

Photon Activation Analysis

Key words

Photon activation analysis; instrumental activation analysis; radiochemical analysis; trace analysis; non-destructive analysis

Fields of application

Analysis of inorganic (e.g. semiconductor material, ceramics, metals, environmental material such as soil, air dust, water) and organic materials (e.g. plastics, biological materials such as plant or animal tissue, food). The method is applied for comparison analyses, certification analysis of reference materials as well as for non-invasive studies of entire objects (e.g. machine components, semi-finished materials, archaeological material and objects of art). Large samples up to kilogramme amounts can be analysed, too.

Methodology and instrumentation

The material studied is exposed to high-energy bremsstrahlung (in the range from 15 MeV to 30 MeV) produced by an electron linear accelerator. The activity of radionuclides produced during irradiation (γ - and/or characteristic X-rays) is measured by appropriate radiation spectrometers. NaI(Tl) or high-resolution semiconductor detectors are used for spectrum acquisition. The quantitative element determination is performed by means of signal comparison using calibration material irradiated simultaneously with the sample. The analysis can be carried out either instrumentally (IPAA) or by radiochemical separation (RPAA).

Items tested

Solid or liquid materials – nearly any matrix can be analysed.

Quantities / characteristics tested

Mass fractions of the following elements can be determined: C, N, O, F, Na, Mg, Si, Cl, K, Ca, Sc, Ti, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Nb, Mo, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Te, I, Cs, Ba, Ce, Nd, Sm, Eu, Gd, Dy, Tm, Yb, Lu, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, Tl, Pb, Bi and U.
In favourable cases non-destructive analyses are possible.

Uncertainty / reliability of results

The achievable uncertainty depends upon various sample parameters, e.g. matrix composition, mass fraction of the analyte (the smaller the fraction the larger the uncertainty) as well as experimental and hardware-inherent parameters. The typical uncertainty of the results ranges from 2 % up to 10 %rel.

Qualification and quality assurance

The 35 MeV electron linear accelerator of BAM is the only one in Germany almost exclusively designed for high energy photon activation analysis. Using this method, comprehensive knowledge and long-term practical experience in the field of radioanalytics and radiation measurement techniques are required. Quality assurance is realised by application of primary calibration materials and appropriate certified reference materials. Successful participation in interlaboratory comparisons (including CCQM-studies); introduction of PAA results into Appendix C of the Mutual Recognition Arrangement (MRA).

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Further information

Sample Characteristics

Solid non-metal samples are irradiated as powders (< 100 µm) or pressed powder pellets. For metals the preferred disc size is 20 mm in diameter and < 1 mm in thickness. Samples are transferred into aluminium irradiation rabbits (see Fig. 1). These are transported to the irradiation position of the accelerator and, after exposure, to the radiochemical laboratory using a pneumatic tube system. The samples are then either subject to a radiochemical separation step or measured directly with the photon spectrometer. Also large volume samples (currently up to 1.5 litres) or entire objects can be activated. Since many physical parameters involved in the analytical process are either unknown or are not sufficiently quantified with respect to the precision required an appropriate calibration material is exposed together with the analytical sample.



Fig. 1: Irradiation containers and samples

Irradiation

In contrast to nearly all other comparable set-ups throughout the world, the linear accelerator of BAM is almost exclusively used for photon activation analysis. The basic operation principle of the accelerator is described in the chapter on photon activation analysis in the catalogue of BAM reference procedures. Electrons produced by a heated molybdenum cathode are accelerated to about 99% light velocity with a travelling radar wave running in a two-segment acceleration tube. After extraction from the vacuum system the electrons are absorbed by a tantalum converter whereby ca. 50% of their kinetic energy is converted to an X-ray continuum with a maximum energy equal to that of the electrons. Samples are exposed to this bremsstrahlung radiation. A magnetic field-operated scanning system can distribute the bremsstrahlung over an area of 10 x 10 cm² which allows the irradiation of large volumes (see Fig. 2).

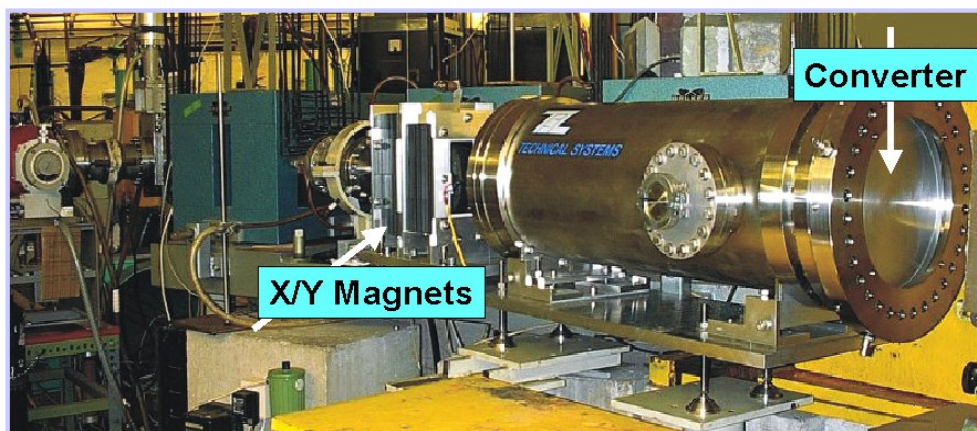
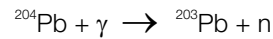


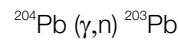
Fig. 2: Bremsstrahlung converter of the linear accelerator

Generated nuclides and spectroscopy

Photonuclear reactions are induced in the material during exposure. This leads to radioactive products in most cases, e.g. lead:

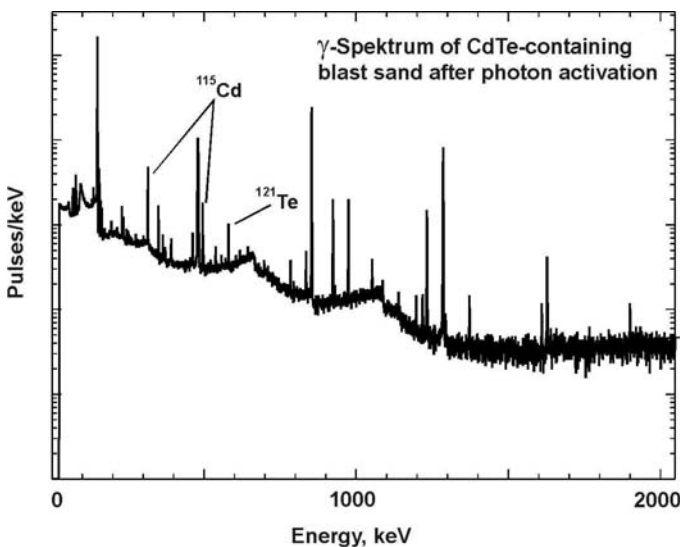


also written as:

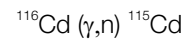


The photon emission of the product nuclides generated (^{203}Pb in the example above) is measured with γ - or X-ray spectrometers. The individual energies of the photon quanta emitted by the radionuclides are converted to electrical pulses processed by a special electronic system. From these signals, after conversion to digital values, an energy spectrum is produced (see Fig's. 3 and 4). Using the spectrum of the calibration material the spectrometer is calibrated, and both qualitative and quantitative analyses can be carried out.

Following the instrumental approach (by omitting separation steps) multi-element analyses can be performed simultaneously.

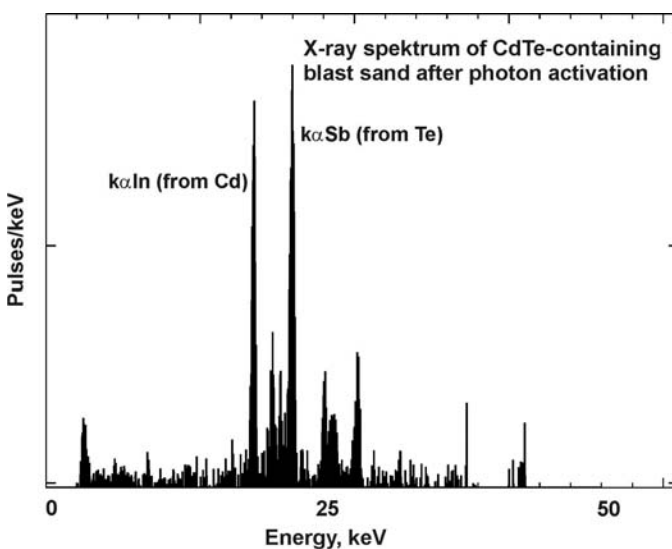


Irradiation induced nuclear reaction:

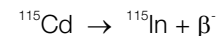


The spectrum shows – among others – the γ -radiation emitted by ^{115}Cd .

Fig. 3: γ -spectrum of blast sand containing CdTe*



^{115}Cd is not a pure γ -emitter but suffers additionally from β^- -decay. This results in an element transmutation to indium:



The characteristic X-radiation of In can be made visible with the aid of a planar detector.

Fig. 4: X-ray spectrum of blast sand containing CdTe*

* example taken from EU project RESOLVED (recycling of used photovoltaic CdTe cells)