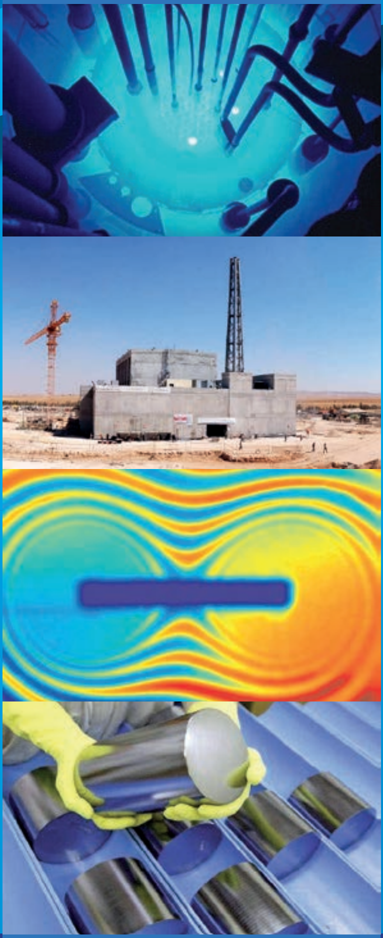
Research Reactors: Purpose and Future



IAEA

60 Years

Atoms for Peace and Development

Foreword

For more than 60 years, research reactors (RRs) have been centres of innovation and productivity for nuclear science and technology. The multidisciplinary research that RRs support has spawned new developments in nuclear power, radioisotope production and nuclear medicine, neutron beam research and applications, materials characterization and testing, computer code validation, various elemental analyses and capacity building for nuclear science and technology programmes.

To date, some 774 RRs have been built, and of these, 243 reactors in 55 countries continue to operate in 2016. However, half of the world's operational RRs are now over 40 years old. Many of them are being refurbished to meet today's technological standards and safety requirements. However, the challenges associated with low utilization of several RRs, ageing, fuel cycle, along with the maintenance of staff and funding for these facilities, continue to be important issues in many countries.

On the other hand, a number of IAEA Member States are increasingly interested in launching nuclear science and technology programmes, including nuclear power programmes. They have approached the IAEA for advice and assistance in building their first RR and to develop their technical and safety infrastructures.

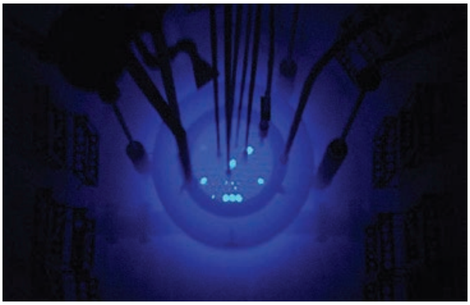
The IAEA has also continued to support several initiatives to assist Member States in core conversion and fuel repatriation projects, organizing topical meetings and workshops, encouraging collaboration through coordinated research projects, as well as supporting the safe utilization of research reactors through national and regional technical cooperation projects. In addition, the IAEA continues to encourage the application of the Code of Conduct on the Safety of Research Reactors and relevant Safety Standards. Upon the request of Member States, the IAEA conducts review and expert missions to assist in enhancing the safety and utilization of these facilities, as well as their operational performances. Furthermore, through strategic planning and allied support, the IAEA assists Member States to become part of RR coalitions and networks to improve all aspects of the utilization, modernization and sustainability of existing RRs. Countries without RRs are encouraged to join these coalitions as a first step in developing their national capabilities, either as a partner or as an end user of RR products and services.

Research reactors are extremely valuable training, research and technological tools, and it is important that their use remains viable. The IAEA is assisting its Member States in attaining these goals, thus helping to fulfil the promise that nuclear science and technology offer for the good of humanity. I hope you will find this booklet provides a useful overview of research reactor applications, associated management issues and the IAEA's support to Member States.

Research reactors

For more than 60 years, research reactors have been providing a source of neutrons for a wide variety of scientific purposes in more than 50 countries around the world.

Research reactors comprise a wide range of different reactor types that are not used for power generation. The primary use of research reactors is to provide a neutron source for research and various applications, including education and training. They are small in comparison with power reactors whose primary function is to produce electricity. Research reactor power ratings are designated in megawatts and their output can range from zero (e.g., critical assembly) up to 200 MW(th), compared with 3000 MW(th) (i.e., 1000 MW(e)) for a typical large power reactor unit.



Looking into the pool of Morocco's TRIGA Mark II research reactor, which was licensed in 2007. Source: CENM, Morocco.

Research reactors are also simpler than power reactors and operate at lower temperatures. They need far less fuel, and far less fission products build up as the fuel is used. On the other hand, their fuel requires uranium with much higher enrichment, typically up to 20% U-235, than that of power reactors (3-5%). Some unconverted research reactors still use highly enriched uranium (HEU) fuel containing up to ~90% U-235.

Research reactors also have a very high power density in the core, which requires special design features. As with power reactors, the core requires cooling, and usually a moderator is required to slow down the neutrons to enhance fission. Many research reactors also use a reflector to reduce neutron loss from the core and to sustain the chain reaction.

TYPES OF RESEARCH REACTORS

There is a much wider array of designs in use for research reactors than for power reactors, and they also have different operating modes, which may be steady or pulsed.

Common designs are pool-type, tank-type and tank-in-pool reactors. In pool-type reactor the core is a cluster of fuel elements sitting in a large open pool of water. In tank-type reactor the core is contained in a vessel, as it is in nuclear power plants. In tank-in-pool type reactors the core is located in a pool, but enclosed in a tank through which the coolant is pumped. The tank contains the moderator/reflector, usually different from the coolant. Between the fuel elements are control rods and empty spaces (channels) for experiments. In one particular design, the Material Testing Reactor, a fuel element comprises several aluminium-clad fuel plates in a vertical box. The water moderates and cools the reactor, while graphite or beryllium is typically used for the reflector, although other materials may be employed. Circular or ellipsoidal beam tubes penetrate the reactor shielding, the vessel, and pool to access neutron and gamma beams from the core for experimental uses in the reactor hall.

The TRIGA reactor is another common design. This kind of reactor is very versatile: because of the unique U-ZrH fuel, it can operate either at steady state or safely be pulsed to very high power levels for fractions of a second (in the order of GW).

Other types of cores are cooled and moderated by heavy water. Less common types are fast reactors that require no moderator and use HEU or a mixture of uranium and plutonium as fuel. Homogeneous type reactors have a core that acts as a tank, containing a liquid solution of uranium salts, i.e., its fuel is liquid.

Many of the world's nuclear reactors are used for research and training, materials testing, and production of radioisotopes for medicine and industry.

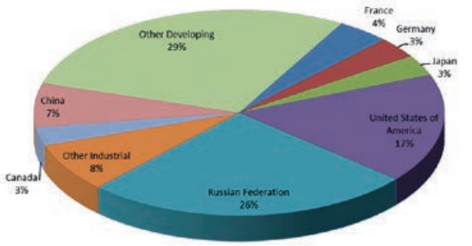
These research reactors are much smaller than power reactors, and many are located on university campuses.

Research reactors worldwide

Research reactors offer a diverse range of uses from basic research to industrial applications.

GLOBAL STATUS

The IAEA lists several categories of broadly classified research reactors. The Russian Federation has the highest number of operational research reactors (including critical facilities) with 63, followed by the USA (42), China (17), France (10), Japan (8) and Germany (8). Many developing countries also have research reactors, including Algeria, Bangladesh, Colombia, Ghana, Jamaica, Libya, Morocco, Nigeria, Thailand and Viet Nam. Other Member States are building or planning to build their first research reactors in the very near future, namely Jordan, Azerbaijan, Sudan, Bolivia, Tanzania, and Saudi Arabia.



Worldwide repartition of operational research reactors. Source: IAEA RRDB

Many research reactors were built in the 1960s and 1970s. Operation reached a peak in 1975 with 373 research reactors in 55 countries, compared with the current number of 264 (including 19 RR temporarily shut down) in 55 states. Indeed, more than 70% of operational research reactors are over 30 years old and more than 50% are over 40. To date, 483 research reactors have been shut down or decommissioned, with some serving as museums of nuclear history.

USES OF RESEARCH REACTORS

Research reactors offer a diverse range of applications, such as neutron beam research for material studies and non-destructive examination, neutron activation analysis to measure minute quantities of an element, radioisotope production for medical and industrial use, neutron irradiation for materials testing for fission and fusion reactors, neutron transmutation doping of silicon, gemstone coloration, etc. Another important area where research reactors have a large contribution is education and training in all nuclear technology areas for operators, maintenance and operational staff of nuclear facilities, radiation protection personnel, regulatory personnel, students and researchers.

Useful links and information

The IAEA publishes information on broadly classified research reactors through its Research Reactor Database (RRDB) available at

http://nucleus.iaea.org/RRDB

TRENDS

Even though many research reactors are not used at their full capacity and many older ones will be shut down and subsequently decommissioned, research reactors will continue playing a very important role in the coming decades. Presently, six new research reactors are under construction, 11 have been constructed during the last 10 years, and 19 were completed between 2005 and 2014. Some of these new reactors are designed to produce high neutron fluxes and will be either multipurpose reactors or dedicated to specific needs for the next generation of fission and future fusion reactors.

Close to complete construction of the Jordan Research and Training Reactor (JRTR), with the 1st criticality achieved in April 2016. Source: JAEC.

IAEA policy and priorities

The IAEA supports international networks of research reactors in its Member States to make them better utilized, modernized, more sustainable, safer and more secure.

IAEA POLICY

The IAEA's policy is to promote, support and assist Member States (MS) in the development and maintenance of dynamic, safe and secure research reactors dedicated to the peaceful uses of atomic energy and nuclear techniques for the benefit of the nuclear industry and the well-being of humanity.

IAEA PRIORITIES

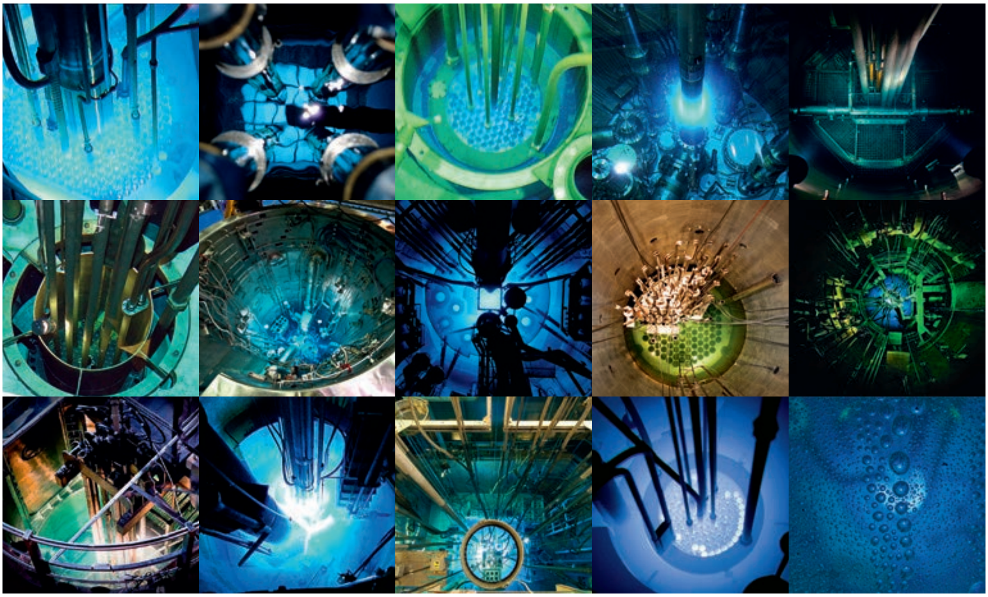
- Enhance the utilization of facilities consistent with their capabilities and objectives, provided there is financial commitment by the national government and/or industry.
- Assist countries within regions to collaborate and address common issues and problems with their governments' support.
- Help to share research reactor resources and assist in the development of state of the art facilities, thus helping in socioeconomic development through the emergence of spin-off technologies.
- Assist MS in addressing safety and security concerns in existing research reactors and associated fuel cycle facilities, and also assist in the decommissioning of shutdown reactors with appropriate political and financial commitment by the national government and/or industry.
- Assist MS in setting up new research reactor facilities including the establishment of necessary national infrastructure.

Three pillars of the IAEA

The IAEA works for the safe, secure and peaceful uses of nuclear science and technology.

It contributes to international peace and security, and to social, economic and environmental development.

Promoting science and technology, safeguards and verification, and safety and security are the three main pillars of the IAEA.



In 2016, there were 245 research reactors operating in 55 countries.

Photographs: Sandia National Laboratories, TU Delft, Centre National de l'Énergie des Sciences et Techniques Nucléaires, Technische Universität München, Czech Technical University in Prague, Dalat Nuclear Research Institute, Australian Nuclear Science and Technology Organisation, Research Centre Rez, Korea Atomic Energy Research Institute, CEA - Commissariat à l'énergie atomique et aux energies alternatives, Oregon State University, Jožef Stefan Institute

Education and training

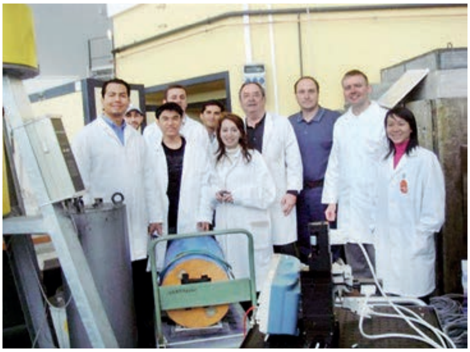
Many research reactors are located at universities or research institutes and serve as key tools in nuclear education and training.

DISSEMINATION AND PRESERVATION OF KNOWLEDGE

Research reactors have the potential to create awareness of the advantages of nuclear technology for social development including the many medical applications. Information and training about the uses of research reactors can be made available to students as well as other interested members of the public. Many research reactors have been built on university premises. Being located alongside academic institutions has enabled research reactors to contribute vastly to higher nuclear education.

Since 2009 the IAEA is offering the Group Fellowship Training Programme to assist Member States that are considering building research reactors, as a first step to develop nuclear competence and infrastructure in the country. This training course helps developing the necessary skills and background to carry out activities related to planning, evaluation, development, construction, commissioning, utilization, operation and maintenance of research reactors, with the full understanding that at the end, a decommissioning plan and a solution for spent fuel are necessary. The Programme has been organized and successfully implemented within the framework of the Eastern European Research Reactor Initiative (EERRI). Four participating EERRI institutions with research reactors have focused on three main goals:

- Provide hands-on training in the areas of nuclear science, radiation protection, nuclear instrumentation and reactor physics.
- Ensure a broad comprehension of the utilization of research reactors through both public and scientific visits and demonstration experiments
- Develop basic know-how for operation of nuclear power plants through platforms for training operators and regulators of nuclear power reactors in some countries.



IAEA Group Fellowship Training Programme within the EERRI. Source: AtomInstitut, Austria.

Training at Czech technical university in Prague, Czech Republic.

Hands-on training

Every research reactor is an important tool of advanced nuclear education and training.

This application should be thoroughly explored and utilized to the benefit of the community.

Applications of research reactors

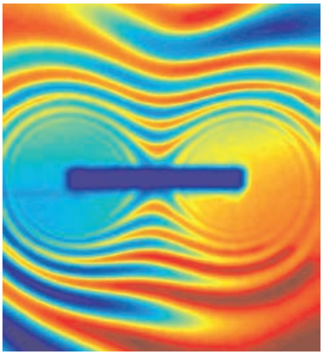
Research reactors are crucial to improving human health and quality of life, manufacturing better industrial products, and advancing science and technology.

IMPROVING THE QUALITY OF LIFE WITH NEUTRONS

Research reactors are mainly used to produce neutrons. However, it is not obvious to most people how the achievements of neutron research have influenced daily life. Research with neutrons started with their discovery by J. Chadwick in 1932 and gained momentum after the mid-1950s through intense techniques for the use of neutron scattering applied by thousands of researchers.

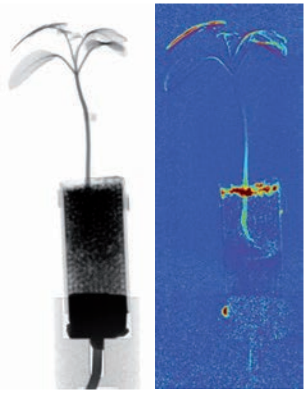
Neutrons, together with protons, are the constituents of an atom's nucleus, but each can also exist alone. In order to understand why neutrons are of interest to physicians, biologists, geologists, physicists and chemists in research and development as well as in many industrial applications, it is necessary to know the special nature of neutrons and the manner in which they interact with matter:

- **Neutrons are electrically neutral.** They are highly penetrating and can test materials non-destructively. For example, neutrons support the construction and quality control of parts of new cars or airplanes.
- **Neutrons are sensitive to light atoms.** Since living material is mostly composed of hydrogen, the lightest element in the universe, neutrons are ideal for investigating biological materials or various devices containing hydrogen as a composite.
- **Neutrons can induce nuclear reactions** and therefore lead to the transmutation and activation of irradiated samples. These processes provide doped silicon to the semiconductor industry or reveal the age of rock samples. One of the major applications of transmutation in research reactors is in the production of radioisotopes, which are used in medical diagnostics and in treating cancers. Neutron activation helps to improve plastics and detergents, to diagnose diseases, or to investigate pollution by analysing sample contents.
- **Neutrons have a magnetic moment** because of their spin. Magnetic structures can be investigated with neutrons and they help to develop new magnetic storage devices. The spin helps to make measurements of material properties more precise.



Magnetic field 'seen' by polarized neutrons. Source: HZB, Germany.

- **Neutrons can have a wavelength from 10^{-15} m to 10^{-5} m.** Structural information from atomic scale to micrometric scale can be studied using neutrons, with the most common applications being between 10^{-11} m and 10^{-5} m.
- **Neutrons can have energies similar to the elementary excitations in solids.** Therefore the dynamics of molecules and lattices can be studied.



Digital neutron radiography applied to study plants. Source: HZB, Germany.

Use of neutrons

- Education & training
- Basic research
- Medicine
- Industry
- Biology
- Agriculture
- Chemistry
- Geochronology

Applied research with neutrons

The unique properties of neutrons make them a highly valuable tool in many scientific and technological investigations.

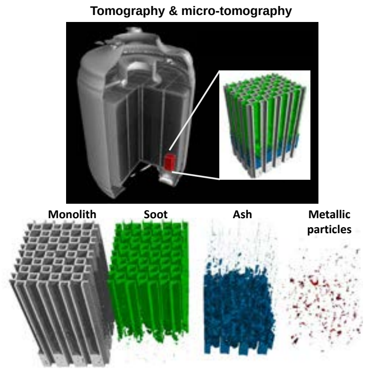
MATERIAL RESEARCH WITH NEUTRONS

Most people know that microscopy and X rays can be used for studying objects in detail. Despite refinements, these methods are not always adequate. A standard microscopy method using neutrons is neutron radiography. In many cases, nuclear applications develop their full potential if they are applied in a complementary manner, for example, combining X ray and **neutron radiography.** The advantage of neutrons is that they are sensitive to many light elements, e.g. water, whereas X rays are more sensitive to heavier elements, e.g. the components of steel. Therefore, this technique can be fully used in an industrial context, essentially for quality control. Using neutrons, glue can be visualized within the metal sheet of a car or plane. Motion radiography is also capable of providing images in real time, as tomography is able to garner three-dimensional information. Even in matters of cultural heritage, such as the arts and archaeology, neutrons are important, as the composition and changes in paint characteristics can sometimes be analysed only by neutrons, for they can discriminate between different types of paints.

Material properties

Neutrons facilitate the study of material properties, e.g. of glasses, plastics, metals, proteins, amino-acids, or magnetic material. Scientists and engineers obtain information about the internal structure, arrangement and dynamics of atoms as well as their magnetic behaviour.

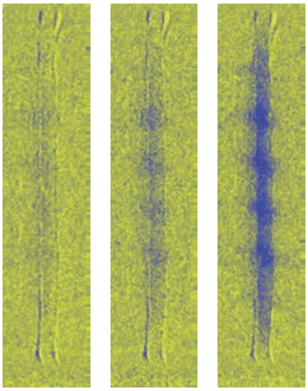
Neutron activation analysis is an important technique for elemental analysis in water, air, soil, fish, meteorites, rocks and even agricultural products and plants. The samples are irradiated in a reactor and later the characteristic gamma radiation emitted by the activated nuclei can identify trace elements in the range of parts per billion (ppb). This technique can be used in environmental analysis to characterize pollution, in archaeology to reconstitute an ancestor's make up, and in biomedicine to perform some hormone diagnostics and detect diseases, among others.



Reconstructed 3D neutron imaging for distribution of soot, ash and metallic particles in a diesel particulate filter. Source: PSI, Switzerland

Thanks to neutrons in **geochronology,** it is possible to go further back in time and date rocks as old as the Earth (4.6 billion years).

Boron neutron capture therapy (BNCT) is an experimental cancer treatment in very specific zones of the human body, such as the brain and mouth. This technique, although still in trial stages, is being explored in a few research reactors around the world and consists of loading the tumour with boron, and then irradiating it with neutrons. Highly ionizing alpha particles are produced by the interaction between neutrons and boron. The particles have a very short range in human tissues, and therefore their high locally deposited energy makes BNCT efficient in killing the tumour cells in only a few sessions.



Water distribution in the membrane of a fuel cell at different operational conditions. Source: PSI, Switzerland.

Development of technology

Neutrons help to examine, qualify and create new materials for research and industry.

Fission neutrons as well as fusion neutrons (the latter more so due to their higher energies) provoke modifications in **material structure.** Depending on the composition and characteristics of materials, they become fragile, elastic or hardened, and can swell, crumble, change their composition, release gas, etc. Each alloy, ceramic and plastic has its own behaviour, which can be verified only by irradiation experiments. Most nuclear power reactors were initially constructed for a 30–40 year lifespan, but the current trend is to extend them to 50–60 years. This life extension of Nuclear Power Plants relies on the tests on materials behaviour performed at research reactors.

Neutrons provide quality assurance before launching a spacecraft. Source: GKSS, Germany.

In fact, since research reactors are able to reproduce mechanical strains undergone by materials in power reactors, they provide essential support to study the ageing of currently operating NPPs, to optimize advanced reactors and to test fuels and materials for innovative reactors (that are likely to be deployed beyond 2050). Research concerning nuclear fusion is also important, since dedicated research and development is needed to find materials that meet the needs for fusion: resistance against temperatures of several million degrees and high energy neutron irradiation.

For the same reasons, research reactors are also used for development, testing, calibration and qualification of **detectors and various instrumentation devices.**

Research reactors for technology

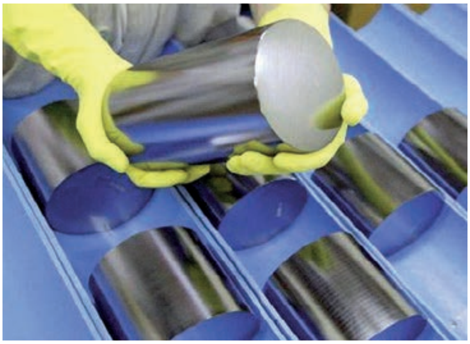
The IAEA assists Member States to improve their standard of living through the benefits flowing from peaceful utilization and application of research reactor technology.

Transmutation is not alchemy

Transmutation in research reactors provides the material to fabricate personal computers or mobile phones, and in the future, it could make spent nuclear fuel less radioactive.

Although the initial nuclear inputs in research, development and production of materials have a relatively low investment cost, they often can contribute in indispensable ways to much larger social and economic enterprises, e.g. in **information technology and energy research.**

Silicon doping is also possible thanks to neutron irradiation facilities. Some silicon atoms are transmuted into phosphorus in a silicon ingot, changing its conductivity as required for semiconductor development. Research reactors can dope large ingots, and techniques have improved the repeatability as well as the homogeneity of the process to meet the growing demands of the electronics industry, including electric cars.



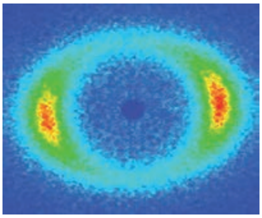
Ingots of silicon ready for neutron transmutation doping. Source: NTP Radioisotopes (Pty) Ltd, South Africa.

From basic research to applications with neutrons

Neutron scattering techniques help to reveal the secrets of nature at microscopic and atomic level.

DYNAMIC DEVELOPMENTS

Neutron scattering techniques are powerful methods to analyse both solid and condensed fluid matter. Generally monochromatic neutrons are used for scattering experiments. The incident neutrons are scattered without a change in their energy (elastic scattering), which provides information about the arrangement of atoms in materials. When neutrons undergo a change in their energy during scattering (inelastic scattering), this can yield information about the movement of atoms in a fluid, i.e. the dynamics of the atom.



This small angle neutron scattering pattern indicates the molecular assembly and how the assembled structure aligns with the flow direction. Source: US National Institute of Standards and Technology.

UNDERSTANDING THE STRUCTURE OF MATTER

Why is the internal structure of matter so important to know and understand? Because structure at microscopic and atomic levels determines the macroscopic properties of a material, including how they react: diamonds and the graphite in pencil lead are both composed only of carbon atoms, but one is transparent and the other black, one is hard and the other brittle, due to their completely different structures. The multiple snowflake shapes correspond to different crystalline structures, and some metals become harder when they are irradiated because of structural changes. Neutrons, owing to their unique properties, contribute to the discovery and understanding of detailed information concerning the structure of matter.

The structure and dynamics of matter revealed

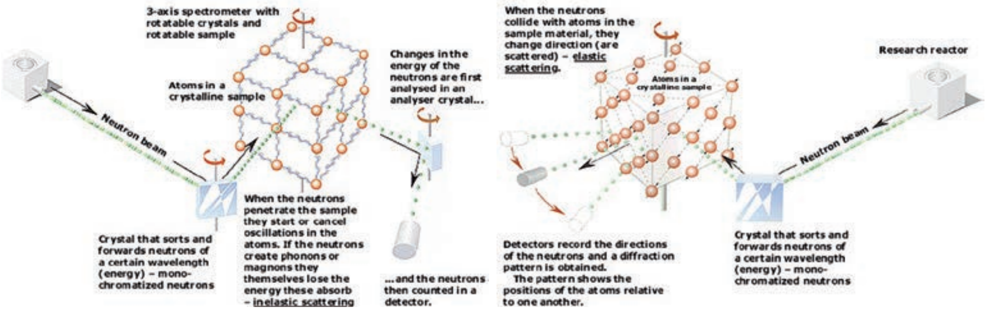
Bertram N. Brockhouse and Clifford G. Shull were awarded the Nobel Prize in Physics 1994 for the development of neutron scattering techniques for studies of condensed matter. The award was the long-awaited culmination of their work to enhance the understanding of material structure conducted shortly after World War II.

For more information, see www.nobel.se

WHY STRUCTURAL KNOWLEDGE IS USEFUL

By performing neutron scattering, biologists understand how bones mineralized during development, or how they repair themselves and decay during osteoporosis. Chemists improve batteries and fuel cells, while physicists create more powerful magnets that could be of use in the future for levitated transport. Neuron experts study proteins essential for the complex functions of the brain. Structure is the key to many breakthroughs in science.

A strong community of several thousands of researchers are using research reactors. However, as neutron scattering is used in widely different areas, new ideas demand new cooperation and new coordinated research integrating different branches of science.



Elastic and inelastic scattering with neutrons. Source: IAEA brochure on RR Purpose and Future (2001).

Neutrons for medicine

Radioisotopes produced in research reactors help diagnose and treat many common diseases including cancer.

According to the World Health Organization, cancer is a leading cause of death worldwide. Furthermore, its occurrence rate is expected to rise as global life expectancy increases. Growing tumour cells are sensitive to irradiation damages, and that is why therapies often employ radioactive isotopes. Depending on their bond capacities with human molecules, it is easy for isotopes to deposit high energy particles in the tumour location, thus performing a local and efficient treatment. Radioisotopes are also very helpful to diagnose many diseases.

Sodium iodide and diagnostic capsules. Source: NECSA (South Africa).

RADIOACTIVE ISOTOPE PRODUCTION

The production of significant quantities of radioisotopes for commercial utilization typically requires a specially adapted research reactor with a higher neutron flux and hot cell processing facilities.

The most important and widely used radioisotope is **technetium-99m (Tc-99m).** Tc-99m is obtained from its parent nuclide **molybdenum-99 (Mo-99),** an isotope which is most commonly produced through the fission of uranium targets in research reactors. The short half-life of Tc-99m (6 hours) and its low energy radiation minimize the patient's irradiation dose while providing diagnosis. It has applications in the evaluation of medical conditions of the heart, kidneys, lungs, liver, spleen and bones, and is also used for blood flow studies.

Key numbers

- 10 000 hospitals use radioisotopes
- 90% of nuclear medicine procedures are diagnostic imaging, 80% of which employ Tc-99m, i.e. 80 000 procedures per day
- More than 200 radioisotopes are currently used

What is a radioisotope?

Atoms are made of protons and neutrons. The number of protons determines the atomic number — the unique identifier of the element. One element can have a different number of neutrons and, therefore, different properties. They are called isotopes. Some are unstable (radioactive) and normally would not exist in nature. These are radioisotopes. Many radioisotopes are produced through the irradiation process in research reactors.

The supply chain for this strategic radioisotope is vulnerable for many reasons. The short half-life of Mo-99 (66 hours) makes distribution logistics difficult and stockpiling impossible. In addition, at present, the majority of the global Mo-99 supply is produced by five industrial producers using eight research reactors for irradiation. Since 2008, there have been widespread shortages of Mo-99 due to unexpected shutdowns at the reactor or processing facilities. To combat this problem, the IAEA supports research reactor coalitions and helps to develop new capabilities for existing research reactors to ensure the stable and secure provision of radioisotopes. In addition, to support international efforts to move away from the use of high enriched uranium (HEU) in civilian applications, efforts to develop targets based on low enriched uranium (LEU) or enriched Mo-98 aim to avoid proliferation without any loss in efficiency.

Typical forms of isotopic radioactive sources. Source: IAEA NE Series publication No. NP-T-5.3 "Applications of Research Reactors", Vienna, 2014

The fuel cycle and related security issues

The IAEA assists MS in RR fresh fuel procurement, spent fuel management, conversion from HEU fuel to LEU fuel, and repatriation of HEU fuel to the country of origin.

RESEARCH REACTOR FUELS

Unlike the fuel utilized in nuclear power reactors (3-5% U-235 enrichment), many civilian research reactors historically have operated using highly enriched uranium (HEU) fuel (i.e., greater than 20% U-235). Higher enrichments can allow for more compact cores with higher neutron fluxes, longer times between refuelling and more varied utilization capabilities. However, most research reactors are currently operated using low enriched uranium (LEU) fuel or could convert to utilize LEU fuel while maintaining the desired performance characteristics.

Given security concerns surrounding the use of HEU, in 1980, a United Nations sponsored International Nuclear Fuel Cycle Evaluation concluded that the U-235 enrichment in research reactor fuels should be reduced to less than 20% to guard against nuclear weapons proliferation. This conclusion followed the creation of the programme for Reduced Enrichment for Research and Test Reactors by the United States in 1978.

Office of Material Management and Minimization

The U.S. Department of Energy – National Nuclear Security Administration's Office of Material Management and Minimization (M3) is dedicated to achieving permanent threat reduction by managing and minimizing nuclear materials. Some of the activities conducted in this office were previously implemented under the Global Threat Reduction Initiative (GTRI).

M3's three missions are:

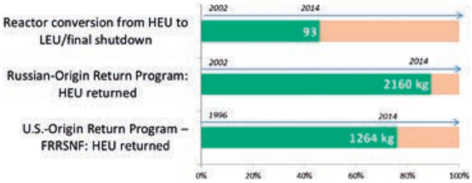
- Convert research reactors and isotope production facilities to non-weapon-usable nuclear material
- Remove excess weapon-useable nuclear material at civilian facilities worldwide and consolidate those materials that remain
- Dispose and manage excess weapon-useable nuclear material, from both domestic stockpiles and material returned from abroad

As of 2015, 93 out of approximately 150 research reactors, operated using HEU fuel, and related facilities have been converted to LEU fuel or verified as shutdown. For those reactors that are unable to convert using existing LEU fuels, international efforts are underway to develop a new generation LEU fuel based on a high-density uranium-molybdenum alloy.

The IAEA also works closely with MS and international partners to support the removal and disposal of HEU from research reactor sites worldwide. The materials include US origin, Russian origin and Chinese origin.

SPENT FUEL MANAGEMENT

Eventually, every Member State with at least one operating research reactor will need to identify a final solution for the storage of spent fuel and other high level waste. This is a subject of key concern relating to the sustainability of the facility, physical security, environmental protection, and, eventually, non-proliferation. Currently spent fuels are stored in a pool for several years before placement into long term surface or underground storage. For countries with no nuclear power programme, the construction of sophisticated geological repositories for the relatively small amounts of spent fuel generated at one or two research reactors may not be feasible. Access to alternative spent fuel disposition options is needed. IAEA supports Member States' efforts to identify the appropriate disposition path for their research reactor spent nuclear fuel.



Combined status of US and Russian Federation nuclear fuel take-back programmes.

Safety of research reactors

As with all applications of nuclear technology, safety is paramount.

As defined in IAEA Safety Fundamentals No. SF-1, the main safety objective in all nuclear installations is to protect people and the environment from the harmful effects of ionizing radiation by establishing and maintaining an effective defence against radiological hazards. This safety objective requires that nuclear installations are designed and operated so as to keep all sources of radiation exposure under strict technical and administrative control.

CODE OF CONDUCT ON THE SAFETY OF RESEARCH REACTORS

The objective of the Code of Conduct on the Safety of Research Reactors is to achieve and maintain a high level of safety in research reactors worldwide through the enhancement of national and international measures. The Code was adopted by the Board of Governors of the IAEA in March 2004 and endorsed by the General Conference in September 2004. The IAEA, within its programme on research reactor safety, continues to assist Member States in the effective application of the Code. This assistance includes:

- Collection and dissemination of information relating to good practices in the application of the Code.
- Organizing regional and international meetings on the application of the Code.
- Providing safety review services.
- Developing relevant safety standards.
- Providing for the application of these standards by advising on and assisting in all aspects of safety management of research reactors.

SAFETY SERVICES FOR RESEARCH REACTORS

The Integrated Safety Assessment of Research Reactors (INSARR) mission is an IAEA safety service offered upon request to all Member States. Within this activity, the safety of the reactor is reviewed against the IAEA's safety standards. Key review areas include design, safety analysis, regulatory supervision, reactor operation and maintenance, experiments and modifications, radiation protection, and radioactive waste management.

IAEA supports and promotes several safety initiatives with regard to research reactors, including:

- Application of the Code of Conduct on the Safety of Research Reactors
- Development of safety standards and guides on research reactor safety
- Improving safety practices in research reactors through various funding programmes
- Providing safety review services for research reactors
- Monitoring and enhancing the safety of research reactors under project and supply agreements

INCIDENT REPORTING SYSTEM FOR RESEARCH REACTORS (IRSRR)

The IAEA also operates the Incident Reporting System for Research Reactors (IRSRR) to improve the safety of research reactors through the exchange of safety related information on unusual events and lessons learned from them. Proper analysis of unusual events can identify the root causes and contribute valuable experiences to be shared among reactor operators, regulatory bodies or reactor designers. To date, some 58 Member States have joined the IRSRR.

INSARR mission at Halden research reactor (Norway).

IAEA supported activities

The IAEA provides substantial assistance and expertise to the research reactor community.

IAEA SUPPORTING ACTIVITIES

In order to promote the safe management and effective utilization of research reactors, the IAEA:

- Provides **Technical Cooperation (TC)** projects. Through training courses, expert missions, fellowships, scientific visits, and equipment disbursement, the Technical Cooperation Programme provides the necessary skills and equipment to establish sustainable technology in the corresponding country or region.
- Organizes **Coordinated Research Projects (CRPs).** These activities stimulate and coordinate the undertaking of research by scientists in IAEA Member States in selected nuclear fields that bring together research institutes in both developing and developed Member States to collaborate on the research topic of interest.
- Organizes **conferences** and **technical meetings to facilitate information sharing amongst Member State RR organizations.**
- Maintains **research reactor and ageing databases.**
- Develops state of the art RR **technical publications and guidelines.**
- Promotes and assists in the **formation of research reactor coalitions and networks.** These networks are conducting joint research or other shared activities, and cover a wide range of topics, for example, enhancing the regional infrastructure and capabilities for neutron sciences, developing new supplies of medicinal radioisotopes, providing new or enhancing existing irradiation products/services, and expanding the reach of education and training.
- Gives its primary consideration to **strategic research reactor plans** for utilization, fuel management, and ageing management, as well as refurbishment, modernization, safety and decommissioning.

Key IAEA publications

- Strategic Planning for Research Reactors, Nuclear Energy Series NG-T-3.16
- Applications of Research Reactors, Nuclear Energy Series No. NP-T-5.3
- Utilization Related Design Features of Research Reactors: A Compendium, Technical Reports Series No. 455
- Safety of Research Reactors, Safety Standards Series No. NS-R-4
- Safety Analysis for Research Reactors, Safety Reports Series No. 55
- Decommissioning of Research Reactors and Other Small Facilities by Making Optimal Use of Available Resources, Technical Reports Series No. 463
- Specific Considerations and Milestones for a Research Reactor Project, Nuclear Energy Series NP-T-5.1
- Feasibility of Producing Molybdenum-99 on a Small Scale Using Fission of Low Enriched Uranium or Neutron Activation of Natural Molybdenum, Technical Report Series No. 478

The IAEA is responding to requests from Member States, for example, by establishing the Research Reactor Decommissioning Demonstration Project (R2D2P) to help implement IAEA safety standards covering all aspects of decommissioning and to provide a model for future decommissioning strategies as well as continues to support Member States' request in their effort to minimize civilian use of highly enriched uranium.

Research reactor coalitions and networks

IAEA is supporting the creation of coalitions and networks among research reactor owners and users to enhance facility utilization.

STRATEGIC PLANNING AND COOPERATION FOR RESEARCH REACTOR NEEDS

There is currently a substantial need to develop strategies for the effective utilization of research reactors on a national, regional and international basis due to the fact that a significant number of these facilities are not utilized to their full potential. On the other hand, some Member States request the IAEA's support for building their first research reactor, which in many cases is viewed as an intermediate step towards a future nuclear power programme. Cooperation provides a new opportunity to share existing regional resources not only in order to increase utilization, but also to ensure a safe means for operation. It is the role of the IAEA to bring together potential partners among research reactor facilities and users in order to foster regional networks.

RESEARCH REACTOR COALITIONS AND NETWORKS

Research reactor coalitions and networks presently supported by the IAEA's regional Technical Cooperation projects aim to consolidate regional nuclear research sectors by establishing grouped entities to serve international users. In 2007–2013, with the assistance of the IAEA, a number of research reactor coalitions were formed, as described in the text box. These cover different areas for collaboration, including radioisotope production, neutron activation analysis, fundamental and applied research, safety and education and training activities. Among their many goals, the coalition partners strive to implement common strategic and management plans, drawing from IAEA guidelines. Coalition partners pursue more detailed market analysis and business development in order to identify opportunities and generate revenue — an important component for sustainability.

IAEA COLLABORATING CENTRES

A Collaborating Centre is an institution that assists the IAEA in implementing its regular budget programme through research, development and training in a relevant nuclear technology. Currently, more than 20 atomic research institutions spanning five continents are designated Collaborating Centres (CCs). Selection by the IAEA is a public recognition of the institution's work and achievements. As an example, two recently nominated research reactor facilities readily promote the development and sharing of knowledge regarding advanced neutron applications: Australia's Nuclear Science and Technology Organisation (ANSTO) as an IAEA CC for Neutron Beam Applications, and the Reactor Institute Delft in the Netherlands as an IAEA CC for Neutron Activation Based Methodologies. IAEA is also encouraging research reactor facilities to consider becoming an International Centre based on Research Reactor (ICERR).

Created RR coalitions and networks

- EERRI - Eastern European RR Initiative, 6 MS
- CRRC - Caribbean RR Coalition, 3 MS
- EARRC - Eurasian RR Coalition, 5 MS
- BRRN - Baltic Research Reactor Network, 10 MS
- MRRN - Mediterranean RR Network, 12 MS
- CARRN - Central Africa RR Network, 9 MS
- CISRRC - CIS RR Coalition, 7 MS
- GTRRN - Global TRIGA RR Network, more than 15 MS

IAEA DESIGNATED INTERNATIONAL CENTRE BASED ON RR

ICERRs make available their RRs, ancillary facilities, and resources to organizations of IAEA Member States (MS) seeking access to such nuclear infrastructure. An ICERR serves to provide a scientific hub for IAEA MS to support nuclear R&D and capacity building objectives, to improve accessibility of existing RRs, and to enhance the utilization of existing RRs while supporting IAEA MS nuclear technology programmes.

IAEA supported research reactor coalitions and networks. See the text box for details.

Key issues and challenges

The IAEA assists Member States to cope with key issues and challenges relevant to their research reactors.

KEY ISSUES AND CHALLENGES

Today, the fleet of research reactors faces a number of critical issues and important challenges, such as ageing, non-existent or inappropriate strategic plans, low utilization, the need for modernization or refurbishment, management of spent nuclear fuel, the need for advanced decommissioning planning and implementation stages and, in some cases, safety and security issues.

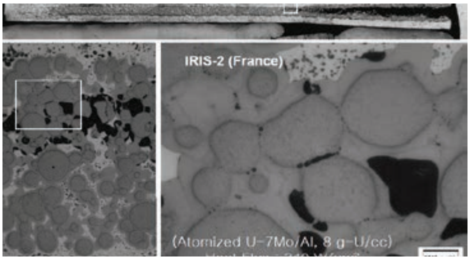
In response to these challenges, the IAEA is taking action and designing activities to tackle these issues and to make sure that promotion, support and assistance to Member States is preserved, in terms of the development and uninterrupted operation of strong, dynamic, sustainable, safe and secure research reactors dedicated to peaceful uses of atomic energy and nuclear techniques.

The future of research reactors is radically changing in a more economically competitive and safety conscious marketplace. To survive in today's difficult environment, research reactors must be actively managed, planned, researched, financed and marketed. The IAEA is helping Member States to pursue viable utilization strategies. The IAEA is also assisting countries to develop strategic plans for the long term sustainability of their research reactors or, alternatively, to decommission the shutdown reactors. This includes helping Member States identify their reactors' present and potential capabilities.

The challenge

To maintain benefits from research reactors the premises upon which they are built and operated must be reconsidered and made compatible with current technical, economic and social standards.

The IAEA stands ready to assist MS in all areas of RR operation, including the construction of new facilities and the decommissioning of the aged ones.



Qualification of high density U–Mo fuel is crucial for successful core conversion from HEU to LEU for nearly 30 operational research reactors worldwide as well as for new research reactors yet to be built. Source: CEA Saclay, France.

IAEA

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