compositions.

Advantages of NAA

NAA has several distinct advantages over most other elemental analytical methods which makes it uniquely useful for a variety applications:

- Because the method detects or 'counts' gamma rays emitted by the decay of individual atoms, it is extremely sensitive.
- It can be applied to solids, liquids, suspensions, slurries, or even gases with little or no physical or chemical processing or the samples.
- It is largely non-destructive.
- It is an intrinsically multi-element analysis which is highly selective for many elements that are difficult to analyze for by other methods (*e.g.*, lanthanides).

Practical Aspects of NAA at the MIT-NRL

Neutron irradiations are performed in the reactor's reflector region which is accessed using either of two pneumatic systems or at a manual insertion location. For irradiations in the pneumatic systems, materials are placed in polyethylene sample holders or 'rabbits'. The rabbits have internal dimensions of either 1" diameter by 3-1/4" length (1-inch rabbits) or 1-3/8" diameter by 6-1/4" length (2-inch rabbits). For irradiations in the manually inserted locations, the total available sample space is 3" diameter by 24" length.

The pneumatic facility for 1-inch rabbits can be used to transfer samples between the irradiation location and a laboratory in the building adjacent to the reactor, which is near where the gamma spectroscopy is performed. This allows for elements which produce activation products with half-lives to be analyzed.

The pneumatic irradiation facilities have thermal neutron fluxes of up to 7.7×10^{12} n/cm² s and 5.6×10^{13} n/cm² s for the 1-inch and 2-inch rabbit irradiation locations respectively. The mechanically inserted irradiation facilities have a thermal neutron flux of up to 1.2×10^{13} n/cm² s. Lower fluxes can be achieved by running the reactor at lower overall power. The 1" pneumatic and 3" manual irradiation locations have highly thermalized neutron spectra (cadmium ratios of approximately 200). The 2" pneumatic irradiation location has a fast neutron flux of up to 3.5×10^{12} n/cm² s, which makes it possible to perform NAA based on fast reactions such as the $^{58}\text{Ni} (n,p) ^{58}\text{Co}$.



Polyethylene 1-inch rabbit. Polyethylene 2-inch rabbit. Titanium 2-inch rabbit.

The laboratory in which irradiated samples are analyzed is currently equipped with three High Purity Germanium (HPGe) detectors. One of these is a well-type detector which provides for very high efficiencies in the collection of the emitted gamma spectrum. Output from the detectors is processed using multichannel analyzers and gamma spectrum analysis software.



In addition to the standard NAA facilities, the reactor also has the ability to perform Prompt Gamma Neutron Activation Analysis (PGNAA). PGNAA is primarily used for the quantification of trace amounts of boron, but can also be useful for the analysis of Cd, Sm, and Gd. The PGNAA facility is installed at a horizontal beam port within the reactor containment building where the thermal neutron flux is approximately 2×10^7 n/cm² s.

Previous NAA-related Research Programs at the MIT-NRL

Studies which have either originated in, or been supported by the NAA lab include work on:

- Fine and coarse atmospheric particulate matter (PM_{2.5} and PM₁₀);
- Atmospheric mercury in vapor and size-segregated particulate phases;
- Biological uptake and partitioning of minerals;
- Deep, dated ice-core samples;
- Historic human hair samples for forensic toxic exposure assessment;
- Raw and processed coal samples, and size-segregated coal-combustion particulate emissions;
- Tree-ring samples for historical toxic contamination estimations.

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