Working Material

Report of the IAEA Technical Meeting on

Access and Utilization of Research Reactors by non-host Member States

10-14 October 2011, Vienna, Austria

Organized by
The International Atomic Energy Agency (IAEA)

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A. Background and Objectives of the Meeting

Background information

Research reactors have been used to address a wide variety of needs and stakeholders. These include using the research reactor as a first step to introduce nuclear power, to develop indigenous capabilities for research and education in nuclear science and technology, and to provide valuable products and services for the medicine, industry, agriculture, archaeology and other sectors. The radioisotopes produced in research reactors are now an indispensible tool in diagnostic and therapeutic nuclear medicine and research reactor applications such as neutron activation analysis are used worldwide to support industry quality management and for assessments of soil quality, fertilizer update, water resources management etc.

A few research reactor facilities have been established as regional centres of excellence or global providers of products and services, however, most research reactor operators (RR) focus their strategy on the fulfilment of national needs and serve national customers and stakeholders. More than half of the world's research reactors have very low utilization, and many are challenged to obtain appropriate funding. On the other hand, many countries do not have access to research reactor services. Any new research reactor project must carefully assess the potential user and funding basis to ensure that the reactor can be operated safely and securely throughout its project lifetime.

In this context, there is a clear potential for increased international cooperation for both existing and new research reactor projects. This would result in facilitated access to foreign nationals, common research and development programmes on a collaborative or commercial basis and more available financial resources for the research reactors. In addition, being in close contact with the enlarged user community, a shared RR will better understand its needs and be able to tailor services or develop additional capabilities as user needs evolve. Thus research reactors with a regional or international perspective have access to a much larger user base and funding. This can be translated into improved sustainability as well as options for increased capabilities or equipment. Non-host countries that subscribe to such research reactors would benefit from access to improved capabilities at lower cost than could be achieved by constructing a national facility.

To access these benefits, a number of issues at the technical, financial, regulatory, and intergovernmental levels must be resolved. There is a need to envisage and develop sound mechanisms to share research reactor facilities between countries regionally and internationally. This technical meeting is the first step in defining the issues and developing guidelines for their resolution.

Objectives of the meeting

The technical meeting was designed to provide a forum to identify existing good practices with international research reactor facilities and to collate practical experience with both successes and obstacles to such international cooperation as well as other relevant information through presentations and brainstorming discussions. The main objectives of this meeting were to:

1. Identify, analyse and understand current obstacles for broadening access to RRs for interested users from foreign countries from both the research reactor and user perspectives.
2. To review the feasibility of the international or regional approach to key research reactor missions such as
    a. Education and training for the "newcomer" states embarking on nuclear energy programmes, or states seeking to expand their scientific nuclear infrastructure.
    b. Provision of analytical and other services in support of industry, agriculture and medicine.
    c. Supply of products such as radioisotopes.

3. To review options for facilitated access to RR facilities and their services for countries without RRs
4. To help strengthen regional and international cooperation between countries with RR centres and countries without such facilities
5. To discuss mechanisms for the enhancement of RR utilization and sustainability through the concept of shared multi-user facilities

Expected output of the meeting

The principal output of the meeting is this report summarizing the presentations, discussions, panel's findings and recommendations. This document provides an analysis of the actual situation and obstacles to widen the regional and international customer base of RR. It also includes a summary of current good practises of sharing RR capabilities among different countries, covering organizational, procedural, legal and financial aspects. Individual contributions have analysed current obstacles and/or provided documented examples of good practices on how multi-user international facilities are created, operated and managed.

B. Work done

This Technical Meeting was organized by the IAEA to explore "Access and Utilization of Research Reactors by non-host Member States". The meeting was attended by 13 participants from 13 Member States around the world and 2 IAEA representatives, namely Mr D. Ridikas (NAPC) and Mr N. Peld (NEFW). Full list of participants is given in Annex J.

After the official host opening words by Director for the Physical and Chemical Sciences Division Ms M.Venkatesh some introductory remarks were given by Mr D. Ridikas, IAEA Scientific Secretary and Technical Lead for the meeting. Immediately following, Mr D. Ridikas (IAEA) gave a brief presentation on issues and challenges in the area of RR utilization and applications, specific region background and main objectives of the meeting.

Mr M.B. Farrar (ORNL, USA) was nominated as a chair person and Mr M.V. Voronov (PNPI, Russia) was appointed as a rapporteur of the meeting. The meeting continued according to the meeting agenda, prepared in advance (see Annex I of this report).

The presentations of the first day were dedicated to evaluation of availability and potential of RRs on providing products and services inside and outside the countries. At the end of the first day Mr P. Adelfang the Head of the Research Reactor Section in the Department of Nuclear Energy gave some welcome and meeting-related remarks.The first half of the second day was dedicated to presentations of non-host member-states who described their experience in nuclear activities and expressed the necessity of international collaboration in different fields involving RRs. Brief summaries of individual presentations are given in Annex K.

After that participants were split into two groups – RR hosts and RR non-hosts in order to discuss the main objectives of the meeting separately. During discussion participants took an active role in terms of sharing available examples, discussions and drafting of requirements and obstacles for broadering access to RRs for non-host MSs and possibilities to overcome these issues.

C. Discussion by countries with RRs

In this discussion a brainstorming conversation took place on the topic. It was universally acknowledged **that funding for each type of activity is the most important obstacle** on solving the problem of the access to RRs. It includes both R&D and subsistence fundings. Also everybody agreed that **local rules and laws** are another issue and in most cases memorandum of understanding is required in order to initiate any cooperation with foreign partners. Besides, participants noted **other such obstacles as**: limited staff and limited availability of equipment, no available space for guest scientists, site specific training and language issues. It was also noticed that in many cases **promotion of capabilities** is urgently needed through various instruments like internet, promotional leaflets, brochures, dedicated seminars, technical visits, etc. The following list of potential products and services, open for international partnership, was generated by the participating RR host countries:

- Hungary: NAA, irradiation services in scientific and industrial domains, neutron scattering, neutron radiography;
- USA: NAA, material irradiation services, isotope R&D, neutron scattering;
- Pakistan: NAA, isotope production, E&T;
- Indonesia: NAA, gemstone coloration, material/fuel irradiation studies, neutron scattering, neutron radiography;
- Morocco: NAA, isotope production, irradiation services in scientific and industrial domains, E&T;
- Russia: NAA, neutron scattering, proton therapy, gemstone coloration, irradiation services, pressure testing, radiography, E&T;
- Austria: neutron scattering, neutron radiography, E&T;
- China: NAA, E&T.

Most of the isotopes can be produced and supplied to other countries by the following member states: USA, Russia, Indonesia, Pakistan, Morocco and China. For Hungary supplying is outsourced.

In order to facilitate access to RR for non-host member states there are different on-going or planned programs:

- USA: neutron scattering user program, WFO, ATR NSUF, ORISE
- Austria: through the IAEA, Academy of Sciences, EU projects
- Hungary: BNC user program, EU projects
- Morocco: through the IAEA, International Training Center, scientific events
- Pakistan: PIEAS (University) and through the IAEA
- Indonesia: through the IAEA, FNCA program

D. Discussion by countries without RRs

In this session a round table discussion took place in order to find a solution to the obstacles mentioned in the main objectives. The following barriers for enhanced use of RRs by non-host countries were noted:

- insufficient financial support
- long and elaborate administrative procedures in getting access to RRs
- the access time is usually granted for a too short periods that is not enough for the requested application

A need to have a poll of RR's designated by host states and linked to the IAEA information system was mentioned. Each RR could identify its area of interest in advance with external partners and such a list could be published and accessed through the IAEA. Promotion of mutual interests between RR host states and users is needed. Special attention was paid to the lack of awareness in RR non-host states about RRs and their capabilities. It was concluded that training specific to NPP programmes will strongly depend on the specific needs of the newcomers and mostly will be defined by the nuclear technology they are likely to select. It was also mentioned and agreed that supplying of commercial products like Si-doping or radioisotopes are purely business-driven opportunities. Finally, it was noted that the IAEA should work closely with respective MS NLOs to involve a diverse variety of organizations and individuals in promoting RR utilization in a wider set of industries and research fields.

E. Executive Summary of Plenary Discussion

The meeting participants individually considered RR capabilities available at one or more of the various RRs discussing the host state actions/requiremens needed to make the capability available and the actions/requirements that the non-host states need to take in order to use these host-state capabilities. The overarching theme was that **host states need to better advertise their capabilities** and that **non-host states need to** understand that their proposed activities at RRs must **be adequately funded**; this includes RR usage costs and the travel, subsistence, and payroll costs for their researchers.

The capabilities evaluated for the RRs represented in the technical meeting are listed below. As a matter of fact, none of the RRs has all of these capabilities and few have the same set of capabilities.

- Neutron Activation Analysis
- Isotope R&D and production(for non-host use)
- Silicon Doping
- Gem "coloration"
- Materials Irradiation R&D
- Fuels Irradiation R&D
- Gamma Irradiation R&D (e.g., in the field of electronics)
- Neutron Radiography/Tomography
- Residual stress mapping
- Neutron Scattering
- Reactor Operator/Technician Training
- Nuclear Engineering Laboratories

First and foremost, the **host states need to advertise their capabilities** such that potential users from the non-host states can evaluate the RR capabilities and its limitations to determine if its needs can be met. Secondly, **providing contact information is also indispensible**, so that the potential users can discuss a project further and arrange for its execution. Finally, but not the least, allocation of some dedicated funds might be useful for partial support of users from non-host countries. The **general information/requirements** needed by regardless of the specific capability are as follows (further details per specific application can be found in Annex H):

- Description of capabilities and limitations

    - The specific details required will certainly vary with the capability. Examples include user program information, turn-around time and capacity, detection limit, range of elements and associated uncertainties, sample type and geometry, prohibited samples, elements not possible to detect
- Contact information
- Product/service delivery time and costs
- A clear procedure/approval process established for commercial or R&D activities
- Knowledgeable support scientific/technical staff
- Special nuclear materials handling and inventory process, if applicable
- Capsule design/fabrication/safety-analysis services available, if applicable
- The final product description, including shipping requirements
    - Physical product (e.g., gem, silicon wafer, isotope, sample)
    - The data or output format (end product) or final report
- Post irradiation Examination (PIE) processes or capability to ship to PIE facility, including waste path
- Primary areas of R&D and any potential joint projects
- The applicable QA/QC program - ISO certification if possible
- International logistics for moving materials across borders
- Education opportunities in capabilities and R&D techniques

Educational & training utilization requires a slightly different set of fulfillments that are listed below:

<u>Reactor Operator/Technician Training or Nuclear Engineering Laboratories</u>

- Training Program overview or Associated University Degree overview
- Contact information
- A syllabus for available classes and labs
- The Training/Educational Program QA issues
- The maximum class size and language requirements
- Trainee prerequisites/prequalification
- Collaborative organizations involved in the program
- A feedback system for continuous improvement
- Certification, diploma or other training/education recognition

The RR non-host countries desiring to use RRs have responsibilities and need to fulfil certain requirements in this process as well. Primarily, they need to understand that **adequate funding** must accompany proposals for the use of a host country's RR capabilities. This would include any necessary subsistence and travel funding for the researchers or technicians sent to work at the RR facility. Proposals should be detailed and technical enough for the host country to evaluate the need and their ability to satisfy the goals of the proposal. Also, the non-host country's proposal **staff should be technically competent** to communicate and collaborate with the RR staff in the planning and execution of the proposed work. In the case where materials or samples must cross borders, the non-host state should have the appropriate qualified personnel, processes, and **logistical arrangements including** a path forward for radiological wastes. This is especially important when transferring activated materials or samples, radioisotopes, or Special Nuclear Materials (SNM).

In a more general context, the below list provides already existing examples or ongoing projects, showing **<u>good practices of host and non-host member states in RR utilization</u>**

- Regional Neutron Scattering Schools (targeted at "non-nuclear" students & scientists)
- Regional Workshops to communicate and promote RR products and services

- Topical workshops on specific RR capabilities (e.g. neutron radiography workshop, k_0-NAA courses, RR related nuclear instrumentation software/maintenance training, etc.)
- Existing regional RR networks and coalitions
- Distance web-based remote RR laboratories (JUST & North Carolina State University (NCSU) internet-based RR laboratory, developed around PULSTAR RR in cooperation with IAEA)
- Regional "high-performance" RR centers of excellence (e.g. ILL, FRM-2, HFIR, etc.)
- TRIGA RR in Slovenia providing RR services and products on the regional basis

F. Conclusions and Recommendations

As the meeting concluded, each participating state elaborated on the useful point and thoughts gained in the discussions. Statements to this affect from some of the states follow:

- **China**: The representative indicated that they are open for RR related training, NAA cooperation, will be offering/exporting MNSR-type facilities
- **Montenegro**: The representative indicated that they are open for low radioactivity measurements & software (ANGLE) collaborations. Also, they expressed a need for building up awareness about RR capabilities among non-host Member States
- **Pakistan**: The representative indicated that they are open for international cooperation as a multipurpose RR facility
- **Vietnam**: The representative indicated that they are developing a NPP programme. The role of their RR in this endeavour has been acknowledged but no future specific role has been identified in this context (NPP programme development). Human resources development and funding issues remain very important to them. There are plans to establish a more powerful RR for both energy and non-energy related applications.

Joint Meeting Conclusions:

- The meeting was a timely, useful and fruitful event bringing together both RR and non-RR Member States; such meetings should certainly be continued on periodic basis to re-examine needs and available capabilities at RR facilities world-wide. Stronger participation of non-RR countries was desired, so their representation should be increased for future events.

- The role of RR in NPP development programmes in the newcomer states should be re-evaluated; e.g. a future IAEA TM on this particular topic has already been scheduled in November 2012 and was acknowledged.

- The major obstacle for cooperation remains funding (both for RR and non-RR member states).

- There is obvious lack of awareness in all countries, and especially in non-RR countries, regarding RR applications, products and services they can provide, including areas of R&D these facilities could support.

- It was noted that capabilities of RR world-wide are enormous and still to be explored; however, these facilities are facing underutilization issues. Many of them are lacking of sufficient resources, clear strategy and professional marketing.

- One of the main purposes of RRs remains R&D in numerous non-nuclear applications and nuclear science & technology (including nuclear power); therefore, continuation to promote utilization and applications of these facilities in different areas of R&D should be continued and intensified.
- The IAEA initiative on RR Centres of Excellence was acknowledged as a good practice that should be emulated.
- The RR Database capabilities need to be further improved and promoted, especially in RR non-host Member States.
- Development of strategic plans remains the crucial starting point to reshape existing RRs or start a new RR project.

Joint Meeting Recommendations

The meeting participants recommended to the IAEA:

- Inform other member states of the outcomes of this meeting by sharing this meeting report as a working document
- Organize periodic meetings (with similar objectives) among RR host and non-host countries
- Continue the role as facilitator/catalyst to improve/intensify awareness and facilitate links between RR and non-RR countries; good example of such awareness build-up would be through the applications in health, cultural heritage, environment, various industries; on request, facilitate bilateral agreements
- Promote, facilitate and continue to support regional neutron scattering schools
- Promote, support and develop RR internet laboratory as a model for interested parties for E&T purposes; in this context, IAEA should facilitate partnership between RR and non-RR countries
- Continue to advance in the initiative on RR Centres of Excellence; good practices of facilities like HFIR, ILL, FRM-2 and others should be used
- Further improve RR Data Base capabilities and promote its use through different international web pages like IGORR, TRTR, international conferences, workshops, and by other possible means
- Support the distribution of software related to NAA on case-by-case basis, so non-RR countries were able to perform spectral analysis outside of a RR facility
- Continue support of strategic plans creation/reviews/follow up; organize promotional and training workshops on strategic and business planning, including implementation RR performance indicators and project management; this should include both RR host and non-host countries
- Support creation of a RR network-coalition in Asia-Pacific, as it is already done in other regions; this should include both RR and non-RR countries

Other recommendations were both to the host and non-host RR countries:

- RR host countries were encouraged to develop dedicated web pages/promotional leaflets/brochures, etc. (in English), promoting their capabilities and readiness for joint projects; this should facilitate for non-RR countries access to the information/contacts and initiation of potential cooperation/business

- RR non-host countries are recommended, before initiating their own RR projects, examine very carefully if their needs cannot be met elsewhere by using existing RRs; IAEA can play a role of facilitator in bringing these parties together for joint bilateral or multi-lateral projects

- RR non-host countries should develop specific strategic plans, including core teams and budget provisions, on how to access RRs and their capabilities in other countries; in this context IAEA could be used more proactively to get in touch (provide information) with (related to) RR countries

G. Work plan for follow up actions

Work-plan (general):

1st Draft report to all participants: **17 October --> Resp. D. Ridikas**

Feedback from participants to the IAEA: **14 November --> Resp. all participants**

Final report published as working material: **28 November --> Resp. D. Ridikas**

Work-plan (specific):

Preparation of draft success stories-papers: **2 January 2012--> Resp.**

- **USA: on HFIR as a Centre of Excellence**
- **Jordan: on internet RR laboratory**
- **Montenegro: on collaboration with Slovenia and other RRs**
- **Other contributions are encouraged (e.g. Hungary, Morocco, …)**

CM to define course of actions and advise on future TECDOC; Q2 2012 --> Resp. D. Ridikas

H. Table of requirements for various applications

Capability	Host State Actions (to make capability available)	Non-host State Actions (to use host-state capability)
Neutron Activation Analysis	• Contact information • Clear procedure/approval established for commercial or R&D activity • Available description of capabilities and limitations (turn-around time and capacity, detection limit, range of elements and associated uncertainties, sample type and geometry, prohibited samples, elements not possible to detect) • Analysis time and costs • Final report for the user: full analysis or raw data • Post irradiation process (keep or return the irradiated samples) • Main areas of R&D, potential for joint projects, cross-checks • QA/QC program should be in place, ISO certification if possible • Promotion and market analysis	• Funding and co-funding opportunities • Travel & subsistence funding • Description of samples and purpose of analysis, other information on request • Main areas of R&D, potential for joint projects • Software, training and staff, in case of raw data or visiting scientist
Isotope Production and R&D (for non-host use)	• Contact information • Special nuclear materials for handling and inventory process • Clear procedure/approval established for commercial or R&D activity • Available description of capabilities and limitations (turn-around time, capacity, allowable sample types and geometry, and reactor irradiation facility features such as in-core instrumentation or gas cooling) • Capsule design/fabrication/safety-analysis services available • Accurate cost estimate or fixed-price • Post irradiation Examination processes or capability to ship PIE facility • Radioactive Waste Infrastructure - path forward • QA/QC program should be in place, ISO certification if possible or required • Promotion and marketing • International logistics	• Funding for RI production services • Funding - Travel & subsistence funding (if visiting during irradiation) • Description of samples, needed detailed assay of the sample irradiation conditions (neutron spectrum/flux, temperature, etc.) and other information on request for safety analysis purposes (e.g., material certifications) • Main areas of R&D, potential for joint projects • International logistics
Silicon Doping	• State whether allowed or not • Contact information • Clear procedure/approval established for commercial activity	• Funding • Description of samples, other information on request

	• Available description of capabilities and limitations (turn-around time and capacity, detection limit, range of elements and associated uncertainties, sample type and geometry) • Transmutation time and costs • Post irradiation process • QA/QC program should be in place, ISO certification if possible • Promotion and market analysis	
Gem Color Enhancement	• State whether allowed or not • Contact information • Clear procedure/approval established for commercial activity • Available description of capabilities and limitations (turn-around time and capacity, detection limit, range of elements and associated uncertainties, sample type and geometry) • Transmutation time and costs • Post irradiation process • QA/QC program should be in place, ISO certification if possible • Promotion and marketing	• Funding • Description of samples, other information on request
Materials Irradiation R&D	• Contact information • Clear procedure/approval established for commercial or R&D activity • Available description of capabilities and limitations (turn-around time, capacity, allowable sample types and geometry, and reactor irradiation facility features such as in-core instrumentation or gas cooling) • Capsule design/fabrication/safety-analysis services available • Accurate cost estimate or fixed-price • Post irradiation Examination processes or capability to ship PIE facility • Radioactive Waste Infrastructure - path forward • QA/QC program should be in place, ISO certification if possible or required • Promotion and marketing	• Funding for irradiation services • Funding - Travel & subsistence funding (if visiting during irradiation) • Description of samples, needed sample irradiation conditions (neutron spectrum/flux, inert gas, temperature, etc.) and other information on request for safety analysis purposes (e.g., material certifications) • Main areas of R&D, potential for joint projects
Fuels and SNM Irradiation R&D	• Contact information • Special nuclear materials for handling and inventory process • Clear procedure/approval established for commercial or R&D	• Funding for irradiation services • Funding - Travel & subsistence funding (if visiting during irradiation) • Description of samples, needed

	activity • Available description of capabilities and limitations (turn-around time, capacity, allowable sample types and geometry, and reactor irradiation facility features such as in-core instrumentation or gas cooling) • Capsule design/fabrication/safety-analysis services available • Accurate cost estimate or fixed-price • Post irradiation Examination processes or capability to ship PIE facility • Radioactive Waste Infrastructure - path forward • QA/QC program should be in place, ISO certification if possible or required • Promotion and marketing • International logistics	detailed assay of the sample irradiation conditions (neutron spectrum/flux, inert gas, temperature, etc.) and other information on request for safety analysis purposes (e.g., material certifications) • Main areas of R&D, potential for joint projects • International logistics
Gamma Irradiation R&D (e.g., electronics dedication)	• State whether available • Contact information • Clear procedure/approval established for commercial or R&D activity • Available description of capabilities and limitations (turn-around time, capacity, allowable sample types and geometry, and gamma irradiation facility features) • Price • Post irradiation process (to return sample to customer) • QA/QC program should be in place, ISO certification if possible • Promotion and marketing • Health physics coverage	• Funding • Description of objects for irradiation, other information on request for safety analysis purposes
Neutron Radiography/Tomography	• Contact information/user office • Neutron Scattering User Program or clear procedure/approval established for commercial or R&D activity • Available description of capabilities and limitations (turn-around time and capacity, sample type and geometry, applicable sample environments, prohibited samples) • Knowledgeable scientific/technical staff • Analysis time and costs • Final report for the user • Post irradiation process (keep or	• R&D Funding and co-funding opportunities • Travel & subsistence funding • Proposal; Description of samples and purpose of analysis, other information on request

	return the irradiated samples) • QA/QC program should be in place, ISO certification if possible • Promotion and marketing - Education in radiography/tomography techniques to build a user base	
Residual stress mapping	• Contact information/user office • Neutron Scattering User Program or clear procedure/approval established for commercial or R&D activity • Available description of capabilities and limitations (turn-around time and capacity, sample type and geometry, applicable sample environments, prohibited samples) • Knowledgeable scientific/technical staff • Analysis time and costs • Final report for the user • Post irradiation process (keep or return the irradiated samples) • QA/QC program should be in place, ISO certification if possible • Promotion and marketing - Education in residual stress mapping techniques to build a user base	• R&D Funding and co-funding opportunities • Travel & subsistence funding • Proposal; Description of samples and purpose of analysis, other information on request
Neutron Scattering	• Contact information/user office • Neutron Scattering User Program or clear procedure/approval established for commercial or R&D activity • Available description of capabilities and limitations (turn-around time and capacity, sample type and geometry, applicable sample environments, prohibited samples) • Knowledgeable scientific/technical staff • Analysis time and costs • Final report for the user • Post irradiation process (keep or return the irradiated samples) • QA/QC program should be in place, ISO certification if possible • Promotion and marketing - Education in neutron scattering techniques to build a user base	• R&D Funding and co-funding opportunities • Travel & subsistence funding • Proposal; Description of samples and purpose of analysis, other information on request
Reactor Operator/Technician Training	• Training program • Class/Lab syllabus • QA program should be in place • State maximum class size, language requirements	• Specified training requirements • A request for detailed curriculum • Funding for course execution • Subsistence for trainees • License/Certification recognition

	• Trainee prerequisites/prequalification • Contact information • Promotion – Collaborative organizations • Feedback for continuous improvement	• Feedback for continuous improvement
Nuclear Engineering Laboratories	• Educational program (if a University based reactor) • Class/Lab syllabus (if a University based reactor) • QA program should be in place • State maximum class size, language requirements • Student prerequisites/prequalification • Contact information • Promotion (if a University based reactor) – Collaborative university organizations (e.g., ORISE) • Feedback for continuous improvement	• Educational program • A request for detailed curriculum • Funding • Degree recognition • Feedback for continuous improvement
Other R&D requests	• Contact information • Open to consider requests not covered above	• Funding • New proposals

I. Meeting Agenda

Technical Meeting on

Access and Utilization of Research Reactors by Non-Host Member States
10-14 October 2011
VIC, Room A2712, Vienna Austria

MONDAY 10 OCTOBER

09.00 Meeting opening, introductions, and nomination of Chair & Rapporteurs
M. Venkatesh – Director, Division of Physical and Chemical Sciences
D. Ridikas – RR Officer, Physics Section, Division of Physical and Chemical Sciences

09.30 – 10.50 Participant presentations – Research Reactors/Hosts (40 minutes each)
AUSTRIA H. Böck/M. Villa
INDONESIA Y.E. Yulianto

Coffee Break

11.20 – 12.40 Participant presentations (40 minutes each)
MOROCCO B. El Bakkari
PAKISTAN M. Khalid

Lunch

14.00 – 15.20 Participant presentations (40 minutes each)
HUNGARY R. Baranyaine
RUSSIAN FEDERATION M. Voronov

Coffee Break

15.50 – 17.10 Participant presentations (40 minutes each)
CHINA Xia P.
USA M. Farrar

18.00 Hospitality Event, VIC Restaurant

TUESDAY 11 OCTOBER

09.00 – 10.20 Participant presentations users/non-Hosts/new RR (40 minutes each)
VIETNAM D.V. Dong
AZERBAIJAN I.A. Gabulov

Coffee Break

10.50 – 11.50 Participant presentations users/non-Hosts/new RRs (40 minutes each)
JORDAN S. Malkawi
MONTENEGRO S. Jovanovic
SUDAN A. Ebrahim

Balance of the day Discussion – 2 groups (with RRs and without RRs): review of highlights from presentations; consider abilities and opportunities for collaboration, needs from within the RR and non-RR communities and related challenges. Assign tasks to complete the draft report. Experts compile draft report using, as a basis, the presented material.

WEDNESDAY 12 OCTOBER

09.00 – 17.00 Experts (in 2 groups) compile draft report using the presented material as a basis

THURSDAY 13 OCTOBER

09.00 – 12.30 Experts (in 2 Groups) compile draft report using the presented material as a basis.
14.00 – 17.00 Plenary, discussions, formulating final conclusions/recommendations

FRIDAY 14 OCTOBER

09.00 – 12.00 Final plenary report to IAEA Meeting Closure

J. List of Meeting Participants

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K. Book of Extended Synopses

A.1. Austria, Boeck

Service of Low Power Research Reactors to the International Nuclear Community

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Abstract:

A number of universities in Central Europe operate low power research reactors for training and educational purposes. Although the main targets are national and international university students these reactors are also able to offer services to the international nuclear community with trainings courses in various nuclear fields. This paper describes the cooperation between Austria, Czech Republic, Hungary and Slovenia in the field of international trainings and education. This so called Eastern European Research Reactor Initiative (EERRI) was established with the support of the IAEA in 2008 and has carried out four training courses for participants from Member States each one lasting for six weeks. More about EERRI can be found at the IAEA webpage:

http://www.iaea.org/OurWork/ST/NE/NEFW/Technical_Areas/RRS/eerri.html

In addition to the EERRI courses the research reactors represented in this coalition also carry out commercial courses on an individual basis. Target groups for commercial courses are other universities without an access to research reactors (i.e Technical University of Bratislava/Slovak Republic or University of Manchester/UK), international organisations (i.e IAEA Dept of Safeguards, training section), research centres (ie. Mol, Belgium) for retraining of their reactor staff or nuclear power plants for staff retraining. The paper describes typical training programs target groups and possible transfers of this courses to other reactors.

1. Involved institutions

1.1. Vienna University of Technology/Atominstitute (VUT/ATI), Austria

The Atominstitute being the closest nuclear facility to the IAEA has long-term experience in organising national and international training courses. The course contents origins from the regular students curriculum at the Vienna University of Technology (VUT). The courses are part of the eligible course during the Masters Program in the Technical Physics Curriculum.

There are three practical courses offered by the Atominstitute which are

[1]. Practical Exercises in Reactor Physics and Kinetics
[2]. Practical exercises in Reactor Instrumentation and Control
[3]. Practical Exercises in radiation protection

Each of these exercises are composed of about 10 topics where the students have to work directly at the reactor in groups of maximum eight students according to the provide programme. Each exercise is introduced by theoretical part and followed by the practical experiment. As the TRIGA reactor is designed primarily for education and training the students also have the possibility to start-up the TRIGA reactor on their own towards the end of the course. Out of these totally 30 exercises any combination of exercises are possible according to the interest for the group. In addition a number of course are available covering all legal and technical aspects of research reactor planning and operation. During the past 5 years the request for training courses have increased from about 10% to almost 50% which poses a limit to the course staff but also to the reactor availability.

The ATI is situated very close to the IAEA headquarters in Vienna, therefore the ATI provides NE&T services to IAEA Member States (MS) since many years as well as to the international community. Due to this fact the ATI has long-term experience in organizing international training courses under various projects.

- Eugene Wigner Course

The Eugene Wigner Course was established in 2005 in cooperation between the TU Bratislava, TU Budapest, TU Prague and the VUT. A group of about 15 students was subdivided into four groups, started all together in Bratislava and then rotated among the involved Technical universities. At this course they carried out practical work at three different research reactors including theoretical lectures, and a final examination which was accredited by their home university with 6 ECTS. During the last two years, financing of this course became very difficult and the course was stopped although the feedback from all participants was very positive.

- Training Course for the MTR+3I EU project

The Atominstitut took part in the above mentioned EU project together with about 25 other European research centres. The contribution of the Atominstitut was to prepare a practical demonstration training course for future reactor operators. This course took place in March 2009 with five international participants and was successfully accepted as a demo course by the EU.

- Nuclear Technology Education Consortium NTEC, UK

In 2007, the NTEC coordinated by the University of Manchester contacted the Atominstitut if it could offer a one week academic reactor course for NTEC students. The contract was signed and since this time totally six courses (two per year) were carried out, each course with six NTEC students. The course is credited by NTEC with six ECTS.

- NPP Staff from Slovakia

Since several years, the Technical University of Bratislava is involved in the re-training of the NPP; staff of the NPP Bohunice and Mochovce. Since Slovakia does not operate a research reactor and Bratislava is very close to Vienna, the Atominstitut was asked to take over the practical part of the training course which has been performed six times since 2002.

- MOL Courses

The Belgian research centre MOL is requested by the regulatory body to offer a re-training programme for their operators. In view of this task, the Atominstitut was asked to host totally 36 operators divided into six groups of six participants each to perform a course using experiments both from the standard reactor physics and kinetics course as well as from the reactor instrumentation and control course.

- IAEA Junior Safeguards Traineeship Program

The IAEA recruits in regular intervals new safeguards inspectors, however developing countries complained that they do not have the prerequisites to apply for this job. Therefore the IAEA initiated as far back as 1984 every two years a 9 month training course for about 6 technicians from developing countries which are then in a position to apply for a job as safeguards inspector. The first practical part of this course takes place at the Atominstitut for one month every two years. In total about 120 junior safeguards trainees have passed through the Atominstitut.

- Eastern European Research Reactor Coalition (EERRI)

In 2008, the IAEA initiated several research reactor coalition programs to increase cooperation and utilization of research reactors in various regions. One region is Central and Eastern Europe and therefore the Eastern European Research Reactor Initiative (EERRI) was created. The Atominstitut is part of this coalition and one target of this initiative is to offer practical training to young professionals. Since the formation of EERRI two such courses were carried out, the first course coordinated by the Atominstitut in cooperation with the Institute Josef Stefan in Ljubljana/Slovenia, the KFKI and Technical University in Budapest/Hungary, the second course was coordinated by the TU Prague in cooperation with the Atominstitut and the Institute Josef Stefan in Ljubljana/Slovenia. More courses are planned for 2011. Participants came through IAEA Technical Cooperation projects from all over the world.

- Selected Courses for IAEA Technical Cooperation projects

The Atominstitut hosts IAEA fellows for periods of one month to one year through IAEA Technical Cooperation projects. Since 1983, more then 200 fellows participated at highly specialised training project from all over the world, the fellows are attached according to their interest to one of the working groups. Experience shows that after their return to their home institute long term relation and cooperation between the two institutes result as a positive outcome from these fellowships.

1.2. Jozef Stefan Institute, Ljubljana, Slovenia

Jozef Stefan Institute (JSI) has been operating a 250 kW TRIGA type research reactor since 1966. In 1991 it was reconstructed and equipped for pulse operation. The reactor has been used for neutron activation analysis, irradiation of various samples (semiconducting detectors, fusion reactor materials, etc.), neutron radiography, training and for testing and development of various computer codes. The reactor physics division at JSI has long-term experience in usage and development of various computer codes for reactor core calculations. Among others they have developed a program package for reactor calculation of TRIGA research reactor cores, TRIGLAV-W (http://www.rcp.ijs.si/triglav/), which is explained and demonstrated during the training courses. Lately they have been working extensively also on validation and verification of modern Monte Carlo computer codes, such as MCNP, which is presented at the courses as well. Since the 1980's the group has been using the WIMS-D computer code together with other home-developed codes for performing core design of the NPP Krško in Slovenia. The WIMS-D is also be presented at the courses. The computer codes mentioned above are one of the most commonly used codes for performing reactor calculations world-wide. The trainees become familiar with the WIMS-D, TRIGLAV-W and MCNP computer packages and learn how to calculate various research reactor physics parameters and models that lie behind the calculations. They also learn the basics of burn-up calculations and core optimization. The lectures are followed by computer exercises and practical case studies.

Practically all nuclear professionals in Slovenia started their career or attended practical training courses at the TRIGA reactor at Jozef Stefan Institute (JSI), including all professors of nuclear engineering and reactor physics at Ljubljana and Maribor Universities, as well as directors and key personnel of the Nuclear Power Plant (NPP) Krško, the Slovenian Nuclear Safety Administration and the Agency for Radioactive Waste. All NPP Krško reactor operators and other technical staff pass training courses on the TRIGA reactor; the reactor is used in regular laboratory exercises for graduate and post graduate students of physics and nuclear engineering at the Faculty of Mathematics and Physics, Ljubljana University and students from other Slovenian universities. The reactor has been used in several international training courses, the latest one being organised by the Eastern Europe Research Reactor Initiative (EERRI) (http://www.eerri.org and http://www.iaea.org/OurWork/ST/NE/NEFW/rrg_EERRI.html).

Together with nuclear training centre at JSI (http://www.icjt.org/an/what/tecaji/tecaji.htm) we organize a lot of training courses ranging from power plant technology to radiation protection and research reactors. With respect to the research reactors JSI can provide the following training capabilities:

- Instrumentation and control systems
  - theory
  - practical course on instrumentation and control systems
- Introduction to atomic and nuclear physics
  - theory
  - practical exercises (radiation detection, half-life measurement
- Reactor physics
  - theory
  - practical exercises on TRIGA reactor
    - Subcritical multiplication
    - Critical experiment
      - fuel adding
      - control rod withdrawal
    - Reactor kinetics (reactor response to step reactivity changes)
    - Reactivity coefficients (temperature, void, power)
    - Control rod calibration
      - rod in
      - rod swap
    - pulse mode operation
    - in core flux mapping
  - reactor core calculations
    - power distribution and power peaking factors
    - neutron flux distribution
    - neutron spectra
    - kinetic parameters
  - utilisation computer codes for research reactor calculations
    - WIMS
    - TRIGLAV
    - MCNP
- Radiation protection and dosimetry
  - personnel monitoring
  - environmental monitoring
  - practical course on radiation protection and dosimetry
- Research reactors overview and utilization
- Safety culture and code of conduct

1.3. The VR-1 Reactor of the Czech Technical University

The operation of the VR-1 reactor was started in 1990 by the Department of Nuclear Reactors of the Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague. The reactor is particularly designed for education and training, but it is utilized also in scientific research, and in promotional activities in the field of nuclear power. The VR-1 Training Reactor is a pool-type light-water reactor based on low enriched uranium with maximum thermal power 1 kW and for short time period up to 5 kW (up to 70 hours/year). The moderator of neutrons is light demineralised water, which is also used as a reflector, a biological shielding, and a coolant. Heat is removed from the core by natural convection. The pool disposition of the reactor facilitates access to the core, setting and removing of various experimental samples and detectors, easy and safe handling of fuel assemblies. The reactor core contains 17 to 21 fuel assemblies IRT-4M, depending on the geometric arrangement and kind of experiments to be performed in the reactor. The reactor is equipped with several experimental devices; e.g. horizontal, radial, and tangential channels used to take out a neutron beam. Detectors for power measurement, as well as experimental samples could be inserted in dry vertical channels. Four laboratories belong to the reactor: laboratory for neutron interaction studies, laboratory for neutron activation analysis, radiation protection and environmental studies laboratory and I&C laboratory.

The reactor is principally used for training of students from technological universities. Training is aimed to areas such as reactor physics, neutronics, dosimetry, nuclear safety and I&C systems. Teaching blocks aimed at the environmental protection are prepared especially for students of natural science and pedagogy. Reactor as a specialized training facility of the Ministry of Education, Youth and Sports, is in addition to students of Faculty of Nuclear Sciences and Physical Engineering open to students of other universities in the Czech Republic.

Depending on the curriculum and orientation of individual faculties, the training is performed in the regular weekly schedule or in the form of batch courses three to five days long. The specific content of the courses is compiled according to the requirements of the teachers from various faculties. Integral part of reactor training is education of students coming from abroad.

Education for foreign students is organized on bilateral on multilateral levels. Multilateral collaboration is providing within the scope of European education network ENEN or Eastern European Research Reactor Initiative EERRI research reactor coalition and bilateral within the scope of agreement between Czech Technical University and partner’s university only.

An example of education and training within ENEN association and how could incorporate research reactor to the educational process is the “Eugene Wigner Course on Reactor Physics Experiments“which is jointly organised since 2003 by four Central European universities from four countries – Slovakia, Czech Republic, Hungary and Austria. Highly specialised three week course focused on experimental reactor physics is intended for nuclear engineering students from last master courses, PhD students or young professionals from nuclear industry or nuclear research. Theoretical lectures in Bratislava are accompanied by experiments at three research reactors in Prague (VR-1), in Budapest (BME-TR) and in Vienna (ATI Triga). Students have chance to compare not only different way of performing and evaluation of the experiments, but also slightly different approach of the reactor operation and safety culture at all three research reactors.

Another examples of the VR-1 Reactor cooperation within ENEN association are the “Experimental reactor physics courses at Training Reactor VR-1” at the Czech Technical University in Prague for students from various European countries like KTH Royal Institute of Technology Stockholm, Sweden, University of Manchester & Defence Academy of the United Kingdom, Aachen University of Applied Science, Germany or Slovak Technical University Bratislava, Slovakia. All courses respect the initial students’ background level in order to provide an effective education at the Training Reactor VR-1.

There are also particular courses organized in cooperation with IAEA, e.g. the Training Course on Research Reactor Operation for future Bulgarian research reactor staff organized in the years 2005 and 2006 or specialists from Libyan Research reactor in Tripoli in the year 2007.

Soon after establishing of EERRI coalition, in the spring 2009, EERRI organised the first training course for IAEA. The six week course was focused on participants from non-nuclear countries, who wish to develop nuclear competence and infrastructure as a first step to develop a national nuclear power programme. The course was aimed at young technical professionals with little or no nuclear experience who can work in future at research reactor licensee or at national regulatory body. The first course attended by eight participants from Vietnam, Azerbaijan, Colombia, United Arab Emirates and Estonia, who spent six weeks at the Triga reactor in Vienna, Austria and both reactors (BME-TR a BRR) in Budapest, Hungary. Lecturers from IJS Ljubljana, Slovenia took part at the course also. The second EERRI training course for IAEA named „Group Fellowship Training Programme on Research Reactors“ was the same as the first course with minor changes. It was held in the spring 2010 at Vienna (ATI, Triga), Ljubljana (IJS, Triga) and in Prague and Rez in Czech Republic (CTU, VR-1 & NRI, LVR-15). The second course attended by eight participants from Jamaica, Brasilia, Azerbaijan, Sudan, Oman and Saudi Arabia. The third EERRI course for IAEA was held on February and March 2011 and the fourth was held on March and April 2011. The third course will be held in Austria and Hungary (same as the first course) and the fourth one will be held in Austria, Slovenia and Czech Republic (same as the second course). The third course attended by eight participants from Jordan and the fourth course attended by five participants from Sudan and Philippines. The total number of participants attended four EERRI courses is 31 from 11 countries.

The six week course for the participants with little or no nuclear experience focused on all aspects of the research reactor operation covering topics from legislative through theoretical and experimental reactor physics, reactor construction, operation to reactor utilisation is a typical example of wide range course, which is extremely difficult to organise by single reactor or single university. Reactor coalition can organise it much more easily.

1.4. KFKI Budapest, Hungary

The KFKI Atomic Energy Research Institute (AEKI) has been operating a research reactor, namely: Budapest Research Reactor (BRR) since 1959. Since its initial criticality, the BRR has been utilized as a neutron source for research and various industrial and health care applications, as well as education and training purposes in the nuclear field. The reactor contribution in the training course is aimed to the practical subjects. Thus, on the basis of the operational and utilization experiences the subjects of the training courses are:

Research Reactor operation and utilization matters

Water chemistry in general and in practice at BRR

Emergency procedures

QA issues at a RR and practical approaches of nuclear project planning and implementation

The listed subjects are divided in theoretical topics and on site training where the students can see how the operating matters are managed in the everyday practice. The students have an opportunity to take an insight into the regulatory environment from the viewpoint of operators as well as from the specific research reactor management practice (the operation and utilization meters are separated) applied at BRR.

1.5. Budapest University of Technology, Hungary

The training reactor of the Budapest University of Technology and Economics is a pool type reactor located at the university campus. The facility was designed and built between 1961 and 1971, by Hungarian nuclear and technical experts. It first went critical on May 22, 1971. The maximum power was originally 10 kW. After upgrading, which involved modifications of the control system and insertion of one more fuel assembly into the core, the maximum licensed power was increased to 100 kW in 1980. The reactor still operates with the original LEU fuel assemblies. The reactor building houses reactor physical, radiation protection, and radiochemical laboratories, and a small hot cell too.

The main purpose of the reactor is to support education in nuclear engineering and physics for Hungarian graduate students, but international training courses (e.g. „Eugene Wigner Course for Reactor Physics Experiments”) are organized and IAEA fellows are hosted too.

The reactor is used, among others, in the following fields: experiments in reactor physics and thermal-hydraulics, activation analysis for radiochemistry and archaeological research, analysis of environmental samples, determination of uranium content of rock samples, nuclear instrumentation development and testing, development and testing of tomographic methods for safeguards purposes, and investigation of radiation damage to instruments/equipment. The subjects in the training course will be the following:

- Thermal hydraulics
- Radiation protection and waste management
- Site requirements
- Public information

The students will calculate various research reactor physics parameters, including introduction models that lie behind the calculations. They will also learn the basics of burn-up calculations and core optimization. The lectures will be followed by computer exercises and practical case studies.

2. Conclusions:

Small and medium research reactors play an important tool to international education and training and the have a solid place in the nuclear community. The nuclear industry should be aware that the first steps for their future engineers take place in these small research centres and should consider close cooperation and also financial support to assure a constant supply of well trained nuclear staff.

A.2. Azerbaijan, Gabulov

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A.3. China, Xia

Summuaries for Application of Miniature Neutron Source Reactor

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Miniature Neutron Source Reactor (MNSR) is China made pool-tank type research reactor. It has a thermal neutron flux of $1.0x10^{12}n/cm^2.s$ in inner irradiation site with reactor power of about 30kW. It is safe, simple and easy to control. The inherent safety of MNSR make it can be built in Cities, Hospitals, Institutes and Universities.

MNSR is used as neutron source for Neutron Activation Analyze (NAA), calibrating of nuclear detector and nuclear instruments, some short lived isotope production, and as a teaching and training tool for researchers and students. It is widely used in many fields.

The MNSR is safe, simple structure, easy to control. The requirement of management is easy to reach by non-host member states at beginning.

The new designed MNSR with LEU fuel and specially adopted for BNCT research is good and safe tool for nuclear technology application.The MNSR can be built in two years after the signing of the contract. The non-host member states can start early to use the MNSR for training the operator and application of NAA and other purspoes in short times.

IAEA support the international cooperation for MNSR. Five Member States have MNSR type facilities and each has its own research group on utilization of research reactor. In which 3 of them are supported by IAEA. The MNSR's operators are trained in China.

Under the international cooperation, the MNSR can accept the researchers from non-host member states to do NAA in particular and education and training in general.

A.4. Hungary, Baranyai

Budapest Research Reactor – as a user facility

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The Budapest Research Reactor (BRR) is one of the major infrastructures in Hungary and in the Central European region. BRR is a 10 MW, tank type reactor, moderated and cooled by light water. The reactor went critically in 1959, two major reconstructions took place:

- Thermal power increased from 2 MW to 5 MW in 1967
- Full scale reconstruction started in 1986 and completed in 1990.

The brand new reactor got the operation license in 1993 which is valid until 2023. The BRR has been utilized as a neutron source for research and various industrial and health care applications. Irradiations are performed in vertical channels (the reactor has now more than 40 channels) they can be used for isotope production (major isotopes: ^{131}I, ^{125}I , ^{60}Co) and material testing. The reactor has ten beam ports (eight radial and two tangential) where the experimental facilities are installed. The utilization of the BRR in the field of basic and applied research are coordinated and managed by the Budapest Neutron Centre. BNC is a consortium of 4 research institute which are: the KFKI Atomic Energy Research Institute, the Research Institute for Solid State Physics and Optics, and the Institute of Isotopes and KFKI Research Institute for Particle and Nuclear Physics also joint to BNC. Budapest Neutron Centre is represented by the KFKI Atomic Energy Research Institute. The role of BNC is to coordinate the reactor utilization and to provide scientific infrastructure for the international user community.

BNC has operated a user program; successfully took part in several EC supported framework programs, and from 2004 has been taking part in the Integrated Infrastructure Initiative for Neutron Scattering and Muon Spectroscopy (NMI3) program. BNC is a recognised partner of the European neutron network.

Since the refurbishment of the reactor the instrument development is continued and now 15 experimental stations are in operation and involved in the user program. The user office coordinates the entire program from the call for proposal to the beam time allocation. The 40-50 % of the yearly beam time is offered through the user access program.

Major steps of the beam time request and allocation:

- Submit proposal to BNC / information is available on the www.bnc.hu webpage (deadline, application form)
- Feasibility review is made by the instrument scientist
- Evaluation and ranking are made the Selection panel (members are invited from the European neutron centres)
- Feedback to the applicants

BNC policy is to give special attention to those applicants coming from countries where no neutron research infrastructure exits.

From 1999, BNC has organised the Central European Training School on Neutron Scattering in every second year. These schools provide an introduction to neutron scattering with special emphasis to hands-on-training at BRR facilities. The majority of the participants come from the CE region.

While the BRR has been fulfilled its traditional mission the public demand for the research reactor has been changed recently. To adopt these changes a research reactor coalition was launched under the name of East European Research Reactor Initiative (EERRI) by the initiation of BRR. The exploratory meeting was held in Budapest, Hungary on January 28-29, 2008 at the invitation of the KFKI Atomic Energy Research Institute (AEKI). This coalition originally was founded by 5 reactors but by the end of 2008 it has 8 research and education/training reactors.

EERRI activities are focused in the four main areas:

- Neutron beam applications
- Fuel and material testing
- Education and training
- Radioisotope production

A.5. Indonesia, Yulianto

Utilization of the RSG-GAS reactor to meet the needs from Overseas.

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RSG-GAS reactor has been more than 20 years with varying operating power 15-30 MW has a neutron flux of 2.5 x 1014 n.cm-2.s-1, which is equiped with:

Isotope production facilities at the irradiation position inside and outside of the core and rabbit systems with capacity for commercial such as ^{125}I, ^{131}I, ^{99}Mo, ^{133}I, ^{192I}r, ^{82}Br, ^{60}Co, ^{14}C, ^{32}P, ^{35}S. ^{198}Au , Zn, ^{24}Na, etc. The planned maximum production of 99 Mo will be developed even up to 1100 Ci 99Mo yearly. Potential partners in radioisotope production are countries: Bangladesh, China, Japan, Malaysia, Korea and Singapore.

5 beam of 6 beam tubes that can be used as a materials test facility. Test and measurement devices that are connected with beam tubes, among others: Diffractometer for Residual Stress Measurement (RSM), Circle Four diffract. / Texture Diffractometer (FCD / TD), High Resolution Powder Diffractometer (HRPD), Neutron Radiography Facility (NRF), Triple Axis Spectrometer (TAS), SANS Spectrometer (SMARTer), High Resolution SANS Spectrometer (HRSANS). Join research in utilization of neutron diffractomer has been conducted between BATAN and Malaysia, Japan, Singapore and USA.

Testing facility for power reactor fuel element pins on the power ramp test facility (PRTF) which has been tested and will be operated in 2012. This facility illustrates the similarity condition of the loop with available pressure of 150 bar under controlled and safe operation.

Doping silicon production facility that being tested and developed its quality to start up for operation in 2012. Irradiated silicon ingots have a measurement of 7 inches diameter and 20 inches lenght. Silicone products will be improved as well as the market needs

Gemstones coloration facility using gamma radiation that produces the colors yellow, green, blue, red and brown in quality. With a production capacity approximately 700 kg per year at the current power level and reactor operation schedule presently.

Center for multi-purpose reactor is under cooperation with BATAN education and training center provides education and training for reactor operators, who provide a practical trained people to operate the reactor in reactor power regulation, power calibration, control rod calibration, reactor core formation, nuclear fuel management and reactor operation safety. Besides, it also organizes education and training on utilization of the reactor in the field of isotope production and neutron activation analysis, which provides a practical technician for the sample preparation, loading samples in the irradiation position, handling techniques and analysis of post-operation samples.

Center for multi-purpose reactor as the RSG-GAS reactor operators have been providing excellent services to meet national needs, especially to its potential customers in hospitals, industry and universities in Indonesia, but still provide space to load the target and opportunity for the state-neighboring countries and international parties to use the services mentioned above. As a source of information to come in our services, please achieve in following address: http://www.batan.go.id/prsg and E-mail: prsg@cbn.net.id for irradiation and isotope production services; http:// www.batan.go.id / ptbin and bsn@batan.go.id to the beam tube utilization. Available service for education and training in reactor operation and samples irradiation can obtain more information on http://www.batan.go.id/pusdiklat and pusdiklat@batan.go.id.

A.6. Jordan, Malkawi

Experience in the Utilization of a Research Reactor through the Internet Reactor Lab.

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The concept of utilizing a research reactor across international borders was demonstrated for the first time through the Internet Reactor Laboratory (IRL). The IRL is a distance educational model based on the utilization of video conferencing and online reactor instrumentation and data acquisition systems to provide reactor laboratory sessions to students at other academic institution. Using this approach, Nuclear Engineering students at Jordan University of Science and Technology (JUST) were able to use the North Carolina State University PULSTAR nuclear reactor for their nuclear reactor physics laboratory

The IRL project was sponsored by the US Department of State under the auspices of the International Atomic Energy Agency and in cooperation with Jordan Atomic Energy Commission.

In order to evaluate the IRL from the point of view of the students at JUST who actually participated in the course; a sample of 15 students (4 of them also attended an IAEA fellowship on RR) were asked to evaluate the course by giving a score (out of 10) for a number of questions. A summary of the answers to the main questions were as follows:

- **Question:** How do you compare this lab to other practical lab courses you took during your study?
    - **Evaluation: 8.3/10 (min: 7, max: 10)**
- **Question**: To what extent did this lab give you the feeling that you are in an actual reactor.
    - **Evaluation: 8.4/10 (min: 7, max: 10)**
- **Question**: To what degree did the lab provide the link between the reactor physics you studied and the actual performance of the reactor?
    - **Evaluation: 8.5/10 (min: 6, max: 10)**
- **Question:** Was the language an obstacle in communicating with reactor operators and understanding the course?
    - **Evaluation: No (all answered: No)**

The overall evaluation of the IRL that it was found to be an excellent tool for educational purposes on Reactor Physics, with the following extra advantages:

- Benefit from an already existing RR with all its accumulative experience.
- Access can be arranged in no time as compared to the construction of a new RR.
- Can accommodate larger number of students in one session, as compared to education on the actual reactor.

- Reduces Safety and security requirements regarding students accessing the RR.

A.7. Montenegro, Janovic

Montenegro – 50 years experience of a small non-nuclear country in research reactor utilization on co-operative basis

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Montenegro is small, developing "non-nuclear" country (14.000 km^2, 650.000 population, 5.400 USD GDP/capita in 2010). The use of radiation sources is modest and limited to ordinary medical and industrial applications, which is likely to remain so in a foreseeable time to come. Nevertheless, taking into account current and near-future state of the matter), there is, or will be, significant need for nuclear knowledge and competence (whereby cooperation with research reactor centres in the region may prove beneficial, as it did largely in the past). It goes about the following areas, the list being far from exhaustive:

- medical uses of radiation sources (diagnostics, radiotherapy, palliation, sterilization of equipment, blood products, etc.)
- environmental protection (radioecology, low and medium activity radioactive waste management, analytical and monitoring services, etc)
- industrial, geological, hydrological, agricultural and biochemical applications (non-destructive testing, various gauges, radioisotope labeling, etc.)
- scientific and educational applications (both nuclear and non-nuclear)
- radiation protection, emphasizing safety and security of radiation sources, radon issues, food and consumables radioactivity control...
- legislative and regulatory aspects, including complying to international safety/security norms and joining international conventions in the field
- preparedness and response to radiological and nuclear emergency situations
- combating illicit trafficking of nuclear and radioactive materials
- forensic applications
- security systems based on X-ray and other nuclear methods
- non-ionizing radiation
- introduction of some future topics (e.g. energy efficiency, nuclear power for electricity generation and sea water desalination, n. fusion)
- information and communication with media, etc.

Montenegro never had nuclear installations, even not a nuclear research centre in its proper sense. University of Montenegro, Department of Physics is the only higher education and research institution in the country dealing with nuclear related topics.

Even though and strange enough, Montenegro has 50 years experience in research reactor (RR) utilization and a decent level of nuclear knowledge and expertise in a number of RR-related fields. Currently there are 7-8 researchers active in the country with scientific background (including PhD's) in RR topics, while many others are scattered in RR centres in EU, Russia, Japan and USA; – we keep in touch with most of them. University Centre for Nuclear Competence and Knowledge Management (UCNC) in Podgorica is recently established around this group. IAEA NKM Expert Mission in 2009 highly prized the UCNC activities and recommended both IAEA and Government of Montenegro to support it further.

RR experience started in the 60's with two Soviet Union origin research reactors installed in Vinca NRI near Belgrade, Serbia (then in Federal Republic of Yugoslavia, where Montenegro belonged). Some of our best students and scholars participated in Vinca RR activities. By the time, Vinca NRI was one of the most reputed in Europe. Vinca chapter in our RR experience ended by mid 80's with closure of the reactors.

It continued with another RR centre in former Yugoslavia: Jozef Stefan, Ljubljana, Slovenia. In the period 1985 – 1991 a strong group worked there on the establishment and utilization of the k_0-NAA method, including 5 researchers from Montenegro. Joint research projects went on with USA and EU on topics like NAA, nuclear data standardization and nuclear education. Meanwhile co-operation was gradually developing also with RR centres in

- Dubna (Russian Federation)
- Gent (Belgium)
- Budapest (Hungary)
- Charlottesville (USA)
- Juelich (Germany)
- Garching (Germany)
- Rez (Czech Republic)
- Gaithersburg MD (USA)
- Saclay (France)
- Pavia (Italy)
- Belo Horizonte (Brazil)
- Athens (Greece)
- Ankara (Turkey), etc.

Numerous PhD's and joint scientific publications were produced as a result of these involvements. Unfortunately, many of the above centres witnessed decline in RR-activities, following reactor closures or quasi-permanent shut downs.

We believe IAEA offers good opportunity for international collaboration in RR. With RR community steadily shrinking, the idea of expanding/reviving their activities by offering facilities to non-host countries in an internationally organized manner is sound and logical. Montenegro expresses hereby its interest and offers its human resources and experience to this aim. Our fields of interest/expertise include:

- NAA (applications in environmental monitoring, geology, biology, medicine,)
- Gamma-spectrometry and semiconductor detector utilization
- Nuclear data standardization
- Neutron transport theory
- Neutron flux measurements/characterization, etc.
- Very low activity gamma-spectrometry, using very high efficiency 6X15X15cm NaI "Pripyat" spectrometer (Belarus production, one of the few in the world); this is also suitable for e.g very long lived activation products

A.8. Morocco, El Bakari

The Moroccan TRIGA Reactor form Licensing till now

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1. Introduction

TRIGA reactor is the most widely used non-power nuclear reactor in the world. The 2MW TRIGA Research reactor at CNESTN ***"Centre National de l'Energie des Sciences et des Téchniques Nucléaires"*** is the first rearch reactor in Morocco. This reactor was firstly critical in 2 May 2007, it reached its nominal power (2MW) on 18 *June 2007, and it finished its endurance testing by September 2007. The Moroccan TRIGA reactor was licensed by the Safety Authority "Ministry of Energy Mines, Water and Environment" on February 2009.*

The reactor core contains 101 fuel elements (5 fuel followers control rods, 2 instrumented fuel elements and 94 standard fuel elements) and 17 graphite elements. The fuel matrix is from U-ZrH1.6, the uranium constitutes 8.5 % from the total mass of the matrix and it's enriched up to 19.9% en U235. The reactor is moderated by light water under natural convection mode. This reactor contains several in and near core irradiation facilities such as:

1. Central thimble: located at the core centre, which allows the irradiation of samples using the maximum thermal flux.
2. Rotary rack: located at the graphite reflector, this system allows the irradiation of 79 long-lived samples at the same time under a homogenous neutron flux.
3. Pneumatic transfer system: located at the G-ring of the reactor core, this system is directly related to the Neutron Activation Laboratory and allows the irradiation of short lived biological, geological and industrial samples under several forms (liquids, solids or powders).
4. Neutron beams: the reactor is equipped with 4 neutron beam ports (one is tangential and 3 are radial ones).
5. Thermal column: located in the side of the reactor shield structure, which facilitates irradiation of large experimental specimens. It consists of three sections. The inner section, which is an integral part of the reactor tank, and a middle section and door enclosure, which are integral to the reactor shield structure. All three sections are aligned on a common axis with the centre of the reactor core.

2. Reactor utilization

Actually, there are several operational and near future programmed activities around the reactor in which we are able to collaborate with every interested country (hosted or non hosted), such as:

- Neutron Activation Analysis: more than 500 samples were irradiated in The Moroccan TRIGA reactor during 2011.
- Radioisotopes production: the CNESTEN planned to start the production of I131 for commercial purposes by January 2012, at national levels.
- Neutron diffractions facility: in the frame of an AIEA-TC project, we start the design of this facility in one of the beam ports, the facility will be used by researchers from Moroccan networks of Material Sciences, Condensed matter and modeling in material science, Moroccan society of Polymers and Soft matter.
- Neutronrdiography facility: tangential beam port will be used for the installation of a neutron radiography facility because their offers a low gamma fluxes. The facility will be used for control services, training and education and R&D.
- Education & Training: TRIGA reactors constitute an important tool for training and education even for physicists or operating personnel. The training program can cover several nuclear fields such as:
  - Short-lived radioisotope production
  - Studies of reactor characteristics
  - Uses of extracted neutron beams
  - Instrumental neutron activation analysis (INAA)
  - Training of operating personnels on procedures and operations involved in reactor operation and safety
  - …

3. Conclusion

In the frame of the best utilization of the Moroccan TRIGA MARK II research reactor CNESTEN and in a the collaboration with US-DOE started the construction of the International Training Centre, this centre will be open specially, for African and Middle East countries, and it will offer a wonderful space for learning and training on the peaceful uses of nuclear.

A.9. Pakistan, Muhammad

Access and Utilization of Pakistan Research Reactors by non-host Member States

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Pakistan is operating two research reactors (PARR-1 and PARR-2) to provide services to the users for the production of radioisotopes and for neutron irradiation. IAEA sponsored trainees from various developing countries for long and short durations have been using these facilities for their specific tasks. Training of operators for nuclear power plants have been carried out at initial stages of their carrier in Pakistan. Nuclear engineering students have utilized the reactors for reactor physics experiments to measure reactor static and kinetic parameters. Physical and biological science, radiation protection and radiological engineering students have access to do experiments in these reactors. Many students from private sector and abroad have availed this opportunity to complete their MS level studies in Pakistan. Neutron activation analysis is primarily carried out in MNSR (PARR-2). A large number of different types of samples are routinely irradiated and analyzed. These samples may be from Pakistan or any other origin. Opportunities for training as well as samples analysis by neutron activation technique from non-host member states are available. The main utilization of PARR-1 has been radioisotope production. A large number of radioisotopes have been produced; these include ^{24}Na, ^{32}P, ^{51}Cr, ^{60}Co, ^{64}Cu, ^{77}As, ^{82}Br, ^{99}Mo, ^{131}I, ^{134}Cs, ^{153}Sm, ^{166}Ho, ^{177}Lu, and ^{198}Au. Production of ^{99}Mo by fission has become the most important activity, due to its vulnerable supply from abroad. Conversion of HEU targets to LEU targets is underway and participation of non-host member states and interested parties are welcomed. PINSTECH is providing in-vivo diagnostic kits to 39 nuclear medical centers in Pakistan, so preparation and quality control techniques of such products can be shared with other countries. Loading facility of fission ^{99}Mo for preparation of ^{99m}Tc generators is in operation for the last ten years, hence expertise exist and non-host member states personnel can get training in generator manufacturing which may be useful for other radionuclide generators as well. Gem coloration experiment is going on at PARR-1. Participation in silicon doping and gel coloration activity has great potential in collaborating with other member states. Neutron diffraction techniques are widely used in the study of condensed matter at PARR-1, instrument and expertise are available, which may be beneficial for non-host member states. Facilities of Prompt Gamma Neutron Activation analysis and neutron radiography exists, which are rarely used, hence involvement of participants from abroad will give boost to these activities. After the up-gradation of PARR-1 from 5 to 10 MW, improvement in instrumentation and control system is continuously being made to enhance the safety and availability of the system. Training and transfer of knowledge to other members should be quite beneficial. Any proposal for training and experimentation at PARR-1 and PARR-2 sponsored by IAEA or non-host member states are welcomed. The proposals will be evaluated by Nuclear Safety Committee of PINSTECH before its implementation.

Key words: Gemstone Coloration, Material Testing, Neutron Activation analysis. Pakistan Research Reactor-1, Pakistan Research Reactor -2, Radioisotope Production, Training.

Introduction

Pakistan Institute of Nuclear Science and Technology (PINSTECH) Islamabad is operating two research reactors (PARR-1 and 2) to provide services to the users for the production of radioisotopes and for neutron irradiation. Salient features of both reactors are presented in Table I and II. Since initial criticality, PARR-1 has rendered invaluable service in the training of manpower, production of radioisotopes and as a source of neutrons for basic and applied research. To reduce nuclear proliferation concerns it became essential that its core be converted for operation with low enriched uranium (< 20% ^{235}U) fuel. The PARR-1 is a swimming pool type research reactor originally designed for a thermal power of 5 MW. Its core has been redesigned to operate with LEU fuel at a power level of 9 MW in 1992 and 10 MW in 1998.

Pakistan Research Reactor-2 (PARR-2) is a 30 kW tank-in-pool type research facility. It uses Highly Enriched Uranium (HEU) as its fuel, light water as moderator and metallic beryllium as reflector. Fission heat generated in the core is removed through natural convection. The reactor core is enclosed in an aluminum vessel suspended in an underground pool. Long-term reactivity compensation is achieved by increasing the thickness of top beryllium reflector. Reactor has ten irradiation sites, five of which are located inside the beryllium reflector while the rest surround the reflector. The thermal neutron fluxes in these sites are 10^{12} and 5 x 10^{11} n/cm^2-s, respectively. These irradiation sites are accessed through pneumatic sample transfer tubes. In foreseeable future, PARR-2 will also be converted to use LEU. The study is underway as a part of the IAEA coordinated research project (CRP) entitled "Conversion of the Miniature Source Reactors (MNSR) to Low Enriched Uranium (LEU)".

Access and utilization of Pakistan Research Reactors by Pakistanis and foreigners is described in this article.

TABLE 1: PAKISTAN RESEARCH REACTOR-I (PARR-1)

General Data
Owner: Pakistan Atomic Energy Commission
Operator: Pakistan Institute of Nuclear Science and Technology Islamabad
Address: P.O. Nilore, Islamabad
Construction date: 1-5-1963
Criticality date: 21-12-1965
Initial cost: 6.6 M US$
Annual cost: 0.5 M US$
Total staff: 30
Operator: 13

Technical Data
Reactor type: Pool
Thermal power, steady, kW: 10,000.000
Max flux SS, thermal, n/cm^2-s: 1.5 x10^{14}
Max flux SS, fast, n/cm^2-s: 6.0 x10^{13}
Moderator and coolant: Light water
Reflector: Graphite, water
Control rod material: Ag, In, Cd
Criticality with LEU: Oct 1991
Power increase; 9 MW in May 1992
Power increase; 10 MW in Feb 1998

Experimental Data
Horizontal channels: 7
Horizontal max flux n/cm^2-s: 4.7 x10^{13}
Horizontal use: Basic research
Vertical use: Neutron activation analysis
Core irradiation facilities: 2
Core max flux n/cm^2-s: 1.5 x10^{14}
Reflector irradiation facilities: 3

Fuel Data
Min critical mass, kg U-235: 4.42
Normal core loading, kg U-235: 6.59
Fuel material: U_3Si_2-Al
Enrichment min%: 19.99
Enrichment max%: 19.99
Origin of fissile material: USA, China

Utilization

Basic/applied research: Neutron diffraction, n,γ reaction, NAA, Radioisotopes
Isotope production: I-131, P-32, Br-82 etc.,
Neutron scattering: Two Diffractometers
Neutron radiography: Yes
Nuclear chemistry: Neutron activation analysis
Training: Reactor supervisors, operators, students

TABLE II: PAKISTAN RESEARCH REACTOR-2 (PARR-2)

General Data
Owner: Pakistan Atomic Energy Commission
Operator: Pakistan Institute of Nuclear Science and Technology Islamabad
Address: P.O. Nilore, Islamabad
Construction date: 1-1-1988
Criticality date: 2-11-1989
Initial cost: 2 M US$
Annual cost: 70 k US$
Total staff: 10
Operator: 7

Technical Data
Reactor type: MNSR (Miniature Neutron Source Reactor)
Thermal power, steady, kW: 30.000
Max flux SS, thermal, n/cm^2-s: 1.0 x10^{12}
Max flux SS, fast, n/cm^2-s: 3.2 x10^{11}
Moderator and coolant: Light water
Reflector: Beryllium, water
Control rod material: Cd

Experimental Data
Vertical channels: 10
Vertical max flux n/cm^2-s: 1 x10^{12}
Reflector irradiation facilities: 10
Small irradiation sites: 8 x 7 cm^3
Large irradiation sites: 2 x 25 cm^3

Fuel Data
Min critical mass, kg U-235: 0.98
Normal core loading, kg U-235: 1.00
Fuel material: Uranium-Aluminum alloy (UAl_4-Al)
Enrichment min%: 90.20
Enrichment max%: 90.20
Origin of fissile material: China

Utilization
Basic/applied research: NAA, Radioisotopes
Isotope production: Short lived
Nuclear chemistry: Neutron activation analysis
Training: Reactor supervisors, operators, students

Public Tours and Visits

Tours and visits of PARR-1 and PARR-2 have been a regular feature of institute activity. Thousands of people have visited these facilities; during such visits lectures on reactor capabilities and usage were delivered by Reactor Operation Group personnel. Most of the tours and visits were arranged for science students, community college students, teachers and other interested groups. Many dignitaries like presidents, prime ministers, army officials, politicians and important foreign delegates have also visited these facilities. Due to current wave of terrorism in the world, some control on such tours and visits has been imposed.

Education and Training

Pakistan Institute of Applied Sciences and Engineering (PIEAS) is a renowned university neighboring to PINSTECH, working under the auspices of Pakistan Atomic Energy Commission. Ones PIEAS was a part of PINSTECH, called Reactor School. PIEAS has broad educational programs of Nuclear Engineering, System Engineering, Nuclear Medicine, Medical Physics, Health Physics, Process Engineering, Materials Engineering, Mechanical Engineering, Laser/Plasma/Computational Physics, Radiation and Medical Oncology. The local as well as foreign students can enroll themselves in MS, M.Phil and Ph.D level studies. All the students have access for the experimentation in PARR-1 and PARR-2 as and when needed basis. Table III gives an incomplete list of foreign country students qualified for MS degree from PIEAS.

TABLE III. INTERNATIONAL GRADUATES MS DEGREE FROM PIEAS

Country	**Graduates**	**Field**
Jordan	16	Nuclear/Systems Engineering
Indonesia	09	Nuclear Engineering
Libya	05	Nuclear Engineering
Myanmar	02	Nuclear Medicine
Algeria	01	Nuclear Engineering
Iraq	01	Nuclear Engineering
Kuwait	01	Nuclear Engineering
Sudan	01	Nuclear Medicine
Syria	01	Nuclear Engineering
Yemen	03	Nuclear Medicine

More than 200 people have also been trained using PARR-1 and PARR-2 for operation and maintenance of Nuclear Power Plants.

Neutron Activation Analysis

Neutron activation analysis (NAA) is the most simple and widely used application of PARR-1 and particularly PARR-2. It is a qualitative and quantitative analytical technique for the determination of trace elements in a variety of complex sample matrices. NAA can be performed in a variety of ways depending on the element and its levels to be measured, as well as on the nature and the extent of interference from other elements present in the sample. NAA laboratory of PINSTECH is the Regional Resource Unit for NAA in the region by IAEA; therefore, they have been providing training to the IAEA fellows from Malaysia, Indonesia, Jordon, Syria, Thailand, Philippine and Bangladesh.

The Laboratory has been a regular participant of International (QA & QC) Analytical Quality Control and Proficiency Tests. Intercomparison Exercise for Certification of Reference Materials of IAEA and have been involved in following IAEA programs:

(i) IAEA-CRP/11297/RO/RB entitled "Marine Pollution Monitoring in Environmental Samples".

(ii) IAEA /RCA Technical Project RAS/2/010 “Quality Assurance and Quality Control in Nuclear Analytical Techniques” (2001)

(iii) IAEA Project C7-INT-1.054 “Preparation of Reference Materials for Proficiency Exercises” (2003)

(iv) Joint UNDP/RCA/IAEA Project RAS/7/013 “Improved Information on Urban Air Quality Management in RCA Region” (2003)

(v) Participation in IAEA Proficiency Test PTXRFIAEA02, trace elements in biological sample. Analysis has been completed and results have been compiled.

(vi) Participation in IAEA Proficiency Test IAEA-436, trace elements in Tuna Fish Flesh Homogenate. Analysis has been completed; results have been compiled and submitted to IAEA.

(vii) Participation in IAEA Proficiency Test, radionuclides in Mushroom Material.

Analysis was completed and results were compiled for submission to IAEA. The Final PT report was also submitted to IAEA.
Monitoring of natural radioactivity in certain parts of country is also performed by gamma/beta spectrometry. 100 samples of soil, rice, husk and water from Bangladesh (brought by IAEA fellow from Bangladesh) were analyzed by NAA mainly for As. Flux Mapping of PARR I. and PARR-2 by gold foils has been performed several times. NAA technique has also been in use for nuclear reaction cross section measurements. The technique is available for determination of elements in different type of samples provided by any party (local/foreign). One IAEA fellow from Bangladesh has got training up to three months in NAA Laboratory. Any country interested in training or use will be welcomed.

Radioisotope Production

For many years Isotope Production Laboratories are meeting all the demands of Sodium Iodide (^{131}I), Phosphorus-32 (^{32}P), PAKGEN ^{99m}Tc generators and cold kits for ^{99m}Tc radiopharmaceuticals for PAEC nuclear medical centers. Now a day PINSTECH is also providing its products to various private and government hospitals, treating patient with nuclear medicine. Radioisotopes find applications in various fields such as nuclear medicine, diagnosis and cure of disease, hydrology, sedimentology, agriculture and industry. Large amounts of Sodium-24, Bromine-82, Chromium-51, Molybdenum-99, Cesium-134, Lanthanum-140 etc., were prepared for such applications.

A. *Radioisotope Processing Facilities*

Various facilities available for radioisotope processing are as follows;

- **i.** IODINE-131 Production Cell (Wet Distillation Technique). Maximum capacity per batch 10 Ci/370 GBq.
- **ii.** Iodine-131 Production Cell (Dry Distillation Technique). Maximum capacity per batch 10 Ci/370 GBq.
- **iii.** Phosphorus-32 Production Cell (Dry Distillation Technique). Maximum capacity per batch 10 Ci/370 GBq.
- **iv.** Sulpher-35 Production Glove Box
- **v.** Molybdenum-99 Loading Facility for preparation of ^{99m}Tc generators.(100Ci/batch)
- **vi.** Mo-99 Production facility (Production started in July 2011)
- **vii.** Hot Cell with Master Slave Manipulators.
- **viii.** Fume Hoods and Glove Boxes (for small scale production of different radionuclides and R&D work)
- **ix.** Workshop for target preparation and sealed source fabrication
- **x.** Laboratories for determination of radionuclidic, radiochemical and biological purity

B. Freeze-Dried Kits for ^{99m}Tc Radiopharmaceuticals

i. Laboratory for synthesis of ligands such as MAG_3, MIBI, DISIDA, HMPAO etc for the preparation of diagnostic freeze dried kits.

ii. Clean laboratory for the production of diagnostic freeze dried kits for ^{99m}Tc radiopharmaceuticals.

C. Quality Control

Radionuclidic quality control laboratory is equipped with, NaI/HpGe detector coupled with Canberra 85, multichannel analyzer, Alpha and Beta counters, dose calibrators and gross gamma counters. Radiochemical quality control laboratory is equipped with, 2π scanner, HPLC, electrophoresis, gamma counter, spectrophotometer, pH meter, radiochromatographic apparatus. Biological quality control laboratory has laminar flow, incubators, oven, biodistribution, sterility, pyrogenicity testing facility.

Cooperation in Isotope and In-vivo Kit Production

A large number of foreign delegates and Pakistanis are visiting Isotope and Kit production facilities from time to time. Since loading facility of ^{99}Mo for Pakgen ^{99m}Tc generators was provided by IAEA/IZOTOP Company, Hungary, many experts from Hungary came for discussions, installation and commissioning of this facility. During their visit they have accessed to not only isotope production facilities, quality control, PINSTECH general workshop, but also for both reactors. Similarly initial agreement for Molybdenum-99 Production Facility was made with German firm and the radiochemical separation of ^{99}Mo from fission products was developed at PINSTECH. They were provided every opportunity for target irradiation in PARR-1. A safeguard approach on the use of HEU for production of ^{99}Mo in PARR-1 and its storage after extraction of ^{99}Mo from fission products in Spent Fuel Bay of PARR-1 was agreed between IAEA and PINSTECH. According to this agreement IAEA Safeguards inspector may visit these facilities any time.

Four Syrian sponsored by IAEA and one Myanmar student were trained in synthesis of precursors and ^{131}I-MIBG production, respectively. A clean room facility for kit production was established with the help of IAEA. An expert from Greece visited during installation and operation of clean room facility. Under a bilateral agreement between Germany and Pakistan, German expert visited many times to PINSTECH and made and guided experiments using PARR-1 and isotope production facilities.

Several Pakistani students from different universities have carried out their MS/M.Phil/Ph.D level research work using PARR-1 and isotope production facilities and some are still performing experiments in this direction.

Several Conferences/Workshops have been organized by Isotope Production Division to introduce or evaluate their radiopharmaceutical by different users in Pakistan. These programs are quite successful and more than 50 participants from nuclear medicine community are attracted in such events.

Production of ^{99}Mo by fission at PARR-1 has become the most important activity, due to its vulnerable supply from abroad. Conversion of HEU targets to LEU targets is underway and participation of non-host member states and interested parties are welcomed. PINSTECH is providing in-vivo diagnostic kits to 39 nuclear medical centers in Pakistan, so preparation and quality control techniques of such products can be shared with other countries. Loading facility of fission ^{99}Mo for preparation of ^{99m}Tc generators is in operation for the last ten years, hence expertise exist and non-host member states personnel can get training in generator manufacturing which may be useful for other radionuclide generators as well.

Silicon Transmutation Doping

Neutron transmutation doping (NTD) of silicon is the process of irradiating ingots of high purity silicon with thermal neutrons to convert some of the silicon to phosphorus through an (n,γ) reaction. The advantage of this doping technique over the non-nuclear techniques is that it is possible to produce better uniformity of the doping material because of the penetrability of neutrons in the silicon. NTD has some attractiveness to reactors because it is a potential income generator. The demand for doped silicon was about 100 tons per year and a large facility can produce 20–30 tons per year [1]. Some experiments were conducted on NTD in PARR-1, but due to lack of market in Pakistan, it was suspended for time being. Non-host member states will find opportunities at PARR-1 to carry out commercial activity in NTD.

Gemstone Coloration

Like Neutron Transmutation Doping of silicon, there is potential for the generation of significant income through gemstone irradiations. Gemstones may be irradiated with neutrons to improve their properties and change to desirable color, in order to increase their demand and monetary value. The most common neutron irradiation being performed at research reactors is for topaz. Various attempts were made by gamma irradiation to change the color of gemstone to more desirable color, but the results were poor. Under RCA program gem irradiation program was started, which is still continued. Interested parties from inside and outside country may engage themselves in this commercial activity.

Neutron Radiography

A neutron radiography set up is present in PARR-1, but due to loss of interest, it is generally not in use, however non-host member states may activate experimentation in this facility.

Prompt Gamma Neutron Activation Analysis

Prompt gamma neutron activation analysis (PGNAA) is a process similar to INAA. While INAA uses the radioactivity emitted by the activation products for analysis, PGNAA uses the prompt gamma rays emitted during the neutron capture. Typical PGNAA applications are analysis of samples in geological and atmospheric sciences. The technique is useful for analysing for H, B, C, N, P, S, Cd, Pb, Sm, and Gd. PGNAA has advantages in the determination of H, B, C, N, over NAA. Few years back its facility was created, which is underused. Interested parties may join this activity.

Instrument Testing and Calibration

Instrument testing and calibrations even for low level radiation protection instruments can be performed in PARR-1 and PARR-2. Typically the work involves neutron and/or gamma ray detection instruments that need to be tested to ensure that they have the appropriate characteristics and need to be calibrated to ensure accurate readings. Involvement of commercial firms in this activity is highly desireable.

Material Structure Studies

Material structure studies are performed using reactor produced neutrons that are extracted from the reactor through beam ports. The energy of these emerging neutrons covers a range from below thermal to several MeV. Using various techniques, neutrons within a small energy band are selected for use in experiments. At PINSTECH, the neutron diffraction programme is centered on a triple axis neutron spectrometer, installed in the early seventies. Over the years, it has been used for the structural studies of cellulose, order disorder transitions in iron based alloys and superionic conductors, determination of thermal parameters of materials, lattice dynamics of mixed alkali halides and copper nickel alloys as well as texture studies of copper and aluminum. Up gradation of neutron spectrometer has been achieved by developing a multi-counter assembly to replace the single BF_3 detector and replacement of older data acquisition and spectrometer control system with PC based system for automated operation. Two Czech Republic scientist worked for few week in the laboratory.

Conclusion

Pakistan Research Reactor-1 is mainly used for radioisotope production and material structure studies, while activation analysis is performed in PARR-2. Training of personnel is carried out in both reactors. The PARR-1 is under utilized; hence non-host member states have opportunities to submit their proposals to Pakistan Atomic Energy Commission. IAEA sponsored trainees were always accepted by PINSTECH management and in future this cooperation will continue and grow.

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A.10. Russia, Voronov

Access on the PNPI's objects

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PETERSBURG NUCLEAR PHYSICS INSTITUTE

Since September 2011 the Institute acts as a part of the National Research Center "Kurchatov Institute" and its full name is Federal State Budgetary Institution "Petersburg Nuclear Physics Institute".

Nowadays two base experimental installations operate at Institute - the WWR-M research reactor and the Proton Accelerator. Mainly, the prospects for the development of the Institute are connected with building of a new high-flux research reactor PIK.

Proton Accelerator

A Center for Stereotactic Proton Therapy at PNPI has been working since 1975. This Center is based on synchrocyclotron with proton energy of 1 GeV. It is designed to cerebropathy therapy, e.g. pituitary adenoma and arterivenous malformation of brain vessels. Small scattering of protons with energy of 1GeV combined with rotational technique of irradiation together provide a high ratio of the dose in irradiation zone to the doze on surface.

By now 1360 patients have been treated with proton therapy. This is a reliable and effective method, but the field of application of this method is limited only with cerebropathy therapy yet.

Nowadays in addition to the existing Center for Stereotactic Proton Therapy the project of **Proton Therapy Center** with controllable energy of protons in the range of 80-240 MeV is being implemented. This Center will cover most requests of oncological diseases treatment in North-West. It is based on two accelerators:

- C80 – a high-current isochronous cyclotron (energy - 80 MeV, current – 100 μA)
- PS240 – a fast cycled proton synchrotron with a variable energy 120-240 MeV.

Features of the new project:

- oncology treatment (precision beam of protons with energies of low-intensity 80 MeV)
- radioisotope production (a high-intensity beam of protons with energies 80 MeV, current 100 μA)
- repetition rate – 1 Hz with a possibility to vary energy within 10 % with a frequency 10 Hz
- the four-dimensional irradiation with variation over the surface, deepness and time of irradiation will be provided
- synchronization of the beam with movable organs while being irradiated.

Production:

- radioisotope production for medical purposes;
- production of generators 82Sr-82Rb (it will allow using of positron emission tomographs (PETs) in medical centers where there are no cyclotrons for PETs emitters production);
- reactor isotopes production.

Completion of the cyclotron C80 construction is planned on 2012.

The WWR-M reactor

Purpose of WWR-M

- nuclear physics and elementary particle physics;
- solid state physics;

- reactor physics and technology;
- irradiation of materials and alloys;
- isotope production.

There is an over reactor chamber that allows reloading works during operation of reactor.

Main characteristics

- Power – 18 MWt
- Neutron-flux density – up to $4 \cdot 10^{14}$ n/cm$^2 \cdot$s
- Number of horizontal channels – 17
- Number of vertical channels – 18
- Operation time per year – 3000 hours
- Stuff – 90

The WWR-M reactor has been working for 50 years and it remains a stably working nuclear installation. According to the results of comprehensive survey the operating life of the WWR-M reactor has been extended up to 2015. Application for a license until 2017 is being prepared.

Experimental installations at reactor

- Universal Liquid Hydrogen Source of Polarized Cold and Ultracold Neutrons
- Neutron crystal diffraction monochromator of polarized neutrons
- 48-counters powder diffractometer for structural investigations
- Crystal difraction gamma-spectrometer GSK-2M. Diffraction Method and Setup for a Neutron EDM Search
- Triple-axis crystal neutron spectrometer with double monochromator "Neutron - 3
- Small-angle polarized neutron scattering setup "Vector
- The Small-Angle Diffractometer "Membrana-2
- Polarized neutrons correlation spectrometer
- Multirotors mechanical monochromator of resonance neutrons
- The facility for the study of neutron capture g-rays
- The neutron reverse Fourrier-type diffractometer for investigations of powder
- Solid Deuterium UCN Source
- Thermal neutron spin-echo spectrometer
- Reflectometer for polarized neutron with vertical plane of scattering (REVERAN)
- Two-modes polarized neutron reflectometer PNR-2M
- Four-circle diffractometer for the magnetic and crystal structure investigation
- Small angle diffractometer of polarized neutrons with 3D analysis of polarization
- Low-temperature helium loop
- The gamma-ray diffractometer

Isotope production

Fuel elements WWR-M5 that are used in WWR-M reactor allow using of the major part of the core for irradiation channels and ampoule placement.

Irradiation and isotope production

1. Six irradiation facilities in the core:
    a. Three spaces consisting of 7 fuel elements in the core center with fluxes $3.5 \cdot 10^{14}$ cm$^{-2} \cdot$s^{-1} (16 MWt);
    b. Two spaces consisting of 4 fuel elements on the core peripheral with fluxes in the center $2 \cdot 10^{14}$ cm$^{-2} \cdot$s^{-1};
    c. One space consisting of 12 fuel elements with absorbing shield for irradiation with fast neutrons.
2. 13 vertical channels in beryllium reflector with fluxes up to $1 \cdot 10^{14}$ cm$^{-2} \cdot$s^{-1}. Three channels outside the reflector.
3. Special ampoules that are installed in the core instead of single fuel assembly.

99Mo production:

- about 300 GBq of 99Mo every week for Radium Institute (SPb) and «Medradiopreparat» plant (Moscow).

125I production.

– Productivity – 700 Ci/year.

106 Ruproduction

– Specific activity –over 100 Ci/gram

192Ir production

– productivity – 20 kCi/two weeks with 600 Ci/gram is evaluated.

Possibilities for production – several times more

Plans for equipment with experimental installations

Ultra cold neutrons source

The reactor has a functional capability that allows placing the source of cold and ultracold neutrons of high intensity with superfluid helium in the existing thermal column that is 1 m in diameter and joined the core. Ultracold neutrons density is 10^4 cm^{-3}.

– gemstone coloration;
– neutron activation analysis and neutron-capture analysis;
– water loop for pressure testing of fuel elements of WWR-M type (carried out for Argonne National Laboratory);
– testing of new types of fuel elements for research reactors, including converting them to low-enriched uranium.

<u>High-flux research reactor PIK</u>

The PIK reactor represents a compact neutron source (core volume 50 l) surrounded by a heavy water reflector. It is fueled by Uranium-235 (enriched to 90%) of total weight ~ 27 kg. Light water is used both as coolant and as moderator.

The design parameters:

- thermal power 100 MW,
- thermal-neutron flux: in reflector - $1.2x10^{15}$ n/cm^2s, in 10 cm-dia. central channel -$4.5x10^{15}$ n/cm^2s, i.e. four times higher
- number of horizontal beam-tubes - 10. Channel diameter - 10 cm, with a possibility of replacement by a 25-cm dia. channel,
- number of inclined beam channels - 6,
- number of vertical thimbles for sample irradiation - 6.

The reactor will be equipped with sources of hot (HNS), cold (2 CNS), and ultracold neutrons.

A low-temperature loop will permit sample irradiation at helium temperatures.

A system of neutron guides (four for the cold, and four for thermal neutrons) of total length 300 m will provide operation with external beams in zero-background conditions of the neutron guide hall adjoining the reactor building. The total number of work stations for location of experimental setups is as large as 50 which will permit simultaneous operation of 50 Groups.

Research program and experimental facilities

Physics of condensed states:
Structural and radiation biology and biophysics.
Radiation physics and chemistry.
Nuclear and elementary particle physics
Materials science.

Possibilities for applied work

1. Production of doped silicon (The output supposed to be up to 50 tons/y.)
2. Purification and upgrading of heavy water (D2O)
3. Production of radioactive isotopes
4. Neutron activation analysis

<u>Critical assembly “Physical model of PIK reactor</u>

The critical facility of PIK with a heavy-water reflector and a light-water core is a full-scale mock-up of the high-flux PIK reactor for physical research.

The core, vessel, reflector, experimental channels and executive units of safety control system are completely the same as reactor PIK has.

The try-out of the PIK's first criticality program was conducted on assembly.

The design power of the assembly is 100 Wt. All the fuel assemblies are dismountable and it also allows fast and flexible carrying out measurements of the core characteristics and conduction of experiments on following improvements of the core construction.

Education

PNPI annually holds the Winter schools in various directions of scientific work of institute since 1966. Within this educational event the Institute holds Schools on:

- School on nuclear and particle physics
- Theoretical physics schools
- School on nuclear reactor physics
- Accelerator physics school
- Condensed state physics school

The Winter Schools contribute greatly to improvement of professional skill and a scientific outlook of employees and especially young experts of the institute. The Schools also provide an exchange of the scientific information and experience of scientific researches. On Winter Schools' materials the collections of the most interesting lectures are published.

A.11. Sudan, Ebrahim

SUDAN 1ST RESEARCH REACTOR

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1.Introduction

Research reactors have played and continue to play a key role in the development of the peaceful uses of atomic energy. Their contribution to medicine, agriculture, industry, environmental sciences and education and training of scientists and engineers is well documented. Sudan is planning to acquire its 1st research reactor to cover a broad range of possible applications and to promote the development of scientific research and the related nuclear technology as well as to foster regional collaborative efforts in these areas. The establishment of the reactor in Sudan will also enable Sudan to acquire its own scientific base and fairly skilled cadres particularly, it has embarked on nuclear program to acquire its first NPP.

2. Justifications of the Project

1- Strengthening the infrastructure for nuclear science and technology in the country.
2- Providing technical facilities in the form of equipment and research tools to support higher studies and professional training programs, research, applications and services in nuclear science and technology at the Sudanese universities and scientific research centers.
3- Providing training tool for manpower required for the management and operation of the nuclear power reactor for electricity production, which is presently under consideration at SAEC and the Ministry of Energy and Mining.
4- Production of short-lived radioisotopes for applications in several fields

3. Phases of the Project

Based on the above, two research reactors are needed to be introduced over two phases:

Phase 1: “building the human resources capacity”

- An operational scientific research reactor with low power, which can be located at SAEC and used mainly for teaching students and training operators and experimenters. Other uses would include reactor physics, neutronics, shielding etc.
- This phase should be concluded in 3-5 years

- Phase 2: “ production of radionuclides for different applications”
  - A Multi Purpose Nuclear Research Reactor used for the production of radioisotopes for applications in several areas including medicine, agriculture and industry, geology and environment, and analytical services, basic and applied physics and engineering research and training.
  - The core of expertise formed in the first phase will be utilized in the implementation of the second phase.
  - This phase is expected to be completed in 5-10 years following the first phase.

4. Education and Training

Nuclear academic programs are curently running in two univeristies in Sudan.Sudan is seeking cooperation for training regarding nuclear programs from the countries in the region having RRs such as Ghana,Syria and Egypt.

5.Neutron activation analysis

The only nuclear capability available in Sudan is 14 MeV neutron generator installed in 1983 at Faculty of Science, University of Khartoum. The generator has mainly been used for neutron activation analysis of limited number of elements and for cross-section measurements .

Meanwile, Sudan calls for services from the neighboring countries which possess research reactors such as Egypt, Syria, Algeria, Ghana and South Africa .Usually samples are sent over for analysis or scientist pay short visits to do their experiments. This collaboration has been initiated and supported under IAEA technical cooperation projects and the AAEC. A number of researchers have benefited from this set-up.

Now Sudan is part of Research Reactor Networks and Coalitions in Central Africa which has been established through TC regional project RAF4022Accra, Ghana, July 2011.

6. Difficulties

The collaboration faces some difficulties as it requires sufficient lead-time for processing and only limited samples can be handled at a time. Moreover, in most cases the practical work is carried out in the absence of the visitor scientist the fact which deprives the visiting researcher from hand-on experience.

7. Recommendations

1. To identify research reactor applications of common interest, where cooperative efforts would lead to regional network/coalitions (e.g., education and training, neutron activation analysis, production of short lived radioisotopes, etc.)
2. To Define possible mode of cooperation and steps to be taken for initiating closer collaboration and eventually creation of the sub-regional research reactor network/coalition

A.12. USA, Farrar

Access to the Research Capabilities of the High Flux Isotope Reactor (HFIR)

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The HFIR is a U.S. Department of Energy (DOE), Office of Science Facility located at the Oak Ridge National Laboratory (ORNL). The mission of the HFIR is to provide world-class research in neutron science. This reactor and supporting facilities are accessible for both scientific and proprietary research involving neutron scattering, isotope production and research, materials irradiation studies, neutron activation analysis and gamma irradiation. Non-proprietary users at HFIR are not charged an irradiation usage fee, however are responsible for other costs associated with the design, and analysis, fabrication, and post-irradiation examination of their experiment.

ORNL began as part of the Manhattan Project during World War II and was centered around the world's first continuously operated reactor, the Clinton Pile. Following the war, this reactor was renamed the Oak Ridge Graphite Reactor and was used to produce the first reactor-generated radioisotopes for medical and research purposes. Other peaceful uses of the reactor ensued including the development of neutron scattering as a materials research tool; work that eventually won Clifford Shull a Nobel Prize. Over the course of time, 13 research reactors were built and used at ORNL. Of these, only the HFIR remains. HFIR was brought critical in 1965 and brought to full power at 100MW in 1966. The power has since been decreased to 85MW due to vessel embrittlement concerns. HFIR has a project life well past the year 2040.

Over the years, ORNL has grown well beyond being a reactor-centered nuclear laboratory and now has a broad set of well-defined research capabilities that are applied to meet the needs of the Department of Energy and other customers with a $1.6B budget from projects of various sizes for a wide range of customers. ORNL has about 4600 employees and 3000 guest researchers each year that use the HFIR and other tools such as the Spallation Neutron Source (SNS), high-performance computers, a center for nanophase R&D, and the Holifield Heavy Radioactive Ion Beam Facility (HRIBF) among others. This wide range of resources is brought to bear on many areas of science including, isotopes R&D, climate studies, materials science & engineering, bio-energy, and other clean energy technologies. HFIR is just one tool in this extensive tool-kit allowing it to be used in innovative ways.

The HFIR mission to produce isotopes and perform materials irradiation studies is supported by three major hot cell facilities in addition to numerous radiological laboratories. These include the Radiochemical Engineering and Development Center (REDC) that is used to process the transcurium targets from HFIR, the Irradiated Materials Examination and Testing facility (IMET) used for beta-gamma materials examinations (e.g., pressure vessel materials), and the Irradiated Fuels Examination Laboratory (IFEL) used to examine irradiated fuel and alpha-emitters.

Despite its original mission to produce trans-curium isotopes, HFIR itself is a multi-purpose reactor with a neutron scattering program that serves over 500 "unique users" each year (1200 total users each year) with 12 instruments on both thermal and cold neutron beams. It produces medical isotopes for diagnosis and therapy, including W-188, Lu-177, and Ac-225/Bi-213; is the only U.S. source for Cf-252 and other trans-curium isotopes for nuclear physics and chemistry research as well as other practical applications; and provides high specific activity Ni-63 for portal detectors. HFIR also supports fission reactor fuels and cladding research for current and next-generation fleets in addition to fission structural materials for current reactors (life extension) and next-generation systems; fusion materials (fundamental and ITER). Finally, two pneumatic tube facilities serve a world-class neutron activation Neutron Activation Analysis (NAA) laboratory and a high-level gamma irradiation facility is available with electrical connections for electronics dedication and sweep gas capabilities. These facilities have produced citations in 106 scientific publications during calendar 2011 as of the end of September.

HFIR neutron scattering research is coordinated by the ORNL Neutron Scattering Science User Program and is open access based on scientific quality. Beam time is awarded though a competitive proposal process which is accessed on-line requiring a 2-page statement of research plus sample description. There are two calls per year. Beam time is awarded based on an external peer review and a determination that the proposal is technically feasible and safe. The experiment is free of charge if results are published in the open literature. Proprietary users (results are not shared) are charged to recover costs.

To attract neutron scattering users, the National School on Neutron and X-ray Scattering is hosted annually by ORNL and Argonne National Laboratory. This school is open to students in North American universities. These are not necessarily typical nuclear physics or engineering students, but those of other disciplines such as biology, metallurgy, or materials science interested in neutron scattering as a tool. 63 graduate students from 43 universities participated in the 2010 school.

One avenue to access HFIR and other U.S. reactors such as the Advanced Test Reactor (ATR) and the MIT Reactor (MITR) for isotope and irradiation R&D is through the ATR-National Scientific User (ATR-NSUF) Program which uses a competitive proposal system similar to the Neutron Scattering Science User Program. However, the budget available to this program is somewhat limited.

Isotope irradiations for production and R&D are coordinated by the DOE through the National Isotope Data Center (NIDC) which is centered at ORNL. However, collaborations on isotopes and materials irradiation research is coordinated through the ORNL Work For Others (WFO) program which opens HFIR to collaborative work that has no Nuclear Non-Proliferation concerns, is in compliance with U.S. Export Compliance laws and regulations, is in compliance with the Price Anderson Act (as amended), and scrupulously adheres to the letter and spirit of the Foreign Corrupt Practices Act (FCPA).

A.13. Vietnam, Dong

Possibility of the Dalat Research Reactor for non-host Member States utilization

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Dalat Nuclear Research Reactor (DNRR) with the nominal power of 500 kW is today the unique one in Vietnam. Up to mid 2011, the reactor has been operated with the total of about 35,500 hrs of safety and effective exploitation. More than 90% of reactor operation time and over 80% of reactor irradiation capacity have been exploited for research and production of radioisotopes. Besides, the utilization for R&D on neutron activation analysis (NAA), basic and applied research on neutron beam ports, as well as research on reactor physics and thermo-hydraulics have also been implemented.

During the last 27 years of operation, the reactor has been successfully used for:

- Producing many kinds of radioisotopes and radiopharmaceuticals used in medicine and other economic and technical fields. Providing about 500Ci per year of radioisotopes including I-131, P-32, Tc-99m generator, KIT in-vivo and in-vitro, Sr-46, Cr-51, etc. Each year, about 500,000 patients have been diagnosed and treated by radioisotopes produced at DNRR that contributed to push forward the development of nuclear medicine in Vietnam.
- Developing a combination of nuclear analysis methods (INAA, RNAA, PGNAA) and physic-chemical methods for accurate quantitative analysis of about 70 elements and constituents in various samples of geology, crude oil, agriculture, biology, environment, etc.
- Experimental exploitation of the reactor horizontal beam tubes for nuclear data measurement, neutron radiography and nuclear structure study.
- Training and education for human resource development in the country and regularly receiving trainees, scientific visitors and postgraduate students from other countries such as Philippines, Malaysia, Cuba, Angola, etc.

The DNRR has played an important role in the technique potential development, enlarging the market for applications of nuclear technology and science, taking part in research program of introducing nuclear power for electricity production into Vietnam, and manpower training for nuclear energy program of Vietnam. The DNRR is open for bilateral and multilateral co-operations and is ready to receive trainees from foreign organizations, especially for non-host MSs utilization in the region.

I. INTRODUCTION

The origin of the DNRR was the 250 kW TRIGA Mark-II reactor built in early 1960's, reached the first criticality in 26 February 1963, and inaugurated in 4 March 1963. The TRIGA reactor was operated with three main purposes of training, research and radioisotope production during 1963-1968 period. It was extended shutdown from 1968 to 1974, and in 1975, all fuel assemblies of the reactor were unloaded from the core and shipped back to the USA.

The national project for reconstruction and enlargement of the TRIGA reactor was implemented during 1981-1983 period and the upgraded reactor, namely IVV-9, went critical in 1st November 1983. The reactor loaded with the Soviet WWR-M2 fuel elements and reached the nominal power of 500 kW in February 1984. Since 20 March 1984, dated of an official inauguration, its regular operation has been done with the purposes of radioisotope production, neutron activation analysis, research and training.

The reactor is operated mainly in continuous runs of 108 hrs, once every 3-4 weeks for above mentioned purposes. The remaining time between two continuous runs is devoted to maintenance works and also to short run for reactor physics experiments.

As an unique research reactor at present in Vietnam, the DNRR has played an important role in the research and development of nuclear technique applications as well as in nuclear power program development of the country.

Main results of the DNRR reactor operation and utilization are presented in this paper and some ideas related to future plans for ensuring reactor safety operation and effective utilization as well as for international co-operation are also discussed.

II. REACTOR DESCRIPTION

The DNRR is a 500 kW pool-type reactor, moderated and cooled by light water, loaded with the mixed core of HEU (36% enrichment) and LEU (19.75% enrichment) fuel assemblies. The reactor tank, reactor shielding, reactor core graphite reflector and neutron beam ports of the former TRIGA reactor were remained but the reactor core with VVR-M2 fuel and in-core irradiation facilities, the control and instrumentation system as well as other technological systems were re-designed by Russian and replaced. Main specifications of the reactor are listed in Table 1 and cross section of the reactor core is shown in Fig. 1 below.

Table 1. Specifications of the DNRR.

Reactor type	Swimming pool TRIGA Mark II, modified to Russian type of IVV-9
Nominal thermal power	500 kW, steady state
Coolant and moderator	Light water
Core cooling mechanism	Natural convection
Reflector	Beryllium and graphite
Fuel types	WWR-M2, U-Al alloy with 36% enrichment and UO_2+Al with 19.75% enrichment, aluminium cladding
Number of control rods	7 (2 safety rods, 4 shim rods, 1 regulating rod)
Materials of control rods	B_4C for safety and shim rods, stainless steel for automatic regulating rod
Neutron measuring channels	6 combined in 3 housings with 1 CFC and 1 CIC each

Vertical irradiation channels	4 in-core (neutron trap, 1 wet channel, 2 dry channels) and 40 holes at the rotary rack
Horizontal beam-ports	4 (1 tangential - No #3 and 3 radial - No #1, #2, #4)
Thermal column	1
Maximum thermal neutron flux	$2.1\text{x}10^{13}$ $n.cm^{-2}.s^{-1}$ (at core center)
Main utilizations	RI, NAA, PGNAA, NR, basic and applied researches, nuclear training
Spent fuel storage	Inside reactor building, next to reactor shielding

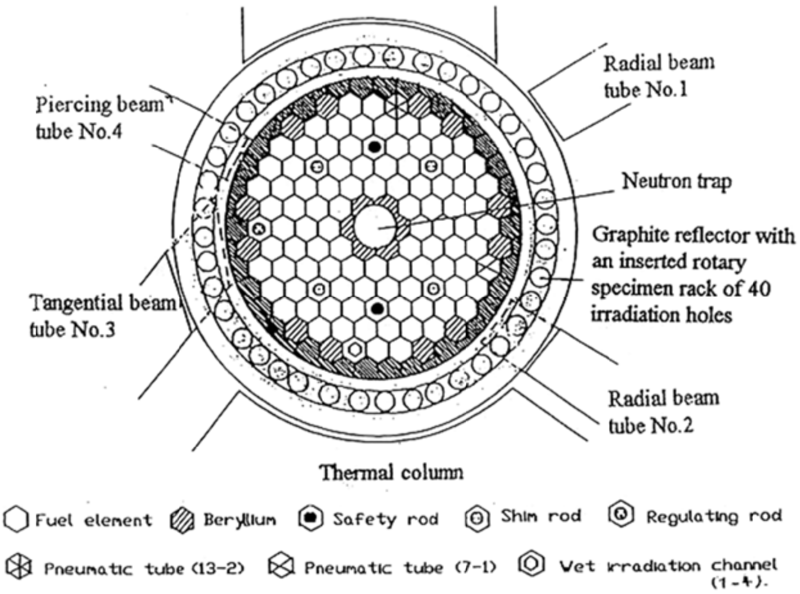

Fig. 1. Cross section of the reactor core.

III. MAIN RESULTS OF REACTOR UTILIZATION

1. RADIOISOTOPES AND RADIOPHARMACEUTICAL PRODUCTION

Research on radioisotope and radiopharmaceutical production serving nuclear medicine and other users such as industry, agriculture, hydrology, scientific research, etc. oriented towards efficient use of the reactor. Such research has led to various products such as ^{131}I, ^{32}P applicators, ^{99m}Tc generators, etc.

For medicine applications, radioisotopes and radiopharmaceuticals have been delivered to more than twenty hospitals in the country. The main radioisotopes, such as ^{131}I in NaI solution and ^{131}I capsule type, ^{32}P applicators for skin disease therapeutics and ^{32}P in injectable solution, ^{99m}Tc generator of gel type by ^{98}Mo(n, γ)^{99}Mo reaction have routinely been produced and supplied once every 2 weeks. Other radioisotopes, such as ^{51}Cr, ^{60}Co, ^{65}Zn, ^{64}Cu, ^{24}Na, ^{86}Rb, etc. were also produced in a small amount when requested. ^{53}Sm in solution form is ready for labelling. It is totaled about 3,500 Ci of radioisotopes have been produced and supplied to medical users so far, giving a yearly average of about 150 Ci (Fig. 2).

In order to support the application of ^{99m}Tc, ^{113m}In and ^{53}Sm radioisotopes in clinical diagnosis and therapeutics, the preparation of radio-pharmaceuticals in Kit form for labelling was carried out in parallel with the development of ^{99m}Tc generator systems. About 17 labeled compounds kits have been regularly prepared and supplied, such as Phytate, Gluconate, Pyrophosphate, Citrate, DMSA, HIDA, DTPA, Macroaggregated HSA and EHDP, etc. The annual production rate is about 1000 bottles for each Kit which is equivalent to 5000 diagnostic doses.

Other applications of radioisotopes produced at the DNRR are radiotracer technique in sedimentology studies, oil exploitation, chemical industry, biology, agriculture and hydrology. Some main products are ^{46}Sc, ^{192}Ir, ^{198}Au, ^{131}I, ^{140}La, etc. Some small sources of ^{192}Ir, ^{60}Co with low radioactivity have also been produced for industry applications.

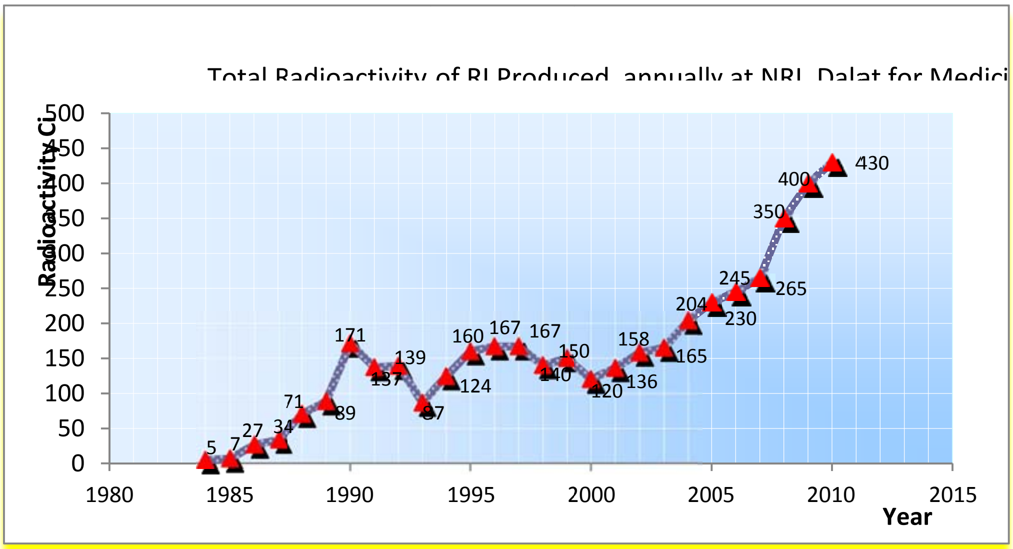

Fig. 2. Status of radioisotope production for medical use from 3/1984 to 12/2010.

Table 2: The supply/demand for radioisotopes and diagnostic Kits in Vietnam.

Product	Supply	Demand at present	Demand after 2015
^{131}I- Diagnostic and therapeutic capsule/solution	20 Ci/month	40-50 Ci/month	Increase to 200%
^{99m}Tc-Generator	20 generators (200-500mCi/each) /month	40 generators (200-500mCi/each) /month	
^{32}P- Solution/Applicator	50 Ci/month	50 Ci/month	
Kits for ^{99m}Tc-Labelling			
- MDP	300 Kit/ month	400 Kit/ month	
- DTPA	100 Kit/ month	200 Kit/ month	
- DMSA	100 Kit/ month	200 Kit/ month	
- PHYTATE	100 Kit/ month	200 Kit/ month	

The status of supply/demand of radioisotopes and diagnostic Kits in the country is shown in Table 2.

Number of nuclear medicine centres in Vietnam now is 23 which are located in almost all parts of the country (see Fig. 3). Main radiopharmaceuticals used in these centres are $Na^{131}I$ solution and capsule, Sodium-(^{99m}Tc) pertechnetate, ^{131}I-Hippuran, Sodium-(^{32}P) orthophosphate, ^{32}P Applicator and the in-vivo Kits of DTPA, DMSA, MDP, Phosphotec, Glucotec, Phytec, EHIDA, DISIDA, HMPAO, MIBI, etc. have also been used.

At present, locally manufactured products take 50% of total market. To get a higher market share of local products in case of ^{99m}Tc generator the production by loading generations with imported ^{99}Mo solution have been done.

Fig. 3. Location of Nuclear Medicine Centers in Vietnam.

2. NEUTRON ACTIVATION ANALYSIS

Research on analytical techniques based on neutron activation and other related processes consisting of the elaboration of analytical processes and the design and construction of analytical instruments.

Requests of many branches of the national economy for various types of samples have been answered. NAA at DNRR meets analytical services for geology exploration, oil prospection, agriculture, biology, environmental studies, etc. Participating to international intercomparison exercises, the results of NAA at DNRR have always obtained good performance

The relatively high neutron flux in irradiation channels of the reactor allows elemental analysis using various neutron activation methods, such as Instrumental NAA, Radiochemical NAA, Delayed NAA and Prompt gamma NAA.

Though the end of 2010, a total of about 60,000 samples have been irradiated at the reactor, giving a yearly average of 2000 samples. It can be estimated that 60% of geological samples, 10% of biological samples, 20% of environmental samples, 5% of soil and agriculture materials, 3% of industrial materials.

For determination of the elements having short-lived radioisotope, the method of cyclic INAA with the alternation of irradiation and measurement was implemented by using the thermal column and vertical irradiation channel. An home-made pneumatic system can transfer a sample from irradiation position to measuring detector about 3 seconds. This technique has been applied for the determination of F, Cu, V, Se, Ag in biological samples.

During the past time, the K-zero method for INAA has been developed to analyse airborne particulate samples for investigation of air pollution; crude oil samples and base rock samples for oil field study. Based on developed k_0-INAA method, a multi-elements analysis procedures have been applied to simultaneously determine concentration for about 31 elements such as Al, As, Ba, Br, Ca, Cl, Cr, Cu, Dy, Eu, Fe, Ga, Hf, Ho, K, La, Lu, Mg, Mn, Na, Sb, Sc, Sm, Sr, Th, Ti, V, Yb, Zn. The K_0-INAA methodology developed at DNRR was introduced to other NAA laboratories in the Asian region.

Since 2007, based on the fact demands from archaeologists regarding many of the ruins of archaeology and cultural heritages which need to be studied, preserved, prepared and restored in Vietnam and due to the capabilities of NAA method which can make a contribution into the solution for above issues as well, a national project for research on provenance of archaeological materials was approved and supported.

3. NEUTRON BEAM UTILISATION

The reactor has four horizontal beam tubes, which provide beams of neutron and gamma radiation for a variety of experiments. They also provide irradiation facilities for large specimens in a region close to the reactor core. In configuration, three of the beam tubes are oriented radically with respect to the center of the core, and one beam tube is tangential to the outer edge of the core. Besides, there is a large thermal column with outside dimensions of 1.2m by 1.2m in cross section and 1.6m in length (Fig. 4).

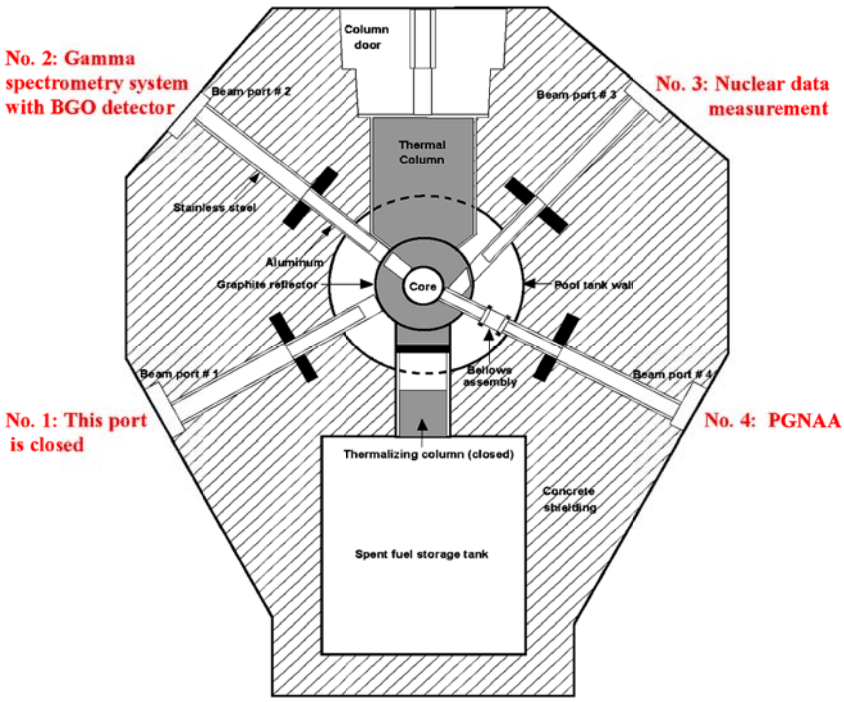

Fig. 4. Horizontal section view of the Dalat Nuclear Research Reactor.

Even there are four neutron beam ports at the reactor, but until now only three of them (No.2, No.3 and No.4) have been used. The filtered thermal neutron beams at the tangential channel No.3 have been extracted using a single crystal silicon filter and mainly used for nuclear data measurement. The filtered quasi-monoenergetic keV neutron beams using neutron filters at the piercing channel No.4 have been used for prompt gamma neutron activation analysis and nuclear data measurement; study on radiation hardness of electronics components, such as transistors, avalanche photodiodes (APD), PiN diodes; and other researches. Typical research activities using neutron beam of the Dalat reactor can be listed below.

3.1. Neutron physics and nuclear data measurement

In the keV energy region, filtered neutron beams are the most intense sources, which can be used to obtain neutron data for reactors and other applications. The following experiments have been carried out at the Dalat research reactor:

- Total neutron cross section measurement for ^{238}U, Fe, Al, Pb on filtered neutron beams at 144 keV, 55 keV, 25 keV and evaluation of average neutron resonance parameters from experimental data.

- Gamma ray spectra measurement from neutron capture reaction of some reactor materials (Al, Fe, Be, etc.) on filtered neutron beam at 55 keV and 144 keV.

- Measurement of average neutron radioactive capture cross section of ^{238}U, ^{98}Mo, ^{151}Eu, ^{153}Eu on the 55 keV and 144 keV neutron beams.

- Measurement of isomeric ratio of $^{82m,\gamma}$Br created in the reaction ^{81}Br(n, γ)^{82}Br on the 55 keV and 144 keV neutron beams.

- Other investigations, such as average resonance capture measurements, using the γ-γ coincidence spectrometer for study on the (n, 2γ) reaction, etc.

3.2. Applied neutron capture gamma ray spectroscopy

- Development of PGNAA technique using the filtered thermal neutron beam in combination with the Compton-suppressed spectrometer for analyzing Fe, Co, Ni, C in steel samples; Si, Ca, Fe, Al in cement samples; Gd, Sm, Nd in uranium ores, Sm, Gd in rare earth ores; etc.

- Utilization of the PGNAA method for investigating the correlation between boron and tin concentrations in geological samples as a geochemical indication in exploration and assessment of natural mineral resources; analyzing boron in sediment and sand samples to complement reference data for such samples from rivers.

- Development of the PGNAA method for in-vivo activation analysis of essential elements Ca, Cl, N and P in the whole body and of the toxic elements Cd, Hg in a body organ for medical diagnosis of various diseases.

- Development of the spectrometer of summation of amplitudes of coinciding pulses for (n, 2γ) reaction research and for measuring activity of activated elements with high possibility of cascade transitions.

4. EDUCATION AND TRAINING ACTIVITIES

Training Center at DNRI which was established in 1999 is responsible for organizing training courses and training in reactor engineering, nuclear and radiation safety, application of nuclear techniques and radioisotopes in the economic sector including industry, agriculture, biology and environment. Training courses on non- destructive evaluation (NDE) including radiographic testing, ultrasonic testing; as well as on security of nuclear facilities and radiation sources have also been done. The center also is the training facility for expertise students from local universities and foreign postgraduate students. Thereby, the human resource development is conducted on the annual basis so that it can deal with scientific works of higher and higher quality and meet a huge demand in the field of nuclear science and technology in Vietnam in the future. Through the bilateral co-operation with the Japan Atomic Energy Agency, US Department of Energy, Bhabha Atomic Research Center of India, and Korea Atomic Energy Research Institute as well we have conducted various training courses for human resource development in the four following key areas:

- Reactor engineering for nuclear power program
- Research and development activities
- State management in the field.
- University lecturer training program.

Besides DNRR as a main tool for practical training, a set of equipment was supported under IAEA TC project, bilateral projects with the Japan Atomic Energy Agency and Bhabha Atomic Research Center of India. The measuring systems for practices at the Training Center can meet the fast increasing demand and move forward to the regional standard in the field of nuclear training.

In general, the DNRR is the most important scientific tool for carrying out the R&D programmes of nuclear technique applications so far, as well as for preparation of human resources for nuclear power program in Vietnam in the near future. Because of that, a strategic plan and long-term working plan for the DNRR has been set up in order to continue its safe operation and effective utilization at least to 2025 for above-mentioned purposes.

5. OTHER APPLICATIONS

Research on sedimentology using radiotracer techniques was carried out to investigate bed load layers displacement at estuaries navigation channel region, in order to explain the sediment deposition phenomenon causing frequent dredging activities.

Research in radio-biology consisting of using gamma radiation associated with other factors for improving agricultural seeds; of applying radioactive tracers for studying biological metabolism, especially nutrition problems. These studies to investigate phosphorus absorption and other nutritional problems during the growing processes of rice and other plants. Irradiation effects on some plants for obtaining higher yield or environment adapted varieties were also studied.

Gemstone coloration of topaz and sapphire in the reactor core, in the rotary rack as well as in horizontal channels has been done.

As research purpose, silicon mono-crystals have been irradiated at the central neutron trap of the reactor. Proper neutron distribution in this irradiation facility and suitable cadmium ratio have resulted in irradiated products of good quality, appropriate for fabrication of power diodes and thyristors.

IV. CONCLUSION

During more than 27 years of operation, the DNRR has played an important role in the use of atomic energy for peaceful purpose in Vietnam including RI production for medicine and industry use, NAA of geological, crude oil and environment samples, carrying out fundamental and applied researches on nuclear and reactor physics, as well as creating large amount of human resource with high skills and experiences on application of nuclear techniques in the country. However, due to the limitation of neutron flux and power level, the out-of-date design of the experimental facilities and the ageing of the reactor facilities, the existing reactor can not meet the increasing user's demands. A plan for building a new multi-purpose research reactor with power level of 10 to 20MW is essential to increase nuclear potential of the country, to meet the requirements of energy and non-energy related applications, creating staff for nuclear industry. The main role of a new research reactor is to serve the nuclear power development program, promote the application of nuclear science and technology, and training scientific and operational staff for the nuclear sector in the future.

In preparation for this project, we call on the international cooperation from the neighboring countries which possess research reactor such as China, Korea, Japan, Indonesia, Thailand … This collaboration should be initiated and supported under IAEA technical cooperation projects in the field of expertise training related to technology of research reactors as well as other application fields, however, it faces some difficulties as financial problems and policies of the Member States. Besides of that, any proposal for training, experiment, international cooperation and access at DNRR under sponsor by IAEA or non-host member states are welcomed. We believe IAEA will offer good opportunity for international collaboration in Research Reactor area.

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