BRAZIL: MULTIPURPOSE RESEARCH REACTOR PROJECT

I. J. Obadia, J. A. Perrotta

R&D Directorate, Brazilian Nuclear Energy Commission

Rua General Severiano, 90, 22.290-901, Rio de Janeiro - Brazil

Email: isaac@cnen.gov.br

1. INTRODUCTION

Nuclear activities in Brazil started in the 1950s when the Brazilian Nuclear Energy Commission was created. Currently the country has two NPPs, several nuclear fuel cycle facilities and the following four research reactors (RRs) in operation: the IEA-R1, a 5 MW pool type RR; the IPR-R1, a 100 kW TRIGA Mark I type RR; the ARGONAUTA, a 500 W Argonaut type RR - all constructed during the 1950s and 1960s and utilized for training, teaching and nuclear research - and a 100W nationally developed critical facility constructed in the 1980s, mainly for the development and qualification experiments in reactor physics.

All these RRs are operated by the Brazilian Nuclear Energy Commission (CNEN), a federal authority of the Ministry of Science, Technology and Innovation (MCTI), and have been fulfilling their mission along the last 60 years. IEA-R1 is the only one that has been used for radioisotope production, but with limited capacity. The 2007-2010 MCTI Strategic Planning proposed a conceptual study of a new RR for radioisotope production to be developed by CNEN.

2. RESEARCH REACTOR JUSTIFICATION AND UTILIZATION PLAN

In the middle of 2008 the authors of this paper received green light from CNEN's R&D Directorate to move forward with the new RR study, which came out with the proposal to extend it to a multipurpose RR.

The Brazilian Multipurpose Reactor (RMB) project was then initially formulated by the documents project Opening Term and Preliminary Project Scope, in accordance to the Project Management Institute Body of Knowledge (PMBOK) [1]. The Preliminary Project was then formally presented and discussed with CNEN's authorities, leading to its approval. In order to comply with a formal government condition, RMB project economic and social feasibility study was prepared according to the corresponding guideline [2] and submitted to the Ministry of Planning, Budget and Management, which officially was approved the project in 2011. RMB project planning and funding were then included in the 2012-2015 and now in the 2016-2019 official Federal Government Planning, and since 2016 it has been prioritized as part of the Federal Government Growing Acceleration Plan, besides being part of the 2016-2019 Science, Technology and Innovation National Strategy.

Brazilian nuclear medicine demands 5% of the world supply of Mo-99, which are used for the manufacturing of Tc-99m generators, providing around 1.5 million nuclear medical procedures per year. The international Mo-99 supply crises in 2009 – 2010 affected significantly the Brazilian nuclear medical services, since 100% of this radioisotope was, at that time, imported only from Canada. That national vulnerable condition enhanced the justification of the RMB project.

The RMB design comprises a 30 MW open pool multipurpose research reactor, using low enriched uranium fuel, with maximum neutron flux higher than $2x10^{14}$ $cm^{-2}s^{-1}$. This reactor is designed to perform three main functions: radioisotope production for medical and industrial applications (mainly Mo-99); fuel and material irradiation testing to support the Brazilian nuclear energy programme; and provide neutron beams for scientific and applied research and innovation. In addition to the research reactor itself, RMB project comprises several associated facilities to perform these functions, such as: laboratory for radioisotope processing and production; cold and thermal neutron beam laboratory for scientific research; NAA laboratory; and post-irradiation laboratory for analysis of materials and fuels specimens irradiated in the reactor. A spent fuel storage pool, for up to 50 years of reactor operation and 100 years of storage lifetime, is also covered by the project, as well as a facility to process and store medium and low level radioactive waste resulting from RMB operation. The project is on the implementation phase and its operation, previously estimated to start in 2022, is now under evaluation due to the economic and political crisis in Brazil.

3. STAKEHOLDERS INVOLVEMENT

At its early stages, the RMB project was presented to the major stakeholders such as the nuclear institutions Electronuclear (NPPs operator), INB (nuclear fuel cycle), CTMSP (nuclear propulsion), the Brazilian Nuclear Medicine Society, and nuclear R&D institutes, in order to identify their needs and consider them while developing the RMB concept design specifications. The project has received formal support from these stakeholders, as well as from universities, scientific societies and associations such as the Brazilian Physics Society, the Brazilian Nuclear Energy Association, and the Brazilian Academy of Science. The Brazilian Government, through MCTI, is fully supporting the project as the only funding provider so far.

4. INFRASTRUCTURE REVIEW

The 19 infrastructure issues suggested by the IAEA [3] were analysed and presented in the sustainability analysis made in 2010 [4]. RMB project status is described in reference [5]. Each infrastructure condition was analysed considering the RMB project organization, planning and management and the related national nuclear legislation and infrastructure. The analysis was made by the RMB project management and technical coordinators, based on their experience on the RMB project development and on their broad knowledge of the national nuclear infrastructure and legislation.

The RMB project is organized under the responsibility of CNEN’s R&D Directorate and project staff is composed mainly of technical personnel from its R&D Institutes: Nuclear and Energetic Research Institute (IPEN); Nuclear Technology Development Centre (CDTN); Nuclear Engineering Institute (IEN); and radiation protection and Dosimetry Institute (IRD). The Project is managed in compliance with its integrated management system requirements, which cover quality, safety, security, environment and economic issues.

The RMB site has already been selected, although 40% of the area is still depending on private land expropriation judicial process. Site related nuclear and environmental issues are being managed as part of the corresponding licensing processes, which have already issued the Preliminary Environmental License (by the environmental regulatory authority, IBAMA) and the Site Approval License (by the nuclear regulatory authority, CNEN). Several presentations by the project team to the chamber of counsellors of the cities nearby the RMB site have helped to overcome communities' concerns about RMB project acceptance.

The RMB project policy is to maximize national industry participation in all project stages. Brazil has expertise in RR project development and operation disciplines. The RMB concept was designed by CNEN's project team based on key stakeholders' needs, and the non-nuclear systems preliminary engineering was designed by a national engineering company, while preliminary and detailed engineering design of the RMB reactor and associated systems are being developed in cooperation with Argentina. A Mo-99 processing facility will also be designed under international cooperation. All engineering design documents and drawings developed by contracted companies are verified and approved by CNEN's project team. The RMB project includes the implementation in Brazil of a dedicated LEU fuel and target manufacturing and supply infrastructure that will assure RMB operation, as well as used fuel and radioactive waste storage facilities to cover reactor operational life and decommissioning.

An independent regulatory body was established sixty years ago in the country and a comprehensive national legal framework that covers safety, security, safeguards, spent fuel, radioactive waste management and decommissioning aspects is well developed and in force. As an IAEA Member State, Brazil adopts internally the Fundamental Safety Principles, and related standards and guides, and is committed to the Global Nuclear Safety Regime. A nuclear emergency preparedness and response network that has been appropriately established in Brazil many years ago due to its two NPP operation can be easily adjusted to cover RMB operation.

5. COST–BENEFIT ANALYSIS

RMB project implementation is a key condition to the Brazilian nuclear medicine and nuclear energy programme sustainability. It will create in the country a strategic infrastructure for national self-sufficiency on radioisotope production and on nuclear material irradiation testing, as well as for the development of nuclear science, technology and innovation.

The RMB project cost is estimated around USD 500,000,000 (five hundred million American dollars), based on a projection of similar RR projects costs. Preliminary engineering design, which is now complete, has confirmed this estimation. According to the economic feasibility study, RMB radioisotope production will provide a return of investment in 24 years of operation, while the facility will operate for 50 years.

6. RISK MANAGEMENT

Major RMB project risks have been identified as funding and human resources, both external and fully dependent on Governmental and political conditions.

7. OVERALL CONCLUSIONS AND LESSONS LEARNED

The RMB project fulfils most of the conditions related to the 19 infrastructure issues analysed. However, although the RMB project is under phase 3 (implementation), some conditions related to phases 1 (pre-project) or 2 (project formulation) are still not fully attended. This situation remarks that in actual RR project development the fulfilment of the infrastructure issues conditions does not happen under a strictly sequential order in relation to project phases and milestones, as suggested by IAEA in [3].

The established national nuclear infrastructure and legal framework, and RMB project objectives, organization and management, favour its implementation and provide conditions for a sustainable operational life cycle for this new research reactor in Brazil. Nevertheless, the absence of long term national policies brings several difficulties for managing such a project since decision makers may change and previous commitments may be compromised. External gaps like funding and human resources impose uncertainties and delays on project implementation.

A new RR project is not a simple one. The performance of a feasibility study needs to be considered as a mandatory stage to be followed. It is a long term project that involves many different infrastructure issues that have to be properly in place as highlighted by the IAEA Milestones publication [3]. Nevertheless, one needs to be conscious that to have a feasible project is just a first step towards a challenging project implementation process.

REFERENCES

[1] PROJECT MANAGEMENT INSTITUTE, Project Management Institute Body of Knowledge, PMI, www.pmi.org (June 2017).

[2] MINISTÉRIO DO PLANEJAMENTO, ORÇAMENTO E GESTÃO, Manual de Apresentação de Projetos de Estudos de Viabilidade de Projetos de Grande Vulto V. 2.0, Brazil (July 2009).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, “Specific Considerations and Milestones for a Research Reactor project”, NP-T-5.1, IAEA, Vienna, Austria (2012).

[4] PERROTTA, J.A., OBADIA, I.J., A sustainability analysis of the Brazilian Multipurpose Reactor Project, Proceedings of 14th International Topical Meeting on Research Reactor Fuel Management (RRFM-2010), Marrakesh, Morocco, 21-25 March 2010; European Nuclear Society, Brussels, Belgium (2010), ISBN 978-92-95064-10-2.

[5] PERROTTA, J.A., OBADIA, I.J., SOARES, A.J., The RMB Project - Development Status and Lessons Learned. Proceedings of the International Conference on Research Reactors: Safe Management and Effective Utilization, 16-20 November 2015, Vienna, Austria.

KENYA: THE JUSTIFICATION FOR A RESEARCH REACTOR

H.Mpakany and J.Mwangi

Kenya Nuclear Electricity Board (KNEB)

Block C Kawi House, Off Red Cross Road, Nairobi, Kenya

E-mail: hildampakany@gmail.com

1. INTRODUCTION

The government of Kenya has recognized the importance and role of research reactors in research and development (R&D), education and training, industry, and medicine. A research reactor project, just like a nuclear power project, is a major undertaking for any embarking country. For a successful RR project there is need for careful planning, preparation and investment in time, money, and human resources as well as a special attention to nuclear safety, safeguards, and security.

Kenya Nuclear Electricity Board (KNEB) launched a 15-year Strategic Plan for a Nuclear Power Programme in Kenya in 2014. One issue that the Strategic Plan recommends for Kenya is to start planning for a research reactor programme which would open doors to a wide range of R&D activities, radioisotopes production, training, industrial and medical applications (KENYA NUCLEAR ELECTRICITY BOARD, 2013). KNEB also conducted an IAEA Integrated Nuclear Infrastructure Review (INIR) Mission from 24th to 31st August 2015, whose key recommendations included training, research and development (INTERNATIONAL ATOMIC ENERGY AGENCY, Mission Report on the Integrated Nuclear Infrastructure Review for the Government of the Republic of Kenya, 24 – 31 August 2015).

Moreover, the Sector Plan for Science, Technology and Innovation (2018-2022) which focuses on revitalizing and harnessing science, technology and innovation for Kenya's prosperity and global competitiveness, has identified the establishment of a Centre for nuclear research for peaceful applications as one of its projects. This project foresees the establishment of a multi-disciplinary nuclear research centre to conduct advanced research and technology development for the peaceful applications of nuclear energy (GOVERNMENT OF KENYA, Sector Plan for Science and Technology and Innovation, Third Medium Term Plan (2018 – 2022), 2017).

According to IAEA Nuclear Energy Series No. NP-T-5.1, *Specific Considerations and Milestones for a Research Reactor Project,* the research reactor programme starts with a justification based on the national or regional needs for its products and services (INTERNATIONAL ATOMIC ENERGY AGENCY, NP-T-5.1 Specific Considerations and Milestones for a Research Reactor Project, 2010). KNEB is carrying out a preliminary study in order to determine Kenya's status and readiness to introduce a research reactor (RR). The overall objective of this study is to develop a justification for a research reactor in Kenya by assessing potential stakeholder needs with reference to the RR utilization.

2. POTENTIAL UTILIZATION

A Kenyan stakeholder needs assessment was conducted on relative importance of various research reactor utilizations for each of the identified potential stakeholders (INTERNATIONAL ATOMIC ENERGY AGENCY, The applications of research reactors, NP-T-5.3, 2014), as illustrated in the Table below. The first six utilizations were considered based on their relative importance and they include: education and training, radioisotope production, testing, neutron activation analysis, material structure studies, and transmutation effects.

	Universities / colleges	Research Centers	Health	Agriculture	Industry	Culture and heritage	Mining	Total
ET	5	4	4	3	5	3	3	**27**
RP	2	4	5	4	5	2	3	**25**
T	2	3	4	2	4	2	3	**22**
NAA	4	5	1	2	2	2	3	**19**
MSS	4	3	1	1	4	3	2	**18**
TE	2	4	1	2	5	1	2	**17**
PS	2	3	5	1	3	1	1	**16**
G	2	2	1	1	2	4	2	**14**
NCT	2	3	5	1	1	1	1	**14**
FMT	1	3	1	1	4	1	1	**12**
PGNAA	1	2	1	1	2	1	2	**10**

KEY

ET: Education and Training; **RP**: Radioisotope Production; **T**: Testing;
NAA: Neutron activation analysis; **MSS:** Material structure studies; **TE:** Transmutation effects;
PS: Positron source; **G:** Geochronology; **NCT:** Neutron Capture Therapy;
FMT: Fuel and Materials Testing; **PGNAA:** Prompt Gamma Neutron Activation Analysis

2.1 Education and Training

Every operating research reactor facility, irrespective of its power level, can be used for education and training (INTERNATIONAL ATOMIC ENERGY AGENCY, The applications of research reactors, NP-T-5.3, 2014). In the Kenyan case, this is a top priority area of application given the need for advancement of education and training. There are inadequate teaching and training facilities for science and engineering students in universities and colleges, especially with the proposed introduction of nuclear engineering course in Kenyan universities. The research reactor will be essential for educational purpose in Kenya as well as offer support to the nuclear power programme through training of future plant operators, inspectors and other relevant staff of the plant. The research reactor will also play a crucial role in public information, creating awareness on nuclear application, and winning public acceptance for the nuclear programme in Kenya.

2.2 Radioisotope Production

Radioisotope production in research reactors is based on neutron capture in a target material, either by activation or generation of radioisotopes from fission of the target material by bombardment with thermal neutrons (INTERNATIONAL ATOMIC ENERGY AGENCY, The applications of research reactors, NP-T-5.3, 2014). Currently, there is no production of radioisotopes in Kenya and within the East African region. Most radioisotopes used within the country are imported from South Africa (GOVERNMENT OF KENYA, Verified inventory of radiation sources in Kenya, Radiation Protection Board, 2009). There has been an ever-increasing need for radioisotopes for radiotherapy and medical diagnosis: radiotherapy and diagnosis are expensive in Kenya even for government funded hospitals. Moreover, it is impossible to import very short-lived radioisotopes for various uses in the country. Thus a research reactor that will be able to produce essential radioisotopes for medical and other applications both for the country and the region will be suitable.

2.3 Testing

Testing is one of the major applications of research reactors. Instrument testing and calibration, and experiments will be utilized in teaching and training, research institutions as well as at the industrial level. Presently in Kenya, Kenya Bureau of Standards (KEBS) has an established secondary standard dosimetry and Non Destructive Testing (NDT) laboratories which perform calibration and testing services for most industrial and medical facilities within the country (KENYA BUREAU OF STANDARDS, n.d.). Therefore, the research reactor is anticipated to offer support to this work and also non-destructive testing/examination by neutrons.

2.4 Neutron Activation Analysis

The NAA is a method for the qualitative and quantitative determination of elements based on the measurement of characteristic radiation from radionuclides formed directly, or indirectly, by neutron irradiation of the material. The research reactor will provide support to the universities and research institutes in carrying out their research and experiments.

2.5 Material Structure Studies

Research reactors introduce techniques to understand the interactions between material elementary components on an atomic scale. The neutrons have smaller wavelength than usual light, therefore it can be used to provide information about smaller structures that are not visible by optical microscopes. Also since neutrons lose their energy mostly by collisions with light isotopes, it is possible to obtain 2D or 3D image of the studied object or quantitative information about its structure. The research reactor with ability to perform material structure studies will be important for the research and industrial applications in Kenya.

2.6 Transmutation Effects

Transmutation is a specific application of neutron beams, which change isotopes as a result of nuclear reactions. The research reactor will provide an opportunity for industries to explore value-added techniques/utilization like neutron transmutation doping and gemstone colouring.

3. COST IMPLICATIONS

Research reactors require a financial commitment to be provided by the national government and/or industry in order to enhance their utilization taking into account their capabilities and objectives. The cost components of a research reactor include capital cost, nuclear fuel cost, operation and maintenance costs, waste management and decommissioning costs. Data on each of these cost components is not readily available with many research reactor operators providing general figures of the costs of their reactors (INTERNATIONAL ATOMIC ENERGY AGENCY, NP-T-5.1 Specific Considerations and Milestones for a Research Reactor Project, 2010). It is also important to note that the intended utilization of the reactors is a key determinant of their costs. Based on the potential utilization of the research reactor in Kenya, which has been identified as education and training, radioisotope production, testing, neutron activation analysis, material structure studies, and transmutation effects, additional costs will be incurred.

Some indicative costs based on data available from Jordan and Australia provide a cost range of between US$ 130 million and US$ 400 million for research reactors. The Australian Nuclear Science and Technology Organization (ANSTO) currently operates the Open Pool Australian Light water (OPAL) research reactor, 20MWth, which first went critical in 2006. The reactor is used to achieve nuclear medicine, research, scientific, industrial and production goals. The cost of building the reactor has been quoted at US$ 400 million (AUSTRALIAN NUCLEAR SCIENCE AND TECHNOLOGY ORGANISATION, n.d.). Jordan completed building the Jordan Research and Training Reactor (JRTR), 5MWth and upgradable to 10MWth, in 2016 at a cost of US$ 130 million. The reactor will be used for production of radioisotopes, neutron activation analysis and training of nuclear scientists and engineers (WORLD NUCLEAR NEWS, 2013).

4. LONG TERM GOVERNMENT COMMITMENTS

The government has established Kenya Nuclear Electricity Board which is a Nuclear Energy Implementing Organization. The board is under the Ministry of Energy and Petroleum, and funded by the Government. KNEB works closely with other relevant stakeholders that include power utilities, national industry, and academia. Further the government has developed a Draft Energy Bill 2016, which has established the Nuclear and Energy Research Agency to promote and implement a nuclear electricity generation programme." This Bill will transform KNEB into the Nuclear and Energy Research Agency, which will carry forward the mandate to manage the development of the nuclear power programme as well as coordinate research and development for the power sector in Kenya.

The government promulgated the Radiation Protection Act Cap.243, which establishes the Radiation Protection Board as the regulator for conventional sources in the country, under the Ministry of Health. Nuclear security and border surveillance are part of Board's mandate through the security laws (Amendment) Act, 2014. In the wake of the nuclear power programme, the government is in the process of drafting the Nuclear Regulatory Bill 2017. The proposed Bill seeks to transform the current radiation protection board to a national nuclear regulatory commission. The Bill is also meant to provide for a comprehensive regulatory framework, for radiation and nuclear safety, nuclear security and safeguards and to provide for: control of radiation sources, nuclear materials and associated waste; the protection of people, property and the environment from the harmful effects of exposure to radiation.

5. REGIONAL AND INTERNATIONAL COOPERATION

Kenya is a Member State of the International Atomic Energy Agency (IAEA) since 1965 and signatory to various International Legal Instruments with regard to Nuclear Energy, Non-Proliferation and Nuclear Security. The country is also in the process of ratifying several additional conventions related to the future nuclear power programme including: Convention on Nuclear Safety; Convention on Early Notification of a Nuclear Accident; Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency; and Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.

The country has an established Technical Cooperation Programme with the IAEA to build capacity for its nuclear power program, and has received additional support through the IAEA Peaceful Uses Initiative. This cooperation includes programmes on building capacity and developing human resources, as well as the development of the legal and regulatory frameworks.

To enhance collaboration in the development of Kenya's nuclear power program, the country has signed Memorandum of Understanding (MoUs) with the following countries: The People's Republic of China, the Republic of Korea, and the Russian Federation. The focus of MoUs is capacity building and technical support in upfront activities for Kenya's nuclear power program. Research reactor project implementation will be pursued within these or expanded MoUs.

Furthermore, Kenya is a member of the Forum of Nuclear Regulatory Bodies in Africa (FNRBA) which was established to support efforts to enhance and strengthen radiation protection, nuclear safety and security and the development of regulatory infrastructure in Africa. The FNRBA seeks to harmonize best practices and it endeavours to support capacity building and promotion of knowledge management.

6. CONCLUSION

The need for a national research reactor for Kenya in commensuration with stakeholders' needs will provide opportunities for utilization in various industrial, education, medical and research sectors within the country and across the region. Research reactor project is a delicate undertaking, with focus on return of investment. Therefore, it is necessary to undertake stakeholder needs assessment to come up with functional specification in order to determine the most reliable and cost-effective research reactor for the country. An opportunity for utilization of a research reactor in Kenya is tenable based on the simple model assessment in this report. With proper national frameworks, infrastructure, planning and collaboration with national and international stakeholders, deployment of a research reactor can be realized within a short time. The next step of this project is to conduct a pre-feasibility study and consequently develop a preliminary strategic plan for research reactor utilization in Kenya.

REFERENCES

[1] KENYA NUCLEAR ELECTRICITY BOARD, "15 Years Strategic Plan for a Nuclear Power Programme in Kenya," PMD/KNEB-RoK/STPL/2013/SP2.0, Nairobi, Kenya, 2013.

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, "Mission Report on the Integrated Nuclear Infrastructure Review for the Government of the Republic of Kenya," IAEA, Nairobi, Kenya, 24 – 31 August 2015.

[3] GOVERNMENT OF KENYA, "Sector Plan for Science and Technology and Innovation, Third Medium Term Plan (2018 – 2022)," Unpublished data, Nairobi, Kenya, 2017.

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, "Specific Considerations and Milestones for a Research Reactor Project," IAEA Nuclear Energy Series NP-T-5.1, IAEA, Vienna (2012).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, "The applications of research reactors", IAEA Nuclear Energy Series NP-T-5.3, IAEA, Vienna (2014).

[6] GOVERNMENT OF KENYA, "Verified inventory of radiation sources in Kenya, Radiation Protection Board," GoK, Nairobi, Kenya, 2009.

[7] KENYA BUREAU OF STANDARDS, "Kenya Bureau of Standards Website," [Online]. Available: https://www.kebs.org/index.php?opt=metrology&view=services. [Accessed 12 June 2017].

[8] AUSTRALIAN NUCLEAR SCIENCE AND TECHNOLOGY ORGANISATION, "Australian Nuclear Science and Technology Organisation website," [Online]. Available: http://www.ansto.gov.au/NuclearFacts/AboutNuclearScience/ReactorsandAccelerators/ResearchReactors/. [Accessed 2 June 2017].

[9] WORLD NUCLEAR NEWS, "World Nuclear News: Go-ahead for Jordanian research reactor," 20 August 2013. [Online]. Available: http://www.world-nuclear-news.org/NN_Go_ahead_for_Jordanian_research_reactor_2008131.html. [Accessed 12 June 2017].

REPUBLIC OF KOREA: FEASIBILITY STUDY FOR KI-JANG RESEARCH REACTOR (KJRR)

I.C. Lim and S.I. Wu

Korea Atomic Energy Research Institute (KAERI)
Daedeok-daero, Yuseong-gu, Daejeon, Republic of Korea

Email: iclim@kaeri.re.kr

1. INTRODUCTION

KAERI has been operating HANARO, a 30 MW multipurpose research reactor, since its first criticality in 1995. It has been utilized for various scientific and engineering applications such as material irradiation, nuclear fuel testing, neutron science using cold and thermal neutrons, neutron radiography, radio-isotope (RI) production and neutron transmutation doping (NTD) of silicon. The technology accumulated from the design, construction, commissioning, and operation of HANARO made it into one of well utilized multi-purpose research reactors in the world. In addition, the strong and continuous support from the Korean government has contributed to establishing HANARO as a competitive basic science and nuclear R&D facility.

Meanwhile, Korea has been trying to build a new research reactor since 2009 to meet the following three main needs. The first one is that user demands are increasing to a level beyond the capacity of HANARO. The second one is the necessity of meeting the growing demand for radio-isotopes including medical isotopes such as Mo-99 and for neutron silicon doping service. Finally, the third one is to enlarge the national capability in research reactor engineering technology.

The feasibility of the new research reactor project, called the KJRR (Ki-Jang Research Reactor) project was confirmed by the study of the Korea Development Institute (KDI) in 2011, and the project commenced on the 1st of April 2012. This report gives a short summary of the feasibility study for KJRR including the justification process, utilization plan, information on stakeholder involvement during the pre-project assessment, and the scope of feasibility study.

2. PRE-PROJECT ASSESSMENT

The major medical isotope produced at HANARO is I-131. Currently, most medical isotopes, including Mo-99, are imported from foreign producers. The shortage of medical RI supply that occurred after 2007 due to unstable operation of major RI production reactors resulted in a discussion about a permanent resolution of the medical isotope supply problem. HANARO shared a significant portion of silicon doping service and the power device market was expected to expand due to the increase of green cars such as hybrid and fuel-cell cars. In addition, KAERI has a good level of competitiveness in NTD services offering high-quality products. Though Korea has developed a lot of technologies for the design of research reactor and utilization facilities, it was suggested that KAERI should experience the development of bottom-mounted control rod drive mechanism as well as the use of plate type U-Mo fuel fabricated by using indigenous atomization technology. These contexts formed a nation-wide consensus for a new research reactor project [1].

In response to the proposal by KAERI to construct a new research reactor in 2009, MEST, the Ministry of Education, Science and Technology, which was the responsible ministry at that time, asked KRIA (Korea RI Association) to conduct a pre-assessment for the project. In Aug. 2009, KRIA formed a project team composed of experts from KAERI, KINS which is the TSO (Technical Support Organization) for nuclear safety regulation in Korea, and professors in nuclear engineering departments or medical schools at universities. The pre-assessment report by KRIA provided the following information:

- Review and prospect of research reactor, RI market, NTD service market;

- Review and prospect of technologies for RI production and NTD service;

- Expected benefits of new research reactor;

- List of technologies to be developed for new research reactor project and its utilization;

- Technical requirements for site selection;

- Preliminary reactor specifications.

KAERI also prepared a separate pre-assessment report that had more details on the reactor system development plan, the project cost estimation, and the technologies required for the reactor facility development and Mo-99 production process development.

3. SITE SELECTION

Prior to the feasibility study, a preferred site was chosen because site characteristics should be fed into the feasibility study. Local governments were informed of a plan to build a new research reactor and nine local governments showed their interest. Using the established criteria, their proposals to host the new research reactor were evaluated by the site selection committee. In parallel, a preliminary site evaluation to review the geologic, seismic and hydrologic conditions of the proposed sites was conducted. In July 2010, through evaluations by the site selection committee of the 9 candidate areas, Ki-Jang County was selected. Ki-Jang County has several existing nuclear power plants in operation and thus, it was expected that there would be no difficulty in terms of site characteristics or in public acceptance. In addition, the site is very close to Busan which is the second largest city in Korea and has an international airport and a harbour that will provide good accessibility for people as well as easy transportation of products [2].

4. FEASIBILITY STUDY

The procedures of the feasibility study [3] for a large scale national project such as the KJRR project are as follows:

- An organization submits a project proposal to the relevant ministry. The project proposal includes a pre-project assessment and preliminary strategic plan. For the case of the KJRR project, the relevant ministry was MEST (Ministry of Education, Science and Technology);

- The relevant ministry reviews submitted proposals and the selected proposals are submitted to MOSF (Ministry of Strategy and Finance), which is in charge of the budgeting and finance of the Korean government;
- MOSF reviews the proposals submitted by all the ministries of the government and selects the proposals for which feasibility studies will be conducted;
- There are two independent governmental institutes in charge of feasibility study. In general, the KDI (Korea Development Institute) conducts a feasibility study for national infrastructure construction projects and KISTEP (Korea Institute of Science and Technology Evaluation and Planning) does the same for R&D projects.

For a national construction project, the feasibility study aims to enhance fiscal productivity by launching large-scale public investment projects selected through transparent and objective project evaluations. The National Finance Act of 2006 provides the legal framework of feasibility study. The feasibility study rule was introduced in April 1999 as a public sector reform initiative in the wake of the Korean financial crisis of 1997 and 1998. All new large-scale projects with total costs amounting to 50 billion Won (about 42M US$) or more are subject to feasibility study. As shown in FIG1, a feasibility study conducted by KDI consists of background study, economic analysis, policy analysis, balanced regional development analysis, and Analytical Hierarchy Process (AHP) [4]. Most of the feasibility study results are directly reflected in budget formulation.

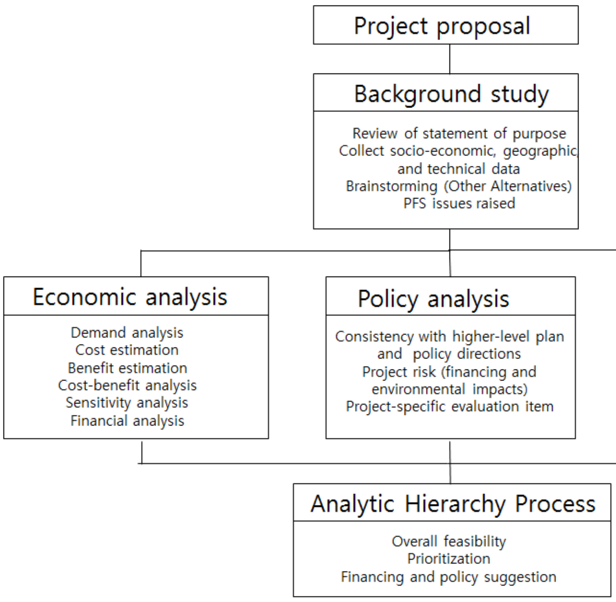

FIG..1 Scope of Feasibility Study by KDI in Korea [4].

The main purposes of KJRR were as follows [1]:

- To fulfil the self-sufficiency of RI demand for Mo-99 and to provide the capacity for export;
- To increase the neutron transmutation doping(NTD) capacity considering the increase of the use of power devices for green cars and renewable energy utilization that employ NTD silicon;

- To validate national research reactor technologies such as the U-Mo plate type fuel, bottom-mounted control rod drive mechanism (CRDM) which will enlarge the research reactor system engineering capability of Korea.

The feasibility study of KJRR placed its emphases on the analysis of technical issues, costs and benefits arising in the course of project and in operation and utilization afterwards. The technical issues were whether the technical provisions would be sufficient to implement the project. Analyses were performed for the costs of site preparation, construction, commissioning, operation, ageing management, waste treatment, spent fuel management and decommissioning. As for the benefit analysis, what was considered were the incomes from the RI supply and the NTD of silicon services, and the economic effects from new technology development, in particular new U-Mo plate fuel. For the economic analysis, the life time of the facility was considered to be 50 years. As Ki-Jang County would host the facility, support from the local government and the effect of project on the local economy were analysed as well. An AHP analysis was conducted to obtain the opinion of experts on the cost/benefit analysis, strategic review and the effect of project on the local economy. The overall evaluation results were positive and KDI recommended the investment of national resource for the KJRR project. MOSF submitted the results to the National Assembly of Korea and the final decision to conduct the project was made in December 2011.

As Korea has experience in the design, construction, operation, and utilization of research reactors, the infrastructure suggested by the IAEA guide [5] was established when the feasibility study for the KJRR project was conducted. However, for the efficient conduction of research reactor project, it was found that the nuclear safety act had to be amended to include a two-step approach that could separate the construction permit from the operating license issue. The KJRR project team asked the National Assembly to create the amendment and the amendment was concluded in April 2014, which was appropriate for the submission of PSAR to acquire the construction permit for KJRR.

5. REACTOR CHARACTERISTICS AND UTILIZATION PLAN

The KJRR project includes the installation of a reactor, a RI production/research facility, an LEU target production facility for Mo-99 production, an NTD facility and a radioactive waste treatment facility. The major design characteristics of the reactor rectified through the conceptual stage are summarized in Table1 [2].

The new research reactor is the first reactor in the world that will use U-Mo fuel at full scale. Also, the adoption of bottom-mounted CRDM makes it easy to load and unload RI targets into and from irradiation holes. In view of safety, the reactor will be equipped with a secondary shutdown system, an automatic seismic trip system, a post-accident monitoring system, an emergency control room and an emergency diesel generator of appropriate size.

The major isotopes to be produced in the new research reactor will be Mo-99, I-131, I-125, and Ir-192. Their production capacities will be 100,000, 3,000, 100 and 300,000 Ci per year, respectively. The technologies to produce I-131, I-125, and Ir-192 have been already developed. However, the technology to produce Mo-99 is being developed in parallel with the reactor facility development. Considering these factors, the target for Mo-99 production in the first operation year is set to fulfil national demand and its capability will be expanded year by year. The production capability for the other major isotopes is expected to reach its capacity from the beginning [1].

TABLE 1: DESIGN FEATURES AND REQUIREMENTS OF THE NEW RESEARCH REACTOR

Item	Value	Production	Irradiation holes		Neutron flux
			No.	Dia. (cm)	($cm^{-2}s^{-1}$)
Reactor Power	~15 (MWth)	Fission Mo and other fission products	4	5~8	~2x10^{14}
Reactor Type	Pool type	Ir-192, P-33, Lu-177, Co-60 (Medical purpose)	4	4~6	~3x10^{14}
Neutron Flux (Max)	> 3.0x10^{14} $cm^{-2}s^{-1}$	I-131, I-125, Cr-51, Re-186, Sm-153	3	4~6	>1x10^{14}
Operation day	~300/year	HTS and PTS for Short half-life RI	1 1	3	~1x10^{14}
Life Time	50 year	Others for research purpose	4~5	3	~5x10^{13}
Fuel	LEU U-Mo plate type (~8.0 g/cc)	6" Silicon ingot	2	~17	~1x10^{13}
Reflector	Beryllium	8" Silicon ingot	3	~22	~1x10^{13}
Coolant & Flow Direction	H_2O & Downward Forced Convection	12" Silicon ingot (replacing 6 or 8" holes)	2	~32	~1x10^{13}
Reactor Building	Confinement				

As for silicon doping, the installation of 6" and 8" ingot irradiation rigs will be made after the completion of the reactor commissioning test, which will provide the reactor characteristics required for the finalization of the irradiation rig design. However, 12" ingot rigs will be installed in conjunction with the development of a large diameter ingot irradiation technique and will depend on the availability of 12" ingots. When all the planned installations are finished, the doping capacity will reach 150 tons per year. The surplus in RI production can be exported to regional countries, which will help to maintain the world Mo-99 production capacity. The increase of capacity in RI production and NTD service will also contribute to the development of the RI and power device industry in Korea.

REFERENCES

[1] LIM, I.C. et al., “Plan of New Research Reactor Construction in Korea”, Proceedings of the International Conference on Research Reactors: Safe Management and Effective Utilization, , Rabat, Morocco. 14-18 November 2011.

[2] WU, S. et al., “Launching of a New Research Reactor Project in Korea”, Proceedings of the IGORR/RRFM Conference, , Prague, Czech Republic, 18-22 March 2012.

[3] LIM, I.C. et al., “Feasibility Study for a New Research Reactor Project”, Proceedings of the International Conference on Research Reactors: Safe Management and Effective Utilization, Vienna, Austria,16-20 November 2015,.

[4] PARK, H., “Preliminary Feasibility Study: Performance and Challenges”, Proceedings of the International Seminar on Improving Public Investment Management for Large-Scale Government Projects, Seoul, Republic of Korea,22-23 May 2007,.

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, “Specific Considerations and Milestones for a Research Reactor project”, IAEA Nuclear Energy Series NP-T-5.1, IAEA, Vienna, Austria (2012).

MOROCCO: REVIEW OF THE FEASIBILITY STUDY UNDERTAKEN FOR THE MOROCCAN TRIGA MARK II RESEARCH REACTOR

A. Boufraqech, B. El Bakkari, A. Jraut, B. Nacir

Centre national de l'Energie des Sciences et des Techniques Nucléaire, Rabat, Morocco

Email : cnem@cnesten.org.ma

1. INTRODUCTION

The Government of Morocco recognized the role and the importance of nuclear technologies in early 1960s. This resulted in the development of various nuclear techniques in several important socio-economic sectors, such as education, medicine, agriculture and industry. The development of these techniques evolved over various organizations, primarily within the Ministries of Research and Education, Health and Agriculture. This development was reinforced in 1986 by the creation of the ***Centre National de l'Enérgie des Sciences et des Techniques Nucléaires*** « CNESTEN », a publicly owned entity with legal and financial autonomy under the supervision of the Ministry of Energy, Mines, and Sustainable Development, with the following main missions:

- Promote nuclear science and technology applications such as nuclear medicine, life sciences, natural resources, environment, non-destructive testing, etc.;
- Contribute to the preparation of the necessary conditions (political, regulatory, technical, human resources, etc.) for the introduction of nuclear power to the country;
- Act as a Technical Support Organization (TSO) to the national regulatory body in the technical areas of nuclear safety and security;
- Manage radioactive wastes at the national level.

In 2008, CNESTEN made a big step forward in the development of its nuclear infrastructure by the commissioning of its first research reactor MA-1 at its center called ***Centre d'Etudes Nucléaires de la Maamora*** (CENM). This 2 MW TRIGA MARK II research reactor has been established under the Project and Supply Agreement INFCIRC/313, January 1984, between the Kingdom of Morocco, the United States of America and the International Atomic Energy Agency (IAEA). The reactor is designed to effectively support various fields of basic nuclear research, production of radioisotopes for their use in agriculture, industry as well as serve as a tool for education and training.

This paper provides an overview of the processes adopted for the research reactor feasibility study for the Moroccan TRIGA Mark II research reactor. The methodology has been aligned taking into account the IAEA guidance [1, 2] as well as the feedback from similar facilities.

2. RESEARCH REACTOR JUSTIFICATION AND STAKEHOLDERS NEEDS

The justification of the research reactor building project started with the evaluation of the potential stakeholders and their needs. Stakeholder involvement was helpful to shape both the specification and the eventual utilization program of the research reactor. This involvement started with the identification of stakeholder groups, their interests, concerns and motivations and by establishing an appropriate dialogue with them. These stakeholders as well as their needs were identified to be [3]:

2.1. Government

- ***Regulatory body:***

  - Ensure the operation, maintenance and utilization of the reactor and associated facilities in total compliance with the safety and security regulatory requirements. Enhance the safety and security culture.
  - Act as TSO to the national regulatory body.

- ***Department of Higher Education and Research:***

  - Partnerships with universities and scientific institutions through research, educational and training programs in nuclear science and technology.
  - Development of the national capacity in nuclear science and technology in the new centre that is able to integrate the national programs in the field of the peaceful use of nuclear techniques.

- ***Department of Health:***

  - Research, development, production and supply of radiopharmaceuticals, mainly I-131 and Mo-99/Tc-99m, which are the most used radioisotopes at the national level, with a market growth of about 10 % per year;
  - Expansion of the scope of the isotope products with the capacity to cover new production of other radioisotopes such as Sm-153, Re-186, Ga-68, Lu-177, and Br-82, etc.

- ***Department of Industry:***

  - Production and supply of radiotracers.
  - Analytical services for quality control, radiotracer application to improve the performance of the industries;
  - Neutron diffraction for the polymer, car and electronics industries to study the evolution of the structures and behaviors of materials under realistic conditions.

- ***Department of Agriculture:***

  - Soil analysis for fertilization and improvements of their productivity, bioremediation;
  - Soil-plant relationships using radioactive tracers.

- ***Department of Energy, Mines:***

  - Geological mapping, mineral ores analysis, petroleum exploration.
  - Training of future NPP operators.

- ***Department of the Environment***

  - Environmental monitoring and pollution studies in food, water, air, soil, etc.

- ***Department of Culture:***
    - Investigation of archaeological artifacts from museums.
- ***Others:***
    - Training in safety, security, forensic samples analysis.

2.2. Upper Management

The need of upper management is ultimately the sustainable operation of the research reactor, justification of its national relevance, and its visibility on a national and regional scale.

2.3. Commercial Clients

Services and products to:

- Hospitals and private units of nuclear medicine: Radiopharmaceuticals and radioisotopes (I-131, Mo-99/Tc-99m).
- Aircraft industries: Non-destructive techniques such as neutron radiography.
- Phosphate industry: Identification of rare earth elements and iodine isotopes in phosphate samples using the neutron activation analysis (NAA) techniques.
- Car industries: Non-destructive techniques such as neutron radiography.
- Mining companies (Ministry of Mines): Environmental monitoring and geological mapping using the NAA techniques.

2.4. Public

Being informed and inform general public on the safe use of nuclear energy and applications.

2.5. International cooperation

International cooperation allows to the MA-1 research reactor to join international and regional collaborations aiming to improve its capabilities thorough participation in projects with laboratories of common interests in education and training, irradiation services as well as analytical techniques, etc. The IAEA and AFRA can be considered as the main actors for the MA-1 research reactor in the field of international cooperation.

3. SAFETY ASSESSMENT

The safety assessment of the TRIGA Mark II research reactor had been carried out since the early siting studied at CENM. It covered mainly the following safety aspects: the geology and seismology, meteorology and atmospheric dispersion of radioactive material, hydrology, natural environment, population distribution and baseline radiological levels. This safety assessment, which had been described in the Preliminary Safety Analysis Report (PSAR), allowed CNESTEN to verify the adequacy of the site characteristics from the safety point of view and to establish related safety criteria that were used for the design of the TRIGA Mark II research reactor.

Aware of the importance of organizing peer review missions, CNESTEN hosted many expert missions to review the above-mentioned safety assessment. In this regard, the IAEA conducted a number of safety review missions that covered, among other aspects, the siting and seismic design of the TRIGA Mark II research reactor.

4. COST IMPLICATIONS

The cost implication of the research reactor building project has been evaluated as USD 27M (twenty-seven million dollars) at the time of project final decision making (around the year of 2000). This cost included main capital costs such as the fresh nuclear fuel inventory (in-core and in-storage), the reactor building and its associated equipment and materials, as well as the characterization costs associated with the candidate site selection.

5. RESEARCH REACTOR CHARACTERISTICS AND CAPABILITIES

5.1. Facility description

The reactor is a standard design, licensed for operation at 2 MW thermal power. The reactor is cooled by natural convection, with a graphite reflector containing beam tubes and a thermal column. The core is located near the bottom of a water-filled aluminum tank of 2.5 m in diameter and about 8.8 m deep. The reactor tank is surrounded by a massive monolithic block of reinforced heavy concrete (i.e. including barite) with a density of 3.2g/cc. The massive concrete structure provides radiological protection for personnel working around the reactor [4].

The TRIGA core is made up of 94 fuel–moderator elements, 2 temperature-instrumented fuel–moderator elements, 5 fuel follower control rods, and other graphite elements. The reactor fuel is a solid, homogeneous mixture of uranium–zirconium hydride alloy with 8.5% by weight of uranium enriched up to 20% ^{235}U. Each reactor fuel element is encapsulated with a 0.51-mm-thick stainless steel clad.

5.2. Existing capabilities

The MA-1 research reactor is designed to have various capabilities both for fundamental as well as applied research, including industrial products and services. These can be categorized as existing and potential capabilities and relate both to those directly available (in-house) and support capabilities with regard to the national needs.

5.2.1. In-core Irradiation Facilities

- **Central Thimble**

The reactor is equipped with a central thimble for access to the maximum flux of the core. The central thimble consists of an aluminum tube of 3.7 cm outer diameter and 3.38 cm inner diameter that fits through the centre hole of the top and bottom grid plates. Experiments with the central thimble include irradiations of small samples and the exposure of materials to a collimated beam of neutrons or gamma rays.

- **Rotary Specimen Rack**

A rotary, 40-position specimen rack located in a well in the top of the graphite reflector, provides for large-scale production of radioisotopes and for activation and irradiation of multiple samples. All positions in this rack are exposed to neutron fluxes of comparable intensity.

- **Pneumatic Specimen Tube**

A pneumatic transfer system permits applications with short half-life radioisotopes. The in-core terminus of this system is normally located in the outer ring of fuel element positions, a region of high neutron flux. The sample capsule (rabbit) is conveyed to a receiver–sender station via 3.18 cm outer diameter aluminum tubing. Effective space in the specimen transfer capsules is 1.7 cm diameter by 11.4 cm height. A typical transfer time is 9 s for a 12 g sample.

The transfer time between the sender–receiver station and the reactor core is about 6 s. After reception, the user can immediately put the sample on the detector for counting. With these features cyclic neutron activation analysis is possible.

5.2.2. Beam Port Facilities

There are 4 neutron beam tubes consisting of 3 radial beam ports and one tangential beam port (see Fig.1). The inner section of each beam port is an aluminum pipe 15.2 cm in diameter, considered as available space.

5.2.3 Thermal Column

The thermal column is a large graphite assembly, located in the side of the reactor shield structure, which facilitates irradiation of large experimental specimens. It will be used for specific applications such as geochronology, large sample NAA and some others.

TABLE 1. NEUTRON FLUXES AT DIFFERENT IRRADIATION POSITIONS.

Location	Neutron flux($cm^{-2}.s^{-1}$)		
	Thermal <0.4 eV	Epithermal 0.4 eV–9.12 keV	Fast >9.12 keV
Central thimble	$7.1x10^{13}$	$2.4x10^{13}$	$3.9x10^{13}$
Pneumatic specimen tube	$1.3x10^{13}$	$1.0x10^{13}$	$1.2x10^{13}$
Radial port (core edge)	$7.8x10^{12}$	$1.5x10^{12}$	$1.5x10^{12}$
Tangential port (core end)	$1.8x10^{12}$	$6.0x10^{11}$	$4.5x10^{11}$
Radial port at reflector edge	$2.7x10^{12}$	$0.4x10^{12}$	$1.5x10^{11}$
Rotary specimen rack	$5.3x10^{12}$		$3.7x10^{12}$
Thermal column: (distance from outside core)			
305 mm	$1.7x10^{11}$	$2.8x10^{9}$	$1.6x10^{9}$
609 mm	$1.7x10^{10}$	$1.07x10^{10}$	$1.1x10^{6}$
914 mm	$1.7x10^{9}$	$4.3x10^{9}$	$8.2x10^{2}$

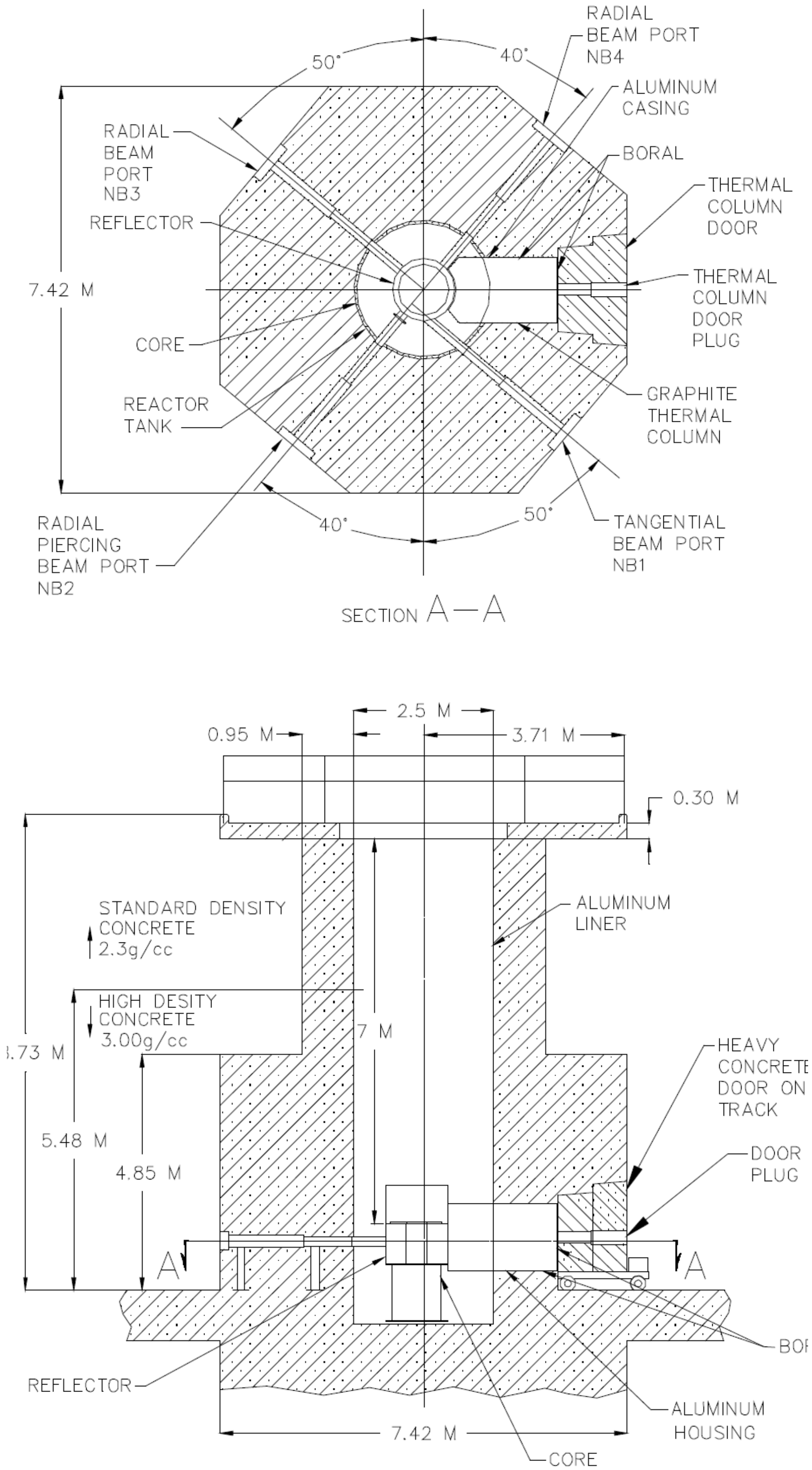

Figure 1: The Moroccan 2MW TRIGA MARK II research reactor layout.

5.3. Potential Capabilities

The following capabilities are regarded as activities and services that will be installed in the near future at the MA-1 research reactor. These facilities need specific equipment (see Table 2), infrastructure development including qualified staff, and therefore are time-demanding and require substantial resources.

TABLE 2. FACILITIES UNDER DEVELOPMENT OR PLANNED.

Capabilities	Current status	Estimated date of operation
Prompt gamma activation analysis	The safety file for the installation of the neutron collimator and filters inside the tangential beam tube is under verification by the Reactor Safety Committee	End of 2018
Neutron radiography	The safety file for the installation of the neutron collimator and filters inside the tangential beam tube is under verification by the Reactor Safety Committee	End of 2018
Neutron diffraction	The safety file for the installation of neutron collimator and filters inside the a radial beam tube is under development	End of 2020
Production of Mo-99	The feasibility study for the project is ongoing	Date is not available

6. MAJOR CHALLENGES

The major risks for the research reactor project have been identified as:

- Human resources: the existence of qualified personnel is always a big issue in developing countries like Morocco; CNESTEN makes the qualification of its personnel a priority in the framework of its international and bilateral cooperation;
- Competition: the presence of several competitors at the national level, especially the ones that deal with the importation of radioisotopes.

7. COMMUNICATION

To gain public acceptance for the research reactor project, CNESTEN created an effective communication programme aimed at the general public, academia, local communities, media, and decision makers. The programme is aimed to:

- Increase the public awareness and confidence in nuclear technology;
- Promulgate the safety and security of the research reactor (e.g. making nuclear safety and emergency preparedness plan public);
- Openly promote and ensure competitiveness of the nuclear techniques in the socioeconomic sector (radioisotope production, neutron activation analysis, neutron radiography, education and training);

- Openly discuss the environmental impact of the project (waste management and release of radioactivity).

This communication programme has been implemented through:

- Exhibitions: participation in exhibitions, seminars and workshops;
- Facility tours: organization of in-site visits for targeted groups;
- Mass media: dissemination of information via news agencies and press;
- On-line promotion: websites, online articles, interviews;
- Education: organization of education and training courses;
- Support programme for universities.

Due to the importance of the public acceptance, CNESTEN's communication programme remains ongoing.

8. CONCLUSION

The research reactor establishment project was a complicated issue taking into account the investment costs, complexity of the implementation of the first nuclear installation in the country and need for the development of an adequate nuclear infrastructure. The presence of a national research reactor in Morocco commensurate with stakeholders' needs will provide opportunities for utilization in various industrial, education, medical and research sectors within the country and across the region.

From the Moroccan experience, the performance of a feasibility study needs to be considered as a mandatory stage to be followed by newcomer countries to nuclear technologies such as research reactors. It is a long term project that involves many different infrastructure issues that have to be properly in place as highlighted by the IAEA Milestones publication related to research reactors and other supporting guidance and technical documents.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, "Specific Considerations and Milestones for a Research Reactor project", IAEA Nuclear Energy Series NP-T-5.1, IAEA, Vienna, Austria (2012).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, "Strategic Planning for Research Reactors", IAEA Nuclear Energy Series NP-T-3.16, IAEA, Vienna, Austria (2017).

[3] CNESTEN, The Moroccan Maamora Research Reactor "Strategic utilization plan" for 2010-2014, Morocco (2010).

[4] CNESTEN, The Moroccan Maamora Research Reactor "Final Safety Analysis Report", Morocco, (2008).

NIGERIA: FEASIBILITY STUDY OF A MULTIPURPOSE RESEARCH REACTOR

F. I. Ibitoye

Nigeria Atomic Energy Commission, Abuja, Nigeria

Email: *Francis.Ibitoye@nigatom.org.ng*

1. INTRODUCTION

Nigeria has more than 12 years of operating experience on the 30 kW miniature neutron source reactor (MNSR) located at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria. The reactor, which first achieved criticality in 2004, is currently undergoing procedures for core conversion, from HEU to LEU fuel.

The MNSR has, to a large extent, been used for neutron activation analysis as well as for education and training. An analysis of the stakeholders needs reveals that radioisotope production, especially medical radioisotopes, is one major application area that cannot be met using the existing reactor due to its very low power. In addition, the reactor is neither suitable for neutron beam experiments, nor other advanced applications. The strategy to overcome these shortcomings of the MNSR is the acquisition of a new research reactor for multipurpose applications. The new reactor should be capable of producing enough radioisotopes to meet local and regional demand for applications in medicine, industry and agriculture. It should complement other efforts in the training of personnel for the nation’s nuclear power programme, especially training of power plant operators and regulatory staff, and also open up opportunities for Nigerian scientists to carry out research in other areas of peaceful applications of nuclear technology [1-3].

Specifically, it is envisaged that a Multi-Purpose Research Reactor (MPRR) will be of immense benefits to Nigeria and the West-African sub-region in general. This assertion is based on the following national and regional needs:

- Nigeria, with its vast oil and gas resource is a large consumer of industrial radiotracers, which are extensively deployed for pipeline integrity checks amongst other oil exploration activities, also in agriculture and hydrological surveys;
- There is an increasing demand for medical radioisotopes as a result of the introduction of nuclear medicine techniques in some hospitals in the country, and as a result of growing incidence of cancer in the country. According to World Health Organisation, Nigeria has the highest mortality of cancer in Africa, with about 100,000 new cases of cancer reported each year [4]. The needed radioisotopes for cancer diagnosis and therapy are currently imported into the country under licences, which places a heavy financial burden on both hospital and patients;
- For a newcomer country like Nigeria, it is expected that the experience gained in the safe operation of a multipurpose research reactor would be of some advantage in the implementation of the nuclear energy programme;
- The multipurpose research reactor will provide the large population of scientists and engineers in academic and research institutions in the country, a platform for research in peaceful applications of nuclear technology for socio-economic development [5,6];
- Local production of the much required radioisotopes for applications in health, agriculture and industrial sectors of the economy will result in significant savings in

foreign currency, and at the same time also generate earnings in foreign currency from export of radioisotopes.

In summary, the new research reactor is expected to provide services in the following main areas:

- Irradiation applications, such as for production of radioisotopes, analytical techniques such as NAA, and neutron transmutation doping;
- Beam-port applications, including radiography, materials structure studies, prompt gamma neutron activation analysis, etc.;
- Training and manpower development in support of the national nuclear power programme.

The multipurpose research reactor project is part of a broader national nuclear energy programme [7-9], and it is aimed at making impact on the socio-economic development of the nation through the multifarious applications of nuclear technology. It also serves as a platform for training of the much-needed manpower for the national energy programme [10]. As a further demonstration of its support for the research reactor project, the government of the Federal Republic of Nigeria in May 2016 signed an intergovernmental agreement with the Russian Federation on cooperation for the "Design, Construction, Operation, and Decommissioning of a Multipurpose Research Reactor Complex on the territory of the Federal Republic of Nigeria".

The research reactor is to be surrounded by an array of ancillary laboratories, plants, facilities and workshops which either directly support the maintenance and utilisation of the reactor itself, or process the output of the reactor for further treatments, analyses, and applications. Essentially the reactor complex is planned to consist of, amongst others, the following:

- The multipurpose research reactor;
- Radioisotope production laboratory;
- Post-irradiation examination laboratory for destructive and non-destructive examinations;
- General purpose laboratory for sample preparation, clean rooms, analytical equipment for physical, structural and chemical examinations;
- Neutron guide hall, for neutron scattering and neutron radiography;
- Waste management facility;
- Computer centre;
- Central mechanical workshop, including liquid nitrogen plant;
- Classrooms, seminar rooms and library;
- Central electrical/electronic Workshop;
- Power supply station.

When completed, the MPRR will be one of the main facilities in this region of the African continent capable of large-scale radioisotopes production. The MPRR is expected to have a huge market share in the supply of radioisotopes in the West-African sub-region, especially medical radioisotopes. It is therefore envisaged that funds arising from sale of radioisotope and other services will form a reasonable percentage of the running costs of the reactor. Funds would also be generated through international collaborations and research.

2. RESEARCH REACTOR STAKEHOLDERS AND THEIR NEEDS

The list of stakeholders for the research reactor programme includes relevant government ministries, agencies and parastatals, the non-governmental organisations, media, and direct users or beneficiaries. The latter group of stakeholders include national and regional entities such as the hospitals, manufacturing industries, oil and gas industry, educational institutions, etc. Major needs of the stakeholders are discussed below.

2.1 Radioisotope Production for Applications in Medicine and Industry

There is an on-going nuclear medicine programme aimed at establishing ten nuclear centres in ten different hospitals at various locations in Nigeria. The programme which is supported by the International Atomic Energy Agency (IAEA) is divided into two phases. In the first phase five hospitals will be equipped with nuclear medicine facilities and necessary personnel appropriately trained. Same facilities will be similarly set up in five other hospitals in the second phase of the programme. At present, two of the centres in the first phase of the programme are now fully functional – the Nuclear Medicine Clinic at the University College Hospital (UCH), Ibadan, and the other one at the National Hospital, Abuja. The demand for radioisotopes for use in medicine, agriculture, and industry is being met through importations. In 2013, for example, the centre at UCH imported twenty-four ^{99}Mo-^{99m}Tc generators and fifty-five ^{131}I therapy capsules from France. The National Hospital, Abuja, on the other hand, has a weekly supply of radioisotopes from South Africa.

In similar vein, in 2014, licences were granted by the Nigerian Nuclear Regulatory Authority (NNRA) for the importation of 117 radioisotopes for industrial radiography, 61 for well-logging, and 53 for nuclear gauging. Each of these licenses, according to the NNRA, was usually for importation of several radioisotopes at each instance. It is expected therefore that the MPRR will fulfil the demand for radioisotopes in all sectors of the national economy. Furthermore, the MPRR will play an immense role in the supply of radioisotopes in this region and beyond.

2.2 Education, Training and Manpower Development

In 2015, Nigeria had 125 universities and 81 polytechnic institutes, with all of them offering courses in science and engineering disciplines. In addition, the Nigeria Atomic Energy Commission superintends over seven nuclear research centres in the country, five of which are based in universities, the latter have specific mandate for manpower development in nuclear and related fields. The research centres are in addition engaged in research and teaching within the scope of their respective universities, producing graduates in nuclear science and engineering. While it is recognised that because of its diverse applications the MPRR may not offer enough window as a training reactor, it is expected that the reactor will nonetheless complement current efforts of the MNSR as a training tool. In addition, the MPRR will play a formidable role in providing a platform for the enhancement of R&D capabilities of Nigerian scientists and engineers in all areas of peaceful applications of nuclear technology. The reactor will not only provide for organized training courses within the academic field but also offer commercial training services to other groups such as industries, hospitals, the regulatory authority and other government institutions. The reactor will play a major role in manpower development for Nigeria's nuclear power programme.

2.3 Neutron Activation Analysis

The proposed reactor will offer services in large-scale neutron activation analysis (NAA) for the identification and quantification of trace elements in bulk materials, owing to its high sensitivity for a wide range of elements especially the rare earth elements. Specific area of application will be the analysis of environmental and agricultural samples. Prompt Gamma Neutron Activation Analysis will also be carried out as appropriate using the MPRR for trace elements in archaeological artefacts, forensic investigations and other non-destructive tests in solids, liquids, suspension and slurry. Major users of this technique will be researchers in academic institutions, national security services for forensic examinations, foods and drugs administration and control, geological agency, raw materials research and a host of other users especially in the industrial sector. Essentially, NAA in any of its various derivatives (e.g. INAA, RNAA, DNC, PGNAA) will be applied particularly in the following main areas:

- Environmental pollution studies;
- Mineral characterisation of mining and geological samples;
- Trace element analysis of biological samples;
- Forensic science;
- Materials characterisation;
- Non-destructive examinations.

2.4 Neutron transmutation doping

Just as in many other tropical African countries, the annual solar insolation in Nigeria is of the order of 3.5 - 7.0 kWh/m^2-day, and there are growing interests in the country to harness this energy form. One major area of application of transmutation doping is in the production of solar cells. Towards this end, the National Agency for Science and Engineering Infrastructure (NASENI) has established a Solar Panel Manufacturing Plant in Karshi, in the outskirt of Abuja, with a total capacity of 7.5 MW/annum. Currently the factory does not produce doped silicon, but imports. The factory is able to make contacts, laminate and package. This makes the production process expensive and moreover, the silicon being used is produced by conventional techniques with problems of variation of dopant concentration. Although solar cell production in Nigeria is new, there is a large market in Nigeria and neighbouring countries for finished products. The use of the research reactor to produce doped silicon ingots will further ensure the country's move towards a low-carbon energy system.

2.5 Applications using neutron beams

It is intended that full advantage would be taken of the numerous applications of neutron beams, such as neutron imaging techniques and neutron scattering experiments for studies of solids and condensed matter, studies of internal structure of materials including biological samples such as proteins as well as archaeological objects.

The capability for materials research using the multipurpose research reactor is expected to attract the attention of researchers from all branches of science and engineering (e.g. iron and steel industry, automobile industry, etc.). The new opportunities will include studies in the development of new materials, behaviour of materials under intense stress or temperature conditions, etc.

One major goal of the research reactor project is to open up or expand the research and development capacity of Nigerian scientists and engineers in order to boost socio-economic development of the country.

3. LEGISLATIVE FRAMEWORK

Legal institutional framework has been developed and established to provide effective regulation of the operations of the nuclear industry in Nigeria. This includes, the Nigeria Atomic Energy Commission Act no. 46 of 1976 which established the NAEC for the development of atomic energy and all matters relating to the peaceful use of atomic energy, and the Nuclear Safety and Radiation Protection Act 19 of 1995, which established the Nigerian Nuclear Regulatory Authority (NNRA) as an independent regulatory body. These and other relevant laws are sufficient and where necessary will be revised and would guide and regulate on:

- Nuclear Security;
- Radioactive Materials and Radiation;
- Nuclear Liability;
- Radioactive Waste;
- Spent Fuel and Decommissioning;
- Environmental Protection;
- Emergency and Early Notification of Nuclear Incidents;
- Foreign Investment;
- Safety of Nuclear Installations, among others.

Furthermore, Nigeria is a party to treaties and international conventions in the context of nuclear technology applications, and a draft bill by the Nigerian Nuclear Regulatory Authority (NNRA) on Nuclear Safety, Security and Safeguards has been developed to domesticate these conventions and is being processed for submission to the National Assembly for enactment into law along with the revised NAEC bill as a comprehensive nuclear law.

4. REGULATORY FRAMEWORK

The Nigerian Nuclear Regulatory Authority (NNRA) established by Act 19 of 1995 has the mandate to perform oversight functions and regulate all nuclear and radiological activities in the country, including the enforcement of the Act and the regulations. It is also empowered to enforce all ratified and/or domesticated nuclear related international laws and treaties. Specifically, Section 19 of NNRA Act, the Authority has power to authorize a source or a practice through a system of application, notification, registration or licensing [11, 12]. In addition, Section 37 empowers the Authority to inspect practices and installation licensed or proposed to be licensed without hindrance. Section 47 empowers the Authority with the approval of the President of the Federal Republic of Nigeria to make regulations.

5. SITING AND SITE ASSESSMENT

The Multipurpose Research Reactor is to be sited at the Nuclear Technology Centre (NTC) of the Nigeria Atomic Energy Commission, located in Sheda, Federal Capital Territory. Sheda is about 75 km southwest of Nigeria's capital Abuja, and about 30 km from the Abuja international airport. One of the important stakeholders, the University of Abuja, is at a distance of about 15 km from the NTC, the site for the MPRR.

The NTC, is located in the Northern part of the Sheda Science and Technology Complex, and within the NTC there are already existing laboratories and other facilities, including the Gamma Irradiation Facility (GIF). At a distance of about 20 m from this facility there is the Power Supply Station and reservoir diesel fuel tanks. The Central Workshop is located another 25 m off the GIF. At about the same distance of 25 m is the Water Supply Station. All these buildings are on one side of the NTC together with the Waste Treatment Plant at distances of about 80 meters or more from the proposed Multipurpose Research Reactor (MPRR) site. On the same side of the MPRR site, roughly 40m away is the Nuclear Instrumentation and Nuclear Security Laboratories under construction. The terrain is a sparse forest with isolated trees and shrubs embedded into a grass land.

The NAEC had in the fourth quarter of 2016 commissioned a comprehensive preliminary assessment of the proposed site of the research reactor [13, 14]. Reports of this assessment included:

- Meteorology and climatology;
- Hydrology and hydrogeology;
- Geotechnics studies;
- Seismicity studies;

- Ecological studies;
- Site security;
- Demography;
- Initial environmental assessment.

6. NUCLEAR SAFETY, SECURITY AND SAFEGUARDS

Nigeria's nuclear power programme is being implemented in compliance with all relevant treaties and international conventions, some of which are already ratified and domesticated. In collaboration with the IAEA, Nigeria is actively building capacity in nuclear safety. The Nigerian Nuclear Regulatory Authority (NNRA) in particular has acquired significant expertise and experience in the regulation of nuclear safety as it pertains to licensing of research reactor and transportation of nuclear and radioactive materials.

Nigeria has established a National Nuclear Security Committee (NNSC) with membership drawn from the NAEC, NNRA, academia, and Office of the National Security Adviser (ONSA). Partnering with the IAEA, DOE-PNS (USA) and other relevant organisations, staff of NAEC, NNRA, ONSA, academia and other relevant stakeholder agencies have participated in various nuclear security training programmes to beef up nuclear security knowledge and culture within the country. In addition, Nigeria has developed the state system of accounting and control (SSAC) of nuclear materials and would update the IAEA on her roles, activities and achievements on annual basis.

7. HUMAN RESOURCE DEVELOPMENT

The Human Resource Development Plan of the Nigeria Atomic Energy Commission [10] is targeted at ensuring that any potential worker in the nuclear industry has requisite basic training in nuclear science and technology. For the MPRR, specialized and job-specific trainings will be provided by reactor suppliers under agreement, while also taking advantage of other existing infrastructure available within the country. Trainees will also be exposed to trainings under arrangement with international laboratories or organisations and the IAEA.

Nigeria's human resource development programme for the MPRR aims at exploiting the above and being able to provide needed manpower at various stages of the lifetime of the reactor. The human resources development policy as contained in the Human Resources Development Plan is designed to fulfil the following broad objectives:

- Produce indigenous scientists and engineers for sustainable implementation of the national nuclear programme;
- Train specialized crop of scientists, engineers, technologists and technicians, in order to create a sustainable pool of human capital for the national nuclear programmes;
- Respond to national needs for professionals in various disciplines of nuclear technology for multifarious applications;
- Develop a specialized cadre of scientists and engineers for basic and applied research, and innovations;
- Develop national capacity for domestication of relevant technologies for a sustainable nuclear programme.

In order to achieve these objectives, certain steps have already been taken. These include:

- Development of Memorandum of Understanding (MOU) with local and foreign institutions for partnership in the implementation of education programmes;
- Curriculum developed for nuclear science and nuclear engineering programmes;
- Introduction of undergraduate and postgraduate education programmes in partnering universities and technical education in polytechnics;

- Creation of appropriate linkages between foreign and local institutions for manpower training, by creating visiting programmes and technical exchange for faculty members.

One of the cardinal mandates of the Nigeria Atomic Energy Commission is to develop the requisite manpower to drive the nuclear energy programmes. Within this scope some young Nigerian scientists and engineers were recruited to undertake Master's degree programmes in Nuclear Science and Nuclear Engineering, in partnership with four Nigerian universities. However, because of very few professionals in this discipline in Nigerian institutions, the NAEC decided to pool few experts available together to a central location in Abuja to teach the core courses of the Master's Programme. The International Atomic Energy Agency (IAEA) also provided assistance by sending some experts to teach some of these courses. These IAEA experts came from the United Kingdom, Pakistan, the United States of America and Canada, giving the programme some international flavour. At the conclusion of the programme in Abuja, the students returned to their respective universities to complete the rest of their academic requirements for the award of Master's degree. Under this scheme, 23 graduates with Master's degree in Nuclear Science and Nuclear Engineering have been produced in the first batch.

In addition to these efforts, Nigeria has a bilateral cooperation with the Russian Federation for the training of Nigerians in various disciplines of nuclear science and nuclear engineering. Nigerians also benefit from scholarship award programmes from the People's Republic of China and the Republic of Korea, under the auspices of the IAEA.

8. FUNDING, FINANCING AND PROCUREMENT

The multipurpose research reactor project requires significant short- and long-term capital commitment from the government. Such capital commitment includes the reactor itself but also many ancillary facilities that boost the functionality of the research reactor. There is also a cost associated with operation, maintenance, waste management and decommissioning. Other costs come through human capital development, physical security, insurance and legal services. It is nevertheless recognised that the Federal Government of Nigeria (FGN) would be responsible for the financing and funding of the multipurpose research reactor project through budgetary provisions. The government is expected to provide a lifelong financial support for safe and secure operation of the MPRR, including decommissioning.

The procurement of a multipurpose research reactor and its ancillary facilities will require a high degree of expertise in project management, research reactor technology and contract management. In addition, the process of procurement must be in line with extant rules in Nigeria and within the guidelines of the IAEA.

9. NUCLEAR FUEL CYCLE & RADIOACTIVE WASTE MANAGEMENT

The national policy on nuclear fuel cycle (PNF) and the national policy and strategy for the Management of Radioactive Waste (RWM) and Spent Nuclear Fuel (SNF) developed for the NPP would be applicable in the multipurpose research reactor project.

10. CONCLUSIONS

Nigeria has had some operating experience with the 30 kW MNSR research reactor. The quest for a multipurpose research reactor stems out of the limitations of the MNSR. The new reactor is expected to provide services in radioisotope production, for use in medicine, agriculture, industry and also in the training of the manpower required for the nuclear energy programme. When completed, apart from providing a platform for advanced research and training in the peaceful applications of nuclear energy, the reactor will also provide services to countries within the West African sub-region, and beyond.

REFERENCES

[1] NIGERIA ATOMIC ENERGY COMMISSION, Feasibility Report for a Multipurpose Research Reactor, NAEC/NRR/02 Rev. 1.0, Nigeria, August 2016.

[2] NIGERIA ATOMIC ENERGY COMMISSION, Strategic Plan for a Multipurpose Research Reactor (2015-2020), NAEC/NRR/01 Rev 1.0, Nigeria, August 2016.

[3] NIGERIA ATOMIC ENERGY COMMISSION, Assessment of the National Nuclear Infrastructure in Support of a new Research Reactor Project in Nigeria, NAEC/NRR/03 Rev 1.0, Nigeria, February 2017.

[4] VANGUARD NEWSPAPER, "The burden of cancer in Nigeria", Abuja, Nigeria, 27 August 2016.

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Applications of Research Reactors, Nuclear Energy Series NP-T-5.3, IAEA, Vienna, Austria (2014).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Research Reactors: Purpose and Future, IAEA Brochure, Vienna, Austria (2016 edition).

[7] NIGERIA ATOMIC ENERGY COMMISSION, Strategic Plan for the Implementation of the National Nuclear Power Programme in Nigeria, NAEC/TECDOC/SP-15, Nigeria (2015).

[8] NIGERIA ATOMIC ENERGY COMMISSION: Strategic Plan for Sustainability of National Nuclear Institutions, Abuja, Nigeria (under preparation).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Specific Considerations and Milestones for a Research Reactor Project, Nuclear Energy Series NP-T-5.1, IAEA, Vienna, Austria, (2012)

[10] NIGERIA ATOMIC ENERGY COMMISSION, Human Resource Development Plan for the Nuclear Energy Programme. NAEC/TECHDOC/TFO, Nigeria (April 2015).

[11] NIGERIAN NUCLEAR REGULATORY AUTHORITY, Draft Safety Regulations for Research Reactors. (Undergoing Review)

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Research Reactors, IAEA Safety Standards Series NS-R-4, IAEA, Vienna, Austria (2005).

[13] VANCEGOLDMAN NIGERIA LIMITED, Site Assessment Report of Sheda: The proposed Site for the Erection of a Multipurpose Research Reactor. Report submitted to Nigeria Atomic Energy Commission, Abuja, Nigeria, (March 2017).

[14] VANCEGOLDMAN NIGERIA LIMITED, Initial Environmental Assessment of Sheda. Report submitted to Nigeria Atomic Energy Commission, Abuja, Nigeria, (March 2017).

PHILIPPINES: CONDUCT OF FEASIBILITY STUDY ON THE ESTABLISHMENT OF A NEW RESEARCH REACTOR

K. M. Romallosa, A. Astronomo, N. Guillermo, R. Olivares, U. Bautista, M. Ramiro, V. Parami

Philippine Nuclear Research Institute
Commonwealth Ave., Diliman, Quezon City, Philippines

Email: kmdromallosa@pnri.dost.gov.ph

1. INTRODUCTION

The Philippines used to have an operating research reactor: the Philippine Research Reactor – 1 (PRR-1). PRR-1, which first attained criticality in August 1963, was operated during the period of 1964-1984 and has a total burn-up of about 570 MW-days. It was used mainly for teaching, research, neutron activation analysis, neutron physics experiments and medical (limited to P-32 only) isotope production. It was an essential facility for building-up the expertise of the country in nuclear science, engineering and technology and was used in part for the training of operators for the Bataan NPP-I.

However, PRR-1 was shut down in 1988 following an upgrade from 1MW to 3MW and never re-operated since. The unintended shutdown had resulted in a) total reliance of the country on imported reactor-produced radioisotopes (RIs) used in medicine, industry and research thereby increasing the prices while reducing availability, b) loss of trained technical personnel with reactor operational expertise, and c) loss of opportunity to undertake locally, any new or continuing studies on areas involving the use of a reactor radiation and facilities due to absence of an operating nuclear facility, among other effects.

Despite the absence of nuclear facilities for isotope production in the country, nuclear technology remains to be widely used in the Philippines and demand is expected to increase in the coming years. In 2015 for instance, there were about a) 70,000 procedures using Tc-99m and I-131 for nuclear imaging, b) 60 nuclear medicine facilities plus more than 20 centres planned and c) 1,000 procedures for PET/CT scans, to list a few. There are at least 20,000 radiation workers and the government has renewed its interest to include nuclear power in its energy mix to meet the future power demand in the country.

The feasibility study (F/S) for the establishment of a research reactor (RR) in the Philippines was therefore conducted to determine the potential of a RR in advancing the country's capacity for nuclear science & technology once again. The study is in line with government policies which state that a) nuclear power is a future energy option and the government should prepare for it and b) scientific and technical knowledge should be continuously developed. The F/S also aimed to support various areas of the 2011-2016 Philippine Development Plan such reduction in the country's dependence on imported RIs and provision of additional services in metrology, radiography, process efficiency and materials analysis through reactor technologies.

This paper presents an overview of the F/S for the establishment of a research reactor facility in the Philippines, which was conducted in 2016. It describes the steps taken to implement the study, key results and recommendations, and way forward for the Philippine Nuclear Research Institute (PNRI) as the implementing agency.

2. OVERVIEW OF THE IMPLEMENTATION OF THE FEASIBILITY STUDY

The conduct of the F/S to establish a RR in the country started in 2014 when the PNRI submitted a proposal to the National Economic Development Authority (NEDA). When the proposal was approved in the mid-2015, the PNRI & NEDA developed the Terms of Reference (TOR). The TOR was completed in September 2016. Bidding of consulting services to conduct the F/S was done in November 2015 with an approved budget of about PhP 24.3 million (USD 487,000). Aspiretech Corp. (AT) was adjudged as the highest rated proposal and in January 13, 2016 the contract and notice to proceed were received.

The TOR describes the scope, expected output, and description of activities of the F/S. The expected output from the consulting firm is the Pre-Project Assessment Report (PPAR) which comprises the following: a) preliminary assessment of the stakeholder profiles, public perception and the rationale/justification for the RR, b) techno-economic evaluation of the functional specifications, candidate sites, personnel requirement and economic and financial viability, and c) policy and organizational framework evaluation of government commitments, operating organization, and relevant legislation & regulation. The TOR also stipulates the expertise requirements and qualifications of the consulting firm, schedule of deliverables, criteria for short listing and institutional responsibilities. Among the key experts required were project manager, research reactor specialist, social scientist, economist, nuclear engineer and geologist. Full details of the TOR can be found in Ref [1].

The FS covered a period of nine months, from January 13 to October 12, 2016. During the conduct of the F/S, the PNRI being the implementing agency established a Technical Working Group (TWG), to oversee the overall implementation of the study, provides inputs as needed by AT as well as review and endorse the progress reports to the NEDA. The TWG also joined AT on all the stakeholder consultation activities of the F/S.

The Final Report (PPAR) provides the basis for the project’s submission to the Investment Coordination Committee of the country for review and approval to build the research reactor. It highlights the rationale and justification for the RR. The report also contains all the results of the activities as required by the TOR such as the conceptual facility functional design, RR type and power, ancillary facilities, rough project costs and schedule estimates. The Final Report therefore contains sufficient information to enable national decision makers to arrive at an informed, knowledgeable commitment to establish a new reactor.

3. STAKEHOLDER NEEDS AND PUBLIC PERCEPTION FOR A NEW RR

Establishing a new RR is a very expensive project particularly for developing countries like the Philippines. Hence, it is essential that the RR to be built will have a significant socio-economic impact and will address the needs of its stakeholders.

The first major step in the F/S is to determine whether there is justification in establishing a research reactor in the Philippines. Stakeholder consultations and needs assessment were conducted nationwide in Manila, Cebu City, Davao City and Bataan to determine if there is still a need for a new RR and which applications are considered most important. A majority, i.e. 72%, of those consulted nationwide supports the establishment of a RR in the country in spite of other competing priorities. Most of the respondents (94%) also consider that the benefits from a RR outweigh the risks, provided that safety and regulatory requirements are followed. The RR applications that were considered to be of high priority by the stakeholders are: a) R&D, b) education and training, c) production of radioisotopes for medicine, research, industry, agriculture and environmental management, and d) neutron activation analysis.

The relevance to the country's needs of RR applications identified by the stakeholders was then studied. Table 1 shows the major stakeholders and their needs, which can be addressed by establishing a new RR. The PNRI being the primary stakeholder needs to increase its R&D output and conduct advanced studies in nuclear science and technology because it is mandated to do so. It also needs to enhance the capabilities of its Nuclear Training Centre and provide additional services such as analytical, isotope and kneb techniques to support needs of the industries. The medical sector on the other hand needs more affordable and increased availability of medical radioisotopes to address the increasing number of nuclear medicine facilities and the projected demand for Tc-99m at 1,500 Ci/yr, I-131 at 850 Ci/yr (at 5% annual growth), and the Ir-192 at 7000 Ci/yr (at 2% annual growth). The academe needs to a) include nuclear science and technology in the education program, b) an available nuclear facility for teaching to help support more than 5,000 graduate students in the sciences, and c) have more opportunities for interdisciplinary research. Also, the power sector needs to build human capacity and technological readiness for an NPP program especially since the current administration is more serious in including nuclear in the energy mix.

After the stakeholder analysis, a public perception survey on research reactors was conducted in the F/S in order to determine the level of public support and understanding of the role of RR. The survey also would like to identify any public or community concerns regarding RR's associated risks, perceived or otherwise. A mixed-mode approach was adopted for the survey, which consisted of a web survey as the main mode of data collection followed by Self-administered Questionnaires in a Central Location for the supplemental community-based survey.

The survey results showed that in general, the public was not familiar with a research reactor. The results also showed that a research reactor is perceived by some to be equivalent to, or the same as, a nuclear power reactor. This idea was based primarily on the negative publicity on the Bataan nuclear power plant (BNPP) and coverage of the Fukushima Daiichi and Chernobyl nuclear power plant accidents. Also while the respondents are aware that there are some risks associated with nuclear reactors, nearly a half would support a RR in their community while the other half indicated that it depends on the benefits to the community.

Information collected from stakeholder consultations and public perception surveys were used to develop a preliminary Communication Plan. The value of public information through an effective communication plan is extremely high in order to obtain public acceptance. The Communication Plan was therefore developed to serve as an initial, basic guide for the operating agency in implementing consistent and effective communications regarding the establishment of a RR in the Philippines. It identifies the communication objectives, approaches, and activities to undertake for various target audiences.

TABLE 1: STAKEHOLDER NEEDS THAT CAN BE ADDRESSED BY ESTABLISHING A NEW RR

Stakeholder & Priority Applications	Need	Size of Demand / Potential Market
PNRI **(Education & Training, R&D, NAA)**	Promote peaceful uses of nuclear energy as mandated	Experienced RR manpower retired
	Revive competencies in reactor technologies	Current personnel has no competence and experience in a RR
	Enhance & expand the capability of the Nuclear Training Center to address its growing demand	900 training participants (2015)
	Increase R&D output and conduct advanced studies in nuclear S&T (e.g. neutron beam science, NAA, tracers)	Chemistry, Biomedical, Applied Physics, Health Physics, Nuclear Materials Research Sections, etc.
	Provide additional services such as analytical, isotope, silicon doping & NDT techniques to support industries	Projected output: 20,000 samples/yr (e.g. geochemistry) >100 operating mines, 5 processing plantsRadiotracers for geothermal energy exploration (the Philippines is the 2nd largest producer in the world) Electronics is one of the top exports of the Philippines
Medical Sector (RI Production)	More affordable and increased availability of medical RIs	Projected demand for Tc-99m 1,500 Ci/yr and for I-131 is 850 Ci/yr (at 5% annual growth) Projected demand for Ir-192 is 7000 Ci/yr (at 2% annual growth) 60 NM Centers, more planned
Academy **(Education, R&D)**	Include nuclear science and technology in the education program	More than 40,000 university students in the sciences and engineering
	Available facility for nuclear science and engineering education	
	More opportunities for interdisciplinary research	5,000 graduate students in the sciences
Power Sectors (E&T)	Build human capacity and technological readiness for an NPP program	New government to study feasibility of an NPP in the country

4. TECHNO-ECONOMIC SPECIFICATIONS

Following stakeholder consultations and evaluation of their needs, the type of RR recommended in the FS is a 10-MW multipurpose, pool-type, cooled and moderated by light water, with a minimum operational lifetime of 40 years, extendable to 50 - 60 years. The RR is referred to as the National Research Reactor for various Applications (NARRA) and will operate 250 days a year. As a note, the NARRA shares its name with the national tree of the Philippines that is known for its strength and durability: very apt to represent the new RR for the Filipino people.

The design of NARRA takes into account a) the current and projected needs over 40 years, b) performance required to accommodate identified utilization areas and c) production capacity that will ensure self-sufficiency for 40 years. It will use low-enriched uranium (LEU) fuel. It will have a neutron flux of up to ~ 3.0x1014 n/s-cm^2 and designed to have irradiation facilities that are sufficient for production of current and projected needs for Mo-99/Tc-99m which is 10,800 Ci/year), I-131 at 7,200 Ci/year, I-125 at 96 Ci/year and Ir-192 at 24,000 Ci/year, as well as other radioisotopes for use in education and research. There will be at least 4 neutron beam ports to provide neutrons initially for neutron radiography instruments and thermal neutron diffraction instruments with provisions for the future addition of small angle neutron scattering instruments, thermal neutron spectroscopy instruments, imaging of large-scale targets with thermal neutrons and supply of a cold neutron source. Figure 1 shows the perspective design of NARRA.

Figure 1: Facility concept design of NARRA

The PNRI will be the operator and primary user of the NARRA. However, even though the Institute has experience in operating radiation and nuclear facilities (such as the PRR-1), there are only 263 permanent positions. In order to support the NARRA's management, operation and utilization, its current personnel needs to be augmented. As such, the FS proposes the creation of a Reactor Operations Centre (ROC). The ROC will require a total of 99 personnel, at least 47 of which will be new positions if the NARRA is located outside the PNRI and 39 new positions if it is located within the Institute's compound. Five (5) shifts of operations, a dedicated engineering and maintenance team, and additional staff for RI production, NAA, neutron beam utilization and education and training are recommended.

Pre-selection of candidate sites for the NARRA was also conducted nation-wide through the F/S. Selection of the sites was based primarily on accessibility to end-users and beneficiaries.

The four candidate sites chosen were: a) the Bataan Nuclear Power Plant in Morong, Bataan, b) PNRI in Quezon City, c) the University of San Carlos (USC) in Cebu City, and d) the University of Southeastern Philippines in Davao. The four sites were then ranked based on the siting criteria for RRs of the IAEA such as topography and drainage, climate and vegetation, geology, hydrology and peak horizontal ground acceleration. The risk of external events like natural hazards and human-induced hazards on the site was also assessed. Accessibility, infrastructure and population density were also considered since it could affect logistics and emergency planning and response programs.

The BNPP site is ranked as the most suitable. The site also has the advantage of having undergone full siting study for an NPP in the past. Among the four sites, the PNRI and USC sites are most accessible to end-users. The PNRI site is ranked 2nd due in part to the lack of space inside the compound. More than a half of hospitals with nuclear medicine departments and universities are in the National Capital Region, making PNRI’s location as the most accessible. Should this be the site however, a more intensified public information program and more complex emergency planning and preparedness will be needed due to the relatively high population density in the surrounding areas.

It should be noted that although these initial locations were selected and evaluated for their suitability to be the site for the NARRA, other potential sites might still be considered in the future. Also, a full siting evaluation involving geological and hydrological surveys to obtain primary data will have to be conducted prior to the selection of the best site.

5. ECONOMIC, FINANCIAL AND SOCIAL ANALYSIS

A research reactor project is an expensive investment, especially for developing countries like the Philippines. Thus it is essential that an economic, financial, and social analysis be performed for the NARRA to determine the total project cost and socio-economic impact of its 40-year lifetime.

The 10MW NARRA facility is estimated to cost PhP 16,450.00 million (~ 300 million USD) before escalation and PhP 18,533.38 million (~370 million USD) after escalation (i.e. 5% per year over 5 years’ construction period). The fixed capital investment cost (with escalation) includes the reactor basic system (PhP 6,860.08 million), reactor and associated laboratory buildings (PhP 6,225.76 million), neutron beam facility (PhP 259.41 million), automatic NAA system laboratory (PhP 518.81 million), hot laboratory for radioisotope processing (PhP 518.81 million), fission moly (Mo-99) laboratory (PhP 2,075.25 million), Si-doping laboratory (PhP 518.81 million) and waste management treatment facility (PhP 1,556.44 million). The decommissioning cost on the other hand is estimated at 7% of the combined cost of the RR system and the reactor associated laboratories.

A turnkey contract, which includes training of NARRA personnel, is recommended. The total period from commitment to conclusion of commissioning is approximately 5 to 8 years, i.e., 2 to 3 years for project formulation (preparation and evaluation of bids, permits etc.) and about 5 years for actual construction and commissioning until full operation. The schedule of phases and the release of cost for the establishment of NARRA was proposed in the F/S.

There are two types of benefits that can be generated by the NARRA facility: direct and indirect benefits. The direct benefits are revenues from the production of RIs particularly Mo-99, I-131, I-125, Ir-192, Cr-51, P-32 and small amounts of other RIs. Revenues can also come from neutron activation analysis (NAA), training courses and silicon doping among others. The indirect benefits are derived in part from the Department of Science and Technology-Philippine Council on Industry and Energy Research and Development (DOST-PCIERD) guidelines on project output valuation, where: a) ISI/SCOPUS Publication is equivalent to PhP 2 million each, b) Patent Filed - PhP 2 million each, c) Masters of Science (MS) Graduate - PhP 500 thousand each, d) PhD Graduate - PhP 2 million each, e) Product - potential total market value for the next 6 years, and f) Public Service Policies - number of users, value of money saved.

Results of the economic analysis show that the NARRA will have the following impact during its 40-year operation:

- NARRA can save foreign exchange from import substitution of Mo-99, I-131 and I-125, by approximately PhP 88,502.59 million or roughly USD 1,800 million from price discount of 80% on the prices of these RIs. This is approximately USD 45 million a year – more than a hundred-fold of the initial investment;
- The lowering of the domestic prices of RIs will stimulate domestic demand benefiting the nuclear medical subsector. It will also induce more participants in the domestic trade and distribution of RIs making the market more competitive. It will also eliminate the logistical difficulty that is typically encountered during entry of imported RIs;
- The direct benefits from the Neutron Activation Analysis, training and other services like irradiation services were estimated to amount to PhP 6,874 million (USD 137 million) and potential for these activities to expand geometrically in the future are large. The NARRA will also provide the platform for silicon doping to help the electronic and manufacturing industries to be more profitable and competitive;
- The total indirect benefits were estimated to amount to PhP 159,300 million. The indirect benefits considered were a) ISI/SCOPUS publications, b) MS & PhD graduates, c) patents, d) avoided economic losses due to red tide, e) avoided loss of life due to early diagnosis of thyroid cancer, f) avoided cost in the O&M of the PNRI Tc-99m generator production facility, g) savings from local training of MS vs. US training, and h) savings from local training of PhD vs. US training;
- The initial HRD investment cost of the project for 50 PhDs and 100 MS will generate spill-over effects i.e., the doubling of formally trained scientists and professionals to generate a cadre of scientists in the nuclear S&T sector. This build-up of professional expertise will result to strategic researchers and generation of science and technology innovations (STI) central to the development needs of the country. The NARRA facility will also help build expertise for nuclear power program.

Build-up of socio-economic component is also the main benefit of the NARRA facility. Hence, in addition to the economic benefits, the intangible social impact of NARRA was also analysed and the results show that:

- The establishment of NARRA will generate a concentration of technical know-how and specialized skilled human capital that will foster socio-economic uplift through innovation, creation of an expanding (new) market, and attractive investments in the country;

- The design and construction of the facility will promote collaboration among the suppliers, facility managers and scientists in coming up with design solutions and research functionalities. For instance, there will be collaboration between applied research and the production of useful products such as radiopharmaceuticals that will give a measurable degree of independence for the Philippines in terms of the domestic production on the one hand and open applied innovation on the other to further connect nuclear technologies to the marketplace;
- Local companies employing local labor force would accumulate know-how and various complementary skills that tend to expand competitiveness in other markets. During construction, universities and other government agencies tend to acquire more sophisticated project management skills that have beneficial effects on socio-economic sector innovators;
- The procurement of advance equipment will have an impact on extending the technological and socio-economic frontier of the Philippines such as spin-offs that occur from specialized technical services and socio-economic multipliers of concentrated economic activities (on jobs, expenditure and income);
- During operations and utilization, scientists and students will have a) an available educational & training facility for nuclear S&T, b) access to the new equipment and technology, and c) increased research contracts, project generation and consultancy.

Overall, the greatest potential socio-economic impact of the NARRA facility thereby lies in long-term research. The facility can be the springboard for the Philippines' S&T sector to propel itself to a new level of competitiveness in terms of STI outputs in Publications, Innovation Patents, and strong human resource capability, internationally recognized professional competence, and solutions to actual problems in agriculture, environment, and improvement of healthcare.

The F/S also presented the analyses which show that a new 10MW RR is financially and economically viable. The financial analysis showed that the net present value of net benefits (NPV) of NARRA is PhP18,799.74 million, benefit-cost ratio (BCR) is 1.98 and financial internal rate of return (FIRR) is 10.29%. The total direct and indirect benefits are estimated at PhP 297 million, 54% of which come from indirect economic benefits while 46% are from direct revenues. The total direct benefit estimated at PhP 155 million comes mainly from production of RIs that are currently imported and partly from neutron activation analysis (NAA), training activities and silicon doping. The proposed 10MW RR project is economically viable with an estimated net present social value in constant prices of PhP 18,926.70 million, economic internal rate of return of 20.88%, BCR of 3.81, return of investment of 42.68%, and payback period of 9.24 years.

6. ASSESSMENT OF GAPS & WAY FORWARD FOR NARRA

The results presented in the previous sections demonstrate that there is a strong justification for the establishment of a new RR in the country. It will address various stakeholder needs particularly in healthcare, research & development, education and provision of services. It has a multitude of socio-economic benefits and it has been shown to be financially and economically viable. However, in order to establish the NARRA and sustain its operations, the country has to be well prepared for it and should start addressing the existing gaps identified in the F/S.

A clear national policy for the country's nuclear programs and issuance of an Executive Order or legislation are needed to authorize the establishment and ensure the sustainability of NARRA. Such initiatives include but are not limited to:

- Authorization to lease or acquire the selected site for the NARRA;
- Addition of 47 new permanent positions to the PNRI to provide the required personnel complement;
- Mechanisms for an effective use of income to ensure sustainability of operations and maintenance;
- Establishment of an independent regulatory body for the licensing and overall oversight of nuclear facilities.

One of the main sources of revenue for the facility is RI production. The NARRA can produce RIs that are sufficient for local needs but initially there will be a surplus as local demand grows. A business and marketing plan therefore needs to be developed for the management and revenue generation strategies of the facility. Among the possibilities to be explored provided by the FS are: a) serve as a back-up supply for other suppliers of Mo-99/Tc-99m; b) export through the current importers; and c) direct export through a business partner.

The PNRI as the implementing agency of the NARRA should then develop and carry out a human resource development plan for NARRA's personnel. The Institute should also work towards geological and hydrological investigations of the selected site as well as other associated analyses as required by regulations. Lastly, to gain support and public acceptance of the NARRA facility, the PNRI should finalize and implement the Communication Plan in order to raise awareness, educate, and persuade the stakeholders and the public of the importance of a RR in the country.

7. CONCLUSIONS

The Philippines through the PNRI has completed the conduct of the feasibility study for the establishment of a research reactor. The study was performed by the consulting firm Aspiretech Corporation in January – October 2016 and was funded by the National Economic Development Authority (NEDA). The total cost of the FS was approximately PhP 23 million (460,000 USD).

Based on the results and findings of F/S, the establishment of a new reactor in the Philippines is strongly recommended. The new reactor will address the needs of the stakeholders to a) have R&D opportunities for students in the sciences and engineering; b) develop human resources for a nuclear power program; c) improve and reduce the cost of healthcare delivery and outcomes through local supply of currently imported radioisotopes; d) enhance industrial competitiveness, agricultural productivity, and environmental management for national development, and e) advance nuclear S&T in the Philippines.

The proposed RR was referred to as National Research Reactor for various Applications (NARRA). The NARRA is recommended to be a 10-MW multipurpose, pool-type, cooled and moderated by light water, with a minimum operational lifetime of 40 years, and will operate 250 days a year. It will have a neutron flux of up to ~ 3.0×10^{14} n/s-cm^2 and four (4) neutron beam ports and irradiation facilities that are sufficient for production of current and projected needs for Mo-99/Tc-99m which is 10,800 Ci/year), I-131 at 7,200 Ci/year, I-125 at 96 Ci/year and Ir-192 at 24,000 Ci/year. Two candidate sites have been selected: the BNPP compound in Morong, Bataan and the PNRI compound in Quezon City. However further site-specific geological and hydrological investigations need to be conducted in order to select the final site.

The total cost of the 10MW NARRA facility is estimated at PhP 16,450.00 million (~ 300 million USD) before escalation and PhP 18,533.38 million and will require 99 personnel for its operations and utilization. The financial and economic viability analyses show that a new 10MW RR is viable. The total direct and indirect benefit is estimated at PhP 297 million and is foreseen to have significant socio-economic impact. It should be noted however that financial, human resource and policy and legislative requirements needs to be in place to ensure the successful establishment and operations of the NARRA.

REFERENCES

[1] THE NATIONAL ECONOMIC AND DEVELOPMENT AUTHORITY, Terms of Reference for the Conduct of Feasibility Study for the Establishment of a Research Reactor, http://www.neda.gov.ph/wp-content/uploads/2015/10/TOR-Research-Reactor.pdf

[2] PHILIPPINE NUCLEAR RESEARCH INSTITUTE, Conduct of a Feasibility Study on the Establishment of a Research Reactor Final Report (Rev.1), Philippines, February 2017.

TANZANIA: PRE-FEASIBILITY STUDY FOR A FIRST RESEARCH REACTOR

S. Mdoe, I. Makundi, J. Ngaile

Tanzania Atomic Energy Commission, P.O. Box 743, Arusha, Tanzania

E-mail: slcmdoe@taec.or.tz

1. INTRODUCTION

United Republic of Tanzania conducted its pre-feasibility phase for consideration of a new research reactor project. This is after careful considerations that a research reactor, if appropriately conceived, managed and supported, will be an extraordinary tool that can contribute to country's scientific resources, improve health care, and help to increase industrial and agricultural productivity. This will require a strong policy and technical infrastructure, and management of long term financial liabilities. The work plan during this phase included: accurate situation analysis of all aspects of infrastructure; identification of potential stakeholders and their needs, concerns and gaps; performance of a rigorous Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis to justify a research reactor; formation of a research reactor project implementing commission comprised of relevant ad hoc government ministry representatives, regulatory body for subsequent research reactor; encouragement for clear institutional, regulatory and governmental nuclear policies and regulations; securing long term government commitment and associated obligations, the preferred candidate site(s) on the basis of existing data, supported by a radiological impact assessment.

The need for a research reactor and capacity building has been emphasized in the country Nuclear Science and Technology policy and the nuclear science and technology strategy [1]. The operation of the research reactor and facilities, if decided, will be according to the requirements of the Regulatory Authority and will furthermore be in line with the requirements as identified in the Strategic Plans of the Tanzania Atomic Energy Commission [2]. The facility will be in full compliance with international treaties and requirements and external review missions will be conducted periodically. The Country is a partner in the Global Nuclear Safety Regime dedicated to maintaining nuclear safety worldwide, with the opportunity to participate in the international cooperation network for nuclear safety. The research reactor will be given full support to ensure that the resources required for efficient operation of the facility and maximum extension of its functional life-time will be forthcoming to the best ability of the future operating organization.

2. PRE-PROJECT CONSIDERATIONS

Tanzania prioritized an action plan for step-by-step work in line with IAEA's research reactor specific considerations which include [3]: accurate situation analysis of all aspects of infrastructure; identify potential stakeholders and identify needs, concerns and gaps; perform rigorous SWOT analysis to justify a research reactor; form research reactor project implementing commission; encourage clear institutional, regulatory and governmental nuclear policies and regulations; secure long term government commitment and associated obligations including adhering to the international obligations and to apply the IAEA Code of Conduct on the safety of RRs [4] and the IAEA safety standards; clear definition of the reactor purpose, utilization programme and users, pre-selection of the reactor type, size, and experimental facilities.

During this pre-feasibility study, the milestones approach as highlighted in the IAEA Nuclear Energy Series (NP-T-5.1) was followed [3]. This guidance provided description on the timely preparation of a research reactor project through a sequential development process. It includes a detailed description of the range of infrastructure issues that need to be addressed and the expected level of achievement (or milestones) at the end of each phase of the project.

The publication provides a discussion of the mechanisms for justification of a research reactor, and for building stakeholder support. It includes both the technical, legal, regulatory and safety infrastructure, and the development of qualified human resources needed for a research reactor. The guidance also addresses the evolution of infrastructure needs from the time that a Member State first considers a research reactor and its associated facilities, through the stages of planning, bid preparation, construction, start-up, and preparation for commissioning. The subsequent stages of operation, decommissioning, spent fuel and waste management issues are addressed to the degree necessary for appropriate planning prior to research reactor commissioning.

The present pre-feasibility study took into considerations the mechanisms for building stakeholder support to justify a new research reactor, and addresses the evolution of infrastructure needs from the time that a country first considers a research reactor and its associated facilities, through the stages of planning. In case of Government decision, considerations will be taken for requirements for bid preparation, construction and preparation for commissioning. This included technical, legal, regulatory and safety infrastructure, and emphasizes the development of qualified human resources needed for a research reactor [3].

3. MAIN OBJECTIVE OF THE PRE-FEASIBILITY STUDY

The pre-feasibility study will form a basis for the country to be in a position to make an informed decision whether to proceed with the research reactor project [3]. This pre-feasibility study included a comprehensive assessment of all 19 infrastructure issues, identification of the gaps and of the means to fill gaps, and incorporates and updates the Pre-Project Assessment Report and the Preliminary Strategic Plan [2, 5]. The pre-feasibility considered the following aspects: technologies required for the project; required infrastructure and human resources capabilities; economic study investigating the cost and benefit of the proposed project, and strategic review. The pre-feasibility study provided the basis for a way for further steps into the project initiation. The study objectively and rationally assessed the strengths and weaknesses for the country to embark into this project and the country be in position to judge its own status and readiness to introduce a research reactor; determine the magnitude of the commitment necessary to ensure that it is fully prepared to achieve the peaceful use of research reactor in a safe, secure and technically sound manner; ensure the efficiency and success of its research reactor, and ensure efficiency and well utilization of the facility once commissioned.

The specific objectives of this study were:

- To perform pre-project assessment and pre-feasibility study evaluating the real needs in order to justify (or not) a research reactor;
- To inform the government of the long term commitment and to fully understand the associated responsibilities related to a research reactor project;
- To perform stakeholders analysis and needs including exploring partnership with public and private stakeholders;
- To have clear definition of the reactor purpose, utilization programme and users, pre-selection of the reactor type, size, and experimental facilities;
- To analyse advantages and disadvantages of using alternative technologies;
- To define the infrastructure needs for building a research reactor and ancillary facilities;
- To identify the requirement to build, strengthen and broaden human capital;
- To create awareness of commitment to establish the necessary safety and technical infrastructures.

4. NEEDS ANALYSIS AND JUSTIFICATION FOR RESEARCH REACTOR

The primary purpose of the research reactor is to provide a neutron source for research and other purposes including capacity building with some commercial aspects in terms of isotope production and material analysis [6]. The RR will further enhance and expedite understanding of basic knowledge in nuclear science for health, agriculture, livestock development, industry and research. In an effort to build human capacity necessary for nuclear science and technology, knowledge gained from research reactor will help to build human capital, know-how and for possible future opportunities for peaceful uses of nuclear technology [7]. In line with preparation of preliminary strategic action plan, the project team is performing needs analysis and benchmarking of the current situation in the need for research reactor technology in order to justify and define strategic action plan for its utilisation. This will consider immediate needs, future known needs and yet unknown needs that may be accommodated in the future. The analysis is done using several methods that include collection of primary and secondary data, desk review, questionnaires, and technological and economic trends data. Outreach and public education programmes were also conducted for potentials users on specific technological characteristics of the research reactors and specific applications of research reactors, specific requirements and safe and effective utilization approach.

5. PROJECT STRATEGY AND METHODOLOGY IMPLEMENTED.

To build support for the project, we executed the following actions in line with IAEA's pre-project guidelines [3]:

- Performed accurate situation analysis of all aspects of infrastructure;
- Identified potential stakeholders, identified needs, concerns and build their spontaneous support;
- Formed an assessment, marketing and project team comprised of operating institute, stakeholder representative, nuclear technology experts, neutron application experts and project management experts;
- Performed rigorous SWOT analysis to justify a research reactor;

- Encouraged clear institutional, regulatory and governmental nuclear policies and regulations;
- Identified long term government commitments and associated obligations;
- Developed multidisciplinary and multinational cooperation;
- Drafted the strategic plan [2];
- Drafted functional and organizational requirements of research reactor;
- Drafted the pre-project assessment report;
- Continued to strengthen and broaden support for research reactor;
- Continued to train and educate for capacity building [8];
- Assessed cost of the project and drafted fund raising strategy.

The final feasibility study report also included preliminary functional and organizational requirements of research reactor; draft research reactor strategic plan; facility cost implication and options; draft fund raising strategy; requirements for regulatory infrastructure for RR following the IAEA milestones; the nuclear science and technology strategic action plan following the approval of nuclear energy and nuclear science & technology policies.

In parallel, a preliminary site evaluation to review the geological, seismic and hydrologic condition of possible sites was being conducted. The site selection criteria are dealing with, among others, the following aspects:

- Safety and security;
- Public acceptance;
- Local Government support;
- Considerations for emergency preparedness plan;
- Meteorological conditions;
- Effects of external events;
- Utilisation aspects;
- Accessibility;
- Inhabitancy.

6. STRATEGIC PLAN FOR ESTABLISHMENT OF THE RESEARCH REACTOR PROJECT

In this pre-project assessment stage, the project team prepared the Preliminary Strategic Plan [2] by determining that there are quantitative scientific, medical and industrial needs that may justify the construction of a research reactor. Furthermore, it was also understood that before embarking on the research reactor project, the country must develop a comprehensive understanding of the obligations and commitments involved [3], and ensure that there are a long term national strategy and resources available to discharge them. The preliminary strategic plan was prepared to define the key elements, major objectives and conclusions. The plan describes justification for the research reactor project, planned facility description, stakeholders analysis, SWOT analysis, strategic considerations, organizational structure, principle objectives of the project, specific objectives, action plans, review and monitoring as well as financing.

7. CONCLUSION

The next phase of the research reactor feasibility study (after pre-feasibility study) will be preceded by a number of activities and preparation of various reports as part of a phased decision-making and development process. The key final documents will include: (i) a Pre-Project Assessment report for a research reactor, required to identify needs and issues and to translate these into outline functional specifications; and (ii) a strategic plan whose main purpose is to communicate needs-based goals and to demonstrate how a project would be implemented on a national and regional level for efficient, optimized and well managed research reactor utilization.

The conclusion of this pre-feasibility study and preliminary strategic plan document jointly and comprehensively sets out the framework and for the follow up detailed feasibility study. In addition it will be necessary for the government to have in place a long term national strategy that reflects policy and within which the research reactor project would sit in alignment with other components of the national strategy. The national position on nuclear and associated issues will have to be clear and specific in order to ensure that the research reactor project objectives are demonstrably compatible with government policy and strategy. This will require that statements about the national position should be supported by official acts or documents issued or endorsed by government, with appropriate references to them included in the report.

REFERENCES

[1] TANZANIA ATOMIC ENERGY COMMISSION, National Nuclear Science and Technology Strategy, TAEC, Arusha, Tanzania, (2013)

[2] TANZANIA ATOMIC ENERGY COMMISSION, Strategic plan for establishment of first research reactor in Tanzania, TAEC, Arusha, Tanzania (2016)

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Specific Consideration and Milestones for a Research Reactor Project, Nuclear Energy Series No. NP-T-5.1, IAEA, Vienna, Austria, (2012).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Code of Conduct on the Safety of Research Reactors, IAEA, Vienna, Austria (2006).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Strategic Planning for Research Reactors, Nuclear Energy Series No NG-T-3.16, Vienna, Austria, (2017).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Applications of Research Reactors, Nuclear Energy Series No. NP-T-5.3, IAEA, Vienna, Austria (2014).

[7] MDOE, S., et al., Establishing a National Network for Nuclear Education, Science and Technology in Africa: Tanzanian Experience; Proceedings of the International Conference on Human Resource Development for Nuclear Power Programmes: Vienna, Austria 12 – 16 May 2014, CN-215, IAEA, Vienna, Austria (2015).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Technical Cooperation project URT1008 Supporting Nuclear Technology Education and Training, IAEA, Vienna, Austria (2016).

THAILAND: A FEASIBILITY STUDY OF THE RESEARCH REACTOR PROJECT FOR THE ONGKHARAK NUCLEAR RESEARCH CENTER

K. Tiyapun, S. Wetchagarun, N. Klaysuban and S. Boonmark

Reactor Centre, Thailand Institute of Nuclear Technology (TINT) (Public Organization)

Email: kan.okrat2008@hotmail.com

1. INTRODUCTION

For more than 10 years, Thailand was interested in initiating a new research reactor project. The new Ongkharak Nuclear Research Center (ONRC) in Nakorn Nayok province is developed and implemented since Thailand has planned to replace the TRR-1/M1 research reactor which located in the Chatuchak district, Bangkok. In brief, in December 26, 1989, the Ministry of Science, Technology and Energy was assigned to immediately consider a new research reactor, to be located at the Ongkharak site. The feasibility of the new research reactor project was conducted in 1990.

The objective of the new research reactor project was to (1) establish the new nuclear research centre to support and coordinate nuclear science and technology study, research and development, (2) establish an isotope production facility for medicine, industry, agriculture, environment and public health, (3) encourage rendering services and applications in several fields including neutron transmutation doping (NTD) of silicon, neutron activation analysis, gem stone coloration, and neutron beam research, (4) establish the centralized waste processing and storage facilities for radioactive waste processing, (5) distribute the advantage of nuclear science technology to the economic, social and environmental aspects, (6) serve as the technology transfer centre and technical support organization. The planned facilities consisted of a research reactor island (multipurpose research reactor), isotope production facility (isotopes and radiopharmaceuticals production), centralized waste processing and radioactive waste storage facilities, supporting facilities (nuclear chemistry laboratory, radiation physic laboratory, nuclear physic laboratory, construction and maintenance workshops and management building).

In June 1997, the Office of Atomic Energy for Peace (OAEP) awarded a turnkey contract to General Atomics (GA) to design, build and commission the Ongkharak Nuclear Research Centre. Unfortunately, the research reactor project was halted and therefore not realised due to the delay of approval and issuance of construction permit for the ONRC site.

More recently, a new feasibility study was conducted again by Chulalongkorn University in 2009. This summary report provides the scope of the feasibility study for the new research reactor including the justification process, utilization plan, and stakeholder involvement during the pre-project assessment.

2. PRE-PROJECT ASSESSMENT

As recommended by the IAEA [1], Phase 1 of the research reactor project activities should be culminated with Feasibility Study Report (FSR) as the achievement of Milestone 1. The feasibility report was conducted by Chulalongkorn University and demonstrated that Thailand was in a position to make an informed decision regarding the new research reactor project. This study, among other efforts, was also supported by the comprehensive self-assessment of national nuclear infrastructure, conducted by Thailand in 2010 and relevant to the nuclear power programme. The Integrated Nuclear Infrastruture Review (INIR) Mission also was carried out by IAEA in 2010 [2]. Some relevant issues from 19 national nuclear infrastructures were beneficial to support a new research reactor project such as national position, legislative framework, regulatory framework, environmental protection, safeguards, emergency preparedness and response, nuclear safety and radiation protection. In addition, research reactor specific self-assessment was done more recently and included research reactor safety aspects, required human resource development, utilization issues as well as educational and training programmes. The gap analysis was made and the progress is conducted to fulfill these gaps for implementation of a new research reactor.

The feasibility study report for the new research reactor provided several issues consisted of (1) review of the prospective of research reactor, (2) the advantages and the potential for the new research reactor in variety services including medical, agriculture, industry, and research and development, (3) projections of the new research reactor utilization estimated from the past to the future, (4) preliminary functional specifications of the new research reactor [3].

3. STRATEGIC PLAN

The strategic plan of the new research reactor was proposed in 2009 and was revised in 2013. The plan consists of the facility description, the TINT capabilities (existing and potential applications), stakeholders (existing and expected in the future), an analysis of strengths, weaknesses, opportunities and threats (SWOT), political, economic, social and technological (PEST analysis), TINT vision and mission, strategic issues, major objectives, specific objectives, action plans, and marketing and financing.

The TINT vision is "to be a leading nuclear solution-based research institute for nation". The mission of TINT are to: (1) Carry out the research and development on nuclear science and technology for sustainable development of the country; (2) Transfer technology and provide consultancy services regarding the utilization of nuclear technology for socio-economic and environmental development; (3) Administrate and operate the research reactor and other nuclear facilities, and provide nuclear technology and nuclear safety services to the public; (4) Promote a nuclear network and cooperate with organizations and research institutes, both domestic and international; and (5) Disseminate and build up public acceptance on the utilization of nuclear science and technology for national development.

Strategic issues for the new research reactor are to: (1) Focus on research and development projects which meet the socio-economic and environmental benefits using new research reactor; (2) Promote cooperation networks in utilization of research reactor with domestic and international organizations; (3) Develop the efficiency and quality of services of the nuclear science and technology, and the nuclear safety; (4) Promote the cooperation network for communication, public relations, and knowledge dissemination to build up understanding and acceptance from all stakeholders and the public for implemented the new research reactor project; (5) Make use of advanced and efficient information technology for administration of databases and knowledge, and of technology transfer to the public; and (6) Develop an organizational management system with flexibility for efficient and effective cooperation.

The strategic considerations involve a number of project stakeholders with the following main task: development of education and training activities programmes; preparation of required human capacity and other necessary infrastructure for the new research reactor; ensuring financial support for the project; establishing users' network between universities, industries and research institutes to promote reactor utilization; implement and promote the new experimental facilities in order to attract the variety of sectors such as academia, agriculture, environment, medicine and industry both for the research and development and the commercial purposes.

4. STAKEHOLDER INVOLVEMENT

It is essential that relevant stakeholders are identified and their requirements are clearly understood. As part of the project, the key stakeholders were identified, including potential customers in the past and future and their needs in terms of expected products and services. This was used as a key component in the justification of a new research reactor and was used as a basis for development of the functional specifications of the new research reactor and its ancillary facilities. The existing stakeholders and the potential stakeholders in the future consist of the government, TINT, research institutes, scientific organizations, research centers, universities, commercial customers, industry sector, hospitals and medical organizations, radioisotope importers, regulatory body, agriculture sector, energy sector, including educational and training and TSO services, media, local public and local communities.

The medical isotope production and radiopharmaceutical services which were planned from the new research reactor are: Cr-51, Se-75, Sr-89, Mo-99, I-131, Cs-137, Pm-149, Sm-153, Gd-153, Dy-165, Ho-166, Yb-169, Lu-177, Re-186, Re-188 and Ir-192. The industrial partners would be interested in geochronology, radiography, material research and testing, silicon doping, radioisotope supplies, gem irradiation, neutron activation analysis (NAA), prompt gamma neutron activation analysis (PGNAA), and non-destructive technique (NDT). Possible contributions to the agriculture sector could be in the area of mutation, genetic engineering, plant breeding, increasing cultivar productivity, and radioimmunoassay for livestock. The research institutes are interested in using radiography, NAA, PGNAA, material structure and dynamic studies with neutron beams such as small angle neutron scattering (SANS), neutron diffraction, triple axis spectrometer, etc.

5. FEASIBILITY STUDY

The procedures of the feasibility study for a large scale national project such as new research reactor project comprised of the following procedures; TINT submitted a revised project proposal to the Ministry of Science and Technology which included pre-project assessment and preliminary strategic plan in 2015. The same was provided to the Office of the National Economics and Social Development Board. The new research reactor project was proposed to the Ministry of Finance for the budget and finance approval.

Chulalongkorn University was responsible for conducting a part of the feasibility study and included chapters on marketing, business plan, and human resource development strategy, SWOT and PEST analysis. The estimated total cost for the new research reactor was approximately between 10 to 12 billion bath (290 - 300 Million US$).

The PEST results showed that the *political factor* has a crucial impact on the new research reactor project via the political influence, decision maker and the national policy. There are numerous *economic factors* which were also considered for the project. With the support and commitment from the government to provide initial funding to the project, it is expected that the project would attract the crucial private sector investment and other commercial stakeholders to make this project commercially viable.

Social aspect is important for the project too. The stakeholders such as public and local community can delay or even stop the project completely. Therefore, TINT together with the local community as well as a specific stakeholder group should work jointly and exchange the information to prevent the possible opposition from the general public.

Technological aspects, in particular implementation of new technologies for the reactor, might bring significant financial risks. Selecting the appropriate reactor technology is also vital, as the related funding will be crucial for the entire life-time of the reactor, from its construction and installation, to commissioning, operation, maintenance, and decommissioning.

Regarding the *legal and regulatory aspects*, in Thailand nuclear legislation and regulations are ensured by the Office of Atoms for Peace (OAP). The licensing process, both for construction and operation, will require approvals by the OAP. Therefore, it needs to be prepared well in advance and in close cooperation with the OAP in order to avoid unexpected delays or postponement of the project as it has been experience in the past.

Environmental aspects, including public participation, are of great importance and indispensable part of the feasibility study and the project. The regulator body (OAP) recommends that TINT should have Environmental Impact Assessments (EIAs) and Strategic Environmental Assessments (SEAs) available for them to review and make decision related to the installation of new research reactor.

The SWOT analysis shows that the *strength* includes, among others, the only institute which has the research reactor in the country, good management and commitment for research and development, availability of various research facilities related to research reactor, being inexpensive for the research service due to the non-profit organizational status, existence of know-how and experienced staff in operating the research reactor, accessible IAEA services to support capacity building and human resource development.

The *weakness* comprises a low utilization of present irradiation facilities, inadequacy of infrastructure to promote external user participation and utilization of a research reactor, retirement of senior and experienced staff, no specific procurement management history/ documentation for research and development projects, not sufficient recognition by the government and international community due to lack of promotion.

The *opportunity* is the multilateral and bilateral linkages between IAEA, FNCA, ANSN, as well as some countries like China, Korea, and the US with existing MoUs, and covering the areas of human capacity building and share of expertise.

Examples of the *threats* are the ageing of the existing research reactor and its auxiliary systems, retirement of senior and experienced staff, lack of interest among students in nuclear science and engineering, and decreasing use of nuclear applications and nuclear techniques in the industry due to more strict regulatory requirements and constraints.

The overall cost/benefit analysis was quite positive and Chulalongkorn University recommended the investment of national resources and human capacity building for the new research reactor project. Early engagement of numerous stakeholders to promote the project and provide/receive up-to-date information was also strongly recommended. Such an engagement will ensure continuous support and interest from various stakeholders and users of the future reactor facility, and will clarify their involvement and strengthen respective commitment for use of the facility when it becomes operational.

6. REACTOR FEATURES

The feasibility study resulted in the following preliminary functional specifications of a new research reactor as detailed in Table 1.

TABLE 1: SOME FUNCTIONAL SPECIFICATIONS OF THE REACTOR FACILITY

Reactor Features and Requirements	**Utilization Purpose**
Reactor Core	
Fuel	- Plate cluster or rod bundles - $UZrH_x$ or U_xSi_y - Initial supply allows operation for 3 years
Reflector	Water or reflector assemblies made of nuclear graded beryllium or graphite
Maximum thermal neutron flux	$>10^{13}$ $cm^{-2}s^{-1}$
Neutron beams	
NB 1	- Tangential, suited for neutron diffraction
NB 2	- Tangential, suited for neutron radiography
NB 3	- Tangential, suited for PGNAA
NB 4	- Tangential, suited and reserved for SANS
Irradiation Facilities	
Irradiation position with thermal neutrons	For standard and large sample NAA
Irradiation position with epithermal neutrons	For standard NAA
Pneumatic system	For NAA with capability to perform cyclic activation
Gem stone coloration	Capacity 3000 kg/year
Neutron transmutation doping	Ingots diameter from 5.0’’ and 6.0” and 12.0” with production capacity not less than 10,000 kg/year
I-131	> 1,200 Ci/year
Ir-192	> 10,000 Ci/year with 100 Ci/source with specific activity > 350 Ci/g
Fission Mo-99	TBD
Irradiation for other isotopes	For different type of isotope production and for NAA with long half-life isotopes

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, “Specific Considerations and Milestones for a Research Reactor project”, Nuclear Energy Series NP-T-5.1, IAEA, Vienna, Austria (2012).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Report on the Integrated Nuclear Infrastructure Review (INIR) Mission to Thailand, Bangkok, Thailand, 13-18 December 2010.

[3] CHULALONGKORN UNIVERSITY, Reactor Feasibility Study and Business Plan, Bangkok, Thailand (2009).