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Sustainability and Self-reliance of National Nuclear Institutions

Proceedings of a Workshop

IAEA

International Atomic Energy Agency

SUSTAINABILITY AND SELF-RELIANCE OF NATIONAL NUCLEAR INSTITUTIONS

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PROCEEDINGS OF A WORKSHOP

INTERNATIONAL ATOMIC ENERGY AGENCY
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FOREWORD

National nuclear institutions (NNIs) established under the national nuclear development programmes of Member States have led the development of nuclear science and the use of associated technologies. NNIs make significant contributions to national development and provide highly relevant services to society, achieving significant scientific results and developing and applying technologies with important positive impacts on the lives of people. While many NNIs have provided commercial services and products that generate revenue, historically they have often been financially dependent on subsidies from national governments. It is becoming evident that different management outlooks and practices are needed to transform the NNIs' management, programmes and approaches in order to sustainably reshape nuclear science and technology programmes and integrate them into national development efforts.

The IAEA regional technical cooperation project entitled Promoting Self-reliance and Sustainability of National Nuclear Institutions was designed to support NNIs in Member States in the Asia and Pacific region in developing their institutional capacity toward self-reliance and sustainability. The project was initiated in February 2018 with the participation of NNIs from Bangladesh, Cambodia, China, Indonesia, Islamic Republic of Iran, Jordan, Kuwait, Lebanon, Malaysia, Pakistan, Philippines, Singapore, Sri Lanka, Thailand and Viet Nam.

As one of the activities under the project, a regional workshop on the sustainability of NNIs took place on 9–12 April 2019, in Daejeon, Republic of Korea. The purpose of the workshop, organized in conjunction with the International HANARO Symposium, was to exchange experience and share good practices and lessons learned towards sustainability and self-reliance of NNIs involved in the provision of products and services on a commercial basis, such as gamma and electron beam irradiation, radioisotope production, multielement analysis, materials testing and capacity building. Participants discussed the issues and challenges faced by participating Member States regarding self-reliance and sustainability of their NNIs, as well as efforts and best practices to cope with such challenges. Eight country reports and four invited papers were presented.

This publication provides the summaries of the presented papers as well as the individual country reports. It is expected to be of benefit not only to the NNIs of Member States taking part in the regional project but also to Member States in other regions in their efforts towards improving the self-reliance and sustainability of their national organizations.

The IAEA expresses its appreciation to all the regional workshop participants for their efforts leading to this publication, and to I.C. Lim (Republic of Korea) for contributions to its drafting and review. The IAEA officers responsible for this publication were D. Ridikas and N. Pessoa Barradas of the Division of Physical and Chemical Sciences and S. Syahril of the Division of Technical Cooperation for Asia and the Pacific.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

The IAEA regional Asia and Pacific project RAS0080 “Promoting Self-Reliance and Sustainability of National Nuclear Institutions” was designed to support national nuclear institutions (NNI) in Member States in developing their institutional capacity towards self-reliance and sustainability. It is becoming evident that a different management outlook and practices are required in order to transform the NNIs’ management and approaches to sustainably reshape and integrate the nuclear science and technology programmes into the overall national developmental efforts [1]. The research and development (R&D) programmes of mature and potentially productive NNIs need to be adjusted for optimum sustainability and for the benefit of all parties concerned, since sole reliance on government funding cannot be guaranteed to provide sufficient resources to support the changing and often expanding missions of the NNIs.

Currently, many Member States with mature NNIs do not possess the required capacity to review critically and adjust the sustainability related approach of their NNIs’ R&D programmes or the interface of these NNIs with other national stakeholders, including the industrial sector. There is an urgent need to support and advise NNIs on how to overcome these shortcomings if their R&D programmes and their — sometimes limited or incipient — offer of commercial products and services are to develop into a cost effective bench to business (B2B) approach, including the development of business units and spin-off entities.

A successful B2B or similar approach in technology transfer could enable the participating NNIs to leverage their resources in a manner that enhances the development of demand-oriented R&D products and services. Many Member States in the region also continue to face staff turnover and staff retention challenges for a number of reasons that are not exclusively of a technical nature, rather structural and programmatic. In this regard it is essential for an NNI to have updated and fit-for-purpose strategic plans, both for the organization and for specific facilities, that properly address aspects in the development, qualification and licensing of products and services using nuclear technologies, as well as in the capacity building and retention of human resources.

The RAS0080 project started in February 2018 and the participants are the NNIs from Bangladesh, Cambodia, China, Indonesia, Iran, Jordan, Kuwait, Lebanon, Malaysia, Pakistan, Philippines, Singapore, Sri Lanka, Thailand and Viet Nam.

1.2. OBJECTIVE

As an activity under the RAS0080 project, the regional workshop on Sustainability of National Nuclear Institutions took place from 9–12 April 2019 in Daejeon, Korea. The workshop was organized in conjunction with the International HANARO Symposium.

The objective of the workshop was to exchange experiences and share good practices and lessons learned towards the sustainability and self-reliance of NNIs, based on nuclear facilities such as gamma and electron beam irradiators, ion beam accelerators, research reactors and associated facilities involved in provision of products and services on a commercial basis, such as gamma and electron beam irradiation, radioisotope production, multielemental analysis, materials testing, silicon doping, gem coloration, capacity building and others.

The workshop therefore discussed and exchanged issues and challenges faced by participating Member States with regard to self-reliance and sustainability of their NNIs as well as efforts and best practices to cope with these challenges. The participants were from the NNIs of Bangladesh, Indonesia, Jordan, Malaysia, Pakistan, the Philippines, Thailand and Viet Nam. The workshop also invited speakers from the regional NNIs in Australia, India, Japan and Republic of Korea, which have well established and efficiently operating facilities. This provided opportunities for participants to hear success stories in the provision of products and services for diverse users and stakeholders, including industry.

1.3. SCOPE

This publication addresses the topics of sustainability and self-reliance of NNIs based on the review and feedback from the individual country reports presented during the regional workshop by the participating Member States. This includes positive examples and success stories on what tools or measures are to be used in practical projects or programmes for achieving management goals towards self-reliance and sustainability of NNIs and therefore will be beneficial to diverse stakeholders of NNIs, including the NNIs themselves.

In addition, this publication includes summaries of good practices and success stories from well-established facilities, also represented at this workshop. Several good examples and practices, considered to be a result of changing management or reshaping R&D programmes, are given.

Examples of governmental policies in support of the self-reliance and sustainability of their NNIs are also presented. Finally, the country presentations in this publication show some examples of how the NNIs cooperate with public or private stakeholders, providing some insights on how business opportunities can be explored by NNIs.

1.4. STRUCTURE

This publication consists of this introduction, followed by two technical sections. Section 2 provides the executive summary of the workshop and describes the elements of self-reliance and sustainability, summarizing the findings from the country presentations. Section 3 provides the summaries of both invited and contributed papers. Some of these summaries also include suggestions for the participating NNIs as good practices to follow. Finally, the individual country reports, the list of participants and the workshop agenda are included as Appendices.

2. SUMMARY OF WORKSHOP DISCUSSIONS

Eight country reports and four invited papers were presented in the workshop. The workshop was valuable for exchanging experiences and sharing good practices and lessons learned towards sustainability and self-reliance of NNIs belonging to the participating countries in Asia and Pacific region. The eight participating NNIs, which operate various nuclear and radiation facilities, were from Member States participating in the RAS0080 project. The invited speakers were from other countries in the region, which have been very successful at enhancing their self-reliance and sustainability through R&D activities and providing commercial services or goods.

2.1. THE ROLE OF NNIS IN NATIONAL DEVELOPMENT

The development of nuclear science and the use of associated technologies [1] in the Member States that participated in the workshop has been led by the NNIs, which were established under national nuclear development programmes to address the lack of trained manpower and scientific infrastructure in the nuclear area, and are usually the prime (in some cases, the sole) national institution contributing to the welfare and prosperity of human society through nuclear research, science and technology.

The NNIs that participated in the workshop operate a wide range of facilities, including electron beam, gamma irradiation and radioactive waste management facilities, radioisotope and radiopharmaceutical production, ion beam accelerators and research reactors.

The NNIs of these countries have demonstrated that they significantly contribute to national development and provide highly relevant services to society, achieving significant scientific results and developing and applying technologies with important positive impacts in the lives of people. They are active in physical sciences, biosciences, food and agriculture, water and environment, engineering and industry, nuclear medicine and medical radioisotopes, health physics, education and training (E&T) in nuclear science and technology, and many other areas. Several NNIs also have the role of technical support organization for nuclear safety and security and for the health and safety of radiation workers and the general public, and some are responsible for the development and enforcement of regulations on the safe uses of radiation. NNIs can also support governmental management of atomic energy, as they are often strongly involved in the development of the national nuclear infrastructure required for a nuclear power programme (NPP).

NNIs assist the development of the economy and, at the same time, play a significant role in the implementation of national policies. Production of radioisotopes can contribute to lowering their cost relative to imports and also reducing the dependency from external producers, which can be seen by governments as an important step to self-sufficiency. This is particularly true when supply chains are fragile, and their disruption may asymmetrically affect developing countries. Irradiation of food and medical equipment has a direct effect on the health of populations and contributes to enhancing exports of products that otherwise might not be accepted in some markets. Research results obtained by NNIs have been transferred from the laboratories to practical applications used in hospitals, agriculture and industry.

While many NNIs have provided such services and products commercially, in many cases generating revenue has not been a priority, and public institutions are often expected to deliver at prices below the cost of recovery of production expenses, sometimes even at nominal or zero cost. Historically, many NNIs have often been financially dependent on subsidies from national governments.

2.2. SELF-RELIANCE AND SUSTAINABILITY

Self-reliance is the ability to do things and make one's own decisions without needing assistance from others. Sustainability means that a process or state can be maintained at a desired level for as long as is needed.

The participants stressed that continued strong governmental commitment to support the development and utilization of nuclear science and its applications is indispensable for NNI sustainability. In particular, there is a limit to the revenue that can be generated by NNIs, and, in general, it cannot cover the operating expenses. Consequently, governmental funding will continue to be an important component of the budget of many NNIs, providing resources for regular operation, renovation and refurbishment of existing facilities and major equipment and for development of new capabilities.

At the same time, increasing the self-reliance of NNIs is perceived to be essential to ensure their sustainability. This goal can be achieved by designing the requisite self-reliance elements and relevant interfaces into the NNIs' programmes with collaborating national stakeholders, including the industrial sector. Such an approach relieves NNIs from nearly exclusive dependence on government funding and transforms the NNIs' innovative potential to contribution to the national socioeconomic development [2].

There are several key elements to be kept in mind for achieving self-reliance and sustainability of NNIs, with brief descriptions of several such elements provided below:

- The first element is strategic, financial and business planning [2, 3]. Strategic planning is an essential management tool. NNIs need to develop a systematic approach to strategic planning, for which they may need to acquire enhanced capabilities to use appropriate tools and methodologies, particularly for developing, qualifying, commercializing and licensing products and services using nuclear technologies. Specific strategic plans can be developed for given facilities or business areas, logically showing the necessary activities or necessary action plans. The NNIs need to also practice business and financial planning, technological planning, marketing planning, and manpower planning accordingly. This may require changing the institutional mindset from the traditional R&D oriented one towards a customer and business-oriented outlook on activity;
- The second element is supply chain management (SCM). SCM is the management of a network of multiple businesses and both intra and inter company relationships. SCM is controlled and supervised to maximize the product availability to the customer. In particular, this is critical for the production of radioisotopes and radiopharmaceuticals or other irradiation services, like food/products sterilization or neutron transmutation doping of silicon;
- The third element is customer and business led management. This is the process of managing businesses by offering what customers need and providing a framework to identify, capture, assess, progress and implement new business opportunities through a deeper understanding of customers' behaviour;
- The fourth element is stakeholder engagement [3, 4]. A nuclear or radiation facility needs support from the government and policy makers and needs to build working relationships with regulators, customers and other research and education institutions,

with outreach and marketing efforts essential in this regard. It also needs to build trust with the public, including the local community, the region, and at national level, for which public information and awareness, stressing the benefits of the facility, needs to be prioritized;

- The fifth element is staff engagement, motivation and organizational culture management. Several NNIs in the region have an ageing workforce, which is compounded by difficulties in attracting new employees and high staff turnover. Human resource development (HRD) and knowledge preservation is seen as critical; it involves effective training, qualification and retraining programmes, but starts with attracting young people to nuclear science and technology career paths, for which clear pathways "from education to employment" need to be available to high school and undergraduate students. For existing staff, employee benefits, a rewarding career management system and other programmes and initiatives to support staff need to be in place;
- The sixth element is comprised of integrated management system (IMS) [5] and continual improvement. The IMS joins in all components of a business into one comprehensive system to assist high quality and safe work practices, customer focused activities and environmental management and protection. An IMS requires several combined activities such as business management, technological management and a quality management system.

2.3. CHALLENGES AND OPPORTUNITIES

One of the objectives of this regional workshop was to share the experiences of NNIs in Member States participating in RAS0080 project in strengthening or implementing the six elements for achieving self-reliance and sustainability.

From the discussions held during the workshop and the review of the country reports, it was clear that the participating NNIs need to further develop and implement their strategic, financial and business planning [2, 3]. Market information on the needs of existing and potential stakeholders, when it comes to direct customers, needs to be gathered and analysed. With improved demand assessment, necessary technology prediction and technology gap analysis, specific strategic and business plans can be developed to increase the NNIs capability to offer services and output products and to stimulate demand for those services and products.

It was also found that the participating NNIs face challenges in human resource development, knowledge management, financial support and securing essential devices and technologies, which prevent them from expanding their capabilities towards self-reliance and sustainability. Even when a clear plan and strategy are developed, if those elements are not in place or are not sufficient to implement the strategy, identified opportunities of development will be missed. At the same time, optimization of the impact of the limited resources available to the NNIs can be promoted by participating in national or regional networks to provide, for example, various analytical or consultancy services. Resources can be pooled through bilateral agreements with other public and private organizations.

For each participating NNI, it was suggested to select one opportunity of development identified for the NNI and to develop a case study addressing subjects such as strategic planning, outreach, leadership and business management practices, management of organization, HRD and knowledge management for the success of case study. These are mentioned in the summaries of the country reports.

Finally, establishment of solid information on the financial and socioeconomic impacts of a nuclear or radiation facility or even of the NNI itself, was seen by the participants as an essential step towards demonstrating the relevance and importance of NNIs, contributing to their self-reliance and sustainability. Besides the direct benefits of expanded stakeholder and customer base and increased revenue, these impacts include non-material direct and indirect benefits, such as to those coming from enhanced capability in nuclear science and technology, improved health of the population through increased availability of nuclear medicine, self-reliance in radioisotopes and attainment of other national goals.

3. SUMMARY OF PRESENTATIONS

3.1. INVITED PRESENTATIONS

3.1.1. Australia

Mr. J. Schulz from the Australian Nuclear Science and Technology Organization (ANSTO) gave an invited talk titled 'Sustainability at the Australian Nuclear Science & Technology Organization'. ANSTO is one of Australia's largest public research organizations and custodian of much of Australian important science infrastructure, including the OPAL nuclear research reactor, the Australian Synchrotron, accelerators, cyclotrons and neutron beam instruments. He explained the strategic framework of ANSTO for sustainability and its key sustainability elements.

The sustainability of ANSTO is defined as the process and systems to ensure the longevity and growth of the organization. As strategic framework, ANSTO has the ANSTO act (which details the organisation's functions, powers, Board, Chief Executive Officer's duties, staffing, finance and other roles and responsibilities), clearly stated vision, values and strategic objectives, a 5 year business plan and a 1 year corporate plan. The key sustainability elements of ANSTO are financial and business planning, supply chain management, customer and business led management, integral management systems and continual improvement, stakeholder engagement and staff engagement and culture management. Regarding financial and business planning, ANSTO operates an Integral Business Planning (IBP) process on a monthly cycle with a 24-month planning zone. The supply chain management is even more critical to produce radiopharmaceuticals as the product decays with time. For customer and business led management, ANSTO has developed the Product Management Process (PMP) which provides a framework to identify, capture, assess, progress and implement new business opportunities. ANSTO has an Integrated Business Management System (IBMS) framework that underpins and enables ANSTO's commitment to high quality and safe work practices, customer focussed activities and environmental management and protection. Stakeholder engagement is extremely important to ANSTO. ANSTO aims to educate, engage and sell the benefits of nuclear science and technology to politicians, decision makers, general public, including the local community. ANSTO engages with its regulators to build trust, relationship and ensure transparency. For staff engagement & culture management, ANSTO provides programmes and initiatives such as support of non-work activities onsite, providing employee benefit, diversity and inclusion programme, succession and talent management, career management system and staff engagement pulse surveys.

3.1.2. India

Mr. C.G. Karhadkar from the Bhabha Atomic Research Centre (BARC) gave an invited talk titled 'Sustainability of National Nuclear Organizations'. His presentation briefly explained the special characteristics of an NPP which have to be kept in mind by government planners and policy makers before any country embarks on a nuclear energy programme. He also highlighted the infrastructures and institutions that are required to be built for sustenance of an NPP with reference to the nuclear energy programme of India.

BARC was established in January 1954 for multidisciplinary research programmes essential for the ambitious nuclear programme of India. BARC is the mother of the R&D institutions such as the Indira Gandhi Centre for Atomic Research, Raja Ramanna Centre for Advanced Technology, Variable Energy Cyclotron Centre, etc., which carry out pioneering research on nuclear and accelerator technologies and industrial establishments. India operates seven research reactors, which have been the backbone of India's nuclear industry. They have provided a valuable support in the development of the Indian NPP in many ways such as testing of materials, fuel, equipment, shielding experiments, validation of codes, etc. During construction of these reactors, a considerable number of new technologies were developed. These turned out to be the forerunners for use in power reactors. India has 22 power reactors under operation, with a total generation capacity of 6780 MWe. Six new 700 MW pressurized heavy water reactors and two new 1000 MW capacity pressurized water reactors are under construction. He mentioned that the key elements for sustainability of nuclear energy programmes are governmental support and funding, legal and regulatory framework, competent human resource development, fuel cycle, radioactive waste management, emergency planning, environmental protection, which belongs to 19 infrastructure issues for a power reactor project as well as for a research reactor project.

3.1.3. Japan

Mr. M. Kaminaga from the Japan Atomic Energy Agency (JAEA) gave an invited talk titled 'Decommissioning of the Japan Material Testing Reactor and Study for Construction of a new Material Testing Reactor'. His presentation delivered the status of research reactors owned by JAEA including the Japan Material Testing Reactor (JMTR), the JMTR decommissioning plan and the JAEA plan for constructing a new research reactor.

JAEA is an independent administrative institution formed on October 1, 2005 by a merger of two previous semi-governmental organizations, the Japan Nuclear Cycle Development Institute and the Japan Atomic Energy Research Institute. The role of JAEA in Japan is to contribute to the welfare and prosperity of human society through nuclear science and technology as Japan's sole comprehensive nuclear R&D institution. JAEA had operated four research reactors before the Fukushima Daiichi accident in March 2011. The seismic resistance reassessment to find a solution satisfying the new regulatory requirements regarding seismic design showed that the seismic reinforcement of JMTR could not be achieved realistically. Thus, it was decided to decommission the JMTR even though JAEA had invested considerable resources to renovate the JMTR before the Fukushima Daiichi accident happened. As the JRR-4 research reactor was already decided to be decommissioned, JAEA will operate only the NRSS and JRR-3M research reactors. Considering that preparatory activities are required, including development of decommissioning technology, the full-scale activity of decommissioning will start in 2028. The Research Infrastructure Working Group established by the Ministry of Education, Culture, Sports, Science and Technology examined the research infrastructure appropriate for the country and suggested to JAEA in April 2018 to carry out a study for the construction of the JMTR successor reactor. Through the design and construction of a new material testing reactor, JAEA plans to transfer the irradiation test technology and post-irradiation test technology accumulated in JMTR to the younger generation.

3.1.4. Republic of Korea

Mr. M.S. Kim from the Korea Atomic Energy Research Institute (KAERI) gave an invited talk titled 'Current Status of HANARO and Challenge for the Sustainability'. He explained the success story of the High Flux Advanced Neutron Application Reactor (HANARO) research reactor and current challenges for sustainability.

KAERI is the government funded research institute established in 1959 to promote the peaceful use of nuclear science and technology in Korea. HANARO, operated by KAERI, is an open pool type multipurpose research reactor with 30 MW thermal power. HANARO has been actively utilized since attaining first criticality in 1995. After the Fukushima Daiichi accident, HANARO had been requested to evaluate the seismic margin for the reactor main components, and the seismic margin assessment led to the reinforcement of HANARO wall. In December 2017, HANARO started the operation after overcoming many issues from a shutdown lasting nearly three years. For the period of long-term shutdown, the circumstances surrounding HANARO such as regulation environment and new research reactor construction project have been drastically changed. To meet the expectations on HANARO to produce world class science and to adapt to the rapidly changing environment, a strategic plan for HANARO was prepared and 4 missions were identified: 1) advancement of neutron science and technology, 2) not only meeting but also creating the needs of the industry, 3) contributions to the national society issues and 4) safe and stable operation of the facility. To achieve the missions, all members related to the HANARO share the same perception that the stable and safe operation of HANARO is the most important. HANARO is working decisively towards establishing confidence for its sustainability and superiority through various activities.

3.2. CONTRIBUTED PRESENTATIONS

3.2.1. Bangladesh

Mr. M. Azizul Haque from the Bangladesh Atomic Energy Commission (BAEC) made the country report presentation. His presentation provided the overview of BAEC and covered the topics related to the HRD programme and explained the challenges that BAEC faces.

The Bangladesh Atomic Energy Commission (BAEC) was established in 1973 to promote the peaceful uses of nuclear energy in the country. At present, the BAEC has grown as the largest organization for scientific and technological research in Bangladesh working towards human welfare and the national economic development. BAEC is a multidisciplinary R&D national organization dedicated to a diversity of areas, including physical and biological sciences, engineering and nuclear medicine. BAEC is also the leading organization responsible for establishing the national nuclear power programme, thus making a substantial contribution to the national energy security for coming generations. BAEC is committed to establish nuclear safety culture as per international conventions and rules.

Government funding, bilateral agreements and memorandums of understanding with several organizations especially with public and private universities are contributing in developing skilled manpower through courses of higher study and professional training. Several universities opened nuclear engineering department: The University of Dhaka in 2012, the Bangladesh University of Professionals in 2014 and the Bangladesh University of Engineering and Technology in 2016. Nuclear institutions in Bangladesh are enriched by young research students from both public and private universities in the country. These university research students are contributing significantly in developing new ideas. Training is an integral part of strengthening the knowledge further and all the NNIs of Bangladesh organize regular training courses on various subjects relevant to their staff. Bangladesh is participating in the activities of the Forum for Nuclear Cooperation in Asia (FNCA), the Asian Nuclear Safety Network (ANSN) and IAEA Coordinated Research Projects and Regional Cooperative Agreement for Research, Development and Training Related to Nuclear Science and Technology for Asia and the Pacific projects. The residential Training Institute of BAEC is committed to HRD of the Commission through arrangement of in-house training courses. A good number of national and international training courses, seminars and workshops have already been arranged at this training institute. Good practices are Instructor Training Courses (ITC) and Follow up Training

Courses (FTC) arranged under the bilateral agreement with Japan. The BAEC personnel are trained in Japan under the ITC courses and after returning home, the trained instructors organize domestic FTC courses in collaboration with Japanese resources.

Mr. M. Azizul Haque summarized the strength of BAEC as follows:

- Strong Government commitment to continue support for the development and utilization of nuclear science and its applications with special priority to develop safe & sustainable NPP;
- Strong public support to deal with nuclear activities including the NPP;
- Strong international support;
- Some research results obtained by BAEC scientists have been transferred from the laboratories to hospitals, agriculture, industries & environment for practical applications, which is the evidence of conducting an effective HRD programme.

He also pointed out some challenges:

- Development of sustainable nuclear human resources;
- Managing & improving the E&T pipelines, strengthening across the skills pyramid with good blending of theory, practical and hands-on experience;
- Development of pathways 'from education to employment' to inspire the next generation to consider nuclear science and technology career paths;
- Nuclear knowledge management and networking.

The case study suggested for BAEC was to prepare a strategic plan on HRD and conduct the corresponding actions including the use of tools and expertise provided by the project.

3.2.2. Indonesia

Mr Heru Umbara from the National Atomic Energy Agency (BATAN) presented the country report on the utilization of the Multipurpose Reactor G.A. Siwabessy (RSG-GAS) in Indonesia. BATAN (was established in 1964 based on Law No. 31 regarding the Main Provisions of Atomic Energy. Meanwhile, with the change in paradigm, in the year 1997, Law No. 10 regarding Nuclear Energy brought the separation of the implementing organization for utilization of nuclear energy (BATAN) from the supervisory organization of nuclear energy Nuclear Energy Regulatory Agency (BAPETEN). BATAN as a government institution under and responsible to the President of Indonesia has been given the mandate to conduct research, development and empowerment of nuclear science and technology and it is responsible to create the science and technology superiority, especially in the regional level. Mr. Umbara's presentation explained the various utilization of the RSG-GAS reactor such as radioisotope production, gemstone coloration, neutron scattering, neutron activation analysis (NAA) and E&T. The RSG-GAS reactor is one of three research reactors operated by BATAN and it was designed and built by Interatom GmBH, Germany in 1982. He reported that RSG-GAS produces medical purpose radioisotope such as Mo-99, radioisotopes for industrial utilization such as Ir-192 and several radioisotopes for agricultural research. He also introduced the international cooperation activities performed under the frames of IAEA, FNCA and ANSN.

The case study of Indonesia suggested under RAS0080 project was "Radiopharmaceuticals Development, Production & Commercialization". Considering the mission of BATAN to ensure a stable supply of radioisotopes for other team members such as Kimia Farma, BATAN needs to prepare and execute a plan which will guarantee the stable operation of RSG-GAS for radioisotope production with high availability and reliability. In addition, it was suggested that BATAN will provide quantitative records which show the contribution of their three research reactors to the self-reliance and sustainability of BATAN.

3.2.3. Jordan

Mr. I. Farouki of the Jordan Atomic Energy Commission (JAEC) presented the country report titled 'Prospects and Challenges in Utilizing and Operating the Jordan Research and Training Reactor'. He reported on the brief history, characteristics and utilization status of the Jordan Research and Training Reactor (JRTR). He also explained the challenges of JRTR in its utilization and proposed measures to overcome them.

JAEC was established in 2008 in place of the Jordan Nuclear Energy Commission to transfer, develop and promote the peaceful uses of nuclear energy. Jordan nuclear programme is aimed for peaceful purposes and its functions are distributed to the following sectors: nuclear sciences and their applications, power reactors, nuclear fuel and nuclear research. JAEC launched a project in 2009 for the construction of a multipurpose 5 MW (upgradeable to 10 MW) nuclear research reactor, namely the JRTR. The JRTR project was able to endure towards completion, marked by successful commissioning of the facility in the year 2016. JRTR has the potential to host a wide spectrum of neutron irradiations for the purpose of radioisotope production, NAA, neutron transmutation doping, gemstone colouring, science and training applications. In addition to irradiation services and neutron science, the JRTR may be used to provide training for the national programme. For the purpose of training, a highly available training mode (50 kW) for reactor physics training is adopted. In addition, JRTR is located at the campus of Jordan University of Science and Technology (JUST) at which a variety of engineering programmes including nuclear engineering are taught. The location contributes to the increased reachability to the reactor. JRTR faced and continues to face its own unique challenges in demonstrating its readiness for effective utilization of the Kingdom's first nuclear facility. Mr. Farouki mentioned that technical, cultural and financial challenges are among the most prominent challenges that are to be managed to ensure the sustainability of this complex and sensitive facility. The details of these challenges are as follows:

- Financial challenge:
  This originated from the overall financial condition in Jordan but have also been amplified by the shift of the Government of Jordan interests away from the Nuclear Energy Programme. This type of challenge may be considered the most prominent for the JRTR and may be the root of many other challenges;
- Technical challenge:
  Although the Jordanian nuclear energy programme (JNEP) has invested significantly in building the required human capacity not only to operate the JRTR, but also to support the overall JNEP, the technical challenge currently exists because of the relatively high employee turnover. The root cause for this is that the JRTR is not able to provide rewarding compensations to retain its valuable experienced human resources. This is an example of how financial challenges have contributed to other challenges;
- Cultural/Political challenge:
  The people of Jordan are characterized by a culture that is related to their history, values and customs, and that is somewhat polarized by political aspects. A nuclear industry requires a very high level of objectivity and detachment from any cultural and political pressures external to the work standards. The creation of such an isolated environment may be considered among the challenges, not only for JRTR but for any nuclear facility.

The countermeasures that he proposed are as follows:

- Effective management of available financial and human resources and culture;
- Effective maintenance, qualification and training programmes;
- Increased outreach and marketing efforts to increase available resources.

JRTR is the first research reactor for Jordan and has a large potential which will contribute to its self-reliance and sustainability. It is believed that it is natural for a new facility to have diverse challenges to be overcome. Although the details of challenges are explained and the key countermeasures are given from the point of view of the presenter, the development of a strategic plan in a systematic approach is recommended. By joining RAS0080 project, JAEC has chosen the build-up of therapeutic radioisotope production capability as its case study and it needs to be the strategic consideration to overcome challenges. Thus, it was suggested as case study for JAEC to prepare a detailed strategic plan specifically on radioisotope production.

3.2.4. Malaysia

Mr. Z M Hashim from the Malaysian Nuclear Agency (MNA, also known as Nuklear Malaysia) presented the country report titled ‘Sustainability of the Malaysian Nuclear Agency: Opportunities and Challenges’. His presentation showed the main aspects of MNA regarding strategy for self-reliance and sustainability, R&D in MNA, commercialization of nuclear technology, opportunities and driving factors and issues and challenges with the introduction for utilization of the 1 MW TRIGA PUSPATI research reactor (RTP).

MNA, established in 1972, is the premier nuclear research institute in Malaysia. Its major operational function is guided by the Malaysian Nuclear Agency Strategic Plan 2012–2020. The purpose of the plan is to ensure a leadership role for MNA in R&D, commercialization and application of nuclear technology for sustainable development. MNA hosts various major facilities and laboratories including the RTP, a gamma green house, an electron beam facility and secondary Standard Dosimetry laboratory. The emphasis of R&D activities is on the application of nuclear technology in various key economic areas including food and agriculture, medical and healthcare, industry as well as water and environment. The commercialization activities in NMA are composed of providing services, training courses and establishment of potentially productive research outputs. The representative success stories include the patent licensing of hydrogel dressing, a private fund initiative for Management, Promotion, Maintenance and Upgrading of Co-60 irradiation facilities and a private fund initiative for Technology Development and Facility Management for Personal Dosimeter Services. Mr Hashim reported the challenges of MNA as follows:

- Public information and awareness on nuclear technology. The public still is afraid and has distrust on the management of risks from operation of nuclear facilities, especially after the nuclear accident in Fukushima, Japan in 2011. Trust, acceptance and awareness of the nuclear technology remain big challenges in sustaining the technology in the country. In that regard, a public information strategy needs to be established to ensure that knowledge and information on the benefits, safety and security of nuclear technologies are disseminated effectively;
- Nuclear safety and security culture. The safety and security culture among the workers in Malaysia need to be continuously strengthened and reinforced. The radiation safety management and emergency preparedness need to be maintained to emphasize radiation safety in order to ensure protection of people and the environment;

- E&T. Currently, the age profile of workforce in MNA is facing an increment of retirements in the short term. Replacements of retired staff by the new workforce are taking place. New workers lack experience and knowledge regarding radiation science and safety. The frequency of continuous training was increased to ensure that the workers understand and are familiar with the procedures and documentation;
- Knowledge based organization – knowledge management. The average age of the nuclear workforce has been gradually rising for the past several years, a phenomenon commonly referred to as the ageing of the workforce. MNA faced challenges in capturing the tacit knowledge before the loss of key individuals as well as capturing the various knowledge repositories that they maintain for personal use in order to maintain and sustain the technology;
- Necessary resources. MNA, as a governmental institute with the task of doing R&D in nuclear science and technology, faces some limitations on the budget granted, also due to the lack of public acceptance of the nuclear technology and government policy;
- Commercialization of nuclear technology. The challenges in the commercialization of nuclear technology are to push technology in the emerging markets, which requires the establishment of various strategies.

The country report pointed out the challenges to be overcome for the self-reliance and sustainability of MNA. MNA proposed several subjects for a case study under RAS0080 project including dosimetry service, establishing radiopharmaceutical cold kit production using Tc-99m and establishing the production of Iridium-192 gamma projector for non-destructive testing (NDT) applications. Once a case study is selected, a specific strategic plan needs to be developed, including the necessary activities and action plans to overcome the challenges that the presenter listed.

3.2.5. Pakistan

Ms. S. Haider from Pakistan Institute of Nuclear Science and Technology (PINSTECH) presented the country report titled 'Strategy for Self-Reliance and Sustainability of Radiopharmaceutical Production Facility in Pakistan'. She showed the status of key elements for pharmaceutical production in PINSTECH such as organization, management, facility, quality assurance, HRD and national and international collaboration. She also mentioned the challenges and strategy for self-reliance and sustainability.

PINSTECH is Pakistan's major nuclear R&D institute established in 1965 to address the lack of trained manpower and scientific infrastructure in nuclear science and technology. R&D developments in Pakistan since 1990 have laid several foundations of radioisotopes production facilities associated with nuclear research reactors, i.e. the Pakistan Research Reactor-I (PARR-I), which is a 10 MW pool type MTR reactor. Pakistan produces various Radioisotopes such as Mo-99, Mo-99/Tc-99m generators, I-131, P-32, Lu-177, Au-198 with the assistance of the nuclear reactor facility. Pakistan has also achieved synthesis of diagnostic cold kits and injection to be labelled with Tc-99m for imaging of different body organs. These radioisotopes and radiopharmaceutical cold kits are being supplied to 18 Pakistan Atomic Energy Nuclear medical centres and 30 Government and private hospitals in Pakistan since 1990. PINSTECH has developed a strategy for stakeholders to fulfil their needs and requirement. This strategy includes customer satisfaction through feedback responses from all centres that ensure the satisfactory delivery of the product and reliability.

With the increasing demand of cancer diagnosis and treatment, PINSTECH is facing certain issues and associated challenges in order to meet the needs and demands of stakeholders. The challenges Ms Haider listed are as follows:

- In order to meet the increasing demand of the subject product, low enriched uranium (LEU) based Mo-99 production facility is required;
- LEU based technical training is also required;
- Import of I-131 production plant and Moly-99m spares to Pakistan has become an issue in order to maintain the regular replacement and provision of spares for stable supply of products to around 42 medical centres in Pakistan;
- Training on the fabrication of quartz instruments that are used in I-131 dry distillation process is required;
- Self-reliance is a strategy for the continuous development in a particular field and area.

The case study suggested for Pakistan is to achieve higher sustainability in radiopharmaceutical supply especially Mo-99 including securing backup supply of Mo-99 for Tc-99m generators. PINSTECH needs to prepare a strategic plan to meet the increasing demand of radiopharmaceuticals, with clearly identified action plans to overcome the challenges mentioned in this country report.

3.2.6. Philippines

Ms P. C. Pabroa from Philippine Nuclear Research Institute (PNRI) presented the country report titled 'PNRI Providing Nuclear Science and Technology for National Development'. Her presentation explained the strategic framework of PNRI and introduced the major research facilities in PNRI. She introduced the concept of OneLab which is the network of laboratories in the Philippines, including PNRI, anchored on an electronic platform to provide a referral system for testing and calibration services at a single touch point.

PNRI is the Philippine NNI mandated to undertake R&D activities in the peaceful uses of nuclear energy, to institute regulations on the said uses and to carry out the enforcement of said regulations to protect the health and safety of radiation workers and the general public. It originated from the Philippine Atomic Energy Commission (PAEC), established in 1958. Its vision is to become an institution of excellence – a provider of innovative and effective nuclear and radiation science and technology for national prosperity. The major facilities of PNRI for service and research are electron beam facility, gamma irradiation facility, radwaste management facility and Tc-99m generation facility. The Tc-99m facility in commissioning will be able to supply more than 40 hospitals in the Philippines which are equipped with nuclear medicine facilities. The local production of these radiopharmaceuticals is expected to save the medical industry up to around 20 percent of the average cost for imported Tc-99m. Considering that the Philippines is composed of 7107 islands grouped into 17 regions, OneLab is being formed to broaden public access to testing services from all Department of Science and Technology (DOST) laboratories and non-DOST laboratories to provide standardized services and fees.

The country report of Philippine showed the efforts of PNRI to promote its self-reliance and sustainability by increasing its capability of service for direct customers as well as participating in nationwide network activity to provide analytical services.

PNRI needs to develop a specific strategic plan for the suggest case study to upgrade the capability of the PNRI gamma irradiation facility to a commercial scale to be able to accommodate the increasing demands for irradiation services in the country.

3.2.7. Thailand

Ms N. Tanboon from Thailand Institute of Nuclear Technology (TINT) presented the country report titled 'Strategy for Self-reliance and Sustainability of TINT: A Lesson Learned from Thailand Nuclear Technology Service Centre'. She presented current technical and utilization status, issues and challenges and strategy for self-reliance and sustainability.

TINT is the Thai research institute which split off from the Office of Atoms for Peace in 2006 according to the policy to separate the nuclear regulatory body and the nuclear utilization activities. TINT is responsible for carrying out nuclear R&D, providing services based on nuclear technology and conducting education, training and outreach programme. There are several nuclear facilities, i.e. a 2 MW fission nuclear reactor, a gamma irradiator facility and a 20 MeV electron beam facility. Moreover, two other main facilities are in progress to enhance TINT's service capacity. An electron accelerator complex for food and medical instrument irradiation located in Pathumthani has a 10 MeV accelerator, a 3MeV accelerator and two convertible 5 MeV accelerators which can be converted to produce X ray. A cyclotron accelerator for medical purposes is under construction in the Nakorn Nayok Province. The Nuclear Technology Service Centre (NTSC) is the nuclear service centre under the supervision of TINT. NTSC is responsible for several types of nuclear technology services, for example, analysis of sample composition by using nuclear techniques, calibration of nuclear and radiation survey meters, NDT, and to certify radiation levels of food products for exporters. NTSC has continuously maintained a high level of service quality and customer satisfaction which leads to achieving the highest growth among TINT's service centres. Its revenue has increased more than 600% within 10 years (from $196,000 to $1.5 million). NTSC has contributed approximately 9 million USD to TINT (in total) and its growth rate is still in an uptrend for eight services. All of NTSC's revenue is contributed back to TINT which later on is distributed into TINT's fringe benefits, incentive regimes, research instruments and R&D projects. Every year, NTSC has launched new services, expanded services, or made new innovations to the market. The HR turnover rate has been almost zero. The key drivers for the success of NTSC are gathering market information and stimulating demand, demand prediction, technology prediction and technology gap analysis and business plan. The challenges that TINT is facing are as follows:

- Saturation of growth in some services, following a sigmoid shaped curve;
- Middle income trap: challenges to tune up R&D to comply with national directions.

Budget challenges also exist and they are as follows:

- Competition (TINT is not a monopoly, or oligopoly);
- Budget allocators benchmark and compare the socioeconomic impact results among the different government R&D organizations;
- Unexpected budget changes or needs.

For long term sustainability and partial self-reliance, the institute needs to enhance the efficiency of services and increase capacity of R&D by partly revenue from services.

TINT is applying the lessons learnt from NTSC with its 2 MW Thai research reactor (TRR-1) especially in satisfying stakeholders such as resource allocators, customers, regulators and staff. It includes the establishment of solid information on the financial and socioeconomic impacts, which will be also helpful to formulate the feasibility study of a new planned research reactor.

In summary, this country report showed a good example on how well-organized activities would contribute to self-reliance and sustainability of an NNI. In addition, the quantitative information on contribution of services to the management of TINT was also very informative and encouraging to other NNIs. TINT needs to include the socioeconomic impact analysis as a part of comprehensive infrastructure assessment for a new research reactor projects, which is the case study under RAS0080 project.

3.2.8. Viet Nam

Mr. D. V. Dong from the Viet Nam Atomic Energy Institute (VINATOM) presented the country report titled 'Results and Lessons Learned from Operation and Utilization of the Dalat Nuclear Research Reactor (DNRR)'. He presented and introduction of the DNRR utilization and explained lessons learnt.

VINATOM was founded in 1976 with the establishment of the Dalat Nuclear Research Institute, only a few years after the DNRR was inaugurated. It is a governmental institution that, acting under the authority of Viet Nam's Ministry of Science and Technology, is dedicated to science, research, development, education and training in nuclear sciences and technology. Since its foundation, VINATOM has become a large multidisciplinary organization with mandate in a diversity of areas, and as such it conducts and deploys basic research in atomic energy; it has the role of technical support organization for government management of atomic energy, radiation and nuclear safety; and provides E&T in the nuclear sciences and technology.

The DNRR, with nominal power of 500 kW, was reconstructed and upgraded from the USA 250 kW TRIGA Mark-II reactor built in the early 1960s. The renovated reactor was put into operation on 20 March 1984. In the framework of the programme on Russian Research Reactor Fuel Return and the programme on Reduced Enrichment for Research and Test Reactor, the DNRR core was partly converted from highly enriched uranium (HEU) to LEU in September 2007. It was designed for the purposes of radioisotope production, NAA, basic and applied research and nuclear E&T. For medicine applications, radioisotopes and radiopharmaceuticals have been delivered to 35 hospitals throughout the country. In total, over 8000 Ci of radioisotopes have been produced and supplied to medical users so far with a yearly average of about 500 Ci. As for the NAA service, a total of about 70000 samples have been irradiated at the reactor by the end of 2018 with a yearly average of 2000 samples. The strategic plan for the DNRR has been set up and regularly updated. The current plan for the next ten years shows that the DNRR could continue its safe operation and effective utilization at least until 2028. DNRR has received support and assistance from the Government, IAEA and bilateral cooperation through national projects, IAEA TC projects, as well as intergovernmental projects, such as the projects for renovation, modification and replacement of the reactor control and instrumentation system; the project on conversion of the reactor core fuel from HEU to LEU, the projects for installation and upgrading of the physical protection system for reactor facility, etc. Based on the on-the-job training a large amount of human resource with high skills and experiences on application of nuclear techniques in the country has been created.

The presentation showed that DNRR is a good example on how to use international or bilateral collaborations for the sustainability of a research reactor. The good practices from the strategic plan of DNRR need to be reflected in the preparation of a strategic plan for the case study under RAS0080 project.

4. CONCLUSIONS

The IAEA regional Asia and Pacific project RAS0080 "Promoting Self-Reliance and Sustainability of National Nuclear Institutions" started in 2018 and is expected to have a duration of four years. Its objective is to support the attainment of self-reliance and sustainability of NNIs in Member States in the region through direct involvement in the development and utilization of the appropriate tools so that any current shortcomings in their strategic plans or their interface with their respective national stakeholders can be addressed in a mutually beneficial manner. NNIs from Bangladesh, Cambodia, China, Indonesia, Iran, Jordan, Kuwait, Lebanon, Malaysia, Pakistan, Philippines, Singapore, Sri Lanka, Thailand and Viet Nam participate in the project.

The RAS0080 regional workshop on Sustainability and Self-Reliance of National Nuclear Institutions took place from 9–12 April 2019 in Daejeon, Korea, organized in conjunction with the International HANARO Symposium, hosted by the Korea Atomic Energy Research Institute and the Korean Nuclear Society. The workshop was attended by participants representing NNIs of Bangladesh, Indonesia, Jordan, Malaysia, Pakistan, the Philippines, Thailand and Viet Nam. Speakers from NNIs with well-established and efficiently operated facilities in Australia, India, Japan and Republic of Korea were also invited to participate in the workshop.

The participating NNIs operate a wide range of nuclear and radiation facilities, such as gamma and electron beam irradiators, ion beam accelerators, research reactors and ancillary facilities to develop R&D programmes, provide E&T in nuclear sciences and technologies, as well as products and services on a commercial basis. Some of the commercial activities of the regions' NNIs are gamma and electron beam irradiation, radioisotope production, multielemental analysis, materials testing, silicon doping, gem coloration and training courses.

The workshop provided a forum to present and discuss issues and challenges faced by participating Member States regarding self-reliance and sustainability of their NNIs as well as efforts and best practices to cope with these challenges. The participants agreed that although governmental policies, support and funding will continue to be a cornerstone for the success of many NNIs, such funding may not be enough to support their changing and often expanding mission. Therefore, the NNIs are encouraged to develop new approaches to effectively transform their R&D outputs into a viable increased offer of innovative products and services for a diversified range of users and stakeholders, including industry and other paying customers.

Several success stories and shared good practices and lessons learned in their efforts to achieve sustainability and self-reliance were presented. The participants agreed that the key elements that need to be considered and established for achieving self-reliance and sustainability are: strategic, financial and business planning; supply chain management; customer and business led management; stakeholder engagement; staff engagement, motivation and organization culture management; and the IMS. An opportunity of development in one or more of these areas was identified for each participating NNI, with emphasis on strategic planning, outreach, leadership and business management practices, management of organization, HRD and knowledge management, which were identified as the areas where more progress is needed.

It was noted by the participants that NNIs are solidly anchored to national goals and to the overall national developmental efforts, to which they are, in general, the main contributors in the area of nuclear science and technology. However, this contribution can be sometimes overlooked since it is not always directly translated into a direct financial and economic impact.

Finally, the participants considered that a methodology to determine the actual impact of NNIs, including non-material direct and indirect benefits, still needs to be established.

APPENDIX I: CONTRIBUTED PAPERS

INDIA: SUSTAINABILITY OF NATIONAL NUCLEAR ORGANIZATIONS

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Abstract

Several countries are planning their first/new research reactor as a key national facility for the development of their nuclear science and technology programmes, including nuclear power. The introduction of a new research reactor in a country requires the establishment of an adequate national infrastructure, covering a wide range of technical areas. This paper briefly describes certain special characteristics of a nuclear power programme which need to be kept in mind by government planners and policy makers before any country embarks on a nuclear energy programme. It also briefly describes the infrastructure and institutions that are required to be built for sustenance of a nuclear energy programme. In the end, it also describes India's nuclear energy programme.

1. INTRODUCTION

The initiation of a Nuclear Power Programme (NPP) in a country is a very important decision, as it requires lot of careful planning, preparation, investment of time and resources, and building of institutions and infrastructure. This is not only because it involves the use of special material which require safety, security and safeguards, but also because the NPP has some special characteristics, such as a long gestation period and fairly large time scale for which commitment is required.

The time required for the commencement of some fruitful economic benefits from the initial consideration of the nuclear energy option by a country is fairly large. Experience suggests that a typical time period from considering a small research reactor to the operation of its first nuclear power plant, one of the most popular applications of Nuclear Energy Programme, is about 10–15 years. This period could also be longer depending on various factors such as resources devoted to the programme and circumstances in the country. The government policymakers need to keep this aspect in mind.

There is one more important consideration that has to be made at the time of embarking on a NPP i.e. the time scales for the programme are fairly long. The programme requires a commitment typically for a period of about a few hundred years, from construction of a facility to its decommissioning and normal waste disposal. Generally, time required for construction of a reactor varies from 5 to 10 years depending on the complexity of the reactor. The operating phase of the reactor can last up to 60 years. Based on the complexity of a reactor and strategy adopted for decommissioning of a facility this activity may take a time period from few years to ~35 years for decommissioning. The disposal of waste generated from a reactor is another activity which requires lot of planning and preparations. The monitoring period for the normal radioactive waste disposal site is expected to be of the order of about 200 years. This period could be much larger in case one is considering backend options, or even if one is considering fuel storage. The policymakers need to take this fact into consideration before embarking on a Nuclear Power Programme.

Out of the total 818 [1] research reactors (RRs) built so far, 443 reactors have been decommissioned, 67 are being decommissioned, and 227 reactors are in operation. The remaining 81 reactors are in a state of temporary/extended or permanent shut down. Many of them are facing problems of obsolescence of equipment, lack of experimental programmes, lack of funding for operation & maintenance, loss of expertise & equipment, and ageing and retirement of staff. The state of these reactors is a matter of concern, from safety considerations.

2. INFRASTRUCTURE REQUIREMENTS FOR NEP SUSTENANCE

A review may be performed based on the 19 infrastructure issues as detailed in the IAEA Nuclear Energy Series No. NG-G-3.1 (Rev. 1) [2] “Milestones in the Development of a National Infrastructure for Nuclear Power”. This document provides guidance for infrastructure requirements for the introduction of nuclear power or even a new research reactor facility. Although this document is primarily meant for a power reactor programme, it is equally applicable for a research reactor.

2.1 SUSTAINABILITY REQUIREMENTS

Governmental Support and Funding at every stage is vital to the success of a nuclear energy programme. These long-term commitments require establishing a sustainable national infrastructure, which cannot be achieved without government support. Government leadership and funding is necessary during the gestation, de-commissioning and waste disposal, as there are no immediate commercial benefits accrued during this phase. During the operating phase, government support may also be necessary as a loan guarantor or for a power purchase agreement etc. One of the most important issue is careful consideration is required regarding the fact that there exists a non-zero possibility of a severe accident, consequences of which the country may need to deal with.

Legal and Regulatory Framework needs to establish responsibilities of all organizations for NPP. “National legislation should comprehensively cover all aspects of nuclear law (i.e. nuclear safety, nuclear security, safeguards and civil liability for nuclear damage). It should implement international legal instruments to which the country is a party or intends to become a party” [2]. Experience has proven that safety and credibility are best served by separating and enabling regulatory aspects of nuclear energy i.e. a complete independence of the regulatory organization from the operating organization is desirable.

Competent Human resource development is as important for the operator as it is for the regulatory body for sustainability. Other than scientific & technical skills, management and administration across most scientific and engineering disciplines are also necessary. Certain roles, like fuel fabrication, fuel reprocessing, reactor operation, etc. require several years of specialized training and experience of specific technology chosen for deployment. To ensure a sustainable workforce and continuity of knowledge, it is important for a country to expand its own education and training capabilities and develop an appropriate infrastructure for a regular supply of qualified and trained human resources.

Fuel Cycle management is one of the most important parts of the NPP. Fuel cycle has two components i.e. “Front End”, which spans from mining to fuel fabrication and “Back End” which spans from spent fuel storage to reprocessing & disposal of high-level waste. Both of the components require development of a fairly large infrastructure. All front-end services are routinely available internationally, however, back end functions are generally provided nationally, hence expertise in this field is necessary if one is considering a closed fuel cycle.

Radioactive waste management: There are three types of waste based on the half-life and the extent of heat generation of the rad-waste i.e. low, intermediate and high-level waste. ‘Near Surface Disposal’ refers to disposal within a few tens of meters, used for low level waste, which can hold the waste for few hundred years. The term ‘geological disposal’ generally refers to disposal in deep, stable geological formations, usually several hundred meters, this is used for intermediate and high-level waste. At present, high-level waste (HLW) liquid waste, generated during reprocessing of fuel, is converted to solids by ‘vitrification’ and is stored in interim storage facilities in absence of the stable geo-repositories.

Emergency Planning: Nuclear plants are designed to minimize the probability of large releases of radioactive material, but the probability is not zero, though very small. Emergency planning ensures capability to take actions that will effectively mitigate the consequences of an emergency, for the safety of plant personnel, emergency workers and public beyond the site boundary.

Environmental protection: During normal operation, small releases take place from the reactors. Though these releases are very small. The assessment of impacts on people and the environment from small releases of gaseous and liquid radioactive effluents during normal plant operation is necessary to ensure that this does not affect the environment.

Industrial Support: Many commodities, components and services are required to construct and support the operation of nuclear facilities; hence the role of industry is vital for sustainability. Facilities require an industry that can comply with nuclear codes, standards and quality requirements. Willingness of industry to participate in R&D activities is also necessary, for which special working and financial models have to be evolved. Development of special material and technology may also be necessary for certain requirements of the NPP, which the industry must cope with.

Stakeholders Support: Support of stakeholders is vital for the success of NPP. Stakeholder involvement is best achieved through an open dialogue between the government, owner/operator and all stakeholders. It is the responsibility of the owner/operator to conduct outreach programmes and to take efforts to convince the stakeholders that the nuclear energy programme is for the benefit of all.

3. REGIONAL CO-OPERATION

Considering the large infrastructure requirements, it is suggested to enhance regional cooperation and sharing of available resources. There exists a lot of scope for enhancing the utilisation of the existing facilities, in the field of basic research, irradiation studies, other experimentation and manpower training. Ideally, mutual agreements target to have a bare minimum number of facilities with maximum utilisation.

4. INDIAN NUCLEAR PROGRAMME

4.1 DEPARTMENT OF ATOMIC ENERGY INDIA

Department of Atomic Energy, India, comprises of 30 Units with 107 installations. Out of the 30 units there are six R&D units like “Bhabha Atomic Research Centre”, “Indira Gandhi Centre for Atomic Research” etc., five public sector undertakings like “Nuclear Power Corporation of India Ltd”, “Uranium Corporation of India Ltd”, “Electronics Corporation of India Ltd” etc. Three industrial facilities like “Heavy water Board”, “Nuclear Fuel Complex”, “Board of Radiation and Isotope Technology” and several other aided institutions as depicted in Fig. 1.

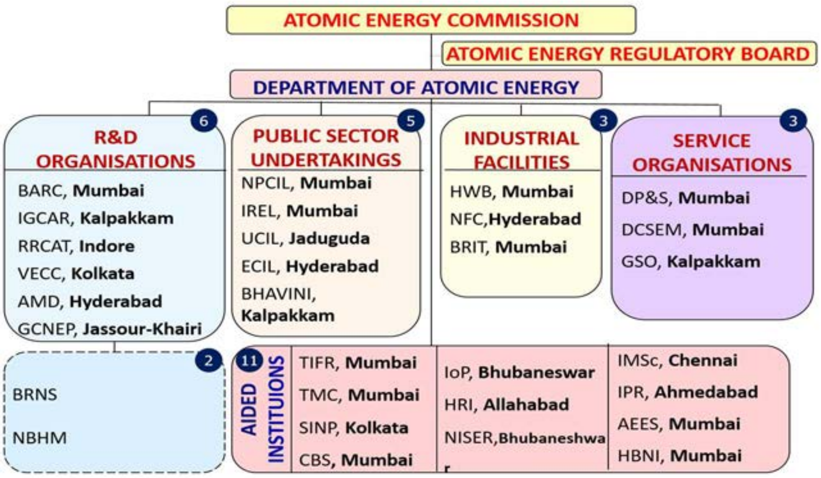

FIG. 1. Structure of the Department of Atomic Energy.

4.2 RESEARCH REACTORS

Research Reactors have been the backbone of the India's nuclear industry. They have provided valuable support in the development of the Indian Nuclear power programme in many ways, viz. testing of materials, fuel, equipment, shielding experiments, validation of codes, etc. During the course of construction of these reactors, many new technologies were developed which turned out to be the forerunners for use in power reactors.

4.2.1 Apsara

Apsara is a 1MW research reactor, founded by the "Indian Nuclear Programme". It became critical for the first time at 3.46 pm on August 4, 1956. Apsara was a swimming pool type reactor, fuelled with highly enriched Uranium as a Uranium–Aluminium alloy clad with Aluminium. The core is suspended from a movable trolley in an SS lined pool, 8.4 m long, 2.9 m wide and 8 m deep, filled with demineralised light water. It produced an average neutron flux of 1012 N/cm2/sec. This reactor was shut down permanently on 5th June 2009 and has been decommissioned.

4.2.2. Cirus

Cirus was a vertical tank type 40 MWth reactor. It was fuelled with natural uranium in metallic form. It was a heavy water moderated, graphite reflected and light water-cooled reactor. It produced a flux of 6.5×10^{13} n/cm^2/s and it became operational in July 1960. The Cirus reactor was permanently shut down on 31st Dec 2010 and is under decommissioning. It is observed that the core components are following the typical Co-60 pattern and radiation fields are reducing by half every five years, hence major activities are expected to decay in a period of 30 to 35 years. Deferred decommissioning policy has been adopted for decommissioning of Cirus reactor, for reducing the decommissioning cost. For the intervening period, the reactor is being maintained in preservation mode. Activities related to harvesting the locked-up data with respect to the behaviour of core structure material with irradiation is being carried out at present.

4.2.3. Dhruva

Dhruva is a 100 MWth tank type reactor, with metallic natural uranium as fuel, heavy water as moderator, coolant and reflector, giving a maximum thermal neutron flux of 1.8×10^{14} n/cm^2/ s.

The reactor became operational on 8th August 1985. It has completed nearly 34 years of operation.

Systematic In-Service Inspection (ISI), structured system performance monitoring & review and Periodic Safety Review (PSR) have been carried out. Based on these reviews, certain mid-term safety upgrades in various systems of Dhruva were executed. To combat obsolescence and aging, extensive refurbishment of certain reactor systems has been undertaken recently, without significantly affecting the reactor availability.

Over 370 TBq of various radioisotopes are produced, processed and supplied in over 5000 consignments to more than 1900 user institutions in India and abroad on monthly basis. Some of the major radioisotopes produced are Mo^{99}, I^{125}, I^{131}, Ir^{192}, Sm^{153}, Co^{60}, Lu^{177} etc.

4.2.4. Advanced Heavy Water Reactor and Critical Facility

The Advanced Heavy Water Reactor (AHWR) is a proposed 300 MWe vertical pressure tube type, boiling light water cooled and heavy water moderated reactor using ^{233}U-Th MOX and Pu-Th MOX fuel. It is aimed at the early utilization of thorium in the three-stage nuclear programme.

For conducting lattice physics experiments for validating AHWR core design parameters, a 100 W variable pitch reactor called Advanced Heavy Water Reactor Critical Facility (AHWR-CF) has been commissioned in 2008.

4.2.5. Apsara-Upgraded

Considering the versatility and ease for carrying out experiments in the old Apsara reactor, which was shut down in 2009, a decision was taken to construct another similar type of reactor with some upgraded features. Hence, a 2 MW pool type research reactor was commissioned in September 2018. Some of the important features of the reactor are given in Table 1.

TABLE 1. MAIN CHARACTERISTICS OF REACTOR APSARA-UPGRADED

Reactor Type	Pool type (with hot water layer & movable core)
Reactor power	2 MW
Max. thermal neutron flux	6.1×10^{13} n · cm^2 · s
Max. Fast neutron flux	1.3×10^{13} n · cm^2 · s
Fuel	LEU U_3Si_2 dispersed in Al, Plate type
Coolant / Moderator	Light Water
Reflector	BeO

4.2.6. Fast Breeder Test Reactor and Prototype Fast Breeder Reactor

The Fast Breeder Test Reactor (FBTR) is India's first fast reactor using plutonium-based fuel and molten sodium as coolant. It produces 40 MW_{th} (13.2 MW_e) power. It is mainly utilized for research and development of fast reactor technologies and it is in operation since October 1985. Major objectives for this reactor were as follows:

- Demonstration of the engineering feasibility of Liquid Metal Fast Breeder Reactor (LMFBR) in India;
- Irradiation test bed for LMFBR material development;
- Sodium coolant and component technology development;

- Fast Breeder Reactor (FBR) reprocessing technology development;
- Thorium utilization research.

A 500 MW prototype FBR has been constructed at Kalpakkam and is under commissioning.

4.2.7. Kamini U^{233} Reactor

Kamini is a 30 kW research reactor. It is the only reactor in the world operating with Thorium based Uranium-233 fuel. It is in operation since October 1996. It is operated only in campaign mode, based on the experimental requirements. Some of the important features of the reactor are given in Table 2.

TABLE 2. MAIN CHARACTERISTICS OF KAMINI REACTOR

Reactor Type	Tank Type
Reactor power	30 kW
Max. neutron flux	$1x\ 10^{12}\ n \cdot cm^2 \cdot s$
Fuel	LEU U^{233}-Al alloy. Plate type
Clad	0.5 mm Aluminium

4.2.8. Status of Power Reactors in India

India has 22 power reactors under operation, with a total generation capacity of 6780 MWe. Most of them are the 220 MW pressurized heavy water reactors (PHWR). 6 new 700 MW PHWRs and 2 new 1000 MW capacity pressurized water reactors (PWR) are under construction; this will enhance the power generation capacity by another 6700 MWs. First of the 700 MW_e reactors is likely to be commissioned by end of 2019. Further, this government has approved another set of ten 700 MW PHWR and two 1000 MW PWRs, this will further enhance the power generation by another 9000 MWs.

5. CONCLUSIONS

Nuclear energy provides a large number of social benefits by way of its applications for various radiation technologies in the field of medicine, industry, agriculture, food preservation, sterilization and research. More than that, it is also a clean source for power generation. Hence, growth of this industry worldwide, especially in the regions where there is rapid economic growth is quite inevitable. A clear understanding of all the implications of entering into the NEP, as brought out above, are required to be taken on board. End to end planning and preparations and building of institutions are necessary to see the programme through and to minimize safety and security risk.

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DEVELOPMENT AND COMMERCIALIZATION OF RADIOISOTOPES AND RADIOPHARMACEUTICALS IN INDONESIA

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Abstract

The National Nuclear Energy Agency (BATAN), established in 1958, is assigned by the government of the Republic of Indonesia to conduct research, development and utilization of nuclear energy in accordance to the provisions of the laws and regulations for the well-being of the people of the country. BATAN contributes significantly to the health sector through research and development of production of radioisotopes and radiopharmaceuticals, and their utilization for cancer diagnostics and therapy. A programme has been developed as an implementation framework and is implemented as a part of the IAEA Regional technical cooperation project RAS0080. This paper reports on the challenges and opportunities to be addressed during the implementation of the programme. Understanding regulation for medicinal products release is one of the challenges, and therefore the National Team has to consult to the National Agency for Drug and Food Control intensively. Another challenge is the slow increase in the number of hospitals that offer services of nuclear medicine. This challenge is quite hard, and it needs the involvement of stakeholders to overcome it. Information sharing from BATAN is necessarily important to increase interest to hospitals and medical communities in utilization of radioisotopes and radiopharmaceuticals for cancer disease management.

1. INTRODUCTION

The National Nuclear Energy Agency (BATAN), established in 1958, is assigned by the government of the Republic of Indonesia to conduct research, development and utilization of nuclear energy in accordance to the provisions of the laws and regulations for the well-being of the people of the country. BATAN contributes significantly to the health sector through research and development of production of radioisotopes and radiopharmaceuticals, and their utilization for cancer diagnostics and therapy.

As the economy of Indonesia develops significantly, the disease pattern of Indonesia changed from communicable diseases to non-communicable diseases. The trend of cancer prevalence in Indonesia is increasing from year to year. Cancer is one of the biggest causes of mortality in Indonesia. BATAN considers the need for radioisotopes and radiopharmaceuticals in Indonesia as increasing due to an increase in cancer cases in Indonesia which reached 1.4% of the population in 2019. The increased need for radioisotopes and radiopharmaceuticals is also due to the increase of hospitals numbers that are equipped with nuclear medical facilities.

The Centre for Radioisotope and Radiopharmaceuticals Technology (CRRT) of BATAN has been developing some radioisotopes and radiopharmaceuticals, and five (5) of them have been approved by the National Agency of Drug Food Control to be used for cancer-related treatment. CRRT-BATAN set up a cooperation with PT Kimia Farma, a government owned enterprise, to utilize the products of research and development of the CRRT for diagnostics as well as therapy in accordance to the regulations: Radiopharmaceutical Kits (MIBI, MDP, DTPA Kits); Labelled compounds (Sm-153-EDTMP and I-131-MIB). The cooperation with PT Kimia Farma is expected to meet the needs of hospitals to reduce the dependence on supplies from abroad, the problems of delivery time and high price in an effort to attain self-reliance in the radioisotopes and radiopharmaceutical fields. The cooperation is also intended to improve research, production and commercialization of radioisotopes and radiopharmaceuticals in Indonesia.

A strategic plan is developed by BATAN and PT Kimia Farma to ensure the sustainability and self-reliance of development, production and commercialization of radioisotope and radiopharmaceuticals in Indonesia. The strategic plan will serve as a guidance and direction for development and commercialization of radioisotope and radiopharmaceutical in the country. The strategic plan is dynamic in nature, so it may be updated according to internal organizational changes, technology and stakeholder needs.

2. OBJECTIVES

The programme is developed with the following objectives:

- New radiopharmaceuticals production facility obtains GMP certification in 2019;
- Increase of radiopharmaceutical products approval by the National Agency for Drug and Food Control from 5 to 7 products in 2020;
- Increase utilization of radiopharmaceuticals produced in the country from 1000 vials to be 3000 vials by the year of 2021.

3. NATIONAL TEAM

A national team is established to manage the programme. The team consists of personnel from BATAN working units responsible for reactor operation, radioisotopes and radiopharmaceuticals development, promotion and dissemination, public relation and cooperation, engineering, and capacity building. There are also personnel from PT. Kimia Farma who are responsible for production, registration and commercialization. Figure 1 shows the organization to implement the programme. Appendix A shows the role sharing among the national team organization.

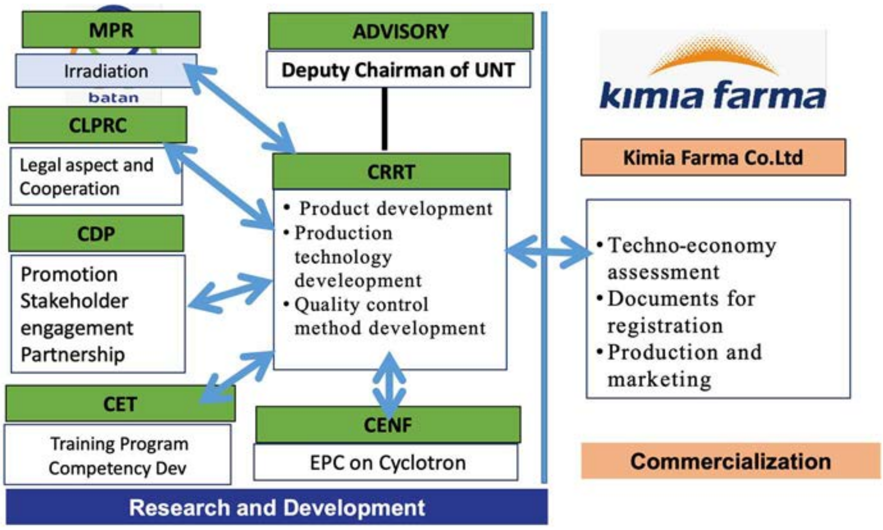

FIG. 1. National Team Organization.

4. STAKEHOLDERS

It is necessary to identify stakeholders, their needs and interests for the development, production and commercialization of the radioisotopes and radiopharmaceuticals (RR). Stakeholders may be grouped as external or internal of BATAN. Table 1 shows the main stakeholders identified so far.

The existing users of radioisotopes and radiopharmaceuticals in Indonesia are 13 hospitals equipped with nuclear medicine facilities, and there are 2 hospitals tied cooperation with BATAN on utilization of research product: Dharmais Cancer Central Hospital and MRCCC Siloam Hospital. In the fields of competence building and product development, BATAN had cooperation agreements some leading universities in Indonesia: University of Padjadjaran, University of Indonesia, Bandung Institute of Technology. The cooperation is aimed to increase utilization and development of nuclear science and technology in the field of Physics, Chemistry, Biology and Pharmacy, Mathematics and Statistics in relation with radioisotopes and radiopharmaceuticals development.

5. FACILITY DESCRIPTION

Development, production and commercialization of the radioisotope and radiopharmaceutical products utilizes the existing facilities of BATAN as follows:

- Nuclear reactor: Multi Purposes Reactor and neutron beam source for radioisotope production;
- Hot cells: facility for irradiated target processing in radioisotope production;
- Mini cells: for producing labelled compound;
- Clean rooms: for preparing radiopharmaceutical kits in aseptic process, with existing freeze dryer of 125 vials /batch (it will be expanded to 1000 vials/batch);
- Quality control equipment: for measuring radionuclide purity, radiochemical purity, sterility, apyrogenicity, pH;
- Management system: Quality Management System, ISO 19075, OHSMS.

It is agreed that the role for marketing and commercialization of the products is given to PT. Kimia Farma, and then consequently, PT. Kimia Farma may use all its facilities and resources to execute this role.

6. PRODUCTION CAPACITY

The existing and potential capacity to produce of radioisotopes and radiopharmaceuticals in Indonesia are given in Table 2.

7. SWOT ANALYSIS AND RISK ASSESSMENT

7.1. SWOT

A SWOT analysis was conducted to identify the influencing factors for the development, production, commercialization and utilization of radioisotopes and radiopharmaceuticals in Indonesia, and the evaluation results are written in Table 3.

7.2. PROBABILISTIC RISK ASSESMENT FOR DETERMINED PRIORITY FOR ACTION

Based on the Weaknesses and Threats of the SWOT analyses that are of significance to the ability of the DCRRI to achieve its strategic issues are given in Table 4.

TABLE 1. STAKEHOLDERS FOR DEVELOPMENT AND COMMERCIALIZATION

No	Stakeholders	Role/Needs
		External
1	Hospitals	- Utilization of the products - Expect sustainable supply with high quality, availability, safety assurance in proper quantity
2	Public	- Users of the products - Expect products safety assurance, healthiness, valid information on RR products and medical procedures, and affordable price
3	Professional Community on nuclear medicine	- Promoters for products utilization - Partners in products development - Expects reliable information related RR products and development, and capacity building
3	Industry: Equipment Distributor and Transportation of RR	Expect sustainable supply of RR to ensure the optimum utilization of equipment
4	Ministry of Health	Provides policy and regulation on nuclear medicine
5	Ministry of Research Technology and Higher education	Provides policy on R & D and product utilization promoter
7	Nuclear Energy Regulatory Agency (BAPETEN), regulation	- Regulator and inspector of nuclear safety - Provides nuclear regulation and inspection
8	National Agency for Drug & Food Control (BPOM)	- Regulator and inspector of safety of food and drug - Provides food and drug regulation and inspection
9	University with nuclear medicine and pharmaceutical programme	- Promoters for products utilization - Partners in products and human resources development - Expects reliable information related RR products and development, and capacity building
10	IAEA	- Promoters for products utilization - Partners in products and human resources development - Provides recommendations and support for capacity building
		Internal
9	Kimia Farma Management	- Promoters for products utilization - Partners in products development and commercialization - Supports Added Value for stakeholders, good Government Corporate practices, business development - Expects reliable information related RR products and development

TABLE 1. STAKEHOLDERS FOR DEVELOPMENT AND COMMERCIALIZATION (cont.)

No	Stakeholders	Role/Needs
		Internal
10	BATAN Management	- Developer of the product - Promoter for product utilization - Provides reliable information related RR products and development, and capacity building
11	Employee	- Executers of the programme - Expect safety, career path, good working environment, and trust

TABLE 2. PRODUCTION CAPACITY

No	RR Product	Existing Capability	Potential Capability	Remark
		BATAN		
1	3 radiopharmaceutical kits (MBI, DTPA, MDP)	1000 vials/year	6000–24000 vials/ year	The potential market demand is 10 hospitals × 3 vials × 5 days × 40 weeks = 4000 vials/year
2	Label Compound ^{153}Sm-EDTMP	200 × 50 mCi/year	600 vials × 50 mCi/year	10 hospitals × 6 per month × 10 months = 600 vials
3	Label Compound ^{131}I-MIBG for diagnosis	100 × 5 mCi/year	1000 vial × 5 mCi/year	
4	Ethambuthol	Registration	Market entry 2020	
5	Label Compound ^{131}I-MIBG for therapy	Dev. process	Registration 2020	
6	Iodine-131 capsule	Dev. Process	Registration 2020	
		Kimia Farma		
7	Hospital / User	6	15	
8	Commercialization target	TBD	TBD	

TABLE 3. SWOT ANALYSIS

STRENGTHS	WEAKNESSES
• Extensive experience in R&D • Extensive experience in pharmaceutical production • Experience in marketing practices during the commercialization phase of several research products • Adequate competence owned by senior HR • Existing Research Reactor with suitable capability for RR production • Application of QMS and OHSMS • cGMP	• Low production capacity • Low product commercialization or low market share • Human resources and facility ageing • Senior-Junior Competence Gap • Limited development of new technology in cyclotron-based RR • Lack of capacity in RR transportation
OPPORTUNITIES	**THREATHS**
• Increasing Specialization in Nuclear Medical • Potential Demand from hospital patients (oncology and cardiology) • IAEA Support • International Network	• The lack of knowledge of Stakeholder on advantages of NM • Lack of competence of end users in RR handling during application • Limited nuclear medicine facility at hospitals • High safety and quality requirements • Rapid development of Cyclotron-based RR • Global & regional free trade • High investment for new facility

TABLE 4. PROBALILISTIC RISK ASSESMENT

No	Risk Area	Risk Definition	Risk Mitigation
1	Low production capacity	Not adequate production capacity	Developing new facility with larger capacity production to increase cap
2	Low product Commercialization	Lack of supply	Cooperation for commercialization, Market study and creation
3	Ageing personnel	Lack of personnel	Hiring new personnel
4	Ageing facility	Facility damage & malfunction due to age	Revitalization of facility
5	Competency gap between senior-junior personnel	Delay in products development and production due to lack of competence personnel	Training and capacity building for potential personnel
6	Limited experience in cyclotron-based RR	High competition between cyclotron-based and reactor-based RR	Training and OJT on Cyclotron Based RR to increase personnel capacity and technology mastery
7	Lack of capacity in RR transportation system.	Failure or delay in on-time product delivery	Cooperation with forwarding services companies to increase the delivery capabilities
8	Lack of knowledge of stakeholders on advantages of nuclear medicine	Unutilized nuclear medical facilities	Engagement programme to increase awareness on advantages of Nuclear Medical Applications
9	Lack of competence of users in handling RR	Unsafe action and inaccurate treatment	Training and OJT on RR handling procedures
10	Limited nuclear medicine facility	Untreated cancer patients due to limited number of nuclear facilities nation-wide	Promoting the advantage of nuclear medical application to increase the stakeholders' interest in new facilities investment
11	High safety and quality requirements	Delay in development, utilization and facility licensing	Giving assistance related to safety and quality requirements
12	Global & regional free trade	More competitive market with RR suppliers from abroad, and the existence of unregistered products	Promoting better services and added value to customers
13	High investment	Limited investment in new nuclear medical facility	Promoting cooperation in facilities operation

8. DECISIONS AND STRATEGY

The outcome of the assessment of the needs of the stakeholders, combined with the SWOT and PRA results are used for decision making and recommendations on the strategies. Based on these considerations, the Indonesian national team developed a capability matrix to overcome the weakness and threat as given in Table 5.

TABLE 5. STRATEGIES: CAPABILITY MATRIX

Weaknesses/Threats	Can do	Could do	Can't do	Don't want to do
Low production capacity	Build new production installation	Work in shifts		
Low Product Commercialization	Collaborative commercialization activities	Mapping potential market and promotion	Direct commercializa-tion	
Aging Personnel	Hire new employee	Outsourcing		
Ageing facility	Gradual Revitalization		Total Revitalization	
Competence gap of senior and junior personnel	Training and OJT			
Limited experience in cyclotron-based RR	Study and Study	Fellowship programme		
Lack of capacity in RR transportation system.	Give technical assistance	Cooperation with transporter	Implemented by Batan	
Lack of knowledge of stakeholders on advantages of nuclear medicine	Awareness on advantage of nuclear medical applications			
Lack of competence of users in handling RR	Training and OJT on handling of RR	OJT on handling of RR		
Limited nuclear medicine facility	Promoting the advantage of nuclear medical applications			
High safety and quality requirements	Give assistance related safety and quality requirement			
Free trade, Competitor	Give better services and added value			
High Investment	Cooperation on Operation			

Based on the SWOT analysis and capability matrix, the following grand strategy is adopted:

- Increase the production capacity RR to match the demand from hospital for oncology and cardiology;
- Use business experience to support development of the nuclear medicine facility in hospitals for potential expansion.

9. TARGETS

9.1. PROGRAMME TARGETS

As is noted above, the main objectives of the programme are to increase development, production, commercialization and Utilization of radioisotopes and radiopharmaceuticals in Indonesia. Table 6 shows the targets set for the programme.

TABLE 6. TARGETS OF THE PROGRAMME

No	RR Product	Target	Year	Remark
1	Develop New Facility RR Production			
	Licensing new facility	cGMP and Safety	2019	
2	Production, Commercialization and utilization of RR in hospital			
	Produce 3 Radiopharmaceutical Kit (MBI, DTPA, MDP)	6000 vial/year	2020	
	Produce Label Compound ^{153}Sm-EDTMP	400 x 50 mCi/year	2019	
	Label Compound ^{131}I-MIBG for diagnosis	200 x 5 mCi/year		
3	Development, Clinical study and product Registration			
	Ethambuthol	Market entry	2019	
	Label Compound ^{131}I-MIBG for therapy	Registration	2020	
	Iodine-131 capsule	Registration	2020	
4	Increased the hospital with nuclear medical facility			
	Hospital/Users from 9-15 hospitals	15 hospitals with nuclear medical facility	2020	
5	Increase The commercialization of RR			
	Market Study and Survey	Potential market in Indonesia	2018	
	Marketing the Product	As Production capacity	2019	

9.2. RISK ASSESSMENT

Based on the weaknesses and threats of the SWOT analyses that are of significance to the ability of the DCRRI to achieve its strategic issues are as follows, a risk assessment was done, summarized in Table 7.

TABLE 7. RISK ASSESSMENT RESULTS

No	Specific Objective	Risk Area	P	I	Risk	Mitigate
1	**Develop New Facility RR Production**					
		Does not meet the specification of lab and equipment Sect	2	5	10	
		Delay in Licensing	4	5	20	
		Delay cGMP facility	3	5	15	
2	**Production, Commercialization and utilization of RR in hospital**					
	Produce 3 radiopharmaceutical kits (MBI, DTPA, MDP), 6000 vial / year in 2020	Does not meet GMP requirements	3	5	15	Technical supervision
		Delay on Procurement equipment	2	5	10	Monitoring and Evaluation
		Competitor product	5	4	20	
		Product complained	3	4	12	
		Delivery Delay	2	5	10	
	Produce Label Compound ^{153}Sm-EDTMP	Unplanned shut down of the RR	2	5	10	
		Does not meet GMP requirement	3	5	15	
		Delay on Procurement equipment	2	5	10	
		Competitor product	2	4	8	
		Product complained	3	4	12	
		Delivery Delay	4	4	16	

TABLE 7. RISK ASSESSMENT RESULTS (CONT.)

No	Specific Objective	Risk Area	P	I	Risk	Mitigate
3	**Development, Clinical study and Product Registration**					
	Ethambuthol, Obtain marketing approval	limited data on efficacy	4	5	20	
		Does not meet GMP requirement	3	5	15	
		Competitor product	2	4	8	
		Product complaints	3	4	12	
	Iodine Capsule and Label Compound ^{131}I-MIBG for therapy	Limited data on efficacy	4	5	20	
		Does not meet GMP requirement	3	5	15	
		Competitor product	2	4	8	
		Product complaints	3	4	12	
4	**Increase number of hospitals with nuclear medical facility**					
	Increase Hospital/User from 9 to 15 hospital	Lack Of nuclear medical facility	5	5	25	
		Lack of Specialist personnel	5	5	25	
		Lack of facility Licensing	4	5	25	
5	**Increase commercialization of RR**					
	Market Survey	Delay of result	2	4	8	
		Un sufficient data	3	5	15	
	Marketing the Product	Delay in supply of RR	1	4	4	
		Product complaints	1	4	4	
		Competitor product	2	4	8	

10. PROGRAM ACTION PLANS

The action plan of the programme is summarized in Table 8. More detailed action plans are given in Appendix B.

TABLE 8. SUMMARY OF THE ACTION PLANS

No	**Activity (PIC)**	**PIC**	**2018**		**2019**				**2020**				**2021**			
			Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	FGD Develop Strategic Planning DCoRRI	CRRT		X												
2	Market Survey	KF		X												
3	Marketing product	KF		X	X	X	X	X								
4	Scaling up production capacity using new facility	CRRT		X												
5	cGMP certification for new facility	CRRT		X	X											
6	Training, coaching and mentoring for young personnel	CET				X	X	X	X	X	X	X	X	X	X	X
7	Promotion of approved radiopharmaceuticals to users	KF		X	X	X	X									
8	Production of RR	CRRT				X	X	X	X	X	X	X	X	X	X	X
9	Development of RR	CRRT				X	X	X	x	x	X	X	X	X	X	X
10	Marketing	KF				X	X	X	X	X	X	X	X	X	X	X
11	Stakeholder engagement for RR hospitals and/or nuclear medicine society	CDP		X			X				X				X	
12	FGD on regulatory aspects	CRRT			X											
13	EPC of Cyclotron	CENF								X	X	X	X	X	X	X

11. REVIEW AND STATUS REPORTING

Reporting on the programme was conducted in each quarter, and the monitoring evaluation was conducted very semester. Management review is conducted every year.

12. FINANCING

The project on the development, production and commercialization of the radioisotope and radiopharmaceutical in Indonesia funded by BATAN and PT Kimia with cost-sharing according to the activities as follow:

- Research and development of radioisotope and radiopharmaceutical technology programme (CRRT-Budget) USD 1 million. From a total budget USD 3 million;

- Training Program related to Nuclear Science and Technology (CET – Budget), USD 0.4 million revenue from USD 2 million, i.e. 20%;
- Dissemination and partnership on Nuclear Science Technology (CDP Budget);
- Feasibility Study, market survey and commercialization (KF Budget).

13. OUTREACH AND MARKETING

To address the challenges in the low commercialization of the RR products, BATAN in cooperation with PT. Kimia Farma will conduct collaborative and integrated market studies and develop promotional campaign strategies to increase stakeholders' awareness and interest. The goals of these collaborative works, illustrated in Fig. 2, are:

- Increasing medical sector stakeholders' awareness in the potential use of RR products to address medical services consumers demand;
- Creating new market for RR products commercialization;
- Increasing the application of RR products to address national health sector challenges;
- Building collaborative cooperation with private sectors in RR products commercialization.

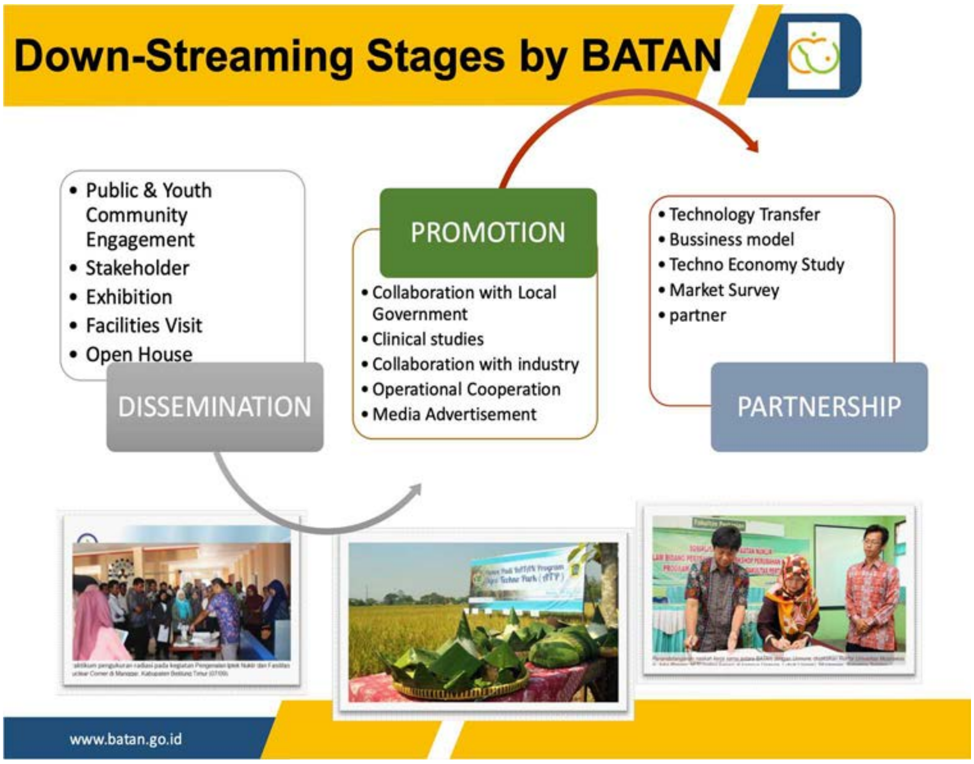

FIG. 2. Down streaming stages by BATAN.

The collaborative programme for RR products commercialization will be carried out through these specific activities:

- Comprehensive market study for RR products utilization
  The study will involve the research on existing and potential demand of RR products at hospitals, the number of interested hospitals for new investment, human resources related aspects, market competition, business process for commercialization stages;
- Promotion and Marketing Activities.
  BATAN will take its role in conducting promotion activities to related stakeholders to increase their interest in RR products utilization, increasing support from related

government agencies in providing proper regulation and assistance to potential users. In the marketing stages, PT. Kimia Farma will take role in promoting RR products to end users through adequate engagement. Several activities identified need to be developed, including:

- o Engagement with hospitals as end users of nuclear medicine;
- o Involving Key Opinion Leaders (KOL) from related agencies and institutions to create cooperative atmosphere among stakeholders in products utilization;
- o Increasing Field Promotion Personnel (Medical Representative) knowledge on RR products to ensure correct information delivery to end users;
- o Engagement activities for medical professionals in the field of oncology, cardiology and urology;
- o Development of export trade business plan for regional and international market expansion;
- o Increasing products and brand awareness by participating in medical professional activities and nuclear related events (exhibitions, conference, seminar, and others);
- o Commercial promotion activities using suitable communication channels.

- Regulatory & Policy Maker Engagement.

14. IMPLEMENTATION

The programme has been implemented, and the targets achieved are shown in Table 9.

TABLE 9. PROGRAMME IMPLEMENTATION

No.	RR Product	Target	Year	Result
1	**Develop New Facility for RR Production**			
	Licensing new facility	cGMP and Safety	2019	License from Nuclear Regulatory Agency (Bapeten) has been obtained. The facility is still evaluated by Food and Drug Control Agency (BPOM) for GMP licensing.
2	**Production, Commercialization and utilization of RR in hospital**			
	Produce 3 Radiopharmaceutical Kit (MBI, DTPA, MDP)	6000 vial/year	2020	Main equipment of new freeze dryer with maximum capacity of 1000 vials per batch has been installed. Qualification of the equipment has been carried out. The qualification results meet the requirements.
	Produce Label Compound ^{153}Sm-EDTMP	400 × 50 mCi / year	2019	The uses of ^{153}Sm-EDTMP increases. Last year about 9 Ci was used in one year. In 6 months of 2020, the use was about 7 Ci (140×50mCi). It is predicted that in 2020 will be about 300x50mCi in a year.
	Label Compound ^{131}I-MIBG for diagnosis	200 × 5 mCi/ year		The production capacity of I-131 as the active material increases to 7 Ci/batch. However, the demand is still low, less than 10×5mCi in a year.

TABLE 9. PROGRAMME IMPLEMENTATION (CONT.)

No.	RR Product	Target	Year	Result
3	**Development, Clinical study and product Registration**			
	Ethambuthol	Market entry	2019	The registration process to Food and Drug Control Agency is still on going.
	Label Compound ^{131}I-MIBG for therapy	Registration	2020	^{131}I-MIBG for therapy is successfully registered. Marketing approval of ^{131}I-MIBG for therapy is obtained from Food and Drug Control Agency.
	Iodine-131 capsule	Registration	2020	The production capacity of I-131 as the active material increase to 7 Ci/batch. In Indonesia, I-131 oral solution is preferred for oral preparation. At present, oral solution product is developed.
4	**Increased number of hospitals with nuclear medical facility**			
	Hospital / User from 9 to 15 hospitals	15 hospitals with nuclear medical facility	2020	At present, active hospitals are still 9 hospitals. Some hospitals are revitalizing the facility and equipment for nuclear medicine services.
5	**Increased commercialization of RR**			
	Market Study and Survey	Potential market in Indonesia	2018	Market survey was conducted by state-own company of PT Kimia Farma. The market size and characterization of radiopharmaceuticals in Indonesia have been surveyed.
	Marketing the Product	As Production capacity	2019	Several national exhibitions have been attended. ^{153}Sm-EDTMP participated in competition of public service innovation in Indonesia for introducing the product to the public. ^{153}Sm-EDTMP becomes one of the Top-45 Public Service Innovation in Indonesia in 2020.

15. CLOSING STATEMENT

Knowing that the needs for radioisotopes and radiopharmaceuticals is increasing, BATAN would like to contribute to the development of radioisotopes and radiopharmaceutical production as well as its commercialization. A programme has been developed as an implementation framework in cooperation with PT. Kimia Farma. The programme is implemented as a part of IAEA Regional TC Project of RAS 0080, and therefore it may obtain IAEA assistance in its implementation.

The potential for utilization of radioisotopes and radiopharmaceuticals is very prospective. Very recently, 153Sm-EDTMP product utilization is appreciated as one of the Top-45 Public Service Innovation in Indonesia in 2020.

Nevertheless, there are many challenges to be addressed during the implementation of the programme. Understanding of regulation for release of medicinal products is one of the challenges, and therefore the National Team has to consult with the National Agency for Drug and Food Control intensively. Another challenge is the slow increase in the number of hospitals that offers service of nuclear medicine. This challenge is quite hard, and it needs involvement of stakeholders to overcome it. Information sharing from BATAN is necessarily important to increase interest to hospitals and medical communities in utilization of radioisotopes and radiopharmaceuticals for cancer disease management.

APPENDIX A

The activities of the National Team are given in Table A.1.

TABLE A.1. ACTIVITIES OF THE NATIONAL TEAM

Description	Activity	Responsible Group	Period	Priority
(1) Scaling-up production facility using new facility	Preparing new facility, validation of production process, document submission to food and drug control agency	Centre for Radioisotope and Radiopharmaceutical Technology	Finish Dec. 2018	High
(2) cGMP certification for new facility	Preparation, Summation, evaluation, Correction, Certification	CRRT	Finish Nov. 2019	High
(2) Market survey, Promotion of commercialized product to users	Preparing promotion kits, promoting product in appropriate events dan direct promotion to users	PT Kimia Farma	Start Aug. 2018	
(3) Introduction of R&D products to users	Preparing introduction kits, promoting product in appropriate events	CDP	2019	
(4) Coaching and mentoring for new personnel	Preparing syllabus, coaching and mentoring, evaluation	CET	2019	
(5) Production of RR	Prepare the raw material, synthesis, separation, purification and QA	CRRT	2019–2021	
(6) Development of RR Marketing	Engagement of end user, increase competencies of medical professionals and medical representatives	KF	2019-	
(7) Stakeholder engagement for RR hospitals and/or nuclear medicine society	FGD, Seminar. Gathering	CDP	2019–2021	
(8) FGD on regulatory aspects	FGD, Consultancy	CRRT/CDP/CET	2019	
(9) EPC of Cyclotron	Cooperation, Design, Engineering, Procurement and Construction, Commissioning and operation	CENF	2021	

APPENDIX B

The Action Plans are given in Table B.1.

TABLE B.1. ACTION PLANS

Activity	Detail	Responsibility	Start	Finish	Resources	Participation
(1) Scaling-up production facility using new facility	Preparing new facility, validation of production process, document submission for Licensing	CRRT	2017	2018	CRRT Budget	
(2) cGMP certification for new facility	Preparation, Summation, evaluation, Correction, Certification	CRRT	Jan., 2019	Nov. 2019	CRRT Budget	
(2) Market survey, Promotion of commercialized product to users	Preparation for tender Tender Market survey Reporting	Kimia Farma Vendor	Jun. 2018	Nov. 2018	Internal funds	Business Development KF
(3) Introduction of R&D products to users	Preparing introduction kits, promoting product in appropriate events	CDP			CDP Budget	
(4) Coaching and mentoring for new personnel	Preparing syllabus, coaching and mentoring, evaluation	CET			CET Budget	
(5) Production of RR						
(6) Development of RR Marketing		KF				
(7) Stakeholder engagement for RR hospitals and/or nuclear medicine society	Preparation, FGD, Evaluation	CPD/CRRT				
(8) FGD on regulatory aspects		CPD/CRRT				
(9) EPC of Cyclotron		CENF				

JAPAN: DECOMMISSIONING OF JMTR AND STUDY FOR CONSTRUCTION OF A NEW MATERIAL TESTING REACTOR

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Abstract

The JMTR operation was once stopped in order to be checked & reviewed in August 2006, and the refurbishment and restart of the JMTR was finally determined by the national discussion. The refurbishment was started in FY2007 and was finished in March 2011. However, on March 11, 2011, the Great-Eastern-Japan-Earthquake occurred, and functional tests before the JMTR restart were delayed. On the other hand, based on the safety assessments considering the 2011 earthquake new regulatory requirements were established on December 18, 2013 by the NRA. The new regulatory requirements include the satisfaction of integrities for the updated earthquake forces, tsunami, the consideration of natural phenomena, and the management of consideration in the Beyond Design Basis Accidents (BDBA) to protect fuel damage and to mitigate impact of the accidents. Analyses related to the new regulatory requirements have intensively been performed timely, and an application to the NRA had been submitted in March 27, 2015. After submission of the application, a seismic resistance assessment of the JMTR reactor building was carried out by assuming the standard earthquake ground motion of 810 gal. As a result, it was found that seismic reinforcement work for reactor building and reactor pool wall were required. As a result, it became clear that at least 7 years of reinforcement work and a cost of about 40 billion yen are required for seismic reinforcement and to meet new regulatory standards. At the same time, it was made clear that high availability such as 8 operation cycles per year as originally planned cannot be expected due to aging problem. For this reason, JAEA positioned the JMTR as a decommissioning facility in the mid- and long-term plan of JAEA announced in April 2017. JAEA started to study the construction of a new material testing reactor. The examination results will be compiled by the end of FY2019.

1. INTRODUCTION

The Japan Materials Testing Reactor (JMTR) is a light water cooled and moderated tank type research reactor with 50MW thermal power [1], [2]. From its first criticality in March 1968, the JMTR has been utilized for the fuel/material irradiation examinations of the LWRs, the HTGR and nuclear fusion research as well as for radioisotope (RI) production. Specifications of the JMTR is shown in Table 1 [2]. A bird's eye view of the JMTR with its related facilities are shown in Fig. 1 and the cross section of the core is shown in Fig. 2.

The JMTR operation was once stopped in order to have a check and review in August 2006, and the refurbishment and restart of the JMTR was finally determined after the national discussion. The refurbishment was started from JFY 2007 and was finished in March 2011. However, on March 11, 2011, the Great-East-Japan-Earthquake occurred, and the functional tests before the JMTR restart were delayed. Based on the safety assessments considering the Great-East-Japan-Earthquake in 2011, new regulatory requirements for research and test reactors were established on Dec.18, 2013 by the NRA (Nuclear Regulation Authority).

The new regulatory requirements include the satisfaction of integrities for the updated earthquake forces, tsunamis, the consideration of natural phenomena, the provision of manuals for full evacuation, and the management of consideration in the Beyond Design Basis Accidents to protect fuel damage and to mitigate impact of the accidents. The above analyses have intensively been performed, and an application to the NRA was submitted on March 27, 2015.

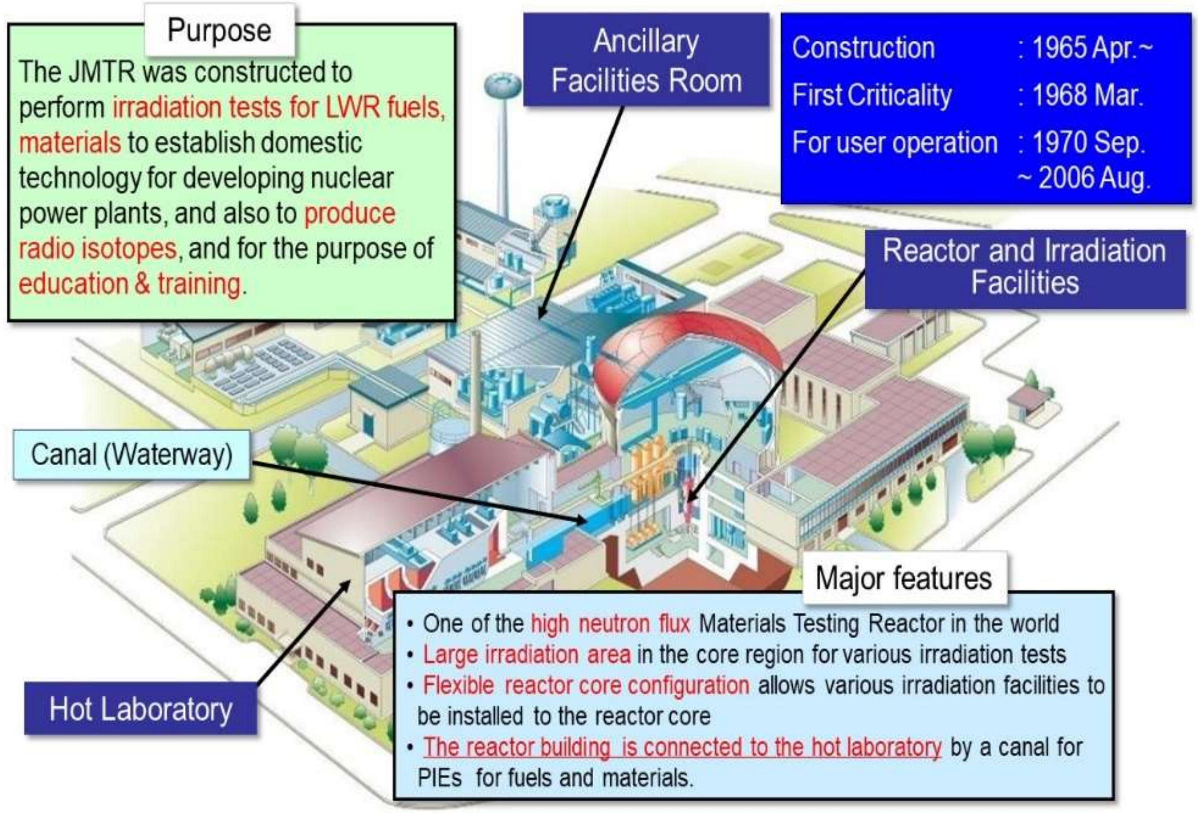


FIG. 1. Bird's eye view of the JMTR.

After submission of the application, a seismic resistance assessment of the JMTR reactor building was carried out by assuming the standard earthquake ground motion of 810 gal. It was found that seismic reinforcement work for reactor building and reactor pool wall were required. It became clear that at least 7 years of reinforcement work period and cost of about 40 billion yen are required for seismic reinforcement and to meet new regulatory standards. At the same time, it was made clear that high availability such as 8 operation cycles per year as originally planned cannot be expected due to aging problem. For this reason, JAEA positioned JMTR as a decommissioning facility in the mid- and long-term plan of JAEA announced in April 2017. JAEA started to study the construction of a new material testing reactor. The examination results will be compiled by the end of FY2019. In this paper, the current situations of JMTR are described.

TABLE 1. SPECIFICATIONS OF JMTR

Reactor Power	50 MWt
Fast Neutron Flux (Max.)	4×10^{18} n · m^{-2} · s
Thermal Neutron Flux (Max.)	4×10^{18} n · m^{-2} · s
Flow Primary Coolant	6000 m^3/h
Coolant Temperature	49 °C / 56°C
Core Height	750mm
Fuel (plate type)	19.8% ^{235}U
Irradiation Capability (Max.)	60 (20*) capsules
Fluence/y (Max.)	3×10^{25} n/m^2
dpa/y of SUS (Max.)	4 dpa
Diameter of Capsule	30–110 mm
Temp. Control (Max.)	2000 °C
Average Power Density	425 MW/m^3

* Capsule with in-situ measurement

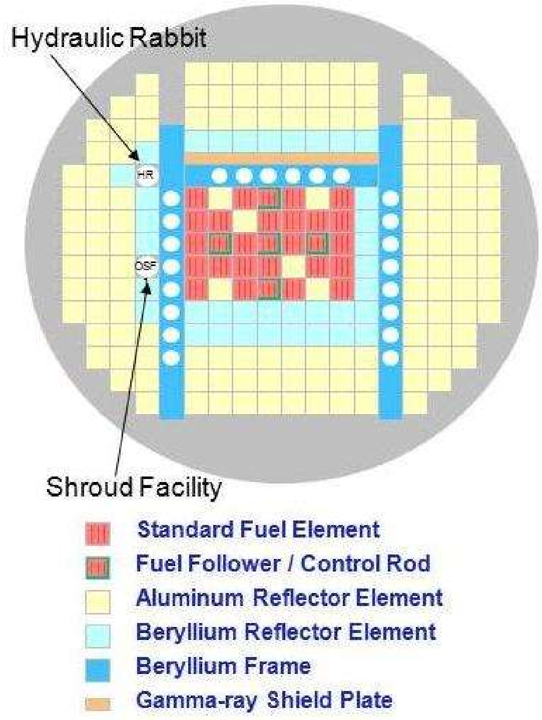


FIG. 2 Cross section of the JMTR core.

2. NEW IRRADIATION AND POST IRRADIATION FACILITIES

The JMTR is expected to be used as important infrastructure for safety research of fuels and materials for nuclear power plants, basic research for nuclear science, industrial utilization, and human resource developments of nuclear engineers as well as operators. In June 2010, the project named "Birth of the nuclear techno-park with the JMTR" was selected as one of projects of the Leading-edge Research Infrastructure Programme by Japanese government. The new project is to install new irradiation facilities and PIE facilities to the JMTR and JMTR-HL in order to promote basic as well as applied research. This new installation of irradiation facilities and PIE facilities are shown in Fig. 3 to Fig. 5. In these facilities, such as BOCA capsules and manipulator in hot cell can be treated until 110GWd/t. And also, in the project, development of user-friendly environment especially for young researchers is highlighted.

3. NEW REGULATORY REQUIREMENTS

Based on the safety assessments considering the Great-East-Japan-Earthquake in 2011, new regulatory requirements for research and test reactors have been established on Dec.18, 2013 by the NRA. Major features of the new regulatory requirements for the research and test reactors are shown as follows [3]:

- Accurate evaluation method on Earthquake and Tsunami. Define "Design Basis tsunami" that exceeds the largest in the historical records and require the protective measures. More precise methods to define design basis seismic ground motion by the 3D observation of underground structure of the site;
- Comprehensive consideration of natural hazards such as a volcano, tornado and forest fire in addition to earthquake and tsunami, and others;
- Provision of equipment and measures to prevent fuel damage and to mitigate impact of the accidents (Beyond Design Basis Accidents);
- Provision of full evacuation of the site in the event that the influence of accident may expand outside of the facility.

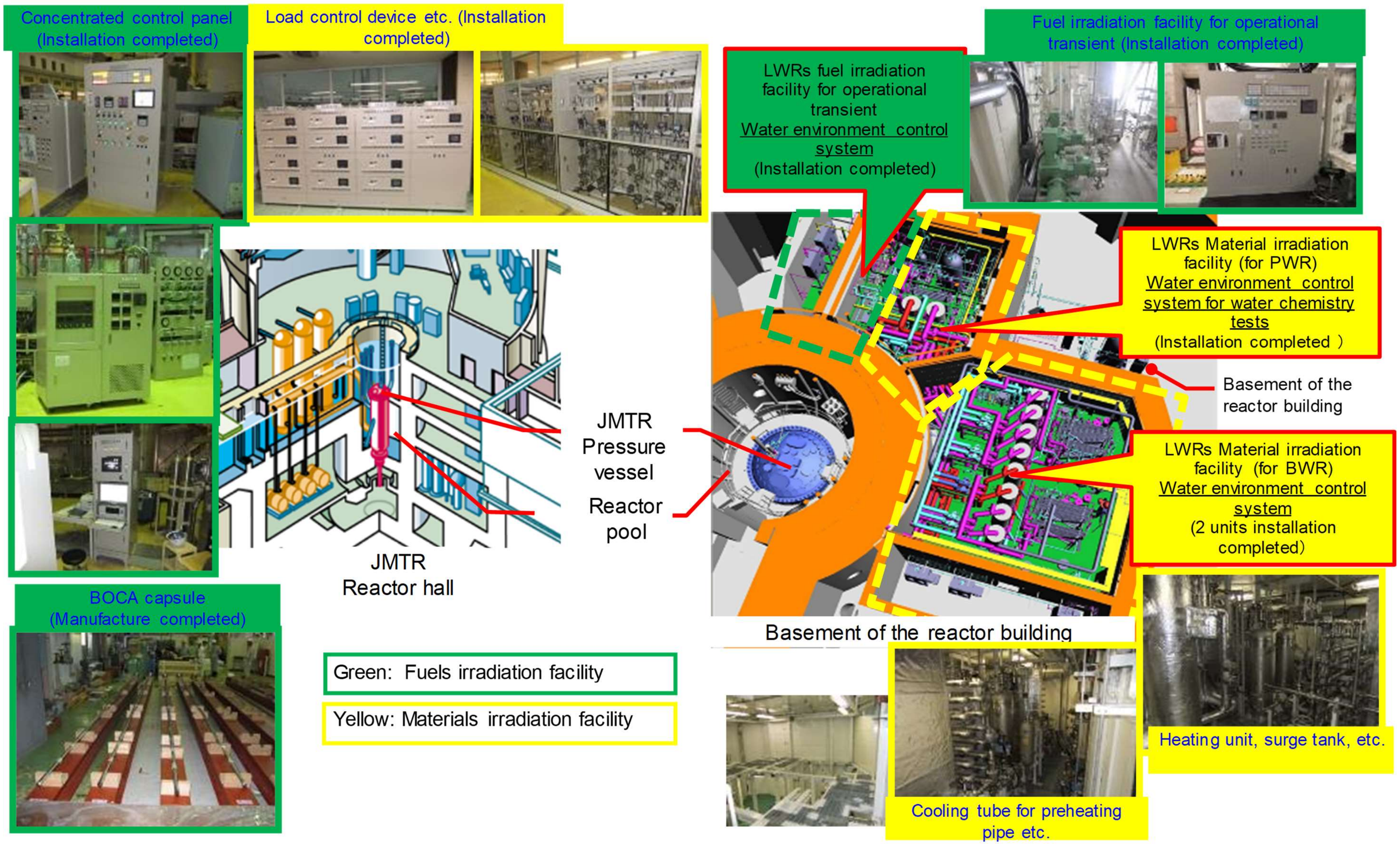


FIG. 3. Installation of new irradiation facilities.

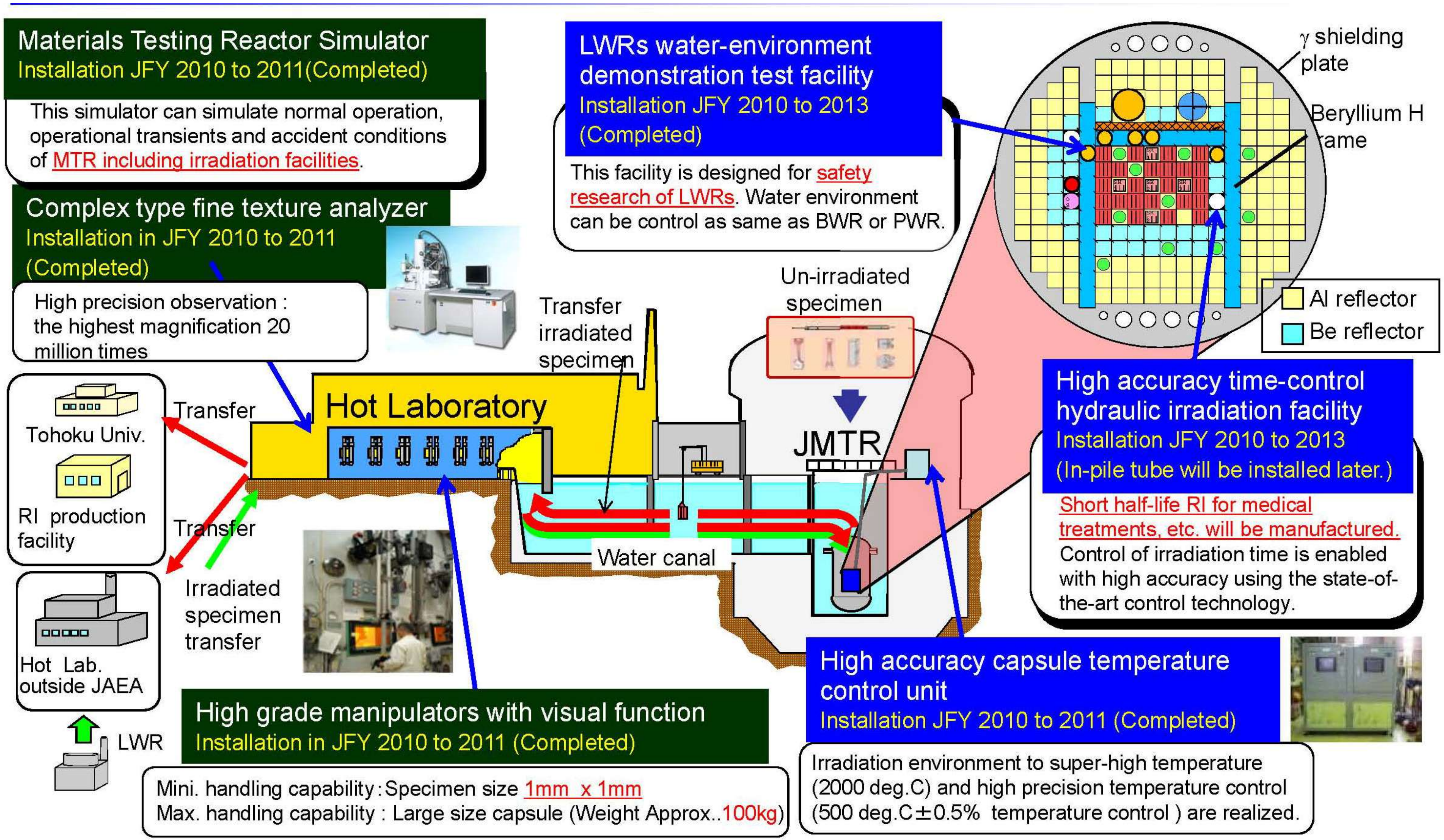


FIG. 4. New irradiation facilities by the project the Leading-edge Research Infrastructure Programme.

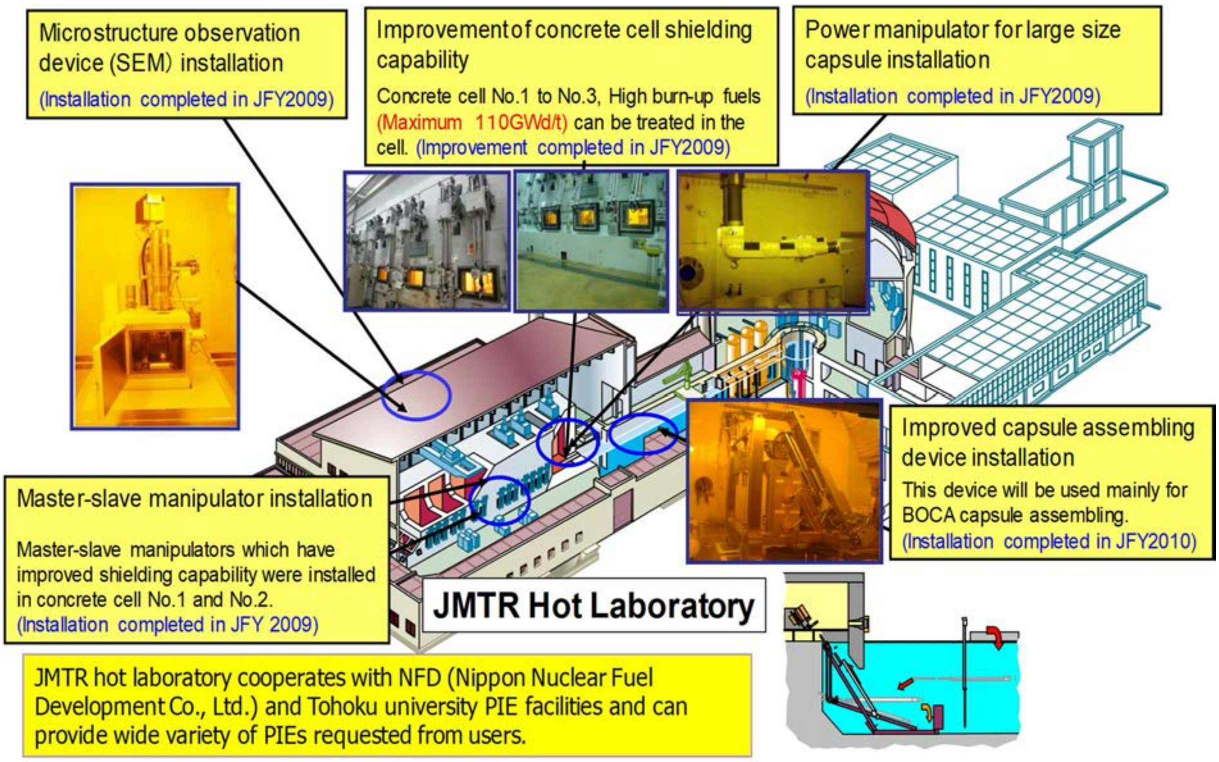


FIG. 5. Installation of new PIE facilities.

3. NEW REGULATORY REQUIREMENTS

Based on the safety assessments considering the Great-East-Japan-Earthquake in 2011, new regulatory requirements for research and test reactors have been established on Dec.18, 2013 by the NRA. Major features of the new regulatory requirements for the research and test reactors are shown as follows [3]:

- Accurate evaluation method on Earthquake and Tsunami. Define "Design Basis tsunami" that exceeds the largest in the historical records and require the protective measures. More precise methods to define design basis seismic ground motion by the 3D observation of underground structure of the site;
- Comprehensive consideration of natural hazards such as a volcano, tornado and forest fire in addition to earthquake and tsunami, and others;
- Provision of equipment and measures to prevent fuel damage and to mitigate impact of the accidents (Beyond Design Basis Accidents);
- Provision of full evacuation of the site in the event that the influence of accident may expand outside of the facility.

The process toward reoperation of research and testing reactors under new regulation is shown in Fig. 6.

3.1 SEISMIC EVALUATION

By the re-evaluation from the undersea fault and geological survey, an earthquake ground motion was estimated, and the design basis earthquake ground motion (DBEGM) Ss of about 0.7 G has been proposed. This value is larger than that of measured value (0.51G) in the reactor building at the Great-East-Japan Earthquake on March 11, 2011. The 3D calculation of reactor building, and facilities were performed. Image of 3D calculation model is shown in Fig. 7.

As to the Tsunami, +16.9m high Tsunami from the sea level has been evaluated in case of similar scale with the Great East Japan Earthquake. However, it is no effect to the JAEA-Oarai because the location is +35 to +40m high from the sea level.

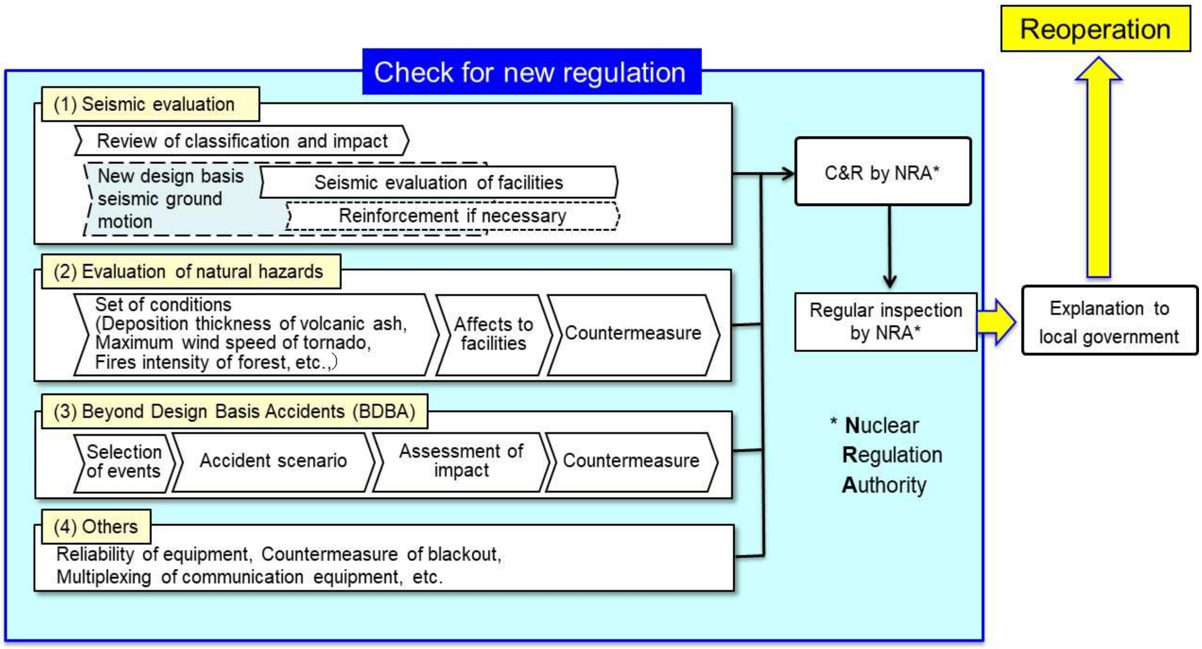


FIG. 6. Process toward the reoperation under new regulation.

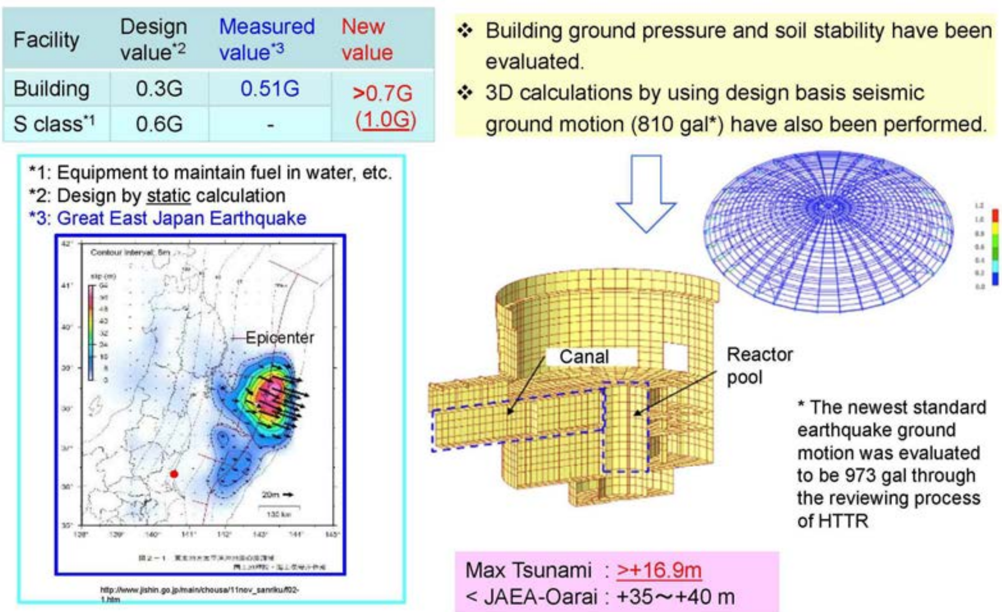


FIG. 7. Image of 3D calculation model for seismic resistance assessment.

3.2 SEISMIC REINFORCEMENT PROPOSED FOR JMTR REACTOR BUILDING

As a result of seismic resistance assessment of the JMTR reactor building, it became clear that at least 7 years of reinforcement work period and cost of about 40 billion yen are required for seismic reinforcement. Seismic reinforcement proposed for the JMTR reactor building is shown in Figs. 8 and 9.

As shown in Figs. 8 and 9, the building underground outer wall is required to be increased 1.5 m by reinforced concreate. On the other hand, steel frame braces are required to be installed at three circumferential positions of the building and around the reactor pool wall.

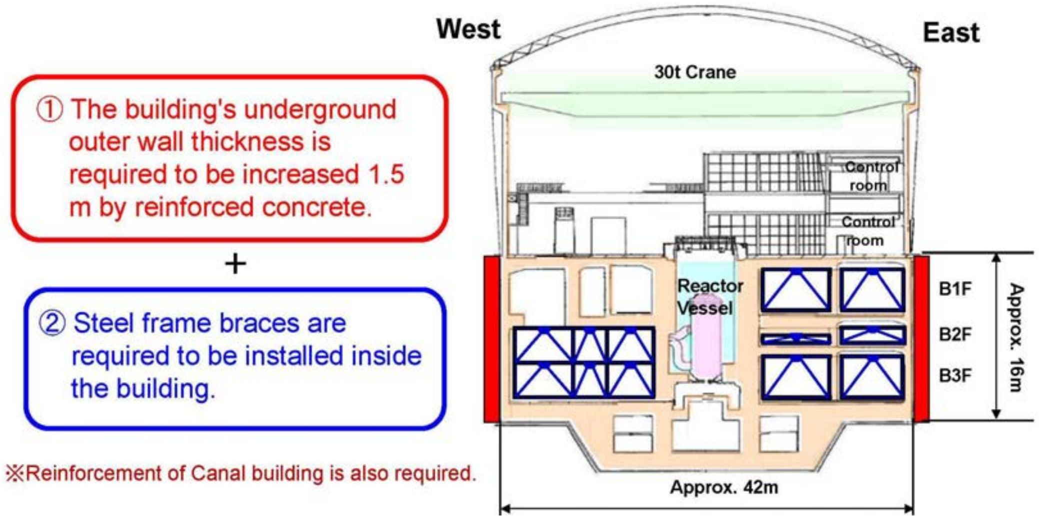


FIG. 8. Seismic reinforcement of the JMTR reactor building, vertical cross-sectional view.

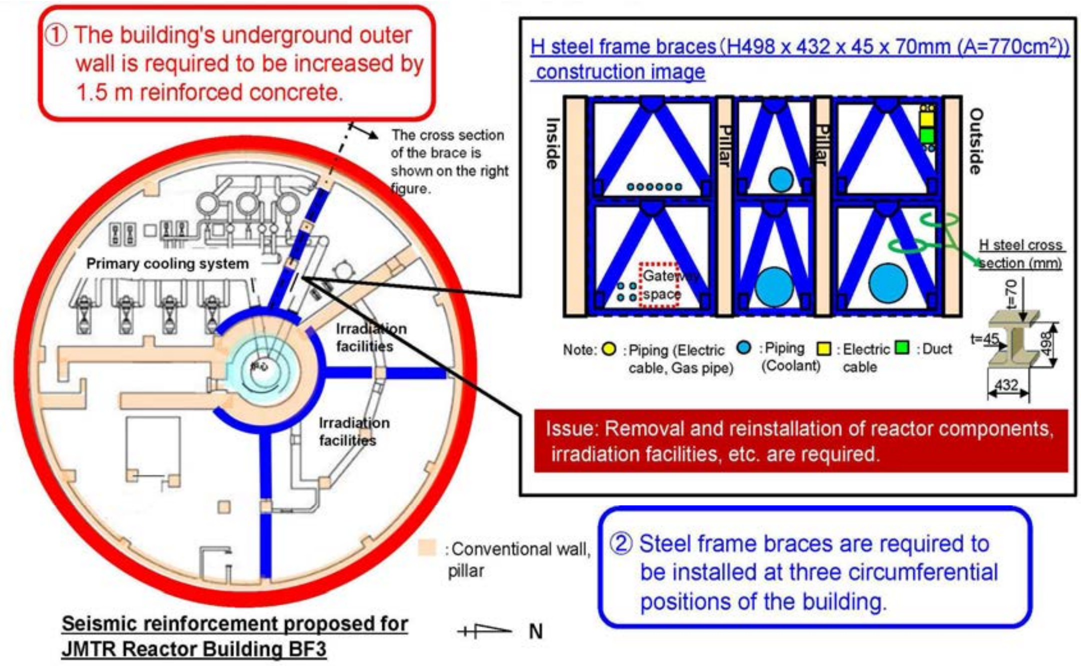


FIG. 9. Seismic reinforcement of the JMTR reactor building, horizontal cross-sectional view.

3.3 DAMAGE DUE TO AGING BECAME REMARKABLE FOR JMTR ANCILLARY FACILITIES

At the same time, pipe corrosion damage due to aging deterioration (Atmospheric stress corrosion cracking) of liquid waste transfer and storage facilities, hot laboratory exhaust stack anchor bolts severe damage due to corrosion, etc. became remarkable. Fig.10 shows the water leakage from SFC (Spent Fuel Cutting) liquid waste transfer line. Same kind of pipe corrosion damages were occurred at different lines. As a result, it is necessary to take measures to prevent aging of the reactor facilities after resuming operation of the JMTR, and it was made clear that high availability such as 8 operation cycles per year as originally planned cannot be expected.

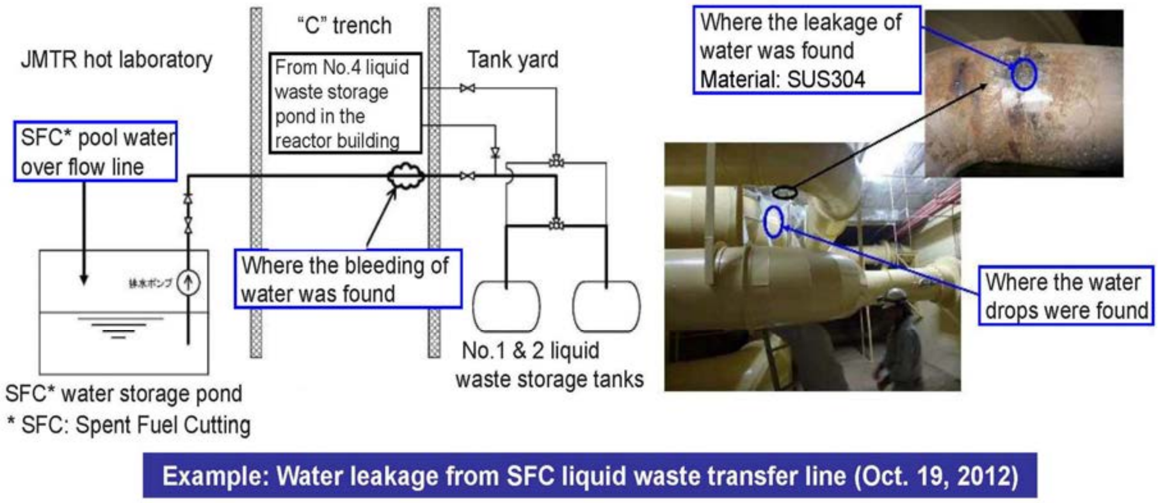


FIG. 10. Damage due to aging; Water leakage from SFC (Spent Fuel Cutting) liquid waste transfer line.

For the reason of a large amount of cost required for seismic reinforcement and requirement of aging facilities management even after reoperation, JAEA positioned JMTR as a decommissioning facility in the mid- and long-term plan of JAEA announced in April 2017 as shown in Fig.11

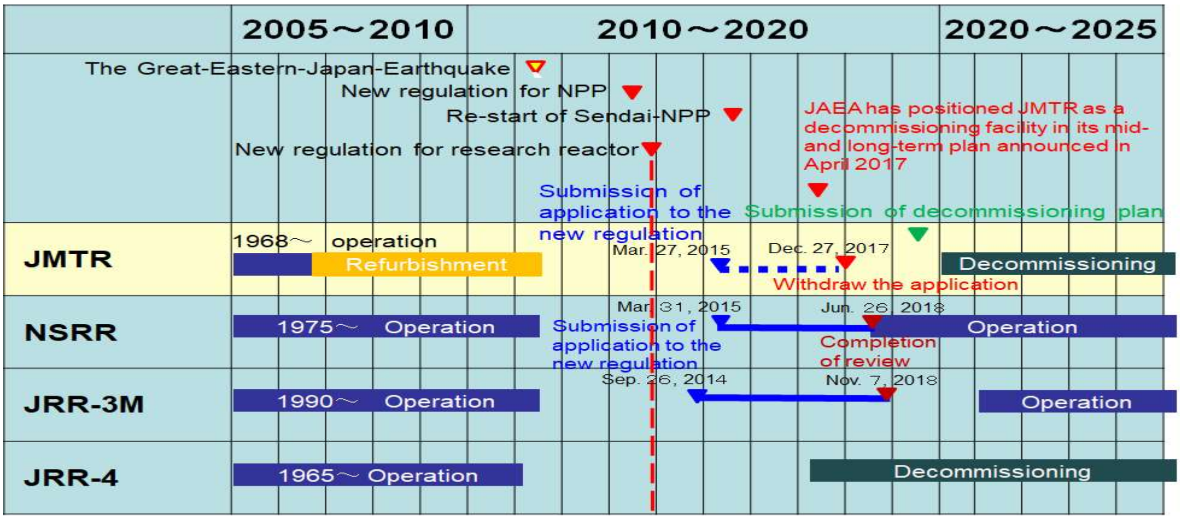


FIG. 11. Recent Status of Major Research and Testing Reactors.

3.4 DECOMMISSIONING OF JMTR

JMTR Decommissioning Preparatory Office was established in department of JMTR in order to prepare the application of decommissioning plan smoothly in December 2017 according to the mid- and long-term plan of JAEA. The application of decommissioning plan will be applied to NRA in FY 2019. Preparation for the application of decommissioning plan is carrying out by referring to the other decommissioning plan made by other research reactors or Power plants. The basic policy of JMTR decommissioning is as follows.

(1) Decommissioning of JMTR will be implemented based on decommissioning plan approved by NRA;
(2) Remaining facility will be maintained the functions which are required at each decommissioning phase based on safety operation programmes, and will be used

appropriately for the radiation management, waste management and so on. Measures to prevent the spread of contamination, countermeasures against radiation exposure, accident prevention measures, and others, will be taken for safety measure as almost same level as operation phase;

(3) An appropriate disposal method will be considered for unused fuel. Spent fuels are transferred to the US Department of Energy (DOE).

Fig. 12 shows planning of JMTR Decommissioning. The implementation plan for 1st stage is as follows.

(1) Shut down reactor function
Control rod will be removed and the electric power cables for control rod driven system will be removed in order to shut down the reactor function (all fuel elements were already removed from the reactor core);
(2) Transfer fuel elements
The function of fuel storage facilities is maintained to store fuel elements (unused and spent) safely until all fuel elements are transferred out of JMTR;
(3) Residual radioactivity inspection
Residual radioactivity will be inspected properly. (Enough decay time has passed. Final operation was finished at August 2006.);
(4) Decontamination of buildings and equipment
Based on the residual radioactivity inspection, decontamination will start from buildings and equipment which can be decontamination;
(5) Safety storage
Structures and components for safety are maintained to keep essential functions. (Safety storage);
(6) Demolition of facilities which are low or non-contamination.

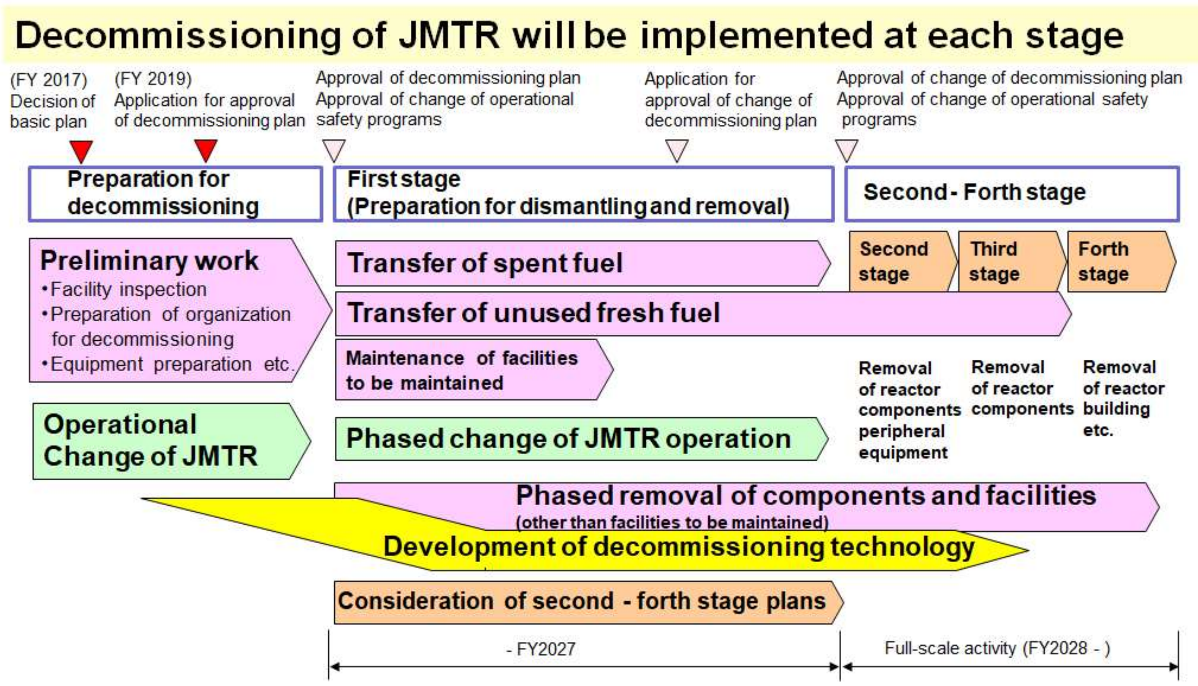


Fig.12 Planning of JMTR decommissioning

Low or non-contamination facilities will be dismantled and removed in which no relation to the structure and components for safety. (Facilities in non-radiation control area will be dismantled and removed partly.
Implementation plan for second to forth stages will be detailed during the first stage. Target of decommissioning facilities in the JMTR reactor building are shown in Fig.13.

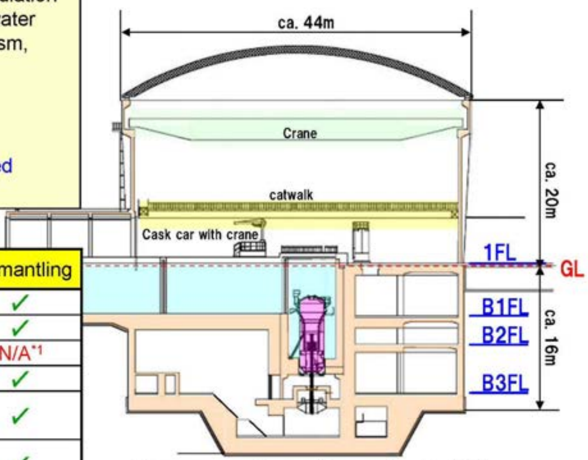
All the facilities and components installed in the reactor building will be dismantling except fuel elements. Fuel elements will be transferred to the US Department of Energy. Decommissioning will be finished after the release of radiation control area of the reactor building.

□Reactor building contains the following equipment
⇒reactor vessel ,control rooms, cubicle for irradiation facilities, primary cooling system, pool canal water circulation system, control rods drive mechanism, liquid waste storage ponds and so on
□Reinforced steel concrete structure
4 floors underground,
1 floor above the ground
The roof is steel pipe steel plate sticking curved surface structure

Example of dismantling facilities

Facility classification		Name of facility	Dismantling
Reactor	Core	Core element	✓
		Core structure	✓
	Fuel	Fuel element	N/A*1
	RPV	RPV	✓
	Radiation shield	Reactor pool lining	✓
		Reactor pool concrete wall	✓
Contain-ment facility	Reactor building	Reactor building	N/A*2

*1 Spent fuels are transferred to DOE.
*2 Release of radiation control area of reactor building.



Cross section of reactor building

Fig.13 Target of decommissioning facilities

4. A NEW MATERIAL TESTING REACTOR

January 2017, the Research Infrastructure Working Group established by the Ministry of Education, Culture, Sports, Science and Technology (MEXT). The Research Infrastructure Working Group examined the research infrastructure appropriate for the country and suggested to JAEA in April 2018 to carry out a study for the construction of the JMTR successor reactor.

Therefore, JAEA established the JMTR successor reactor reviewing committee and started to study the construction of a new material testing reactor. The examination results will be compiled by the end of FY2019. Through the design and construction of the new material testing reactor, we plan to pass on the irradiation test technology and post-irradiation test technology accumulated in JMTR to the younger generation.

5. CONCLUSIONS

New regulatory requirements for the research and test reactors were established on Dec.18, 2013 by the NRA. Confirmation of conformity for the updated design basis seismic ground motion, design basis tsunami are required to reoperation of reactors. Consideration of natural hazards, full evacuation, management for Beyond Design Basis Accidents are required in the new regulatory requirements. Seismic resistance assessment of the JMTR reactor building was performed. As the results, it was made clear that seismic reinforcement of the reactor building was required. At the same time, pipe corrosion damage due to aging deterioration (Atmospheric stress corrosion cracking) of liquid waste transfer and storage facilities, etc. became remarkable. As a result, it is necessary to take measures to prevent aging of the reactor facilities after resuming operation of the JMTR, and it was made clear that high availability such as 8 operation cycles per year as originally planned cannot be expected. Due to large capital costs required for seismic reinforcement and the requirement of aging facilities management even after reoperation, JAEA positioned JMTR as a decommissioning facility in the mid- and long-term plan of JAEA announced in April 2017. Application for approval of a decommissioning plan will be submitted to the NRA in 2019. On the other hand, study for "Construction of a new material testing reactor" was started and will compiled the end of FY2019.

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JORDAN: PROSPECTS AND CHALLENGES IN UTILIZING AND OPERATING THE JORDAN RESEARCH AND TRAINING REACTOR

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Abstract

The Jordan Research and Training Reactor (JRTR) is Jordan's first critical nuclear facility, owned and operated by the Jordan Atomic Energy Commission (JAEC). The reactor was successfully commissioned in 2016, has obtained its operating license from Jordan's nuclear regulatory body, and is currently working on optimizing and extending its operation and utilization activities. In this work, prospects of utilizing the JRTR are presented by describing potential utilization applications suitable for the JRTR and of interest to its stakeholders, and afterward, challenges on the way of realizing and implementing those applications are discussed.

1.INTRODUCTION

1.1. BRIEF HISTORY

The Government of Jordan (GoJ) took a decision in 2007 to embark on a national peaceful nuclear energy programme with the outlook to deliver an economically feasible, reliable, and sustainable source of electrical energy. The adopted policy for this ambitious national programme emphasized building, and eventually relying on, domestic human resources and capabilities in order to develop, operate, and sustain the programme.

To propel this approach forward, the Nuclear Engineering Department at the Jordan University of Science and Technology (JUST) campus was established (2007) and equipped with facilities to support its mission, which includes nuclear measurement laboratories and the Jordan Subcritical Assembly (JSA) [1].

Afterward, the Jordan Atomic Energy Commission (JAEC) launched a project in 2009 for the construction of a multipurpose 5 MW (upgradeable to 10 MW) nuclear research reactor, namely the Jordan Research and Training Reactor (JRTR), also at the JUST campus.

Soon after the JRTR project had been initiated, events such as the Fukushima accident (2011), the drastic drop in oil prices (2008, 2014), booming of solar and wind power, and lower than expected growth in electrical demand all contributed to delays in Jordan's nuclear energy programme [2].

Despite those delays, the JRTR project was able to endure towards completion, marked by the successful commissioning of the facility in the year 2016. However, the JRTR faced (and continues to face) its own unique challenges in demonstrating its readiness for effective utilization of the Kingdom's first nuclear facility. Technical, cultural, and financial challenges are among the most prominent challenges that are to be managed to ensure the sustainability of this complex and sensitive facility.

The JRTR is viewed as a state-of-the-art facility that can effectively contribute to industrial, medical, educational, and academic development. Through effective management and planning (as demonstrated through the Initial Operation Phase which led to the issuance of the Operation

License by the regulatory body in 2017 [3]), effective operation of the facility can be achieved, which may eventually attract external support towards additional utilization and eventually towards self-sustainability of the facility.

1.2. OBJECTIVE OF THE JRTR REACTOR

The JRTR project was envisioned to be one of the cornerstones for the domestic nuclear energy programme and to serve as a hub for training and research in the fields of nuclear engineering and neutron science and their applications. The two main objectives of the JRTR project were:

(1) To support human resource development for the Jordanian Nuclear Energy Programme;
(2) Development of nuclear applications for the benefit of the domestic and regional industries and communities.

1.3. THE VERSATILITY OF THE JRTR DESIGN

JRTR core employs plate-type fuel assemblies (namely 18 fuel assemblies for the current operations at 5 MW), surrounded by beryllium blocks and a heavy water reflector. A top view of the reactor is given in Figure 1.

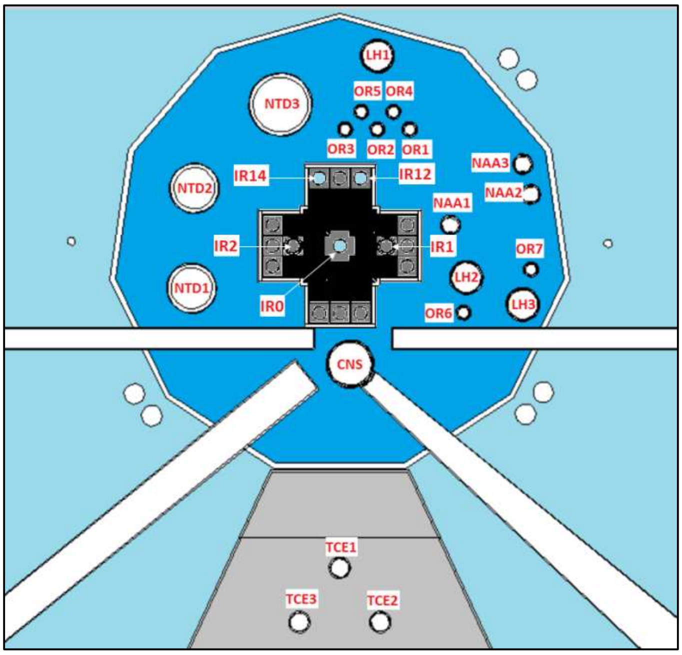

FIG. 1: Top view of the JRTR Core.

The JRTR core was designed with a multitude of irradiation channels of various sizes and neutronic characteristics in order to accommodate a variety of irradiation applications. At the current (5 MW) power rating, the maximum thermal neutron flux at these irradiation locations ranges from 7×10^{13} n/cm2s at the Beryllium reflector to about 1×10^{13} n/cm^{2}s at the edges of the heavy water reflector, apart from the central flux trap which offers up to 1.5×10^{14} n/cm^{2}s [4].

Four beam-tubes are also available for neutron beam applications. Two are dedicated for neutron science, one for radiography, and one for cold neutron source facility. These beam tubes are currently plugged and are devoted to the future installation of required instruments [5].

The reactor has been designed and built to enable a power upgrade to 10 MW. Specifically, structures and primary piping can handle operation at up to 10 MW. Such a power upgrade will require replacement of cooling pumps and heat exchangers to dissipate the higher heat load, and modifications to the core configuration to compensate for increased reactivity feedback. A preliminary upgrade report that was issued by the JRTR designer is available, but a thorough safety analysis report will be required before the operation at 10 MW is licensed.

The power upgradability is a strong potential which can serve to expand the irradiation and neutron beam services when needed, but its value may be appreciated only when the utilization applications expand to a level that would benefit from such an upgrade.

2. UTILIZATION PROSPECTS OF THE JRTR

2.1 IRRADIATION SERVICES

Given the large number and variety of irradiation channels, a wide range of irradiation applications can be adopted at the JRTR; ranging from irradiation for the purpose of radioisotopes production, neutron activation analysis, neutron transmutation doping or even gemstone colouring.

Up to 15 vertical irradiation channels located in its Beryllium reflector are appropriate for radioisotopes production. These channels offer a maximum thermal neutron flux at around 7×10^{13} n/cm^{2}s and offer forced cooling to satisfy heat removal requirements. The abundance of local medical institutions which are active in the field of nuclear medicine makes that involvement of the JRTR in the radioisotopes production field instantly rewarding, as a source of financial income and a source of positive public awareness.

In fact, the JRTR has commenced, since December 2018, commercial production and distribution of Iodine-131 in the form of medical-grade Sodium Iodide after obtaining the required license and approvals from the Jordanian Food and Drugs Administration (JFDA). Positive feedback and the public awareness value have been nearly instantaneous.

Variants of the Neutron Activation Analysis technique can also be applied at the JRTR given the wide variety of irradiation channels available. Three of the irradiation channels had also been complemented with pneumatic sample loading systems coupled to a sample preparation and measurement facility. The wide range of (integral) thermal to epithermal ratios, ranging from $\approx$9 at the NAA1 channel to $\approx$750 at the TCE channels, enables the application of various flavours of NAA.

The (high purity) heavy water reflector installed as part of the JRTR core serves to minimize the radial gradient of the thermal neutron flux in that region. The radial uniformity enables the irradiation (doping) of Silicon ingots (NTD) at the required uniformity for industrial applications. The JRTR heavy water reflector is designed with three NTD holes: two 6” holes and one 8” hole, offering a thermal neutron flux that is around 2×10^{13} n/cm^{2}s.

One last irradiation application that has been explored and found to be suitable for the JRTR is Gemstone colouring. This application requires fast neutrons rather than thermal, and it has been demonstrated through internal investigations that the central flux trap, combined with a well-designed irradiation container is a viable option.

The JRTR is particularly suitable to provide pure irradiation services; not only because the reactor core consists of more than 30 vertical irradiation holes, but also because pure irradiation services enable the JRTR to focus on operating the reactor safely and reliably, rather than having to diversify its operations to accommodate a variety of processes.

2.2. RESEARCH AND TRAINING

As mentioned earlier, four beam-tubes are also available for future neutron beam applications. Two are dedicated for neutron science, one for radiography, and one for cold neutron source facility. These beam tubes are currently plugged and are devoted for future installation of beam guides and instruments.

In addition to irradiation services and neutron science, the JRTR may be used to provide training for the national programme. For the purpose of training, a highly available training mode (50 KW) for reactor physics training is adopted, in addition to a multitude of fluidics and instrumentation systems which may be considered as potential training areas also. The fact that the JRTR is located at the campus of Jordan University of Science and Technology (JUST) at which a variety of engineering programmes including nuclear engineering are taught, also increases the reachability to the reactor.

3. UTILIZATION AND OPERATIONS CHALLENGES

3.1. OUTLINE OF EXISTING CHALLENGES

The previous section has served to demonstrate the fact that the JRTR is indeed a multipurpose facility that has the potential to host a wide spectrum of neutron irradiation, science, and training applications.

However, that potential cannot unleash itself passively. An active team of diligent workers is needed to overcome challenges towards the realization of the potential utilization applications. As mentioned earlier, the JRTR faced and continues to face challenges, most of which fall into one of the following categories:

(1) Financial: These challenges originate from the overall financial condition in Jordan but have also been amplified by the shift of the Government of Jordan interests away from the Nuclear Energy Programme. This type of challenge may be considered the most prominent for the JRTR, and maybe the root of many other challenges;

(2) Technical: It goes without saying that operating a nuclear reactor is a technically demanding task that requires significant technical capacity. For example, designing irradiation devices or facilities entails technical challenges. More importantly, strategic and operational planning for the facility throughout its lifetime also requires devoted resources.

Although the Jordanian Nuclear Energy Programme (JNEP) has invested significantly in building the required human capacity not to only operate the JRTR, but also a significant number to support the JNEP, the technical challenge currently exists because of the relatively high employee turnover. The root cause in the JRTR inability to provide rewarding compensations to retain its valuable experienced human capacity. This is an example of how financial challenges have contributed to other challenges;

(3) Cultural/Political: Like any other community, the people of Jordan are characterized by a culture that is related to their history, values, and customs, and that is polarized (more or less) by political aspects. A nuclear industry requires a very high level of objectivity and detachment from any cultural/political pressures external to the work standards. The creation of such an isolated environment may be considered among the challenges, not only for the JRTR but for any nuclear facility.

3.2. OVERCOMING CHALLENGES

Examples cited above demonstrate how the consequences of a challenge that face the sustainability of the JRTR tend to contribute to increasing other challenges; specifically, for example, financial challenges may amplify technical challenges which in turn may degrade stakeholders' support, further decreasing available funds and amplifying the financial challenge.

Figure 2 depicts this potential cycle' and proposes introducing countermeasures to break it. Proposed countermeasures include:

- Effective management of available financial and human resources, and culture;
- Effective Maintenance and Qualification and Training programmes;
- Increased outreach and marketing efforts to increase available resources.

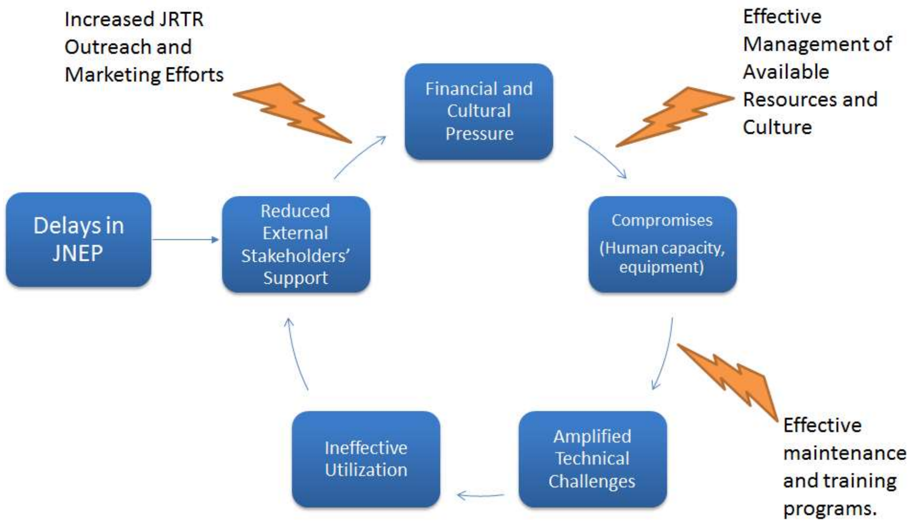

FIG. 2: Feedback loop of challenges, and proposed countermeasures to break the loop.

4. CONCLUSIONS

The JRTR is a versatile facility with a wide range of interconnected systems that need to be harmonized and maintained to work flawlessly and managed diligently for the reactor to achieve safe and effective operation. To achieve such a goal at the JRTR, a strategy for overcoming technical, cultural, and financial challenges is crucial.

The JRTR was designed and constructed as a multipurpose research reactor, hence it is envisioned that the JRTR will realize effective utilization only when multiple activities are conducted simultaneously. Certainly, the ramping up of JRTR utilization activities needs to be carefully planned to ensure that the safety of the facility, workers and the environment are maintained.

Given the limited available financial resources, a strategy that focuses on retaining highly competent human capacity, combined with an effective partnership with external stakeholders and user communities may be the only option available to proceed forward.

Significant challenges towards realizing a wide range of utilization applications at the JRTR do exist. But realizing and analysing these challenges is the first step towards conquering them.

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KOREA: CURRENT STATUS OF HANARO AND CHALLENGE FOR THE SUSTAINABILITY

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Abstract

HANARO has been actively utilized since attaining first criticality in 1995. In 2009, the cold neutron source was installed inside the reflector tank. The main utilization fields of HANARO are neutron beam applications, nuclear fuel and material test, radioisotope production, neutron activation analysis and neutron transmutation doping. After the Fukushima accident, HANARO had been requested to evaluate the seismic margin for the reactor's main components, and the seismic margin assessment led to the reinforcement of HANARO's wall. In December 2017, HANARO started operating after overcoming many issues for about a 3 year-shutdown. For the period of long-term shutdown, the circumstances surrounding HANARO, such as research reactor regulation and new research reactor construction project, has been drastically changed. To meet the expectations of HANARO to produce world-class science and to respond to the rapidly changing environment, a strategic plan for HANARO was prepared, and 4 missions were re-established. They are 1) advancement of neutron science and technology, 2) not only meeting but also creating the needs of the industry, 3) contributions to the national society issues, and 4) safe and stable operation of the facility. To achieve the missions, all members involved in the HANARO shared their same perception that the stable operation of HANARO is the most important. HANARO is trying hard to give the confidence for its sustainability and excellence through the various activities.

1. INTRODUCTION

HANARO is an open pool type multi-purpose research reactor of 30 MW thermal power in KAERI (Korea Atomic Energy Research Institute) [1]. The HANARO Project started in 1985. In 1995, the first fuel was loaded, and the first criticality was achieved. In 2009, the first cold neutron was generated, and the cold neutron research facility (CNRF) was inaugurated the next year. In the second half of 2014, HANARO had a long-term shutdown period for reinforcement of the reactor building wall, and HANARO was undergoing difficulty in the stable operation.

HANARO uses the rod type U_3Si-Al LEU fuel made by KAERI, and it has a heavy water reflector. The one operation cycle is composed of 28-day operation and 14-day maintenance, and the nominal operation target days are 200 days per year. HANARO has 7 horizontal neutron beam ports and 36 vertical holes for various utilizations. Fig. 1 shows the annual operation record of HANARO.

2. HANARO UTILIZATION

The main utilization fields of HANARO are as follows:

- Neutron beam applications for basic science and industrial requirements;
- Nuclear fuel and material test for national nuclear R&D program;
- Radioisotope production for medical and industrial uses;
- Neutron activation analysis and related nuclear analysis techniques for science and industrial needs;
- Neutron transmutation doping for silicon industry;
- Education & training.

FIG. 1. Annual operating record of HANARO.

Neutron beam applications: Neutron beam instruments in the reactor hall are HRPD (high resolution powder diffractometer), Bio-C (bio camera; image plate-based diffractometer), FCD (four circle neutron diffractometer), RSI (residual stress instrument). NRF (neutron radiography facility), Bio-D (bio diffractometer), and ENF (ex-core neutron irradiation facility). And, neutron beam instruments in CNRF are 40M-SANS [2], 18M-SANS (small angle neutron scattering instrument), DC-ToF (disk chopper time of flight spectrometer), KIST-USANS (KIST ultra-small angle neutron scattering). REF-V (vertical neutron reflectometer), and Cold-TAS (cold neutron triple-axis spectrometer). Fig. 2 shows the HANARO cold neutron research facility. There have been several high-impact neutron diffraction studies using HANARO neutron research facility. The neutron imaging facility had been used for the development of fuel cell vehicles. Residual stress measurement for thick metal plate is used for the large shipbuilding.

Radioisotope production: HANARO has four hot cells for radioisotope production and related researches. HANARO produces several radioisotopes for medical (I-131, Re-188, Y-90, Ho-166, Ir-192) and industrial uses (Ir-192, etc.). HANARO supplies about 70% of domestic needs for I-131 and Ir-192. The new research reactor project dedicated to the radioisotope production has been launched.

Irradiation Tests: HANARO has been actively utilized for the irradiation tests requested by numerous users to support the national research and development programs on nuclear reactors and nuclear fuel cycle technology. HANARO irradiation test contributed to the safety and life-extension of power reactors, RPV (reactor pressure vessel) material development, and nuclear fuel assembly development. It also contributes to the several R&D Projects such as the development of system-integrated modular advanced reactor and research reactor fuel and materials.

FIG. 2. HANARO cold neutron research facility.

Neutron Activation Analysis: HANARO has three pneumatic transfer systems (PTS) for thermal neutron activation analysis. And, cold neutron activation station (CONAS) using cold neutron is composed of PGAA (prompt gamma activation analysis), NIPS (neutron induced pair spectrometer), and NDP (neutron depth profiling).

Neutron Transmutation Doping (NTD): HANARO has two vertical holes with excellent condition for the NTD. The commercial NTD service for 5, 6, 8-inch silicon ingots have been going on. The world market share of HANARO NTD production was about 18% in 2012.

3. LONG-TERM SHUTDOWN DUE TO REINFORCEMENT OF HANARO WALL

After the Fukushima accident (March 2011), regulatory body requested to evaluate the seismic margin for the reactor main components such as reactor core and reactor concrete island (RCI), reactor building and exhaust stack of HANARO. As the result of seismic margin assessment (SMA), it was found that the main components and stack have enough margin for the design earthquake. However, 4.8% of reactor wall did not meet the design criteria. This was confirmed by advanced seismic analysis technology which did not exist at the design stage of HANARO. In March 2015, the regulatory body officially requested KAERI to reinforce the reactor wall. Thus, the construction work for reinforcement of HANARO wall was carried out from September 2015 to April 2017.

FIG. 3. The construction work for reinforcement of HANARO wall, and the HANARO view after the reinforcement of wall.

In the middle of the construction work, an earthquake occurred in Gyeongju located at the eastern coast of Korea on Sep.12, 2016. Its magnitude was 5.8, and, it was the largest earthquake in Korean peninsula since 1978 (the National Weather Service has officially recorded the magnitude of earthquake from this year). After the earthquake, the regulatory body tightened the regulation on the seismic safety of the nuclear facility. So, the verification activities for the reinforcement of HANARO have been performed, and the verification team concluded in September 2017 that the reinforcement process of HANARO was conducted satisfactory and enough seismic margin is guaranteed. However, the regulatory requirements become more stringent since then, which is one of main factors to cause a lot of difficulties in the stable operation of HANARO.

4. STRATEGIC PLAN FOR THE FUTURE

The strategic plan (SP) for HANARO was established in accordance with the IAEA guideline [3] and it is being revised regularly. The SP reflects the national nuclear policies. The HANARO SP contains the subjects and plans for about 5–10 years related to the human resources, budget, utilization, operation and maintenance, spent fuel, ageing management and waste management, etc. The last SP has been revised in 2017 [4]. In this revision, the circumstances surrounding HANARO were analysed at first. And, the missions of HANARO in the national research and development program were presented. Then, the most important item for the next few years to achieve the missions was deduced and shared with all HANARO members.

For the period of long-term shutdown, the circumstances surrounding HANARO like research reactor regulation environment and new research reactor construction project has been drastically changed.

Strong pressure for production of world-class output: Substantial time has passed since HANARO operation began in 1995. The experimental facilities and equipment with a significant level have been furnished. Accordingly, the production of world-class research output using HANARO has been strongly requested by stakeholders.

Long-term shutdown: As mentioned in previous chapter, a long-term shutdown period was necessary due to the work for reinforcement of HANARO wall, and it became a huge challenge on the HANARO utilization.

Regulatory requirements: The regulations on the nuclear facilities is increased. The regulatory body shows the intension to impose the stronger regulation for any kind of the nuclear reactors.

New research reactor (Kijang Research Reactor, KJRR) project: The construction project of new research reactor has been launched to solve the insecurity of medical radioisotope supply in 2012 (Fig. 4). The main purpose of the KJRR is to produce the medical radioisotope such as Mo-99, I-131, etc., and it will have large capacity of silicon doping.

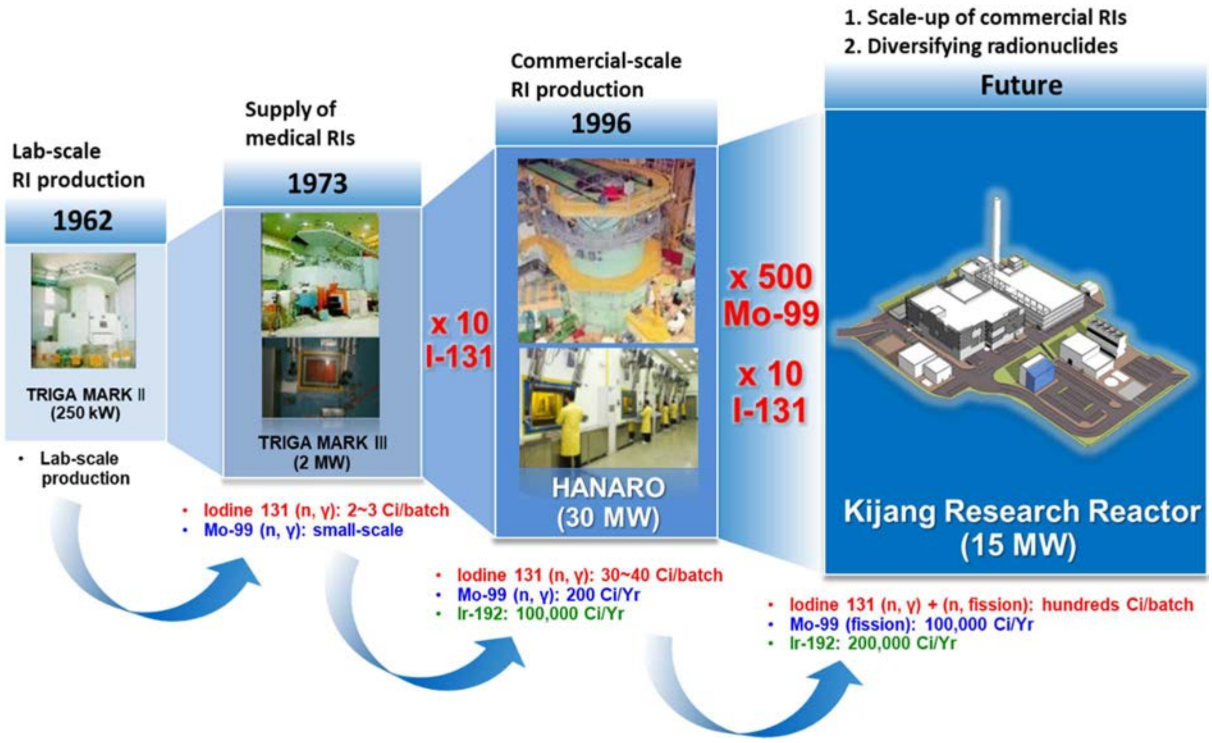

FIG. 4. The history of the radioisotope production in Korea and future vision through the Kijang research reactor [5].

The missions given to HANARO were analysed and re-established as follows reflecting the environmental change:

- Advancement of neutron science and technology;
- Not only meeting but also creating the needs of the industry;
- Contributions to the national society issues;
- Safe and stable operation of the facility.

To complete the above missions, a detailed action plan has been drawn up:

- To achieve best use of existing resources by using select and concentration strategy in the allocation of resources for the projects and facilities;
- To create better results by enhancing cooperative relations with reactor users and by fostering elite manpower;
- To make sure that users propose a new facility or instrument and supply an amount of matching fund;
- To establish proper complementary function with the new reactor (KJRR);
- To enlarge the training and education programs for the next generation of scientists and teachers in science and engineering fields;
- To establish the facility operation and utilization system authorized by international community by becoming one of the International Centre on Research Reactor (ICERR) and setting up the international advisory committees for reactor operation and each utilization area.

To achieve the missions, all members involved in the HANARO share their same perception that the stable operation of HANARO is the most important. HANARO is trying hard to give the confidence for its sustainability and excellence through the various activities.

5. CLOSING REMARKS

HANARO is the only large-scale research reactor now in Korea, but it will soon be joined by another which specializes on radioisotope production and neutron transmutation doping. At this critical moment, HANARO has suffered a setback and lost several years of operation time. Stable operation of HANARO without further disruption is essential to boost other utilization sectors. Thus, it is important for HANARO to have the strategic plan to deal with the situation and to prepare for the next few decades. If the proper actions are executed according to the plan, it is certain that HANARO will continue to operate for a foreseeable future and produce a substantial amount of quality output.

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MALAYSIA: SUSTAINABILITY OF THE MALAYSIAN NUCLEAR AGENCY: OPPORTUNITIES AND CHALLENGES

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Abstract

Malaysian Nuclear Agency (Nuklear Malaysia) established in 1972 is a premier nuclear research institute in Malaysia. The major function of Nuklear Malaysia is leading research and development in nuclear technology along with commercialisation of nuclear technology. Its operation is guided by the Malaysian Nuclear Agency Strategic Plan 2012-2020. Nuklear Malaysia hosts various major facilities and laboratories including a TRIGA PUSPATI research reactor (RTP), Gamma Green House, Electron Beam Facility and Secondary Standard Dosimetry Laboratory. In addition, Malaysia also has a long experience in safely operating a National Waste Management Centre since 1984. At the international level, Nuklear Malaysia is recognised by the International Atomic Energy Agency (IAEA) Collaborating Centre (ICC) in Non-Destructive Testing and IAEA-ICC for Radiation Processing of Natural Polymers and Nanomaterials. Malaysia has also hosted 15 IAEA Postgraduate Educational Courses (PGEC) in Radiation Protection and the Safety of Radiation Source Safety since 2004. This paper aims at presenting opportunities and challenges faced by Nuklear Malaysia to enhance its relevance and sustainability.

1. INTRODUTION

Malaysian Nuclear Agency (Nuklear Malaysia) was established in 1972 as a national premier nuclear research institute in Malaysia. Its establishment was mooted from an idea of the then Malaysia's Deputy Prime Minister, Tun Dr. Ismail Dato Abdul Rahman, who envisioned that Malaysia should play a role in the development of nuclear science and technology for peaceful purposes. The initial setting up of Nuklear Malaysia, then known as Tun Ismail Atomic Research Centre (PUSPATI), was for the country's preparation to embark on nuclear power programme. However, the programme was postponed due to the discovery of oil and gas in the Peninsular Malaysia in mid-1980s. As a result, Nuklear Malaysia has shifted its activities toward sectors others than energy [1].

Since the establishment of Nuklear Malaysia, nuclear technology has earnestly developed in the country in various key economic areas including food and agriculture, medical and healthcare, industry, water and environment [2]. Among its functions are to conduct research and development (R&D), services, training and commercialisation of nuclear technology. In order to properly implement its functions, Nuklear Malaysia is equipped with major facilities including a 1 MW TRIGA PUSPATI research reactor (RTP), Gamma Green House, Electron Beam Facility, Secondary Standard Dosimetry Laboratory (SSDL) and National Waste Management Centre. Some of these facilities are unique in the country. Through these facilities, nuclear science and technology plays an important role in supporting national development programmes.

Being the only national nuclear research institute for nearly five decades, Nuklear Malaysia has evolved over time to adapt to the dynamic and complex nuclear technology ecosystem in the country. Thus, this paper aims at presenting opportunities and challenges faced by Nuklear Malaysia to enhance its relevance and sustainability.

2. STRATEGY FOR SELF-RELIANCE AND SUSTAINABILITY

Presently, Nuklear Malaysia's operation is guided by the Malaysian Nuclear Agency Strategic Plan 2012-2020: Strategy and Action Plan. The purpose of the plan is to ensure a leadership role for Nuklear Malaysia in R&D, commercialisation and application of nuclear technology for sustainable development [3]. Considering the issues and challenges faced by Nuklear Malaysia as well as national policies and current scenario, the plan has outlined 7 strategic thrusts as the backbone of the plan as shown in Figure 1. Based on these strategic thrusts, the plan has further outlined 25 strategies and 100 activities to be implemented for 2012–2020. The plan is monitors and reviews periodically to ensure its implementation is carried out effectively and in line with government policies.

The successful implementation of the plan will help Nuklear Malaysia in achieving its objectives including to perform as the Technical Support Organisation (TSO) in nuclear science and technology.

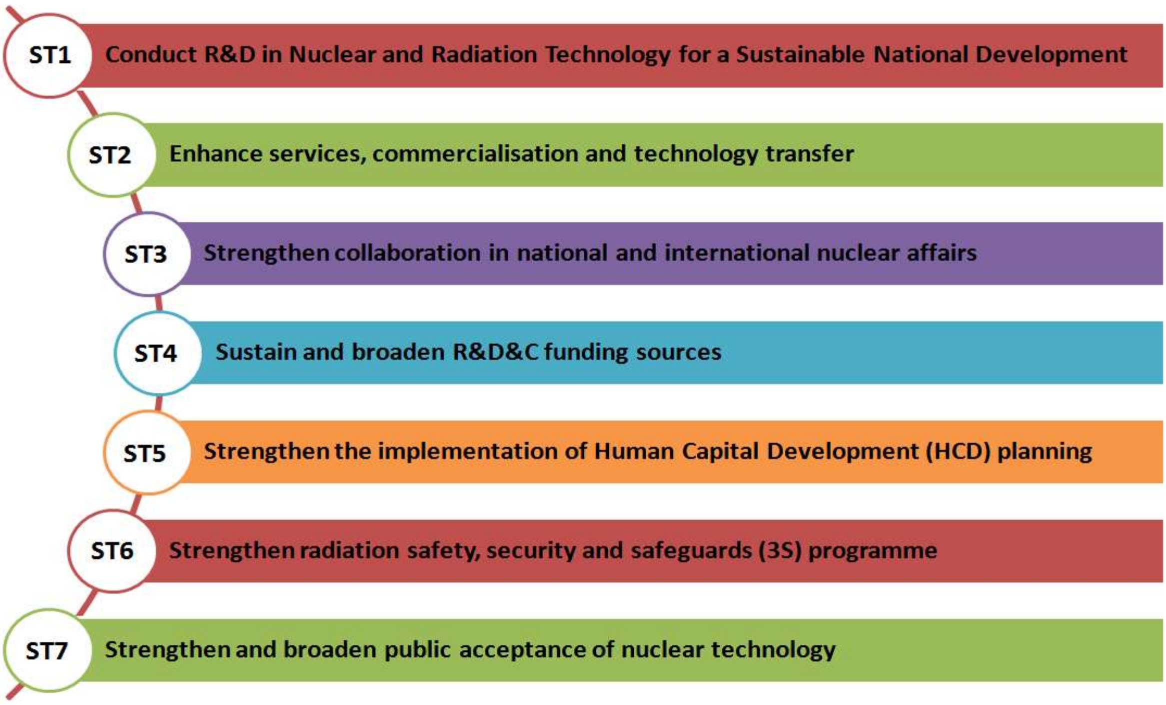

FIG. 1. Seven strategic thrusts of the Malaysian Nuclear Agency Strategic Plan 2012-2020: Strategy and Action Plan (note: ST in the figure represents strategic thrust).

3. R&D IN NUKLEAR MALAYSIA

Having spearheaded extensive R&D in various aspects of nuclear technology, Nuklear Malaysia continues to forge ahead in its R&D involving nuclear and related technologies. The R&D activities in Nuklear Malaysia are conducted based on market and strategic needs to enhance the capability, competitiveness and sustainability of its research outputs at national and international levels. In this context, the emphasis of R&D activities is on the application of nuclear technology in various key economic areas including food and agriculture, medical and healthcare, industry as well as water and environment.

The R&D activities carried out in Nuklear Malaysia have led to various research outputs such as products, processes, procedures, databases and software. During the period of 2007–2017, a total of 447 research outputs were produced, including 215 products, 68 processes, 102 procedures, 37 databases and 25 software, as shown in Figure 2 [4]. Another important research output is the scientific and technical publications in which Nuklear Malaysia published a total of 5450 publications from 2007 to 2017, including books, national and international journals, conference papers and technical papers.

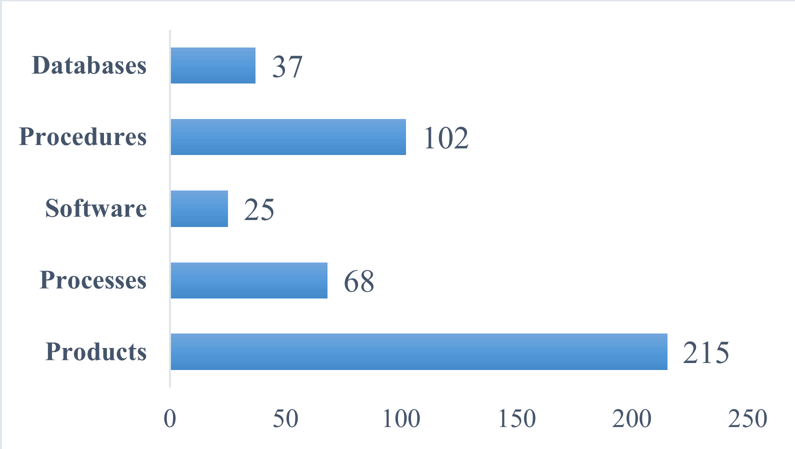

FIG. 2. R&D outputs produced from 2007 to 2017.

Nuklear Malaysia has reached several notable milestones through implementation of various research, development and commercialisation activities. Some of the activities are implemented in collaboration with other research institutes, universities and industries. This is evidenced by the collaborations between Nuklear Malaysia and various universities and industries that have been implemented through Memorandum of Agreement (MoA) or Non-Disclosure Agreements (NDA).

At the international level, Nuklear Malaysia has been designated as an International Atomic Energy Agency (IAEA) Collaborating Centre (ICC) for Radiation Processing of Natural Polymer and Nanomaterials from 2016–2020 and ICC in Non-Destructive Testing (NDT) from 2015–2019. The appointment as an ICC is a recognition of the expertise and excellence in Nuklear Malaysia as well as close and valuable cooperation between Nuklear Malaysia and the IAEA in various regional activities, including R&D, training and education. In 2014, the IAEA named Nuklear Malaysia as a recipient of "FAO/IAEA Achievement Award" in plant mutation breeding. The international award was conferred as recognition to Nuklear Malaysia on its contribution in the field of plant mutation breeding in Malaysia and the Asia Pacific region.
The sustainability of the R&D programme in Nuklear Malaysia was also supported by collaborative activities at regional and international levels. Nuklear Malaysia is actively involved in regional and international cooperation with various agencies such as the IAEA, the Regional Cooperative Agreement in Asia and the Pacific (RCA), Forum for Nuclear Cooperation in Asia (FNCA), and the Preparatory Commission of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). The collaborations aim to develop local capability and expertise as well as to obtain new technologies to enhance the national nuclear science and technology programme.

4. COMMERZIALIZATION OF NUCLEAR TECHNOLOGY IN NUKLEAR MALAYSIA

Nuklear Malaysia performs commercialisation of nuclear technology, as one of its functions. The commercialisation in Nuklear Malaysia is composed of providing services, trainings and producing potentially productive research outputs.

In order to maximise the benefits of nuclear technological innovation, particularly for the R&D outputs could benefitted the society or commercialised by appropriate economic sectors, Nuklear Malaysia has undertaken continuous efforts to generate intellectual property (IP) from the R&D outputs, through filing for patents, and to commercialise the R&D results through technology transfer and licensing agreements with industries. These efforts have resulted in revenue generation, which was used to support the development of R&D on nuclear science and technology in the country.

While the commercialisation of such viable R&D outputs is important for the country, efforts also need to be undertaken to maximise the non-commercial benefits of nuclear R&D for public and occupational safety and health, environmental protection, industrial safety, as well as national and societal well-being in general, including through the provision of technical consultancy and training services for various aspects of peaceful, safe and secure use of nuclear technology.

5. OPPORTUNITIES AND DRIVING FACTORS

Nuklear Malaysia continues to provide training, services and consultancy to the stakeholders in the field of nuclear science and technology. It includes radiation safety, radioactivity analysis of samples, radiological monitoring (personnel and environment) and assessment, and radioactive waste management. As the only premier nuclear research institute in the country, Nuklear Malaysia has great opportunities to become the Technical Support Organisation (TSO) in nuclear science and technology.

According to the IAEA, TSOs deliver technical and scientific services to national nuclear regulatory authorities and industry and may advise governments to assist them in achieving the highest possible levels of safety and security for nuclear, waste management and radiation protection. TSOs also have available and engage professional experts who maintain high levels of competence, experience, and are able to provide technical and science based solutions [5]. TSOs provide competent experts needed to support many organisations, including research organisations, regulatory bodies and government.

In this regard, Nuklear Malaysia has continuously developed, operated and maintained facilities and infrastructures as a driving factor in sustaining the peaceful uses of nuclear technology.

Nuklear Malaysia has been operating the RTP which is the only nuclear research reactor in the country. The RTP went critical on 28 June 1982 with a maximum capacity of 1 Megawatt. The RTP operates with several experimental facilities, including units for neutron radiography, small-angle neutron scattering and neutron activation analysis. These facilities provide support for production of short-lived radioisotopes, R&D, education and training for hands-on learning of the research reactor operation.

The establishment of the Waste Technology Development Centre (WasTeC-Nuklear Malaysia) in 1984 was recognized as the National Radioactive Waste Management Centre and the only centre in Malaysia currently given the responsibility to manage radioactive waste throughout the nation.

Nuklear Malaysia's SSDL is the national centre for the calibration of radiation measuring instruments for dosimeters used in radiotherapy and for the radiation protection. SSDL calibrate up to 5000 equipment per year and serve 20000 radiation workers in the country every month. Requirement for calibration of radiation measuring instrument is enshrined under the Atomic Energy Licensing Act 1984 (Act 304), Radiation Protection (Basic Safety Standards) Regulations 1988 (amended 2010). The SSDL Calibration Laboratory has been accredited in accordance with the MS ISO/IEC 17025:2005 standard since July 2004. All measurement and calibration are traceable to the primary and international standard laboratories.

Nuklear Malaysia's Biological Dosimetry (BIODOS) Laboratory was established in 1986 to carry out a chromosome aberration test to monitor the radiation dose of radiation workers in Malaysia. This service is implemented to fulfil the requirements of the Basic Safety Standards, Regulation Radiation Protection and to support the Atomic Energy Licensing Board (AELB) on dose monitoring of radiation workers. BIODOS is a member of the World Health Organization (WHO) Bio dosimetry Network that serves as a reference centre for bio dosimetry and radiation biology.

Nuklear Malaysia has provided radioanalytical services and radiochemical analysis of soil, sediment, sludge, water, food, fauna and flora through its Radiochemistry and Environment Laboratory since its inception in 1984. Serving public and commercial needs, this laboratory is approved by the Ministry of Health (MOH) to conduct radioactivity contamination tests on imported food in the event of a nuclear emergency. This laboratory also provides radioactivity analysis in mineral water and bottled drinking water as part of the MOH's licensing requirement under the Food Act 1983 (Act 281).

Nuklear Malaysia is also recognised as one of 166 laboratories under the IAEA's Analytical Laboratories for the Measurement of Environmental Radioactivity (ALMERA) network. The network was established by the IAEA in 1995. The laboratories under this network are expected to provide reliable and timely analysis of environmental samples in the event of an accidental or intentional release of radioactivity.

6. ISSUES AND CHALLENGES

It is inevitable that there are huge prospects of nuclear technology development in the rapidly growing Malaysian socioeconomic conditions. However, there remain certain challenges to ensure the best usage of nuclear technology as the following:

6.1 PUBLIC INFORMATION AND AWARENESS ON NUCLEAR TECHNOLOGY

In Malaysia, issues related to nuclear and radiation have had an impact on the public acceptance of nuclear technology. For example, in 1984, the mishandling of nuclear waste by the Asean Rare Earth (ARE) company and fear of irradiation and lead poisoning has decreased the public trust in the radiation and nuclear technology. ARE is a Japanese-Malaysian joint venture company to manufacture rare earth mineral, a process involving the generation of radioactive by-products, established in 1982. Lack of preparation, including laws and regulation, enforcement, safety precautions, and technical expertise were the most severe challenges for Malaysia to handle in the management of the process related to nuclear material and wastes during that time [6]. The lesson learnt from the incident has been to highly prioritise those industries dealing with nuclear, radioactive, and other harmful substances. In 2012, the operation of the Lynas Corporation's rare earth separation plant with thorium as a by-product of the process, has been approved and licenced under the Act 304 with the supervision and monitoring by the AELB after several demonstrations [7]. The public still has fear and distrust of the management of the risks of the operation, especially after major nuclear accidents happened in Fukushima, Japan in 2011 [8].

In term of nuclear energy, in general, Malaysian public seem to have a very strong perception on most issues, but their real understanding remained indeterminate. This could be seen when the issue of nuclear energy was raised as most of the Malaysian public are supportive of having a nuclear power plant in the future, but in comparison with their understanding on the issue, the knowledge is uncertain [9].These indicate that trust, acceptance and awareness on the nuclear technology remain big challenges in sustaining the technology in the country. In that regard, public information strategy needs to be established to ensure the knowledge and information disseminate effectively.

6.2 NUCLEAR SAFETY AND SECURITY CULTURE

In nuclear and radiation safety, factors of individuals' commitment, managers' commitment, and policy commitments had not been identified and were not quantifiable compared to other sectors in the Malaysian workplace [10]. There was also lacking in correlation and a significant study between safety climate variables and safety performance. Job safety, supervisor safety, as well as safety programme and policy determined had a significant relationship with safety behaviour of industrial radiographers [11]. However, there is no evidence on the reliability and validity of the relationship.

Those studies indicate that the safety and security culture among the workers were uncertain and need to be strengthened in Malaysian culture. The radiation safety management and emergency preparedness need to be maintained to emphasise radiation safety in order to ensure protection of people and environment.

6.3 EDUCATION AND TRAINING

Education and training are keys to sustainability of the nuclear industry. With lifetime extensions of an ageing workforce and the growing demands for decommissioning and nuclear waste disposal solutions, the shortage of appropriately trained and qualified personnel risks becoming a severe constraint.

Currently, the age profile within the workforce in Nuklear Malaysia in particular, had facing the increments of retirements in the short term. The replacement of the new workforce was taking place. The big challenges dealt with new workers were their lack of experience and knowledge regarding radiation science and safety. The frequency of continuous training was increased to ensure the workers did understand and were familiar with the procedures and documentation. Without education and knowledge of radiation safety and consequences of the hazard, the new workers may take for granted on every task given, even with possible high-risk operation.

6.4 KNOWLEDGE-BASED ORGANISATION — KNOWLEDGE MANAGEMENT

In addition, the use of nuclear technology relies on the creation, storage and dissemination of knowledge. The IAEA nuclear knowledge management activities assist in transferring and preserving knowledge, exchanging information, establishing and supporting cooperative networks, and training the next generation of nuclear experts [12].

Worldwide, the average age of staff working in the nuclear sector has been rising for the past several years [13]. As staff gradually reaches retirement age, their knowledge and experience, accumulated over entire careers in nuclear science and technology, could be lost if nuclear knowledge management activities do not address this issue. This ageing of the work force is also happening in Nuklear Malaysia, as it was established for more than 40 years.

Nuklear Malaysia faced challenges in capturing the tacit knowledge before the loss of key individuals as well as capturing the various knowledge repositories that they maintain for personal use in order to maintain and sustain the technology. The other challenge is to find the successors to whom this knowledge could be transferred as well as developing an effective tools and techniques for knowledge management.

6.5 NECESSARY RESOURCES

As a developing country, Malaysia has limited resources for the research and development activities. This become among the biggest challenges as well in sustaining the nuclear science and technology development in the country. The proportion of the government budget allocation for R&D has been therefore very much less than the ones in developed countries. In 2015, Malaysia R&D expenditure as a percentage of gross domestic product (GDP) was 1.30 compared to Korea 4.23, Japan 3.28 and United States 2.79 [14]. Nuklear Malaysia as a governmental institute with the task of doing R&D in nuclear science and technology faces even more limitation on the budget granted since various misperceptions, misleading information and unbalanced understanding are common in the society due to the public acceptance of the nuclear technology and government policy.

Challenge in sustaining the nuclear technology and further development of the technology, in particularly nuclear power plant programme is the national position. The national position is the outcome of a process that establishes the governmental strategy and commitment to develop, implement and maintain a safe, secure and sustainable nuclear power programme. This process will face challenges on a national decision that require clear national policy, as well as the commitment to proceed according to the international obligations of the national and international norms and standards that requires political, economic, social, environmental studies and analysis.

6.6 COMMERCIALISATION OF NUCLEAR TECHNOLOGY

The challenges in the commercialisation of nuclear technology are to push a technology driven in the emerging markets that need various strategies. Emerging industries are those where no clear or establish value chain currently exist. These can either be those where a new technology exists and there is no clear market and therefore no route to market, or those where a market exists but the introduction of a new technology could rearrange or destroy the existing value chain or industry. These challenges can be encounter through diversification of orientation strategy based on ecosystem by the market or demand through market pull strategy or technology push strategy.

7. CONCLUSIONS

Having spearheaded extensive R&D and commercialisation of nuclear technology, Nuklear Malaysia continues to forge ahead as a national R&D institution involving nuclear technologies. Having in its possession the unique facilities, competent personnel and internationally certified laboratories, Nuklear Malaysia has great opportunities to become the TSO in nuclear science and technology in the country. The acceptance on the nuclear technology, adequate resources and funding to run the R&D activities are among the key challenges to enhance Nuklear Malaysia’s relevance and sustainability in R&D and commercialisation of nuclear technology.

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PAKISTAN: STRATEGY FOR SELF RELIANCE AND SUSTAINABILITY OF RADIOPHARMACEUTICAL PRODUCTION FACILITY IN PAKISTAN

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Abstract

Production of different Radioisotopes i.e. Mo-99, Mo-99/Tc-99m generators, I-131 , P-32, Lu-177, Au-198 etc, diagnostic cold kits MIBI, MDP, DTPA, and adenosine injection (for different body organ imaging) as well as research and development is carried out at Isotopes Production Division (IPD) at PINSTECH. Pakistan has a population of ~200 Million and the number of nuclear medical centres practicing nuclear medicine are more than 36, in which 18 belongs to Pakistan Atomic Energy Commission (PAEC), and other belongs to private entities, whereas some more are expected to function in the coming years. The big cities like Karachi and Lahore, as well as capital city of Islamabad, has most of these nuclear medical centres. More than 500,000 patients are treated each year in PAEC Nuclear Medical Centres. Molybdenum-99 (Half-Life: 66 hours) is used to manufacture Technetium-99m generators, the most widely used isotope in Nuclear Medicine. Its short half-life of six hours and the energy emitted (140 keV) makes it an ideal imaging agent. The Isotope Production Division is producing molybdenum-99 weekly for manufacturing of PAKGEN 99Mo/99mTc generators in Mo-99 Loading Facility at PINSTECH, Islamabad. PAKGEN 99Mo/99mTc generators and I-131 supplied to all medical centres throughout Pakistan on weekly basis. These Radioisotopes are being produced in Pakistan Research Reacor-1. IPD/PINSTECH also producing diagnostic cold kits for different body organs imaging. These products are produced under Good Manufacturing Practices (GMP) and pass through strict quality control as laid down in the European Pharmacopeia and IAEA guides. All the IPD laboratories are ISO 9001-2015 certified and are licensed by PNRA. The division also holds Drug Manufacturer Registration of the Government of Pakistan.

1. INTRODUCTION

The attributes of radioisotopes give rise to several applications across numerous aspects of modern-day life. There is prevalent awareness of the use of radiation and radioisotopes in medicine, particularly for diagnosis (identification) and therapy (treatment) of various medical conditions. Pakistan is producing such medical grade radioisotopes along with the cold kits to be labelled with imaging agents. These isotopes emit electromagnetic radiations and can be detected using imaging devices in order to study the dynamic processes taking place in body.
Research and development in Pakistan since 1990 have laid several foundations of radioisotopes production facilities associated with nuclear research reactor i.e. Pakistan Research Reactor-I (PARR-I). PARR-I is the state-of-the-art research facility in Pakistan. Pakistan is producing various Radioisotopes i.e. Mo-99, Mo-99/Tc-99m generators, I-131, P-32, Lu-177, Au-198 with the assistance of the nuclear reactor facility. Pakistan has also excelled in synthesis of diagnostic cold kits and injection to be labelled with Tc-99m for different body organ imaging.

Pakistan has a population of ~ 200 Million and number of nuclear medical centres practicing nuclear medicine are more than 36, in which 18 belongs to Pakistan Atomic Energy Commission (PAEC), and other belongs to private entities, whereas some more are expected to function in the coming years. The big cities like Karachi and Lahore as well as capital city of Islamabad has the most of these nuclear medical centres. More than 500,000 patients are treated each year in PAEC Nuclear Medical Centres.

Manufacturing such radioisotopes and cold kits requires pharmaceutical industry expertise within the safety constraints of a nuclear facility. Therefore, such a facility has to observe the

Good Manufacturing Practice of the pharmaceutical industry. Observing to the As Low As Reasonably Achievable principle of the nuclear industry, Pakistan research facilities are aimed at protecting the radiation workers, non-radiation workers and the environment.

Sustainability of a production plant aims at utilizing available resources and tools to maintain the production rate or growth rate at a desired level. It includes the prevention of the depletion of natural resources in order to sustain an environmental balance. In order to maintain consistent production and supply of our products, we have planned administrative processes correlating to production processes.

2. CURRENT TECHNICAL AND UTILIZATION STATUS

2.1. TECHNICAL STATUS OF FACILITIES

Radiopharmaceutical Production Facility comprises of four main production units (Table 1).

TABLE 1. MAIN PRODUCTION UNITS (1–4) OF THE RADIOPHARMACEUTICAL PRODUCTION FACILITY

Sr. No.	Production Facility	Production frequency
1	Molybdenum-99 (Mo-99) Production facility (MPF)	Weekly
2	Generator Production facility (GPG, ^{99m}Tc generators).	Weekly
3	Iodine-131 (I-131) Production facility	Weekly
4	Diagnostic freeze-dried cold kits	Weekly
5	Other isotopes like P-32, Lu-177, Au-198, Sm-153, etc	On demand

2.2. FACILITY UTILIZATION STATUS

Radiopharmaceutical Production facility has been providing the services and fulfilling the demands of 18 PAEC medical centres and 30 other Government and Private medical hospitals since 1990. The Following departments are playing critical role under one roof of isotopes Production Division:

- Production of radioisotopes such as I-131, Tc-99m, Lu-177 and P-32 for nuclear medical centres all over Pakistan;
- Providing services to agricultural and industrial sectors by delivering radiopharmaceuticals;
- Facilitating students of different universities by providing technical guidance and radiopharmaceuticals for research purpose;
- Production of Radiopharmaceuticals cold kits for imaging of human body.

2.2.1. Molybdenum-99 (Mo-99) Production facility (MPF)

Researches and experimentations have been conducted to produce Mo-99m indigenously to meet future demands in our country. Indigenous production of fission Mo-99(Half-Life: 66 hours) in the chemical form of Sodium Molybdate is being carried out regularly since 2012. Molybdenum-99 is used to manufacture Technetium-99m generators, the most widely used isotope in Nuclear Medicine. Its short half-life of six hours and the energy emitted (140 keV) make it an ideal imaging agent. Certain researches have been conducted in order to materialize the Mo-99m production plant. Following procedures have been developed:

- A new chemical process was developed at PINSTECH with the help of German experts for separation of Mo-99 from fission products;

- Optimization of parameters was achieved in IPD laboratory;
- Fission Iodine-131 and Xenon-133 as by-product.

2.2.2. PAKGEN 99Mo/99mTc Generators

PAKGEN ^{99}Mo/^{99m}Tc Generator is locally manufactured for ^{99m}Tc production. Parent radionuclide ^{99}Mo ($T_{1/2}$ 66 hrs) is adsorbed on generator columns filled with alumina [1]. Daughter radionuclide ^{99m}Tc ($T_{1/2}$=6.02 h, E_{γ}=140 keV) reaches equilibrium with ^{99}Mo after about 23 hrs and can be washed from the column with saline. It provides sterile, pyrogen-free and isotonic solution of Sodium pertechnetate ($Na^{99m}TcO_4$), which can be used directly for intravenous/oral administration or for aseptic preparation of ^{99m}Tc labelled radiopharmaceuticals.

The generators are dispatched after proper quality control of each consignment. Production of PAKGEN ^{99}Mo/^{99m}Tc is carried out every Friday with Monday reference date activity. The capacity of plant is 100 Curie. More than 1600 consignments per year of these generators of activities ranging from 200 mCi to 600 mCi (reference activity) have been supplied to ~ 37 different hospitals in Pakistan.

2.2.3. Sodium Iodide (131I) solution

Sodium Iodide (^{131}I) solution is locally manufactured system which provides solution of sodium iodide-^{131}I [1, 2]. The solution is carrier free, without any stabilizers. The pH is adjusted to 9 with carbonate buffer. ^{131}I (half-life 8 days) is produced by neutron bombardment of stable tellurium in a nuclear reactor for oral administration. $^{131-}$I produces beta (β^-) rays (0.608 MeV) and gamma (γ) rays (0.364 MeV), used for diagnosis and radiotherapy of thyroid disorders. The capacity of plant is 10 Curie. About 07 Curie is dispatched weekly to PAEC as well as private hospitals including Aga Khan Hospital and Shoukat Khanum Hospital.

Other Radioisotopes i.e. Phosphate (P-32), Lu-177 and Au-198 are also produced for R & D purpose for nuclear medical centres.

2.2.4. Cold kits for 99mTc-radiopharmaceuticals

Under technical assistance Programme IAEA has provided a clean room facility for the preparation of cold kits for Tc-99m radiopharmaceuticals. Since 1990 these kits are regularly produced and PINSTECH is meeting nearly all the demands of nuclear medical centres. In case of cold kits for 99mTc-radiopharmaceuticals, PINSTECH charges 50% of the cost compared to imported ones and ~ 70% price of the imported Iodine-131, Tc-99m generators and other isotopes. Ten types of freeze-dried kits are regularly supplied to nuclear medical centres for imaging of different body organs.

3. STAKEHOLDERS AND THEIR NEEDS

These radioisotopes and radiopharmaceutical cold kits are being supplied to 18 Pakistan Atomic Energy Nuclear medical centres, and 30 Government and private hospitals in Pakistan since 1990.

IPD has developed a strategy for stakeholders to fulfil their needs and requirement. This strategy includes the following assured key points:

- We ensure the product quality and dispatch feedback forms to the stakeholders;
- We ensure the delivery of the product in time to the customers;
- We ensure that the package in which we are supplying our product is user friendly to the technicians employed at medical centres. If they ask any technical assistance, we send one of our technical officers to the respective medical centre to assist the technicians there or otherwise arrange a Hands-on-training for medical centres;
- We ensure the product accessories like saline and vacuum vials which is needed to elute the product from the generator body;
- Information about product dose and administered dose is written on flyers which we deliver with each package;
- Reliability.

4. CURRENT ISSUES, CHALLENGES AND CONSTRAINTS

With the increasing demand of cancer diagnosis and treatment, we are facing certain issues and associated challenges in order to meet our criteria of fulfilling the needs and demands of our stakeholders. Constraints and limitations are a big challenge for us in order to cope with the increasing demand.

PAKGEN ^{99}Mo/^{99m}Tc Generator is locally manufactured for ^{99m}Tc production. Parent radionuclide ^{99}Mo is adsorbed on generator column filled with alumina. The production of Mo-99 is research reactor based. Molybdenum-99 is separated from neutron irradiated uranium in Pakistan Research Reactor-1 at Molybdenum-99 Production facility:

- In order to meet the increasing demand of the subject product, LEU based Mo-99 production facility is required;
- LEU based technical training is also required;
- I-131 production plant and Moly-99m spares export to Pakistan has become a worrisome issue in order to maintain the regular replacement and upkeeping of spares. This problem makes us concerned about uninterrupted supply of both the products to around 42 medical centres in Pakistan;
- We are in need to get training on the fabrication of quartz instruments that are used in I-131 dry distillation process.

5. STRATEGY FOR SELFRELIANCE AND SUSTAINABILITY

Self-reliance is a strategy for the continuous development in a field and area. Self-reliance of an organization truly depends on if an organization can sustain a process with utilizing the available resources or seeking for new resources by its own.

5.1. STRATEGIC, FINANCIAL & BUSINESS PLANNING

Strategic quality objectives are planned to initiate for continual improvement of the facility. The objectives are based on SMART technique i.e. Specific, measurable, attainable, realistic and time-barred. The follow-up of these objectives is supervised and ensured to be executed for the facility development.
Financial and business planning is a quantitative measure of strategic objectives and planning which guarantee us of the objectives to be implemented for the national interest. The business planning of these objectives carves out the management of raw materials, resources, utilities availability and execution of the strategic planning.

5.2. SUPPLY CHAIN MANAGEMENT

The production of radiopharmaceutical products requires supply chain management at a proactive attitude because their supply is the most critical assignment of all the process as the product decays with time.
Supply chain management is controlled and supervised to maximize the product availability to the customer. In this regard, the irradiation time, production time and delivery time are optimized. Resources and their availability for next 5 years is ensured with the technical procurement in order to avoid any delay in the production.

5.3. CUSTOMER & BUSINESS LEAD MANAGEMENT

Customer acquisition management and business lead management leads to resolve and generate new business client age and powerful impact of merchant on their client. Customer inquiry is carried out whether the client or customer is all set to lock a business deal with their interest in something being offered. As the client/customer contact signals the acceptance of the offer provided by us, the lead of the customer is entertained through various stages of confirmation of order and their requisites to purchase the radiopharmaceuticals.

After screening of the customer lead, the authorizing contact persons of client/merchant deliver a dialogue conversation to seal the deal.

Afterwards, the merchant/client contract is sealed for a financial year about the demand of radiopharmaceutical and freeze-dried kits. This demand is entertained throughout the year and feedback is gathered after each delivery every week.

5.4. STAKEHOLDER ENGAGEMENT

Stakeholder engagement is an obligatory practice to engage the stakeholders effectively through the lifecycle of the project or any venture based on the prospective influence of the project success. PINSTECH formulated stakeholder's management plan which comprise of interactive sessions among the interested parties of a project/process. These include:

- Customers feedback against weekly production of all radiopharmaceuticals and freeze-dried kits;
- Nurture client- merchant relationships by organizing educational events
- Resolve for the right customer needs;
- Technical scientific workshops and hands on training for all customers/stakeholders;
- Government/local scientific tours and international tours.

5.5. STAFF ENGAGEMENT & CULTURE MANAGEMENT

Staff engagement and culture management proves to be an articulative strategy to maximize the staff morale, their productivity and efficiency. This engagement gives organization a competitive advantage in order to secure challenging score in the growing market. PINSTECH and PAEC provide their staff a basic cultural engagement activity that include:

- Research and innovation platforms;
- Monthly dialogue;
- Talent management Programmes;
- Career counselling and management for future researches;
- Employee benefits;

- Childcare centre;
- Financial study services for staff children;
- Daily Pick and Drop for all employees;
- Handsome salary packages.

5.6. INTEGRATED MANAGEMENT SYSTEMS & CONTINUAL IMPROVEMENT

Integrated management system joins in all components of a business into one comprehensible system to assist the achievement of its purpose and operation. This management system highlights the clear image of the organization and its effectiveness in order to achieve a specific goal for national and international interests.

Integrated management system in PINSTECH circulates around many factors to be monitored. These include:

- Highly qualified engineers and scientists;
- Policy making;
- Comprehensive planning;
- Implementation of policies and methodologies;
- Operation monitoring;
- Performance assessment;
- Feedback analysis;
- Suggestion and improvement strategies;
- Management review.

For continual improvement and effectiveness of the organization, Quality Management system in PINSTECH plays a very important role. This approach enhances the monitoring and implementation of basis strategies for potential challenging environment.

2.2.5. ISO 9001:2015 Certification

PINSTECH Radiopharmaceutical Production facility is ISO 9001:2015 Certified [3]. The quality management system comprises of Quality Action Team (QAT) comprising of scientists and engineers to look after the planning and policy making of quality management system. Plan-Do-Check-Act PDCA Cycle is observed in PINSTECH. This management system comprises of following clauses:

- **Management**
  Radiopharmaceutical demand and supply management is monitored weekly to cater the demand of medical centres. Resources management is carried out by monitoring and technical procurement methods to ensure uninterrupted supply of radiopharmaceuticals;
- **Customer Requirements and Demands**
  Customer requirement and demand is supervised and entertained by certain communication channels such as: emails, faxes or phone calls and control documents are being recorded containing these demands;
- **Policy, Procedure, Planning, Performance**
  Quality policy is formulated and implemented in whole division to fulfil the procedures and planning regarding production of radiopharmaceuticals. Key performance indicators are established to perform every function according to Good Manufacturing Practices with utilizing maximum strength and minimum resources in optimized time frame;

- **Objective control and Monitoring**
  Quality Objectives are formulated according to SMART (Specific, Measurable, attainable, realistic and time bared) objective. The resources and planning procedures are highlighted with factual time frame in order to materialize the objective to its full strength. For example: the enhancement of production capacity of I-131 in three years with deadline 31 December 2021;
- **Management Review and Auditing**
  Management Review committee arranges Management Review Meetings (MRM) quarterly to monitor and observe the working capacity of each production facility. In this meeting agenda for three months is discussed and internal audits are planned. Management Representative of Radiopharmaceutical Production Facility carried out internal audit and performs Gap Analysis to the ISO 9001:2015 certification;
- **Decision Making**
  Decision making is a key tool to increase productivity and strength of organization. At each step of production procedure, decision making policies help us reach out the final cover of procedure;
- **Corrective action/Preventive Action**
  In accordance with the ISO 9001:2015 Quality management system, the corrective actions are applied to minimize the risks associated and preventive actions are carried out. In past recent years, we have started a proactive approach to mitigate the risks and challenges. But this proactive approach demands highly integrated and oriented system to maximize the effectiveness of the production procedures with available resources. Maintenance management of Production Plants interprets the Pro-active maintenance schedule in which replacement of equipment after a scheduled time is carried out;
- **Nonconformity Monitoring**
  Non-conformance monitoring is carried out by managing control documents which include: Quality Policy, Group Manual, Quality Objectives, Risks and mitigation plan, Data analysis of production annually;
- **Risk Identification, Assessment, Mitigation Planning**
  Risk identification is a critical procedure to seek for risk and managing its occurrence probability with respect to its weightage of occurrence and level of intensity. When risk is identified, it is assessed according to expertise available in the form of operation manual and manpower experiences. This risk is tried to be mitigated afterwards by planning and past experiences reports of that risk. The mitigation planning and corrective actions are observed and checked frequently according to the occurrence probability. Risk index and residual risk factor is calculated. If the residual risk factor approaches to ZERO, the mitigation plan is re-formulated and implemented. This practice enables us to minimize the interruptions during production schedule of radiopharmaceuticals.

6. CONCLUSIONS AND OUTLOOK

This paper focuses on current ongoing activities in Isotopes Production Division (IPD) in PINSTECH. This article also highlights the challenges and problems that we are facing to increase the potential demand of radiopharmaceuticals. PINSTECH is producing several Radioisotopes i.e. Mo-99, Mo-99/Tc-99m generators, I-131, P-32, Lu-177, Au-198 etc and diagnostic cold kits for different body organ imaging along with the research and development for new radiolabelled diagnostic kits. Different Precursors for cold kits are also needed for kits formulation.

With the assistance of IAEA Regional workshop on Sustainability of National Nuclear institutions under TC Project RAS0080, In order to meet the increasing demand and to face the production challenges, LEU based Mo-99 production facility and Tc-99m Generator loading facility along with the technical training is required. We are also in need of several instruments like Multi Channel Analyser (MCA), LSA and Alpha Dose calibrator and their standard sealed sources for quality control processes of several kits. We face severe difficulty in the import process of TeO_2 powder which is used for the production process of I-131.
PINSTECH is also providing services to agricultural and industrial sectors by providing radiopharmaceuticals. PINSTECH Human Resource Management Department also facilitates the students of several universities by providing technical guidance and radiopharmaceuticals for research purpose.

Supply chain management is controlled and supervised to maximize the product availability to the customer. Customer acquisition management and business lead management leads to merchant/client contract that is sealed for a financial year regarding the demand of radiopharmaceutical and freeze-dried kits. Staff engagement and culture management proves to be an articulative strategy to maximize the staff morale, their productivity and efficiency. For continual improvement and effectiveness of the organization. PINSTECH Radiopharmaceutical Production facility is ISO 9001:2015 Certified. The quality management system comprises of Quality Action Team (QAT) comprising of scientists and engineers to look after the planning and policy making with Plan-Do-Check-Act PDCA Cycle.

For self-reliance and sustainability of Radiopharmaceutical Production Facility in PINSTECH, we need regular assistance of IAEA to cope with the increasing demand and challenges in future perspective.

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THAILAND: STRATEGY FOR SELFRELIANCE AND SUSTAINABILITY OF TINT

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Abstract

Thailand Nuclear Technology Service Centre (NTSC) is a nuclear service centre under the supervision of Thailand Institute of Nuclear Technology (TINT), established in 2006. NTSC is responsible for several types of nuclear technology services, for example, analysis of samples' compositions by using nuclear techniques, nuclear and radiation survey metres' calibration, non-destructive testing, and to certify radiation levels of food products for exporters. NTSC has continuously maintained a high level of service quality and customer satisfaction which leads to achieving the highest growth among TINT's service centres. Its revenue has grown more than 600% within 10 years (from $196,000 to $1.5 million). All of NTSC's revenue is contributed back to TINT which later is distributed into TINT's fringe benefits, incentive regimes, research instruments, and R&D projects. The circulation of this revenue, therefore, could back up TINT to secure its fundamental expenses in both organisational development and in R&D. Thus, the following questions arose, what have NTSC and its staff done to become successful? In addition, what could TINT learn from them if TINT desires to adopt NTSC management practices to other centres? Good service quality, a certified standard of services, a reasonable price, and quick response to customers' queries are central strengths and means for differentiating NTSC from other organisations. These strengths create additional perceived value to customers and build up a recognisable brand image. Additionally, long-term direction, continuous development, i.e. in products, services and processes, knowledge on customer behaviour by a comprehensive database, NTSC's management commitment, and strong teamwork with trust could be the factors influencing the success of the outcomes. The report concludes that technology service management becomes more an integrative discipline between nuclear technical knowledge, and business and management. It seems both tangible and intangible resources drive the value creation in this service organisation. The study of key drivers and their functions at each unit could be beneficial for the institute to accomplish and sustain the service organisation strategically.

1. INTRODUCTION

The Thailand Institute of Nuclear Technology (TINT) is a Thai research institute. It split off from the Office of Atoms for Peace (OAP) in 2006 to separate the nuclear regulatory body and the nuclear utilization activities. Recently, while OAP is the nuclear regulatory body, TINT performs the nuclear R&D and utilization role. TINT can design its management and regulation system to improve its flexibility. Nevertheless, it still partly receives financial support from the Thai government.

TINT mainly focuses on R&D for nuclear and radiation technology as well as nuclear technology products and services, such as radioisotope, gemstone and food irradiation, non-destructive testing and radioactive waste management. The institute is under the supervision of the Ministry of Higher Education, Science, Research and Innovation.

After OAP and TINT were divided into two different institutes, TINT has grown steadily. In terms of performance, the number of publications increased from 61 papers in 2006 to 96 papers in 2018. During this period the revenue was raised from 625,000 USD to 4.375 Million USD. The major research facilities were increased during this time period from 2 major facilities (research reactor, and gamma irradiation facility) to 5 main facilities (research reactor, gamma irradiation facility, Electron accelerators for Gems irradiation and for food irradiation, and Cyclotron accelerator).

2. CURRENT TECHNICAL AND UTILIZATION STATUS

TINT is currently operating five main facilities with the purpose of conducting R&D and providing technological services. The primary research facility is the Thai Research Reactor (TRR-1/M1). The reactor can operate with a maximum steady power of 2MW and in the pulse mode with a maximum power of 2,000 MW for a short period of 10.5 milliseconds. The reactor is used as a research facility in the areas of medicine and agricultural products and supports the service by providing gemstone neutron bombardment services, radio-isotope production and determining the concentrations of elements by a neutron activation analysis service. The reactor control system was upgraded in 2015 because the institute lacked instruments and spare parts. Since then, the maximum power was set to 1.2 MW and the pulsing mode was removed from the control system.

Beside the research reactor, the 20 MeV electron accelerator and gamma irradiation facility which are in Nakorn Nayok Province, provides gemstone irradiation and material science research services. The gamma irradiation facility in Pathum Thani Province provides irradiation services for food and agricultural products, such as spices, herbs, fruits, and seafood, but also for gemstones, and research in the area of material science.

The radiopharmaceutical production facilities provide radioisotope and radiopharmaceutical services for medical, industrial, and research purposes. The radioactive waste management facility is assigned to organise and maintain a centralised radioactive waste management service in the country. It is composed of a solid waste treatment facility, a liquid waste treatment facility, and a storage facility. Besides being used for waste management services, it is also used as a research facility for environmental science and radiation safety.

Moreover, the two main facilities are in progress to enhance TINT's service capacity. An electron accelerator complex for food and medical instrument irradiation located in Pathum Thani has a 10 MeV accelerator, a 3MeV accelerator, and two convertible 5 MeV accelerators which can be converted to X-ray. A cyclotron accelerator for medical purposes is under-construction in Nakorn Nayok Province.

3. CURRENT ISSUES, CHALLENGES AND CONSTRAINTS

TINT conducts R&D and provides nuclear technology services. The institute therefore has to balance two different dimensions, the academic dimension when conducting R&D and the industrial dimension when offering technological services.

On the one hand, Thailand´s national policy encourages R&D institutes in Thailand to focus on national economic and industrial growth. The outcome of R&D is expected to support competitive advantages and national innovation. Hence, the national R&D policy focuses on the support of 10 industrial targets: next generation automotive, smart electronics, medical and wellness tourism, agriculture and biotechnology, Food for the future, robotics, aviation and logistics, biofuels and bio chemicals, digital society and medical hub.

Concerns have been raised that TINT was advised to adjust its R&D projects to the national policy and to determine their usefulness to society. Otherwise, the budget received, already limited, could be threatened by a mismatch between national directions and TINT's research projects, since the national budget allocation is distributed according to the national framework. TINT therefore conducts academic research to support national agendas and satisfies stakeholders by providing R&D outputs that fit national expectations on solution-based R&D.

On the other hand, the industrial culture in nuclear technology services created different complications and made TINT's service centres work commercially. Customers expect TINT's service centres to be like other revenue-seeking players in the market. In other words, TINT is simply just seen as another supplier. Efficiency, flexibility, reasonable prices, customer relations, and after-sale services are only a few characteristics that the companies expect from service centres. This tension drives TINT's service centres to develop themselves to be more customers focused and business orientated.

This dichotomy of the roles may create either a conflict or an opportunity for one another. TINT has created some opportunities. TINT has used the combination of academic work and practical problem-solving services as the sources of intellectual pluralism. Hence, it is represented by TINT that it is possible to use direct economic benefit from the service centre to stabilise partly the organizational annual budget. The revenue from commercialized services is utilized intra-organization in term of employees' incentive, HRD, and enhances R&D capacity. In this meaning, TINT needs to maintain its roles on both academics and commercial activities. The details are explained in section 4.

4. STRATEGY FOR SELF-RELIANCE AND SUSTAINABILITY

Organizational self-reliance cannot be achieved without the establishment of technical capacity, human capacity, and R&D capability. TINT works towards creating those issues, aiming to enhance the technological knowledgebase, to improve internal management systems and to install necessary facilities. However, all these activities need financial support. Therefore, TINT has initiated a strategy to generate its own financial liquidity for investing in necessary operational activities, research equipment and service facilities without relying only on governmental budget. Therefore, a system for financial circulation between R&D and services was introduced in 2009.

The concept of the financial circulation is that the financial factor is one of the most important factors to develop R&D [1] and to ensure that other parts of the institute can operate sustainably (see Fig. 1). However, one of the key constraints for TINT is a limited and unpredictable governmental budget. Meanwhile, the budget set by TINT's own revenue, is more controllable and allows TINT to conduct on-going projects or fundamental research projects sturdily. In this way, the utilization of the cash flow from services can sustain R&D activities. The main role and duty of nuclear services, therefore, is to enhance the utilization of nuclear technology in the most efficient manner and to earn revenue from the services provided. Then, TINT can feed that revenue into the intra-organizational budget in R&D operations, developing R&D facilities, establish a motivation system, and develop HR competency. The financial circulation can be seen as TINT´s approach to create the self-reliance.

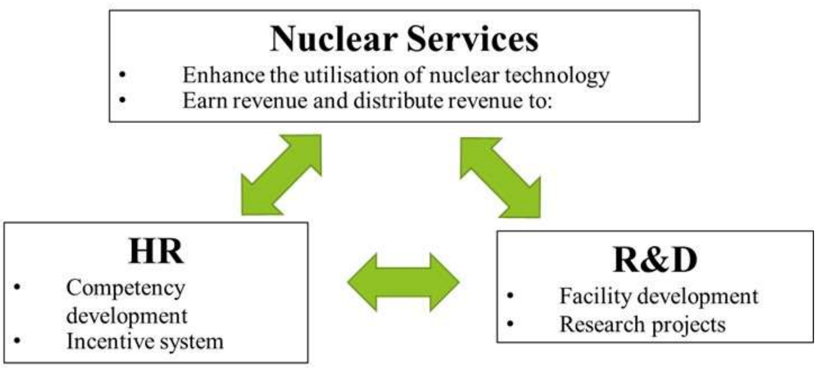

FIG. 1: The circulation of cash flow between nuclear services to other components.

Among TINT's five key service centres, the Nuclear Technology Service Centre (NTSC) has shown remarkable achievements. Therefore, this paper will highlight on a lesson learnt from NTSC as a success case.

NTSC was established in 2006 and along with TINT it was separated from OAP. It was classified as a revenue centre with the mission to generate revenue from its nuclear technology services. At its first establishment, NTSC had 11 employees with three key services- NDT and column scan, certified export foods, and personal dosimetry. Recently, it has nearly 50 permanent and temporary employees.

In terms of financial contribution, in 2007, NTSC contributed 0.191 million USD to TINT. The revenue has increased regularly to 1.468 million USD in 2018. Within the past 10 years, NTSC has contributed approximately 9 million USD to TINT in total. (see Figure 2).

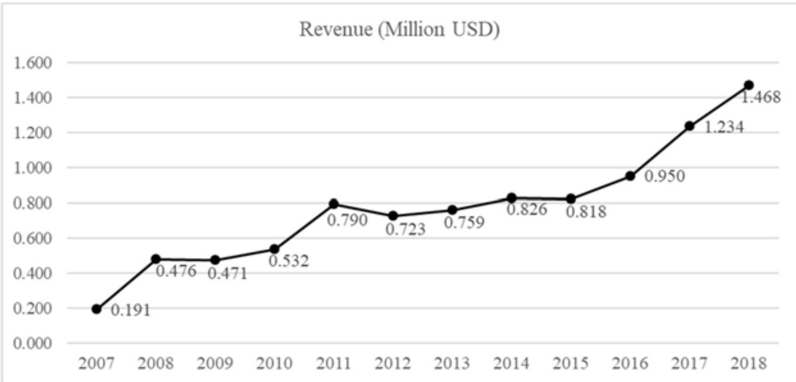

FIG. 2: Revenue of NTSC between 2007-2018.

Besides the revenues, NTSC has proven its professionalism in technological management by continuously introducing new services to the market. Recently, it has expanded its business from 3 to 8 key services: import/ export products, radiological monitoring, elemental analysis, non-destructive testing services, distillation column inspection using Gamma scanning, personal dosimetry services, industrial X-ray machine safety inspections, packaging and Gamma-ray projector safety inspection services, Radiation survey meter and dosimeters calibration services. NTSC key services and the contribution to NTSC's revenue are shown in Figure 3.

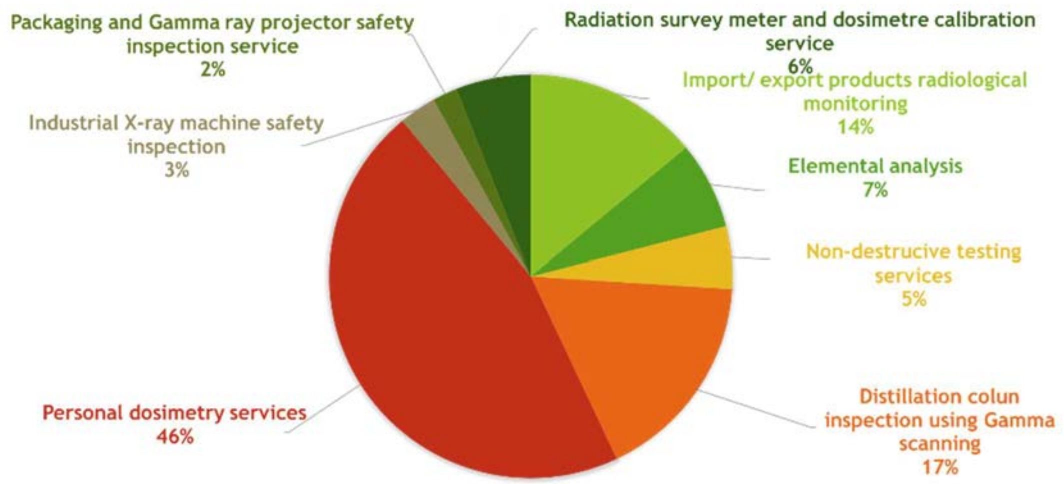

FIG. 3. NTSC's services and revenue contribution.

In terms of HR management, NTSC has proven its professionalism in HR management by a zero percent turn-over rate. The employees' engagement, the integrated management systems and the continual improvement are key success factors for HR management [2]. The details will be examined in sections 4.4, 4.5, and 4.6.

4.1. STRATEGIC, FINANCIAL & BUSINESS PLANNING

Strategic planning is an essential management tool [3]. NTSC has adopted the strategic planning discipline and practices financial planning, technological planning, marketing planning, and manpower planning accordingly. These actions have resulted in a consistent growth of NTSC's performance.

In alignment with the corporate strategy, all nuclear service centres need to establish a strategic plan for creating revenue in order to feed into TINT's financial pot. The requirements and market information from users are key input factors for effective strategic planning [4][5].

In 2011, NTSC proposed its business plan highlighting the expansion of 2 businesses, namely (1) Gamma scanning and (2) calibration and OSL. The plan was the result of market information gained from marketing activities such as road shows, customer meetings, and exhibitions. The information from users allowed NTSC to make growth predictions for the distillation column inspection using Gamma scanning, and personal dosimetry. Hence, NTSC used this market information to identify and analyse business opportunities and to formulate a business plan.

This business plan combined needed financial investments, such as the investment for facilities and recruiting, with other aspects like majoring the gaps the NTSC needed to develop, such as technology gaps, or manpower and HRD planning. It was planned to recruit an NDT team for Gamma scanning and to establish a standard laboratory for personal dosimetry service based on ISO 17025 standard. It was expected that the centre will break even after 5 years' time.

After illustrating a solid business plan, the plan gained approval from TINT's board of directors to invest and run the projects. Hence, a solid business plan with commitment and clear targets reveals its ability to gain resources and financial support from the management.

4.2 SUPPLY CHAIN MANAGEMENT

Supply chain management (SCM) is a network of multiple businesses and relationships of both intra- and inter-company. Hence, SCM is a business process that represents an approach of managing businesses and relationships with other parts of the supply chain.

The three primary aspects of NSTC as each part of supply chain has identified: (1) the supply chain's member, (2) the structure of supply chain network, and (3) the process that link across the network. These three aspects are related to the implementation of the process that business is already approach; for example, customer relationship management, customer service management, demand management, service flow management, procurement, and product development.

However, what NTSC has done so far is mainly user management such as customer relationship management, customer service management, demand management, service flow management, and product development. Still, the procurement process which is one of a key part of supply chain management is centralised in the procurement division.

4.3 CUSTOMER & BUSINESS LEAD MANAGEMENT

The major strategy NTSC has focused on and leads to the great success is Customer Relationship Management (CRM). Good relationships and keeping up with customers' demands are fundamental for customer retention. CRM is a strategy to manage customer relationships and interactions by providing a source of customer information which is useful for a deeper understanding of customers' behaviour [6]. The marketing team can use this information to forecast short and long-term of the market trends. The after-sale-service can track the communication between sales and customers and in this way gain information on the customers' expectations.

In particular, during the customers' inquiry process, TINT utilises an online platform for customers to submit their products and services' inquiry and to track purchasing orders. In the product delivery process, NTSC provides the promised delivery date which customers can track through the TINT's interface. For after-sale services, customers can easily connect with NTSC via smartphone using the Line Chat Application by simply scanning the QR code and then directing the communication to the after-sale service.

However, NTSC is in process to improve its customers' database. The completed data base is expected to be a key source of customer information and to become a key point for the managing service agreement. Furthermore, it is expected to be fully utilised as a source of information for market predictions.

4.4 STAKEHOLDER ENGAGEMENT

NTSC has an obligation to its stakeholders to go beyond the scope of simply satisfying their ambitions and expectations. The following steps are an approach taken by NTSC for its stakeholder management strategy and implementation.

NTSC has created a stakeholder list and information about who the stakeholders are and how they can be contacted. As a result of this NTSC was able to identify four categories of key stakeholders: resource allocators, regulators, customers and communities, and NTSC's staff. Then, NTSC identified its most relevant stakeholders' and their expectations. For example, resource allocators, such as the Bureau of Budget or the Office of Public Development Commission may expect economic impacts that NTSC can contribute to the country. For TINT, the income contribution is one key aspect to fulfil TINT's expectation. For the regulatory bodies, NTSC has a strong commitment and obligation to fulfil all features in nuclear and radiation safety as well as to maintain the standard in service, laboratory and environmental safety. For customers, some key aspects are reasonable prices, a high service quality as well as the ability that NTSC solves their operational problems. Regarding its employees, HR management's and HR development's major task is to stimulate NTSC's staff motivation by providing job satisfaction, a good work-life balance, and job fulfilment.

More importantly, the results from the stakeholder analysis were used to plan interventions to manage stakeholder relationships [7]. The interventions to customers satisfaction will be illustrated in section 4.3, and the interventions to employee's engagement will be explained in section 4.5.

4.5 STAFF ENGAGEMENT & CULTURE MANAGEMENT

Engagement is about passion and commitment, the willingness to invest oneself and expand one's discretionary effort to help the employer succeeding, which is beyond simple satisfaction [8]. NTSC has done several activities to maintain its staff's engagement. The result is 0% turn-over-rate of its employees over the past 10 years.

NTSC emphasises on its staff's engagement by using both structural interventions and behavioural interventions. From the structural side, NTSC starts its staff engagement from the recruitment process. It recruits appropriate employees who fit with both, job and culture. It has a mentor system to create a good relationship among supervisors and colleagues. Besides that, a clear organizational structure and a systematic cascade of TINT's KPIs to NTSC and to the individual allows the staff to understand the importance of their daily job on TINT's output. In this way, structural intervention creates a sense of belonging.

Regarding the behavioural perspective, most of NTSC's services are done by teamwork, for example, NDT and column scan. The informal communication among employees and management through a flat organizational structure, the mentor system and the informal activities encourage the staff to build up a close relationship among the team. Informal communication also nurtures teamwork and establishes a positive attitude held by the employees towards the organization.

Moreover, the management provides support to the staff and recognition where appropriate. NTSC management helps its employees to grow through career and skills development through the training programme, whether in the national or international training course. With the activities, NTSC's employees mostly are aware of their job context, and their job to work with their colleagues to improve NTSC's performance for the benefit of the organization.

4.6 INTEGRATED MANAGEMENT SYSTEMS & CONTINUAL IPROVEMENT

NTSC´s integrated management system emerged from the idea to exploit the synergies between different management systems. A system for integrated workflow management requires several combined activities such as business management, technological management, and Quality Management System (QMS). The key motivations which drove NTSC to adopt the integrated management were to satisfy NTSC's stakeholders, such as continual improvement, customer satisfaction management, and to comply with the international safety standard.

NTSC's integrated management system was constituted by the implementation of a fundamental Quality Management System on TINT's ISO 9001:2015 and NTSC' ISO 17025, and incorporated with the requirement in other safety standards such as IAEA TS-R-1, IAEA Safety Series 16. The second idea of this system was to integrate the fundamentals with the concept of business management. For filling this gap, the Business Development (BD) unit was established in 2012 in order to be a bridge between the technical part and the business management concept, especially from the financial and marketing perspective.

Continual improvement became a common practice in all activities [9]. NTSC manager deployed a continual improvement policy to all divisions and encouraged all employees to keep an innovative thought. Today, NTSC commits itself to initiate at least one new product or service every year. A clear and ambitious goals, the commitment between managers and staff, as well as team encouragement and support are the foundation that continuous improvement has become NTSC's culture, that leads to the great success.

5. CONCLUSIONS AND OUTLOOK

This report is based on the premise that for a nuclear organization to be self-reliable, it has to identify the environment in which it operates as well as future business trends. Furthermore, the organization establishes its strategy and operations accordingly. In the case of TINT, it can learn from NTSC which has been very successful in operating its nuclear services. The key drivers for NTSC are demand-driven, market predictions, continuous improvement, expertise integration, and stakeholder's satisfaction management. However, in terms of a wider agenda, TINT can gradually apply these aspects to other facilities and collect some key common issues. This new gained information could be useful for analysing the characteristics of each facility, the common challenges, and how to transfer successful operating drivers from one facility to another. In conjunction with theory and practice, this could supply the organizations with further valuable knowledge and experiences which will be highly relevant for the continuous improvement scheme.

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VIET NAM: RESULTS AND LESSONS LEARNED FROM OPERATION AND UTILIZATION OF THE DALAT NUCLEAR RESEARCH REACTOR

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Abstract

The Dalat Nuclear Research Reactor (DNRR) with the nominal power of 500 kW was reconstructed and upgraded from the USA 250-kW TRIGA Mark-II reactor built in early 1960s. The renovated reactor was put into operation on 20th March 1984. It was designed for the purposes of radioisotope production (RI), neutron activation analysis (NAA), basic and applied researches, and nuclear education and training. During the last 35 years of operation, the DNRR was efficiently utilized for producing many kinds of radioisotopes and radiopharmaceuticals used in nuclear medicine centres and other users in industry, agriculture, hydrology and scientific research; developing a combination of nuclear analysis techniques (INAA, RNAA, PGNAA) and physic-chemical methods for quantitative analysis of about 70 elements and constituents in various samples; carrying out experiments on the reactor horizontal beam tubes for nuclear data measurement, neutron radiography and nuclear structure study; and establishing nuclear training and education programmes for human resource development. In recent years, there have been several lessons learned in exploiting the effectiveness of DNRR which has been drawn from the results of application deployment, in mainstreaming and transfer of nuclear science and technology to national socioeconomic development programmes. This paper presents the results of operation and utilization of the DNRR. Beside this, the current status of safety, operation and utilization of the reactor is given and some aspects for improvement of commercial products and services of the DNRR are also discussed. Lessons learned on good practices and limitations in the operation and exploitation of the DNRR are also mentioned in detail in this paper.

1.INTRODUCTION

The DNRR is a 500-kW pool-type reactor loaded with Soviet WWR-M2 fuel assemblies. It was reconstructed and upgraded from the USA 250-kW TRIGA Mark-II reactor built in early 1960s. The first criticality of the renovated reactor was on the 1st November 1983 and its regular operation at a nominal power of 500 kW has been since March 1984. The first fresh core was loaded with 88 fuel assemblies enriched to 36% (Highly Enriched Uranium, HEU).

In the framework of the programme on Russian Research Reactor Fuel Return (RRRFR) and the programme on Reduced Enrichment for Research and Test Reactor (RERTR), the DNRR core was partly converted from HEU to Low Enriched Uranium (LEU) with 19.75% enrichment in September 2007. Then, the full core conversion of the reactor to LEU fuel was also performed from 24th November 2011 to 13th January 2012. Recently, the DNRR has been operated with a core configuration loaded with 92 WWR-M2 LEU fuel assemblies and 12 beryllium rods around the neutron trap.

The reactor is used as a neutron source for the purposes of radioisotopes production, neutron activation analysis, basic and applied research and training [1].

The reactor is operated mainly in continuous runs of 130-150 hours for cycles of 2-3 weeks for the above-mentioned purposes. The remaining time between two continuous operation cycles is devoted to maintenance works and also to offer short beam times for reactor physics experiments.

From the first start-up until December 2018, the reactor was in operation of about 46,100 hours, that is given a yearly average of about 1350 hrs of safety and effective exploitation.

More than 90% of reactor operation time and over 80% of reactor irradiation capacity have been exploited for research and production of radioisotopes. During the operation, the reactor has been successfully used for producing many kinds of radioisotopes and radiopharmaceuticals used in medicine and other economic and technical fields. Supplied about 8736 Ci of radioisotopes for using in medicine, including I-131, P-32, Mo-99/Tc-99m, Sm-153, Lu-177, Cr-51, Co-60, Ir-192, that contributed to push forward the development of nuclear medicine in Viet Nam.

In recent years, there have been several lessons learned in exploiting the effectiveness of DNRR which has been drawn from the results of application deployment, in mainstreaming and transfer of nuclear science and technology to national socioeconomic development programmes.

2. BRIEF REACTOR DESCRIPTION AND ITS OPERATION

The reactor consists of a cylindrical aluminium tank 6.26 m high and 1.98 m in diameter of the original TRIGA Mark II reactor. Specifications are given in Table 1. The reactor core, positioned inside the graphite reflector, is suspended from above by an inner cylindrical extracting well to increase the cooling efficiency for coping with higher thermal power of the reactor. The vertical section view of the reactor is shown in Fig. 1 and the cross-section view of the reactor core is shown in Fig. 2.

TABLE. 1 SPECIFICTIONS OF THE DNRR

Reactor type	Swimming pool TRIGA Mark II, modified to Russian type of IVV-9
Nominal thermal power	500 kW, steady state
Coolant and moderator	Light water
Core cooling mechanism	Natural convection
Reflector	Beryllium and graphite
Fuel types	WWR-M2, dispersed UO2-Al with 19.75% enrichment, aluminium cladding
Number of control rods	7 (2 safety rods, 4 shim rods, 1 regulating rod)
Materials of control rods	B4C for safety and shim rods, stainless steel for automatic regulating rod
Neutron measuring channels	6 combined in 3 housings with 1 CFC and 1 CIC each
Vertical irradiation channels	4 (neutron trap, 1 wet channel, 2 dry channels) and 40 holes at the rotary rack
Horizontal beam-ports	4 (1 tangential - No #3 and 3 radial - No #1, #2, #4)
Thermal column	1
Maximum thermal neutron flux	2.1×1013 n $\cdot$ cm^{-2} $\cdot$ s^{-1} (in the neutron trap at core centre)
Main utilizations	RI, NAA, PGNAA, NR, basic and applied research, nuclear training

FIG. 1: Left: The reactor building. Right: Vertical section view of the reactor core.

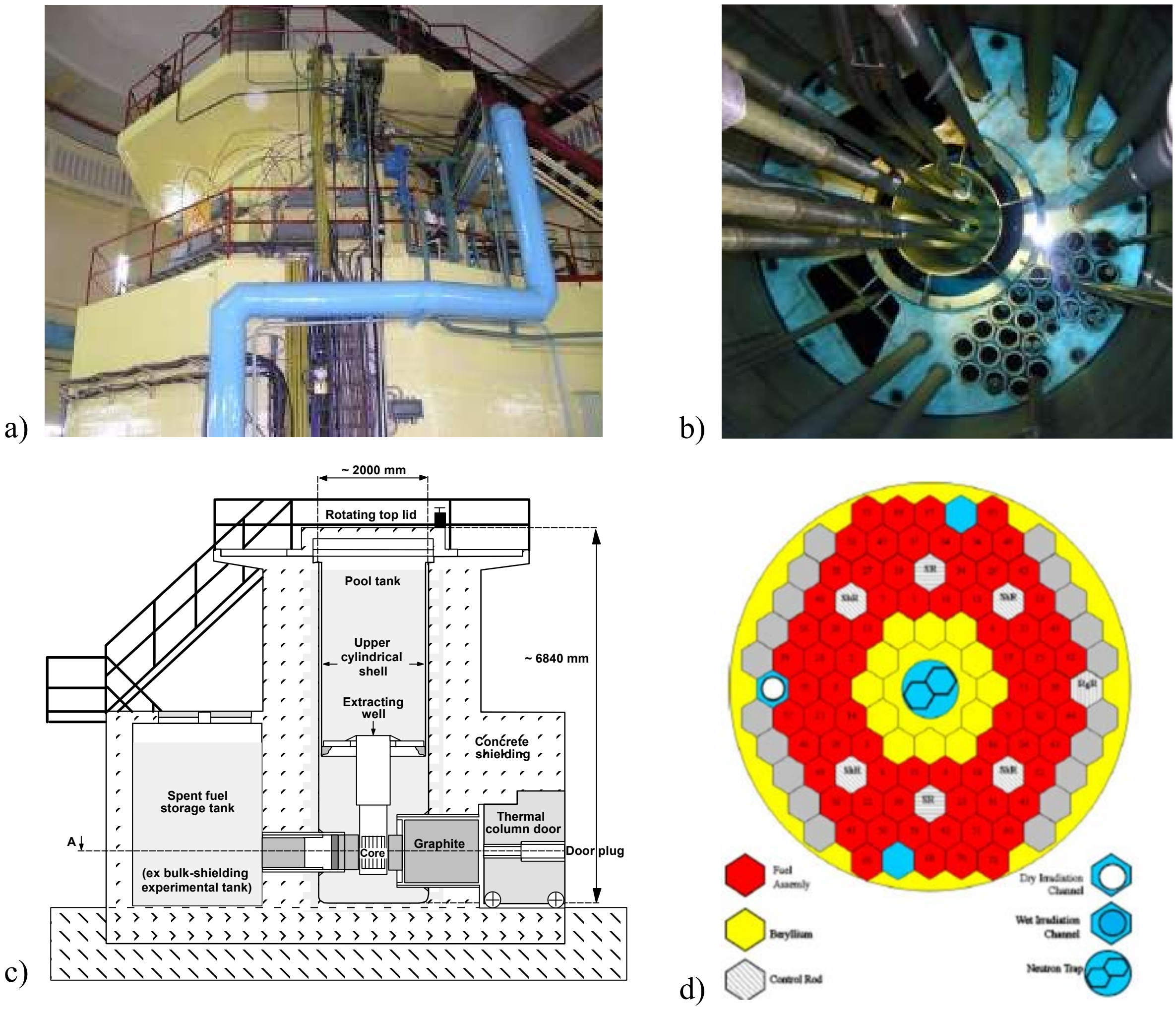

FIG. 2: a) Reactor pool. b) Reactor core. c) cross-section view of the reactor core. d) Core loading.

The reactor core has a cylindrical shape with a height of 60 cm and a diameter of 44.2 cm, that is constituted of 92 LEU fuel assemblies, 7 control rods, a neutron trap at the core centre and 3 in-core irradiation facilities.

Type of fuel with a ^{235}U enrichment of 19.75% of UO_2+Al covered by aluminium cladding is used. Each LEU fuel assembly contains about 50.5 g of U-235, distributed on three coaxial fuel tubes, of which the outermost one is hexagonal shaped, and the two inner ones are circular.
At present, the DNRR is operated mainly in continuous runs of 130 or 150 hrs, once every 2–3 weeks, for radioisotope production, neutron activation analyses, basic and applied researches

and training. The remaining time between two consecutive runs is devoted to maintenance activities and to physics experiments. From the first start-up to the end of 2018, it totalled about 46,100 hrs of operation, namely a yearly average of 1350 hrs, and the total energy released was about 760 MWd. Detailed yearly operation time of the DNRR is given in Fig. 3.

So far, the reactor has proven to be safe and reliable, as it has never suffered from any incident, which significantly affected the environment, and annual operation schedules have been rigorously respected. The unscheduled shutdowns were mainly due to unstable working of the city electric network.

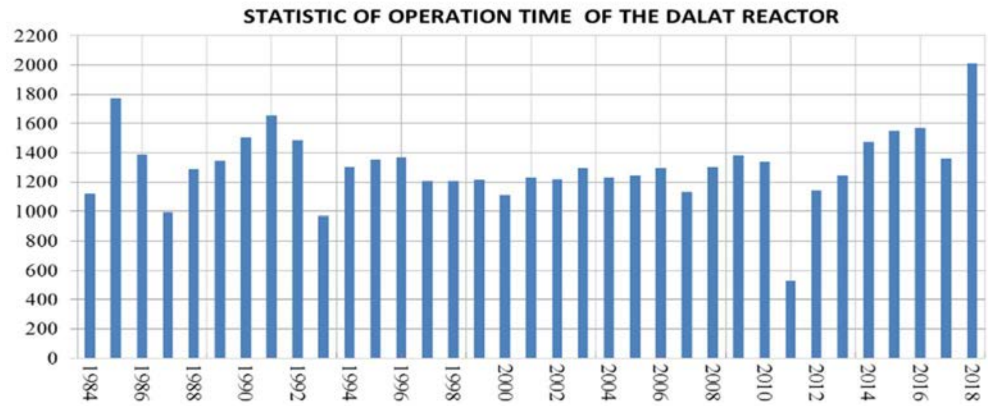

FIG. 3. Yearly operation time of the DNRR.

3. MAIN RESULTS OF REACTOR UTILIZATION

3.1. RADIOISOTOPE AND RADIOPHARMACEUTICALS PRODUCTION

Research on radioisotope and radiopharmaceutical production serving nuclear medicine and other users such as industry, agriculture, hydrology, scientific research, etc. oriented towards efficient use of the reactor. Via such research a variety of products including ^{131}I, ^{32}P applicators and solutions, ^{99m}Tc generators, etc. were produced [2].

For medicine applications, radioisotopes and radiopharmaceuticals have been delivered to 35 hospitals throughout the country. The main radioisotopes, such as ^{131}I in NaI solution and ^{131}I capsule type, ^{32}P applicators for skin disease therapeutics and ^{32}P in injectable solution, ^{99m}Tc generator of gel type by ^{98}Mo (n, γ)^{99}Mo reaction have regularly been produced and supplied once every week. Other radioisotopes as ^{51}Cr, ^{60}Co, ^{177}Lu,^{153}Sm, etc. were also produced in a small amount when requested. Totally, about 8736 Ci of radioisotopes have been produced and supplied to medical uses so far with a yearly average of about 500 Ci (Fig. 4) correspondingly.

In order to support the application of ^{99m}Tc, ^{113m}In and ^{153}Sm radioisotopes in clinical diagnosis and therapeutics, the preparation of radiopharmaceuticals in Kit form for labelling was carried out in parallel with the development of ^{99m}Tc generator systems. About 17 labelled compounds kits have been regularly prepared and supplied including Phytate, Gluconate, Pyrophosphate, Citrate, DMSA, HIDA, DTPA, Macroaggregated HSA and EHDP, etc. The annual production rate is about 3000 vials for each Kit which is equivalent to 5000 diagnostic doses.

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

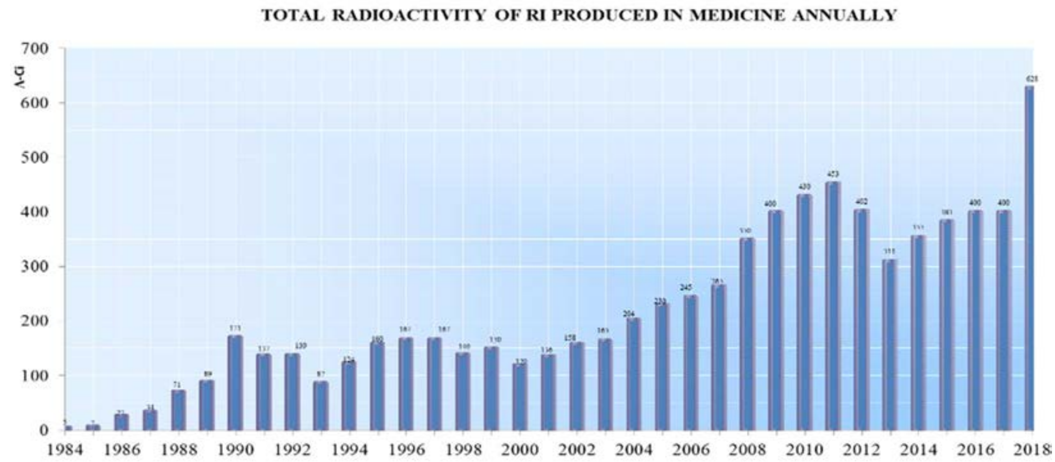

FIG 4. Total radioactivity of RI produced annually at NRI, Dalat for medicine.

3.2. NEUTRON ACTIVATION ANALYSIS

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

Requests of many branches of the national economy for various types of samples have quickly been responded. NAA at DNRR has always been met the demand of analytical services for geology exploration, oil prospecting, agriculture, biology, environmental studies, etc.

The relatively high neutron flux in irradiation channels of the reactor allows elemental analysis using various neutron activation approaches, such as Instrumental NAA (INAA), Radiochemical NAA (RNAA), Delayed NAA (DNAA) and Prompt gamma NAA (PGNAA). By the end of 2018, a total of about 70,000 samples have been irradiated at the reactor with a yearly average of 2000 samples. It can be estimated that those make up 60% of geological samples, 10% of biological samples, 20% of environmental samples, 5% of soil and agriculture materials, 3% of industrial materials.

In order to determine the elements having short-lived radionuclides, the method of cyclic INAA with the alternation of irradiation and measurement was implemented by using the thermal column and vertical irradiation channel. An auto-pneumatic transfer system installed in 2012 at the DNRR can transfer a sample from irradiation position to measuring detector about 3 seconds. The k-zero method for INAA has been also developed to analyse airborne particulate samples for investigation of air pollution; crude oil samples and base rock samples for oil field study. Based on developed k0-INAA method, a multi-elements analysis procedures have been applied to simultaneously determine concentration for about 31 elements including Al, As, Ba, Br, Ca, Cl, Cr, Cu, Dy, Eu, Fe, Ga, Hf, Ho, K, La, Lu, Mg, Mn, Na, Sb, Sc, Sm, Sr, Th, Ti, V, Yb, Zn.

3.3. NEUTRON BEAM UTILIZATION

The reactor has four horizontal beam tubes, which provide beams of neutron and gamma radiation for a variety of experiments. They also provide irradiation facilities for large specimens in a region close to the reactor core. Besides, the reactor also has a large thermal column with outside dimensions of 1.2m by 1.2m in cross section and 1.6m in length (Fig. 5).

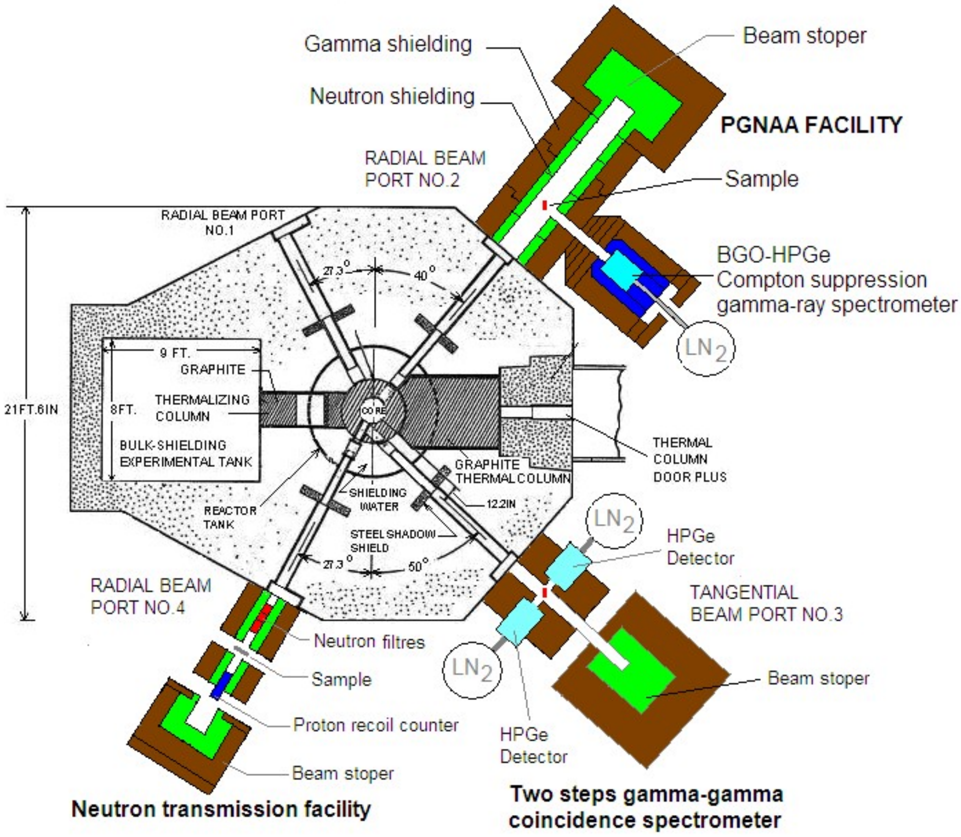

FIG. 5. Horizontal section view of the Dalat research reactor.

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

3.3.1. Neutron physics and nuclear data measurement:

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

- Total neutron cross section measurement for ^{238}U, Fe, Al, Pb on filtered neutron beams at 144 keV, 55 keV, 25 keV and evaluation of average neutron resonance parameters from experimental data;
- Gamma ray spectra measurement from neutron capture reaction of some reactor materials (such as Al, Fe, Be, and others) on filtered neutron beam at 55 keV and 144 keV;
- Measurement of average neutron radioactive capture cross section of ^{238}U, ^{98}Mo, ^{151}Eu, ^{153}Eu on the 55 keV and 144 keV neutron beams;
- Measurement of isomeric ratio created in the reaction ^{81}Br (n, γ)^{82}Br on the 55 keV and 144 keV neutron beams;
- And other investigations, such as average resonance capture measurements, using the γ-γ coincidence spectrometer for study on the (n, 2γ) reaction.

3.3.2. Application of neutron capture gamma ray spectroscopy

The following applications have been implemented:

- Development of PGNAA technique using the filtered thermal neutron beam in combination with the Compton-suppressed spectrometer for analysing Fe, Co, Ni, C in steel samples; Si, Ca, Fe, Al in cement samples; Gd, Sm, Nd in uranium ores, Sm, Gd in rare earth ores, and others;
- Utilization of the PGNAA method for investigating the correlation between boron and tin concentrations in geological samples as a geochemical indication in exploration and assessment of natural mineral resources; analysing boron in sediment and sand samples to complement reference data for such samples from rivers;
- Development of the spectrometer of summation of amplitudes of coinciding pulses for (n, 2γ) reaction research and for measuring activity of activated elements with high possibility of cascade transitions.

3.4. EDUCATION AND TRAINING ACTIVITIES

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

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

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

3.5. OTHER APPLICATIONS

3.5.1. Reactor conversion from HEU to LEU fuels

In the framework of the programme on Russian Research Reactor Fuel Return (RRRFR) and the programme on Reduced Enrichment for Research and Test Reactor (RERTR), the DNRR core was partly converted from HEU to LEU in September 2007.

After this success, the full core conversion study from HEU to LEU of the DNRR was also done during years 2008–2010. The results of neutronics, thermal hydraulics and safety analysis showed that a LEU core loaded with 92 fuel assemblies and 12 beryllium rods around the neutron trap satisfies the safety requirements while maintaining the utilization possibility similar to that of the previous HEU and recent mixed fuel cores.

Physics and energy start-up of the DNRR for full core conversion to low enriched uranium (LEU) fuel were performed from November 24th, 2011 until January 13th, 2012 according to a planned programme that was approved by Viet Nam Atomic Energy Institute (VINATOM). At 15:35 on November 30th, 2011 the reactor reached criticality with core configuration including 72 LEU FAs and neutron trap in centre. Then the fuel loading for working core and power ascension test were also carried out from December 6th, 2011 to January 13th, 2012. Experimental results of physical and thermal hydraulics parameters of the reactor during start up stages and long operation cycles at nominal power showed very good agreement with calculated results and met the safety requirements.

3.5.2. Other applications

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

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

4. STRATEGIC PLAN FOR THE FUTURE

The purpose of this strategic plan is to establish a framework that will allow the DNRI to join "*Strategy for Peaceful Uses of Atomic Energy up to the year 2020"* in Viet Nam. The strategic plan has been developed to focus on the safe and reliable operation of the DNRR and the improvement of its utilization in order to meet the needs of the society. In addition, a new research reactor with power level of 15 MW is expected to be put in operation between 2023-2025, and therefore, this strategic plan has also taken into account the connection with the strategic plan for the new research reactor project [3–5].

4.1. ROLE OF THE DNRR IN THE NATIONAL POLICY DIRECTION

On 3 January 2006, the "*Strategy for Peaceful Uses of Atomic Energy up to the year 2020*" was signed by the Prime Minister. This decision determines the objectives and roadmap for atomic energy development in Viet Nam on both non-power and power applications [5].

According to "*Strategy for Peaceful Uses of Atomic Energy up the to 2020*" the DNRI will participate in the project on establishment of a Centre for Nuclear Science and Technology (CNEST) with a new 15-MW research reactor. In connection with the project on the first NPP in Viet Nam, the DNRI will also participate in other areas such as environmental monitoring and assessment, site survey, emergency planning, and public information.

4.2. MISSION, MAJOR AND SPECIFIC OBJECTIVES

The mission, major objectives and specific objectives are outlined in Fig. 6. Its major objectives focus on expanding capacity through 1) maintaining safe and reliable operation of the reactor, and 2) expanding the reactor utilization in order to meet the needs of the society. The plan's first set of specific objectives addresses activities to ensure that the objective of safe and reliable operation of the reactor is reached while the plan's second set of specific objectives focuses on measures to enhance and expand the capability of reactor utilization in the next decade.

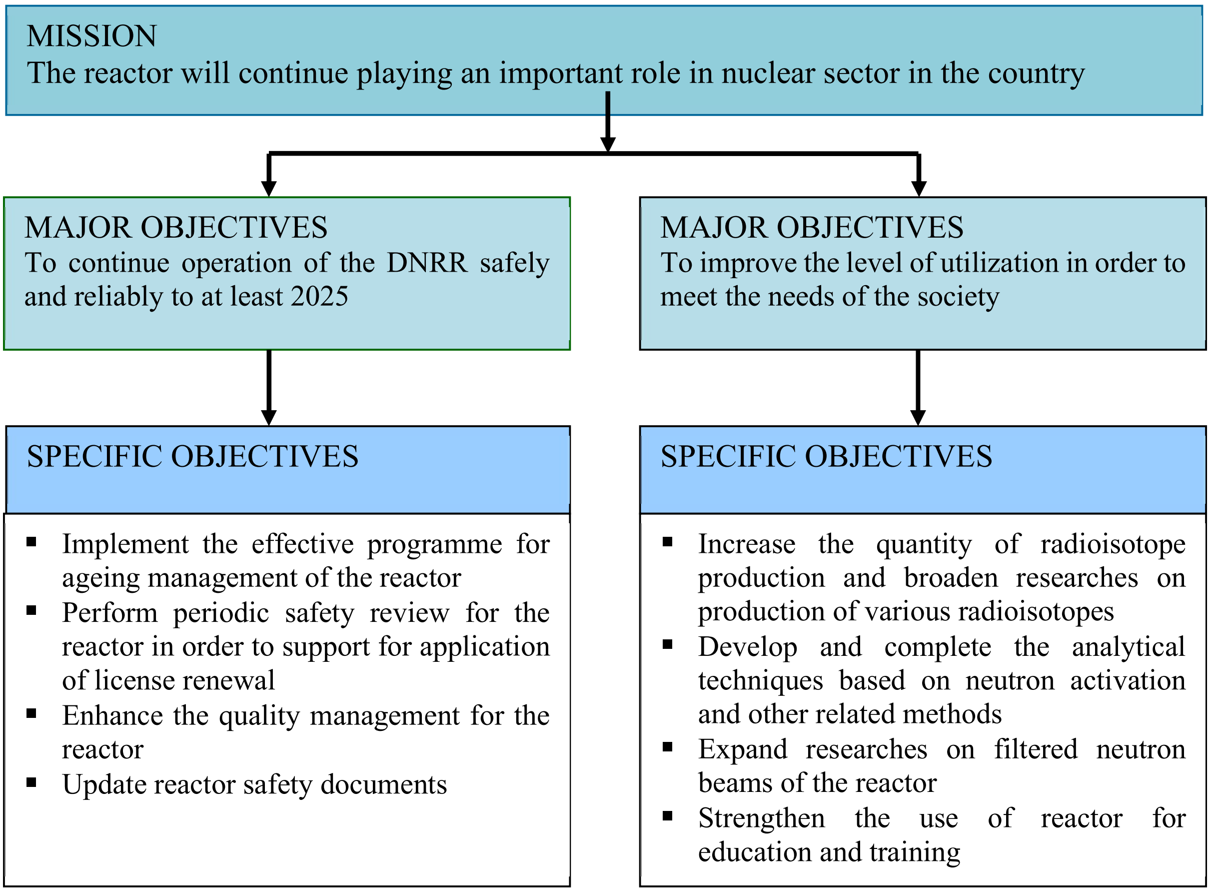

FIG. 6. Outline of the strategic plan for the DNRR.

4.3. DETAILED ACTION PLANS

4.3.1. Effective programme for ageing management of the reactor

To achieve this specific objective, the methodology used to detect and evaluate ageing degradation and countermeasures used for prevention and mitigation of ageing degradation will be continued to improve. In addition to updating of the ageing management programme for the DNRR, other safety documents will also be updated to maintain their conformity with the actual status of the reactor.

To cope with ageing degradation of SSCs important to safety, the measures such as mitigation, refurbishment or replacement of some components/systems will be carried out in stages 2017-2020, namely:

- Beam ports: enhancement of ensuring the quality of the reactor water in order to mitigate the development of defects due to corrosion;
- Electric power system: replacement of the existing transformer system by a new one;

- Reactor cooling loops: re-design and replacement of the existing pump of primary loop by a new one, upgrading the cooling tower.

4.3.2. Perform periodic safety review for the reactor in order to support for application of license renewal

After fulfilment of full core conversion from HEU to LEU fuels for the DNRR, the license for operation and utilization of the reactor with the validation of the 10-year duration was granted on 7 February 2013.

For the purpose of application of license renewal, the periodic safety review of the DNRR will be conducted in years 2018–2022 comprising 4 phases: (1) Preparation of the PSR project (2018–2019), (2) Conduct of the PSR (2019–2021), (3) Regulatory review (2019–2021) and (4) Finalization of the integrated implementation plan (2020–2022). The safety assessment of the reactor will be based on the safety factors as recommended in the IAEA Safety Guide.

4.3.3. Enhance the quality management for the reactor

The enhancement of quality management for the DNRR will focus on the following work:

- Continue to improve and complete the existing quality assurance programme of the DNRR based on the annual assessment of the results of reactor operation and utilization, staff quality, completeness of safety documents, record keeping, and others;
- Perform a gap analysis to move from the management system based on quality assurance programme to the integrated management system according to IAEA guidance.

4.3.4. Update the reactor safety documents

This objective aims at ensuring safe operation and implementing the effective ageing management for the DNRR. The updating of safety documents is to maintain their conformity with the actual status of the reactor and reflect modifications of existing experimental devices and systems. The updating will consist of such safety documents as safety analysis report, operational limits and conditions, operating procedures, the emergency plan and decommissioning plan.

4.3.5. Increase the quantity of radioisotope production and broaden researches on production of various radioisotopes

The increase of the quantity up to about 550 Ci per year of radioisotopes and broadening of researches on production of various radioisotopes (such as Mo-99, Y-90, Ho-166, Lu-177 and Ir-192) will be a priority in the next ten years. To achieve the objective of increasing the radioisotope quantity, the reactor operation regime of 150 hrs/cycle (instead of 130 hrs/cycle at present) will be applied and the facility upgrade for RI production will also be carried out. The research and production of various radioisotopes from the reactor will also be carried out through the implementation of national research projects in the next few years.

4.3.6. Develop and complete the analytical techniques based on neutron activation and other related methods

Development and completion of nuclear analytical techniques with and without use of reactor and related analytical techniques in order to offer a wide range of materials elemental analysis will continue to pay much attention at DNRI in the next ten years. Especially, the continuing development of analytical methods such as cyclic NAA, epithermal NAA, k-zero method in prompt gamma neutron activation analysis (k_0-PGNAA) and the improvement of automatization for NAA techniques will be one of the priority issues at the DNRI. These are being carried out under a ministerial research project during the years 2015–2017.

4.3.7. Expand researches on extracted neutron beams of the reactor

Among the activities using filtered neutron beams of the DNRR that will continue to be pursued are:

- Continue to carry out the measurements for neutron physics and nuclear data, and continue to improve the precision and sensitivity for PGNAA technique using the neutron beams extracted through beam port of the reactor;
- Expand the basic and applied researches on extracted neutron beams by developing neutron scattering and neutron radiography facilities.

4.3.8. Strengthen the use of reactor for nuclear education and training

In order to meet the rising demand in development of human resources for national nuclear power programme, the DNRR will continue to play an important role in the nuclear education and training for students from universities and professionals with interest in reactor engineering. In the next ten years, the DNRI will continue to offer two types of training course utilizing the research reactor as mentioned above: a one-week practical training course and a two or three-week training course on reactor engineering. The reactor will also be used for training staff who will participate in the operation and utilization of the new research reactor of CNEST. Besides, the association with universities in the country and the bilateral co-operation with international organizations for nuclear education and training will continue to be promoted.

5. LESSONS LEARNED ON GOOD PRACTICES IN OPERATION AND UTILIZATION OF DNRR

The following lessons learned on good practices in operation and utilization of the DNRR have been derived:

- Strategic Plan (SP) for the Dalat NRR (DNRR) has been set up and regularly updated;
- Five-year and yearly plans for inspection and maintenance of the reactor facilities have been prepared and approved by the authorized person (Director of Dalat Nuclear Research Institute), managed by the DRR manager (Director of Reactor Centre) and implemented by the staff of Reactor Centre;
- Having support and help of related authorities such as MOST and VINATOM. Yearly ministerial project has been approved and implemented for the maintenance, upgrading and operation of reactor facilities.

Having support and help of the Government, IAEA and bilateral co-operation through national projects, IAEA TC projects, as well as inter-governmental projects, such as the projects for renovation, modification and replacement of the reactor control and instrumentation system; the project on conversion of the reactor core fuel from highly enriched uranium (HEU) to low enriched uranium (LEU); the projects for installation and upgrading of the physical protection system for reactor facility, etc.

The investment of private sector for production and application of radioisotopes and radiopharmaceuticals in medicine and nuclear techniques in other areas for national economic development has been increased (3 from 9 cyclotrons and many equipment, were invested by the private sector, etc.).

Having a good legal framework for reactor management, operation and utilization including Atomic Energy Law (in force in 2009), Strategy on peaceful use of atomic energy up to 2020 (approved by Prime Minister in 2006), Master Planning for the peaceful development and utilization of atomic energy up to 2020 (approved by PM in 2010), Detailed Planning on application of atomic energy in Medicine (approved by PM in 2011), Detailed Planning on application of atomic energy in Industry (approved by PM in 2011), Detailed Planning on application of atomic energy in Agriculture (approved by PM in 2010), Detailed Planning on application of atomic energy in Geology and Environment (approved by PM in 2011), as well as Ministerial Circulars, Institutional Procedures, Norms, Decisions, etc. Besides, IAEA safety standards and guides for RR have been applied.

Good cooperation in the framework of multilateral collaboration (IAEA, RCA, Asian-Pacific, FNCA,), and bilateral co-operation with other countries and organizations. Based on these co-operations, technologies on RR application have been transferred and manpower has been developed.

Based on the on-the-job training a large amount of human resource with high skills and experiences on application of nuclear techniques in the country has been created.

6. CONCLUSIONS

During 35 years of operation, the DNRR has played an important role in the use of atomic energy for peaceful purpose in Viet Nam. The reactor has been used for radioisotope production for medicine and industry purposes, NAA of geological, crude oil and environmental samples, the performance of fundamental and applied research on nuclear and reactor physics, as well as the creation of a large amount of human resource with high skills and experiences on application of nuclear techniques in the country. A strategic plan and long-term working plan for the DNRR have been set up in order to continue its safe operation and effective utilization at least to 2025. To achieve that, maintaining and upgrading the reactor technological facilities have been done with high quality. The reactor physics and thermal hydraulics studies have also provided the important bases for safety evaluation and in-core fuel management to ensure its safe operation and effective exploitation. The safety and security for the reactor are also one of the main issues that national and local authorities are particularly interested in and strongly support up.

Although we have achieved much success, we have also faced many challenges such as:
DNRR has a small capacity so it does not meet the requirements of users for applications such as radioisotope products and channel scattering research. DNRR has a very long life, so the problem of corrosion and aging of equipment systems is always a matter of concern for investment and survey.

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APPENDIX III: WORKSHOP AGENDA

Tuesday, 9 April 2019; celebration of the 60th Anniversary of KAERI; VIP speeches; plenary session Venue: National Science Museum		
09:00 – 10:00	Registration	*All*
Celebration of the 60th Anniversary of KAERI		

Wednesday, 10 April 2019; plenary session Venue: National Science Museum		
09:00 – 10:00	Arrival and registration	*All*
10:00 – 10:30	HANARO Symposium Opening Ceremony	*High level Officials from the Republic of Korea*
10:30 – 11:30	Chaired by Mr In-Cheol Lim, KAERI	
Keynote talk (1): • *Jordan Research and Training Reactor (JRTR), S. D. Kahook, JAEC, Jordan*		
11:30 – 12:30	Chaired by Mr Sangik Wu, KAERI	
Oral invited (2): • *IAEA's support towards self-reliance and sustainability of national nuclear institutions, D. Ridikas, IAEA* • *Decommissioning of JMTR and Study for Construction of a New Material Testing Reactor, M. Kaminaga, JAEA, Japan*		
12:30 – 14:00	*Lunch break*	
14:00 – 16:00	Chaired by Mr J. Schulz, ANSTO	
Oral invited (2): • *Current status of HANARO and challenge for the sustainability, Myong-Seop Kim, KAERI, Republic of Korea* • *Sustainability of National Nuclear Organizations in India, C.G. Karhadkar, BARC, India* *Oral contributed (3):* • *Sustainability of National Nuclear Institutions in Bangladesh, M. A. Haque, BAEC, Bangladesh* • *Utilization of Multipurpose Reactor G.A. Siwabessy (RSG-GAS) in Indonesia, H. Umbara, BATAN, Indonesia* • *Prospects and Challenges Facing the Utilization of the Jordan Research and Training Reactor, I.F. Farouki, JAEC, Jordan*		
16:00 – 16:20	*Coffee break*	
16:20 – 17:20	Chaired by Mr M. Kaminaga, JAEA	
Oral contributed (3): • *Sustainability of Malaysian Nuclear Agency as National Nuclear Institution: Opportunities and Challenges, M. Z.M Hashim, Nuclear Malaysia, Malaysia* • *Radioisotopes Production in Pakistan, S. Haider, PAEC, Pakistan* • *The Philippine Nuclear Research Institute providing nuclear science and technology for national development, P. C. B. Pabroa, PNRI, Philippines*		
17:30	End of Plenary Session	

<table>
<tr><th colspan="3">Thursday, 11 April 2019; parallel sessions
Venue: Daejeon Convention Centre</th></tr>
<tr><td>09:00 – 09:30</td><td>Arrival and registration</td><td>All</td></tr>
<tr><td>09:30 – 11:30</td><td colspan="2">Chaired by C.G. Karhadkar, BARC</td></tr>
<tr><td colspan="3">Oral invited (1):
• Sustainability at the Australian Nuclear Science & Technology Organisation, J. Schulz, ANSTO, Australia

Oral contributed (3):
• A New Concept for Higher Vocational Education Program in Nuclear Technology in Indonesia, E.G.R. Putra, BATAN, Indonesia
• Sustainability of National Nuclear Institutions: A lesson learnt from Thailand Nuclear Technology Service Centre (NTSC), N. Tanboon, TINT, Thailand
• Results and Lessons Learned from Operation and Utilization of the Dalat Nuclear Research Reactor, V. D. Duong, DNRI, Vietnam</td></tr>
<tr><td></td><td>Continuation of HANARO Symposium Agenda</td><td></td></tr>
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<table>
<tr><th colspan="3">Friday, 12 April 2019
Venue: Daejeon Convention Centre</th></tr>
<tr><td>09:00 – 09:30</td><td>Arrival and registration</td><td>All</td></tr>
<tr><td></td><td>Continuation of HANARO Symposium Agenda</td><td></td></tr>
<tr><td>12:00 – 13:00</td><td colspan="2">Lunch break</td></tr>
<tr><td>13:00 – 15:00</td><td colspan="2">Chaired by D. Ridikas, IAEA</td></tr>
<tr><td></td><td>Drafting IAEA workshop report, including conclusions and recommendations</td><td>Restricted to RAS0080 participants only</td></tr>
<tr><td>15:00</td><td colspan="2">End of IAEA workshop</td></tr>
</table>

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ABBREVIATIONS

ANSN	Asian Nuclear Safety Network
ANSTO	Australian Nuclear Science and Technology Organization
B2B	Bench to business
BAEC	Bangladesh Atomic Energy Commission
BAPETEN	Nuclear Energy Regulatory Agency of Indonesia
BARC	Bhabha Atomic Research Centre
BATAN	National Atomic Energy Agency of Indonesia
DNRR	Dalat Nuclear Research Reactor
DOST	Department of Science and Technology of Philippines
E&T	Education and training
FNCA	Forum for Nuclear Cooperation in Asia
FTC	Follow up Training Course
HANARO	High Flux Advanced Neutron Application Reactor
HEU	Highly enriched uranium
HRD	Human resource development
IMS	Integrated management system
ITC	Instructor Training Course
JAEA	Japan Atomic Energy Agency
JAEC	Jordan Atomic Energy Commission
JMTR	Japan Material Testing Reactor
JRTR	Jordan Research and Training Reactor
JUST	Jordan University of Science and Technology
KAERI	Korea Atomic Energy Research Institute
LEU	Low enriched uranium
MNA	Malaysian Nuclear Agency, also known as Nuklear Malaysia

NAA	Neutron activation analysis
NDT	Non-destructive testing
NNIs	National nuclear institutions
NPP	Nuclear power programme
NTSC	Nuclear Technology Service Centre of Thailand
PAEC	Philippine Atomic Energy Commission
PARR-I	Pakistan Research Reactor-I
PINSTECH	Pakistan Institute of Nuclear Science and Technology
PNRI	Philippine Nuclear Research Institute
R&D	Research and development
RSG-GAS	Multipurpose Reactor G.A. Siwabessy
RTP	PUSPATI research reactor
SCM	Supply chain management
TINT	Thailand Institute of Nuclear Technology
TRR-1	Thai research reactor
VINATOM	Viet Nam Atomic Energy Institute

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