International Conference
Nuclear Energy for New Europe 2007
Portorož /Slovenia /September 10-13
port2007@ijs.si
www.nss.si/port2007
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PORT2007, Nuclear Society of Slovenia, Jamova 39, SI-1000 Ljubljana, Slovenia

Utilization of a Typical 250 kW TRIGA Mark II Reactor at a University

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ABSTRACT

The 250 kW TRIGA Mark-II reactor operates since March 1962 at the Atominstitut Vienna/Austria. Its main tasks are nuclear education and training in the fields of neutron- and solid state physics, nuclear technology, reactor safety, radiochemistry, radiation protection and dosimetry, and low temperature physics and fusion research. Academic research is carried out by students in the above mentioned fields coordinated and supervised by about 70 staff members with the aim of a masters- or PhD degree in one of the above mentioned areas. During the past 15 years about 580 students graduated through the Atominstitut. In addition, the Atominstitut co-operates closely with the nearby located IAEA in research projects, coordinated research programs (CRP) and supplying expert services. Regular training courses are carried out for the IAEA for Safeguard Trainees, fellowship places are offered for scientists from developing countries and staff members carry out expert missions to research centres in Africa, Asia and South America. Special Nuclear Material (SNM) is stored for calibration purposes at the Atominstitut belonging to the IAEA.

1 INTRODUCTION

The paper focuses especially on the important results in neutron- and solid state physics and the co-operation between the low power TRIGA reactor with high flux neutron sources in Europe such as the Institute Laue-Langevin (ILL) in Grenoble, the Paul Scherrer Institut (PSI) in Villigen and the Technical University in Munich. Experiments are set up for test purposes at the TRIGA reactor and then transferred to the powerful neutron sources. Different new perfect silicon channel-cut and interferometer crystals are prepared and then tested at the Bonse-Hart camera, which is a double crystal (or triple axis) diffractometer and at the interferometer set-up. Historically, the first verification of neutron interferometry at a perfect crystal device has been achieved at the 250 kW TRIGA-reactor in Vienna in the year 1974. Also the co-operation with the PSI and the TU Munich in the field of neutron radiography and neutron tomography will be mentioned.

The second topic treated in this paper shows the international co-operation in the field of superconductors. This research work is carried out under two European TMR-Network programs.

The third topic in this paper focuses on the co-operation in the field of safeguard and with other Universities in Europe. Being the closest research reactor to the IAEA headquarters various departments of this organization use extensively the TRIGA facility mainly in the fields of Nuclear Safeguards. Every two years a four weeks training course is carried within the Safeguards Traineeship Program of the IAEA to train future Safeguards Inspectors from developing countries to fulfil the application criteria for Safeguard Inspectors. In the past 15 years approximately 80 trainees have passed through these courses at the Atominstitut. As a result of this co-operation with the IAEA, international courses in the field of reactor physics and kinetics and reactor instrumentation and control were developed. These courses are offered on a European level under the European Nuclear Engineering Network - ENEN. These courses are also part of the UK MSc programme in Nuclear Science and Technology. A co-operation with the University of Manchester has started this year.

2 PAPER FORMAT

The TRIGA Mark-II reactor was installed by General Atomic (San Diego, California, U.S.A.) in the years 1959 through 1962, and went critical for the first time on March 7, 1962.

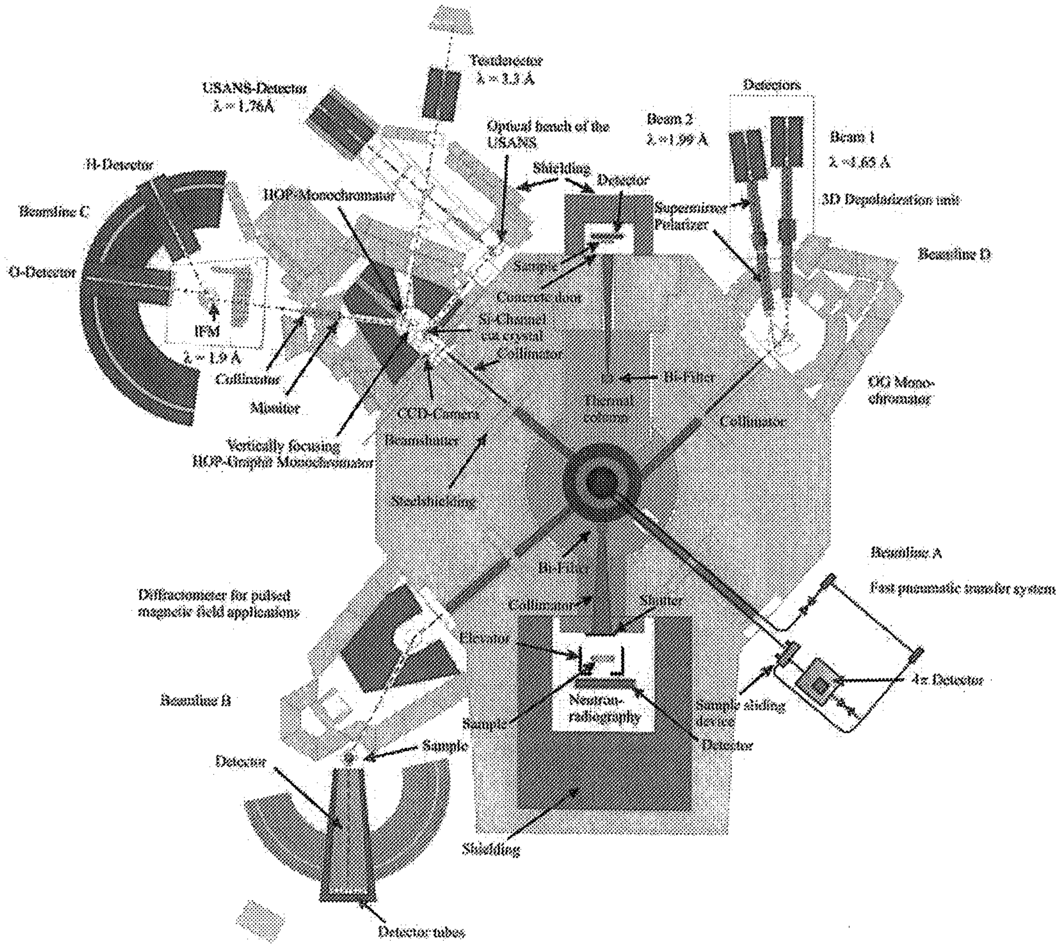

Figure 1: Experimental set-up at the TRIGA Mark-II reactor, Atominstitut Vienna

Operation of the reactor since that time has averaged 220 days per year, without any long outages. The TRIGA-reactor is purely a research reactor of the swimming-pool type that is used for training, research and isotope production (Training, Research, Isotope Production, General Atomic = TRIGA). The TRIGA reactor Vienna has a maximum continuous power output of 250 kW (thermal). Since the moderator, zirconium hydride, has the special property of moderating less efficiently at high temperatures, the TRIGA reactor can also be operated in a pulse mode (with a rapid power rise to 250 MW for roughly 40 milliseconds). The power rise is accompanied by an increase in the maximum neutron flux density from 1x10^{13} $cm^{-2}s^{-1}$ (at 250 kW) to 1x10^{16} $cm^{-2}s^{-1}$ (at 250 MW). In accordance with its purpose as a research reactor, the TRIGA Mark-II is equipped with a number of irradiation devices (Fig. 1):

5 reflector irradiation tubes
1 central irradiation tube
1 slow pneumatic transfer system (transfer time 4 seconds)
1 vertical fast pneumatic transfer system (transfer time 0.3 seconds)
1 horizontal fast pneumatic transfer system (transfer time 20 milliseconds)
4 neutron beam holes
1 thermal column
2 neutron radiography facilities

The different experiments located at the beamlines of the TRIGA Mark-II reactor in Vienna were the starting point for different international co-operations.

3 THE CRG-C EXPERIMENT S-18 AT ILL, GRENOBLE

In the year 1974 perfect crystal neutron interferometry has been introduced by test measurements at a 250 kW TRIGA Mark-II reactor in Vienna [1,2]. It provides widely separated coherent beams and reasonable intensities due to the nondispersive action of the reflecting crystal plates and the possibility to use rather large beam cross sections. The perfect crystal interferometer technique has been developed before for X-rays [3] and profits from the availability of large perfect silicon crystals. In a joint undertaking between the Atominstitut in Vienna and the University Dortmund and according to an invitation of H. Maier-Leibnitz, the director of the ILL at that time, a prototype interferometer was installed at the high flux reactor at Grenoble [4]. After the shutdown of the 58 MW High Flux Reactor (HFR) in Grenoble (replacement of reactor vessel), and the restart of the HFR in January 1995 the whole set-up of the S-18 instrument was replaced and adapted to new technologies.

In parallel to the interferometer set-up a perfect crystal Bonse-Hart [5] small angle scattering camera has been installed [6], which takes advantage of a new tail suppression method [7]. This double crystal diffractometer (DCD) is an integral part of the instrument. Also polarized neutrons can be adapted by magnetic prism deflection within the air gaps of two prism shaped permanent magnets placed between the monochromator and the interferometer. In 1998, the combined interferometer and ultra small angle neutron scattering (USANS) instrument S18 at the HFR at the ILL started operation.

Due to the installation of the new supermirror guides at the HFR at the ILL, the intensity at the instrument position has been increased by a factor of five and the signal to background conditions have been improved considerably. The neutron interferometer set-up S18 has been upgraded to a triple axes instrument and an advanced Bonse-Hart ultra small angle scattering camera has been added. Both instruments use a highly vibration isolated optical bench and a common data acquisition system.

Since the first test measurements in 1998 several experiments in the field of neutron interferometry, ultra small angle scattering and polarized neutrons have been performed. Small and ultra small angle neutron scattering investigations on fusion relevant SiC/SiC_f ceramic composite materials (this work has been carried out within the association EURATOM-ÖAW, ADV1.1.1 - Advanced materials, SiC/ SiC_f ceramic composites - Thermodynamical properties and material characterization) [8], Permanent magnetic field-prism polarizer for perfect crystal neutron interferometers [9] and Diffraction enhanced imaging (DEI) has been tested.

4 NEUTRON RADIOGRAPHY AND NEUTRON TOMOGRAPHY WITH PSI, SWITZERLAND AND TU MUNICH

Neutron radiography provides a very efficient tool in the field of non-destructive testing as well as for many applications in fundamental research. A neutron beam penetrating a specimen is attenuated by the sample material and detected by a two-dimensional imaging device. The image contains information about materials and structure inside the sample because neutrons are attenuated according to the basic law of radiation attenuation. Nevertheless, there are many aspects of structure, both quantitative and qualitative, that are not accessible from two-dimensional transmission images and, therefore, there is interest in three-dimensional neutron imaging. At the Atominstitut der Österreichischen Universitäten neutron radiographic examinations have been carried out for more than 35 years. Presently, two neutron radiography facilities are located at the 250 kW TRIGA Mark-II reactor. Main data of these facilities are shown in Table 1.

Table 1: Main characteristics of the neutron radiography facilities at the Atominstitut

	STATION 1	STATION 2
FLUX DENSITY ($cm^{-2}s^{-1}$)	$3x10^5$	$1.3x10^5$
L/D-RATIO	50	125
BEAM DIAMETER (cm)	40	8
Cd - RATIO	3	20

At one of these facilities a neutron tomography facility has been installed (Figure 2). The neutron flux at this beam position is $1.3x10^5$ neutrons/(cm^2s) and the beam diameter is 8 cm. For a three-dimensional tomographic reconstruction of the sample interior, transmission images of the object taken from different view angles are required. Therefore, a rotary table driven by a step motor connected to a computerized motion control system has been installed at the sample position.

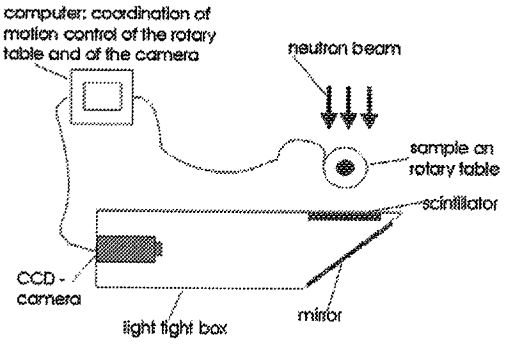

Figure 2: Neutron tomography facility

In parallel a suitable CCD-camera based imaging device [10] has been designed. It can be controlled by a computer in order to synchronize the software of the detector and of the rotary table with the aim of an automation of measurements. Reasonable exposure times can get as low as 20 s per image. This means that a complete tomography of a sample can easily be performed within one working day. Calculation of the 3D voxel array is made by using the filtered backprojection algorithm.

First reconstructions have been made at TU Munich and in parallel at Paul Scherrer Institute. Figure 3 shows the neutron tomography of a diode, as an example of a neutron tomography made at the Atominstitut. Part of this work has been financed by the EURATOM-ÖAW association, UT4 - Underlying Technology Project. Neutron Inspection of Fusion - Relevant Materials, Neutron Micro - Radiography.

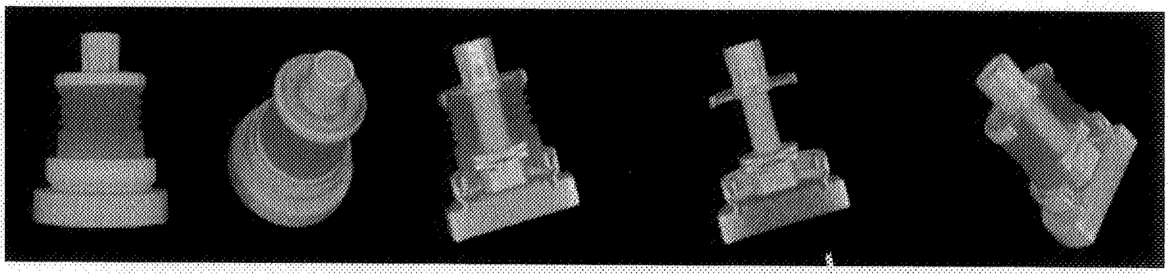

Figure 3: Neutron tomography of a diode

5 HIGH CRITICAL CURRENT SUPERCONDUCTORS FOR TECHNICAL APPLICATIONS

Superconductors for technical applications are required to carry very high currents without losses in the presence of magnetic fields. Decades of research have led to highly satisfactory results for metallic alloys and compounds at 4.2 K. With the advent of high temperature superconducting compounds, an enormous step forward was expected, since the cryogenics involved are much less sophisticated and expensive. However, in view of the complicated nature of these compounds, e.g. the anisotropy of their physical properties and the generally weak flux pinning structures, the achievement of high currents at elevated temperatures turned out to be extremely difficult. Nevertheless, a few compounds are emerging at present, which could meet these requirements, if appropriately tailored and characterized, such as YBCO monoliths for bearings and levitation as well as BiSSCO tapes and coated conductors for cables. These issues are vigorously addressed in the United States and Japan. The present consortium will respond to this challenge, carry out highly innovative research objectives, expects to achieve major steps towards technical applications through this co-operative effort, and provides the European Union with well trained manpower that will be urgently needed when the envisaged applications are realized in practice. The Vienna group, in particular, is involved in the optimization of the defect structure for flux pinning in all technologically relevant high temperature superconductors. One of the most successful ways to enhance the critical current densities at the boiling temperature of liquid nitrogen consists of artificially introducing extended defects by radiation techniques [11]. Fast neutrons, e.g., produce spherical collision cascades, which act as efficient flux pinning centres in high temperature superconductors with a more "three-dimensional" magnetic micro-structure, such as YBCO, whereas extended columnar defects (thermal neutron induced fission tracks in materials with small additions of ^{235}U) are most efficient in more "two-dimensional" superconductors, such as BiSCCO tapes [12]. As a consequence of these defect modifications, the critical current densities can be enhanced by orders of magnitude. The research work in this field is part of the TMR Network "Supercurrent".

6 RADIATION EFFECTS ON FUSION REACTOR MATERIALS

The radiation response of various superconducting magnet components [13] is investigated by exposing them to a mixed neutron and gamma radiation environment. Special emphasis is placed on the ITER [14] magnet insulation systems. ITER relevant data are generated for their mechanical properties under various static and dynamic load conditions prior to and following irradiation. Selected superconductors are investigated as well with regard to the radiation-induced changes of the critical current densities. The research reactor of the institute, which represents a well characterized radiation source, is employed and supplementary irradiation experiments in a pure gamma environment are made at a partner institute within the Euratom associations. Based on the results of previous research programmes [15] and considering the extensive materials development and testing programmes which are presently under way in the framework of the ITER programme, we address the following subjects, which are all related to radiation effects in fusion magnet materials. Firstly, radiation effects on superconducting magnet components are assessed. The material of primary concern for the lifetime performance of the magnet is certainly the insulation of the magnet windings. Following extensive scaling experiments [16] to assess suitable sample geometries for the small irradiation volumes in the reactor, we proceed with testing newly developed fibre reinforced plastics and assess their mechanical properties in tension as well as in the interlaminar shear mode both under static and dynamic loading conditions [17]. A special effort is made to investigate fatigue effects under tension and shear of these materials following irradiation at ambient temperature. The materials are provided by the US, Japanese and European manufacturers involved in the fabrication of the ITER test coils. Secondly, radiation effects on superconducting materials selected for ITER are investigated with the equipment available at the institute, the main parameter being in this case the change of the critical current density. Finally, new developments, e.g. the implementation of superconducting current leads, based on high temperature superconductors, and their radiation response, are investigated as well.

7 COOPERATION WITH INTERNATIONAL ORGANIZATIONS

As a university institute the Atominstitut has strong international relations with similar institutions not only with all European countries but also with many overseas institutions. One big advantage for the Atominstitut is the proximity of the IAEA and the CTBTO which is practically around the corner. Several of our graduates were hired by these two organisations during the past. In addition the Atominstitut carries out research projects on a contract basis which are usually implemented into a Masters- or PhD thesis, in this case the IAEA/CTBTO benefits of highly qualified manpower and the student usually benefits of financial support.

Areas of research contracts are mainly in the development or improvement of safeguards instruments both in software or hardware such as portable gamma spectrometers for access control or improvement of automatic gamma identification. Further the Atominstitut carries out regular courses for IAEA Junior Safeguards Trainees since 1984, since that year more than 100 trainees spent about 4 weeks of intensive practical training at the Atominstitut and many of them joined the IAEA as safeguards inspectors.

Another cooperation task is the acceptance of IAEA fellows for practical training in the field of research reactor operation and -utilization. Within this program the Atominstitut has accepted about 100 fellows mainly from developing countries who spent from 1 to 12 month within the reactor group for on the spot training. The knowledge acquired during the years in the reactor group is also transferred by IAEA expert missions to related institutions in Asia, Africa and South America. More than 70 such missions have been carried out during the last two decades.

Out of these contacts strong ties and bilateral cooperation between the Atominstitut and the counterpart institutions continue throughout the years. The staff of the Atominstitut is also participating in several EU projects related to Knowledge Management such as European Nuclear Engineering Network (ENEN), Nuclear European Platform of Training and University Organisations (NEPTUNO) and the ENEN Association. These international projects aimed to increase the mobility of students and university professors among EU countries especially in the nuclear field and the mutual recognition within the ECTS credit system. One direct result from these projects is the Eugene Wigner training course, which is carried out in cooperation between the Technical Universities of Bratislava, Budapest, Prague and Vienna/Atominstitut. During the three weeks course students and junior professionals carry out practical experiments at three different types of research reactors together with reactor theory courses and a final test accepted by their home university.

As a result of the national utilization of the TRIGA facility also international users are attracted by the training possibilities at the Atominstitut, therefore special courses are organised for interested groups on a cost-refund basis, typical users were the Gesellschaft für Reaktorsicherheit/Cologne, for staff of the NPP Jaslovse Bohunice and Mochovce, the University of Manchester (NTEC-program) and the UK Navy (HMS Sultan). Interested groups may select from a range of about 20 practical experiments carried out directly at the TRIGA reactor together with the relevant theoretical introduction and textbooks all in English language. Such courses usually last five full working days. Besides these activities the Atominstitut is members of many associations such as TRIGA Users Group, Research Reactor Operators Group (RROG), European Atomic Energy Society (EAES), Arbeitsgemeinschaft Forschungsreaktoren (AFR), Research Reactor Fuel Management Group (RRFM), International Group of Research Reactors (IGORR) and several others. The regular meetings of these groups allow personal contacts and knowledge transfer on nuclear fields of common interest.

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