Determining Elemental Composition with Neutron Activation Analysis (NAA)

TECHNICAL BULLETIN

Neutron Activation Analysis (NAA) is a sensitive and accurate analytical method that identifies and quantifies elements in a sample through analysis of characteristic gamma rays emitted during radioactive decay after being irradiated in a nuclear research reactor. These distinct energy-signatures provide positive identification of the targeted elements present, while their intensity is proportional to the concentration of the element in the sample.

The NAA Method

Samples are measured directly thus avoiding problems that are common with other techniques: incomplete dissolution, loss of volatile elements or contamination from laboratory chemicals.

NAA is considered a referee method, being based solely upon nuclear, not chemical properties. The chemical forms of elements present in a sample have virtually no effect on the results.

Applications of NAA

NAA is well suited to:

- **Quality control programs** testing for high purity – quartz and silica, carbon/graphite, chemicals, pharmaceuticals
- **Difficult matrices** – quartz, oils, plastics, textiles
- **Volatile elements** – bromine, chlorine, iodine, fluorine

It is also used to verify the homogeneity of reference materials given its multi-element capability and dynamic range of analysis. The accuracy of NAA makes it valuable for certification of elemental composition and for comparison with other trace element analytical techniques.

Advantages of NAA

Analyzing samples with this technique poses the following advantages:

- Free of contamination from lab chemicals
- Limited matrix effects
- No/minimal sample preparation
- Applicable for most matrices: soil, sediment, rock, vegetation, humus, moss, coal, ash, ores and concentrates, liquids, air filters – quartz, graphite, textiles, plastics/polymers, food, pottery and oil/petroleum products
- Cost effective analysis of 30+ elements[1]
- Ability to analyze large (40g) samples, minimizing subsampling error
- Effective for limited sample quantities where only milligrams of precious material are available
- Total sample analysis, not just extractable or surface analysis as with some other analytical techniques

[1] NAA is not suitable for the analysis of lead, bismuth, or phosphorus.

Geochemical Exploration Applications

Geological surveys use NAA to test stream and lake sediments for gold and associated elements, such as arsenic and antimony. Table 1 shows the typical analysis.

Table 1: Gold +33 package (typical detection limits)

ELEMENT	ppm	ELEMENT	ppm
Antimony	0.1	Nickel	10
Arsenic	0.5	Rubidium	5
Barium	50	Samarium	0.1
Bromine	0.5	Scandium	0.2
Cadmium	5	Selenium	5
Cerium	5	Silver	2
Cesium	0.5	Sodium	200
Chromium	20	Tantalum	0.5
Cobalt	5	Tellurium	10
Europium	1	Terbium	0.5
Gold	0.002	Thorium	0.2
Hafnium	1	Tin	100
Iridium	0.05	Tungsten	1
Iron	2,000	Uranium	0.2
Lanthanum	2	Ytterbium	2
Lutetium	0.2	Zinc	100
Molybdenum	1	Zirconium	200

Halogens

NAA is applied for measurement of total Chlorine and Bromine in rocks and ores because dissolution and contamination are a problem with other techniques due to the volatility of the elements and their use in mineral acids.

Platinum Group Elements (PGE)

NAA provides results for all six PGE compared to traditional fire assay techniques that commonly determine Platinum and Palladium as shown in Table 2.

Table 2: Platinum Group Elements

ELEMENT	ppb
Platinum	20
Palladium	20
Rhodium	5
Iridium	1
Ruthenium	50
Osmium	10

Biogeochemical Exploration

Table 3: Key Elements Analyzed in Vegetation and Humus[2]

ELEMENT	ppb
Gold	0.2 ppb
Antimony	0.02 ppm
Arsenic	0.1 ppm
Mercury	0.05 ppm
Selenium	0.5 ppm
Tungsten	0.5 ppm

Iridium

The unusual abundance of Iridium in a rock layer may indicate a meteor impact. NAA is used to investigate this Iridium anomaly because of its capability of measuring Iridium in the sub-ppb range.

[2] No ashing required

Quartz / Carbon

NAA easily measures ultratrace impurity levels in quartz sands and silica wafers, as shown in table 4. Similarly, NAA can be applied to analysis of graphite and carbon. There is no requirement to get the difficult matrix into solution and large sample sizes can be processed. Measurement of impurities by NAA is used for quality control during the manufacture of semi-conductors, solar power cells, lenses, optical fiber and lighting. Similar detection.

Table 4: Typical Detection Limits Commonly Measured in Quartz[3]

ELEMENT[3]	PURE QUARTZ SAND (ppb)
Antimony	0.1
Arsenic	0.1
Cerium	40
Cesium	2
Cobalt	15
Copper	100
Lanthanum	10
Lutetium	0.5
Mercury	0.5
Molybdenum	2
Potassium	100
Silver	10
Sodium	20
Tantalum	1
Thorium	1
Tungsten	0.1
Uranium	0.3

Iodine in Food and Pet Food

NAA is used to measure iodine levels added to food and pet food, as shown in table 5. As samples are analyzed directly without heating and dissolution, total iodine is reported as there is no loss of this volatile element. In addition to iodine, chlorine, bromine, many other elemental concentrations can be reported as they are analyzed simultaneously with iodine.

Table 5: Typical Detection Limits of Impurities Commonly Measured in Food and Pet Food[3]

ELEMENT	FOOD / PET FOOD (ppm)
Aluminum	100
Bromine	1
Calcium	100
Chlorine	20
Iodine	0.1
Magnesium	100
Manganese	1
Sodium	5

Medical Products and Research

Silver nanoparticles have been added to certain products to prevent bacterial growth, reduce the risk of infection and speed up healing time. Silver-containing products include bandages, dressings, syringes, urinary catheters, breathing tubes, contact lenses and lens cases. Research is also being conducted on the application of gold and silver nanoparticles for treatment of cancer.

NAA is the preferred method of analysis for gold and silver nanoparticles because it measures the sample directly, providing a sensitive, total concentration of the element present. This is valuable for quality control, assuring the appropriate amount of nanoparticle has been applied to the product to ensure biocide efficacy.

[3] Other elements are available.

Oils & Plastics

NAA is used for the trace elemental analysis of plastics, oils, and polymers to determine additives and contaminants. There is no requirement for sample preparation with NAA, making it amenable to direct analysis of matrices that can be challenging to work with using other techniques. See Table 6 for the detection limits.

Table 6: Typical Detection Limits of Elements Commonly Measured in Polyethylene[3]

ELEMENT	POLYETHYLENE
Aluminium	5 ppm
Barium	1 ppm
Calcium	5 ppm
Chlorine	2 ppm
Copper	1 ppm
Iodine	0.05 ppm
Magnesium	50 ppm
Manganese	0.1 ppm
Potassium	10 ppm
Sodium	5 ppm
Vanadium	0.01 ppm

Archaeological Fingerprinting

NAA is used for characterization of archaeological artefacts (pottery, obsidian, chert, basalt and limestone) and relating the elemental profiles to that of the geographic source material. In doing so, archaeologists have learned about prehistoric trade routes and movement of people.

Only a small portion of the precious archaeological artefact is required for analysis by NAA, which measures 34 elements simultaneously providing an informative elemental profile for comparison.

Fluorine

The volatile nature of fluorine makes it challenging to measure in the laboratory using some methods as the element can be lost during sample preparation. Depending on the matrix, NAA has the advantage of improved sensitivity (1 ppm) compared with measurement by ion selective electrode (50-60 ppm).

For these reasons, NAA is used to measure the quantity of fluorine in various products for quality control:

- **Textile industry** – fluorinated compounds added to carpet fiber and apparel to improve water-, oil- and stain-resistance and improve durability
- **Polymers** – dissolution of polymers can be extremely difficult for other test methods
- **Oral hygiene products** – fluoride added to toothpaste and mouthwash
- **Pharmaceuticals** – about 20% of pharmaceuticals contain fluorine

Luminescence Dating

Luminescence dating measures the last time an object was exposed to sunlight and is an important method for dating archaeological artefacts.

Bureau Veritas provides precise measurements of the elements that produce ionizing radiation (uranium, thorium, potassium and rubidium). See Table 7 for the detection limits. This data is used in the age calculation along with the luminescence reading. Precision (uncertainty) can be reported with results.

Table 7: Luminescence Dating

ELEMENT	DETECTION LIMIT (ppm)
Potassium	50
Thorium	0.5
Uranium	1
Rubidium	10

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