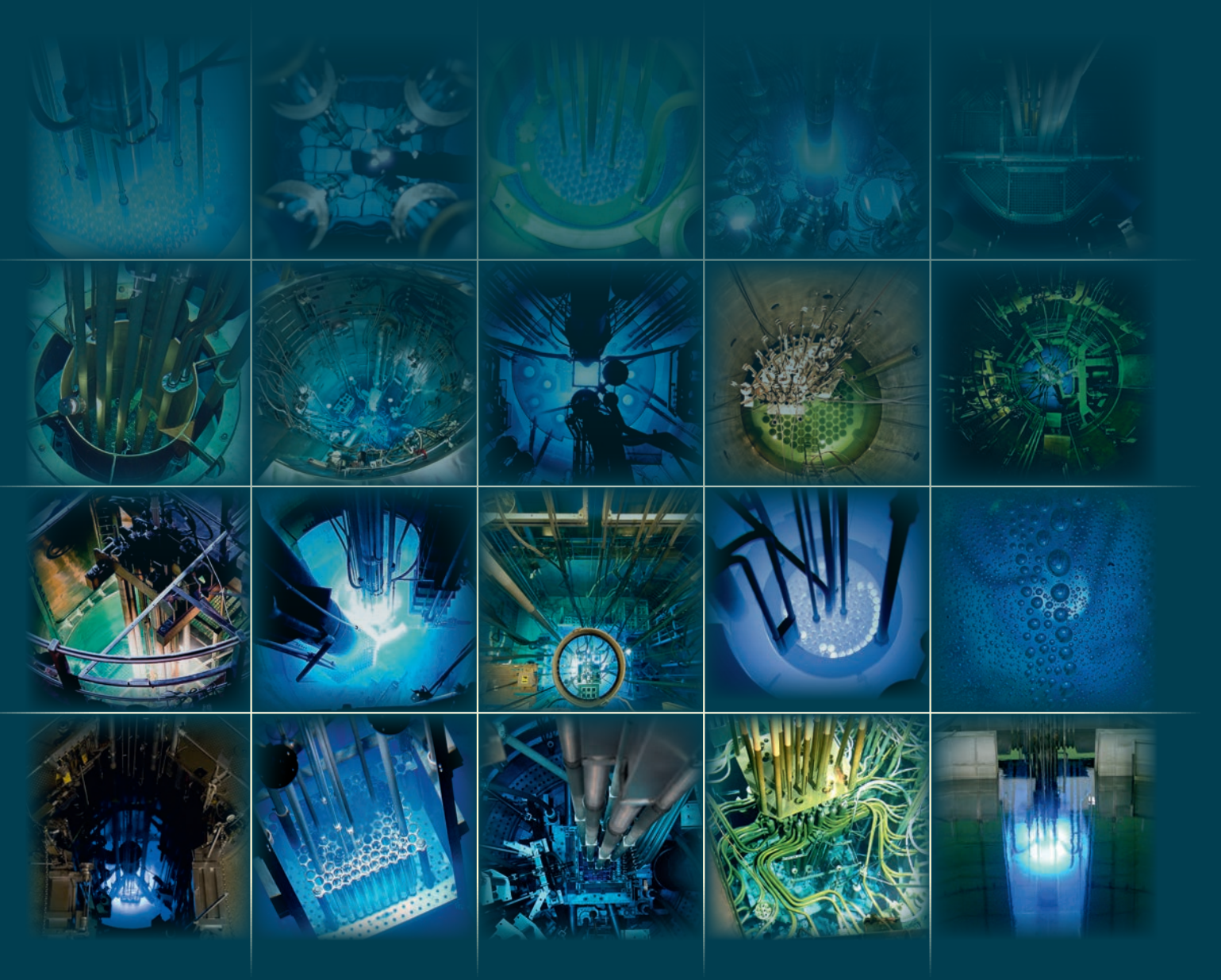
Research Reactors: Addressing Challenges and Opportunities to Ensure Effectiveness and Sustainability

Summary of an International Conference
Buenos Aires, Argentina, 25–29 November 2019



IAEA
International Atomic Energy Agency

RESEARCH REACTORS: ADDRESSING CHALLENGES AND OPPORTUNITIES TO ENSURE EFFECTIVENESS AND SUSTAINABILITY

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PROCEEDINGS SERIES

RESEARCH REACTORS: ADDRESSING CHALLENGES AND OPPORTUNITIES TO ENSURE EFFECTIVENESS AND SUSTAINABILITY

SUMMARY OF AN INTERNATIONAL CONFERENCE
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INTERNATIONAL ATOMIC ENERGY AGENCY
AND HOSTED BY THE GOVERNMENT OF ARGENTINA
THROUGH THE NATIONAL ATOMIC ENERGY COMMISSION
AND HELD IN BUENOS AIRES, 25–29 NOVEMBER 2019

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FOREWORD

Since the 1950s, research reactors have been centres of innovation and development for nuclear science and technology programmes around the world. Research reactors primarily generate neutrons — rather than power — for research, education and training purposes, as well as for applications in areas such as industry, medicine and agriculture. According to the 2019 figures in the IAEA Research Reactor Database, 247 research reactors are in operation in 53 countries, and around 30 new research reactor programmes are being planned and developed.

The International Conference on Research Reactors: Addressing Challenges and Opportunities to Ensure Effectiveness and Sustainability was organized by the IAEA and the National Atomic Energy Commission of Argentina and held in Buenos Aires on 25–29 November 2019. The conference was attended by 300 participants from 53 Member States. It brought together experts from across the field — from operators and users to regulators, designers and suppliers.

Feedback from IAEA activities indicates that ensuring the safety, security, effectiveness and sustainability of research reactors involves several challenges. The main challenges facing the research reactor community include the need to ensure regulatory effectiveness, manage the ageing of the facilities and staff, and improve utilization programmes and strategic planning. Leadership and management for safety and security, management of spent fuel, the need to ensure supply of fresh fuel for some research reactors and the need to establish sustainable nuclear infrastructure for new research reactor programmes also pose challenges. The conference provided a forum for reactor operators, managers, users, regulators, designers and suppliers to exchange best practices and to learn from each other, particularly in addressing common issues, challenges and strategies.

The conference, which is held every four years, is one of several IAEA activities supporting countries in addressing the opportunities and challenges related to research reactor programmes. The IAEA develops safety standards, and security and technical publications for research reactors and supports their application through peer reviews on safety, security, operation and maintenance, utilization, and national infrastructure building. The IAEA also organizes capacity building activities, including meetings, workshops and training activities.

This publication provides a summary of the conference, the major findings and conclusions of the sessions, and the opening and closing addresses. The supplementary files available on-line include the individual technical papers and presentations.

The IAEA wishes to express its appreciation to the members of the Technical Programme Committee, the chairs of the technical sessions, the authors of the submitted papers and all those who gave presentations and provided posters for their contributions to the success of the conference. The IAEA officers responsible for this publication were A.M. Shokr of the Division of Nuclear Installation Safety, R. Sharma of the Division of Nuclear Fuel Cycle and Waste Technology and N. Pessoa Barradas of the Division of Physical and Chemical Sciences.

EDITORIAL NOTE

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EXECUTIVE SUMMARY

The International Conference on Research Reactors: Addressing Challenges and Opportunities to Ensure Effectiveness and Sustainability was held in Buenos Aires, Argentina, 25–29 November 2019. The Conference was organized by the International Atomic Energy Agency (IAEA) and hosted by the government of Argentina through the National Atomic Energy Commission (CNEA). This Conference was the sixth in a series of quadrennial International Conferences on Research Reactors; the previous Conference was held in 2015 at IAEA Headquarters, Vienna, Austria.

The objective of the Conference was to foster exchange of information on operating and planned research reactors. It is a forum in which reactor operators, managers, users, regulators, designers and suppliers can share experience and address challenges and opportunities to ensure effectiveness and sustainability in all relevant areas including safety, security, operation, utilization, infrastructure and management.

Three hundred participants from 53 Member States attended the Conference. A total of 81 papers were presented orally and 79 papers were presented in poster sessions. Seven topic areas were covered in the Conference including: 1) Utilization and applications; 2) Operations and maintenance; 3) New research reactor programmes; 4) Safety of research reactors; 5) Security of research reactors; 6) Fuel management and decommissioning; 7) Common management considerations.

The Conference was opened by Mr Juan Carlos Lentijo, IAEA Deputy Director General and Head of the Department of Nuclear Safety and Security, joined on the podium by Mr Julian Gadano, the Deputy Secretary of Nuclear Energy, Argentina, Mr Osvaldo Calzetta, President of CNEA and Chairman of the Conference Programme Committee (TPC), and Mr Amgad Shokr, Head of the IAEA Research Reactor Safety Section and Lead Scientific Secretary of the Conference.

Four side events were organized at the margins of the Conference: 1) Safety enhancement of research reactors based on the IAEA INSARR Safety Review Service; 2) Safety enhancement of research reactors based on the IAEA IPPAS missions; 3) IAEA Peer Review Service — Operation and Maintenance Assessment for Research Reactors (OMARR); and 4) Contribution of International Centres Based on Research Reactors (ICERR) network to enhancement of capacity building.

A panel session on effectiveness and sustainability of research reactors was held on Friday 29 November 2019 at the end of the paper presentations. At this session the conclusions and recommendations of the conference were presented, and summary remarks were made by the panellists.

The Conference closing session included closing remarks made (via video record) by Ms N. Mokhtar, IAEA Deputy Director General and Head of the Department of Nuclear Sciences and Applications, and Mr O. Calzetta, President of CNEA. After the closing session, two technical tours were offered to interested participants, one to the construction site of the RA-10 research reactor at the Ezeiza Atomic Centre, and the second tour to the construction site of Argentina's Small Modular Reactor prototype, CAREM.

The summary of the technical sessions, side events and panel sessions, as well as conclusions and recommendations of the Conference are presented in the respective chapters of this report.

Full papers and presentations provided by Conference participants are presented in the Annex to this report.

OPENING SESSION

In his opening remarks, Mr Lentijo noted the progress made in several areas since the latest international conference and highlighted the continued interest of the community on research reactors considering the important role they play in the society.

Mr Lentijo also stressed the need to ensure effectiveness and sustainability of research reactors and outlined the challenges in this regard. He included the need to maintain a high level of nuclear safety and security, establish sustainable nuclear infrastructure for new research reactor programme, improve strategic planning and utilization programme, manage ageing of facilities and staff, ensure effective management systems, and manage spent fuel radioactive waste. He also highlighted the support provided by the IAEA to assist Member States in addressing these challenges. This support includes the development of safety standards and related publications, peer review services, assistance to Member States on capacity building and facilitating international cooperation and sharing information and experience. Mr Lentijo expressed his appreciation to the conference organizers and wished everyone a successful Conference.

Mr Gadano welcomed the participants and described the current status of research reactors in Argentina, including the RA-10 research reactor which is under construction. He highlighted the essential role of research reactors for technological development as they are used for research, training and education. He wished for this Conference fruitful interactions and productive sessions.

Mr Calzetta indicated in his opening remarks that Argentina has a vast experience in the field of research reactors and highlighted the role of CNEA in this field as well as its commitment to the peaceful development of the associated technology. He thanked the IAEA for the organization of this Conference and wished everyone a successful and fruitful conference.

The full text of the opening remarks made during this session is provided below.

OPENING REMARKS

Mr Juan Carlos Lentijo
IAEA Deputy Director General
Department of Nuclear Safety and Security

Opening speech as provided, verbatim.

Dear Mr Gadano, dear colleagues, good morning!

Welcome to the International Conference on Addressing Challenges and Opportunities to Ensuring Effectiveness and Sustainability of Research Reactors, organized by the International Atomic Energy Agency, which I represent, and the Government of Argentina through the National Commission of Atomic Energy. We thank the CNEA for co-organizing and hosting this Conference, which is the largest gathering of the international research reactor community.

This community is diverse. Here in this hall, we have more than 300 research reactor regulators, operators, managers, users, suppliers and other stakeholders from 53 Member States. All of you have your own unique perspective and expertise, be it related to research reactor nuclear safety and security, organizational effectiveness, management, operation, utilization or infrastructure. During this week, you will share experiences and good practices — I hope and expect that this exchange will help all of you to enhance the effectiveness and sustainability of research reactors.

The IAEA organizes these major research reactor conferences every four years to support the research reactor community in its strive for excellence. Progress was observed in several organizational and technical areas at Member States based on the results of the last Conference, held in 2015 in Vienna. These results also helped tailor the IAEA programme and activities on research reactors to suit the needs of the community. This year, 82 paper presentations and 87 posters presentations will lay the basis for discussions that will bring further progress.

Dear colleagues,

Interest in research reactors remains high, with good reason, considering the important role they play in our society. Since the 1950s, hundreds of research reactors around the world have benefited us all in many ways. The 224 research reactors that are in operation now continue to be a cornerstone of the development of nuclear science and technology programmes in 53 countries. Over 30 new research reactor programmes are being planned and developed, some of them in countries with no experience of operating a nuclear installation.

Research reactors are key to not only nuclear education and training but also to scientific, industrial, medical and agricultural development. And they can contribute to the development of nuclear power programmes.

The sustainability of research reactors depends on several factors, including continuous improvement of safety and security, effective operation management and efficient utilization of the facilities. All research reactor programmes, including those in the planning stages, should be managed in a coordinated manner that involves all stakeholders and provides for effectiveness and sustainability of the programmes.

Dear colleagues,

Feedback from the IAEA's activities indicates that ensuring the effectiveness and sustainability of research reactors involves several challenges. These include:

- For new research reactor programmes, the need to establish sustainable national nuclear infrastructure.
- The need to manage ageing facilities as well as staff turnover– about 60 percent of the research reactors currently in operation are more than 40 years old, and their safety and availability could be impacted by the effects of ageing.
- The need to enhance regulatory effectiveness, leadership and management for safety and security.
- The need to improve strategic planning and utilization programmes.
- The need for effective management of spent fuel and the need to plan for and manage decommissioning – there are several dozen research reactors awaiting decommissioning at this moment.
- Some reactors face challenges with sustainable supply of fresh nuclear fuel.

These challenges must be addressed, and this conference gives us an opportunity to do so. As always, the IAEA is ready to assist Member States in addressing these and other challenges. Let me give a few examples of how we do this.

The IAEA has developed a Research Reactor Milestones approach to help countries build the needed capacity for safety, security and safeguards. This approach offers guidance for the justification, planning, constructing, operating and effective utilization of research reactors. It notes that this is a process that requires ample time, money, and human resources. The Research Reactor Milestones approach is built on the experience of a similar approach used for power reactors for several years.

The IAEA also recently launched the Integrated Nuclear Infrastructure Review for Research Reactors mission as a peer review service. Several missions have been conducted, including recent ones in Nigeria and Vietnam.

The IAEA supports the research reactor organizations around the world to continue to improve safety and security of the facilities, including through the use of periodic safety review processes and the implementation of safety upgrades identified on the basis of the lessons learnt from the Fukushima Daiichi nuclear power plant accident. We also see increased security, with many research reactors planning, implementing or improving physical protection systems — with IAEA support on request.

Security and safety measures must be well-coordinated to avoid that efforts in one area undermine the other. Because research reactors are often located in research institutes or universities, and because researchers need frequently access to the reactors, this can pose a challenge. In this area, too, the IAEA assists.

Dear colleagues,

The IAEA also supports Member States' efforts in their application of the Code of Conduct on the Safety of Research Reactors. We also develop safety standards for research reactors and support their application, for example through the Integrated Safety Assessment of Research Reactors (INSARR) peer reviews. We also offer training opportunities, networks and platforms for the dissemination of operating experience and good practices. Our Operation and Maintenance Assessment for Research Reactors (OMARR) peer review service assists Member States in addressing operational performance and reliability of the facilities. An adapted version of our Safety Aspects of Long Term Operation (SALTO) service — an established power reactor peer review — was conducted in 2017 at the Belgian Research Reactor 2. More of such missions have been requested, with the next one planned for next year at the High Flux Reactor in the Netherlands. I invite you to take advantage of these services.

Dear colleagues,

Strong leadership and effective management systems are crucial for research reactors' effectiveness and sustainability. The IAEA support in this field includes safety standards and technical guidance, training workshops and the Independent Safety Culture Assessment (ISCA) missions, which are tailored to the mandate and nature of research reactor organizations. Recent missions were held in Norway, the Netherlands, Thailand, and South Africa.

Among the challenges I mentioned is the need to improve utilization. Many research reactors are not utilized to their full potential. As part of our support in this field, we have reviewed 50 research reactor strategic plans since 2015. We also support the International Centres based on Research Reactors, which facilitate cooperation among Member States for the development of specific competences. And we support other networks and coalitions to help countries increase utilization and to build capacity in countries without research reactors through experience sharing. Earlier this year, we held a pilot of a new service called the Integrated Research Reactor Utilization Review at Italy's University of Pavia.

Dear colleagues,

Regarding the research reactor fuel cycle, we support global efforts to convert research reactors from high-enriched to low-enriched uranium fuel. The IAEA also supports the development of spent fuel management options, in particular for Member States where the research reactor is the only nuclear facility in the country and where the amount of nuclear waste will be relatively small.

These topics and more will be discussed here in the coming days. I trust that you will make this Conference a successful endeavour that continues to improve research reactors worldwide.

I wish you a successful Conference. I look forward to hearing about the outcome of your discussions.

Thank you.

Mr Julian Gadano
Undersecretary of Nuclear Energy, Argentina

Opening speech as provided, verbatim.

Welcoming to the Conference

Good morning everyone. I am Julian Gadano, the Deputy Secretary of Nuclear Energy in Argentina since 2015, and the President of Nucleoeléctrica Argentina (the operator of the Argentine NPPs) since 2019. I am honoured to be here, opening the 2019 International Conference on Research Reactors: Addressing Challenges and Opportunities to Ensure Effectiveness and Sustainability, along with my friends Mr Lentijo and Chairman Osvaldo Calzetta, and I am pleased to be welcoming all of you in my city, Buenos Aires.

The importance of research reactors and their technological development

Nuclear energy is much more than only electricity generation. Nuclear technology has several beneficial uses that represent well-being and higher life standards for our societies. These uses cover a wide range of sectors from nuclear medicine, to agricultural applications, food irradiation, sterilization of disease carriers, and water desalination, within others.
In this framework, research reactors are essential for these purposes and for further nuclear technological development as they are used for research, training and education.

Currently, there are 224 nuclear research reactors operating, in 53 countries, and it is amazing to witness how developing countries keep making their best efforts towards this important asset!

Argentina: research reactors and its exporter profile

I believe Buenos Aires is an excellent location for this 2019 Conference, because Argentina has a longstanding tradition and broad experience in the construction and operation of research reactors and has achieved a strong exporter profile by exporting its technology to Peru, Algeria, Egypt, Australia, The Netherlands and Brazil.

The National Atomic Energy Commission has currently 5 research reactors under operation. Specifically, the RA-3 located in the Ezeiza Atomic Centre counts with 10MW of power and is the biggest radioisotope producer in Latin America. This reactor is used for radioisotope production for medical and industrial uses, research and material testing.

Currently, in that same Atomic Centre, the Reactor RA10 is under construction. The RA-10 project is an Argentine design. It will provide medical and industrial radioisotopes as well as scientific research capacities. It will assure the supply of radioisotopes for medical use at a national level and for export.

This year, on July 31st, was installed the service pool of the RA-10, one of the principal components of the reactor.

The completion of the RA-10 will create a strategic impact for our country for the following sectors: health, industry, applied research, technological development and services. This reactor will be the biggest of its type in our country, and probably worldwide.

Closing remarks

To conclude, under my capacity as Argentine Deputy Secretary of Nuclear Energy, I want to officially welcome you to the 2019 International Conference on Research Reactors: Addressing Challenges and Opportunities to Ensure Effectiveness and Sustainability. I look forward to several productive sessions and I am sure we will all harness this opportunity to have fruitful interactions and create a successful precedent for further development in this matter.

If you can, and if time permits, enjoy spring in Buenos Aires. It is a beautiful season to be here. Enjoy its nightlife, its food and its people. We are much more than tango.

Welcome! Thank you.

Mr Osvaldo Calzetta Larrieu
President of the National Atomic Energy Commission, Argentina Republic, and Chairman of the Programme Committee

Opening speech as provided, verbatim.

Dear Deputy Director General, Mr Juan Carlos Lentijo, dear Undersecretary of Nuclear Energy of the Argentine Republic, Mr Julian Gadano, dear colleagues, good morning.

On behalf of the National Atomic Energy Commission of the Argentine Republic and as the Chairman of the Program Committee of this prestigious International Conference on Research Reactors, I would like to welcome you all and thank you for being here. As the Deputy Director General Mr Lentijo mentioned, gathered today in this room it is represented the most relevant worldwide stakeholders involved in the development of research reactor technologies. In this sense, I would like to convey the warmest greetings on behalf of my country and my institution to all of you and especially to those who have travelled from far away to join us here today. As you all already know, Argentina has a vast experience in the subject that brings us together, and particularly CNEA has played a central role in the development of these relevant capabilities. Moreover, our national nuclear industry was born around the activities carried out by the CNEA at the beginning of the 50's, and all along these decades, the scientific and production working groups around the research reactors became a central axis of its growth. This allow us to position ourselves as an undisputed reference in this field, which is reflected in the amount of papers and posters presented by Argentinian colleagues. It is good to know that today we have here representatives of several countries that have relied on my country´s experience and its nuclear organizations such as CNEA and INVAP, to export strategic nuclear facilities including, particularly, research reactors. In this sense, it must be highlighted the role of CNEA in the field of research reactors, underlining that during this process it has exhibited an unquestionable commitment to the peaceful development of the associated technology, as indicated by the development and manufacture of targets of low enrichment uranium for the production of Mo-99 for nuclear medicine. That reinforces our commitment with the development of nuclear technology for peaceful uses, complemented with an active international cooperation role. The core conversion (from HEU to LEU) of the Argentinian research reactors in operation was concluded, as well as the exportation and technology transfer of those developments, highlighting the exports made by INVAP with CNEA's support for countries such as Algeria, Egypt or Australia. Currently, Argentina is engaged in diverse projects that will allow an international projection and collaboration in the near future. An example of that is the RA-10, a multipurpose research reactor that CNEA is building at the Ezeiza Atomic Center. Within the framework of this Conference it is planned on Friday a visit to the site, hoping you all join us, in order to know our capabilities from first-hand. In this regard, I would like to point out that in Argentina, as in the rest of the 53 countries operating the 224 nuclear research reactors mentioned by the Deputy Director General, the safe operation of these facilities is a fundamental tool for capacity-building. The development of new experiences and knowledge, both in terms of human resources training and in the multiple peaceful applications of the nuclear technology, are also key factors for the operation of research reactors.

I hope that this International Conference will allow us to address all the challenges and opportunities outlined by my predecessors and that your week in Buenos Aires allows you to enjoy the wide options offered by this wonderful city.

I would like to finish by thanking the International Atomic Energy Agency for trusting us for the organization of this International Conference and all those who have made it possible. I wish you a successful and fruitful Conference.

Thank you.

SUMMARY OF TECHNICAL SESSIONS AND PRESENTATIONS

Session 1: Utilization and applications

Thirty-six papers were presented in Session 1 (a keynote, 4 invited and 12 contributed oral and 19 poster presentations). These papers described mainly the current status and strategic planning and utilization of research reactors as well as opportunities and challenges in the future. The use of research reactors for various applications was also presented by several authors, including in education and training, health and nutrition, activation analysis and industry.

Oral presentations

Part 1: Strategic planning and utilization of research reactors

Mr N. Pessoa Barradas (IAEA) presented, in his keynote address for Session 1, an overview on the status of research reactors worldwide and described the IAEA programme related to utilization and applications of research reactors. He identified several key challenges for the IAEA in supporting Member States in research reactor utilization and emphasized that strategic planning is essential to a sustainable utilization of a research reactor. Development of a sound strategic plan helps the reactor management to find a realistic answer on basic questions like (i) what can I do now with the RR? and (ii) what do the users expect me to do in the future?

Mr Pessoa Barradas indicated that the most common areas of research reactor utilization are: education and training; neutron activation analysis (NAA); isotope production; and neutron radiography. Several IAEA services and publications are available in addition to specific workshops and software instruments to assist Member States to enhance research reactors utilization, identify new stakeholders and train new staff. The presentation introduced some of the instruments available, among them the Internet Reactor Laboratory (IRL), various e-learning courses and practical exercises like proficiency tests for NAA laboratories. A new IAEA service called Integrated Research Reactor Utilization Review (IRRUR) Mission was developed and is now available to Member States. A pilot IRRUR mission was conducted in April 2019 at the 250 kW TRIGA MARK II reactor of the University of Pavia, Italy.

Ms M. Venkatesh (India) gave in her invited talk an overview of the importance of research reactors for the production of medical radioisotopes, which have been used in healthcare since almost eight decades. From the beginning, research reactors have played a vital role in the production of radioisotopes, a fact which is often completely unknown to the end user. In the early days, radioactive isotopes were primarily used for therapeutic purposes, whereas in the last few decades diagnostic nuclear medicine became more and more important with Tc-99m as the 'Work horse of nuclear medicine'. In the last two decades we witnessed a fast growth in the production and use of positron (β+) emitting isotopes, especially F-18, to provide high resolution images using Positron Emission Tomography (PET). Thanks to the innovations in the various related fields, nuclear medicine nowadays gained a unique place in medical diagnosis as well as in therapy, especially for various cancers diseases. Besides neutron rich isotopes (including e.g. Lu-177, Sm-153, Re-188, Re-186 and Y-90), the use of alpha emitters for therapy has gained much attention in recent years cancer treatment. 'Theranostics', the use in both diagnosis and therapy, has evolved as the new approach for personalised therapy, owing to the availability of suitable radioisotopes. The majority of these radioisotopes are reactor produced, I-131 being the oldest yet extremely useful and Lu-177 recording the fastest growth for targeted therapy.

In her concluding statement Ms Venkatesh expressed her opinion that, although radioisotope production in accelerators has seen a huge growth, it is beyond doubts that research reactors are essential for production of a huge range of important radioisotopes, especially for therapy, in large quantities and at affordable cost.

Mr N. Mohamed (Egypt) reported on the design of a new irradiation facility for the production of Ir-192 for medical use at the ETRR-2 reactor. This reactor is already used for the production of medical isotopes and previously the core has been modified in order to provide two irradiation channels

for the production of Mo-99 from low enriched uranium. For the planned production of Ir-192 based on the neutron capture reaction on the metallic iridium two irradiation positions are under investigation. One position is located in the centre of the core, the other one in the Be-reflector. The Monte Carlo N-Particle (MCNP) transport code MCNPX2.7.0 was used for calculations of neutron flux distribution at the two positions. It is assumed that 10 foils (32 mg each) are loaded per irradiation can.

With MCNPX2.7.0 the resulting thermal, epithermal and fast neutron fluxes in the iridium targets for the two irradiation positions were calculated. Since iridium has a strong absorption cross section and high density, depletion in the neutron flux in the targets can be observed. In Ir-191 strong absorption resonances are observed in the energy region between 10 and 100 eV. Therefore, in the calculations, the interaction rate for the entire neutron spectrum was considered. From the results of the MCNP calculations Mr Mohamed concluded that production of Ir-192 at TRR-2 is feasible, however long irradiation time is needed, taking into account the current reactor utilization and operation scheme (around three days per week at full power).

Mr G. Wakabayashi (Japan) introduced the UTR-KINKI research reactor that is designed for university education and research, and which is operated by the Atomic Energy Research Institute of Kindai University. The reactor is an Argonaut type, light water moderated, graphite reflected, heterogeneous thermal neutron reactor with a thermal power of 1 W. UTR-KINKI achieved its first criticality in 1961 as the first university-owned and private nuclear reactor in Japan. Mr Wakabayashi reported that UTR-KINKI is one of the three remaining research reactors in Japan. Its role in human resource development in nuclear science and technology has become increasingly important in recent years. UTR-KINKI is open to domestic and international students as a joint use facility. Various basic experiments on reactor physics, radiation measurement and neutron application are offered to graduate and undergraduate programmes. Since the first criticality, UTR-KINKI has been operated without any technical trouble, but it had to be shutdown for three years from 2014 due to Japan's new regulatory standards for research reactors, which was established in 2013 after the Fukushima accident. UTR-KINKI resumed operation in 2017 as the first research reactor which was allowed to be operated under the new regulatory framework. In his concluding remarks, Mr Wakabayashi stated that Kindai university hopes to operate the reactor as long as possible to respond to expectations by the nuclear science and technology community in Japan. However, there are many challenges for a private university such as economic burdens and management of ageing of the reactor facility.

Mr A. Salvini (Italy) indicated in his presentation that the Laboratory of Applied Nuclear Energy (LENA) of the University of Pavia operates a 250 kW TRIGA Mark II research reactor to support education and training programmes, NAA, medical and industrial research and nuclear applied science in general. The research reactor has been in operation since 1965 without unplanned shutdown periods. In the phase of extending the five-year operating license, the management of LENA decided to draw up a preliminary strategic plan and, furthermore requested the IAEA to carry out a pilot IRRUR Mission. The IAEA responded positively to the request and the mission was held in the period 1–5 April 2019.

The IRRUR mission, which is being developed by the IAEA, aims at performing an independent and objective review of the overall situation of a research reactor regarding its current and potential utilization. In preparation of the IRRUR mission a series of documents were prepared, among a new Strategic Plan, which was developed in accordance with IAEA Nuclear Energy Series NG-T-3.16. Mr. Salvini concluded that the mission was a positive experience that directly involved the upper management and increased the awareness of developed capacities and development opportunities. Furthermore, the mission was very helpful to develop a systematic approach in the valuation of assets and planning for the development of LENA. The final report provided by the IAEA IRRUR-team contained a number of very valuable recommendations and suggestions to review and further develop the research strategy of LENA.

Part 2: Opportunities and challenges for utilization of research reactors

Mr K. Unlu (USA) presented the strategies developed to enhance the utilization of the Penn State University Radiation Science and Engineering Centre by improving the different applications of

the 1MW TRIGA reactor. This included the work performed by developing a new more efficient neutron beam port giving more experimental capacity to scientists and the on-going new neutron beams facility to be open next year**.** Mr Unlu gave an example of valorisation of services provided by research reactors with an indication of commercial incomes covering half of the operation budget.

Mr P. Cantero (Argentina) described the work performed by CNEA for establishing, in cooperation with IAEA, an IRL within Latin America. The IRL is fully operational (around 30 students/year). He indicated several examples of training that have been given with a positive feedback from the universities, which integrated such training in their academic programmes.

Mr C. El Younoussi (Morocco) described the preparatory work performed by CNESTEN on the 2MW TRIGA MARK II reactor which was selected to be the host facility as an IRL for Africa region (first countries to use this IRL are: Tunisia, Kenya, Tanzania and South Africa) with the support of the IAEA which provided the data acquisition system. The broadcast system is already installed, and first training sessions will start in 2000.

Mr S. Mirvakili (Islamic Republic of Iran) gave an overview of Iran Research Reactors in support to Capacity building with a focus on Teheran Research Reactor (TRR). Various courses are provided by the university to engineers, scientists who, after their degrees, work for governmental bodies or private sector (more than 200 PhD were given). He indicated that stakeholders of the TRR are both from private and public sectors.

Part 3: Infrastructure for utilization of research reactors

Mr S. Choi (Republic of Korea) gave an overview of the cooperation in neutron beam research in the Asia and Pacific Region, starting with a presentation of the major neutron sources in the region, which included both research reactors and accelerator-based sources. The user communities in the Asia Pacific region formed the Asia-Oceania Neutron Scattering Association (AONSA) in 2008, to share knowledge and to cooperate in various aspects of neutron beam research. AONSA has currently members from Australia, China, Indonesia, Japan, Republic of Korea and India, as well as the Taiwan, China Neutron Scattering Society, and observers from Malaysia, Thailand and Singapore. The presentation described AONSA activities in training of the young generations of neutron beam scientists in the region, and how AONSA was instrumental in combating the prolonged shortage of neutron beams in the region after the shutdown of some Japanese and Korean research reactors.

Mr L. Sklenka (Czech Republic) presented the on-going activities to enhance the experimental capabilities of the research hub of the Czech Technical University centred around the Training Reactor VR-1, by building the new VR-2 subcritical assembly and new experimental instrumentation and laboratories for expanded research. The main motivation is the high utilization of the VR-1 reactor, which cannot satisfy all users requests from academia, particularly during semester periods when academic education at VR-1. The current capabilities and utilization of VR-1 experimental hub, and the plan to systematically maximize synergies for utilizations while optimizing the operational costs of the hub were described in detail. VR-1 is also, replacing the ISIS research reactor as European host for the IAEA Internet Reactor Laboratory, with transmissions planned to start late 2020.

Mr D. Hergenreder (Argentina) gave a comprehensive description of the methodology, criteria and objectives established in the design process of a Liquid Deuterium Cold Neutron Source (CNS). The design of the CNS was based on the experience acquired from the OPAL (Australia), RA-10 (Argentina) and RMB (Brazil) research reactor projects. The main components of the system, as well as its neutronic design criteria and basis, were described. The main features and performance parameters of the CNS, such as neutron fluxes, neutron spectrum and heat deposition were presented, demonstrating the methodology. Mr Hergenreder described the intended utilization of the CNS in neutron reflectometry, small angle neutron scattering, time of flight and backscattering spectrometry,

and three-axis spectrometry, for the study of organic molecules, polymers, proteins and other organic structures, and in industrial applications.

Mr A. Burukin (Russian Federation) described the research infrastructure based on the RIAR-Research Institute of Nuclear Reactors, Joint-Stock Company Dimitrovgrad site, including the MIR.M1 and RBT-6 research reactors. He presented in detail the experimental characteristics and irradiation capabilities of these facilities, including irradiation rigs, in-pile gauges and loop facilities for testing materials and advanced LWR fuels under different temperature and coolant chemistry conditions. He also presented experimental results of ramp experiments, power cycling, loss of coolant accidents, limiting regimes with fuel melting, fuel radiation creep and re-sintering were also presented. The presentation concluded with an overview of the offer of the RIAR R&D infrastructure as an IAEA designated ICERR.

Part 4: Various applications of research reactors

The last part of Session 1 included 4 paper presentations composed of an invited paper on a low-cost high quality neutron computed tomography system, two papers on neutron activation analysis: NAA application in authenticity and traceability of agro-food product: Malaysian Rice and Edible Birds' Nest, contribution of neutron activation analysis for nutritional status assessment of children under five in Java, Indonesia, and a paper on radiobiology in research reactor MARIA.

Mr B. Schillinger (Germany) delivered an invited presentation on low-cost but high-quality neutron computed tomography system. In brief, it contains a digital imaging detector based on a scintillation screen, mirror and cooled scientific CCD camera. A prototype system using this camera and dedicated control system has been installed and tested at the 250 kW radiography reactor of Idaho National Laboratory in the US and has delivered high-quality neutron computed tomography images that match the quality of the 20 MW FRM II reactor. The design details and construction steps for the detector system are available on request, including the control software. This setup can be used as a standalone system at low and medium power research reactors that have an available neutron beam port.

Mr N. Abdoullah Salim (Malaysia) presented a paper describing the use of NAA for authenticity and traceability of agricultural food products and goods. In Malaysia, food traceability is one of the key elements of the national agro-food policy 2011–2020 and the food safety policy. The Malaysian government had targeted to achieve 100% self-sufficiency level by 2020 while ascertain the quality control and safety of rice. Just to cite one example, in the framework of the IAEA technical cooperation project RAS5062, same rice variety 'MR 220CL' was distinguished from 3 cultivation regions based on 10 elements and 2 stable-isotopes. The elements were established thanks to the NAA technique including aluminium, arsenic, bromine, chlorine, potassium, magnesium, sodium, rubidium, and zinc. The chemometric approach using principle component analysis and linear discriminant analysis successfully classified 98.1% of rice correctly. The speaker concluded that high accuracy rate of classification model in rice geographical identification has to provide advantages for branding strategy purposes, restraining fraudulent practice and enhancing consumer confidence and protection of rice industry.

Ms M. Santoso (Indonesia) talked about importance of NAA for nutritional status assessment of children under five in Java, Indonesia. In his study the food samples were taken by duplicate diet with 24-hour recall method of 120 children. The NAA results for more than 20 elements of food samples were detected. It was found that the average percentages of fulfilment of RDA for Na in Bandung, Lebak and Lamongan were 131%, 109%, and 50% respectively, for K were 22%, 16%, and 9.5% respectively, for Fe were 70%, 47% and 63% respectively, for Zn were 88%, 52% and 50% respectively. These results allowed concluding that these children are still lacking in micronutrient intake especially for Fe and Zn, and most of them are below the recommended daily allowance. In the future, the results obtained are expected to be used as a scientific-based reference by various stakeholders to take appropriate and targeted steps and policies in efforts to reduce the case of malnutrition in Indonesia.

Mr M. Gryzinski (Poland) presented a set of examples of using Maria research reactor in the area of medicine, in addition to medical radioisotope production. One of the projects presented involved the description of DNA damage and repair pathways after induction by boron neutron capture therapy (BNCT) in aggressive tumours with no effective treatment using in vitro model. The speaker noted that currently the BNCT is experiencing a renaissance, in particular at accelerator-based facilities located in hospitals, and it has occurred that BNCT therapy is dedicated to the treatment of aggressive tumours that do not respond well to conventional therapies and might have a fatal result in short time after diagnosis such as lung and skin cancers, and recurrent head and neck cancers. Evaluation of the biological effects of neutron mixed-beam used for BNCT is crucial in order to obtain the reduction of side effects and prove the effectiveness of this therapy. The speaker terminated his presentation by adding that planned in-vitro experiments will contribute to a better understanding of mechanisms of DNA repair and potential damage after BNCT therapy, and therefore contributing to the acceptance of this targeted therapy method.

Poster presentations

This session included 25 contributed poster papers, of which 19 were presented and 6 were absent. The posters addressed general and new utilization programmes and activities of research reactors, including education and training, isotope production and irradiation.

Mr Chiarvetto (Argentina) and co-authors presented a poster on the neutronic and process system design of the "Liquid Poison System - LPS", which will ensure the dynamics of power ramps for the irradiation Loop, planned to be used at the RA-10 reactor, for testing and qualifying NPP fuel elements.

Ms Paula Delgado (Argentina) and co-authors presented a poster on the engineering design of an in-pool neutrongraphy system which could be operated from the top of the reactor pool. They provided a description of the mockup facility used for the experimental validation of this system and confirmation of its compliance with the standards of the RA-10 design.

Mr J. Longhino (Argentina) and co-authors presented a poster on a mobile device designed for characterization of mixed radiation fields' detectors. This device was constructed and tested at the 1MW research reactor RA-6 (Argentina) for providing selectively filtered configurations of the neutron beam for BNCT project.

Mr Reichenberger (USA) and co-authors presented a poster on modernization of the Radiation Measurements Laboratory (RML) at the Advanced Test Reactor Complex (ATR), with a description of the primary functions of the RML which was founded in the 1960s to support the operation of the ATR. He discussed the challenge related to the turnover of experienced staff and presented the improvements and upgrading to ensure the sustainability of the RML.

Mr D. Mangiarotti (Argentina) and co-authors presented a poster describing the implementation of the Internet Reactor Laboratory (IRL) at the RA-6 as a host facility. This implementation was achieved in the frame of a bilateral agreement between IAEA and CNEA, according to which the IRL for Latin America should perform six selected experiments: Nuclear instrumentation, critical approach, control rod calibration, anti-reactivity margin, temperature coefficient, and void coefficient.

Mr S.P. de Jesus (Brazil) and co-authors presented a poster on utilization experience of the Argonaut research reactor (10 KW) located at the Institute IEN/CNEN in Rio de Janeiro, Brazil. This reactor has been used mainly in the areas of research & development in nuclear techniques and training of human resources in nuclear physics and reactor physics.

Mr Bitelli (Brazil) and co-authors discussed the main experimental utilization of the IPEN/MB01 zero power reactor during the last 30 years in the areas of reactor physics, operator training

and retraining. Utilization of the reactor included, in particular, the determination of critical mass, initial criticality, calibration of control rods, and nuclear power calibration and measurement of isothermal reactivity coefficient.

Mr Salvini (Italy) and co-authors presented the design and future utilization of a Prompt Gamma Neutron Activation Analysis (PGNAA) facility which has been recently implemented in the beginning of 2019 at the 250 kW TRIGA Mark II research reactor of the Laboratory of Applied Nuclear Energy (LENA) at the University of Pavia, Italy. PGNAA non-destructive technique will be used for the Boron Neutron Capture Therapy (BNCT) to measure B concentration in biological samples, for dosimetry and in archaeometry and cultural heritage to characterize the elementary composition of ancient manufacts.

Mr Keil (Argentina) and co-author presented a poster on a didactic model of laboratory practical training in virtual environments designed with the tools available in Reactor RA-0 and using the competency-based training approach.

Mr P. Bellino (Argentina) and co-authors presented a poster on spectral analysis of the currents from two compensated ionization chambers (CIC) from which the prompt neutron decay constant and the reactor power were estimated for a subcritical configuration of the RP-10 Peruvian research reactor. The estimated values of power calibration coefficient at subcritical levels were found in agreement with those obtained at critical configuration of the reactor (both with the neutron noise technique at low power and with thermal balance at high power).

Mr A. Cintas (Argentina) described the irradiation service which will be provided by the new RA-10 research reactor, currently under construction, and expected to be operational by 2023, to dope silicon for the semiconductor industry. He indicated that this reactor will have the capacity of doping up to 80 tons per year of silicon ingots.

Mr A. Cintas (Argentina) and co-authors presented a conceptual study concerning the capability of the new Argentinean multipurpose reactor RA-10 to produce alternative radioisotopes for medical use. It can be employed for simultaneous purposes of therapy and imaging (known as theragnostics). Target materials of 47Sc, 64Cu, 188Re, 153Sm and 90Y were studied and the results indicate the need of using enriched targets to obtain radionuclides with a reasonable high specific activity.

Mr M. Carta (Italy) and co-authors discussed the experimental characterization of neutron flux spectrum performed in the central channel and in the Lazy Susan irradiation facility of the 1 MW TRIGA RC-1 reactor located at ENEA Casaccia Research Centre. The neutron activation technique was used to measure the intensity, the energy spectrum, and the spatial distribution of the neutron flux.

Mr V. Fabrizio (Italy) and co-authors presented the methodology that will be followed during the new characterization campaign of the TAPIRO (TAratura PIla Rapida a Potenza zerO - Fast Pile Calibration at 0 Power) , which is a 5 kW fast neutron research reactor located at ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development). This characterization will start in December 2019 and will include measurements of the neutron flux intensity and the energy spectrum distribution in different experimental channels.

Mr J. Santisteban (Argentina) and co-authors presented the implementation, planned at the RA-10 reactor, of a National Neutron Beam Laboratory called LAHN: “Laboratorio Argentino de Haces de Neutrones”. The main challenges of this project are to implement a suite of state-of-the-art neutron scattering instruments, build a solid neutron scattering user community, and train the human resources necessary for defining, implementing, operating and using the instruments.

Mr F. Bellino (Argentina) presented capabilities of the Educational Reactor Simulators (ERS) and described INVAP experience using ERS in the training of human resources of new reactors

designed. He indicated that the ERS are powerful tools providing virtual on-the-job training as they reproduce the reactor console allowing the users to assimilate basic operation procedures through interactive exercises. The education of future staff for a new reactor using an ERS, includes practices and lectures that go from introduction to simulator, its interface and basic actions, up to simulation of events. This experience gives the trainee not only a feeling of the reactor routine tasks, but how to manage accident scenarios. He concluded that the ERS help to narrow the gap between the theoretical studies in reactor operation and the real operation of the reactor itself.

Ms M. Cruz (Argentina) and co-authors presented an analysis which identified several new multipurpose radioisotopes for nuclear medicine with increasing demand in the last years. From a large number of potential radioisotopes analyzed, the selected radioisotopes are 90Y- 177Lu, 186 Re and 188 Re were selected, based on technical and economic criteria. The possible routes of production in research reactors of the selected radioisotopes were also discussed.

Mr A. Johnson (USA) and co-authors presented a poster on educational uses and research services of the Maryland University Training Reactor (MUTR). Outreach programmes are developed for primary and secondary school students; using labs and tours to teach about radiation, the uses of nuclear reactors, and the nuclear power industry. Within the University of Maryland the reactor is used to support classes, labs, and research in the Engineering, Physics, and Chemistry departments. Additionally, a training programme is established for undergraduate students to become reactor operators.

Mr Wang (Canada) and co-author discussed the use of the code WIMS/TRIAD in core-following, flux and power simulations, and production of irradiation data for fuel experiments in the NRU reactor. They indicated that TRIAD, a 3D two-group neutron diffusion code, cannot provide meaningful power or burn-up for experiments that contain minimal or no fuel materials. They also indicated that WIMS, a 2D multi-group neutron transport code, cannot provide non-fission heating that dominates in experiments with minimal or no fission. They also indicated the use of MCNP, a 3D Monte Carlo transport code, to supplement WIMS and TRIAD to provide timely irradiation data for experiments.

Session 2: Operation and maintenance

Twenty-seven papers were presented in Session 2, including a keynote from the IAEA, 3 invited talks by experts from Member States, 14 contributed papers and 9 posters. The presentations covered wide range of topics including the IAEA activities, examples from facilities on their programmes for improving maintenance and operation practices, ranging from new techniques for management of research reactors to practical techniques for evaluating components under high radiation conditions. One of the major aims of the various maintenance programmes was the improvement of facility reliability and availability.

Oral Presentations

Part 1: Programmes for improving maintenance and operation practices

Mr R. Sharma (IAEA) in his keynote gave an overview of the IAEA activities in operation and maintenance of research reactors. These activities, which cover many areas to support Member States, include:

- Organizing technical meetings, workshops, Coordinated Research Projects (CRP), maintaining updated data bases, and establishing technical guidelines. Technical meetings on ageing management, refurbishment and modernization, and on upgrades to digital instrumentation and control systems for research reactors, are held every two-year. Training workshops on in-service

inspection, non- destructive examination and on-line monitoring techniques, and on integrated management systems, are also organized every two-year;
- Conduct of peer reviews (OMARR, INSARR) and expert missions. Establishment of the new Integrated Research Reactor Utilization Review (IRRUR) service is under finalization;
- Implementation of four CRPs: Improved instrumentation and control maintenance techniques for research reactors; Establishment of material properties database for irradiated core structural components for continued safe operation and lifetime extension of ageing research reactors; Condition monitoring and incipient failure detection of rotating equipment at research reactors; and Benchmarks of computational tools against experimental data on fuel burnup and material activation for utilization, operation and safety analysis of research reactors;
- Updating RR Information Resources: RRDB (information on research reactors worldwide), RRADB (repository of the worldwide experience in managing ageing of structures, systems and components (SSCs) at research reactors) and RR-MPDB (material properties database for irradiated core structural components for continued safe operation and lifetime extension of ageing research reactors).

Mr J. Du Bruyn (South Africa) in his invited talk provided the historical backdrop to how the SAFAR-I reactor became one of the most utilized research reactors in the world and some of the challenges faced in commercial production of radioisotopes and rendering of irradiation services to various stakeholders in a cost-effective manner. SAFARI-1 had also successfully addressed challenges related to 300 days per year operating cycle and life cycle factors related to operational safety, in-core fuel management, changing political strategies, regulatory environment, organizational changes, strategic focus or objectives, facility ageing factors, human capacity and skill development. He described the plans up to 2030 with the long term goal to replace the SAFARI reactor with a 20 to 30 MW Multipurpose Reactor. It will fulfil all the current and potential radioisotope demands, research needs and support for South Africa Nuclear New Build Programme.

Mr N. Abubakar (Nigeria) gave an overview of the ageing management programme for the Nigeria Research Reactor-1 and recent core conversion activities. Most of the ageing management activities in the facility were implemented prior to the fuel conversion of NIRR-1 from HEU to LEU, including structural integrity checks and life-time assessment of structures, systems, and components. The lessons drawn from the operational experience and these ageing management activities were useful in preparation of new Ageing Management Programme following the IAEA safety standards and guidelines, which will eventually be incorporated into an integrated management system.

Mr M. Shohag (Bangladesh) presented the operation and maintenance experience, ageing management and upcoming challenges & opportunities of BAEC TRIGA research reactor. He described modifications, modernizations and upgrading activities for the continued safe operation and utilization of the reactor. An Annual Development Project (ADP) has been initiated for life extension of the reactor for another 15–20 years. Upon successful implementation of this project, the reactor will be useful in meeting the growing demands of stakeholders, including radioisotope production, complementing the programme to construct a new research reactor.

Mr F. Genezini (Brazil) reported on the four operating research reactors in Brazil and the plans for the introduction of a fifth multipurpose research reactor, expected to be operational in 2024. The presentation focused on the core conversion of IEA-R1 from HEU to LEU fuel, upgrading from 2 to 5 MW and enhanced utilization. An integrated management system (IMS) has been structured, based on ISO-9001, with first certification in 2002. The IMS was upgraded to meet 2015 ISO requirements in 2018. Mr Genezini concluded with the vital products and services provided by the IEA-R1 including training of operators and the production of 177Lu.

Mr Oleksii Diakov (Ukraine) provided a brief on challenges faced in ensuring the sustainability of the WWR-M research reactor. He described the process of core conversion to LEU that was completed in 2011, and the subsequent time and efforts required to get license for the facility post core conversion as many structures, systems and components had reached the end of their useful

lives or required detailed justification for their continued use. This resulted in partial primary pipeline replacement, periodic safety review and stress tests using the recommendations of the latest IAEA safety standards. As a result, the life of the reactor vessel was extended with license to operate it until 2023. Future utilization programmes will include the production of radioisotopes, work to support nuclear power industry, irradiation of gems and continuation of scientific research. Work for testing different equipment and materials for NPP will also be continued.

Part 2: Improvement of research reactors reliability and availability

Mr S. Wetchagarun (Thailand) discussed the experience gained with modernization of I&C system of research reactor TRR-1/M1 in 2017 to a digital system, with technical support from Korea Atomic Energy Research Institute (KAERI), Republic of Korea. The reactor protection system has been maintained as a hard-wired system. The reactor regulating system and operator information system have been modernized to computer based digital system. The new system is functioning as required with improved performance and reliability, ease of maintenance and surveillance and valuable experience and skill of operating staff.

Mr Y. Zhang (China) presented the possibilities and challenges anticipated in continuation of the operation of one of the oldest research reactors 'Swimming Pool Reactor (SPR)' in operation for 55 years, to meet the national requirements for materials testing, fuel irradiation testing, radioisotope production, neutron activation analysis and human resource development. The major issues included a) ageing of control system; b) corrosion of swimming pool wall; c) meeting the current regulatory requirements and d) the impact of Urban regional functional planning. Several modifications and upgrades have been carried out which included addition of two safety rods, battery powered emergency power supply, fire detection and alarm system and emergency core cooling system.

Mr L. Nahari (Indonesia) discussed how the reliability of the protection system of RSG-GAS research reactor was assessed using the Fault Tree Analysis (FTA) method with Open-FTA software. The input on probability of component failure was derived from the IAEA TECDOC on generic component reliability data for PSA of research reactors. This helped in improving maintenance practices and reducing reactor scrams due to component failures.

Mr B. Achuthan (India) presented the challenges faced in operation and maintenance of two diverse research reactors: Sodium cooled 40 MW Fast Breeder Test Reactor and 233U fueled 30 kW reactor. Major challenges like sodium leaks, rupture disc failure, choking of cover gas (argon) lines, fuel failures, fuel handling incidents, steam generator tube leaks and post-Fukushima seismic retrofits in fast reactor were described. KAMINI reactor faced the challenges including non-reproducibility of critical height, replacement of control rod drive mechanism, upgrading of I&C system to computer-based system. Experience gained in major refurbishment of both reactors to address obsolescence and ageing and to meet the current safety standards; was also covered.

Mr N. D. Nguyen (Vietnam) gave a comprehensive description of conversion of 500-kW Dalat Nuclear Research Reactor (DNRR) from HEU to LEU fuel, the limitation of the irradiation facilities to meet the growing demand of users, especially for healthcare purpose and the preliminary results of conceptual design of proposed 10-MWt multi-purpose research reactor to meet the demands in future.

Mr F. R. Kungurov (Uzbekistan) discussed the operation and maintenance experience with the sixty–year–old WWR-SM research reactor, elaborating upon the modification and upgrading of the reactor from 2 to 10 MW; core conversions from 90% enriched fuel to 36% enriched IRT-3M type fuel and again to 19.75% enriched IRT-4M type LEU fuel; the emergency core cooling system; emergency ventilation system; second cooling circuit and instrumentation and control systems including radiation monitoring. This helped in efficient operation with enhanced safety and effective utilization to meet the increasing demand of stakeholders.

Part 3: New techniques for operation and maintenance

Mr P. Sumanth (India) introduced the applications of On-Line Monitoring techniques for condition-based calibration and in-service response time measurement of sensors commonly used in NPPs. He presented an overview of I&C upgrades carried out in the 100 MW DHRUVA reactor, which has facilitated on-line monitoring of instrument channels. The I&C upgrade included the replacement of pneumatic instrumentation by electronic instrumentation, replacement of solid state and relay logic by computer-based systems and introduction of Data Acquisition Systems and On-line Monitoring systems for equipment. As a result, the calibration intervals have been increased with significant contribution to the enhancement of safety and availability and reduction in surveillance and maintenance requirements.

Mr H. Obeng (Ghana) discussed the experience of Ghana with respect to the conversion of 30 kW Miniature Neutron Source Reactor (MNSR) GHARR-1 from HEU to LEU in 2017. The project began in 2006 under the aegis of the IAEA CRP involving all countries operating the MNSR and USA DOE to perform feasibility search for qualified LEU fuel that can be used to convert MNSR with little modifications to the core configuration and reactor performance. Thereafter, the process of HEU removal and LEU installation spanned a period of three years, which involved Ghana, China, USA and the IAEA. An important outcome of the project is the availability of a full-scale MNSR Core Removal Training Centre (CRTC) in Ghana for potential conversion of other MNSRs. The presentation also covered the assistance provided by the IAEA to ensure safety of the conversion programme through the safety review mission INSARR.

Mr B. Meffert (USA) provided an overview of the reduction in performance of reactor water clean-up system for the 10 MW(th) MURR after 52 years of service. The deterioration of the rubber liners inside the resin columns in the system was attributed to ageing and gamma radiation dose. The old ion-exchange resin tanks were replaced by larger tanks of Stainless Steel. This modification provided improved purity of the coolant, longer service life of the ion-exchange bed and reduction in radiation dose rates.

Mr M. Dougdag (Algeria) presented the work done to study the effects of thermal stripping on the lifetime of some nuclear reactor components for different coolant systems with focus on water, sodium and lead-bismuth eutectic (LBE) in new nuclear research reactors. Major indicator of thermal striping, due to the coolants, depends on the high stresses inside the wall thickness of components. The study indicated that the lowest risk is obtained for LBE at low temperature and sodium at high temperature.

Mr J. Milthorpe (Australia) discussed the upgrades carried out on OPAL reactor control and monitoring system. The context surrounding frequent upgrades to the reactor control and monitoring system including success and challenges, was presented. The trends in industrial control systems, operational technology hardware and software that have led to a significant reduction in the supported lifecycle were attributed to increasing reliance on commercial IT equipment for some functions. The project was completed at cost which was a small fraction of the previous major upgrade with minimal impact on the reactor operation.

Mr A Zuniga (Peru) presented a hybrid method that integrates experiment and simulation results with the SERPENT code, used to determine the average neutron flux data in fuel elements for the RP-10 reactor. The intent is to reduce the time and tedious procedure in performing this function during the commissioning of research reactors without losing precision. Detailed experimental protocols based on activation method using Au and Cu were provided including validation. The paper concluded that the hybrid method provides an effective way using fewer fuel elements to determine the average power during reactor commissioning.

Poster presentations

Mr M. Irigaray (Argentina) and co-authors presented the issue related to the control of water chemistry modification in the Liquid Poison System which will be used in the new research reactor RA-10 to develop power ramps in the in-pile irradiation module through changes in dematerialized water boric acid concentration. They indicated that such modifications are mainly due to water radiolytic decomposition.

Mr F. Giacobone (Argentina) and co-author described a preliminary study of the use of hydrogen peroxide as a biocide in wet storage facilities for aluminium-clad spent fuel elements. Aluminium Alloy AA6061 specimens were tested in 0.001 M chloride solution with addition of either 0.0015M or 0,0030M hydrogen peroxide. The tests carried out showed that a concentration of 0.0015M hydrogen peroxide solution would be safe to use in a storage site.

Mr H.A. Adamu (Nigeria) and co-author described the conceptual design and the hardware implementation of a data acquisition system for NIRR-I research reactor, which is a Miniature Neutron Source Reactor (MNSR) type. The reactor is operated by using a reactor control console or a computer-controlled interface. The data acquisition system presented is intended to process the signals associated with a pair of thermocouples that measure the reactor water inlet and outlet temperatures; and to be used in case of a discrepancy between the temperature values provided by the reactor control console and the computer controlled interface.

Mr A. Horvath (Hungary) and co-author reported on the feasibility of increasing the excess reactivity of the BME Training Reactor which was built at the end of the 1960's (current authorized power: 100 kW). During the reactor's lifetime, the reactivity reserve was relatively low (75 cents in December 2014) and it is becoming necessary to increase it in the near future. Two options to increase the reactivity reserve of the core were investigated and discussed.

Ms S. Kustituantini (Indonesia) and co-authors presented the conceptual design of the Bandung TRIGA research reactor? from using the standard TRIGA Mark II fuel elements into the locally manufactured MTR plate type. This conversion is motivated by the very limited number of available TRIGA fresh fuel elements, and by the decision of the fuel manufacturer General Atomics to stop the production of fuel elements. The basic design and detailed design of the reactor conversion are expected to be completed at the end of 2019.

Mr C. Humphrey (Australia) and co-authors reported on light water chemistry practices adopted for OPAL reactor. They discussed the operating experience on this topic and provided details on the main radionuclides found in the reactor primary coolant water and on their formation mechanisms. The actions taken to identify the sources of water contamination and to capture contaminants were described. The change of the mixed bed ion exchange media type used for pool purification has increased the operating life of the bed from 3-4 months to 7 months.

Mr B. Piwowarski (Poland) reported on ageing management programme of concrete structures of Maria research reactors. The programme was established for the concrete containment building and for the concrete biological shield. Details were provided on the monitored parameters as well as on the results of destructive and non-destructive tests of these concrete structures.

Mr A. Asuncion-Astronomo (Philippines) and co-authors presented the project for utilizing the Philippine Research Reactor-1 TRIGA fuel in a Subcritical Assembly (SCA). The Philippine Research Reactor-1 has been shut down since 1988. The Philippine Nuclear Research Institute (PNRI) has decided recently to reuse the slightly irradiated TRIGA fuel rods that have been in wet storage for

30 years, in a subcritical assembly aimed at re-establishing nuclear expertise in the Philippines. The options considered for PNRI decision and an overview of the SCA design and utilization plan were also presented.

M. Marticorena (Argentina) and co-authors presented a general description of the on-line Automatic Condition Monitoring System which was installed at RA-6 research reactor. The system is intended to detect and diagnose potential mechanical failures in the primary coolant circuit pump, the decay tank and the primary coolant circuit piping. In case of anomaly detection, the system will display an alarm in the control room for rapid action and presents the information online for analysis by specialized groups.

Session 3: New research reactor programmes

Eight papers were presented in this session; including a keynote, 2 invited and 5 contributed oral papers, plus 13 poster presentations (one poster was absent). The papers covered the IAEA services to Member States to establish the necessary national nuclear infrastructure for new reactor programs, progress reports of research reactors under constructions, a feasibility study of new reactor projects, and safety considerations and licensing process of some other new projects.

Oral presentations

Part 1: Infrastructure for new research reactor programme

Mr R. Sharma (IAEA) presented, in his keynote, an overview of the IAEA support to new research reactor programmes. Member States undertaking such programmes face many challenges in the justification of the facility, stakeholder involvement, funding, human resource development, licensing, site selection, securing fuel supply, etc. IAEA Milestone approach and safety standards provide guidance in addressing these challenges. Mr Sharma further described the IAEA services including the Integrated Nuclear Infrastructure review for Research Reactors (INIR-RR) peer review mission, safety review missions such as INSARR, the IRL, regional research reactor schools, Eastern European Research Reactor Initiative (EERRI) group fellowship course and advanced training opportunities available through International Centres based upon Research Reactors (ICERRs). The IAEA further assists Member States with training workshops and publications on related topics.

Mr Herman Blaumann (Argentina) presented, in an invited paper, an update on the status of the RA-10 research reactor project. He outlined that RA-10 is being built for several purposes including production of radioisotopes, material testing, silicon doping, beam research, neutron activation analysis and irradiation loop experimentation. The project includes three additional buildings for ancillary facilities. The construction license was granted in October 2014 and at present about 60 % of civil work has been completed. The plan is to complete civil work and cold commissioning by August 2022. Training of the first operating crew has already been started in February 2016. Challenges faced include managing the interfaces between several contractors. When in operation, RA-10 together with an upgraded Moly Processing Facility, will enable 1200 to 1800 6–day Ci-EOP supply of Mo-99 per week.

Mr Jean Pierre Coulon (France) presented an update on the construction at Cadarache of JHR, which will be a leading Material Testing Reactor. It will be used to conduct material and fuel irradiations to support nuclear power plants, and to irradiate Mo-99 with a peak capacity of 4800 6–day Ci-EOP per week, as well as other isotopes. Large progress has been made in recent years in the completion of the project, with the civil works fully completed, as well as the reactor pool lining. The starting of the reactor block pile integration, constitutes a new phase of the project; focused on integration of mechanical components and on preparation of the commissioning phase. According to the project plan, JHR will be commissioned and start operation in 2025.

Mr T. Tielens (the Netherlands) introduced the PALLAS project launched with the objective to replace the High Flux Reactor (HFR) in Petten with financial support from the government, to be able to continue and expand its lead role in the production of medical radioisotopes, in the nuclear infrastructure development, and regional economy. Currently, PALLAS project is progressing well with the support from INVAP consortium and focusing on sustainability; positive impact on people, planet and profit; several objectives at local, national and global level and actively engaging various stakeholders in a systematic way. Basic design will be completed in 2020, construction will begin in 2022. In 2025, a four-year transition period is planned to finish construction and commissioning of the reactor and transfer of all irradiation programmes from the HFR to the PALLAS reactor.

Part 2: New research reactors projects and licensing experience

Mr A. Tuzov (Russian Federation) presented, in an invited paper, the current status and prospects of MBIR construction project and RIAR's SM-3 reactor core refurbishment project. He pointed out the usefulness of operating and research experience accumulated at the BOR-60 reactor, engineering infrastructure, qualified scientific and technical personnel, for the implementation of MBIR project. He indicated that this project will expand the experimental base of the Russian Federation's nuclear technology and provide the industry with experimental and testing tools to justify and support projects of innovative and evolutionary reactor technologies. The SM-3 reactor core refurbishment project is being carried out to extend its operational lifetime beyond 2040 and expand the RIAR's experimental and isotopes-related production capabilities.

Mr M. Al. Qahtani (Saudi Arabia) discussed design characteristics of the 30 kW Low Power Research Reactor (LPRR), the first research reactor in Saudi Arabia. The main design characteristics are the low excess reactivity, large safety margins and the negative feedback coefficients. The construction is progressing well, and commissioning is scheduled by the end of 2021. It will support human resources development plan and become a tool for research and development.

Mr S. Kim (Republic of Korea) presented licensing experience with the safety review and assessment for construction license concerning a new 15 MW Ki-Jang Research Reactor (KJRR), a medium flux and open tank in pool type reactor with plate type U-Mo fuel. The safety review and assessment to evaluate the conformity with the technical standards and the regulatory requirements were carried out by the Korea Institute of Nuclear Safety (KINS) and the construction permit was issued. The first criticality is planned for 2023.

Mr A. Ben-Ismail (Tunisia) described initiation of feasibility study, in collaboration with the CEA (French Atomic Energy Commission) and the IAEA, for construction of a sub-critical assembly (preferred over a low power research reactor) to support human capacity building and nuclear research at Tunisian Center for Nuclear Sciences and Technologies (CNSTN). A roadmap has been established to reach completion of the feasibility study in accordance with the IAEA guidelines by the end of 2019.

Poster presentations

Ms T. Amarjargal Tsendsuren (Mongolia) and co-authors presented the design study of a first research reactor envisaged for Mongolia with the main purpose of producing radioisotopes and other applications. As the technical specifications of the envisaged research reactor have not been decided yet, they discussed the results of a preliminary neutronic analysis on three different cores of the Russian Federation type reactors (VVR-M2, VVR-KN, IRT- 4M) at three different power levels (500 kW, 5 MW, 10 MW). The study showed that the core with IRT-4M fuel assemblies will be capable to produce Mo-99 with highest specific activity in 72 hours of irradiation time.

Mr M. A. Ibrahim (Egypt) and co-author presented a comparative study of using Uranium Nitride (UN) fuel and using U3 O8 –Al fuel with the same amount of fissile uranium in a reference 10

MW research reactor. Details were provided on the calculation codes used and on core modelling. The calculation results indicated that UN-Al has lower peak fuel and clad temperature than U3 O8 –Al fuel.

Mr R.A.E. Ahmed (Sudan) presented the results of the identification of the challenges in establishing a first research reactor in Sudan by using self-assessment methodology of national nuclear infrastructure. He mentioned that 4 specific nuclear infrastructure issues out of 19 IAEA's infrastructure issues have been selected and evaluated for Sudanese nuclear infrastructure for phase one (pre-project phase) by using the IAEA's self-assessment method. These issues are: national position, nuclear safety, legislative framework, and radioactive waste management. The self-assessment gave a valuable picture of the current national infrastructure to determine the weakness and actions that need to be taken by a country to meet the requirements of a research reactor. He indicated that this study can be carried out for all other 15 infrastructure issues, which will provide an overall picture for the Sudanese nuclear infrastructure in order to establish the research reactor. He concluded that the results of a self-assessment could be considered as an advantage when Sudan receives the IAEA's Integrated Nuclear Infrastructure Review for Research Reactors (INIR-RR) missions.

Mr G. Marinsek (Argentina) and co-authors described the general operation of the Graphic Simulator Instruction and the strategy adopted to carry out the training of the operators. They indicated that the training of operating staff for the new RA-10 research reactor is being carried out with the use of an interactive graphic simulator as a tool to define and test normal and abnormal operation conditions. The training plan was split in two phases: one covering all the theoretical contents needed for licenses and the other part focuses on the specific training on the RA-10.

Mr G. Arias (Argentina) and co-author described the surveillance programme for RA-10 research reactor which is aimed at assessing the structural integrity of critical core components in order to ensure safe and reliable long term operation. In particular they described the methodology of the implemented surveillance programme, the test specimens, their locations and the tests to which they will be subjected. They pointed out a lack of general guidance in this field for research reactors and indicated that ad-hoc surveillance programmes have to be developed for research reactors considering the peculiarities of each design.

Mr Perrota (Brazil) and co-authors presented the project of a new research reactor, named RMB (Brazilian Multipurpose Reactor) which is a 30 MW open pool-type reactor using low enriched uranium fuel, with several associated facilities. This project is currently under development stage before construction on a site about 100 kilometres from São Paulo city. The reactor will be used for different nuclear applications, including production of radioisotopes and use of neutron beam for research activities. Updated information was provided on the technical design and the safety features of the reactor and the overall installation, on current status of the RMB project and associated licensing process.

Mr A. Dos Santos (Brazil) described the new critical core configuration of the IPEN/MB–01 research reactor, constituted with plate-type fuel elements and using Cadmium wires as burnable poison. This configuration will be used to validate, in the frame of the new research reactor project, the core of the 30 MW Brazilian Multipurpose Reactor (RMB), in particular the RMB calculation methodologies, as well as the nuclear data libraries used in the calculations.

Mr C.P. Camusso (Argentina) and co-authors presented the design objectives of the RMB research reactor from the neutronic point of view and discussed how these objectives were addressed. They provided detailed description of the reactor and results from detailed engineering concerning the reactor core, reflector, shutdown system and fuel irradiation facility.

Mr J. Mburu (Kenya) and co-author presented a case study of the need of Kenya to acquire a research reactor. They explored various utilizations, by identifying key economic sectors of the country that might benefit from the project, and also the possibility of expanding to a regional level. They identified stakeholders with their needs, which fall in the category of government, industry, scientific organizations, medicine, energy, and agriculture.

Mr R. Pachayev (Azerbaijan) discussed considerations on improvement areas for the existing infrastructure in accordance with the relevant IAEA safety standards and related publications. The decision to consider the construction of the first research reactor entailed the needs to improve the existing infrastructure, review the legislative framework, train personnel, review, adopt and implement requirements of relevant international treaties, and identify future needs to determine the technical parameters of the envisaged research reactor. A period of 10 years was estimated to design, build and commission a new research reactor.

Mr J. Ryu (Republic of Korea) presented the current status of the new 15 MW Ki-Jang pool-type Research Reactor (KJRR), to be built at Ki-Jang near the Kori Nuclear Power Plant complex in the south-eastern province of the Republic of Korea. The construction permit for this facility was issued on May 10, 2019 and the Final Safety Analysis Report (FSAR) will be submitted to the regulatory body in order to apply for an operation license. Preparation work for the construction contract, including the decision of the bidding method and the construction documents, is in progress with the aim to secure a contract by the end of 2020.

Mr M. Tufa (Ethiopia) and co-author presented the infrastructure assessment performed on the basis of the IAEA Milestones approach for new research reactor programmes. Potential stakeholders have been identified and their requirements or needs were determined through discussion and data collected via questionnaires. The analyses showed that the research reactor for isotope production, education and training, and neutron activation analyses are the primary areas of stakeholders' needs.

Mr C. Niane (Senegal) presented the on-going project on the development of the Strategic Plan for utilization of planned research reactor in Senegal. He mentioned that the request was made to the IAEA for the approval of a project related to the "Establishing a Research Reactor in Senegal", as part of the Agency's Technical Cooperation Programme. He outlined that the project will be divided into three parts: 1) Preparing the infrastructure and building the research reactor; 2) Construction and commissioning of the RR; 3) Optimizing the use of the research reactor. He informed that the objectives for the Senegalese Research Reactor-1 in the new Research Centre under construction encompass the following areas: 1) Research on iodine content of Senegalese foods and diets; 2) Neutron activation analysis; 3) Mineral and geological mapping of granite gold-bearing ores; 4) Soil mapping and fertilizers in agricultural applications, and 5) Production of short lived radioisotopes for radiotracer and human health applications; 6) Training and education of nuclear workforce.

Session 4: Safety of research reactors

Forty-three papers were presented in Session 4, including a keynote, 3 invited and 14 contributed oral presentations and 25 poster presentations (9 posters were absent). The first part of Session 4 included: a review of the IAEA sub–programme on safety enhancement of research reactors and three papers on the actions taken by Member States to enhance the safety of research reactors through improving safety analysis regarding handling of nuclear fuel and radioactive material, revision of safety analysis to conform with up-to-date safety requirements, and the operating organization safety oversight of experiments. The second part focused on application of the IAEA Code of Conduct and Member States experience on regulatory supervision and inspection programme for research reactors, with particular emphasis on core conversion and ageing management. The papers in the third part were mainly on Member States experience with planning and implementation of processes of periodic safety reviews. The papers in the fourth part covered leadership and management for safety, evaluation of operating experience, approaches to the development of probabilistic safety assessments, land safety upgrades based on the lessons learnt from the Fukushima accident.

Oral presentations

Part 1: Safety enhancement for research reactors

Mr A. Shokr (IAEA) discussed, in his keynote, the IAEA's sub-programme on safety enhancement of research reactors. Feedback from the various activities indicates that attention is still needed in several areas: regulatory effectiveness; ageing management; decommissioning plans; and the safety-security interface. There is also a need to establish national nuclear infrastructure in countries planning their first research reactor. Mr Shokr reviewed the IAEA's activities in support of application of the Code of Conduct on the Safety of Research Reactors. He noted an improved application by Member States of the Code in several areas, including regulatory inspection and operational safety programmes, and increased trends in establishing processes for periodic safety reviews and systematic ageing management programmes. However, further improvements are needed in these areas, and work is needed to improve leadership and management for safety, emergency preparedness, and decommissioning. The IAEA safety requirements for research reactors have been revised to address the lessons learnt from the Fukushima accident, and significant progress was achieved in revision of relevant safety guides. Work is ongoing to ensure effective application of these safety standards. The efficiency of the IAEA peer review services to research reactors continues to be enhanced and increased requests from Member States for these services are observed. Other activities include enhancing safety of research reactors under the IAEA Project and Supply Agreements, capacity building, and support to technical cooperation projects and implementation of safety upgrades that were identified based on the lessons learnt from the Fukushima accident. Mr Shokr highlighted that ensuring and maintaining a high level of safety are essential for ensuring the sustainability and effectiveness of research reactor facilities. For the future, it is anticipated that work will continue to support Member States in effective application of the IAEA safety standards; establishing effective ageing management programmes, improving safety and regulatory infrastructure, including for first (and new) research reactor projects; and improving management of the interface between safety and security.

Mr F. Nicolas (France) discussed managing the safety of equipment handling for research reactors in France from the regulatory prospective. The paper provided detailed discussion on the efforts of the French Nuclear Safety and Radiation Protection Institute (IRSN), as the main technical support organization to the French Nuclear Safety Authority (ASN) in this regard. The original safety demonstration of the French research reactors was mainly focused on preventing accidents associated with the reactor core and mitigation of the consequences of these accidents. Over the years, safe handling of nuclear fuel, radioactive waste, and experimental devices, which could involve the handling of heavy loads inside the reactor building, became an integral part of the safety demonstration of French research reactors. IRSN and ASN have, as a result, reviewed the relevant regulatory requirements and processes to address this issue. The research reactor operators have been required to include a reassessment of their facility practices on safety of handling of nuclear fuel and radioactive material using current standards in the scope of the periodic safety review, which is required every ten years. In addition, this topic is included in the safety requirements of design of new reactors (and modification of existing ones) as well as for design of experimental facilities.

Mr F. Fejt (Czech Republic) presented the revised safety assessment of the VR-1 training reactor in line with with the new national nuclear law (issued by Act No 263/2016). The license of the reactor was obtained in accordance with the requirements of this law in 2017, as the first reactor in the country to be evaluated against these new requirements. Mr Fejt indicated that the lack of regulatory guidance on the new regulations was the main challenge in the preparation of the revised safety assessment, which was addressed by following the IAEA safety standards in the relevant areas. Mr Fejt, in his presentation, classified the revisions made to the safety analysis report in this regard as mainly related to review of the reactor operational history and use of operating experience; expanding format and content of the safety analysis report; review of the postulated initiating events considering operating experience and performance of the accident analysis using verified and validated computational tools and methods. He reported improvement in several areas as results of this work including in the quality of the safety analysis and safety documents.

Mr Scibetta (Belgium) discussed the safety management of the experimental devices and experiments at the BR2 reactor through the safety committee of the operating organization. The presentation discussed the procedures for irradiation experiments at the BR2, including classification of experiments based on their safety significance, and the associated requirements on design, safety analysis, installation, and review and assessment. Mr Scibetta also discussed the process for management of an experimental project at the BR2, which is divided into four phases: conceptual design, detailed design, construction and qualification, and operation. The presentation also highlighted the role and responsibility of the operating organization, safety committee and the national regulatory body in this regard. Emphasis was placed on the functioning of the safety committee, including its composition, competence, independence from reactor management, reporting, and on the methodology that is established and used by the committee for review of proposals on new experiments. Mr Scibetta also highlighted the self-assessment performed by the BR2 operating organization (including the safety committee) and its role in defining several improvements in management processes and operating procedures, and explained the contribution of the safety committee processes to enhancing culture for safety within the reactor operating organization.

Part 2: Regulatory supervision of research reactors

Mr A. Adams (USA) discussed, in his invited talk, of the IAEA Code of Conduct for the Safety of Research Reactors (Code of Conduct) and how the U.S. Nuclear Regulatory Commission's (NRC's) regulation of research reactors is in harmony with the Code. After an introduction to the NRC and an overview of the research reactors it regulates, Mr Adams described the history of the Code of Conduct. The NRC's self-assessments of the application of the Code of Conduct identified two possible areas for enhancement: the maintenance of safety analysis reports and regulatory requirements in the area of human factors. Mr Adams discussed the steps taken by NRC to enhance regulation in both these areas. He then reviewed the roles of the State and the regulator presented in the Code of Conduct with details of how the NRC's regulation of research reactors is in harmony with the provisions in the Code of Conduct. Mr Adams emphasized that the Code of Conduct is one of the most important IAEA publications for research reactors and both new and mature regulators should carefully consider the Code of Conduct for enhancements to their regulation of research reactors.

Ms S. Nemtsova (Ukraine) presented details on regulatory supervision of the neutron source including legislative and regulatory framework, the licensing process in general, as well as the status of the neutron source licensing in Ukraine. The neutron source is based on the sub-critical assembly driven by a linear electron accelerator which is utilized for generating neutrons from photonuclear reactions with high mass number material. Since this is the first experience in licensing of such type of facility in Ukraine, both sides (the operator and the regulatory body) faced challenges that have led to a delay in project implementation. However, all of these challenges have been resolved by close working interaction through development of a new regulatory framework. The operator is about to apply for obtaining the individual permits for the physical start-up and trial operation of the neutron source with the target of commissioning in 2020.

Mr G. Lazaro (Peru) presented the Ibero-American Forum of Nuclear Regulatory Bodies' (FORO) achievement on the project (PT-16) for the standardization of the inspection process for research reactors (RRs) in collaboration with the IAEA. He mentioned that the IAEA training material on regulatory inspection programme for research reactor was the main source for such development. The motivation of this project is to enhance capability of the regulatory oversight for research reactors operated in the Ibero-American countries. The PT-16 project was initiated in 2018 and planned to generate two products such as an inspection manual that serves as a reference to the regulators in the region and other countries that have similar reactors, and a guide for the regulatory oversight of the ageing management programmes of the RRs. The manual is expected to be completed by the end of 2020. The second product for the regulatory oversight of ageing management is currently under development. The use of the 13 generic inspection procedures regarding topics such as radiation protection, maintenance, operation and nuclear safety are being piloted by the Peruvian regulatory body

at the RP-10. The lessons learned from applying the procedures to the RP-10 and the research reactors of the countries participating in this project will be used to improve the implementation of the inspection programmes.

Mr A. Awalludin (Indonesia) presented the regulatory and technical aspects of the reactor fuel conversion in Bandung TRIGA 2000 research reactor from the UZrH cylinder-type fuel to silicide MTR plate-type fuel due to the shortage of cylinder-type fuels in a few years. The applicant can propose two options such as a revised license renewal through a modification process or a new reactor license. Both choices have an impact on the permit that will be issued by the regulatory body (BAPETEN) and on the regulatory requirements that need to be met by the licensee. BAPETEN has been identifying potential problems that may be faced during the licensing of reactor core conversion with the basis of both regulation and technical aspects. The regulation, administrative and technical preparations for the regulatory review of the fuel conversion matters were introduced.

Ms E. Retfalvi (Hungary) presented the Hungarian results of the EU Topical Peer Review (TPR) for ageing management (AM) in a research reactor. This paper is the summary of the Hungarian regulatory body's (HAEA's) activities on the TPR and TPR results on the AM of the research reactor in Hungary. The main concern for the AM programmes for research reactors in the EU is that the programmes are not regulated or implemented as systematically and comprehensively as for commercial NPPs. This may be justified due to the potentially lower risk significance of RRs compared to NPPs. The TPR report concludes that the AM meets the expected level. This paper also includes the TPR methodology followed in Hungary, the AM requirements for research reactors, the analyses results and the conclusions of the Hungarian licensee, the corresponding HAEA assessments and the follow up actions after TPR.

Part 3: PSR for research reactors

Mr C. Perrin (Argentina) presented an invited paper about the safety review of research reactors in Argentina with an example of application to the zero power Argonaut type research reactor RA-0, which followed the specific regulatory guide set by the Nuclear Regulatory Authority (ARN). He described the contents of this guide and mentioned that the operating license of a research reactor has a limited validity. For its renewal it is required that the operating organization performs a comprehensive safety review and submits to the ARN the review reports, one year before the license expiration date. Mr Perrin presented the different stages of periodic safety review implementation and presented relevant results from the comprehensive safety review of the RA-0 research reactor. He indicated that the ARN issued in October 2017 a new Operating License, valid for 3 years; subject to compliance with a set of requirements related to the corrective actions indicated in the approved Implementation Plan. He concluded that comprehensive safety reviews have proven to be an effective tool for detecting weaknesses, updating and improving the safety of research reactors.

Mr A. Carpentier and F. Nicolas (France) presented results of periodic safety review (PSR) for the 25 MW CABRI research reactor which is used for fuel testing. The last CABRI PSR was performed in 2004. The reactor has been renovated and equipped with a new experimental loop containing pressurized water. The first experiment in the pressurized water loop took place in April 2018. The French regulations concerning PSRs, the current context of PSRs regarding French research reactors, and the relationship between the category of research reactor and the extent to which their PSR reports are reviewed by the regulator (ASN), were discussed. Mr A. Carpentier and F. Nicolas also discussed the general strategy used to define the scope and the extent of the review of the CABRI PSR files based on a graded approach and provided examples of safety topics assessed in the frame of the regulatory review of PSR files. They indicated that this review is still proceeding, and some safety improvements have already been identified for the research reactor and its operating organization. An action plan, resulting from the periodic safety review, has been developed by the operator in order to correct non compliances and to enhance the research reactor safety.

Mr David Vittorio (Australia) presented plans for detailed reviews of OPAL safety and security which are recognized internationally as good practice. The regulatory body ARPANSA and the operating organization ANSTO have determined that the next review for OPAL should have the safety and security aspects concurrently assessed. The relationship between safety and security, both in terms of management, operational synergies, and conducting detailed reviews has been of interest to the research reactor community in recent years. The Periodic Safety and Security Review (PSSR) is conducted following the joint ARPANSA/ANSTO Regulatory Guide on Periodic Safety and Security Review of Facilities, which is the primary reference for the review plan. In the development of the review plan, ANSTO has taken into consideration the following: OPAL PSR from 2011 and the Physical Protection and Security Review in 2012, international practice in the conduct of PSR (SSG-25 and the soon to be released guide for research reactors), interfaces between safety and security (IAEA-TECDOC-1801), guidance on Nuclear Security (INFCIRC-225), and International missions and bilateral reviews on security (2017 IAEA IPPAS mission).

M. Gaheen (Egypt) presented the ETRR-2 Periodic Safety Review (PSR) plan, which will be implemented with support from the IAEA. An IAEA expert mission in February 2019 provided the review team with practical information on management, planning and performing a PSR. The review approach includes a safety factor review, global assessment, and integrated implementation plan. The reactor facility documentation and status will be reviewed against the national regulations and current applicable safety standards. Findings will be categorized based on their safety significance. Each finding will have a corresponding corrective action or safety improvement measure and will be further analysed as part of the global assessment. The global assessment will take account of interfaces, overlaps, and omissions from the safety factors review to ensure completeness and consistency and prioritize the corrective actions and safety improvements based on categorization. The global assessment report will be submitted to the national regulatory body (ENRRA) for review and assessment. An integrated implementation plan consisting of corrective actions and safety improvements, that are considered reasonable and practicable, will also be submitted.

Part 4: Leadership and management for safety

Mr J. Offerein (The Netherlands) discussed in his invited talk the leadership and management of safety at NRG. He introduced NRG, the Petten site, the high flux reactor and their history. This was followed by an overview of medical isotopes. Mr Offerein discussed issues in safety culture and reactor operation that led to a number of improvements in safety. The first improvement was the performance of four INSARR missions during the past 15 years that contained several useful recommendations and suggestions. Two periodic safety reviews were performed and resulted in a number of improvement measures that were implemented. The asset integrity programme was developed to reduce potential safety and reliability issues with a focus on ageing management. An independent safety culture assessment (IAEA ISCA mission) was performed to create a common understanding of the organization's culture, resulting in positive concrete results. Mr Offerein also discussed the NRG leadership development programme. These efforts led to a positive impact on safety and reliability of the facility.

Mr S. Rashid (Pakistan) discussed the importance of an organization learning from its own and other organization's experience. This is especially important in nuclear activities. Mr Rashid discussed how the Pakistan Nuclear Regulatory Authority (PNRA) uses a systematic process for evaluating operating experience to improve its regulatory activities including the review of licensing applications. The operating experience is gathered from the IAEA and other regulatory bodies. This operating experience is screened, evaluated and used to make recommendations to the PNRA and its licensees. Mr Rashid presented several examples of how this process improved regulatory inspection plans and decision making, and the operational practices of licensees.

Ms M. Grinberg (Argentina) discussed approaches in the development of probabilistic safety assessment (PSA) for research reactors. She explained the PSA regulatory requirement in Argentina and the generic process for the development of PSA for research reactors. The identification, selection

and postulation of initiating events were explained followed by the development of a level 1 PSA which allows the identification of event sequences that can lead to a core damage state. The progression to level 2 PSA and the core damage sequences were also discussed as well as the level 3 with the calculation of individual radiological risk for members of the public and workers. With this description of the methodology of PSA, Ms Grinberg concluded by presenting a case study for a reference research reactor.

Ms K. Niedzwiedz (Germany) discussed what was learned from the Fukushima accident and how that related to challenges and best practices in safety improvements for German research reactors. The basic design of the three impacted reactors, the FRMZ in Mainz, a 100 kW(t) TRIGA reactor with pulsing capability, the BER-II in Berlin, a 10 MW(t) MTR-type reactor, and the FRM II in Munich, a 20 MW(t) pool reactor, was outlined. The history of stress tests for German research reactors with a thermal power level greater than 50 kW was discussed. Stress tests were performed using the power reactor methodology while applying a graded approach. Natural hazards, expanded postulated events, emergency preparedness and man-made hazards were evaluated. While overall the reactors were found to be sufficiently robust, safety margins varied and generic and facility-specific recommendations for further safety improvements were made. A level of robustness was assigned for the outcome of each evaluation area for each reactor. The review results for each reactor were presented and a follow up review was performed to verify the implementation of the recommendations.

Mr A. Belchior (Brazil) discussed the analytical and experimental analyses that were performed on safety-related aspects of the Brazilian Multipurpose Reactor (RMB), which is in the detailed design phase. After a brief overview of the reactor, Mr Belchior described thermal-hydraulic transient and accidents calculations that have been performed using computational fluid dynamics (CFD) and the RELAP5 code. The limitations and advantages of both computational methods were discussed. The results concerning the performance of siphon breaks during loss of coolant accidents were discussed. RELAP5 and CFD analysis were validated against experimental results from the POSTECH siphon breaker facility and a RELAP5 model was used to simulate the performance of a siphon break to protect against various failures of the primary coolant system. Protection of fuel was demonstrated in the simulations.

Poster presentations

The posters presented on safety of research reactors dealt with neutronic and thermal-hydraulic calculations (5), safety analysis and safety assessment (10), I&C (5), safety related equipment (2), and general topics (3).

Mr O. Kukhotskyi (Ukraine) presented the Thermal hydraulics safety studies performed by the State Scientific and Technical Center for Nuclear and Radiation Safety (SSTC NRS) in the frame of the licensing of the neutron source subcritical facility. The studies were performed for normal operation and transient conditions corresponding to loss of coolant scenario. The calculation results showed that the heating of fuel assemblies does not lead to damage of their cladding.

Ms B. Srimok and co-author (Thailand) presented an evaluation of the methodology for determining probabilistic inspection and maintenance frequency for SSCs of TRR-1/M1 research reactor that are important to safety. The evaluation concluded that the actual maintenance period for systems and components according to the TRR-1/M1 inspection and maintenance plan is well within the calculated expected time to their next failure.

Mr P. Ramirz (Argentina) and co-authors discussed how the Defense in Depth concept is used to provide a framework for the elaboration and performance of safety assessments in a methodical manner. They indicated that the approach is largely based on the insights from the IAEA standard SRS 46 (Assessment of Defence in Depth for Nuclear Power Plants). They also indicated that the RA-10 reactor has been designed assuring that the three fundamental safety functions are achieved.

Mr F. Beretta (Argentina) and co-authors presented the analysis of a blackout event combined with the failure of the shutdown system of the RA-1 research reactor. The analysis was performed with the thermal-hydraulic code RELAP. The focus of the analysis was the transition from forced to natural circulation in the reactor pool, and the study of the core cooling after the loss of power supply. The results showed that the reactivity feedback due to moderator and fuel changes was enough to reduce the power level to decay values and to obtain a broad safety margin.

Mr L. Claramonte (Argentina) and co-authors presented the results of the analysis of the research reactor RA-10 behaviour during a loss of external power supply combined with the failure of the emergency power supply. For this analysis the RELAP5 code was used. The results showed that the RA-10 reactor can be properly shut down and cooled by natural circulation by transferring the residual heat to the reactor pool.

Mr M. Caputo (Argentina) and co-authors presented a methodology for quantification of workers radiological risk applied to research reactors, which is based on the radiological risk definition and the concept of individual radiological risk for members of the public according to the regulatory body criteria. This risk can be expressed as the product between the exposure probability times the fatality probability due to the dose received by the worker. They described two scenarios of application of the methodology. The first one is related to workers exposure events as result of initiating events with or without reactor core damage and/or irradiation devices damage. The second one corresponds to direct radiological exposure situations caused by the failure of structures, systems and components and/or human errors during operational tasks.

Mr F. Spadavecchia (Argentina) and co-author described the design and implementation of an online reactivity meter. Reactor reactivity can be measured by processing the signal delivered by an ionization chamber and implementing a numerical scheme that solves the inverse point kinetic equations.

Mr A. Di Benedetto (Argentina) and co-author discussed the challenges associated with the adaptation of general safety requirements to zero-power reactors. They indicated that most of the main requirements for fundamental safety functions are related to coolant and are not applicable for these reactors. The functions related to the control of reactivity and exposure to radiation, are applicable. They concluded that for a zero-power reactor, like RA-0, the analysis can be focused on the dose received by an operator and the capability of the reactor to auto shutdown.

Mr A. Maître (Argentina) and co-authors presented the design of the primary neutron guide shutters of the Brazilian Multipurpose Reactor (RMB) which includes neutron beams provided with neutron guides that allow carrying out experiments requiring high intensity neutron sources outside the reactor pool. The neutron guide shutters are aimed at ensuring acceptable dose rate levels at the reactor hall when the neutron guides are not used. The efficiency of shielding was estimated by a 3D calculation of dose rates from neutrons and gammas, in front of the shutter gate, which was carried out with the Monte Carlo probabilistic code MCNP6.

Mr F. Boschetti (Argentina) and co-author described the validation made for the standard deterministic calculation line employed by INVAP for the determination of the kinetic parameters for the Multi-purpose Brazilian Reactor (RMB). This validation involved a complete evaluation of the delayed neutron fraction and prompt neutron lifetime which was done by means of the MNCP code.

Mr S. Rashid (Pakistan) and co-authors discussed the regulatory oversight of ageing management for long term operation of research reactors in Pakistan. They indicated that the regulatory authority PNRA reviews the ageing management programmes and performs inspections to verify their implementation. PNRA also verifies that comprehensive periodic safety review is performed for license re-validation. The decision to allow long term operation for research reactor is based on extensive safety assessment regarding effectiveness of measures taken by licensee to prevent/mitigate ageing degradation and justification that design safety margins are within the acceptable limits.

Mr H. Graine (Algeria) and co-authors presented the source term assessment for a Hypothetical Research Reactor (HRR) and the calculation of the radiological consequences in case of a Loss of Coolant Accident (LOCA). They indicated that it is necessary to estimate the nature, amount and kinetics of the radioactive products likely to be released out of the installation and then to use PC-COSYMA code to decide the adapted countermeasures.

Mr L. Bedhesi (South Africa) and co-authors described the reactor calculation platform OSCAR-5 code system, which was developed and maintained at the South African Nuclear Energy Corporation (Necsa). They indicated that OSCAR-5 system is a software platform supporting SAFARI-1 reactor operation and allowing easy data transfer between different codes.

Ms L. Mataloni (Argentina) and co-author presented a computational model to design the irradiated target transport container which was developed to assess the cooling of the targets according to the design criteria considered (< 450 °C). A full model of the irradiated target transport container was also built to estimate the maximum temperatures in the targets and in the lead shielding.

Mr Ferrari (Argentina) and co-authors presented the neutronic and radiation protection analysis for the fuel irradiation facility of the 30 MW Brazilian Multipurpose Reactor. Details on the neutronic design requirements and the radiological shielding were provided.

Mr G. Quesada (Argentina) and co-authors presented the qualification tests programme of the RA-10 reactor protection system which should be performed in view of licensing of this system. This programme included testing of system robustness, Electro Magnetic Compatibility, temperature, humidity, and vibration tests.

Mr C. Verrastro (Argentina) and co-authors presented the reliability analysis for different configurations of a trip final actuator interface (FAI) for protection system of RA-10 research reactor. They indicated that this analysis is useful to decide which configuration is applied for the safety system as the FAI to meet the specified requirements.

Mr E. Villarino (Argentina) presented the validation of INVAP computer codes against experimental data on fuel burnup and material activation, in the frame of the IAEA Coordinated Research Programme. He indicated that validation of the calculation line against a wide type of experiments and reactors was successfully done. The design models and calculation procedures used for this validation showed a good agreement with the performed benchmarks on burnup and material activation.

Mr M. Gaheen (Egypt) and co-authors discussed the safety issues related to a restart of high flux MTR reactors after unexpected SCRAM. In such situation, the core excess reactivity is an important parameter to compensate for the increase or decrease of xenon poisoning. The proposed exchange of core reflector positions to compensate for the increase of xenon poisoning increases the maximum allowable time to restart the reactor promptly after a SCRAM.

Mr A. Cervantes (Argentina) and co-author described a signal emulator equipment designed for the RA-10 reactor protection system verification process. This equipment will be used in the functional, EMI and environmental tests of all individual units and electrical cabinets used in RA-10 protection system.

Mr G. Caceres Vivanco (Peru) and co-authors discussed the thermal-hydraulic evaluation of the RP-10 reactor using Uranium Silicide U3Si2 fuel assemblies. They indicated that the operating conditions of the reactor with the new silicide fuel elements meet the requirements of nuclear and radiological safety as with the original fuel.

Mr W. Farro (Peru) and co-authors presented an evaluation of the behaviour of the RP-10 research reactor when subjected to power excursion accidents due to reactivity insertions of 1.5 $ in

0.30 s and to loss of the primary coolant flow accident. The results showed that in case of reactivity accident, the maximum temperature of the fuel plate aluminium clad will be 258.41 °C (below the blister temperature of aluminium which is 450 °C) and 94.82 °C in case of loss of coolant flow accident.

Ms M. Koenen (The Netherlands) reported on the experience of the Nuclear Research and consultancy Group (NRG), which was acquired from carrying out the 10-yearly safety evaluations. Detailed information was provided concerning the challenges and lessons learned from the different phases of the 10-yearly evaluation, including the preparation process, the review and the implementation.

Mr Y. Pramono (Indonesia) and co-authors discussed the regulatory assessment of SAMOP (Subcritical Assembly for Mo-99 Production) test facility, which is a subcritical assembly used to produce Mo-99 radioisotopes for medical purposes. They indicated that the national regulations do not cover the subcritical assemblies and therefore the safety evaluation was made on the basis of the IAEA safety standards.

Mr H. Abou Yehia (France) and co-author reported on a new publication concerning research reactors, which was issued very recently by the Institute for Radiological Protection and Nuclear Safety (IRSN). This publication entitled "Elements of Nuclear Safety: Research Reactors" is aimed at sharing information and knowledge related to the safety and utilization of research reactors as well as to the prevention and management of their associated risks. The publication covers, in a comprehensive manner, the various safety topics relevant to research reactors.

Session 5: Security of research reactors

Five papers were presented in this session consisting of a keynote, an invited, 3 contributed oral papers and 2 poster presentations (1 poster was absent). They covered the IAEA activities in support of nuclear security, an overview of the Moroccan safety and security inspection and capacity building, the enhancement of nuclear security management, and the quantification of security risk posed by nuclear and other radioactive materials.

Oral presentations

Mr D. Shull (IAEA) described the IAEA nuclear security activities in support of research reactors beginning with a brief overview of nuclear security, nuclear security regimes, and the objectives of a state's physical protection regime. The IAEA nuclear security guidance NSS No. 19 on establishing the nuclear security infrastructure for a nuclear power programme was described and was applicable to research reactors using a graded approach. The general activities of the Division of Nuclear Security were described to include the development of guidance publications, assistance and expert missions, technical visits, and regional and national training courses. Specific nuclear security research reactor programme activities were presented. These activities include the IAEA Coordinated Research Project on the Security of Research Reactors and Associated Facilities (RRAF) (J02006) tasks descriptions as well as the research reactor specific training courses and past events. The publication on Nuclear Security Management for Research Reactors and Related Facilities (IAEA-TDL-004) was described as well as the ongoing development of the Handbook on Hypothetical Atomic Research Institute (HARI) Model developed as a reference document for the research reactor community and for use in research reactor specific training courses. The briefing concluded with a description of the Member States' benefits of the Integrated Nuclear Security Support Plans and International Physical Protection Advisory Service.

Mr K. Mrabit (Morocco) provided an overview of Morocco's safety and security inspection and capacity building. Morocco has signed and ratified all international treaties and conventions. In 2016, Morocco upgraded their regulatory framework and established an independent regulatory body,

the Agency for Nuclear and Radiological Safety and Security (AMSSNuR). Its main functions include regulatory development, authorization and inspection, support to the government in domestic physical protection and international negotiations, and to communicate with the public and relevant stakeholders. AMSSNuR's six strategic objectives from 2017 to 2021 include: upgrading the regulatory framework; enhancing the level of nuclear and radiological safety and security; developing and implementing the national nuclear security system and the emergency response plan; developing and maintaining human and organizational capacities; establishing and implementing a transparent and reliable communication policy; and strengthen regional and international cooperation. AMSSNuR is planning an integrated management system (IMS) to continuously develop, improve, and maintain nuclear safety and security. AMSSNuR has a national inspection programme that includes the inspection model for research reactors based on the IAEA model. A detailed description of the licensing and inspection strategy, processes, and programme was provided as well as follow-up inspection programme and a summary of follow-up results. The Moroccan systematic and integrated national capacity building approach includes: human resource development; education and training; knowledge management; and knowledge networks. A description on the progress on human resource development was provided with an emphasis on gender equality, as well as their national strategy for nuclear safety and security education and training which includes national, regional and international cooperation.

In conclusion, good progress in implementing AMSSNuR's Strategic Plan 2017-2021 in the areas of regulatory framework, nuclear safety and security, capacity building, IMS, and regional and international cooperation was reported. Continuous improvements are planned to enhance safety and security leadership and strengthen national, regional and international cooperation.

Mr M. A. Addo (Ghana) described how Ghana Atomic Energy Commission (GAEC) has employed international standards in strengthening nuclear security management regimes and maximizing protection of nuclear materials. The paper highlighted GAEC's most recent nuclear security enhancements, discuss the challenges encountered, and lessons learned. Nuclear security enhancements include the conversion of GHARR-1 from high enriched uranium to low enriched uranium to decrease the proliferation risks, and enhancements in the areas such as policy development and upgrades of the physical protection systems (PPS) at the nuclear facility. Other advances have been in human resource development for education and training and the continual monitoring and improvement of the workforce's performance. Ghana is establishing a Nuclear Safety and Security programme. and is accredited for programmes in nuclear sciences. Ghana has established a Safety and Safeguards Centre (SSC) under the direct supervision of the Deputy Director-General for safeguards administration of GAEC. Ghana has continued to demonstrate a strong commitment in international cooperation in the area of nuclear security by ratifying a number of international treaties and conventions. GAEC has made significant progress through legislation and strategies, and also through international engagements in strengthening the nuclear security infrastructure to safeguard GHARR-1 and other nuclear facilities. Some challenges still remain. These challenges include: need to increase operator qualified staff in the area of nuclear security and enhance insider protection measures as well as ways for the sustainability of staffing for both the regulator and operator organizations.

Mr A. Sfetsos (Greece) described the work conducted by the IAEA CRP on "Nuclear Security for Research Reactors and Associated Facilities (RRAFs)-J02006" Task 2: "Comprehensive Measurement of Security Risk for RRAF" to determine a methodology to estimate the holistic security risk posed by the unauthorized removal and sabotage of nuclear and other radioactive material targets at a RRAF. The scope of the present research is to identify factors for developing a comprehensive normalized ranking scheme for security risk posed by nuclear and other radioactive materials while considering the unique characteristics of RRAFs. Risk has been defined as the potential for an unwanted outcome resulting from a nuclear security event as determined by its likelihood and the associated consequences if it were to occur. Factors ranked as "Attractiveness factors" include: nuclear material/radioactive material; accessibility; facility locations; potential to initiate events; ease of handling/detection avoidance; and portability. Consequence factors include health effects and economic costs. Each of the identified factors is assigned to a relative scaling value, with the factor "potential to initiate events". A weighted sum of the squared scaled values of the attractiveness factors is implemented to reach the final attractiveness value for each material in a RRAF. The output of the

methodology will be the relative risk quantification of the NM/RM materials determined by plotting the attractiveness versus consequences placed on “X-axis” and “Y-axis” respectively. Curves representing constant values of the product of attractiveness with consequences could also be established that show groups of NM/RM with similar relative risk priorities. Input data from the IAEA Hypothetical Atomic Research Institute (HARI) facility description was used as the representative facility. The methodology demonstrated that is possible to compare nuclear material and radioactive material under a common risk ranking scheme and identify priorities for a facility that includes both types of materials. The development of the methodology is ongoing.

Mr M. Mladenovic (Serbia) described both of research reactors RA and RB built in the 1950s prior to the introduction of nuclear security measures by design. Serbian experts have been aware for a long time of the potential consequences regarding the malicious use of nuclear and radioactive material. As a result, Serbia has established a long-standing cooperation with a bi-lateral partner which has significantly improved their nuclear security system. Various upgrades were implemented, following all the IAEA recommendations and international best practices. In addition to defining and assessing the ‘traditional’ risks, Serbia has established a team to address emerging risks. One of the best examples of emerging risks is the cyber terrorism. A cross-cutting team from both research reactor group and nuclear security experts has launched series of projects to enhance cyber security. Other areas of concentration are the physical protection system’s equipment maintenance and sustainability, nuclear safety and security interface, and nuclear security culture. In bi-lateral cooperation Serbia has arranged for extended warranty and maintenance for all the security upgrades and has established an innovative maintenance approach to those systems based on the reliability.

Nuclear safety, security and safeguards (3S) experts are involved in all the processes regarding the design and testing of physical protection systems as the so-called ‘good insiders’ due to their specific knowledge regarding the nuclear and radioactive material. This is a clear sign that nuclear security is not left solely to the Department for Nuclear Security and shows the very high level of knowledge about nuclear security among the operator management team. Serbian experts participated in the IAEA Coordinated Research Program (CRP) on the Development of Nuclear Security Culture Enhancement Solutions, and follow-on actions include the Director of the Public Company "Nuclear Facilities of Serbia”, who has become the project manager for nuclear security culture, recognizing the importance of a strong management supported nuclear security culture.

Poster presentations

Two posters were presented focusing respectively on security challenges and risks for a research reactor, and on the security of transport of radioactive materials.

Mr A. Syuryavin (Indonesia) and co-author presented an evaluation of security challenges and risks of the RSG GA SIWABESSY research reactor, based on IAEA nuclear security recommendations.

Mr Y. Kilic (Turkey) discussed the nuclear security of research reactors with a focus on the security of transport of radioactive materials and on incidents which occurred due to the lack of knowledge in this field.

Session 6: Fuel management and decommissioning

Six oral papers were presented in this session, including an invited paper. There were 10 posters presented (4 posters were absent). Oral presentations in this session covered spent fuel management and decommissioning planning and execution. The posters presented information on spent fuel storage and treatment, new fuel designs, fuel burnup analysis, and decommissioning experiences.

Oral presentations

Ms F. Marshall (IAEA) provided a keynote presentation with summarizing the variety of IAEA activities to support Member States with their fuel cycle and decommissioning issues. All IAEA initiatives are aimed at increasing Member States' knowledge and capability. Activities to achieve this aim include coordinated research projects (CRPs), technical meetings, publication development, support for bilateral technical cooperation projects, and user networks. Upcoming research reactor fuel cycle activities include technical meetings on dry storage of research reactor spent fuel and accelerator driven subcritical system applications, support for radioactive waste management solutions, and new publications on research reactor fuel types and spent fuel storage practices (both wet and dry).

Ms P. Ameglio (Australia) discussed, in her invited presentation, the challenges and strategies for research reactor spent fuel management. Pool storage has challenges of safeguards and security, as well as corrosion possibilities. She indicated that final disposal without intention of retrieval is needed as well as the geological disposal for final disposal of waste or fuel. Fuel return programmes are not a reasonable long–term solution. Processing techniques used for NPP fuel can also be used for RRSNF – resulting in a calcine or glass waste form. ANSTO's spent fuel solutions for the Moata, HIFAR, and OPAL reactors were presented, as well as the options that were considered. Spent fuel from USA was returned, and some was sent to the UK, but UK stopped processing, so the fuel in the UK was sent to Orano in France. OPAL has license limits for the on-site SNF storage, and long–term strategy is for processing in France, with waste return. Details of the logistics for Opal fuel shipments were provided.

Mr S. Semenov (Russian Federation) discussed decommissioning of the RFT and MR reactors at the Kurchatov Institute. Both reactors were used for fuel testing in loops. The RFT reactor was constructed and operated first, then the MR reactor was constructed in the same building. Thus, the decommissioning of these reactors is occurring simultaneously. Surveys have been completed, and most of the waste can be classified as low- or intermediate-level waste. Challenges include lack of knowledgeable staff and the wide variety of equipment (large and small) to be removed. Remote radiation detection and removal equipment were used to minimize personnel doses. 34 tons of graphite were removed. Dust suppression techniques were used to minimize additional contamination. A new waste storage building holds 1100 m^3 of solid waste, 650 m^3 of liquid waste, and 1400 tons of dismantled equipment. The maximum individual dose was less than 50 micro Sv/year during the entire project. Some of the material challenges are the beryllium and graphite reflector blocks. About 70% of the soil is sufficiently uncontaminated that it can be reused elsewhere at the Institute.

Ms A. Talbi (France) reported on the services that Orano can provide to research reactors in managing research reactor spent fuel and radioactive waste, and decommissioning. Orano assumed all AREVA fuel cycle responsibilities, including recycling, logistics, and dismantling. Processing is a mature technology, the optimized form of processing product results in no safeguards, risk reduction, optimized disposal, and predictability of spent fuel management costs. Marcoule (La Hague facility predecessor) has processed fuel from 21 reactors in 11 countries. Future work includes special fuel processing (fast, MOX, and other fuel types), offering flexibility to customers. Many canisters are already approved for shipping and storage of vitrified waste in many countries. Orano also provides services for decommissioning and solutions for many types of small waste volumes (metallic, liquid, tools, cement). Orano also is decommissioning some of their own facilities, as well as French research reactors. A new technology "Dem&Melt" will provide in-can vitrification in the future.

Ms Madalina Budu (Russian Federation) reported on contributions from the Russian Federation to IAEA projects related to research reactor spent fuel management. The first one is a publication regarding the spent fuel processing services that are available, and the other is a coordinated research project (CRP) on the options available to Member States for their research reactor spent fuel management. The information included data from two primary service providers of commercial services for spent fuel processing, the types of shipping containers currently being used for research reactor spent fuel, and the decision support tools developed during the CRP to assist Member States to select among several spent fuel management options. An accounting of the number of research reactor spent

fuel assemblies was shown, highlighting that this is, collectively, a large problem the research reactor community is facing. Several IAEA publications on research reactor spent fuel were discussed. A summary of the spent fuel options CRP was provided and comments from an IAEA General Conference Side Event were offered as evidence of wide interest in the results of the CRP.

Mr Angorro Septilarso (Japan) reported on a general research reactor decommissioning plan and how it could be applied to a specific reactor, KARTINI (100 MW TRIGA) in Indonesia. Indonesia has three research reactors, so there is a need to start decommissioning planning. The project started by developing a list of all activities to be performed during the decommissioning. Then a work breakdown structure was developed to ensure that related activities were properly planed in the project timeline. Project management parameters (staff hours, waste inventory, radiation dose) and performance metrics were developed. The International Structure for Decommissioning costing (ISDC), as developed by OECD, was used for the cost estimating. Additionally, lessons learned from the decommissioning of a Japanese research reactor were used to assist in development of the project management parameters. The results of the application of ISDC to the KARTINI reactor were displayed. It is necessary to make assumptions about the labour rates, radiation doses, labour effort (staff hours), duration of activities, and the timing of the activities (i.e. which activities will be performed immediately, and which will be deferred until later years). Results of the cost estimates were displayed. The largest staff effort and waste volume load is biological shield removal. Earlier dismantling lowers costs, but maybe waiting a few years could result in smaller amount of radioactive waste.

Poster presentations

Ten posters addressed topics of spent fuel storage, fuel design, spent fuel processing, decommissioning, and waste management.

Mr M. Shaat (Egypt) and co-authors presented a poster about the decommissioning plan developed for the first Egyptian Research Reactor, ETRR-1, which operated between 1961 and 2011. The poster reported the contents of the plan and associated implementation activities, including the characterization, licensing, safety assessment, and dismantling activities. The proposed decommissioning plan covered considerations of transport of the nuclear fuel to the country of origin or storage in wet or in dry facilities.

Mr C. Diaz (Argentina) presented information on dismantling of the Argentine Reactor RA-8. The strategy to be applied for the retirement of service and dismantling was to initiate the work as soon as personnel and budget were available. In this case, contaminated structures, systems and components (SSCs) would be removed, decontaminated, or stored (in RA-6) to such a level that, the facility can be released for unrestricted use. Uncontaminated SSCs that do not require dismantling may remain at the site of the installation for later use or may be taken to other CNEA facilities for reuse or included in a museum of research reactors.

Mr J. Perrotta (Brazil) and co–author described the fuel management strategy for Brazil's new research reactor, named RMB (Brazilian Multipurpose Reactor) to be built on a site about 100 km from São Paulo city. The RMB fuel cycle management system has developed a coordinated project, putting together the fuel technology actors in Brazil, in order to establish an infrastructure for producing fuel assemblies for RMB operation, and uranium targets for Mo-99 production. The poster presented details of the project to ensure sustainability of the RMB fuel supply.

A. Chesnokov (Russian Federation) and co-authors presented information about the spent fuel disposition resulting from closure and preparation of decommissioning of the MR and RFT research reactors. One challenge was the loss of fuel assembly records due to change in personnel and recording media, requiring occasional inventory inspections, which costed money and took staff time from other duties. Some fuel assemblies were damaged and required special handling before shipment. Over 1000 fuel assemblies had been moved to the Mayak facility for processing by 2016.

Ms E. Linardi (Argentina) and co-authors presented information on the Corrosion surveillance programme of research reactor spent fuel elements in interim wet storage facilities in Argentina. The programme was initiated as part of an IAEA CRP and has been continued since completion of the CRP. The results obtained from the surveillance programme through the years show that the water quality in the storage sites was improved since the beginning of the project, and consequently the spent fuel elements degradation has been reduced considerably. The results are a good incentive to continue maintaining high water quality in the storage pools.

Ms A. Florencia Forte Giacobone (Argentina) and co-authors presented information about changes in bacterial populations at a spent nuclear fuel facility. The spent fuel elements from nuclear research reactors in Argentina are stored in demineralized water basins for long periods of time, sometimes for more than 30 years. This kind of environment allows the development of communities of microorganisms, belonging mainly to the domain of bacteria. The analysis of these populations has been subject of studies both for safety reasons and for their potential use in bioremediation. Results are not final, as the analysis continues.

Mr H. Seoung Park (Republic of Korea) presented information on decommissioning procedures and activities on the rotary specimen rack (RSR) for the Korean Research Reactor 2 (KRR2). The RSR is the largest component resulting from the decommissioning activities, and detailed characterization was performed to maximize the amount of material that could be classified and stored as low-level waste.

Ms A. Talbi (France) and co-authors presented information about Orano's experiences in assisting research reactors with waste and spent fuel management and decommissioning. As an owner-operator and service provider, Orano has accumulated extensive experience in dismantling and decommissioning of nuclear facilities worldwide. In addition, with more than 10 000 m3 of waste conditioned each year and continuous R&D efforts, Orano has built comprehensive waste management solutions, including characterization, processing and conditioning, as well as optimized logistics solutions.

Mr A. Hossen (Bangladesh) and co-authors presented information on benchmark calculation of thermal neutron flux of OPAL research reactor using MCNP5, performed as part of an IAEA CRP. This work is being performed in preparation for development of a design for a new higher-flux research reactor. It was concluded that this is a good model to follow for the new reactor analysis.

Mr F. Kungurov (Uzbekistan) and co-authors presented information on decommissioning of IIN-3M pulse research reactor ("Foton") at JSC in Tashkent. Some lessons learned are to make more conservative estimates of concrete activation, times for activity completion need to be adequate, and regulatory requirements need to be well understood at the beginning of the project. All work has been completed and the site has now been released for unrestricted use.

Session 7: Common management consideration

Ten papers were presented in Session 7, including a keynote talk from the IAEA, two invited talks by experts from Member States, six contributed papers and one poster presentation (one poster was absent). Part 1 included: a keynote (IAEA) on managing the interface between nuclear safety and security for research reactors; three papers on Member States' programmes and activities to enhance management of research reactors through strengthening safety and security cultures, use of a graded approach in the regulatory system of nuclear facilities, and a methodology for application of a graded approach to research reactors in Germany. Part 2 of this session included: two invited speakers on French experience in management of the interface between nuclear safety and security for research reactors, and the Brazilian experience on considerations and challenges of research reactor management; three papers on Member States' programmes and activities for nuclear knowledge

management for decommissioning of research reactors, safety considerations for management of research reactor during extended shutdown and transition period, safety management and integrated management system for nuclear research reactors from Argentinian RA-6 Reactor experience.

Oral presentations

Part 1: Management Considerations for enhanced safety and security and effective utilization I

Mr A. Shokr (IAEA) presented, in his keynote addressed to Session 7, an overview of the IAEA's approach and support to Member States in managing the interface between safety and security for research reactors. He reviewed the recent IAEA activities to support Member States to address the interface between safety and security, including revision of the IAEA safety standards, periodic organization of technical meetings, and publication of the TECDOC 1801 on this topic. He discussed the need for managing this interface for research reactors in view of potential conflicts in some measures to enhance both areas. He highlighted inadequate regulatory guidance, cultural differences, traditional organizational separation and lack of consideration of the interface between nuclear safety and security at the design stage as main challenges in this area. Mr Shokr also discussed similarities and differences between safety and security in various areas, including regulatory framework, safety and security cultures, optimization of protection, training of personnel and use of a graded approach. He also discussed safety and security interface during different stages of research reactor lifetime and provided practical examples of safety measures (in design, construction and operation phases) that can result in security improvements and vice-versa. Areas of potential conflicts between safety and security during lifetime of research reactors were also covered by the presentation, including the exchange of operating experience feedback, access control, modification of safety systems or physical protection systems, and maintenance and operating procedures.

Mr Shokr concluded his presentation that safety and security are developed as separate disciplines; both have the same objective and unless well managed, measures to reinforce one discipline can compromise the other. In the case that conflicts between the two disciplines are unavoidable, work has to be guided by minimizing the overall risk. With good management they can reinforce each other.

Ms T. Le (USA) discussed an organizational governance template for nuclear security at research reactors. Such a template is proposed as a reporting and communication tool for research reactor operators and users and can be tailored to the circumstances and requirements of a given research reactor facility. The presentation also reviewed the identified gaps in security measures for research reactors, and the challenges of implementing such measures for existing research reactors. Ms Le provided an overview on the on-going research in addressing these challenges with emphasis on how to incentivize stakeholders to demonstrate proactive security, especially as new threats emerge in the fast-changing technology space. She also emphasised the interest in engaging regulators and operators in the discussion on "reasonable" security culture aiming at having solutions that are cost-effective, non-intrusive to existing schedules, and tailored to specific governing structure. The presentation also described the ongoing cooperation between Stimson's (USA) and JM-1 research reactor (Jamaica) to have a better understanding of how senior leadership understands the organizational decision-making process on foreseeable threats and security vulnerabilities, and how this eventually impacts the beliefs and attitudes of those at the operational-level at a reactor facility.

Mr A. Sapozhnikov (Russian Federation) discussed the ongoing national regulatory activities regarding use of a graded approach in application of the safety requirements to nuclear installations. The presentation reviewed the activities of a task force established by the regulatory body to establish criteria for application of a graded approach. It also discussed the criteria of hazard categorization of the facilities based on the radiological consequences in case of accidents, power level, and status of the facilities. With respect to radiological consequences, four categories were identified: consequences to public; hazards remain within "buffer area"; "facility territory"; "compartments" where works are carried out. With respect to power level of the facility, three categories were adopted: research reactors of power less than 1MW, of power between 1 and 20 MW, and higher than 20MW. With respect to the

facility status, three categories were established: facilities under operation, in shutdown awaiting decommissioning, and those that are in design or construction phases. The presentation also showed how the risk matrix of the facilities is developed based on the criteria mentioned above. The safety requirements for research reactors in the Russian Federation are developed on the basis of the IAEA safety standards. Based on the identified potential risk of the facilities, the regulatory oversight activities are adopted, for application of these requirements, including in the scope and frequency of the regulatory inspection programmes.

Mr M. Trapp (Germany) discussed a methodology for application of a graded approach to research reactors in Germany. The presentation provided a review of the application of a graded approach following the IAEA safety standards, and in other countries such as Canada, France, and USA. It also discussed a methodology for systematic categorization of the potential hazards of the research reactor facilities in Germany based on three elements: "utilization of the research reactors", "cooling of the fuel", and "confinement of radioactive material". The presentation then described a methodology to develop "risk matrix" on the bases of the three elements mentioned above. Examples on the use of the risk matrix in grading specific requirements for nuclear power plants (reactivity control and diverse shutdown systems) for application to the case of research reactors were also provided.

Part 2: Management Considerations for enhanced safety and security and effective utilization II

Mr J. C. Niel (France) presented the management of the interface between nuclear safety and security starting from their definition and given an overview on the history of the process which led to the current state of the art. Starting from the results that safety and security are two sets of fundamental principles where there are several parallels and interaction, concepts were discussed with examples. The French framework was used as an example of the management of the interface between nuclear safety and security and considerations were presented on best practices in all phases of a research reactor' lifetime.

Mr. J.A. Perrotta (Brazil) discussed relevant aspects of management of a research reactor. He started with fundamental concepts on the variety of research reactors and the associated complexity of operation, their utilization, risks and the application of the graded approach aspects on management. To do this he presented some principles to guide the application of the graded approach to research reactors. He also presented the role of the IAEA on research reactor management with highlights on the IAEA Code of Conduct on the Safety of Research Reactors and the publications and activities in this field. Considerations and challenges were also presented on relevant areas for research reactors management such as operation, safety, utilization, management system, human resources, fuel management and emergency preparedness. Mr Perrotta presented, as an example, the experience with the new Brazilian Multipurpose reactor (RMB) showing that some of the points discussed on research reactor management were considered in the decision of the project specification.

Mr. H. Elsayed (Egypt) presented an introduction on the role of a research reactor and how the nuclear knowledge management can support the organizational processes. A list of high-level objectives for a successful and effective nuclear knowledge management programmes was presented. The decommissioning plan is a key document used in defining and controlling a decommissioning project. The operating organizations normally possess only limited knowledge of relevant technologies and processes related to various aspects or phases of decommissioning projects, for this there are specialized organizations and companies providing those services. He discussed the conditions and arrangements needed for a successful decommissioning strategy. As a conclusion, he mentioned that the decommissioning of research reactors and other small facilities is achievable. It requires adequate planning, the use of commonly available technologies and methods and the effective management of project delivery.

Ms I. Maksimovic (Serbia) reported on the experience with the management of a heavy water research reactor during a state of extended shutdown and during the transition period. She presented the

socio-political situation related to the history of the reactor and discussed the safety considerations for the extended shutdown and transition phases when some reactor systems are partially or fully dismantled. In September 2001, Vinca Institute proposed the project "Decommissioning of RA Research Reactor in Vinca Institute" through the IAEA Technical Co-operation Programme. At the same time, the proposal to both Federal and Republic Governments was sent to bring decisions about the final shutdown of the RA reactor. It was also proposed to solve the problem of spent fuel disposal and the transport of fresh highly enriched uranium fuel from Vinca to the country of origin (Russian Federation). Ms Maksimovic provided details on the conditions of the facility after 18 years of extended shutdown and presented the activities performed in the pre-decommissioning and decommissioning phases. She concluded that due to the lack of manpower and missing financial resources, the RA reactor decommissioning was not realized as planned. Nevertheless, the nuclear fuel elements were repatriated in 2010 and the RA reactor is now free of fissile material.

Mr S. Acuña (Argentina) presented the RA-6 research reactor and its activities. He indicated the preparation of an integrated management system (IMS) process for the reactor. He discussed the approach used, the methodology and the tools developed together with a description of obstacles encountered and leverage elements that facilitates the understanding of the problem. The IMS is applied to the safety management and operation of a generic research reactor. To establish priorities for implementation, the IAEA Graded Approach was applied to the process of the IMS looking for what process makes the greatest contribution to safety.

Poster presentations

One poster was presented on management issues of research reactors.

Mr H. Elsayed (Egypt) presented the poster specifying interfaces between nuclear safety and nuclear security systems and contribution of LEU into supporting and strengthening the process.

SUMMARY OF CONFERENCE SIDE EVENTS

Side Event 1: Safety enhancement of research reactors based on the Integrated Safety Assessment for Research Reactors (INSARR) missions

Side event 1 provided an overview of the IAEA's Integrated Safety Assessment for Research Reactors (INSARR) review missions. About 60 participants representing research reactor operating organizations and regulatory bodies attended the event. An introductory presentation was made by Mr Shokr (IAEA) addressing the INSARR mission history, methodology, and outcome. He also mentioned the IAEA efforts to continue to enhance the efficiency and effectiveness of the mission, including revision of the IAEA Guidelines on conduct of the mission, publication of guidelines on self-assessment of research reactor safety, and dissemination of feedback from the missions. Two presentations were made on experience and benefits with INSARR missions: Ms M. Koenen and Mr J. Offerien (High Flux Reactor, the Netherlands), and Mr G. Grant (Jamaica Research Reactor, Jamaica).

The benefits from INSARR missions, as highlighted by the presentations provided at the event, included the support for further safety improvements in several areas such as organizational and management policies, ageing management, periodic safety review and continued safe operation, safety of modification, including core fuel conversion from highly enriched uranium to low enriched uranium, as well as operational safety enhancements.

The questions and answers part, moderated by Mr H. Abou Yehia (France), included the participants' feedback which indicated that the INSARR is widely recognized by Member States as a service providing for safety improvements through effective application of the IAEA safety standards, encouraged Member States who did not request INSARR mission to do so, and indicated that IAEA should continue to improve the efficiency and effectiveness of the service, including dissemination of the feedback from the missions.

Side Event 2: Nuclear security enhancement of research reactors based on IAEA International Physical Protection Advisory Service (IPPAS) missions

Side event 2 consisted of a panel discussion concerning the IAEA IPPAS missions' benefits and lessons learned. About 15 conference participants representing operating organizations, regulatory bodies and State governments attended the event. Mr K. Horvath (IAEA) provided a briefing of the history, the objectives, preparation and conduct of the IPPAS missions, highlighting the importance of an effective and sustainable national nuclear security regime as central to facilitating the peaceful use of nuclear energy and that by the end of 2019, 90 IPPAS missions will be conducted in 54 States. As invited speakers, Mr P. Marzano (Australia), Mr M. Addo (Ghana), Ms E. Retfalvi (Hungary), Mr R. Palapa (Indonesia) and Mr J. L. Castro (Peru) presented their respective Member States IPPAS mission experiences and lessons learned. The speeches were followed by a question and answer session.

The speakers and the participants agreed that hosting an IPPAS mission demonstrates strong commitment of a State to nuclear security and its continued enhancement, IPPAS assists States, upon request, in strengthening their national nuclear security regimes, systems and measures. It was agreed that the advice provided by teams of international experts during an IPPAS mission helps the host countries to strengthen their nuclear security by improving the physical protection of nuclear and other radioactive material, as well as associated facilities and activities. Such advice is provided based on a comparison of a State's existing practices with those recommended in the IAEA's nuclear security publications and those established in the relevant legal instruments. As a further benefit of IPPAS, each mission benefits not only the host country, but also the global nuclear security community, as good practices identified during missions are added to an IAEA database, established in 2016, which is available to Member States through the protected Nuclear Security Portal (NUSEC). In addition, some participants expressed their intention to host IPPAS missions in the near future.

Side Event 3: IAEA Peer Review Service – Operation and Maintenance Assessment for Research Reactors (OMARR)

Side event 3 on IAEA Peer Review Service "Operation and Maintenance Assessment for Research Reactors (OMARR)" was well attended with some 30 participants joining the event. The main objective was to highlight the assistance that the IAEA offers to Member States in improving operational performances with enhanced availability and reliability over the extended lifetime of their research reactors. Mr Sharma (IAEA) introduced the mission's outlining scope, objectives, methodology and benefits. It was noted that the mission also identifies areas for improvement, addresses specific operational challenges and creates a space for sharing experiences and good practices. Mr Mohammad Bodhroddoza Shohag (Bangladesh) presented the outcome and benefits derived from the mission conducted for the 3 MW research reactor BTRR-1. He mentioned that the mission was very useful in execution of Annual Development Project (ADP) that is already undertaken, in preparation of an executable programme for refurbishment and modernization of the reactor to continue its operation for 15-20 years more and improving management system. Mr F. Kungurov (Uzbekistan) explained how the OMARR recommendations had been utilized in refurbishment and modernization of the systems of the 10 MW research reactor WWR-SM and improving the strength and competencies of operating staff. Jupiter Sitorus Pane (Indonesia) presented the benefits of self-assessment performed by the staff of Bandung TRIGA2000 research reactor in improving competencies and in selection of best option for future plans either to continue the reactor operation using current TRIGA fuel, or alternatively convert the reactor to use domestic plate type of fuel elements.

The participants noted that the OMARR peer review service was useful in preparation and execution of plans for efficient operation and effective utilization of research reactors on long term basis, especially in view of ageing fleet of research reactors in operation worldwide.

Side Event 4: Contribution of International Centres Based on Research Reactors (ICERR) network to enhancement of capacity building

Side event 4 was attended by 35 conference participants and included five panellists representing each of the five designated ICERR facilities. Ms Frances Marshall (IAEA), chairing the event, provided a summary of the background and objectives of the ICERR programme. Each of the ICERR representatives provided a short summary of their facility and how it had been used to support the ICERR affiliate requests. Mr G. Bignan (France) emphasized that this is not a standard training program (i.e. classrooms), but rather a professional collaboration, and that the affiliates need to be prepared to provide resources to perform work at ICERR. It is possible that some IAEA Technical Cooperation (TC) funding can be used for work at an ICRRR (e.g. travel), based on the individual Member State's TC project scope. Mr A. Tuzov (Russian Federation) commented that the benefit to ICERR is for the promotion of their institute and its capabilities, as well as to increase the utilization of research facilities.

The ICERR representatives made several comments about the logistics of the ICERR/affiliate relationship, which are bilateral agreements, without IAEA participation. While is important for the affiliate to consider the ICERR's applications (e.g. education and training, joint R&D), the agreement could include other activities not specifically identified in the ICERR designation, if both ICERR and affiliate agree on the work scope. M. Bignan stressed that the affiliates need to be clear in what they want to achieve before approaching ICERR with a request. Mr M. Scibetta (Belgium) and Mr Tuzov stressed the need for the affiliate to communicate extensively with ICERR early in the request for ICERR resources. Mr Bignan and Mr Scibetta remarked on a joint CEA/SCK-CEN event scheduled for 2020, emphasizing that the affiliates can have relationships with more than one ICERR.

For Member States and institutions considering applying for the ICERR designation, Mr H. Vogel (USA) emphasized that a broad support by the institution's senior management is needed to make the ICERR a success. It is a commitment by the whole institution, rather than just one facility or research

programme. Mr Sangik Wu (Republic of Korea) commented that as the newest ICERR, they are still learning what it means to be an ICERR, but they have some affiliates with whom they are negotiating the project work scopes.

The panellists concluded that the ICERR programme is viewed as a success by the currently designated ICERR organizations, and they anticipate growth of the program. Representatives from two Member States indicated their intention to submit an ICERR application. Ms Marshall announced that a letter of intention to apply for ICERR status from CNEA (Argentina) has been received by the IAEA.

SUMMARY OF THE PANEL SESSION

The final panel session of the Conference was chaired by Mr Calzetta (Argentina), and included the Conference Rapporteur Mr H. Abou Yehia (France) and expert panellists: Ms M. Venkatech (India), Ms E. Pashina (Russian Federation), and Mr K. Mrabit (Morocco) – who was not able to attend the session but his contribution was delivered by the Conference Rapporteur. The panel session included presentation (by the Conference Rapporteur) of the Conference's conclusions and recommendations. The Conference participants were invited to submit comments and additions through the Conference App for consideration to be included in the final meeting report.

The panel session also included statements of the panellists followed by comments by the participants and questions and answers.

Statements of the panellists

Ms Meera Venkatesh (India) congratulated the IAEA Secretariat for the thoughtful planning and successful organization of the Conference and the host CNEA for the excellent arrangements as well as the very relevant tours to the construction sites of the new reactors RA-10 (multipurpose research reactor) and CAREM (small modular reactor). She also appreciated the keen interest and engagement shown by the participants that resulted in interesting and interactive sessions. Ms Venkatesh noted that every research/production facility, especially in the current times, has to be founded on strong reasoning for the need and utilization, which is also true for 'research rectors'; and all the other aspects related to how the facility should be run, namely, operation, maintenance, safety, security and final closure at the end of the life of a facility, are consequential, and certainly would need to be addressed with due diligence. The importance of addressing the 'Utilization' was well brought out in the Conference through the various invited talks and proffered presentations that spanned over the whole week, in four sub-sessions. In addition, the talks on the 'New Research Reactors' also strongly focused on the 'utilization' aspects while bringing out the rationale for the new builds.

The numerous important applications of research reactors were brought out lucidly by the speakers. It was very clear that the 'production of medical radioisotopes', (specifically mentioning Mo-99-Tc-99m and therapeutic radioisotopes Lu-177, I-131etc.) was the most emphasized one for societal impact, especially for justifying a new build; and the other applications such as silicon doping, material testing, NAA, neutron imaging and neutron scattering were also very important, and operators of the individual research reactors make the decision on their utilization based on the demands and needs. She noted that the use of research reactors for training and education remained an important goal of many Member States and some research reactors were exclusively dedicated to these purposes, which are important for knowledge management and human resource development, including NPP utilities, technical support organizations and safety authorities.

Ms Venkatesh deeply appreciated the IAEA's efforts in supporting its Member States in their endeavour not only to build new research reactors but also to manage the existing ones, through a variety of tools and options, as showcased in the keynote presentations. In particular, the offer to help from the planning stage, through assistance in feasibility studies, reviews of the strategic plans, offering IRURR missions, preparing relevant technical documents, providing assistance in training personnel through appropriate teaching materials, e-learning materials and training courses with hands-on exercise at research reactors, implementing CRPs, meetings/workshops and specific individual expert advice through TC projects, were extremely valuable to the Member States as also brought out through the repeated reference by the participants. She underscored the importance of research reactors for availing the vital radioisotopes as well as for other diverse applications, including capacity building. Although it is difficult to assign economic values to the societal benefits derived from the use of radioisotopes for better healthcare or in scientific research or in building human resources, under the current economic atmosphere around the world, it is becoming increasingly necessary for institutions and facilities to seek for self-reliance and economical sustainability. This was evident from the presentations on the new reactors planned. Hence it is imperative for all the stakeholders in the research reactor community to

work collectively towards sustainable plans and for the local government and the other supporting entities to recognize the need to support research reactors. And, while research reactors may not be built as a profit-making venture, it is nevertheless important to plan a new facility strategically, with long term sustainable usage as the goal, learning from the others and seeking and making use of the excellent help and advice offered by the IAEA.

Mr Mrabit (Morocco) indicated in his statement that nuclear security is an important sovereign responsibility but like in safety, any serious incident or nuclear security event anywhere could have a negative impact everywhere. Therefore, while nuclear security within a State rests entirely with that State, it is recognized widely that there is a global shared responsibility. We have therefore to continue working to improve and sustain nuclear security infrastructure in general and nuclear security of research reactors in particular. He mentioned that the issue of sustainability has been covered in the IAEA Nuclear Security Series and the IAEA has been helping its Member States, upon request, in establishing and/or strengthening their effective and sustainable nuclear security infrastructure through the provision of education and training, peer reviews and advisory services, R&D, equipment, information exchange, knowledge networking, etc.

In the Nuclear Security Fundamentals publication, approved by the IAEA Board of Governors in September 2012, under the Essential Element 12, it is mentioned that to keep the nuclear security regime effective, it must be sustained over the long term at both the national and operational levels. Such nuclear security regime ensures that each competent authority and authorized person and other organizations with nuclear security responsibilities contribute to the sustainability of the regime by:

- Developing, implementing, and maintaining appropriate and effective integrated management systems including quality management systems;
- Demonstrating leadership in nuclear security matters at the highest levels;
- Developing, fostering and maintaining a robust nuclear security culture;
- Allocating sufficient human, financial and technical resources to carry out the organization of nuclear security responsibilities on a continuing basis using a risk informed approach;
- Routinely conducting maintenance, training, and evaluation to ensure the effectiveness of the nuclear security systems;
- Having processes in place for using best practices and lessons learned from experiences;
- Establishing and applying measures to minimize the possibility of insiders becoming nuclear security threats;
- Routinely performing assurance activities to identify and address issues and factors that may affect the capacity to provide adequate nuclear security, including cyber security, at all times.

The Implementing Guide on the sustainability provides guidance to States, competent authorities, authorized persons, other organizations with nuclear security responsibilities and stakeholders on the principles and corresponding implementing actions required to sustain the State's nuclear security regime, both at national and operational level. This publication addresses the sustainability of the nuclear security regime and it is relevant for States who have an established regime as well as a State that is in the stage of establishing it. It includes guidance on how to sustain an established nuclear security regime over time and how to address challenges to sustainability. It also addresses the initial establishment and implementation of the nuclear security regime as a contribution to its sustainability, particularly from the design stage. It also focuses on how to address the challenges in sustaining the regime.

Mr Mrabit stated that the Kingdom of Morocco is implementing the above-mentioned nuclear security guide with a view to sustaining its nuclear security regime and AMMSNuR stays ready to share the Moroccan experience and lessons learned from these efforts.

Ms Pashina (Russian Federation) indicated that for many years research reactors and related comprehensive projects used to be mostly perceived as purely scientific projects. However in the modern global paradigm we have to acknowledge that one of the main objectives of any technological project is to ensure quality of life of the final user and this is indeed relevant to research reactor projects — which are a great tool not only for countries' scientific development but also for their socio-economic growth, education enhancement, industry boost and climate change mitigation. The implementation of research reactor projects contributes to countries' aim to achieve the United Nations

Sustainable Development Goals. Ms Pashina pointed out that in order to contribute to countries' sustainable development it is important for research reactor projects to fit stakeholders' needs, such as country's government, academic institutions, commercial and industrial entities, regulatory body and general public. Considering that such a solution can provide comprehensive benefits for various stakeholders it is essential to involve all of them from the beginning into the short- and long term planning of the project. Having mentioned the undisputable benefits of research reactor projects, Ms Pashina noted that currently the majority of research reactors are ageing and thus the challenges, such as shortage of the radioisotopes production or incompliance with current safety and security requirements, are becoming more likely. It is extremely important that during the Conference many discussions were focused on refurbishing and modernization of the existing reactors to ensure their efficient and safe operation as well as research reactors new build. Both topics are indeed important since research reactors are no longer just a scientific solution but can also improve the quality of life, thus they are a vital tool for many countries striving for sustainable development.

Indeed, today many countries are considering building new research reactors. Taking into account the above-mentioned goals for sustainability and better life, new RR projects have to be focused on stakeholders needs and requirements and defining configuration of future facilities. The first step for newcomer countries aiming to develop nuclear research within the country could be a project based on a research reactor, a tailor-made set of laboratories and related facilities such as an irradiation centre or cyclotron based nuclear medicine centre – a broader version of how a modern centre for nuclear science and technology may look like. A centre customized according to the needs of stakeholders' configuration is capable to provide countries with access to the whole range of required non-energy nuclear applications and becomes a tool to boost stable growth in strategic areas such as healthcare, agriculture and education and contribute to human capacity building within the country, social wellbeing, industrial development and global partnerships creation. Thinking of implementing a project based on a research reactor with a set of laboratories and additional facilities, the importance of ensuring step-by-step development of the national nuclear programme was found. Such approach will allow countries to build solid expertise within the country and achieve technological advancement in various fields to provide best opportunities for the new generations.

Ms Pashina noted that it is crucial that the IAEA is providing all the assistance for countries to ensure safe and sustainable research reactor projects, strategic planning, implementation and development. This Conference therefore was a great example of how the IAEA provides the research reactor community with an opportunity to share professional and technological expertise, and have a broader look at how research reactor projects can help Member States to move towards the desired sustainable development goals with the support of nuclear technologies, and with the room for international cooperation on the basis of IAEA designated research centres.

Discussions

The discussions following the panel statements highlighted the role of research reactors in supporting the attainment of several sustainable development goals, including those related to education quality, health, nutrition, and partnership. Examples were referred to including several papers presented in the Conference.

Several participants noted that developing and maintaining a high level of safety and security is essential for the effectiveness and sustainability of the facilities. Dealing with ageing management and addressing management of spent fuel and radioactive waste are of a particular importance. Capacity building and development of human resources in safety, operation, and utilization are also vital for the suitability of operating and new research reactor programmes. Other participants highlighted the importance for sound justification, strategic planning and utilization plan for the sustainability of new research reactor programmes.

A meeting participant commented that although medical radioisotopes are needed in every country, this does not mean that every country should have its own research reactor. International cooperation and partnership in this regard are effective.

Another participant noted the satisfaction of the research reactor community on the IAEA efforts and the progress made in the implementation of the 2015 Conference recommendations, including improvements of the IAEA peer review services, publication of numerous guidelines on important topics such as strategic planning, self-assessment of safety, periodic safety review, interface between safety and security, feasibility study for new research reactor programmes, regulatory inspection, and ageing management.

The Conference participants also continued to note the outstanding level of coordination of the IAEA research reactor programmes within the IAEA and encouraged the continuation of such coordination in planning and implementation of relevant activities, including those addressing the recommendations of this Conference.

CLOSING SESSION

The Technical Programme Committee (TPC) of the Conference organized a poster contest amongst young professionals. The criteria for the winning posters were based on the quality of the poster in terms of its technical and scientific contents (including consistency with the accepted synopses) and organization (i.e. clarity and attractiveness of the poster). The TPC evaluated the posters of the interested participants within the context of this contest and selected five winning posters. The awards were distributed at the beginning of the closing session to the following authors: Ms M. Cruz (Argentina), Mr O. Kukhotskyi (Ukraine), Ms T. Amarjargal Tesndsuren (Mongolia), Ms A. Asuncion-Astronomo (Philippines), and Mr L. Gilde (USA).

The Conference closing remarks were provided (via video record) by Ms N. Mokhtar, IAEA Deputy Director General and Head of the Department of Nuclear Sciences and Applications. The full text of the closing remarks is provided below.

Mr Calzetta and Mr Shokr also expressed their thanks and recognition to the participants and to all persons who contributed to the success of the Conference.

CLOSING REMARKS

Ms N. Mokhtar
IAEA Deputy Director General
Head of the Department of Nuclear Sciences and Applications

Opening speech as provided, verbatim

Good afternoon, ladies and gentlemen.

I thank you for your participation in the sixth quadrennial International Conference on Research Reactors: Addressing Challenges and Opportunities to Ensure Effectiveness and Sustainability. I am especially pleased that more than 300 participants from 53 Member States participated. A total of 82 papers have been presented orally, along with 87 poster presentations. The large attendance and number of papers reflect a strong interest in exchange of information and experience and in learning from one another with the goal of enhancing the effectiveness and sustainability of the research reactors in your countries.

The Conference has covered a comprehensive list of topics, ranging from new reactor projects and common management considerations, through utilization, applications, safety, security, operation and maintenance of the existing reactors, to spent fuel management and decommissioning. This wide variety of topics demonstrates the broad interests and priorities of the world–wide research reactor community.

The Conference programme included 7 keynote presentations from the IAEA staff, which summarized the IAEA's work in the various topic areas, along with the publications and services available to the Member States. This shows the importance that the IAEA gives to this area, and I invite you to take advantage of these services. The Secretariat is pleased at the renewed interest in new research reactors, especially in countries that want a first research reactor as an important tool for development of the human resources and infrastructure necessary for future nuclear applications, including nuclear power. I encourage Member States to make use of the IAEA's programmes to ensure that new reactors and adequate infrastructure make use of international best practices, including the IAEA Milestones Approach and Safety Standards and security recommendations, thus ensuring a high level of safety and security, along with effective operation and sustainable utilization.

During this week, we have heard of progress in many important areas that contribute to the effectiveness and sustainability of research reactors: safety and security, use of research reactors in education and training, scientific and industrial applications, stabilized supply of radioisotopes such as ^{99}Mo, maintenance practices and core fuel conversion to LEU. However, issues and challenges remain. Some of these include: lack of a clear analysis of national needs and strategy for sustainable utilization in some research reactors, leading to a weak justification of some new research reactor programmes; continued challenges in development of LEU fuel for high–performance research reactors; ageing of many research reactors, with impact on their effective and reliable operation and potentially on their safety; and lack of planning for decommissioning in many cases. Paths to address these challenges have been presented and discussed during the conference. As always, the Secretariat stands ready to assist the Member States in working to address these issues and challenges.

Last but not least, I would like to thank the host CNEA and the conference Chairman Mr Osvaldo Calzetta, and to recognize the three Scientific Secretaries Mr Amgad Shokr, Mr Ram Sharma and Mr Nuno Pessoa Barradas, and Ms Martina Neuhold of Conference Services who were instrumental in organizing the Conference. Special thanks go to the members of the Conference's Technical

Programme Committee and to all the speakers and poster presenters for your effort. Without you, we could not have had this successful Conference.

Once again, I thank you for your participation in this Conference, and I wish you a safe and pleasant journey home or wherever your travels may take you.

CONCLUSIONS AND RECOMMENDATIONS OF THE CONFERENCE

The discussions held throughout the Conference served to develop the following conclusions and recommendations which are a valuable source of information for specialists involved in research reactor operation and utilization as well as for regulatory authorities in the IAEA Member States.

The conclusions and recommendations expressed here are personal views of authors, participants, and chairpersons and do not necessarily represent the views of the IAEA, its Member States or of the nominating organizations.

Session 1: Utilization and application

1. The Conference recognizes that progress has been made in improving utilization of many research reactors for a variety of purposes, including research, education and training, and production of radioisotopes for medical and industrial applications. This contributes to the attainment of several United Nations Sustainable Development Goals (SDGs). However, there are many research reactors that are not utilized to their full potential. Strategic planning is vital to sustainability of these facilities. Proper justification of new research reactor projects, based on the needs and with involvement of all relevant stakeholders, is also essential for sustainability.

2. The Conference notes the IAEA support to Member States in developing strategic plans and enhancing the utilization of facilities through publications, capacity building, and the newly established Integrated Research Reactor Utilization Review (IRRUR) service. Member States are encouraged to take advantage of these resources.

3. The Conference recognizes the important role of the IAEA in coordinating and providing support to Member States in the field of radioisotope production. This support should continue because it further facilitates regional and international cooperation in this area. The Conference also recognizes that accelerators have potential in the production of some radioisotopes. Nevertheless, it is noted that research reactors will remain, for the foreseeable future, the primary facilities for producing a wide range and large quantities of medical radioisotopes. Furthermore, the Conference recommends that the IAEA continues to provide support for the entire radioisotope production and supply chain, including waste management and regulation.

Session 2: Operations and maintenance

1. Member States are continuing to address ageing issues, as one of the major challenges to research reactor safety, availability and sustainability, through implementation of systematic ageing management and operation and maintenance programmes based on the IAEA Safety Standards and guidance publications. The Conference recognizes the well-coordinated IAEA support in this regard, including the establishment of a safety review service on ageing management and continued safe operation. This review service is based on the experience gained from the IAEA Safety Aspects of Long Term Operation (SALTO) missions for nuclear power plants, conduct of Operations and Maintenance Assessment of Research Reactor (OMARR) reviews, operation of ageing management databases, and regular meetings for collection and dissemination of experience on safe and effective implementation of refurbishment and modification projects.

   The Conference encourages Member States to continue the utilization of these resources and to contribute to these activities by providing information to the databases and sharing experience. The conference also recommends that the IAEA continues to support, upon request, Member States in addressing ageing issues.

Session 3: New research reactor programmes

1. Member States continue to demonstrate interest in research reactors, and more than 30 new programmes are being planned or implemented in several countries. The Conference encourages Member States to consider new research reactor programmes to explore, in the feasibility study, regional cooperation and to access existing facilities. While it is recognized that building a new research reactor is a national decision, the Conference appreciates the importance of the IAEA's well-coordinated role in assisting Member States, upon request, in developing their national nuclear infrastructure based on the IAEA Milestone approach and safety standards.

2. The Conference notes the progress made since the last international conference, held in Vienna in 2015, in the area of development of nuclear infrastructure, including publication of the IAEA guidance on preparation of a feasibility study and launching the Integrated Nuclear Infrastructure Review for Research Reactors (INIR-RR) peer review service. Member States planning or implementing new programmes are encouraged to benefit from the IAEA services. This includes INIR-RR and safety review missions such as the Integrated Safety Assessment of Research Reactors (INSARR) at the appropriate time of the implementation of a reactor project (e.g. at the design stage and before the first fuel loading into the reactor core).

3. Member States, planning or implementing their first research reactor programmes, are also encouraged to consider accessing existing well-utilized research reactor facilities to build their national nuclear capacity, including the Internet Reactor Laboratory. Also, the IAEA-ICERR scheme and network can be a valuable tool to share competences among experienced and newcomer Member States as well as on research and development projects.

Session 4: Safety of research reactors

1. The Conference recognizes that developing and maintaining a high level of safety is essential for ensuring the effectiveness and sustainability of research reactors. The Conference notes the improved implementation by Member States of the provisions of the Code of Conduct on the Safety of Research Reactors (the Code). The Conference encourages Member States to continue to use the Code as a primary reference for safety management of research reactors, and to share their experience and lessons learned in this regard during the international meetings on application of the Code.

2. The Conference appreciates the significant progress that has been achieved since the latest international conference, in the IAEA activities on safety of research reactors, including revision of safety standards incorporating lessons learned from the accident at the Fukushima-Daiichi nuclear power plants, supporting application of safety standards, and conducting peer review services. These activities should continue to support Member States in achieving further safety enhancement.

3. The Conference notes the increased interest of research reactor organizations worldwide to initiate and implement periodic safety reviews for research reactors, based on the guidance provided by the IAEA Safety Report Series on this topic (in printing), which was developed in response to the recommendations of the 2015 international conference. The Conference recommends that the IAEA continues to provide Member States with support in application of this guidance.

4. The Conference notes enhancement of the efficiency and effectiveness of the INSARR, including revision of the INSARR Guidelines and publication of guidelines on self-assessment of research reactor safety as well as the increased implementation by Member States of the recommendations of their missions. The Conference notes the increased requests reported by Member States for INSARRs and recommends those organizations which have not requested an INSARR to consider doing so.

Session 5: Security of research reactors

1. The Conference notes the continued improvement of the IAEA's support in enhancing nuclear security of research reactors, including publication of IAEA-TDL-004 on Nuclear Security Management for Research Reactors and Related Facilities, the conduct of a Coordinated Research Project on the Security of Research Reactors and Associated Facilities, and the development of specifications of a Hypothetical Atomic Research Institute to be used as a reference for security case studies and training. The Conference, however, highlights that nuclear security continues to evolve and the IAEA support in this area needs to reflect that evolution.

2. The Conference recommends that IAEA guidance be further developed on the following topics: vital area identification; regulatory inspections; graded protective measures for research reactors; and determining the trustworthiness of research reactor employees and visitors.

Session 6: Fuel management and decommissioning

1. Several challenges were noted, including the continued supply of fresh fuel for some types of reactors, and back-end options for spent fuel for countries that do not operate nuclear power plants. The Conference notes the recently developed IAEA publication on addressing back-end options for research reactors and encourages Member States to utilize the guidance provided by it. Operators and regulators are urged to strengthen regional and international cooperation to address these issues. The IAEA is requested to foster this cooperation.

2. The lack of preliminary decommissioning plans for many operating research reactors is noted and development of such plans should start as soon as possible. This is also true for new research reactors. The Conference recommends that the IAEA continues to assist Member States in developing decommissioning plans and in preparation for decommissioning through establishment of guidelines on managing the transition between operation and decommissioning.

   The Conference also recommends that operators continue to adopt good practices in the operation and utilization of the reactors to minimize generation of radioactive waste and to facilitate ultimate decommissioning. It is also recommended that Member States, having a research reactor in extended shutdown, decide whether to restart the reactor or decommission it without unnecessary delay.

Session 7: Common management considerations

1. The Conference notes the increased focus of Member States on strengthening leadership and management, and establishing integrated management systems aimed at developing and maintaining strong culture for safety and for security, as well as improving organizational effectiveness. The Conference appreciates the IAEA's efforts in developing and implementing Independent Safety Culture Assessment (ISCA) missions for the benefit of several research reactor operating organizations during the past few years. The Conference encourages Member States to benefit from this service.

2. The Conference notes the efforts by the IAEA and Member States in capacity building, which is a corner stone for sustainability of a research reactors. Recent capacity building activities included development of IAEA training materials, e-learning modules, workshops, and networking. In this regard, the Conference recommends the IAEA to continue these activities with more involvement of the regional networks — such as the Asia Nuclear Safety Network (ANSN), and the Forum for Nuclear Regulatory Bodies in Africa (FNRBA) — with a view of strengthening Member States' capacity and self-assessment capabilities at the regional level.

3. The Conference notes the progress achieved in Member States in several organizational and technical areas based on the results of the 2015 international conference. These results also helped tailor the IAEA programmes and activities on research reactors to suit the needs of the community. The Conference recommends that these efforts continue with more emphasis on systematic collection and analysis of feedback from the implementation by Member States of the recommendations of this international conference.

4. The Conference notes the increasing recognition in Member States of the need for effective management of the interface between safety and security in all research reactor activities throughout the life cycle of a facility, and appreciates the guidance offered by the IAEA-TECDOC-1801 on Management of the Interface between Nuclear Safety and Security at Research Reactors. The Conference recommends the IAEA to continue its efforts in assisting Member States in this area.

ANNEX: SUPPLEMENTARY FILES

The supplementary files for this publication can be found on the publication's individual web page at www.iaea.org/publications

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