

# Integrated Nuclear Analytical Chemistry at MLZ, Garching, Germany

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Heinz Maier-Leibnitz Center (MLZ) in Garching is one of the largest neutron-beam facilities of the world. It operates 26 instruments mainly utilizing neutron scattering of cold, thermal, and hot neutrons. Our reactor (FRM II) offers unique possibilities in nuclear analytical chemistry with the strongest cold neutron beam of the world. Recently, we have been working on the combination of the different nuclear analytical techniques to achieve an integrated chemical analysis with detecting all possible particles emitted by the nuclei in the samples during and after the irradiation.

The flux at the prompt gamma activation analysis (PGAA) facility reaches  $6 \times 10^{10} \text{ cm}^{-2} \text{ s}^{-1}$ . This flux compares with those at smaller reactors dedicated to neutron activation analysis (NAA). Hence, besides PGAA, this beam can also be used for the activation of samples. The combination of these methods called in-beam activation analysis has been routinely applied in the analyses of great number of different samples. While the sample is irradiated, the PGAA measurement is also performed in parallel. The short-lived activation products are counted with beam off right after the irradiation. When using the same detector for both prompt and decay counting, has the advantage of a simpler calibration procedure, however, using a detector placed much closer to the sample increases the sensitivity of the method. The rest activity is counted in a low-background chamber to determine the elements producing longer-lived radionuclides. Exploiting this possibility, a broad circle of elements can be determined with much better sensitivities than with PGAA alone.

The FRM II reactor also offers highly thermalized irradiation channels with high neutron fluxes. The NAA as performed using these irradiation facilities enable 2–3 orders of magnitude lower detection limits for most of the typical trace elements. NAA has been introduced into the proposal system, and it is now available for external users and it seems to be an important addition to the analytical capabilities available until now.

Our cold neutron beam has also been used for neutron depth profiling (NDP) where the charged particles induced in the surface layers of the samples are detected. The energy spectrum provides information on the concentration profiles of certain elements (mostly B and Li) in the upper 10–50  $\mu\text{m}$ . The method has been developed in the 1970s, but recently it has gone through a real resurrection, as the investigation of lithium-ion batteries arouse strong interest. We have shown that NDP and PGAA can be performed in parallel studying the concentration profile and determining the bulk composition of the sample.

Another combination of methods in our arsenal is the so-called prompt gamma activation imaging (PGAI) where PGAA is performed on small sample parts using a neutron beam and also the gamma-ray detection collimated down to a few millimeters, and the selection of the parts of interest is driven by radiography/tomography scanning. The strong collimation certainly means a significant loss in both neutron and gamma intensities, i.e. this technique can only be performed in extremely strong beams. The presentation will give an overview of the recent developments in the integration of the neutron-induced methods and their typical applications.

