BRR (Budapest Research Reactor)

A THE FACILITY

A.1 Neutron capture gamma-ray facility of the Institute of Isotopes

The Institute of Isotopes operates the neutron capture gamma-ray facility at the Budapest Research Reactor. This equipment is the only capture-gamma facility at a reactor beam line in Europe at present. The BRR is the largest one in Central Europe. The 10 MW reactor power provides a maximum thermal neutron flux of 2.2×10^{14} $cm^{-2}s^{-1}$ and with a fast neutron flux of 10^{14} $cm^{-2}s^{-1}$. The reactor has 10 horizontal beam tubes (eight radial and two tangential). At one of the tangential beam tubes a cold neutron source (CNS) has been installed. Three neutron guides originate from the point where the CNS is installed providing neutron measurement site in the guide hall adjacent to the reactor hall. The neutron guides can be used either with thermal or cold neutron spectra.

Two instruments are located at the end position of neutron guide No. 1. The prompt gamma activation analysis (PGAA) instrument serves for non-destructive analysis of elemental composition by observing neutron-capture prompt gamma rays. The neutron induced prompt gamma ray spectroscopy (NIPS) instrument serves for different nuclear spectroscopic measurements analysing the prompt gamma radiation of material activated in neutron beam.

The experimental area is a 3×5 m^2 place at the end of guide No. 1, and is surrounded with a biological shielding made of concrete. The whole area is enclosed in a cabin made of iron screening, facilitating stable and noiseless operation of the detectors and electronics.

The neutron beam is collimated into two sub-beams with sizes of 2×2 cm^2, and can be operated separately. The sample chambers are located in a sectioned beam tube made of aluminum that can be evacuated or filled with ^{4}He or other gaseous atmosphere to decrease the background caused by the interaction of neutrons with nitrogen of the air. The chamber is lined on the inside with slow neutron absorbers made of a ^{6}Li containing plastic sheet. A beam chopper can optionally be mounted before the first chamber either in the upper or in the lower beam. The first sample chamber is used for prompt gamma neutron activation analysis, the target position is at a distance of 1 m from the guide end and 30 cm from the chopper. The neutron beam can further be collimated at the beginning of the chamber using a series of neutron collimators. The average thermal equivalent neutron flux at the sample position is $5\cdot10^7$ $cm^{-2}s^{-1}$, as measured by gold foil activation. The second neutron beam passes below the PGAA sample chamber, from which it is separated with a neutron absorber sheet.

Small samples are typically fastened with Teflon strings onto an aluminum frame that can be put perpendicularly, parallel or at an angle of 30 degrees to the beam direction. The maximum size of the sample that can be put into the chamber is about $5 \times 5 \times 5$ cm^3, though the observed volume is about 10 cm^3. Even larger samples can also be irradiated after removing the whole section of beam tube.

The gamma radiation emitted by the sample reaches the detector through a 10-cm long, 2-cm diameter lead collimator. The sample to detector distance is kept at 235 mm, which is large enough to minimize the effect of the peak summing. The basic gamma-spectroscopic instrument consists of a 25% n-type high-purity germanium (HPGe) main detector with closed-end coaxial geometry and a BGO scintillator guard detector annulus, surrounded by a 10 cm thick lead shielding. The HPGe-BGO gamma-ray spectrometer can be used in Compton-suppressed and annihilation-pair modes with the appropriate gating, in order to simplify the spectra for low and high energies, respectively. The data are collected by a 16k personal computer-based MCA.

Carefully constructed neutron and gamma shieldings ensure an environment with the lowest achievable radiation level. The room background is 0.5 cps, while the beam background is 8 cps when both beams are open and 4 cps when only one of them is operating.

The second sample chamber is located in a narrow beam tube downstream from the PGAA system. The distance of the sample position is 2 meters from the guide end. The neutron beam is collimated to 1×1 cm^2. The thermal equivalent neutron flux at the sample position is $3 \cdot 10^7$ cm^{-2}s^{-1}. Three different detectors can be placed around the chamber as close as 2.5 cm from the sample. This layout enables double, or even triple coincidence measurements of gamma rays. This so called Neutron Induced Prompt-gamma Spectroscopy (NIPS) instrument serves for longer investigations of nuclear level schemes. At present two coaxial HPGe and a planar HPGe detectors, as well as NaI(Tl) and two BaF_2 scintillators are available for prompt γ-γ coincidence measurements.

A sample preparation laboratory is also accessible to the users.

A.2 Quality of research

The capture gamma-ray facility at the Budapest Research Reactor, operated by the Institute of Isotopes, is one of the most important PGAA laboratories in the world. In their scientific activity they concentrate on two fields, the basic research and the application of the PGAA method. The data library of capture gamma lines appeared in the recently published Handbook of Prompt Gamma Activation Analysis with Neutron Beams (G.L. Molnár ed., Kluwer Academic Publishers, Dordrecht/London/Boston, 2004), mainly written by the scientists of the Institute of Isotope. A systematic series of measurements has been performed to determine the partial gamma-ray production cross-section of every naturally occurring element. The complete data library can be used in any PGAA laboratory of the world, and this is the only complete set, covering the naturally occurring elements, measured with the same instrumentation, using the same setup. The internal standardization method, used for chemical analysis in this laboratory, enables the precise determination of thermal neutron capture cross-sections of nuclides, too.

The application of the library data in routine analysis provides an immediate verification of the cross-section data. The successful analyses on a large number of different samples gave the possibility of improving the quality of the data and also prove the high quality of the measured values. A few types of the many different samples are the following: archaeological samples (stone tools, Roman fibulae and dishes), catalysts, cements and concretes, rocks and minerals, soil samples etc.

Though the flux is relatively small at the facility at present, the low-background environment and the careful and accurate calibration of the spectrometer makes possible cross-section measurements with a high accuracy. This list shows a few highlights:

- Determination of partial gamma-ray production cross-sections and the energies of the most important gamma-lines for every naturally occurring element, i.e. the establishment of the PGAA data library.
- The high-precision determination of the total capture cross-section of ^{238}U, and for several gamma lines of ^{235}U and ^{238}U.
- The determination of partial cross-section and emission probabilities for high-energy efficiency standards: ^{35}Cl, natural chromium, ^{14}N, ^{12}C.
- The determination of the total and partial capture cross-section for ^{99}Tc, ^{129}I, Te isotopes.
- The determination of capture cross-section of ^{209}Bi (in cooperation with scientists from IRMM and other laboratories).

The Institute of Isotopes is the member of the Budapest Neutron Center, a consortium formed by three Research Institutes of the Hungarian Academy of Sciences to coordinate their research activities associated with the Budapest Research Reactor. BRR is mainly used for neutron research; this research possibility was offered to the European Scientists in the 5th Framework Programme of the European Commission. BNC continues the successful Access Programme under the NMI3 project of FP6.

The neutron capture facility is one of the most frequently visited one by European scientists within BNC. Many colleagues from different fields (archaeology, material science, geology) apply for beam time at the well-calibrated PGAA instrument. The International Atomic Energy Agency regularly sends trainees to the Institute of Isotopes to study prompt-gamma activation analysis, nuclear data, or the activation techniques.

The Institute of Isotopes has many cooperations with Hungarian universities and academic institutions, also European laboratories (IRMM, ILL), as well as academic and scientific institutions worldwide (International Atomic Energy Agency, National Institute for Standards and Technology, Lawrence Berkeley National Laboratory, Kentucky University). The staff is involved in several joint projects, and co-ordinated research projects (coordinated by the IAEA) in the fields of application of the PGAA method and in the improvement of nuclear data.

A.3 New opportunities for access

The well-calibrated equipment of the neutron capture facility at the Budapest Research Reactor provides an excellent opportunity for the high-precision determination of capture cross-sections of different nuclides at thermal and subthermal neutron energies. In the frame of the BNC access programs, researchers of all fields have the opportunity to utilize this facility, thus mainly scientist having interests in elemental analysis of different materials, consume the available beam-time. In the frame of the EFNUDAT the Institute of Isotopes offers an additional 400 beam hours that will be dedicated entirely to cross-section measurements.

B MANAGEMENT OF THE ACCESS PROVIDED

B.1 User access to the infrastructure

The neutron capture facility at the Budapest Research Reactor provides cold neutron beam for two experiments at a time. Individual scientists or small research groups can apply for access to the facility by submitting a research project. Allocation of beam time will be based on the evaluation by the EFNUDAT PAC, pursuing high standards of scientific or technological quality and originality.

A research group of maximum four persons can apply for beam-time; however one person is typically enough to perform the experiment and evaluate the results. The Institute of Isotopes offers a local staff providing scientific and technical support during regular working hours. in sample preparation, operation of the instrument and also in evaluation of the gamma spectra On the other hand visiting scientists are greatly encouraged to work in the greatest autonomy.

The reactor cycles last for 9 contiguous days including a weekend, starting at Tuesday night. It is reasonable to locate one (or two) experiments in a cycle. Two complete cycles are offered to perform experiments in the frame of EFNUDAT, preferable one in each semester. The schedule of the measurement is a subject of agreement with the local staff. Operations needing a support from the staff members have to be carried out during the working hours. Depending on the necessity of time-consuming sample handling, one or two days prior the start of the irradiation is normally enough for all the preparations needed. A typical cross-section measurement does not need any change in the existing experimental setup, so one or two days after finishing the experiments are normally enough for collecting, cooling and packing the samples and collecting the results.

B.2 Scientific, technical and logistic support

B.2.1 Scientific support

The Department of Nuclear Research of the Institute of Isotopes involves scientists from fields of nuclear physics and radiochemistry with broad experience in gamma-spectroscopy, neutron activation, chemical analysis, handling of analogous and digital data acquisition systems and other measuring electronic units, calibration procedures, Monte Carlo simulation and modelling, as well as the evaluation of gamma spectra. This expertise is offered to scientist visiting the facility in the frame of

EFNUDAT. Because of the cooperation with other departments and institutions on site, an access to other facilities or analytical techniques can also be arranged.

The scientific support of the experiments involves the design and the optimum scheduling of the experiment, the application of the optimum setup of the instrumentation and help in the evaluation of the gamma spectra, in case of a chemical analysis the help in the determination of the composition.

B.2.2 Technical and logistic support

External visitors performing experiments at the capture gamma-ray facility will be assigned office space and receive all administrative and computing support that is adequate for their needs. They have access to the same services as the local staff (e.g., telephone, fax, internet access, library, meeting rooms and restaurant).

A sample preparation laboratory is available for the preparation of solid or liquid targets. Fine chemicals of all naturally occurring elements, solvents, acids are also available in the case of necessity for additional sample preparation.

A technical support is also available in the sample preparation, setting up the instrument, in sample changing and also in the operation of the instrumentation.

B.2.3 Training

To users, visiting the facility for the first time, a special training will be held, including detailed instructions on safety rules and, if needed, the use of the instrumentation at the facility, as well as the sample preparation laboratory. The visitors may also participate in seminars and lectures organised at our department.

A thorough training and assistance is provided in the evaluation of gamma spectra, which is a crucial step in neutron activation experiments.

B.3 Peer review procedure

The peer review procedure, common for all Transnational Access Activities, is described under Activity NA1-Management of the I3, part B.3.2.4.

C EUROPEAN ADDED VALUE: European interest in the infrastructure

C.1 Community interest in the infrastructure

C.1.1 International users in the past

IKI is a member of the Budapest Neutron Centre consortium, and it offered a part of its beam-time for European users supported by FP5 and FP6. In 2004 and 2005 5–5 cycles (almost 1200 hours in each year) have been used by guest scientists from the European Union. Since the establishment of the BNC, the neutron capture facility of the IKI receives one the most applications. Scientist arrived from different fields, mainly archaeology, geology and material science. Cross-section measurements in international collaborations also take place in the facility. The institute has international collaborations with partners outside Europe, as well. In one cycle in each year measurements were performed for colleagues in Lawrence Berkeley National Laboratory, USA.

C.1.2 Future demand

The facility accepts the maximum number of users in the frame of BNC. 400 beam-hours are offered to outside users for experiments in the frame of EFNUDAT. That results in a slight increase in the number of experiments in international cooperation at this facility: 4–5 experiments in the frame of BNC, and 2 others in the frame of EFNUDAT.

C.2 Expected impact

The access of the neutron capture facility at the Budapest Research Reactor for cross-section measurements to be performed in the frame of EFNUDAT will shift the emphasis towards nuclear physics from applications. This results in a more efficient utilisation of the facility, because another scientific community is addressed this way. Cross-section measurement takes the advantage of high-precision measurement, enabled by the well-calibrated instrument, which is less employed in routine chemical analysis. These series of experiments harmonise with the data library project going on at the Institute of Isotopes.

At present the capture gamma-ray facility at the Budapest Research Reactor is the only operating one in Europe. (The ones at ILL, France and PSI, Switzerland were shut down several years ago, and the new facility in Garching by Munich, at FRM-II is far from its start.) The facility at Budapest with its high-precision calibration is especially suitable for accurate determination of neutron capture cross-section at thermal and subthermal energies supplementing the high-energy measurements made in other large European laboratories.

C.3 Attracting potential new users

Besides the common advertising activity in the frame of EFNUDAT an additional propagation of the possibilities at the Budapest facility will be made. In the past 10 years Progress Reports of the Budapest Neutron Centre have been published every second year describing the instruments, the possibilities, the improvements in the instrumentation and also the experiments performed at the facilities. This also appears on the homepage of the BNC (www.bnc.hu) together with the recent call for proposals. This form of publicity will be continued in the case of EFNUDAT experiments, too: short reports will be published on each experiment and they will also appear on the homepage of the Department of Nuclear Research. The results achieved in the frame of EFNUDAT will be advertised in the way usual to the scientific community, in the form of scientific publications, presentations on international conferences and workshops

D ACCESS OFFERED BY THE INFRASTRUCTURE

D.1 Annual implementation plan

The project is planned for four years. The Institute of Isotopes offers per year two 9-day cycles, 200 beam-hours each for experiments in the frame of EFNUDAT. There are 15 reactor cycles in each year. The cycles start Tuesday night and last till the next Friday morning, including a weekend. This interval can be used for two “one-week” experiments, or just for one consuming the whole cycle, depending on the decision of the PAC. Two visitors are planned for two 7-days visits for one cycle. Table 5 shows the Implementation plan.

D.2 Activities connected with access

Access offered to the external users will include user training, scientific and technical support during the experiment, office services, computers and administrative and logistic support. The costs (on the basis of user fees) are justified in detail in part D.3. Also costs for travel and subsistence related to visits of users will be supported at charge of the contract.

D.2.1 Training

Special trainings will be held to the external users on the operation of the instrumentation at the facility, on the use of the sample preparation laboratories and on the evaluation of the gamma spectra.

D.2.2 Scientific and technical support

One scientific and one technical staff member will be available to the external visitors. The local scientist will introduce the visitor to the instrumentation, and the sample preparation laboratory, and will provide assistance in the evaluation of the gamma spectra.

Technical support will also be available to solve technical problems during the measurement, to provide the continuous beam operation and the stable operation of the measuring electronics. Computers with the needed software (e.g. spectrum evaluation software) and the necessary databases will be available for the users.

D.2.3 Administrative and logistic support

External users will get access to the same services as the IKI staff e.g. office space, standard office services (telephone, fax, internet services) and meeting rooms, library and restaurant.

D.2.4 Travel and subsistence costs

Travels to experiments in the frame of EFNUDAT, approved by the PAC will be, together with their subsistence costs.