

nELBE : The neutron time-of-flight source and other neutron generators at Dresden-Rossendorf

(A) THE FACILITY

A.1 General description of nELBE

The neutron time-of-flight facility nELBE at the radiation source ELBE of the Forschungszentrum Rossendorf in Dresden uses the high brilliance electron beam from a superconducting linear accelerator to produce very short bunches of neutrons. Electron beam intensities of up to 1 mA at energies between 12 MeV and 35 MeV have been delivered to sub-mm size spots with a wide variability in the electron pulse structure. The small emittance of the electron beam permits the irradiation of very small volumes. These beam parameters allow to convert the intense picosecond electron pulses into sub-ns neutron pulses by stopping the electrons in a high atomic number radiator and producing neutrons by bremsstrahlung photons through (γ,n)-reactions. In order to enable measurements of energy resolved neutron cross sections by a time-of-flight arrangement with a short flight path of only a few meters, it is necessary to keep the volume of the radiator for neutron production as small as possible; this avoids multiple scattering of the emerging neutrons which would broaden the neutron pulses. The energy deposition of the electron beam in the small neutron radiator is that high that any solid material would melt.

Therefore a novel neutron radiator was designed and the experience to be gained with it will become available to all participants of the I3 via the JRA3. It is based on liquid lead flowing through a channel of molybdenum with a wall thickness of only 0.5 mm. Up to 20 kW power will be deposited into only 0.3 cm³. This heating power is removed through a heat exchanger in the liquid lead circuit, typically flowing with 2 m/s. The electrons that are not stopped in the radiator and the secondary radiation are dumped in a water cooled aluminium beam dump. By decoupling the neutrons at an angle of 96° with respect to the impinging electrons and by collimating them through 2.6 m of iron loaded concrete the background in the measuring area is minimized. Respective simulations were carried out using the Monte Carlo codes MCNP and FLUKA. These calculations predict a neutron flux of several 10⁶ n/(cm²·s) at the measuring place 4 m away from the radiator; this time-of-flight distance allows for an energy resolution in the range of 1%. The usable neutron energy ranges from 0.02 to about 8 MeV with 500 kHz beam pulse repetition rate.

Alternatively the installation at Rossendorf allows to combine photo-neutrons from ELBE to neutrons from a generator driven by a 250 keV deuteron beam, which is preferentially used in combination with a tritium target to obtain 14 MeV neutrons. Such a combined spectrum is of special interest for the investigation of the radiation response of materials to be used in a thermonuclear fusion reactor, but it can also be of use to obtain nuclear data for schemes aiming for the transmutation of nuclear waste.

In both installations the charged particle beam (electrons respectively deuterons) is available at the neutron radiators since several months and the optimization of the neutron generation from them is presently under way. Access to intense neutron beams can realistically be expected to be available to first users by late 2006 and regularly by early 2007.

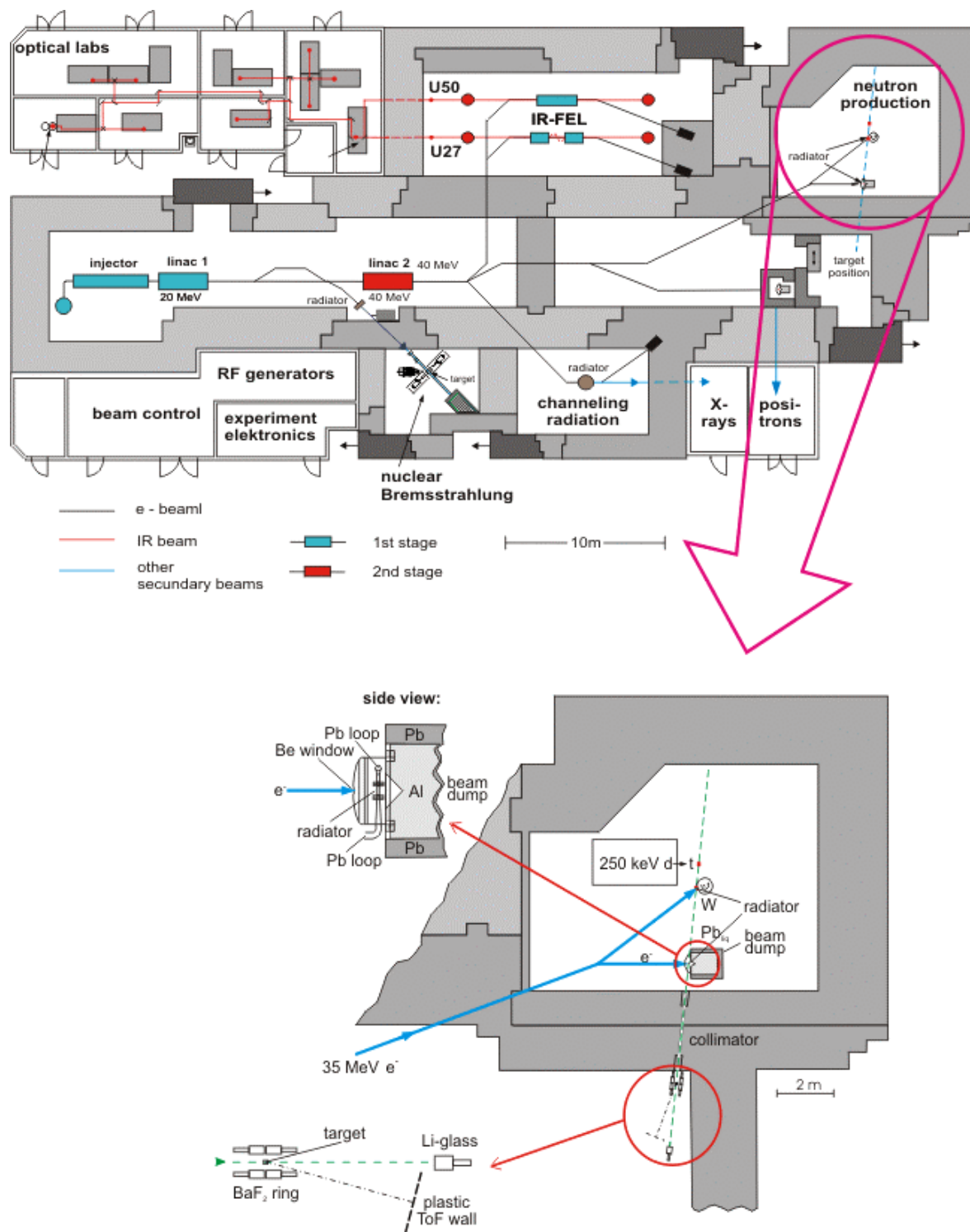


Fig. 1, top: Floorplan of the ELBE radiation source with the neutron area in the top right. **Bottom:** Neutron production targets, electron beam line (in blue) and neutron collimator with the planned experimental site for nELBE; enlarged plans are shown for radiator (i.e. converter) and typical detector assemblies. Also shown is the position of the deuterium-beam based neutron generator.

A.2 Quality of research

It is the objective of nELBE to determine neutron cross sections for the selection of radiation hard construction materials for nuclear reactors and especially for the handling of waste from such reactors in order to find processes which transmute long-lived radioactive nuclides into short-lived and finally stable ones. The photo-neutron spectrum is similar to the one from fission and the compact dimensions of the n-radiator and the strong reduction of moderating material guarantee it to be delivered to the experiments nearly unchanged. The fact that the installation delivers the right energies needed to measure cross-sections of importance for fast fission reactors is allowing high quality measurements for this kind of research. It should be noted here that the majority of neutron sources used for nuclear data measurements in the past have delivered less well suited energy distributions to their users.

The nuclear physics research performed at the ELBE facility during its first two years of operation has resulted in strongly improved and comprehensive information on the response of medium heavy and heavy nuclei against electromagnetic dipole radiation – comprising level density distributions – over a wide range of excitation energy up to the neutron emission region. Information of this type is a prerequisite for a theoretical understanding and theoretically based systematic predictions for nuclear reaction data as those to be obtained from the EFNUDAT initiative.

A.3 Relationship between nELBE and other secondary radiations from ELBE

The Radiation Source ELBE is based upon a superconducting electron linac delivering up to 40 MeV; intense secondary radiation is produced from the high brilliance electron beam of 1 mA: For the medium and far infrared (IR) the free electron laser (FEL) principle is used, whereas keV-X-rays are produced via electron channeling and later possibly by Compton backscattering.

Bremsstrahlung photons in the MeV range are a very interesting probe for investigations in nuclear spectroscopy and nuclear astrophysics. In these latter fields active research has been and continues to be performed at FZR, partially in collaboration with groups from TU Darmstadt, Charles University Prague, the Bulgarian Academy of Sciences, Notre Dame University (Indiana, USA) and Konan University (Japan). The long experience of the laboratory in the domain of nuclear physics is a very good basis for successful nuclear data measurements. Besides the presence of experienced experimenters and technicians with a large stock of equipment and software also the availability of theoretical support is of importance here.

A.4 New opportunities for access -- equipment and services offered

For measurements of neutron-induced reactions, different detector types have been developed at FZR. For neutron-capture γ rays, a BaF₂ scintillation detector array of up to 60 crystals is being built. The crystals have a length of 19 cm and a hexagonal cross section with an inner diameter of 53 mm. They are read out by fast Hamamatsu PMTs R2059, which are UV sensitive to be able to measure both the slow and the shorter wave-length fast component of the BaF₂ scintillation light. This allows to use pulse shape discrimination (PSD) to separate photon signals from intrinsic α -particle background. The time resolution reached with a ⁶⁰Co γ -source is typically 650 ps (FWHM). The read out will be performed with dedicated ADC/TAC modules that allows simultaneous measurement of timing and energy signals including PSD in VMEbus standard. The system will be controlled by a RIO3 real-time UNIX computer. Starting in 2006 a fully digital data taking electronics will be installed; the corresponding software will be designed and tested within the JRA2 of this I3. Also within the I3 investigations are planned on alternative anorganic scintillators to be used for the γ -ray detection after neutron capture. One very appealing material on the market since recently is LaBr₃ doped with Cerium; it has a better energy resolution than BaF₂ and a shorter pulse length, allowing to use neutron pulse repetition rates in the MHz range as delivered from superconducting electron accelerators like ELBE. FZR has foreseen an investment budget to start R&D for the use of LaBr₃(Ce) as n-capture detection material; the plan is to establish a cooperation with Saint-Gobain Ceramics & Plastics, Inc.,

the company which developed that material. Such a development will heavily profit from an integration into JRA2, where other developments of detection devices will take place.

For determining the neutron flux distribution Li-glass scintillators and a plastic scintillator wall is being built. The plastic scintillator wall will allow detection of fast neutrons from approx. 500 keV kinetic energy through proton recoil in the scintillation material. The wall will cover an active area of approx. 1m² consisting of 10 scintillation panels (100 x 12 x 1 cm³) read out on both ends. For neutron energies below 500 keV Li-glass scintillators are used. They are enriched with ⁶Li up to 18% and allow detection of low-energy neutrons mainly through the reaction ⁶Li(n,t)⁴He. For other types of n-detectors for these lower energies prototypes are under construction and test at nELBE; R&D within this I3 will be devoted to make them available for nuclear data measurements.

(B) MANAGEMENT OF THE ACCESS PROVIDED

B.1 Quality of the management

The Forschungszentrum Rossendorf (FZR) at Dresden is a research centre within the Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz (WGL), one of the German national institutions responsible for extra-university research. Using radiation and radioactivity the centre is active in investigations on the structure of matter as well as in the life sciences and in environmental research. The Institute of Nuclear and Hadron Physics (IKH) in the FZR is engaged in fundamental research on the structure of subatomic systems and it strongly pursues the transfer of knowledge to other fields of science. Interdisciplinary transfer is especially aimed for in the research performed at the "Strahlungsquelle ELBE" operational since nearly three years at the FZR. The Institute for Safety Research (IfS) is active in various fields related to safety issues in large industrial plants and especially in installations for nuclear energy. Together with central departments of the FZR the two institutes named above have initiated, designed and commissioned the neutron time-of-flight facility at ELBE and they will be active users of it. The Dresden contribution to the present Integrated Infrastructure Initiative, named nELBE, also includes a neutron generator on the basis of a 250 keV electrostatic accelerator, put into operation by a TU Dresden group at the ELBE site; this group closely works together with the FZR groups.

Expert scientific knowledge, relevant to the nELBE users, are available in the fields of accelerator technology, nuclear physics and radiochemistry, condensed matter physics and materials science, as well as in radiation biology and biophysics. Many of the scientific staff members belong to the leading experts in their fields. These experts can be addressed for help by external users during the phases of planning, performing and analyzing the experiments. The Forschungszentrum Rossendorf, has acquired special competence in the field of accelerator based technological applications: This has been funded in the 4th Framework Program of the EC under the action "Support for Access to Research Infrastructure", as "Centre for Application of Ion Beams in Materials Research". FZR also has participated in the Integrated Infrastructure Initiative "THz-Bridge" within FP5 and the Free Electron Laser section FELBE of the radiation source ELBE was selected as EU Large Scale Facility in 2003; FELBE is a member facility in the Integrated Infrastructure Initiative (I3) on synchrotron and free-electron laser science (IA-SFS) within the 6th framework program of the EU. These activities are based on the availability of intense long wavelength electromagnetic radiation generated by fast electron beams from the ELBE accelerator. This large experience in running a research infrastructure will be of use also for the nELBE facility. In addition, the FZR has been funded by the EC under the IHP Program as a "Marie-Curie Training Site", entitled "Development of Functional Layers Using Ion Beam Techniques"; in addition, the FZR has been selected as coordinator for the research activity JRA-IR within the FP6-I3 project EuroMagNET.

A dedicated division of the FZR has the full operation responsibility for the ELBE facility and its annexes FELBE and nELBE. It is headed by an experienced scientist and consists of 4 further staff scientists/engineers, 12 specialized technicians and 2 administrative staff. Since most of them have already actively participated in the build-up of the accelerator and the ancillary beam-lines, highest possible continuity is guaranteed. Operators of this group will control the electron beam and the parameters for neutron generation according to the requests of the users.

There is a one aspect worthwhile to be mentioned, a geographical one: ELBE is located – in Dresden - relatively far east with respect to the “old” EU borders. With the inclusion of the new member states in central and eastern Europe, it moves, however very much into the centre. This offers a great chance for these states, because they will have much more convenient access to nELBE than to other nuclear data infrastructures located in France and Belgium, respectively.

B.2 Access to the infrastructure and support offered to users

There are several possible interaction modes of external users with nELBE, which depend on the experience of the user and on the complexity of the planned measurement. In principle, the user has large freedom and flexibility and also empty space to bring and set up his/her own additional equipment if wanted. Nevertheless, one staff scientist will be appointed as a contact person to provide help and assistance if necessary; this staff scientist will be member of the Institute for Nuclear and Hadron Physics. If a user wishes to use more complex equipment for his/her experiment, he/she will collaborate closely with an in-house staff scientist who is familiar with this equipment. Such a procedure has to be coordinated already a few weeks before the scheduled beam time. The users are expected to publish their results, if successful, in first-rate scientific journals and give proper acknowledgment to the support by the EC as well as to the participating staff of nELBE and the Forschungszentrum Rossendorf (FZR). In the case of more complex experiments with in-house equipment this usually implies co-authorship on the publications.

The nELBE facility will operate in a mode of 3 shifts per day (5 days a week), with 8 hours each (8 a.m. to 4 p.m. and 4 p.m. to 12 p.m.). The first shift each week is used to set up the nELBE beam according to the user's requirements, thus effectively 14 shifts will be available to the user for his/her experiments. Typical user experiments are scheduled for all 14 shifts in one week, but it is possible that one project may use only part of a week and have a second run a few months later.

In the building of the ELBE facility there is 60 m² office space for nELBE users with up to 10 computers/terminals, internet and intranet connection, connection to all scientific journals available at the FZR (more than hundred in the fields of nuclear science and nuclear chemistry). As described above, the Forschungszentrum Rossendorf is a multi-disciplinary research centre and therefore can offer a wide range of scientific, technical and logistic expertise and support. There is a well equipped computer centre, which also provides user support, and there is a central library on the site with a large number of books and subscribed scientific journals, which are accessible via the intranet. A central department can be asked for help in developing and fabricating electronic and mechanical components. There is a special opportunity for users who have to do some final target preparation immediately before the actual experiment as there is a state-of-the-art clean room available as well as an evaporation facility. At the FZR site there also exist radiochemistry laboratories with hot cells, where targets from radioactive material can be prepared; if extensive support from FZR radio-chemists is essential, a respective collaboration can be formed at the user's wish.

Logistic support also includes the assistance in making the travel arrangements and accommodation in the guest house or a hotel. Even a pick-up limousine service is available in certain cases. There is an on-site cafeteria, lodging for users is provided in a special building in walking distance (owned by FZR), or in hotels/pensions a few km away, but all reachable by public transportation. The city of Dresden itself is a leading centre of research in many fields of science, as evidenced by several Max-

Planck and WGL Institutes, apart from the wide expertise available at Technical University (TU) of Dresden.

The Institute of Nuclear and Particle Physics of this university has an active research program on neutron interactions with materials in use for thermonuclear fusion reactors; it closely collaborates with the FZR and it runs several installations at ELBE of use for neutron physics studies. The most important of these is an electrostatic accelerator supplying a deuteron beam of 250 keV and 10 mA, from which neutrons can be generated with deuterium or tritium targets. On the basis of an existing contract with TU Dresden its Institute of Nuclear and Particle Physics is to be considered a subcontractor of nELBE; the facilities it runs at the site of ELBE can therefore be used by the I3-users of nELBE and resulting costs will be reimbursed to TU by FZR.

B.3 Selection process for the access of users to the infrastructure

The peer review procedure, common for all Trans-national Access Activities, is described under Activity NA1-Management of the I3, part B.3.2.4. This will help assigning an experiment to the most appropriate of the facilities. Every half year, a Call for Proposals covering a six-month period will be published in the I3 web page and eventually also in appropriate journals. The date of the submission deadline should be around three months before the beginning of the respective beam-time period to ensure fast response.

(C) EUROPEAN ADDED VALUE

C.1 Community interest in the infrastructure

As mentioned above the neutron generator assembly of ELBE is still in the process of assembly and optimization. However, there is already a large number of competent and dedicated staff members in the relevant groups in the Forschungszentrum Rossendorf. There is good evidence that there will be significant demand of international users after the infrastructure is operative. This has become obvious by several expressions of interest by scientists from several EU and associated countries. Below is a short list of users who have expressed their interest in beam-time at nELBE.

Name	Country	Organization
F. Becvar	Czech Republic	Charles Univ. Prague
K. Czerski	Poland	Szczecin University
J. Durell	U. K.	Univ. Manchester
Th. Kirchner	France	Ecole des Mines Nantes
D. V. Kamanin	Russia	JINR Dubna
L. Kostov	Bulgaria	INRNE / Acad. of Sciences
A. Krasznahorkay	Hungary	ATOMKI Debrecen

The Forschungszentrum Rossendorf traditionally has a high-volume visitors programme, and in particular benefits from its good contacts to the new member states in central and eastern Europe. A number of visitors have successfully performed experiments with beams and other equipment available at ELBE and there is no doubt that a number of these visitors also will be glad to use the possibilities of nELBE. A group at ELBE is currently member of the "EURONS" Integrated Infrastructure Initiative within FP6 and it is expected that members of that I3 show interest in using nELBE. It has to be stressed that although some of these scientists also have access to accelerator facilities which are geographically closer to their home institutions, it is the unique parameters of nELBE (short neutron pulses with high repetition rate etc.) which makes it so interesting for them.

C.2 Expected impact

After the end of the period for which we apply for support with the present proposal, we expect that nELBE will be an European-wide highly recognized facility for science performed with neutrons in the fission neutron energy range. The international standing of nELBE at that time should ensure continuation of the operation of the facility without the Community's financial contribution, although support for a continued support for service to the European scientific community will be aspired.

C.3 Measures to attract potential new users

Already shortly after the decision to construct this facility, a workshop was organized in 2000 to inform scientists on national and international levels about the project and show them the possibilities relevant to their fields. There were 30 talks and a panel discussion; some 50 external participants from 10 countries were present (UK, France, Belgium, Sweden, Finland, Switzerland, Italy, Poland, Bulgaria, Germany). The mailing lists of these scientists are still in evidence and they will be readily informed in advance, as soon as beam-time can be offered. With some of them even an ongoing collaboration exists already. More recently, a summer school/workshop was held in 2002 at Dresden on the use of small accelerators in applied research with special emphasis on nuclear science. In the near future, the Forschungszentrum Rossendorf will co-organize the IEEE Nuclear Science Symposium & Medical Imaging Conference to be held at Dresden. This will allow to present the capabilities of nELBE to a wide range of scientists in Europe and from further away.

An information brochure about the radiation source ELBE is already available and is being distributed to guests, at workshops and at various other occasions. The facility is also regularly presented at international conferences, workshops and at external seminars.

ELBE has a continuously updated web-page which contains a presentation of the neutron beam facility, describing the technical specifications, the in-house research programme as well as the present status of the radiation source. Finally, calls for proposals will be made there and by other appropriate means. A special web-page will be created for EFNUDAT (see network Activity NA8). This web-page will be linked to the web-page of ELBE, to the home-page of the FZR and, if possible, to the CORDIS server. The annual reports of the FZR and its institutes for nuclear physics and for safety research will clearly advertise the access opportunities and the web-route to the EFNUDAT web-page. A concerted EFNUDAT action on advertisement may also be envisaged, using 'cross-linked' web-pages with a description of the consortium of facilities and their research opportunities.

(D) ACCESS OFFERED BY THE INFRASTRUCTURE

D.1 Multi-annual implementation plan

The first operation of the neutron time-of-flight set-up is expected for mid 2006 and its commissioning is expected for the end of 2006, but that year will be mostly used to gain experience in running the facility. This will happen during experiments by in-house users and some external collaborations. Reliable operation as a research infrastructure will commence in 2007. Thus, although the present I3 action should start in 2006, regular access to the nELBE research infrastructure will be available only by 2007; however, at least one EU-user project may be supported already in 2006.

Thus the implementation plan covers a project duration of 36 months only. If the proposal can be accepted a reasonable estimate is that we can offer (in addition to in-house use of nELBE) each year a minimum of 19 experiment-shifts; this corresponds to 150 supplementary data-taking hours per year. The average duration of an experiment is estimated to be 10 - 20 shifts, so that 1 or 2 additional experiments per year can be performed within this I3. As the DT-generator is not only in the ELBE-building, but also an integral part of nELBE, it also is offered for use by I3-members. The group at TU-Dresden operating this set-up is to be considered a subcontractor of the FZR team, and running costs originating from I3-users will be transferred to TU-Dresden from FZR according to an existing mutual agreement.

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 backing. 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

All starting projects at ELBE are submitted to a specific procedure for hazard identification and risk assessment. Special training sessions are organised for newcomers on health and safety at work, including radiation protection issues for activities in controlled areas. In addition, new users will be given a detailed facility-specific newcomers training. If needed, first-time users will get all training they need to get acquainted with the novel measurement techniques applied at the facility. Young researchers can also benefit from various lectures organised within the FZR.

D.2.2 Scientific and technical support

A local senior scientist will be designated by the FZR as local scientific contact. He will be in charge of the external users during their whole measurement period. He will introduce the users to all facility aspects. He functions as a liaison with the machine operators, with the other scientific staff and with the administration and technical service of the FZR.

Technical support laboratories and workshops are available on site as described under B.2.

D.2.3 Administrative and logistic support

Users will get access to the same services as the FZR staff e.g. standard office services (telephone, fax, internet services) and meeting rooms, library and restaurant (cf. sec. B.2). The secretaries of the institute can be contacted for administrative or personal problems, such as lodging, contacts with local administration, schools and hospitals.