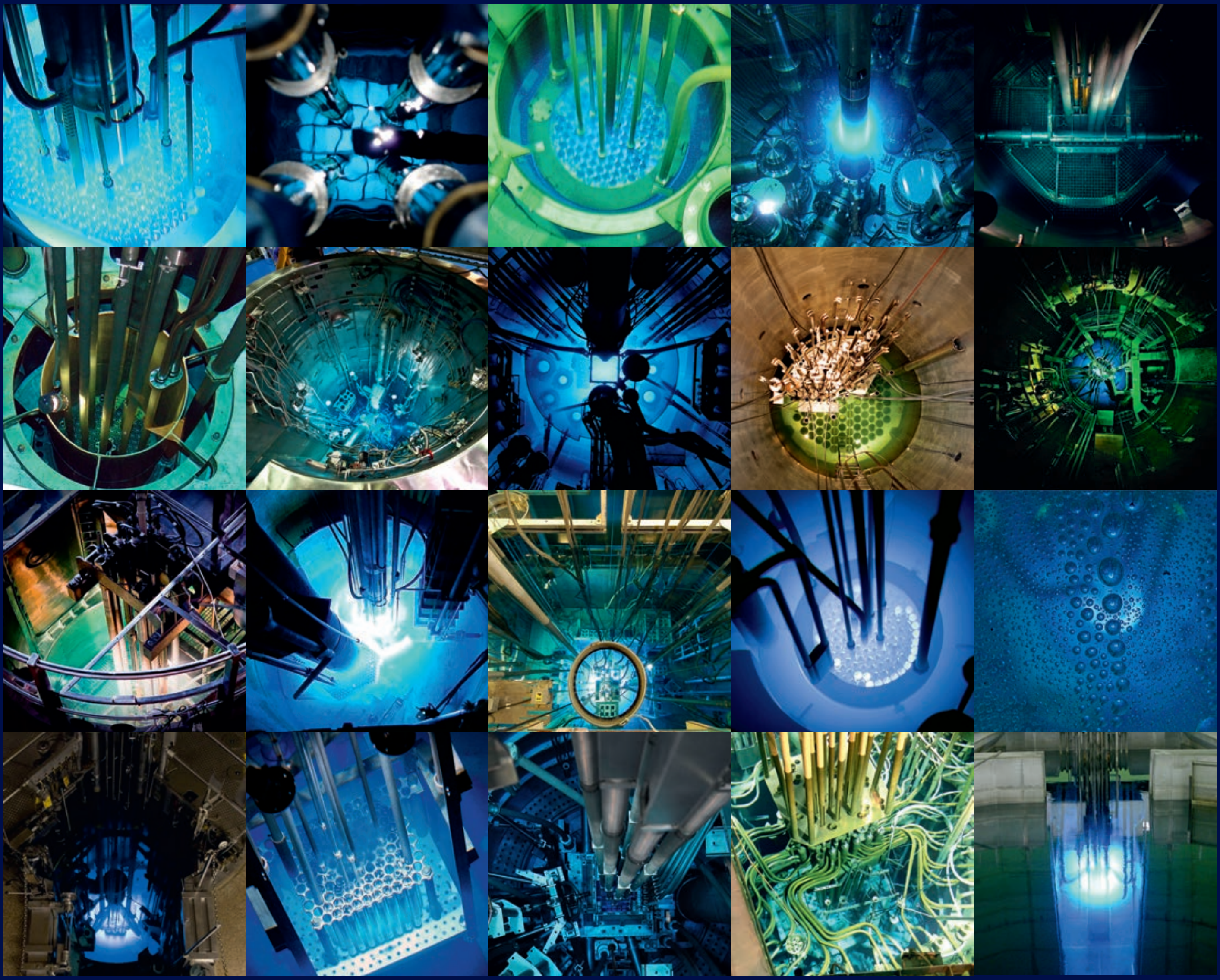
Research Reactors:

Safe Management and Effective Utilization

Summary of an International Conference

16–20 November 2015, Vienna, Austria



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RESEARCH REACTORS: SAFE MANAGEMENT AND EFFECTIVE UTILIZATION

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PROCEEDINGS SERIES

RESEARCH REACTORS: SAFE MANAGEMENT AND EFFECTIVE UTILIZATION

SUMMARY OF AN INTERNATIONAL CONFERENCE ORGANIZED BY THE INTERNATIONAL ATOMIC ENERGY AGENCY AND HELD IN VIENNA, 16–20 NOVEMBER 2015

INTERNATIONAL ATOMIC ENERGY AGENCY
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FOREWORD

For more than 60 years, research reactors have been centres of innovation and productivity for nuclear science and technology programmes around the world. The multidisciplinary scientific and technological applications that research reactors support have spawned advances in industry, medicine, food and agriculture. According to 2016 figures in the IAEA Research Reactor Database, 747 research reactors had been built in 67 countries and of those, 243 reactors were in operation in 55 countries.

The International Conference on Research Reactors: Safe Management and Effective Utilization was organized by the IAEA and held in Vienna on 16–20 November 2015. The fifth and largest of its kind, it is regarded as the major networking event for the research reactor community worldwide. Research reactor organizations need to address challenges such as: the management of ageing of facilities and staff; the more effective and efficient utilization of the facilities to justify operation and maintenance costs; the need to enhance regulatory effectiveness and to address the relevant lessons learned from the Fukushima Daiichi nuclear accident; the security of fuel supply and the management of spent fuel; the need for increased vigilance to prevent malicious acts; and the strain of shrinking resources, both financial and human, while fulfilling an expanding role in support of nuclear science and technology development. New research reactor projects also challenge Member States in developing their national infrastructure and human resources to ensure successful implementation. The conference provided a forum at which reactor operators, managers, users, regulators, designers and suppliers could all share experience and lessons learned, as well as address common issues, challenges and strategies.

The IAEA, through its programmatic activities, is committed to providing support to Member States in addressing these challenges through knowledge sharing of good practices for all aspects of the research reactor life cycle, guidance based on safety standards and technical publications, and promotion of scientific research and technological development using research reactors by highlighting the unique products and services these facilities can offer.

This publication provides a summary of the conference, the major findings and conclusions of the sessions, and the opening and closing addresses. The accompanying CD-ROM includes the individual technical papers and presentations.

The IAEA wishes to express its appreciation to the members of the Technical Programme Committee, chairpersons of technical sessions, the authors of the submitted papers and to all those who gave presentations for their contributions to the technical success of the conference. The IAEA is especially grateful to L.W. Deitrich as the principal Rapporteur of this conference, and to T. Desai, D. Jinchuk and A. Zhukova for the preparation of the proceedings. The IAEA officers responsible for this publication were A. Borio di Tigliole of the Division of Nuclear Fuel Cycle and Waste Technology, D. Ridikas of the Division of Physical and Chemical Sciences, and A.M. Shokr of the Division of Nuclear Installation Safety.

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EXECUTIVE SUMMARY

Background

The International Conference on Research Reactors: Safe Management and Effective Utilization was held at the IAEA Headquarters, Vienna, Austria, 16–20 November, 2015. The Conference was organized by the International Atomic Energy Agency (IAEA). This Conference was the fifth in a series of quadrennial International Conferences on Research Reactors; previous Conferences were held in: Lisbon, Portugal (1999); Santiago, Chile (2003); Sydney, Australia (2007); and Rabat, Morocco (2011).

Three hundred thirteen (313) delegates and observers from 56 Member States and 3 international organisations participated in the Conference. A total of 74 papers were presented orally and 74 papers were presented in poster sessions. Seven topical areas were covered in the Conference, namely: A) Utilization and Applications of Research Reactors; B) Common Management Considerations; C) Safety of Research Reactors; D) Research Reactor Operations and Maintenance; E) Research Reactor Spent Fuel Management and Decommissioning; F) New Research Reactor Projects; and G) Security of Research Reactors. In addition, three side events were organized: 1) IAEA Support to Education and Training Based on Research Reactors; 2) IAEA Assistance to New Research Reactor Projects; and 3) IAEA Assistance in Addressing Research Reactor–based Radioisotope Production Issues. The Conference was closed with a panel session at which the Conference Conclusions and Recommendations were presented and summary remarks made by the panellists. After the Conference, a technical tour to the Atominstitut of the Vienna University of Technology, hosting a research reactor facility, was offered to interested participants.

Objectives

The purpose of this Conference was to foster the exchange of information on operating and planned research reactors and to provide a forum at which reactor operators, managers, users, regulators, designers and suppliers could share experience and lessons learned, as well as address common issues, challenges, and strategies.

Opening Session

The Conference was opened by Mr. M. Chudakov, Deputy Director General and Head of the Department of Nuclear Energy, joined on the podium by the Deputy Directors General Heads of the Departments of Nuclear Sciences and Applications Mr Aldo Malavasi, Nuclear Safety and Security Mr Juan Carlos Lentijo and Technical Cooperation Mr Dazhu Yang. Mr Chudakov emphasized the cross–cutting nature of the Conference and of the Agency’s activities on research reactors (the speech of Mr Chudakov is available in a separate Section of this Summary Report).

There are 246 research reactors currently in operation in 55 countries, and close to 30 new research reactor projects in various stages of implementation. Mr Chudakov mentioned some challenges that the research reactor community is facing and the IAEA activities to support Member States in addressing these challenges. In particular, increased interest in new research reactor projects, and the need to ensure appropriate infrastructure; maintaining a high level of safety, including safety re–assessment in the light of the Fukushima–Daiichi nuclear power plant accident, and implementation of the Code of Conduct on the Safety of Research Reactors and Safety Standards; maintaining research reactor operational performance and developing maintenance and ageing management programmes; improving utilization, since a large number of research reactors around the world are not utilized to their full potential; and the research reactor fuel cycle, including security of fuel supply, core conversion from HEU to LEU, and viable spent fuel and waste management options. The Agency also supports Member States with research reactors in security and physical protection, incident and emergency preparedness and capacity building. With the large number of ageing reactors and those no longer in operations, decommissioning is also an important area.

Mr Chudakov expressed his appreciation to the Conference organizers and the participants, and wished everyone a successful Conference.

Overall Conclusions and Recommendations [1]

Session A: Utilization and Application

1. The Conference notes that there are many research reactors that are effectively used for a variety of purposes, but also that there are many that have a low utilization factor and are not utilized to their full potential. Proper strategic planning is essential to sustainable utilization of a research reactor. Member States are urged to make use of the IAEA services available to support strategic planning and implementation.
2. Increased use of networking and participation in regional coalitions has been shown to be effective in improving transfer of knowledge and experience from one installation to another. An example is the Eastern European Research Reactor Initiative (EERRI). Bilateral agreements between institutions can also be effective. The Conference notes that IAEA offers assistance in creating and maintaining such coalitions, and Member States are urged to take advantage of this assistance.
3. Several well–developed facilities for neutron science and testing can make their capacity available to scientists from other countries, in some cases at no cost. The Conference recommended that the IAEA expand the Research Reactor Data Base (RRDB) to include a list of facilities offering confirmed access for various types of research reactor utilization, such as neutron imaging and other neutron beam techniques, material testing and neutron activation analysis (NAA).
4. The Conference recognizes the important role of the IAEA in coordinating and providing support to Member States in the production and supply of radioisotopes. This support can continue expanding on regional and international cooperation and joint actions to facilitate reliable availability of the widely used radioisotopes produced in research reactors. Furthermore, the Conference recommends that the IAEA provide enlarged assistance covering the entire radioisotope production and supply chain, from preparation and irradiation of the targets, through processing, waste management, quality control and assurance, and regulatory issues.
5. The Conference recognises that validity of NAA results is very important, especially if the materials being characterized are related to environmental problems, health–related studies, industrial products or forensic cases. The Conference recommends that the

[1] The views and recommendations expressed here are those of the named authors, participants and session's chairmen and do not necessarily represent the views of the IAEA, its Member States or of the nominating organizations.

IAEA continue its efforts in supporting NAA laboratories in Member States to assess and further improve their performance and the analytical quality of their analyses.

Session B: Common Management Considerations

1. The Conference notes the importance of integrated management of all activities in the research reactor organization, and encourages all research reactor operating organizations to make use of the Agency's documentation and services to ensure that safety and security and their interface are properly integrated into their management system.
2. There is increasing recognition in the Member States of the need for effective coordination of the interface between safety and security in all research reactor activities throughout the life cycle of the facility. The Conference notes that it is essential that measures in security do not unduly impact measures in safety and vice versa, and requests the Agency to continue its efforts in providing support to Member States in this area.
3. Several challenges for TRIGA reactors were noted, including continued supply of new fuel in the long term, back–end options for spent fuel and high–level technical support from that original reactor manufacturer. The Conference encourages TRIGA operators to strengthen regional and global cooperation to address these issues, enhance effective utilization and improve relations with stakeholders. The Conference also recommends that the IAEA uses its good offices to foster this cooperation.
4. The Conference notes the effective coordination of the IAEA's cross–cutting activities for research reactors, and encourages the Agency to continue to work toward integration, harmonization and synchronization of these activities to maximize the benefits to the Member States.

Session C: Safety of Research Reactors

1. The Conference appreciates the significant progress that has been achieved in IAEA activities on safety of research reactors, including supporting application of the Code of Conduct on the Safety of Research Reactors, development of Safety Standards, supporting their application and conducting safety reviews. The Conference encourages the Agency to continue with these activities for the benefit of Member States. The Conference recommends that Member States take advantage of safety review services, especially the Integrated Safety Assessment of Research Reactors (INSARR) service. In addition, the Conference recommends that the Agency continue to support establishment of an adequate regulatory and safety infrastructure in Member States planning to acquire their first research reactor.
2. Many research reactor organizations have performed safety re–assessments in light of the lessons learned from the Fukushima–Daiichi nuclear power plant accident, with the objective of improving their ability to withstand extreme external events. The Conference encourages Member States that have not yet performed safety reassessments to do so.
3. The Conference recommends that the IAEA continues its efforts to disseminate the relevant lessons learned from the Fukushima–Daiichi accident and to support Member States to address them through implementation of technical meetings, workshops, peer reviews and advisory missions. It also recommends that the lessons learned be considered in the design of new research reactors.
4. Member States are continuing to address ageing of research reactors through implementation of a systematic ageing management programme based on the IAEA Safety Standards, including refurbishment and modernization activities. The Conference recognizes the IAEA Research Reactor Ageing Management Database

(RR–AMDB) as an important information resource for Member States and encourages Member States to contribute information to the database to strengthen it for all. The Conference recommends that the Agency continue to support ageing management of research reactors.

5. Several Member States have initiated a process of periodic safety review (PSR) for research reactors, although there is no current Agency guidance. The Conference recommends that the Agency develops such guidance and support Member States in establishment of a PSR process on the basis of experience from similar processes for nuclear power plants.

Session D: Operations and Maintenance

1. The Conference appreciates the Agency's activities in support of research reactor operations and maintenance (O&M), including ageing management and establishment of an integrated management system. The Conference recommends that Member States avail themselves of the opportunity to request an IAEA Operations and Maintenance Assessment of Research Reactors (OMARR) review service.
2. The Conference appreciates the progress that has been made in conversion of research reactor cores from HEU to LEU fuel, and the accompanying fuel development work. Continued work on development of fuels suitable for high–performance research reactors is needed. The support of the Agency with coordination and expertise is appreciated, and the Conference recommends that it continues.

Session E: Spent Fuel Management and Decommissioning

1. The Conference recognizes that decommissioning planning is necessary and that it should start as soon as possible, even in the design stage of a new research reactor. The Conference recommends that the Agency continues to assist Member States in developing decommissioning plans and providing the platform for related information exchange through a technical cooperation programme. The Conference also recommends that that Member States having a research reactor in extended shutdown decide whether to restart or decommission without unnecessary delay.

Session F: New Research Reactor Projects

1. The Conference recognizes that the IAEA–developed Milestone Approach and supporting technical documents and Safety Standards provide valuable guidance to Member States planning and implementing new research reactor projects. Such documents are well known and used by Member States. The Conference recommends that IAEA guidance on the preparation of a feasibility study for a new or first research reactor project be finalized as soon as possible. The Conference also recognizes the value of the newly established Integrated Research Reactor Infrastructure Assessment (IRRIA) review service and urges the IAEA to implement this service as soon as possible.
2. The Conference recognizes that building a new research reactor is a national decision and that the Agency is ready to assist Member States in all stages of such projects. Newcomers to research reactor Member States are also encouraged by the Conference to consider accessing existing well–utilized research reactor facilities to build their national nuclear capacity. The Conference also recognizes that the recently IAEA–developed International Centres based on Research Reactors (ICERR) scheme can be a valuable tool to share competences among experienced and newcomer Member States for nuclear capacity building as well as research and development projects.

Session G: Security of Research Reactors

1. The Conference notes that nuclear security for research reactors now has a well–defined structure within the Agency. However, the Conference observed that there are areas which need to be further structured and explained from the implementation perspective. The Conference recommends that IAEA guidance be developed on: vital area identification; definition of unacceptable radiological consequences; the interfaces between nuclear safety and nuclear security design; evaluation analysis and contingency versus emergency response; cyber security threats and protective measures for research reactors; and determining trustworthiness of research reactor employees and visitors.

Closing Session

The Conference was closed by Mr J. C. Lentijo, Deputy Director General and Head of the Department of Nuclear Safety and Security. On behalf of the IAEA Director General, he thanked everyone for their participation in the Conference. He noted that the large attendance and number of papers reflect a strong interest in exchange of information and experience, and a healthy desire in the research reactor community to learn from one another and to continue improving (the speech of Mr Lentijo is available in a separate Section of this Summary Report).

The Conference has covered a comprehensive list of topics, ranging from new reactor projects and common management considerations, through utilization, applications, operation and maintenance of the existing reactors, to spent fuel management and decommissioning, plus the overarching considerations of safety and security. This wide variety of topics demonstrated the broad interests and concerns of the world–wide research reactor community. The Conference programme included 5 keynote presentations from the IAEA staff, which summarized the Agency's work in the various technical topic areas, along with the documents and services available to the Member States. Mr Lentijo invited Member States to take advantage of these services.

Mr Lentijo noted the increased 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 a future nuclear power programme. He encouraged these countries to make use of the Agency's resources to ensure that new reactors and adequate infrastructure make use of international best practices and guidance, including the IAEA Safety Standards, to ensure a high level of safety and security, along with effective utilization.

There has been progress in many important areas: safety and security; use of research reactors in education and training; scientific and industrial applications; maintenance practices and core fuel conversion to LEU. However, issues and challenges remain. Some of these include: lack of new fuel for TRIGA reactors and continued challenges in development of LEU fuel for high–performance research reactors; completion of safety re–assessments in light of the Fukushima–Daiichi nuclear power plant accident and implementation of needed improvements; ageing of many research reactors, with the potential impact on safety and reliability and supply of important medical isotopes; and lack of planning for decommissioning in many cases. As always, the IAEA Secretariat stands ready to assist the Member States in working to address these issues and challenges.

Mr Lentijo noted that preparation of the Conference has been a "one–house" undertaking. He recognized the three Scientific Secretaries Mr Andrea Borio di Tigliole, Mr Danas Ridikas, and Mr Amgad Shokr, and Ms Martina Neuhold of Conference Services, who were instrumental in organizing the Conference. He also thanked the members of the Technical Programme Committee and all of the speakers, poster presenters and participants.

WELCOME ADDRESS & OPENING REMARKS[2]

M. Chudakov
Deputy Director General
Head of the Department of Nuclear Energy

Dear distinguished participants, dear colleagues, ladies and gentlemen,
Good morning!

I am Mikhail Chudakov, Deputy Director General and Head of the Nuclear Energy Department. On behalf of the Director General of the IAEA, Mr Yukiya Amano, it is my pleasure to welcome you to this International Conference on the safe management and effective utilization of research reactors.

The IAEA organizes this conference every four years as the largest gathering of the international research reactor community. This year we have more than 300 delegates from 56 Member States. It is a forum for reactor users, operators, managers, regulators, suppliers and other stakeholders to share experience, exchange information and discuss common issues, challenges and strategies.

We are pleased to host this year's conference in Vienna. Four IAEA Departments have come together to organize it. And to recognize the cross–cutting nature of research reactors activities and to demonstrate the importance for the Agency's to support such activities with a "one–house approach", I am particularly pleased to share the podium this morning with the Deputy Directors General and Heads of the Departments of from Nuclear Science and Applications, Nuclear Safety and Security, and Technical Cooperation.

Ladies and Gentlemen,

For more than 60 years, research reactors have been centres of innovation and productivity for nuclear science and technology programmes in 67 countries around the world. Research reactors provide a multidisciplinary environment to catalyse scientific, industrial, medical and agricultural development. They are facilities for nuclear education and training of young scientists and technicians, and they can contribute to the development of nuclear power programmes.

According to the IAEA Research Reactor Database, there are 246 research reactors currently in operation in 55 countries, and close to 30 new research reactor projects are at different stages of implementation. Many of the operating reactors are several decades old and face ageing management issues. These reactors must be operated and maintained with due regard to safety and security.

Some reactors face challenges with sustainable supply of fresh fuel. Others are looking to improve utilization, which is linked to justifying adequate resources for operation, maintenance and refurbishment. As some of the fuel return programmes are expected to wind down in the near term, the community will need to find solutions for spent fuel and waste management. And taking into account the large number of reactors, about 140, no longer in

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operation, as well as ageing reactors coming to the end of their lifecycles, decommissioning is an important area of sharing experience and best practice. You will have an opportunity to discuss these and other issues over the course of the conference.

I would like to focus on a few of the emerging challenges to highlight some IAEA activities in recent years.

First, we have seen increased interest in new research reactor projects, particularly where it would be the first nuclear installation in the country. This means development of an adequate safety and security regulatory infrastructure, as well as a system for accounting for the country's first nuclear material. Building capacity for safety, security and safeguards and getting the interfaces right will be the key. It is clear that a new research reactor project is a significant national undertaking that requires careful preparation, planning, implementation and investment of time, money, and human resources. We have developed the IAEA Research Reactor Milestones approach to provide guidance to our Member States for assessment and development of their national nuclear infrastructure including for human resources development. We have recently launched the Integrated Research Reactor Infrastructure Assessment (IRRIA) mission as a peer review service. The first mission is scheduled to take place in Mongolia early next year.

The next emerging challenge is the safety re–assessment of research reactor facilities in light of the accident at the Fukushima–Daiichi nuclear power plant. Many of the lessons learned from the accident are relevant to research reactors and there is a need to assess the robustness of the reactor systems and components in case of extreme external events, tacking ageing effects into consideration; and reviewing the capabilities of emergency response to events at reactors with potential off–site radiological consequences.

We continue to focus on the Code of Conduct on the Safety of Research Reactors and of the IAEA safety standards through training, networks, and the Integrated Safety Assessment of Research Reactors (INSARR). We are also supporting Member States to address safety and operational implications of ageing facilities. Approximately 55% of the research reactors currently in operation are more than 40 years old and 75% are more than 30 years old. We recently established the Operation and Maintenance Assessment for Research Reactors (OMARR) peer review service to assist Member States to address operational performance and reliability of such facilities.

The third challenge is improving utilization. A large number of research reactors around the world are not utilized to their full potential. The IAEA has recently developed some new programmes to support member states in this area. We recently launched a new initiative called the International Centre based on Research Reactor (ICERR), which aims to facilitate cooperation between Member States for the development of specific competences. During the 59th General Conference, the French CEA, through its research centres at Saclay and Cadarache, was designated as the first ICERR and we expect more to come. Similarly, we are pleased with the success of the Internet Reactor Laboratory (IRL) project, which was initiated as a pilot project a few years ago and is now under implementation in Latin America, Europe and Africa. We continue to support other networks and coalitions as well to not only increase utilization of existing facilities, but also to build capacity in countries without research reactors through regional and international sharing of experience.

Finally, I would like to highlight the work being done around the research reactor fuel cycle. We support global efforts to minimize the civilian use of HEU, while maintaining scientific research capabilities and the operating performance of research reactor facilities. We are assisting in the conversion of research reactors from HEU to LEU fuel, in the removal of HEU fuel and in the development of LEU target designs for radioisotopes production. We continue to support the development and qualification of new research reactor high density LEU fuels, which would enable the majority of high flux reactors to convert from HEU to LEU. The IAEA supports development of viable 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 are only a few of the areas in which the Agency is supporting Member States with research reactors. Our cross–cutting programmes span the work of the Agency, from incident and emergency reporting, to nuclear safety and nuclear security and physical protection programmes, to fostering international cooperation and capacity building. Many of these activities are supported under national, regional and interregional technical cooperation projects.

At this conference, more than 150 scientific and technical papers will be presented in oral and poster sessions under 7 different technical track areas. You will have an excellent opportunity to voice your opinion on the issues that matter most to you. There will be several IAEA staff contributing as well, and I trust that we will hear important conclusions and recommendations resulting from your discussions.

In conclusion, I would like to express my appreciation to the organizers who have worked so hard to prepare this event and to you, the participants, who will contribute greatly to its success.

I wish you a successful Conference and a pleasant stay in Vienna.
Thank you.….

SUMMARY OF TECHNICAL SESSIONS AND PRESENTATIONS[3]

SESSION A: UTILIZATION AND APPLICATIONS

Thirty five (35) papers were presented in Session A (1 keynote, 3 invited and 12 contributed oral and 19 poster presentations). The papers described the present utilization of both new research reactors and those that have been in operation for many years and are still very well utilized, along with opportunities and challenges for utilization in the future.

Papers, Part 1

In the keynote address for Session A, **Mr Danas Ridikas (IAEA)** presented an overview of the research reactor situation worldwide and the IAEA support programmes to the research reactor user community. He emphasized that proper strategic planning is essential to sustainable utilization of a research reactor. Strategic considerations include: understanding the needs of stakeholders and building their support; improving the quality and quantity of services; sustainable knowledge management; and understanding the socio–economic and research impact of the reactor. Several IAEA services and publications are available to assist strategic planning. Another topic was networking and regional coalitions of research reactors. The IAEA offers assistance in creating and maintaining such coalitions.

Mr Ridikas noted that the four most common areas of research reactor utilization are: education and training; neutron activation analysis (NAA); isotope production; and neutron radiography. Education and training initiatives include the Internet Reactor Laboratory (IRL), the Eastern European Research Reactor Initiative (EERRI), train–the–trainer workshops, and various schools and workshops, some with hands–on training. Support to NAA has focused on automation and proficiency tests for NAA laboratories. Support to isotope production focuses on production of ^{99}Mo by neutron capture and promotion of reactor production using LEU targets. A coordinated research programme and training workshops support neutron imaging. Overall, there are now 19 national and 4 regional TC projects having a research reactor utilization and application component; some will end this year, but 14 new projects will start in 2016.

The next three papers emphasized use of research reactors in education and training.

In his paper, **Mr F. Foulon (France)** discussed the impact of education and training based on research reactors on building knowledge, competencies and skills in nuclear programmes. He concluded that development or sustainability of nuclear programmes needs the availability of human resources with adequate knowledge, competencies and skills. Achieving an adequate level of qualification needs a complex combination of knowledge, know–how, skills and experience in a working environment. The study that was conducted emphasized the important impact of education and training on research reactors in the global

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learning process. Both research reactors and simulators make specific contributions to development of the knowledge, competencies and skills that cannot be gained only on one of these tools. Research reactors provide hands–on training on a real reactor that cannot be gained on a simulator, while a simulator allows training in situations not possible on a real reactor, such as accident simulations. The practical experience gained through education and training on a research reactor helps to ensure an adequate safety culture for all the personnel involved in the design, operation and control of a nuclear reactor.

Mr S. Malkawi (Jordan) compared use of the Internet Reactor Laboratory (IRL) with a subcritical assembly in nuclear engineering education. The Jordan University of Science and Technology (JUST) partnered with North Carolina State University (USA) on an Internet Reactor Laboratory from 2010 to 2013. Jordan is building its own new research reactor at JAEC. He concluded that every research reactor facility, regardless of its power, can be utilized for education and training. The IRL approach benefits from an already existing research reactor facility in another location by utilizing it as a remote reactor laboratory. However, an on campus reactor facility is needed to provide education, training, experimental research and hands–on experience for students and trainees. Nuclear Reactor Laboratory course objectives and learning outcomes are attainable by both approaches. He emphasized that for Nuclear Engineering Education, the need is to have an access to a research reactor facility.

Mr L. Sklenka (Czech Republic) discussed using research reactors for sharing experience from Europe with partners from Asia and Africa. Research reactors offer education and training opportunities in two principal areas: first, the reactor itself as a complex nuclear installation, in which the typical reactor experiments can be performed, and hands–on experience in operational matters can be gained; second, the reactor is a source of radiation for experience in the various applications, such as NAA and neutron imaging. Starting from the experience of the EERRI, the Agency developed and used a questionnaire aimed at obtaining a general overview of education and training needs and capabilities in Asia and Africa. It was followed by development of regional courses based on utilization of the research reactors. Sharing of experience and practice in the frame of regional course development has proven to be effective and will be further developed by the IAEA.

Papers, Part 2

This session included 3 contributions on utilization of research reactors and one presentation dealing with the assessment of the needs for experimental data:

In an invited paper, **Mr N Kardjilov (Germany)** addressed neutron imaging in science and technology. He reported that over the last 10 years, significant developmental work has been performed to expand the radiographic and tomographic capabilities of the neutron imaging facility at Helmholz–Zentrum Berlin. He gave an overview of the improvements in flux and performance of cold neutron imaging on the CONRAD–2 beamline. New techniques have been implemented, including imaging with polarized neutrons, Bragg–edge mapping, high–resolution neutron imaging and grating interferometry.

He gave examples of diffraction contrast (use of Bragg edges to distinguish martensite and austenite in steels) and dark field phase contrast (use of magnetically scattered polarized neutrons to image magnetic flux retained inside a piece of superconducting lead). These methods have been provided to the user community as tools to help addressing scientific problems over a broad range of topics such as superconductivity, materials research, life sciences, cultural heritage, palaeontology and some others.

Mr P. Mikula (Czech Republic) reported on the use of thermal neutron beams at the medium–power LVR–15 reactor in Rez for competitive neutron scattering. He gave an overview of LVR–15, its refurbishments, and described the inability to put in cold sources and guides due to space constraints, and showed the variety of thermal neutron scattering and nuclear techniques available at Rez. Thermal neutron depth profiling, while sensitive to few light elements, is the instrument most in demand. He concluded that a wide variety of competitive experiments of basic, interdisciplinary and applied research can be carried out at the medium power research reactors. Low and medium power neutron sources offer excellent opportunity for education and training of young scientists.

Mr A. Izhutov (Russian Federation) reported on modern methods for testing materials and fuel in the research reactors of the Russian Institute of Atomic Reactors (RIAR) centre. He gave an overview of the test and research reactors available in the RIAR's fleet and described the technical capabilities of the various in–core materials testing rigs and facilities at each reactor (dpa/year, temperature etc.). RIAR's research reactors SM–3, MIR.M1, BOR–60, RBT–6 and RBT–10/2 are used in a wide range of applied research in nuclear power engineering and radioisotope production. These reactors are operated at a high capacity factor (~65–75%) with a high experimental load. There are plans to use the reactors and extend their operating lifetime until 2020 and further. Recently, some updated and new techniques have been implemented at the reactor facilities to test materials and fuels for both fast reactors with different coolants in addition to water–cooled reactors with a moderated neutron spectrum. Research reactors are used to implement Russia's programmes and to perform tests under contracts with foreign customers. Reactor facilities are accessible for research programmes in all aspects of innovation in nuclear power engineering and radioisotope production.

In the final paper of this session, **Ms T. Ivanova (OECD/NEA)** presented an overview of the NEA activities related to experimental needs. She gave a description of the evolution of the databases and associated handbooks developed and maintained by the NEA for the OECD Member States. The NEA has been collecting experimental data and evaluated benchmarks in several different technical areas. Research reactors have been an important source of the experimental data, including operational data. With the new trends in nuclear science and engineering, high–priority experimental needs include: certificated data and benchmark models for validation of multi–physics and multi–scale simulations; data on fundamental properties and behaviour for advanced core materials and components (Gen II, Gen III and Gen III+); differential and integral data to support minor–actinide management technology; plant measurement and observation. Regular review of experimental needs and capabilities is needed, requiring a cross–disciplinary approach. A long–term activity has been launched at the NEA/Nuclear Science Section to support and coordinate this process in different areas.

Papers, Part 3

To open this session, **Mr C. Grant (Jamaica)** presented the lessons learned in strategic planning for enhanced utilization of low power research reactors, specifically the SLOWPOKE reactor at the International Centre for Environmental and Nuclear Science of the University of the West Indies. After 31 years of operation the research reactor still remains the flagship analytical tool of the institution. Neutron activation analysis is the principal utilization of the reactor, applied to studies of geochemistry, agriculture and health. Its convenient location on the university campus has allowed the Centre to make use of inter–institutional (University/Government Ministries) and international collaborations to ensure that the research activities are relevant to all stakeholders; in particular, the transfer of knowledge between academia and government with a major objective being the development of the human and economic resources of the country. Strategic planning is essential to sustainable utilization of a reactor facility; it ensures that all essential components (not just technical) are adequately addressed.

Mr P. Bode (Netherlands) discussed improving performance of neutron activation analysis laboratories by inter–laboratory comparison rounds followed by feedback workshops. Confidence in the validity of NAA results is essential and proficiency testing is one way to improve confidence. Workshops emphasize performance of quality control and assurance, calibration and validation of results. The inter–laboratory comparisons and feedback workshops have to be done periodically to train new people and ensure that quality is maintained. E–learning study modules are available. Mr Bode emphasized that knowledge and communication are keys to success. Feedback workshops for interpretation of inter–comparison results are a very effective way to sustainable improvement of measurement results.

Ms L. Hamidatou (Algeria) presented an overview of NAA methods applied at the Es–Salam research reactor. She discussed development of the k_0–NAA technique, the cyclic delayed neutron counting technique for detecting low concentrations of uranium, and various applications of NAA in medical seeds and plants, human health, nutrition, archaeology and mining.

Mr L. Snoj (Slovenia) discussed advances in utilisation of the 250 kW TRIGA Mark II reactor at the Josef Stefan Institute. This reactor has a varied utilization, including standard activities such as NAA, radiography, development of bio–dosimeters, production of trace elements, education and training, as well as advanced applications in nuclear safeguards, radiation hardness studies and experimental reactor physics benchmarks. Mr Snoj concluded that small reactors are also very flexible, and well suited for non–routine applications.

Papers, Part 4

Mr B. Ponsard (Belgium) gave a very comprehensive presentation on the status of radioisotope production in research reactors, in particular on the production of ^{99}Mo and role of the international AIPES organization on the planning of the irradiation of targets worldwide. He also showed that the decision to refurbish the BR–2 reactor in Belgium is a very important, in that it contributes to the stability of the world's supply of ^{99}Mo for the next decade. The refurbishment may allow a 35% increase in production of ^{99}Mo.

Mr Kochnov (Russian Federation) presented the past experience and prospective future development at the Karpov Institute of Physical Chemistry, Obninsk, for increasing production of radioisotopes for medical applications, particularly production of ^{99}Mo and ^{99}Mo–^{99m}Tc generators under good manufacturing practices (GMP) and standards. Some promising radiopharmaceuticals for cancer treatment were also discussed.

Mr B. Luong (Vietnam) presented the plans for upgrading the use of the Dalat Nuclear Research Reactor (DNRR). The major objectives are continued safe and reliable operation until at least 2025 and improved utilization to meet the needs of society. They plan to implement an effective ageing management programme, perform a periodic safety review for license renewal, improve quality management and update the safety documents. Also, they plan to improve radioisotope production, analytical techniques based on NAA, expand research on filtered neutron beams and strengthen education and training programmes.

In the final presentation of Session A, **Mr M. Salam (Bangladesh)** presented the importance of the Bangladesh TRIGA Research Reactor (BTRR) in the education and training of nuclear specialists and the work done in support of the implementation of a nuclear power programme in the country. A strategic plan has been developed to the enhancement of utilization of the BTRR.

SESSION A: POSTER PAPERS

This session included 22 contributed poster papers, of which 19 were presented and 3 were absent. Four posters were addressing general and new utilization, 3 were on education and training, 2 on isotope production, 2 on NAA, 2 on neutron beam facilities, 1 on material damage testing, and 5 on new reactor instruments.

Several innovative neutron flux monitoring systems were presented. The importance of neutron spectrum characterization for radiation damage studies was emphasized. Nuclear forensics was identified as a potential new area for NAA laboratories at research reactors. There is increasing interest at existing reactors for the analytical opportunities of external neutron beams, e.g. for prompt gamma activation analysis or neutron imaging.

General and New Utilization

Ms R. Baranyai (Hungary) presented a poster on the multiple utilization of the Budapest Research Reactor. It provided a research and development base for the energy sector in Hungary. Areas of utilization include material irradiations, isotope production, neutron beam experiments, and education for the university, both at graduate and under–graduate levels. The Budapest Research Reactor is a founding member of the Eastern

European Research Reactor Initiative and hosts participants in the Central European School of Neutron Scattering.

Ms L. Superlina (Indonesia) presented a poster discussing utilization of the RAS–GAS reactor. Isotope production dominates the reactor utilization and scheduling. However, enhancement of utilization through cooperation with universities or regionally through overseas arrangements is being explored.

Mr S. Landsberger (USA) discussed utilization of a research reactor and some of its associated facilities in nuclear forensics, in particular in the areas of radiochemistry, chemical instrumentation and nuclear instrumentation.

Mr F. Kungurov (Uzbekistan) and co–authors discussed the utilization of the WWR–SM reactor at the Institute of Nuclear Physics related to reactor fuel and nuclear materials.

Education and Training

Mr J. Rataj (Czech Republic) and co–authors presented a poster on enhancement of the VR–1 research reactor at the Czech Technical University in Prague for practical education using a portable neutron generator. The neutron generator allows study of the reactor's response to neutron pulses for determining its reactivity and kinetic parameters.

Mr F. Foulon (France) and co–authors presented an overview of experience with the Internet Reactor Laboratory (IRL) project of the IAEA and utilization of the ISIS research reactor in reactor laboratories. Through the IRL, reactor laboratory sessions are broadcasted to other European institutions for training of students who do not have access to a reactor for education purposes.

Mr K. Gyamfi (Ghana) and co–authors discussed the role of the Ghana Research Reactor – 1 in development of nuclear science and technology in Ghana and in the region. The reactor is used as a teaching and training laboratory for students in the Graduate School of Nuclear and Allied Sciences, the IAEA's regional centre for professional and higher education in nuclear science and technology, as well as in development of uses of nuclear techniques in industry, health and agriculture.

Isotope Production

Mr Y. Ellethy (Egypt) presented a poster on the strategic plan for isotope production in the ETRR–2 complex, which consists of the ETRR–2 research reactor, the fuel manufacturing pilot plant and the radioisotope production plant.

Mr B. El Bakkari (Morocco) and co–authors presented a poster on a feasibility study and safety analysis of production of ^{131}I, using two in–core irradiation positions in the Moroccan TRIGA research reactor.

Neutron Activation Analysis

Mr T. Tegas Sutondo (Indonesia) and co–authors presented a poster on studies of using a beam port at the KARTINI research reactor for prompt gamma activation analysis, including analysis of the neutron energy spectrum, gamma dose at the experimental area, and possible designs of collimators, filters and shielding for various beam port options.

Mr I. Silachyov (Kazakhstan) discussed use of an internal mono–standard method as an alternative to using certified reference materials in mineral resource investigations for rare–earth element content using instrumental neutron activation analysis.

Neutron Beam Facilities

Mr C. El Younoussi (Morocco) and co–authors presented a poster on design studies of a new thermal neutron beam facility at the Moroccan TRIGA Mk II research reactor. The work concentrated on obtaining a well–thermalized neutron beam with minimum gamma content.

Mr A. Zakaria (Bangladesh) and co–authors presented a poster on characterization of spinel oxides using X ray and neutron powder diffraction techniques performed at room temperature.

Material Damage Testing

Mr A Salvini (Italy) presented a poster on utilization of the TRIGA reactor at the University of Pavia for experiments on radiation damage in materials, including a complete characterization of the neutron spectrum in the reactor.

New Reactor Instruments

Mr E. Griesmayer (Austria) and co–authors presented a poster on a neutron flux detector using a new diamond detector technology, which allows measurements in a high irradiation environment. Testing at the Vienna TRIGA Mk II reactor showed that the detector can be effectively used for neutron diagnostics in a research reactor.

Mr L. Sklenka (Czech Republic) and co–authors discussed development of a test facility called MONTE–1, intended to provide a means to test detection systems and sensors in a mixed field of radiation from fission radionuclides such as would be encountered after a reactor accident.

Mr L. Snoj (Slovenia) and co–authors presented a poster which discussed the experimental and computational biases and uncertainties in fission rate profile measurements made at the TRIGA Mk II reactor at the Josef Stefan Institute using absolutely calibrated miniature fission chambers.

Ms L. Nassan (Syria) presented a poster which discussed use of metal films deposited on Teflon as neutron threshold detectors in a miniature neutron source reactor.

Ms K. Kaiser (USA) and co–authors presented a poster which discussed a new neutron monitoring system for the Annular Core Research Reactor. The new system is intended to extend the low–flux capability of the reactor for irradiation of components.

SESSION B: COMMON MANAGEMENT CONSIDERATIONS

Ten papers were presented in Session B, including 2 invited talks by experts from Member States, a keynote talk from the IAEA, 5 contributed papers and 2 posters.

Papers, Part 1

The first invited paper delivered by **Mr G. Storr (Australia)** highlighted the nexus between safety, security and safeguards in research reactors with the common overall objective to protect people and environment. The talk focused on definitions, culture, practices and experience gained in the management of simultaneously addressing safety and security challenges at the OPAL reactor. Mr Storr noted that the goal of safety is to avoid, protect against and mitigate design basis accidents, while the goal of security is to do the same for the design basis threat, that is, intent. Regulators need to be sure that regulations are coordinated. OPAL has done a periodic safety review and a security review, as well as a safety reassessment. Integrated reviews are now a license requirement in Australia.

The second invited talk was delivered by **Mr K. Du Bruyn (South Africa).** He described in detail the well–structured elements of the Integrated Management System (IMS), Configuration and Document Control as applicable to RR, based on the practices instituted at SAFARI–1 reactor in South Africa. The IMS is a framework establishing all the necessary processes to address and achieve the overall goals of the RR facility. This includes inter alia safety culture, quality and environmental aspects. Key elements of configuration management and document control (disciplined processes) were outlined. He concluded that there are multiple benefits in having an IMS with Configuration Management (CM) and documentation control integrated into this system. Configuration management and document control within an integrated management system are essential requirements for the safe operation, utilisation and modification as well as up–to–date information of any research reactor.

Mr H. Böck (Austria) reviewed the history of the TRIGA research reactors. Sixty–six TRIGA reactors were built in 23 countries; 35 are still operating, about half of which are well utilized. He outlined the many areas in which TRIGA reactors have been used. Several challenges facing the TRIGA operators were highlighted, specifically: continued supply of TRIGA fuel; back–end options; high–level technical support from the original manufacturer; strengthening of regional ties to address challenges; enhancing utilization; and improving relationship with national and international stakeholders. All that is being reflected in the new Agency publication “History, Development and Future of TRIGA® Research Reactors”, TRS No 482.

Mr A. Mahjoub (Arab Atomic Energy Agency) outlined the challenges faced by the RRs and critical facilities in the Arab countries. The AAEA operates under the auspices of the League of Arab States; fifteen Arab nations are members. Its programme is focused on human resource development. The use of nuclear technology in Arab countries has increased significantly in different social and economic aspects of life (e.g., medicine, industry, agriculture and research, etc.). Many Arab countries have or are planning to have research reactors. There are currently nine operating research reactors, two under construction and five being planned or considered. There is a working group on safety management of research reactors within the Arab Network of Nuclear Regulators.

Papers, Part 2

The keynote talk by **Mr A. Shokr (IAEA)** brought out the Agency efforts in providing holistic support on research reactor matters through implementation of cross–cutting activities across different Agency departments and divisions. Most of the issues and challenges on research reactors include components of safety, technology and utilization and require implementation of the relevant activities in a coordinated manner. Effective coordination of the activities resulted in improved services to Member States by avoiding duplication, synchronizing activities, ensuring consistency, and harmonizing approaches. The activities were mainly related to infrastructure development and capacity building, ageing management, refurbishment and modernization, Technical Cooperation programmes, coordinated research projects, HEU minimization, safety of utilization programmes and the interface between safety and security. Efforts will continue to enhance the coordination of the IAEA activities on research reactors to further enhance the services to the Member States.

Mr Y. Ellethy (Egypt) described the application of graded approach to quality assurance during construction of the ETRR–2 facility and to maintenance, periodic testing and inspection during operation. A quantitative system for grading was applied based on many factors, such as, safety, availability, reliability, complexity, design state, costs of failure and experience with the component. Weighting factors are applied and point values are assigned based on judgment and anecdotal criteria. The numerical results are used to determine the quality level or the maintenance programme for a component or system.

Ms K. Niedzwiedz (Germany) presented their experience in applying a graded approach in the periodic safety review (PSR) according to their National Atomic Energy Act. There are 7 RRs in operation in Germany, including two large pool reactors (FRM II in Munich and BER II in Berlin), one TRIGA reactor (Mainz) and three low–power training reactors. Reactors are classified on the basis of thermal power, hazard potential (inventory of ^{131}I and ^{137}Cs) and presence of safety–relevant cooling systems. The focus of the presentation was evaluation of risk potential of individual reactors and development of a graded approach to periodic safety reviews.

Ms J. Leach (USA) presented how safety programmes can be extended to leverage and improve and support security programmes, in place of building similar capabilities within security organizations. Three programmes can result in a holistic approach to safety and security: the Integrated Management System; formality of operations and maintenance activities; and training exercise programmes. However, there are some aspects of security that do not have direct parallels with safety. There are distinct differences between safety and security.

SESSION B: POSTER PAPERS

Two posters were presented on safeguards and security challenges for research reactors.

Mr C. Pickett (USA) presented a poster focused on the safeguards and security challenges with research reactors and new approaches needed to improve awareness of experiments being conducted, target materials being used and methods to conceal such activities.

Mr T. Bonner (USA) presented a poster focused on integrated management of programmes for protection against sabotage and theft.

SESSION C: SAFETY OF RESEARCH REACTORS

Twenty–eight papers were presented in Session C, including 1 keynote, 3 invited and 13 contributed oral presentations and 11 poster presentations. In the following summary, the oral papers are grouped by subject matter rather than sequentially.

Papers, Part 1:

The first part of Session C included: a review of the IAEA sub–programme on safety enhancement of research reactors, 5 papers on actions taken by Member States for improving the robustness and defence–in–depth of their facilities following safety reassessment in light of the Fukushima–Daiichi accident, and a paper on establishing specific regulations based on IAEA Safety Report No. 80.

In his keynote address for Session C, **Mr A. Shokr (IAEA)** discussed the activities of the Agency'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; ability to perform safety assessment; operational radiation protection; emergency planning; decommissioning plans; and the safety–security interface. There is also a need to establish infrastructure in countries planning their first research reactor. Mr Shokr reviewed the Agency's activities in support of application of the Code of Conduct on the Safety of Research Reactors. He noted improved application by Member States of the Code of Conduct. However, there is a need for further improvements in some areas, including regulatory supervision, human factors, emergency preparedness, and decommissioning. The set of IAEA safety standards for research reactors is now complete, but continued work is needed to ensure their effective application. The quality of the IAEA peer review services to research reactors continues to be enhanced and increased requests from Member States for these services is observed. Other activities include monitoring of research reactors under Project and Supply Agreements with the IAEA; capacity building;

and support to technical cooperation projects and a survey of Member States' safety re–assessments in light of the Fukushima–Daiichi nuclear power plant accident and implementation of safety improvements.

For the future, Mr Shokr anticipated work in: maintaining and expanding worldwide application of the Code of Conduct and the IAEA safety standards; maintaining adequate safety levels of ageing research reactors; improving regulatory effectiveness, including infrastructure for first research reactor projects; dissemination of the relevant lessons learned from the Fukushima–Daiichi NPP accident; improving management the interface between safety and security; and improving exchange of operating experience and networking.

Mr H. Abou Yehia (France) presented an invited paper in which he highlighted safety enhancements of research reactors based on safety re–assessments following the Fukushima–Daiichi accident. While most of the effort on safety re–assessments and 'stress tests' was focused on nuclear power plants, many countries expanded the scope of stress tests to include research reactors and applied the same methodology as for NPPs. In this process, priorities were given to research reactors according to their risks and following a graded approach (in some cases the re–assessments were performed only for research reactors having power levels above a certain threshold value). The emphasis of the safety re–assessments carried out was to evaluate the following: robustness of the facilities and their ability to withstand effects of extreme hazards more than those considered for the design basis; defence–in–depth; and performance of fundamental safety functions and continuity of facility monitoring. One adequate approach applied by many operators was to first assess the current status of the facilities and verify their conformity with the design basis and license conditions, and then expand the scope of the assessment to Design Extension Conditions, which included consequences of external events (earthquake, flooding, etc.) combined with a total loss of electrical power supply, and verification of existing margins to severe accidents (reactor core damage, containment damage and off–site releases). The safety enhancements resulting from performed safety reassessments included: improvements in regulatory supervision and emergency planning; corrective measures for improving defence–in–depth, operational safety, accident management and measures to prevent or mitigate unacceptable consequences from fundamental safety function failures. For some research reactors, safety demonstrations were improved to include: consideration of Design Extension Conditions in the safety analyses; implementation of additional engineered safety features for ensuring performance of fundamental safety functions; and updating of safety documents to take into account site specific hazards. Mr Abou Yehia concluded by remarking that safety re–assessments performed for research reactors in light of the Fukushima–Daiichi NPP accident resulted in an effective strengthening of the Defence–in–Depth and improvements of the capabilities of facilities to withstand beyond design events for many of them. Mechanisms should be established for ensuring regular updates at the international level on implementation status of safety re–assessments and resulting safety enhancements for research reactors. The specific surveys launched by the IAEA and the safety review missions conducted in many countries could be an adequate means for collecting and reviewing information on this subject. Peer review of different safety matters related to research reactors should be continued and facilitated by the IAEA, through technical meetings and workshops aimed at sharing good safety practices. Safety enhancements implemented following post–Fukushima safety re–assessments should not in any case reduce the attention to prevention of accidents.

Mr C. Karhadkar (India) presented the safety re–assessment and upgrade proposed for the Dhruva reactor. He noted that the safety of the reactor was demonstrated up to the design basis flood level, but that a 'cliff–edge' effect due to loss of electrical equipment is possible for a beyond design basis flood based on an upper–bound value for a postulated cyclonic storm. It was decided to construct a new seismically–qualified building and provide two 625 kVA air–cooled diesel–generator sets in this building at higher elevation with adequate diesel fuel storage facility. For the interim period a 200 kW portable diesel–generator set has been identified and ear marked for this purpose. To ensure cooling, a new pump house, with two pumps and independent make up line, was built and made external flood proof, up to BDBFL. An additional hook–up point to provide a high–pressure water source for directly driving the turbines and providing secondary cooling, external to the reactor building has been made. Modifications were proposed to provide direct hook–up points in loop#1 turbine inlet and outlet lines and primary heat exchanger for driving one turbine and providing secondary cooling, using any water source (like fire hydrant water). An additional down comer from OHST was proposed for improving redundancy. Considering various improvements made/ proposed in the system configuration, it was felt that it would be possible to cope with an overwhelming beyond–design–basis natural event as described above in a preventive regime.

Mr E. Grolleau (France) reported on French post–Fukushima complementary safety assessments (CSAs) and safety improvements. In France, the Institute of Radiation Protection and Nuclear Safety (IRSN) was responsible for the review. Although the CSA identified the systems, structures and components (SSCs) of facilities whose loss or failure may lead to significant radiological or toxic consequences, they determined that given the uncertainties about the levels of extreme hazards, and given the simplified approaches implemented for assessing the facilities, the IRSN recommended that a more robust and systematic approach be adopted to accurately identify the improvements to ensure the resistance of nuclear facilities against extreme hazards. From this the concept of "hardened safety core" (HSC) was developed with the purpose of ensuring that nuclear facilities could withstand beyond–design–basis accidents. The hardened safety core must ensure ultimate protection of nuclear facilities according to the following objectives: prevent a severe accident or limit its progression; limit large–scale releases in the event of an accident which is not possible to control; and enable the licensee to perform its emergency management duties. The HSC may be composed of existing SSCs (that might need to be strengthened) and new SSCs (that shall be designed and sized to withstand extreme hazards). Effective implementation of the HSC on facilities implies the characterisation of extreme natural hazards (intensity, duration, magnitude, frequencies, etc.) and the use of robust methods to design new SSCs or to verify existing SSCs belonging to the HSC. This information shall be determined with the aim that the HSC will be able to ensure, with a high degree of confidence, its functions in case of extreme events.

The example given was for the High Flux Reactor (HFR) operated by the Laue–Langevin Institute (ILL), with a maximum thermal power of 58.3 MW. The Laue–Langevin Institute used the defence–in–depth principle in the development of the HSC. The three main components were: prevention of severe accidents (core water supply systems); mitigation of severe accidents (containment isolation devices); and emergency management (emergency control room). The modifications made have significantly improved the robustness of the installation in the event of extreme natural hazards.

Mr Y. Barnea (Israel) addressed implementation of regulatory guidelines for safety re–assessment based on IAEA Safety Report No. 80. Based on regulatory decree, the approach adopted by the operators of the Soreq Nuclear Research Centre (SNRC) IRR research reactor was implementation of the IAEA Safety Report No.80. This took the form of developing an action plan which included the following analyses: re–evaluation of the seismic database on the IRR–1/SNRC site; dynamic analyses of systems of the primary cooling system, aluminium windows; and selected "critical" SSCs. In addition, a new PIE, the 'flapper' valve intended to facilitate natural convection core cooling after shutdown stuck closed, was analysed. Upgrading of SSCs included: installation of a high quality accelerometer, connected to the SCRAM system; enhanced remote monitoring capacity from the SNRC Command Room; modification of water supply systems; power system upgrades; and complementary procedures, training and education. Planned future activities include: dynamic analysis of the emergency core cooling system (ECCS) water piping; modification of the cooling tower pipes configuration as an additional emergency water source; and accident analyses of consecutive external events (i.e., earthquake & fire, fire & SBO). The action plan was submitted to the regulator and approved and the first installation of two ground accelerometers took 8 months and was considered as proof that the 3– year overall project was feasible based on the time taken for the first activity initiated and completed.

Mr S. Malaka (South Africa) reported on safety re–assessment and modifications to the SAFARI–1 reactor. A directive was given by the regulator that a safety re–assessment be completed to evaluate the response of the SAFARI–1 reactor to extreme external events. A defence–in–depth approach was adopted. The safety re–assessments made resulted in several modifications: improvement of the fresh fuel storage facility; installation of emergency water systems; provision of portable electrical power systems; implementation of an emergency control room; installation of core flooding nozzles in the event of a LOCA; installation of seismic trips; installation of a second shutdown system; and improvement of containment. A number of the above mentioned modifications were underway, however, larger modifications, such as building reinforcements would best be dealt with under the ageing management programme.

Papers, Part 2

The second part of Session C included: 4 papers on maintenance, thermal–hydraulic and safety analysis, and extended shutdown. Note that the presentation by Mr. T. Sato (Japan) on the status of the JRR–3 reactor after the great East Japan earthquake was cancelled due to his inability to join the Conference and the following paper was substituted.

Mr F. Gajdos (Hungary) discussed maintenance and ageing management at the Budapest Research Reactor. He reviewed the normal periodic, preventive and corrective maintenance and inspection practices, as well as the more extensive summer maintenance work. Following this, he reviewed the various maintenance–related events and the associated corrective actions.

Mr Y. Boulaich (Morocco) reported on thermal–hydraulic and safety analysis for their TRIGA Mark II research reactor. Thermal–hydraulic parameters for the Moroccan 2 MW TRIGA reactor were discussed. Steady–state and transient analysis was performed using the PARET and MCNP Codes, and the modelling was validated by comparison between calculated and measured fuel temperatures. Reactivity insertion and LOCA events were analysed using the model. It was concluded that the reactor remained within the safety margins for the postulated abnormal events.

Mr K. Krezhov (Bulgaria) presented a detailed account on the history of the management of the IRT–Sofia Research Reactor which was unfuelled and now been in extended shutdown for 26 years. The numerous obstacles that exist were catalogued, it was concluded that the required budget for re–commissioning the facility had not been granted due to the uncertainty of nuclear power as part of the Bulgarian energy mix. Present funding is only sufficient to maintain physical protection, nuclear safety and radiological monitoring.

Mr H. Kim (Rep. of Korea) presented an analysis of the thermal–hydraulic behaviour of a reflector system, considering both performance–related and safety–related studies. The events investigated originate in the heavy water reflector system. They are analysed with a best estimate code, RELAP5/MOD3.3, using conservative assumptions and conservative initial conditions. It is concluded that performance and safety can be assured.

Papers, Part 3

The third part of Session C included 3 papers on periodic safety review of research reactors.

The invited talk of **Mr A. Sapozhnikov (Russian Federation)** covered the methodology and experience in application of the PSR for enhancement of safety of nuclear research facilities in the Russian Federation. He emphasized that PSR provides a consistent, reliable means for identifying and taking timely preventive measures for deficiencies in safety and is an effective tool for improving safety through implementation of international good practices by both operating organization and regulatory body.

The presentation of **Mr A. Shepitchak (Ukraine)** highlighted the safety reassessment performed for WWR–M reactor in Ukraine. The license for continuation of the reactor operation was granted by the regulatory body based on this assessment that included analysis for design extension condition and completion of specific safety improvements identified. The safety reassessment also included updating of safety documentation.

The presentation of **Mr J. Sterba (Austria)** described the new Austrian legislation that requires a yearly review by the Competent Authority, and a periodic safety assessment every ten years for nuclear facilities. The first PSA for their TRIGA–type RR was initiated in 2011 and submitted in 2014; it has been accepted. Replacement of the instrumentation and control system was required; this is already nearly done. A number of pre–emptive replacements of SSCs have been done. They will enter into a three–week period of non–nuclear testing, followed by a 3–month nuclear trial run. The results will be submitted to the Competent Authority as the basis for regular operation with a yearly assessment.

<u>Papers, Part 4</u>

The final part of Session C included 4 papers on regulation of research reactors.

Ms J. Adamcyzk (Poland) presented the Polish regulatory body's follow–up of implementation of recommendations resulting from the 2013 INSARR mission to MARIA research reactor. She summarized the INSARR team's observations, the regulatory body's actions, and the results. The results of this follow–up and the benefits of the implemented IAEA INSARR mission in improving the safety of the Maria reactor were highlighted.

Mr A. Adams, Jr. (USA) discussed the application of a graded approach in regulation of research and test reactors by the US Nuclear Regulatory Commission. He emphasized that, as risk increases the strictness of regulation also increases. This approach was detailed in IAEA Safety Guide SSG–22. Grading was applied in the licensing process, technical requirements, security, inspection and financial considerations. It was based on the power rating and whether the reactor is used for research and development or for commercial purposes. He discussed the details of grading in each of the categories. Graded approach started with the Atomic Energy Act and has been used from the earliest days of reactor regulation in all aspects of NRC regulation.

Ms F. Nasser (Pakistan) discussed the role of Pakistan's Nuclear Regulatory Authority in ensuring safety of their research reactors. Regulatory activities include: development and maintenance of the regulatory framework; licensing; regulatory oversight; operator licensing; and coordination with the licensee. A graded approach was applied throughout. Regulatory infrastructure was developed and in place for ensuring safety of research reactors in Pakistan. Regulatory processes were defined. Strong regulatory oversight was one of the significant factors in safe operation of research reactors for almost five decades.

Mr M. Abubakar (Nigeria) discussed safety of the Nigerian NIRR–1, a miniature neutron source reactor (MNSR) supplied by China and the role of the Nigerian Nuclear Regulatory Authority (NNRA). He presented the functions of the NNRA and problems faced in some detail. Current challenges include: modification of the reactivity control system of the reactor; core conversion from HEU to LEU; adequate infrastructural arrangements for decommissioning; and adequate professional training for regulatory officers on research reactors review and assessment of SAR and other submissions.

SESSION C: POSTER PAPERS

Six of the posters presented on safety of research reactors dealt with criticality and neutronic calculations, 2 with thermal–hydraulic calculations and 3 with safety analysis.

Criticality and Neutronic Calculations

Mr S. Sikorin (Belarus) presented a benchmark on criticality experiments using Uranium–Zirconium fuel assemblies composed each of 7 fuel rods (uranium enriched at 21%). Experimental and calculation results were presented for the studied fuel configurations.

Ms R. Abou–Alo (Egypt) presented criticality safety analysis for wet spent fuel storage of WWR–C research reactor in normal conditions and in case of LOCA. The results of calculations made using a Monte Carlo (MCNP–5) code confirmed the sub–criticality of the studied fuel configurations.

Ms L. Suparlina (Indonesia) presented core calculations of the IAEA 10–MW MTR research reactor benchmark using SERPENT and DYN3D codes for both HEU (93%) and LEU (20%) uranium silicide fuel having different fuel loadings.

Mr M. Margolis (Israel) presented detailed core calculations of the IAEA 10–MW MTR light–water pool–type reactor benchmark using the Serpent/DYN3D code system. Both HEU and LEU cores were considered in BOL and EOL configurations.

Mr D. Sumkhuu (Mongolia) presented results of dynamic modelling of the IBR–2M pulsed reactor aimed at establishing safe and reliable operation.

Mr R. Khan (Pakistan) presented a calculation of reactor safety parameters using MCNP–5 (control rods worth, excess reactivity, shutdown margin, flux density distribution and power peaking factor) with measurements for the 10–MW PARR–1 research reactor.

Thermal–hydraulic Calculations

Mr B. Lee (Republic of Korea) presented calculations related to the two phase vertical stratification in decay tank of a 15–MW pool–type research reactor. In case of a pipe break accident in an inverted U–shape cooling pipe, ambient air can be inhaled into the pipe and accumulated in the decay tank before it reaches the reactor core. The results showed that the fuel damage by air ingression in the core was not expected until the decay tank becomes almost empty.

Mr J. Park (Republic of Korea) presented a simulation of the flow inversion in a uniformly heated thin rectangular channel array (using ANSYS–CFX code). The results for coolant, plate temperature and flow rate through the flap valve were in agreement with those obtained using RELAP5 Code.

Safety Analysis

Mr Y. Pesnya (Russian Federation) presented accident analyses made in the frame of the conversion of the IR–8 research reactor to LEU fuel. The accidents studied include unplanned insertion of positive reactivity during reloading, full instantaneous primary coolant pipe rupture (LOCA) and spontaneous withdrawal of the automatic regulation rod with subsequent loss of flow and failure of safety rods.

Mr P. Kohut (USA) presented the results of a radiological hazard study for the University of Massachusetts–Lowell 1–MW research reactor by postulating a fuel plate failure resulting in a release of accumulated fission products. The objective of the study was to provide a comprehensive review of a methodological approach for consequence analysis, which was consistent with recommendations of NUREG–1537.

Mr P. Domitr (Poland) presented the results of a dynamic analysis for a TRIGA reactor, which showed that the present technical specification limits on fuel temperature for pulsing were adequate to ensure safe operation of TRIGA reactors.

SESSION D: OPERATIONS AND MAINTENANCE

The session on operations and maintenance included 34 papers: 1 keynote, 2 invited and 12 contributed oral presentations, and 19 poster presentations. It was clear that O&M has many faces – system upgrades, equipment design, material condition assessment and ageing management, safety reviews, new facility designs – but all desire the same end result, service to the customers and increased utilization of the reactors. The presentations covered a range of topics including IAEA activities and examples from facilities of their programmes for improving maintenance and operations activities, 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 improvement of facility reliability and operations. In addition, one half of Session D was largely dedicated to reactor fuel issues, concentrating on the development of LEU fuels and the conversion of research reactors to LEU cores.

Papers, Part 1

In her keynote address, **Ms F. Marshall (IAEA)** presented the IAEA activities in operations and maintenance of RRs. The activities are broad, covering many areas to support Member States, with the following initiatives of particular note:

- The Operations and Maintenance Assessment of Research Reactors (OMARR) service provides for peer review of the O&M practices at a facility; it is an important approach to improve O&M practices and reliability. There have been 2 OMARR missions to date and another is planned in 2016;
- Organizing of technical meetings, conferences, workshops and Coordinated Research Programmes (establishment of material properties data base, monitoring, etc.);

- Set–up competences for in–service inspection (IAEA provides support of experts and training in using non–destructive equipment.);
- Publication of various TECDOCs, Safety Standards, safety reports and guidance documents;
- Development of a research reactor ageing data base (description of main issues, corrective actions, etc.).

The IAEA Research Reactor Section recommended that Member States make use of the opportunity to request an OMARR mission.

In an invited paper, **Mr D. Elliot (Australia)** presented the work that has been done at OPAL RR in developing the Asset Management programme. This is an integrated approach to maintenance where one of the main objectives is to improve the reliability of the reactor, its safety and support commercial activities. The asset management programme is based on the ISO 55000 standard and uses the Plan–Do–Check–Act concept. Key components of the programme include application of reliability–centred maintenance (e.g., vibration analysis of rotating equipment), which leads to higher reliability and reduction in unplanned shutdowns. It was noted that no unplanned shutdowns have stemmed from equipment which has thus far been included in the Asset Management programme. It was noted that planning and a planning system are vital for success. The result was an RR that is safer, more reliable, and with a more controlled budget. OPAL RR achieved 302 Full Power Days (FPDs) of operation last financial year.

Mr M. Shaat (Egypt) presented the ageing management programme and modifications performed on the two Egyptian research reactors ETRR–1 and ETRR–2 with the aim of ensuring long–term safety and reliability of these reactors. He defined two kinds of ageing effects, physical ageing and obsolescence. He mentioned the replacement of the I&C systems in control room for ETRR–1 and the maintenance programme implemented at ETRR–2. Safe operation of the reactor was ensured using an ageing–management maintenance concept, an ISI programme and routine maintenance as detailed in the IAEA Standards and guideline documents.

Mr A. Pichlmaier (Germany) presented work done at the FRM–II to extend the lifetime of core components that will be affected by irradiation effects using fracture mechanics. These components, the central channel, beam tubes, and instrumentation tubes are made of aluminium (EN AW–5754). Initially, using extremely conservative boundaries, the schedule of core components replacement was developed. FRM–II proposed to modify this approach by using fracture mechanics to determine the need to replace these specific selected core components. An extension of 10 years has been granted by the regulatory authority for the beam tubes and instrumentation tubes; the extension for the central channel was still under discussion. The worldwide data base on fracture of aluminium was limited; FRM–II requested data to be shared by other Member States to improve the data base.

Papers, Part 2

In his invited paper, **Mr E. Koonen (Belgium)** gave an overview of the status of development of high density fuel for HEU to LEU conversion. Uranium–silicide dispersion fuel was used in many reactors, but cannot have high–enough uranium density for high–performance reactors. European development work centres on uranium–molybdenum dispersion fuel. Various coatings of the fuel particles have shown improved swelling resistance, but the fuel still exhibited unacceptably high swelling at high burnup, so it was not yet suitable for conversion of high–performance research reactors. Work in the U.S. focused on monolithic U–Mo fuel and developing an industrial production process. The European HERACLES collaboration has been formed to do irradiation testing with strong support from the US efforts.

Mr J. Stevens (USA) gave an overview of what has been achieved since 2011 on conversion of reactors from HEU to LEU fuel. In total, 92 facilities no longer use HEU after conversion to LEU or (25) have been shut down prior to conversion. Some like the SLOWPOKE in Jamaica have been unexpectedly difficult to convert, in this case due to special challenges in the supply chain. Basically all facilities that are “easy" to convert have been converted by now. Both the high flux reactors in Europe and the US require LEU fuel with a high uranium density which was not yet available. Significant activities in the field of fuel development were ongoing (see E. Koonen's paper) and clearly needed.

Mr P. Chakrov (Kazakhstan) reported on the conversion of the WWR–K reactor in Almaty. While the fuel has already been successfully tested, numerous other activities were still ongoing in the facility. The period of core conversion was also used to significantly overhaul and improve the reactor as a whole. The I&C systems were being replaced, new control rods and drives were being installed, an uninterruptable power supply was being installed for the emergency cooling system, radiation monitoring systems were being refurbished and new and more efficient cooling towers have been installed. Finally the reactor tank and primary cooling loop have been inspected. Start–up after completion of the programme was foreseen later in 2015.

Mr K. Kamajaya (Indonesia) gave a talk on the Bandung TRIGA reactor in Indonesia. Because of the current uncertainties in availability of TRIGA fuel and the ability of Indonesia to manufacture its own plate–type fuel a conversion from standard TRIGA fuel to plate–type fuel is being investigated. The neutronics calculations have already been successfully completed. Next, detailed calculations on the thermal–hydraulics were required as well as a redesign of the primary cooling loop for the operation with fuel plates at 2 MW power. All these activities would help to obtain a new license for the Bandung reactor. If everything went as planned, a restart of the reactor with the new plate–type fuel was foreseen for 2019.

Mr Y. Mahlers (Ukraine) reported on the conversion of the WWR–M research reactor in Kiev. Initially, HEU fuel was replaced with LEU fuel during normal scheduled reloading. However, since this is slow process, efforts have now been put in place to achieve conversion faster. Hence open positions in the core were filled with either aluminium–dummy–elements or beryllium–elements. Some of the Be–elements have more than 40 years of (partially) unknown history, so a conservative approach was used to compensate for the unknown ^{3}He poisoning. Given the constraints of the reactor design, this resulted in an asymmetric core. With more experience gained, some the Be–elements were shuffled; improvements for better neutron flux, especially at the beam tubes with position unfavourable with respect to the asymmetric core, could be achieved. It was clear that conversion and fuel development were ongoing activities. To achieve the goal of conversion of all reactors from HEU to LEU a lot of significant work remained to be done. The support of the Agency with coordination and expertise was appreciated.

<u>Papers, Part 3</u>

Mr J. Sandoval (Colombia) discussed thermal power calibration and neutron flux measurements in the nuclear research reactor IAN–R1. The reactor had a TRIGA converted–core, operated at a maximum power of 30 kW with LEU fuel. The I&C system was upgraded in 2012 in collaboration with ININ of Mexico. The thermal power calibration was performed using the calorimetric method adopted in the TRIGA IAN–R1 Reactor, what enabled accurate determination of thermal neutron flux levels. Accuracy of the calibration allowed good performance by the Laboratory of Neutron Activation Analysis (CGS) during the first round of proficiency testing in the Wageningen Evaluating Programmes for Analytical Laboratories (WEPAL) in 2015, supported by the IAEA.

Mr K. Konoplev (Russian Federation) reported on an upgraded core for the PIK reactor, which has been under construction since 1976. It is a very large, powerful reactor, with 10 horizontal channels for beam extraction, as many as 50 irradiation positions, hot, cold and ultra–cold neutron sources, neutron guides and a cryogenic loop at liquid helium temperatures. The changes in the PIK reactor core would solve the main problem of increasing the operational cycle from two weeks to four, and will improve the reactor's research capabilities. Neutron physics computations with improved fuel assemblies showed that the neutron flux in the experimental channels will remain at the high level of $1–5x10^{15}$ $cm^{-2}·s^{-1}$.

Mr M. Reichenberger (USA) reported on development and testing of micro–pocket fission detectors. The goal was to develop a small size detector that would not perturb the flux in a test capsule. It was designed to work in $1x10^{14}$ $cm^{-2}·s^{-1}$ thermal neutron flux environment and withstand a high fluence allowing use for more than 1 year at most research reactors. The current design showed good correlation between power and detector response and good power tracking results in transient tests. They now used natural uranium, but hoped to go to HEU to improve sensitivity. The goal was to have 5 years life in a neutron flux of $1x10^{14}$ $cm^{-2}·s^{-1}$.

Mr H. Obeng (Ghana) reported on ageing management at the Ghana Research Reactor–1, a Miniature Neutron Source Reactor (MNSR) used primarily for neutron activation analysis and education and training. The adding management programme focused on physical ageing and obsolescence, and included procedures for operation, maintenance, periodic testing and inspection, radiation protection and administration, along with detection, monitoring and trending of ageing. The maintenance programme included both proactive (routine and preventive) and corrective components. A screening system was used to prioritize based on the importance to safety and difficulty of repair or replacement. Refurbishment and upgrading was part of the programme; recent examples included the control rod drive mechanism, deionized water plant and the microcomputer system. Preparations were now underway for core conversion to LEU fuel. A staff training and succession plan was in place, including a graduate school, to manage ageing of the reactor staff.

Mr N. Arkangelskiy (Russian Federation) discussed the Rosatom activity in research reactors. Rosatom has under its jurisdiction 35 steady–state and 57 pulse research reactors, 7 of which have power rating greater than 10 MW, located in 4 institutes. The reactors and associated post–irradiation examination facilities are used for irradiation testing of materials, production of radioisotopes, fundamental research and education and training. Stress tests following the Fukushima–Daiichi NPP accident led to safety improvements, most importantly, installation of seismically–qualified diesel generators and additional pumps for emergency cooling. Ageing was a problem, as only one of the high–power reactors was less than 35 years old. They have countered this problem by modernization and building a new reactor, the Multipurpose Fast Research Reactor (MBIR). A proposal for construction of Centres of Nuclear Research including a multipurpose research reactor as the main experimental facility of the Centre has been developed.

Mr B. Munkhbat (Mongolia) described a dedicated facility for mass–production of doped silicon. A new doping facility with a large irradiation capacity for NTD–Si may need to be constructed to ensure an adequate supply of doped silicon to meet expected demand on the order of 1000 tons/year in the next decades. Purpose of study was to design small and simple nuclear reactors for doping of large–diameter NTD–Si ingots using PWR fuel elements. The reactors would be intended for industry (only for Si doping); not for research, so they needed to make a profit and provide a stable and reliable supply of doped Si. Requirements include low construction and operating cost, the ability to dope large–diameter ingots with uniform irradiation to achieve a high production rate and a stable and reliable fuel supply, such as could be achieved by using fuel supplied by several vendors. Mr Munkhbat reported studies of two possible designs comparing full–length and shortened PWR fuel elements. He concluded that both could produce more than 100 tons/year.

SESSION D: POSTER PAPERS

Nineteen posters were displayed in the Operations and Maintenance category, 7 covering a broad range of topics including: instrumentation and control, 3 ageing management, 4 fuels; and 5 general operations and maintenance.

Instrumentation and Control

Mr M. Villa (Austria) and co–authors discussed the new fourth–generation I&C system installed at the TRIGA Mk II reactor in Vienna. The digital system was produced by the Skoda and DataPartner companies of the Czech Republic. It was capable of monitoring and controlling processes and the status of components and system, and maintaining predefined project and safety limits.

Mr J. Sandoval (Colombia) presented the details of the I&C upgrade at the TRIGA IAN–R1 reactor at the Colombian Geological Survey in Bogota. The system, supplied by ININ (Mexico), was partially digital and used direct wiring for the protection system instead of software. The changes have improved safety and flux stability, resulting in improved precision in irradiation of samples and better neutron activation analysis results.

Mr M. Kropik (Czech Republic) and co–authors described testing of a new reactor protection system intended for the LVR–15 reactor, first using simulated signals to validate the response of the new system, and then using the VR–1 training reactor. The successful tests supported licensing of the new system.

Mr J. Matousek (Czech Republic) and co–authors described the refurbishment of the I&C system for the LVR–15 reactor, focusing on the qualification, licensing and testing of the new system, and the first operational experience.

Mr L. Rodriguez (France) and co–authors described the computerized and non–computerized solutions for the safety I&C systems for new research reactors and modernization of existing reactors offered by AREVA.

Mr E. Tomarchio (Italy) presented a poster on maintenance operations on the nuclear instrumentation of the 50 years old AGN–201 reactor “COSTANZA” at the University of Palermo. A failed ionization chamber was removed from the reactor and repaired, and protective devices applied to prevent future corrosion due to parasitic electrical currents.

Mr N. Abubakar (Nigeria) and co–authors presented the design of a manual control unit for a pneumatic sample transfer (‘rabbit’) system at the NIRR–1. This system was intended to substitute for an automatic system that was out–of–service pending repair and could serve as a redundant back–up system in the longer term.

Ageing Management

Mr M. Izzerrouken (Algeria) and co–authors presented results of gamma radiation tests of polyethylene (PE) and polyvinyl chloride (PVC) cable insulation components. The results indicated that the PE insulation presented a successful behaviour under gamma dose similar to that in a reactor tank, but the PVC became far less durable.

Mr H Boeck (Austria) and Mr D. Winfield (Canada) presented a historical summary of reactor tank corrosion events, the root causes and consequences, along with recommendations for designers and operating organizations.

Ms T. Schmidt (Germany) described the preventive maintenance programme for the SUR–100 teaching reactor at the University of Stuttgart. Ageing management was essential for continued operation of the facility, since it was no longer supported by the manufacturer (Siemens).

Fuels

Mr T. Makmal (Israel) and co–authors presented a simple non–destructive method for evaluation of the burnup of an MTR fuel element using gamma spectroscopy. The method was simple and could be used for samples having a very irregular irradiation history, typical of many research reactors that operated intermittently.

On behalf of Mr R. Irkimbekov (Kazakhstan) and co–authors, Mr P. Chakrov discussed methods for determining the energy released in a test fuel assembly during a transient experiment in the Impulse Graphite Reactor (IGR). The method included a three–dimensional space–time kinetics code that simulated the effects of control rod position and core heating on the thermal neutron flux. The calculation could be validated by temperature measurements in the test sample so long as the sample is not destroyed in the experiment.

Mr H.–J. Kim (Republic of Korea) and co–authors presented the status of qualification tests and licensing of plate–type fuel for the new Ki–Jang Research Reactor in Korea. The new fuel is U–7%Mo/Al–5%Si dispersion with a U density of 8 g/cm^3 in most of the plates, and 6.5 g/cm^3 in the outer plates.

Mr R. Abdel Aziz (Sudan) presented results of calculations of neutronic parameters and fuel consumption rates for three different densities of U_3Si_2–Al fuel in an MTR aimed at providing data that could be used to optimize the fuel density for optimised consumption rate.

General Operations and Maintenance

Ms M. Varvayanni (Greece) presented a poster on the issues raised regarding restart of the Greece Research Reactor–1 after a period of extended shutdown. A programme of refurbishment of the primary cooling system to meet IAEA safety standards has not been completed due to lack of funds; however the reactor infrastructure has been maintained. A proposal has been formulated and submitted for refurbishment and restart of the GRR–1.

Mr K. Dinesh (India) discussed 30 years of operating experience of the Fast Breeder Test Reactor. This sodium–cooled, mixed–carbide fuelled reactor has undergone extensive ageing management, life extension and safety enhancement work, including modifications to protect against flooding, tsunami and seismic events in a post–Fukushima retrofitting programme. This work, along with various maintenance issues was discussed.

Mr M. Palomba (Italy) presented a poster on activities at the TRIGA RC–1 reactor at the Casaccia Research Centre of ENEA. The work focused on improved techniques for determining fuel burn–up, modernization of area radiation monitoring instrumentation and flow meters. A new irradiation facility in the reactor shield tank was described.

Ms N. Ramli (Malaysia) presented a poster on refurbishment and upgrading projects carried out to improve the safety and long–term availability of the PUSPATI TRIGA reactor.

Mr R Schickler (USA) discussed reflector replacement at the Oregon State University TRIGA reactor. The original reflector had filled with water, leading to reduced neutron fluxes in exterior beam ports and reduced core excess reactivity. A new, water–tight reflector was installed, and other preventive maintenance work was carried out to improve operation of the reactor.

SESSION E: SPENT FUEL MANAGEMENT AND DECOMMISSIONING

Seven papers were presented in this session, including 1 invited and 3 oral presentations, plus 3 poster presentations. Oral presentations of Session E covered spent fuel management, transition from operation to decommissioning, implementation of decommissioning, and safety assessment related to the different types of research reactors and fuels.

Mr C. Karhadkar (India) presented an invited paper on behalf of Mr. R.C. Sharma, in which the transition from shutdown and decommissioning of the research reactor CIRUS was discussed. CIRUS was the first large reactor in India for production of radioisotopes, testing of materials, fundamental research and human resource development. It was permanently closed at the end of 2010, after a two year transition period. During the transition, experiments in the reactor were completed, some experimental facilities moved to other reactors, fuel utilization was optimized and redeployment of personnel planned. Planning also included preparation of procedures, technical specifications and obtaining regulatory approval for shutdown. After shutdown, the core was unloaded, although some SSCs continued in operation. Heavy water was removed, the in–core pressurized loop was removed and staffing reduced. Access controls were maintained as before. A decommissioning organization has been set up. A radiological characterization has been performed, and estimates of radioactive waste volumes and activity prepared. Deferred dismantling has been selected as the decommissioning option, with a deferral period of 15–20 years to allow decay of ^{60}Co. The site being within the BARC campus will not be released to the public domain, but may be used for another laboratory or facility in future.

Ms S. Kanamori (France) discussed the safety assessment of the OSIRIS reactor and the decision for final shutdown at the end of 2015. The main outcomes of a review of safety of OSIRIS included that the reactor building is not designed to withstand an airplane crash or external explosion; the approach used in safety demonstration should be updated; and that improving the gas tightness of the containment would significantly reduce noble gas and iodine release in a ‘Borax–type’ accident. The French regulatory authority (ASN) decided that OSIRIS should be shut down in 2015. However, CEA requested an extension to 2019 to avoid a gap in medical radioisotope production until availability of the Jules Horowitz reactor in 2019. The government informed the CEA at the end of July 2015 that the decision of a final shutdown of OSIRIS in 2015 was maintained.

Mr G. Nabkhtiani (Georgia) discussed decommissioning of the Georgian research reactor. Decommissioning was accomplished under several TC projects. The selected strategy was core entombment in place. All fuel, fresh and spent, was removed and sent out of Georgia. The core region in the reactor tank was entombed by underwater concreting. Also, decommissioning involved dismantling the primary and secondary cooling systems, dismantling the connection to the cryogenic station and dismantling the cryogenic station itself. Waste management was a challenge due to large volumes and possibility of liquid wastes. A project to install a small neutron source reactor into the existing reactor tank is still under consideration.

Mr L. Ramanathan (Brazil) reported on development of coatings for safe long–term wet storage of Al–clad spent fuels. This work was motivated by the fact that there are over 64 000 spent research reactor fuel elements in wet storage. Over 90% of these assemblies are clad with Al or Al–alloys, and are susceptible to pitting corrosion. Many countries have no clear plans for reprocessing or otherwise disposing of this spent fuel. A chemical coating appears to be the only solution to protection from pitting corrosion. Numerous trials of various coatings were conducted over a period since 2007. It has been found that a process involving simple immersion in several solutions to form a cerium–containing hydrotalcite (HTC) coating on Al alloys increases significantly the pitting corrosion resistance of the alloy. This process can be scaled–up to increase the corrosion resistance of Al–clad spent RR fuel assemblies during long term wet storage.

SESSION E: POSTER PAPERS

Three posters provided addressed topics of decommissioning and waste management.

Mr X. Masseau (France) presented a poster addressing management of the transition from definitive shutdown to dismantling of the Phenix sodium–cooled fast reactor, including regulatory aspects, the periodic safety review and the authorization process for dismantling.

Mr F. Foulon (France) and co–authors presented a poster that addressed decommissioning of the ULYSSE reactor, including the various tasks involved in the period between shutdown and the decommissioning decree. Waste management during the dismantling was also discussed.

Mr G. Mank (Germany) and co–authors (France and USA) described the management and technical strategy under development for disposal of the graphite–based fuel from the German HTR reactor, including investigation of how to ship the fuel to the US and development of a method for digesting the fuel for reprocessing.

SESSION F: NEW RESEARCH REACTOR PROJECTS

Thirteen papers were presented in this session; including 1 keynote, 2 invited and 6 contributed oral papers, plus 4 poster presentations.

Papers, Part 1

Mr A. Borio di Tigliole (IAEA) gave the statistics of new research reactor projects and the status of guidance document publication and review missions. The IAEA 'milestone' approach for research reactors was found in Nuclear Energy Series Report NP–T–5.1. Thirty

Member States were planning new research reactors, 13 of which were working on their first research reactor project. Seventeen States were at Phase 1 (consideration); 6 were at Phase 2 (preparatory work); and 8 were at Phase 3 (implementation). Guidance for strategic planning and for preparing the feasibility study for a research reactor was forthcoming. The Integrated Research Reactor Infrastructure Assessment (IRRIA) service would also start in 2016. Mr Borio presented also the new IAEA–developed International Centres based on Research Reactors (ICERR) scheme to facilitate establishment of bilateral relations between Member States for nuclear capacity building and R&D projects. The French CEA was the first organization designated as an ICERR. Mr. Borio emphasized that even a low power RR requires establishment of an adequate national nuclear infrastructure to ensure safe, secure and effective construction and operation of the facility. Such infrastructure, even if to a lesser extent, was similar to the infrastructure required for a nuclear power programme. Under–estimating the national commitments related to development of such infrastructure might seriously compromise the success of the research reactor project. The IAEA did not encourage or discourage the construction of new RRs but offered assistance to Member States, upon their request and with a holistic approach, to take an informed decision on the feasibility of such projects. Once the decision to proceed was taken by a Member State, the IAEA also offered assistance, through several different means (often through technical cooperation projects) for safe and secure construction, operation as well as effective utilization of such facilities.

In an invited paper, **Mr H. Blaumann (Argentina)** gave a detailed description of the technical and safety requirements for the new RA–10 reactor of CNEA constructed by INVAP. The safety approach emphasized defence–in–depth and maintenance of safety functions, with consideration of design basis events outlined in Safety Requirements NS–R–4 and extreme external events. Siting studies included seismic, hydrology and aircraft crash. SSCs are classified according to importance to safety and acceptance criteria formulated according to the classification. In Argentina regulations require compliance with risk–based criteria, so a PSA is essential. An extensive external event safety assessment was conducted based on the information provided by the site evaluation; this evaluation led to raising the site 1 meter to accommodate possible flooding. Mr. Blaumann also discussed technical requirements and design objectives for the reactor.

Mr J. Perrotta (Brazil) talked about the status and future plans for the RMB project of Brazil. The RMB reactor would be the centrepiece of a new research centre located at Ipero, 110 km from Sao Paulo. The design was based on the OPAL reactor in Australia. Its principal purpose would be isotope production combined with neutron beams research. Mr Perrotta reported that the conceptual and basic designs were finished and the environmental permitting and licensing activities for a construction permit were being conducted. However, the budget for the project was not all available. More support from the government and the local people were needed.

Mr A. Tuzov (Russian Federation) explained the background, characteristics, international cooperation scheme and status of the MBIR project which was being conducted by Research Institute of Atomic Reactors (RIAR) in Dimitrovgrad. The MBIR was a 150 MW (t) sodium–cooled fast reactor intended to be the centrepiece of an international research centre. It was scheduled for commissioning in 2020. Mr Tuzov reviewed the design of the reactor, the heat transport system and experimental facilities. He reported that the foundation plate pouring was completed in September 2015, a sign of smooth start of the construction phase.

Papers, Part 2

Mr I–C. Lim (Republic of Korea) presented an invited paper on a Feasibility Study for a New Research Reactor Project, where he addressed the scope of the feasibility study, the general content of the feasibility study report and presented an example of the feasibility study for the KJRR. He emphasized that newcomers should pay close attention to infrastructure issues in a feasibility study. Mr Lim also reported the status of KJRR project, including qualification of new high–density U–Mo LEU fuel. The KJRR was now 43% implemented. Irradiation of a lead test assembly started one week ago in the Advanced Test Reactor (ATR) in the USA; the target burnup was 65% average and 85% peak. The basic utilization of the KJRR would be radioisotope production and silicon doping, but some elements in the design were included to have additional capability later but not taken into consideration in the feasibility study.

Mr I. Rotaru (Romania) discussed the role of a research reactor in the development of the national infrastructure for nuclear science and technology. In addition to their applications in research, isotope production, imaging and neutron activation analysis, research reactors can have a large contribution in education and training in all areas of nuclear technology. In countries having nuclear power, as programmes matured the role of research reactors in job–specific training decreased; full–scope simulators were now the main tool for nuclear power plant operator training. For embarking countries, a research reactor could help to build confidence in nuclear technology, build capacity and public acceptance. Having a research reactor was good, but not mandatory; its value to the nuclear power programme might diminish once the power plant is in operation.

Mr M. Gurisha (Tanzania) discussed development of supporting infrastructure for a new research reactor project in Tanzania. Developing a research reactor was a primary instrument to achieve Millennium Development Goals (MDG) and National Vision 2025. For Tanzania the main issues were: legislative and regulatory framework, radiation protection, human resources development, stakeholder involvement, site survey and selection, radioactive waste management, which were being shaped with the IAEA assistance through TC project. There was a need for research reactor in Tanzania because the facility would have an impact in every aspect of social and community development. It would contribute to a country's scientific and educational resources, raise living standards through improved health care, industrial and agricultural productivity, and pave the way to the utilization of nuclear energy. It would be an extraordinary tool with capabilities that include training of scientists and engineers, research and technology, testing of materials, radioisotope production (for industrial and medical applications), and other commercial applications.

Mr J. Lu (People's Republic of China) addressed the design of miniature neutron source reactor (MNSR) with LEU core, which was an improved version for medical and scientific application with an enhanced epithermal beam for boron neutron capture therapy (BNCT). An overview of the design features of the new MNSR with LEU core was presented. The fuel was more closely packed, leading to better safety and a harder neutron spectrum. Fuel was UO_2 at 13% enrichment. Actual power for the new facility was 30 kW but it was expected to increase to 45 kW.

Mr N. Waeckel and Mr G. Bignan (France) jointly presented a paper on the key role of materials testing reactors in support to nuclear industry. They gave an example of the Jules Horowitz Reactor (JHR) and the ICERR scheme. In–pile testing was required to ensure that fuel elements withstand normal operation and the transients to which they may be exposed. Design and safety margins were challenged by new fuel management schemes, new design standards and specific safety issues to be accounted for in safety analysis. Improved modelling, calculation tools and testing, safety design methods and an improved fuel product could generate additional margin to accommodate the challenges. The JHR was expected to provide a facility for in–pile simulation of normal and accident conditions and satisfy these needs of the industry. Mr Bignan reported on the status of the JHR and preparing the JHR international community, including the annual seminar, three working groups, the secondee programme and the recent ICERR designation by the IAEA. The ICERR centred on the JHR would serve as an international resource for better utilization and sharing of research reactor facilities, in particular to the countries without such capabilities.

SESSION F: POSTER PAPERS

Ms J. Lupiano (Argentina) presented a summary of the thermal/hydraulic design of the COQUI reactor, which was a set of two twin 10 MW reactors for radioisotope production now in the preliminary design stage (Phase 2).

Mr T. Sembiring (Indonesia) presented the status of research reactors operated by BATAN in Indonesia and a conceptual design of new multipurpose reactor in Phase 1.

Mr B. Munkhbat (Mongolia) showed a conceptual study of a research reactor for radioisotope production to meet the local needs of Mongolia.

Mr H. Chae (Republic of Korea) presented the design characteristic of KJRR and its implementation status, which was in Phase 3.

SESSION G: SECURITY OF RESEARCH REACTORS

Twenty–one papers were presented in this session including 1 invited, 4 contributed oral papers and 16 poster presentations.

In an invited paper, **Mr D. Ek (USA)** discussed how the changes in the global threat environment raised concerns about nuclear security. In response, international community steadily improved the concepts and approaches to nuclear security, leading to establishing risk–informed security levels for research reactors stemming from a performance–based approach. He outlined the relationship between safety and security events and the resulting security development, and described the resulting risk–based nuclear approach to security management. The effectiveness of three fundamental security system capacities – detection, delay and response – can be achieved by the individual robustness of each of these three fundamental capacities against the adversary; the efficiency of integration of these three capacities for all adversary scenarios; and the effectiveness of the systematic approach to security management, which includes quality controls. He discussed the introduction of design basis threats, a more structured approach to sabotage analysis, methods to effectively address insider adversaries, a quantified and performance–based system vulnerability assessment approach and a security risk management approach to inform decision makers. This improvement is a result of collaboration by international community and has resulted in a mature, systematic, and structured approach to nuclear security management. Mr Ek emphasized three points: not all adverse consequences are unacceptable and that all unacceptable consequences require security resources; all unacceptable consequences are not equal and a graded approach is necessary; and the likelihood of unacceptable consequences cannot be reduced to zero and some risk is acceptable. Attempts by an adversary cannot be controlled, but their success can be controlled. Nuclear security has common objectives with nuclear safeguards – to protect the material.

Mr E. Ryan (Australia) described a new Agency technical guidance document for research reactors and associated facilities (RRAFs), Nuclear Security Management for RRAFs, which builds on the recommendations of INFCIRC–225, Rev. 5 and Security of Radioactive Sources. Nuclear security was a key part of the Integrated Management System (IMS) of the facility. The facility IMS incorporated the overall facility organization management components in a single framework or structure. The Nuclear Security Management System (NSMS) was practices for executing and monitoring the Nuclear Security Programme. NSMS components were operations, processes and security forces. The NSMS interfaced with processes in the Facility IMS – importantly safety.

Mr J. Lolich (Argentina) addressed safety considerations when implementing security at RRAFs. Nuclear security and nuclear safety shared the same ultimate goal: to protect individuals, the public, and the environment from harmful effects of ionizing radiations. The activities that addressed nuclear safety and security had different focus and sometimes actions that were taken in one area can have implications for the other one. Nuclear safety and nuclear security were similar, but they were not identical. Safety and security measures must be designed and implemented in an integrated manner so that security measures did not compromise safety and safety measures do not compromise security. A safety/security interface was needed. Appropriate application of design concepts and criteria for nuclear safety and good operational safety practices would enhance the protection against sabotage. Specific attributes in some areas related to nuclear safety and nuclear security might lead to conflicts in the implementation of the relevant activities. This conflict should be managed by proper coordination of the methods and approaches, and operating practices through the RRAFs lifetime. Access and operations by emergency teams must be facilitated for safety reasons, but access to certain areas must be permanently controlled.

Ms R. Leitch (USA) presented an overview of international policies and tools for protecting against radiological sabotage in nuclear and radiological facilities. The paper highlighted the role and responsibilities of competent authority and site operator regarding vital area identification process protecting sabotage and cooperation among the entities for mitigation measures. She introduced several PC–based user tools for sabotage analysis and radiological assessment.

Mr G. Heo (Republic of Korea) introduced a method for cyber security risk evaluation using event trees (ETs) and a Bayesian Belief Network (BBN) for cyber security of digital instrumentation and control (I&C) systems in research reactors. The paper proposed using event trees to deduce the critical I&C assets in various hazard scenarios and a Bayesian Belief Network to quantify models based on qualitative values. Mr. Heo noted USNRC Regulatory Guide 5.71.

SESSION G: POSTER PAPERS

Mr E. Ryan (Australia) presented a poster on developing a security plan. The poster described essential information and relevant guidance to be included in preparation. Additionally, it explained that the level of detail and depth of content should be commensurate with the category of facilities and material to be protected.

Ms E. Susilowati (Indonesia) presented a poster on the nuclear security management system to be implemented at the GA SIWABESSY RR. The poster described how adequate security management by way of an early and continued safety/security interface allows an efficient security programme.

Mr D. Ek and co–authors (USA) presented a poster on the adversary threat environment and its impact on nuclear security. This poster described the inadequate process of using open–source data in developing a threat assessment (TA) which in–turn is used to determine a facility’s physical protection regime. The poster also alluded to the opinion that the typical physical security regime is static and may not be adequate for today’s dynamic threat environment.

Mr D. Ek and co–authors (USA) presented a poster that describes the various benefits of table top exercises in identifying gaps in security systems, incorrect assumptions made by operators and first responders about each other’s actions and differences in understanding between responder agencies, and help identify ways to mitigate vulnerabilities.

Mr D. Ek and co–authors (USA, Australia, and IAEA) presented a poster on a coordinated research project (CRP) on strengthening research reactor security. The poster described the benefits and process (topics) for Member States conducting a Coordinated Research Project (CRP).

Mr D. Ek and co–author (USA) presented a poster discussing the similarities and differences between safety analysis and sabotage analysis. The poster described how safety and sabotage analysis both benefit a facility and explained the potential differences between the two. It also described the difference in maturity between the two analyses.

Ms M. Williams (USA) presented a poster on a practical assessment of a facility nuclear material accounting and control (NMAC) system for nuclear security. The poster described the benefits and criteria related to the IAEA guidance for NMAC security.

Mr T. N. Bonner (USA) presented a poster on a table–top methodology for addressing the insider threat. The poster described the benefits and process of performing table– top exercises in evaluation of measures against an insider threat.

Mr T. Edmunds (USA) presented a poster on insider threat analysis and mitigation in research reactors. The poster described the dangers associated with insider threats and a process for performing various analyses to develop an effective insider threat mitigation programme.

Ms M. Williams (USA) presented a poster on steps to be taken to protect against the insider threat. The poster described the benefits of an insider threat mitigation programme to protect the NMAC and the availability of IAEA guidance in assisting in establishing effective insider threat mitigation programmes for facilities.

Mr R. Anderson (USA) presented a poster on the need for cyber–informed engineering expertise for research reactors. The poster described the potential vulnerabilities of digital equipment and the need for cyber security in facilities.

Mr D. Stanford (USA) presented a poster on radiological sabotage training based on the IAEA recommendations in INFCIRC 225, Rev. 5. The poster described the benefits of the PNNL–developed radiological training course for facility managers and operators tasked with implementing the IAEA recommendations.

Ms R. Leitch and co–authors (USA) presented a poster on 'worst–case unacceptable radiological consequence (URC) evaluation, using QLRAM. The poster describes the benefits, capabilities and limitations of using QLRAM software to perform 'worst–case' dispersion analysis which allows users to determine credible threats from a sabotage event.

Mr R. Hoffman (USA) presented a poster that described the differences in the cyber security environment between commercial power reactors and research reactors and the potential cyber security risks to research reactor facilities as a result of these differences.

Mr S. Datres (USA) presented a poster on commercial off–the–shelf technology that could be used as a force multiplier at research reactors. The poster described commercially available, cost–efficient technology that would allow facility security and responders to use cellular phones for communications in providing an effective response to a malicious act.

Mr G. White (USA) presented a poster discussing simple institutional and user best practices that can be applied to computer– and network–based systems for industrial control, physical protection, and material control and accounting in order to improve cybersecurity.

SUMMARY OF PANEL SESSION[4]

The final panel session of the Conference was chaired by Mr P. Adelfang (Argentina), and included the Conference Rapporteur Mr L. W. Deitrich (USA) and expert panellists: Mr H. Abou Yehia (France); Mr A. Bychkov (Russian Federation); Ms T. Ivanova (OECD/NEA); Mr N. Ramamoorthy (India); and Mr G. Storr (Australia).

CONCLUSIONS AND RECOMMENDATIONS

Mr Deitrich presented the draft of the Conference Conclusions and Recommendations to the assembled participants. Participants were invited to submit comments and additions through the Conference 'app' for consideration for inclusion in the final meeting report. The final Conclusions and Recommendations are found above.

STATEMENTS OF THE EXPERT PANELLISTS

Mr Abou Yehia highlighted three positive and important aspects of progress in safety. The first aspect was the increased application of the provisions of the Code of Conduct on the Safety of Research Reactors, such as the performance of periodic safety reviews (PSR) and the implementation of effective ageing management programmes. The second positive aspect was the safety improvements resulting from the safety re–assessments performed in light of the Fukushima–Daiichi nuclear power plant (NPP) accident, in particular in the capabilities of the facilities to withstand beyond design events and in safety management, including regulatory oversight and emergency preparedness and response. The third positive aspect was the improved awareness of national authorities and organizations concerning the challenges associated with the establishment of a first research reactor. These challenges were related to the necessity of capacity building and establishment of sound safety and regulatory infrastructures in compliance with the Code of Conduct and supporting IAEA Safety Standards.

Mr Bychkov addressed three important aspects of the Conference. First, it was a pleasure to see the presentations on new research reactor (RR) projects. The Jules Horowitz Reactor, MBIR and others would bring new opportunities for future R&D and innovative nuclear technologies. It was very important that these instruments are created as international projects from the beginning. The key role of the Agency was to facilitate access of scientists and engineers from many countries to these prospective instruments through regional coalitions and ICERRs. Second, stable and safe operation and utilization of the current research reactor fleet was a key instrument for capacity building for many countries. Establishing new research centres based on research reactors was a valuable step for development of national nuclear programmes and safety culture education. Nuclear industries and national scientific communities needed a lot of trained specialists in different fields. The

[4] The views and recommendations expressed here are those of the named authors, participants and session's chairmen and do not necessarily represent the views of the IAEA, its Member States or of the nominating organizations.

role of the Agency here was also crucial. Newcomer Member States could choose a traditional research reactor, a simple neutron source or an innovative accelerator–driven system. Whatever the choice, the national programmes with research reactors provided a good school for engineers, designers, regulators, radiation protection specialists, scientists and others. Third, new IAEA instruments in combination with existing ones and other support systems could provide a unique service for Member States: to prepare a strategic and qualified decision before establishing new nuclear centre or laboratory. As a former head of the big research centre (RIAR–Dimitrovgrad) who managed during the crisis period, Mr Bychkov highlighted that all decisions related to research reactors should be made after comprehensive analysis. The world economy was not stable and financial support of national R&D programmes could be stopped or reduced unexpectedly. There was a statement about Uzbekistan reactor that the Government decided to stop it. All new projects, new upgrading and conversion programmes should be initiated only after detail consideration. It was noticed that the IAEA proposed now a number of institutional instruments for Member States in order to prepare for an informed decision.

Ms Ivanova highlighted the role of research reactors as an important source of the experimental data contributing to the extensive knowledge preservation programme and joint projects coordinated by the OECD/Nuclear Energy Agency. With the new trends in nuclear science and engineering, the need for integral experiments at large scale remained a high priority including certificated experimental data and benchmarks for validation in reactor physics, nuclear data, multi–physics and multi–scale simulations, experimental tests of fundamental properties and performance for advanced core materials and components, and fuel behaviour, as well as differential and integral data for support of minor actinide management technology. Although the operational flexibility of most research reactors and on–going modernization of the current fleet reported on the conference allowed addressing the major needs identified for the nuclear industry, it has been recognized that specific actions were required through international collaboration in order to pool resources, identify qualified facilities and measurement techniques.

Mr Storr addressed safety and security issues in research reactors. He expressed his support to the good management and leadership, because good management and leadership will invariably lead to great outcomes in a business. For the research reactor community that translated to reliable operations and great utilization of our reactors. The maturation of the approach in nuclear security where it became an activity that was systematic and integrated into operations has been discussed in this Conference. This integration means that the interface between safety and security requires awareness, then understanding, followed by practice in making sure that safety and security issues received the attention and treatment they deserved. Practical examples and experiences that could be shared using the graded approach in safety and security and how the interface between safety and security issues was managed would lead to benefits for operators and regulators of research reactors. Looking to the future, it was clear that for new facilities which were being designed and built and existing facilities which were operating and undergoing upgrades cyber–security would be a key factor in operations and utilization. Finally, good leadership leverages human capital and resources – and in safety and security the culture of RR staff was paramount in helping to protect RR facilities from accidents and threats.

Mr Ramamoorthy noted that the successful conduct and outcome of the 2015 International Conference was the culmination of the efforts of the (international) Technical Programme Committee (TPC) and of the IAEA Secretariat. As the Chair of the TPC, he conveyed his appreciation for the successful conduct of the event and thanked the Co–Members of TPC, many of whom were in attendance at the Conference, for their fine contributions. The topical Session on 'Common Management Considerations (CMC)' has been instituted for the first time in this Conference series by the TPC to highlight the need and importance of integrated management of all aspects and activities of research reactor organizations. Establishing and implementing an Integrated Management System (IMS) would be the key in this context. An IMS aids achieving an effective interface and smooth overlap between inter–connected and inter–related management functions, as for example, O&M of the research reactor vis–à–vis ageing management vis–à–vis utilization; and safety and security of the facility. All stakeholders in research reactor organizations derived benefits from the IAEA's support and services – most of which were directed towards addressing CMC and delivered through cross–cutting activities planned and implemented by the IAEA Secretariat, along with expertise of Member State academia and industry called upon as required for specific domain competencies. It was imperative to continue to nurture and further strengthen such cross–cutting activities and services. Repeated reference made to the IAEA documents and publications in almost all the presentations at this Conference was yet another endorsement of the high utility and value of these IAEA products to the entire research reactor community and associated stakeholders, be they operators, academia, regulators, Government, etc. The research reactor community looked forward to the continued delivery of IAEA publications and their periodic revisions and update as needs aroused.

DISCUSSION

One participant suggested that guidance for PSR for research reactors be emphasized because the only Agency guidance available was for nuclear power plants.

It was also suggested that the research reactor community paid more attention to spent fuel disposition, because the fuel take–back programmes would end and the issue would return with urgency.

Another participant reported that a license condition for his facility requires a combined periodic safety and security review. This would require early preparation, since this was a new undertaking and it was not clear how to address it. It was also noted that effective coordination among the reviewers was important, especially if they were from different government agencies.

With respect to application of the graded approach, another participant suggested that the Agency needed to go farther into interpretation and application of the concept than was currently available. The principle was known but application in practice was difficult. A comprehensive document would be useful. The Conference also noted that a Technical Meeting on the graded approach was being organized for May 2016.

One participant noted that the research reactor user community was not well–represented at the Conference and suggested that an effort be made to increase involvement of this community in future Conferences.

Finally, the Chair noted with pleasure the outstanding level of cross–cutting coordination in the research reactor programmes and the culture of cooperation that has developed in the Agency.

CLOSING SPEECH[5]

J. C. Lentijo
Deputy Director General
Head of the Department of Nuclear Safety and Security

Good afternoon, ladies and gentlemen.

On behalf of the IAEA Director General, I thank you for your participation in this, the fifth quadrennial International Conference on Research Reactors: Safe Management and Effective Utilization. I am especially pleased that more than 300 participants from 56 Member States are here. A total of 74 papers have been presented orally, along with 74 poster presentations. The large attendance and number of papers reflects a strong interest in exchange of information and experience, and a healthy desire to learn from one another and to continue improving.

The Conference has covered a comprehensive list of topics, ranging from new reactor projects and common management considerations, through utilization, applications, operation and maintenance of the existing reactors, to spent fuel management and decommissioning, plus the overarching considerations of safety and security. This wide variety of topics demonstrates the broad interests and concerns of the world–wide research reactor community. The Conference programme included 5 keynote presentations from the IAEA staff, which summarized the Agency's work in the various topic areas, along with the documents and services available to the Member States. 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 a future nuclear power programme. I encourage these countries to make use of the Agency's resources to ensure that new reactors and adequate infrastructure make use of international best practices and guidance, including the IAEA Safety Standards, to ensure a high level of safety and security, along with effective and utilization.

During this week, we have heard of progress in many important areas: safety and security, use of research reactors in education and training, scientific and industrial applications, maintenance practices and core fuel conversion to LEU. However, issues and challenges remain. Some of these include: lack of new fuel for TRIGA reactors and continued challenges in development of LEU fuel for high–performance research reactors; completion of safety reassessments in light of the Fukushima–Daiichi NPP accident and implementation of needed improvements; ageing of many research reactors, with the potential impact on safety and reliability and supply of important medical isotopes; and lack of planning for decommissioning in many cases. As always, the Secretariat stands ready to assist the Member States in working to address these issues and challenges.

[5] The views and recommendations expressed here are those of the IAEA's Deputy Director General and do not necessarily represent the views of the IAEA or its Member States.

Preparation of this Conference has been a “one–house” undertaking. In particular, I want to recognize the three Scientific Secretaries Mr Andrea Borio di Tigliole, Mr Danas Ridikas and Mr Amgad Shokr, and Ms Martina Neuhold of Conference Services were instrumental in organizing the Conference. Special thanks go to the members of the 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.

SUMMARY OF THE CONFERENCE SIDE EVENTS[6]

Side Event 1: IAEA Support to Education and Training Based on Research Reactors

Side event 1 provided an overview of the IAEA's education and training activities on safety, operations, maintenance and utilization of research reactors with emphasis on activities that directly involved the use of research reactor facilities. About 40 conference participants representing operating organizations, regulatory bodies and State governments attended the event. Mr R. Altamimi (Jordan) related experience with the Eastern European Research Reactors Initiative (EERRI), which used research reactors in Austria, Czech Republic, Hungary and Slovenia for theoretical and hands–on training of students from around the world. Mr F. Foulon (France) presented the capabilities and opportunities available with the Internet Reactor Laboratory (IRL) centred on the CEA–ISIS research reactor in France, which internationally broadcasts reactor physics experiments online. Mr W. Kennedy (IAEA) reported on regional workshops on regulatory supervision, which includes simulated inspections of research reactors in the host countries. Mr A. D'Arcy (IAEA) introduced new IAEA training packages covering safety of operations and operational radiation protection to be published in 2016.

The participants' feedback indicated that IAEA should continue to develop and promote education and training activities based on research reactors, with the greatest interest being in expanding access to existing activities such as EERRI and IRL (or creating similar activities in other regions), providing activities that were relevant to regulatory bodies and reactor designers and increasing activities of a cross–cutting nature, such as computer codes and models for research reactor analysis.

Side Event 2: IAEA Assistance to New Research Reactor Projects

Side event 2 on IAEA assistance to new research reactor (RR) projects 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 embarking on new RR projects, to share lessons learned from the new RR projects and to obtain feedback on the IAEA services offered to its Member States. The presentation by Ms A. Zhukova (IAEA) covered the IAEA's milestones approach; a companion presentation by Mr D. Sears (IAEA) covered specific safety considerations in different phases of a new RR project. The invited speakers included Mr G. Bignan (France), Mr K. Abu Saleem (Jordan) and Mr M. Gurisha (Tanzania), who reported on their new RR projects, which covered a broad range of power levels and different phases/stages. The invited speakers shared their experience and highlighted the main challenges of the new RR projects their country. The lessons learned and feedback highlighted the importance of strong stakeholder support, suitable site selection, a robust

[6] The views and recommendations expressed here are those of the named authors, participants and session's chairmen and do not necessarily represent the views of the IAEA, its Member States or of the nominating organizations.

feasibility study, and adherence to the IAEA Safety Standards during all phases of the project.

It was highlighted that an RR project is a major undertaking that requires careful preparation, planning, implementation and investment in time, money, and human resources. New RR projects need to be justified based on the national and/or regional needs for RR services, a robust utilization programme, availability of a suitable site, and full awareness of and national commitment to establish the necessary safety and technical infrastructure. The Member State were suggested to develop a comprehensive understanding of the obligations and commitments involved, and ensure that there was a long term national strategy and resources available to discharge these obligations. Establishment of the safety infrastructure would need to start early in the process and be achieved progressively during different phases of the project. Safety infrastructure was best achieved through the effective application of the IAEA's Code of Conduct on the Safety of Research Reactors and the supporting Safety Standards.

In concluding remarks, Mr A. Borio di Tigliole highlighted that the IAEA offered assistance to Member States, upon their request and with a holistic approach, to take an informed decision on the feasibility of such projects. The participants' feedback indicated that IAEA needed to continue to assist Member States in establishing the infrastructure using a phased approach that was matched to the needs of the project, and to support the achievement of associated milestones for each phase of the project.

Side Event 3: IAEA Assistance to Addressing Research Reactor–based Radioisotope Production Issues

Side event 3 was attended by some 35 participants. The IAEA presentation by Mr J. Osso Junior covered the resources, mechanisms and initiatives available to support Member States in radioisotope production and supply. Mr N. Ramamoorthy (India) emphasized the different approaches to get the assistance, evaluating the real needs of the country and the possible routes of production, including alternative pathways. Mr V. de Villiers of the World Council on Isotopes (WCI) expressed the need for an approach to promotion of radioisotope utilization, focusing on radioisotopes employed also in other applications, not only medical.

During the discussions, the important role of the IAEA in advising and providing support to Member States in the production and supply of radioisotopes for several applications was highlighted. It was emphasized that the support needed to reach the regions and not only the specific individual countries and expand cooperation and joint actions to address the demand–supply chain, including continued cooperation with the OECD/NEA. Furthermore, the side event participants recommended that IAEA needed to provide enlarged assistance covering all the radioisotope production–supply chain, from the preparation and irradiation of the targets, going through the processing, waste management, quality control and assurance and regulatory issues, both radiological– and health–related.

ANNEX

CONTENTS OF THE ATTACHED CD–ROM

The attached CD–ROM contains the technical programme of this Conference as well as all papers and posters presented. The reader needs to click on ***GO button*** or ***Index* of the CD–ROM** to view its contents and navigate through the available documents.

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