STRATEGY FOR SUSTAINABLE UTILIZATION OF IRT-SOFIA RESEARCH REACTOR

M. MITEV, T. APOSTOLOV, K. ILIEVA, S. BELOUSOV, T. NONOVA
Institute for Nuclear Research and Nuclear Energy of Bulgarian Academy of Sciences,
Sofia,
Bulgaria
mlmitev@inrne.bas.bg

1. INTRODUCTION

The research reactor IRT-2000 at the Institute for Nuclear Research and Nuclear Energy (INRNE) in Sofia was built and put into operation in 1961. It was temporarily shut down in 1989 for improvement. The reconstruction into IRT-200 is being carried out under the decision of the Council of Ministers of Republic of Bulgaria in 2001. The strategy for sustainable utilization considers the IRT-200 as a national base and aims to satisfy the society needs for:

- Education of students and training of graduated physicists and engineers in the field of nuclear science and nuclear energy;
- Implementation of applied methods and research; and
- Development and preservation of nuclear science, skills and knowledge.

2. REFURBISHMENT DETAILS

The IRT-200 technical design is in process of elaboration. The IRT-200 will be reconstructed into a reactor:

- Of thermal power 200 kW;
- With low enriched uranium-235 fuel (LEU);
- With six vertical and seven horizontal experimental channels; and
- One of the horizontal channels will be used for medical application of boron neutron capture therapy (BNCT).

An up-to-date system for monitoring the IRT-200 site has been built through the European Community’s PHARE programme under the project “Innovation of the Radiation Monitoring System” and “Technical Assistance” from 2002 to 2005. The radiometric laboratory is equipped with 2 modern high resolution gamma spectroscopy systems; 2 ultra-low level alpha/beta systems; a wide range of portable beta, gamma and neutron probes; 2 aerosol monitors and a system of 35 individual electronic dosimeters for individual dosimetry control. Samples taken from not only the reactor building but also from the IRT-200 surrounding area (i.e., the sanitary protection zone) are to be measured there.

The research reactor will use LEU fuel of type IRT-4M. The replacement of the high enriched, 36% uranium-235 (HEU) fuel IRT-2M with LEU fuel is in accordance with the current requirements of the security of transportation and storage of nuclear and other radioactive materials. This work is being carried out with the support of the US Department of Energy in the frame of the RERTR program for conversion from HEU to LEU fuel.

Preliminary three dimensional neutron transport calculations with MCNP code [1] for reactor core arrangement with LEU, together with the BNCT channel regarding its construction (i.e., geometry and material composition of the BNCT beam collimator and filter) and design, have been carried out (Fig.1). The BNCT beam tube design is similar to the US Massachusetts Institute of Technology (MIT) tube design [2]. The BNCT channel will supply an epithermal neutron flux of about 4.5×10^{9} $cm^{-2}s^{-1}$ [3] with quality that fulfills IAEA recommendations [4]. In the other experimental channels the maximum fast neutron flux will be about 3×10^{12} $cm^{-2}s^{-1}$, and maximum thermal flux about 8×10^{12} $cm^{-2}s^{-1}$.

Returning the HEU spent research reactor fuel to the Russian Federation, where it was originally enriched, is being done with the support of the US Department of Energy in the frame of the RRRFR programme [5]. All activities within this program are going on according to the cooperation plan.

3. REACTOR UTILIZATION

3.1. Current activities

INRNE together with the Technical University of Sofia have proposed to the Ministry of Education a new program for the education of students in nuclear energy. The Nuclear Energy course will be obligatory for obtaining the Master of Science Degree of the Technical University in Sofia. The educational classes include: types of research reactors, main characteristics and design of the reconstructed IRT, safety assurance and licensing, reactor physics and thermo-hydraulic characteristics determination, accident analyses, fresh and spent fuel management, radioactive waste management and governmental categorization norms and rules. In addition, acquaintance with calculational codes such as the MCNP code for neutron transport and WIMS-ANL code for criticality calculations and preparation of neutron cross sections for diffusion calculations, the REBUS code for fuel burn-up calculations, the SCALE code system for spent fuel transport and storage devices safety assessment, the PLTEMP/ANL code for calculation of thermo-hydraulics at steady state, and the PARET and RELAP5 codes for transients, among others, is planned. Preliminary acquaintance with neutron activation analysis and BNCT is included in the educational programme.

Seminars are held nowadays with the first student group in INRNE. Exercises on radiation monitoring are carried out in the renewed and modernly equipped laboratory for radiation measurements.

The development of the BNCT facility is supported through two National Science Fund projects. A BNCT Scientific Information System has been developed with the purpose to foster the development of BNCT at the reconstructed research reactor IRT-200. It has been built as a subsystem to the INRNE Intranet. The information system is based on a server and set of notebooks and is implemented through the INRNE information network. It provides reliable access to specific data, periodic publications and a possibility for continuous exchange of information relating BNCT researchers jointly working on BNCT development in Bulgaria from the national BNCT network. The information system also supplies easy and fast access to basic and current information to young specialists just starting with BNCT.

The building of the BNCT scientific infrastructure is currently ongoing. A specialized Treatment Planning System (TPS) as a basic component of NCT will be created for treatment of patients with malignant tumors. The NCT TPS will include computer codes and a database for patient data storage with a capability to be extended by additional data when available. Its anatomo-topographic module will be adapted from already existing and verified modules. The irradiation beam characteristics will be described by a new dosimetry module. This development imposes solutions during design elaboration and specialization of personnel for the types of activities before the reactor re-commencement after its reconstruction. The NCT infrastructure requires creating, enforcing and managing a multidisciplinary team. That is why the NCT infrastructure building includes also the strengthening of the national NCT network and cooperation with experienced and interested Balkan region countries as well. The TPS will be applied for a parallel study of photodynamic therapy (PDT) [6] and NCT as well as the possibility to combine both. PDT and NCT are modern cancer treatments that have showed their efficacy in treating malignant tumours during the last ten years. PDT and NCT are both binary modalities for cancer treatment involving activation of tumour cell localized sensitizers with light or low energy neutrons. Both therapies allow local control with minimal side effects, which are common in some other cancer treatments.

Radiopharmaceuticals labeled with ^{99m}Tc were produced until 2005 at the IRT-200's first class radiochemical laboratory for applications in nuclear medicine diagnostics. These kits consist of lyophilized non-radioactive compounds which form stable complexes. Eight products were produced and licensed for clinical use [7]. The radiochemical purity of radiopharmaceuticals has been determined by means of gel chromatography on Sephadex and thin layer chromatography on plastic foil silica gel. The comparison of the kits shows an equal level of complex formations with ^{99m}Tc. The biodistribution demonstrated that the application of HEDP allows earlier scanning than MDP. MDP and HEDP show equal effectiveness during clinical investigations. HEDP kits demonstrate a shorter period of accumulation and equivalent complex formation levels, so it can be used in routine nuclear medicine diagnostics together with the MDP kit. ^{99m}Tc(V)-DMSA has proved to be suitable for imaging of medullar thyroid carcinoma, amiloidosis, osteosarcoma, primary and metastatic bone and tissue tumours. The MDP for labelling red blood cells (RBC) with ^{99m}Tc was studied and introduced in nuclear medicine practice. Labelled MDPRBC imaging is used for a number of different clinical investigations such as assessment of cardiac function, blood pool imaging, detection of vascular abnormality, detection of bleeding from the gastrointestinal tract and the detection of haemangiomas. The references received from medical doctors for the produced radiopharmaceuticals are excellent, and together with the low cost, this made INRNE kits valuable and desired from nuclear doctors throughout the country.

3.2. Utilization after refurbishment

After reconstruction, the IRT-200 will be used for carrying out specific training exercises on the reactor: reactor start up; manual and automatic control; control rod calibration; delayed neutron group measurements; subcritical multiplication and shutdown margin measurements; excess reactivity and shutdown margin measurements; reactor physics measurements of static and kinetic reactor parameters; reactor dosimetry; measurements of the spent fuel characteristics in the hot cells; radiological characterization surveys using alpha, beta and gamma measurement techniques; contamination measurements; and more.

The reconstruction of the IRT-200 includes an arrangement for a BNCT facility. Combating a major disease, i.e., cancer, is one of the priority themes of the European Community Seventh Framework Programme within the pillar "Translating research for human health," corresponding to a major political and strategic choice of the European Union. This is also a response to the expectations of society for increasing the quality of life, at national as well as at European Community level. BNCT is a form of radiotherapy that has the potential to selectively kill cancer cells embedded within normal tissue. It uses the B-10 isotope, which emits two short lived high energy particles when irradiated with a beam of thermal energy neutrons. Due to the very short path length of the particles in tissue (equal to one cell dimension), the treatment is lethal to cancerous cell containing boron atoms, but has a much less damaging effect to the surrounding normal tissue. Treatment using BNCT is mostly applied on the head and neck; malignant melanomas and brain tumours, particularly glioblastoma multiforme; and the liver as well. The current worldwide practice in BNCT is to irradiate the patients with a neutron beam from a reactor.

Feasibility studies within the national network of the Medical University of Sofia, the National Centre of Radiobiology and Radiation Protection, the Institute of Experimental Pathology and Parasitology and Institute of Electronics of the Bulgarian Academy of Sciences and the Faculty of Physics of Sofia University are being carried out. The transfer of knowledge from institutes experienced in BNCT, such as the Joint Research Centre, Petten in the Netherlands, VTT of Finland and NRI Rež of the Czech Republic, is being conducted. Human, social and economical results due to BNCT for patients from the Balkan region are anticipated. It could be considered an advantage for a good infrastructural connection with the Oncology Hospital, which is located about 3 km from IRT-200.

Neutron activation analysis (NAA) is planned to be developed. It is a sensitive analytical method for the determination of elements and their traces (i.e., nanograms) in various types of samples and specimens, such as in metals and inorganic compounds; in animal, plant and fish products; soil, river waters, sea sand, rain, snow and rocks; cosmic materials; archaeological objects; medicine and criminology. NAA is the most widely used and beneficial application of research reactors worldwide. It is estimated that approximately 100 000 specimens are analyzed annually. The material under investigation is irradiated with neutrons. The element whose content is to be determined is activated, and its half-life could be of several minutes to several days.

The hot cells available at IRT-200 allow for the production of radioisotopes, particularly radioisotopes for industry and medical applications in vivo and in vitro, e.g., Br-82, Na-24, Ar-41, La-140, and K-42).

A study of defects in the crystal metal lattice produced by irradiation of metal specimens will be carried out. An investigation on reactor steel embrittlement will be used for development of a model for prognosis of VVER reactor pressure vessel lifetime.

A positron beam could be obtained from irradiation of appropriate targets with thermal neutrons or hard fission gamma rays. Positrons can be used as particle probes, suitable to detect material defects with dimensions smaller than a micrometer.

The development of a metrological system for testing and calibration of instruments needed for measurements of neutron and gamma fluxes as well as of radiation field monitors for measurements of dose received is also planned. Such a metrological system will guarantee uniformity of the neutron and gamma measurements throughout Bulgaria.

The development of neutron radiography will give an effective method of non-destructive testing that allows imaging of defects in a variety of objects (e.g., electronic, mechanical, military). The neutron beam penetrates a specimen, attenuates depending on the element contents, and interacts with a neutron absorbing screen. As a result, secondary radiation is produced that creates an image on a special film.

4. FINAL REMARKS

The IRT-200 research reactor is approaching the final stage of its refurbishment. Despite its low power, it will be possible to apply numerous applications both commercial and scientific. The inclusion of a BNCT facility in the technical project gives the unique possibility to better integrate the irradiation channel, and thus obtain a high quality beam which may result in the attractiveness of the Bulgarian facility for patients from abroad too.
The Integrated Management System of INRNE is a base for hosting the QA management of IRT-200 services. Certified since 2003, it has been developed in conformity with ISO 9001 for quality, ISO 14001 for environment, Bulgarian Nuclear Regulatory Agency requirements, governmental requirements for occupational health and safety, and for security.

5. REFERENCES

[1] MCNP — A General Monte Carlo N-Particle Transport Code, Version4C, BRIESMEISTER, I.F., Ed., LA-13709-M, RSICC ORNL, Code Package, CCC0700, 2000.
[2] HARLING, O.K., et al., The fission converter- based epithermal neutron irradiation facility at the Massachusetts Institute of Technology Reactor, Nucl. Sci. Eng. **140** (2002) 223–240.
[3] BELOUSOV, S., ILIEVA, K, Preliminary modelling of BNCT beam tube on IRT in Sofia, Applied Radiation and Isotopes **67** (2009) S230–S233.
[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Current Status of Neutron Capture Therapy, IAEA-TECDOC-1223, IAEA, Vienna (2001).
[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Experience of Shipping Russian-origin Research Reactor Spent Fuel to the Russian Federation, IAEA-TECDOC-1632, IAEA, Vienna (2009).
[6] AVRAMOV L., BORISOVA E., TOWNSEND, P., and VALBERG, L., Potential and current uses of luminescence in medical diagnosis, Mater. Sci. Forum **480–481** (2005) 411–416.
[7] AYRANOV, M., STREZOV, A., YORDANOVA, A., PIPERKOVA, E., SERGIEVA, S., HRISTOVA, N., TZINGILEV, D., KUIKIN, V., KOVACHEVA, S., Clinical application of some Bulgarian radiopharmaceutical kits for nuclear medicine diagnostics, Rentgenologiya i Radiologiya **38** (1999) 31–34.