IAEA Activities Related to Neutron Imaging

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Outline

- RR issues and challenges

- Examples of efforts related to neutron imaging
  - ✓ Finished CRP on neutron imaging
  - ✓ Active CRP on materials R&D for nuclear energy
  - ✓ New CRP in the area of cultural heritage
  - ✓ Round-Robin tests
  - ✓ TM on network for advanced neutron imaging
  - ✓ Summer school on neutron imaging
  - ✓ Project under PUI funding

- Conclusions

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Major Activities within Physics Section

Assistance and support of Member States in the field of

1. **Accelerators**
2. **Research Reactors**
3. Controlled Fusion
4. Nuclear Instrumentation
5. Cross-cutting Material Research

Based on Member States needs, requests & recommendations

Planning & implementation of P&B activities

Proposal and implementation of CRPs

Management of Data Bases

Organization of Conferences, Technical & Consultancy Meetings

Organization of ICTP workshops, training schools and courses

Support of TC projects

Promotion of Nuclear Sciences, Applications and Technologies

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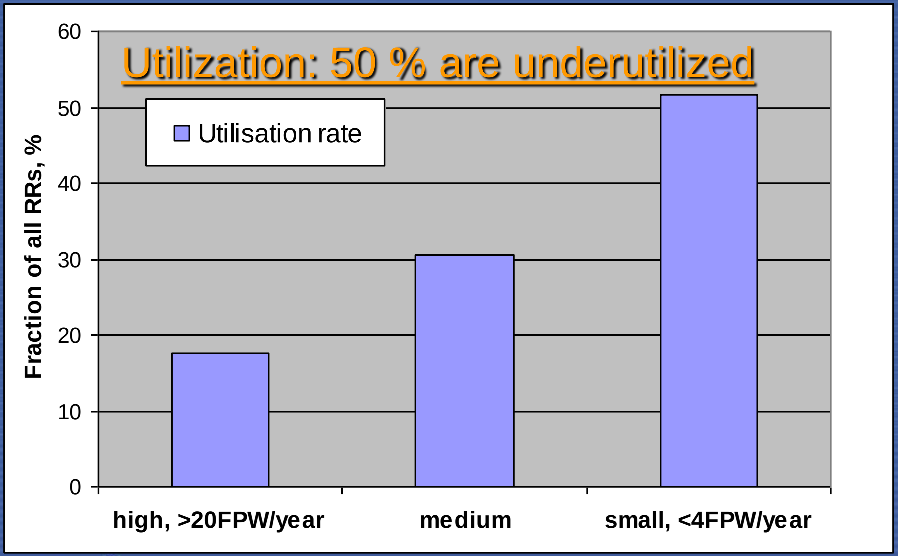
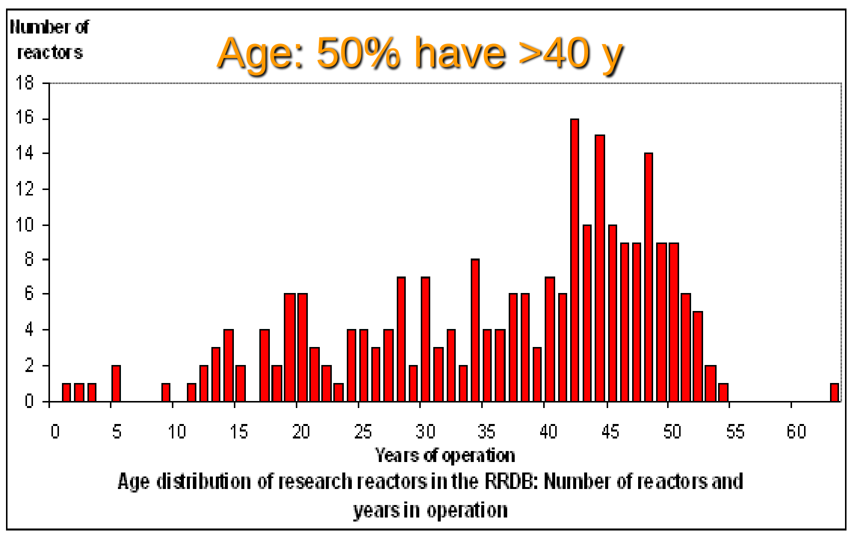
Key issues and challenges in RR utilization

- Number of operational RR is decreasing
- These are very old facilities & need constant modernization/refurbishment
- 50% of RRs remain heavily underutilized
- "Paradox": requests by newcomers to assist in the first RR project





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Source: IAEA RRDB, February 2011

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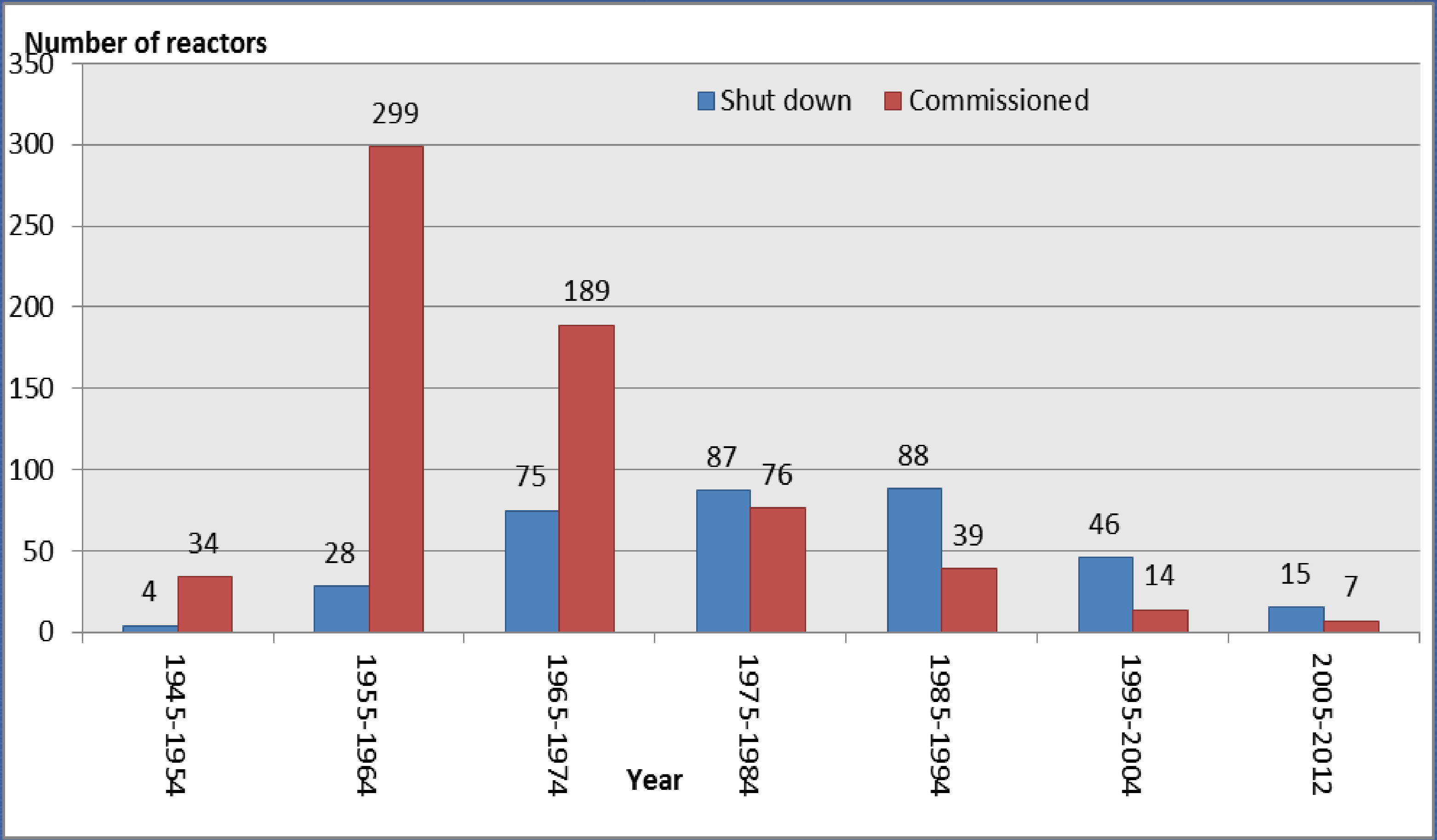
Trend for decreasing number of RRs



-1 RR per year since 2005

-2 RR per year since 1995

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Major reasons for RR Underutilization

- **Lack of purpose** (and strategy); objectives formulated long time ago; no new/clear strategy available

- **Lack of budget** (and staff); prefer operate on "survival" level rather than shut-down and decommission; no plan/funds for decommissioning

- **Lack of pro-activity** (and motivation); no action to search for new users/clients; no action to analyse/penetrate the market for potential commercial products and services

- **Lack of QA/QC** (and Integrated Management System); decreased confidence from major stakeholders (funding and regulatory authorities); decreased chance to go commercial; no courage for re-organization

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In-house strategy for enhanced RR utilization

Today existing or planned RR facilities should concentrate on three major issues:

Strategic Planning
&
Performance Monitoring

International Cooperation
&
Networking

Sustainability
through
Provision of Products & Services

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IAEA Research Reactor DataBase (RRDB)

http://nucleus.iaea.org/RRDB/

Includes:

*** Detailed information of 680 facilities**

*** Operational status**

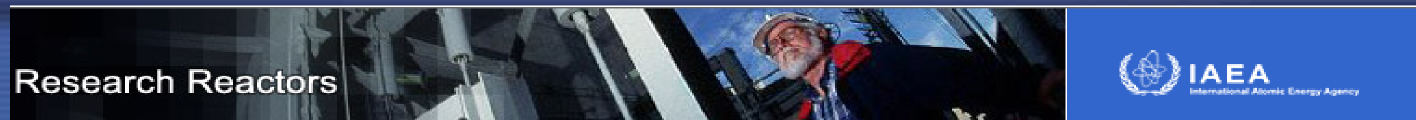
*** Reactor data**

*** Fuel data**

*** Utilization records**

***…**

Jointly coordinated and managed by NAPC & NEFW.



Home | By Location | By Category | By Utilisation | Summary Reports | Admin

Location Location Filter (-)

Countries

- Algeria
- Argentina
- Australia
- Austria
- Bangladesh
- Belarus
- Belgium
- Brazil
- Bulgaria
- Canada

Reactor Name Standard Filter (-)

Reactor Status

- OPERATIONAL
- TEMPORARY SHUTDOWN
- UNDER CONSTRUCTION
- PLANNED
- SHUT DOWN
- DECOMMISSIONED
- CANCELLED

Add New Reactor

Generate Report

- ReactorOnly
- FuelOnly

Category Advanced Filter (-)

Power: Any

Flux: Any

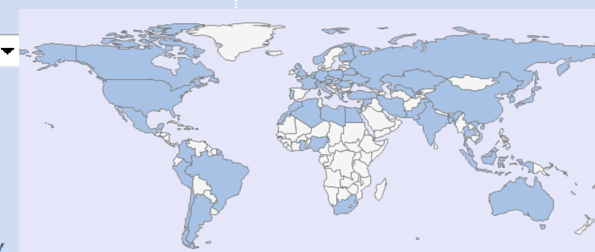
Age: Any

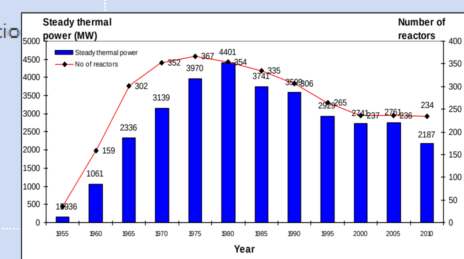
Utilisation: Any

Utilisation

- Generating Isotopes
- Neutron Scattering
- Neutron Radiography
- Material/Fuel Irradiation
- Transmutation Si Doping
- Transmutation Gemstone Coloratio
- Teaching / Training
- Neutron Activation Analysis
- Geochronology
- Boron Neutron Capture Therapy
- Other Application

Find   Reset Filter





Now possible:

*** Online updates**

*** Multiple search**

*** Up-to-date statistics**

*** Maps, and**

*** Much more!**

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RR application-oriented functions of RRDB

Application	Number of RR involved	Involved / Operational, %	Number of countries
Education & Training	161	67	51
Neutron Activation Analysis	122	51	54
Radioisotope production	90	37	44
Neutron radiography	68	28	40
Material/fuel testing/irradiations	60	25	25
Neutron scattering	48	21	32
Nuclear Data Measurements	42	18	20
Gem coloration	36	15	22
Si doping	35	15	22
Geochronology	26	11	21
Neutron Therapy	20	8	13
Other	95	40	29

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Indispensable to define priorities and plan our activities!

IAEA and ISNR survey of neutron imaging facilities

- 23 replies out of 68 contacts (~30 %)
- 23 countries represented out of 40 involved (~50 %)
- Both big (>10MW) and small RRs (<1MW) covered

Neutron Imaging Facilities Survey

Table of Contents

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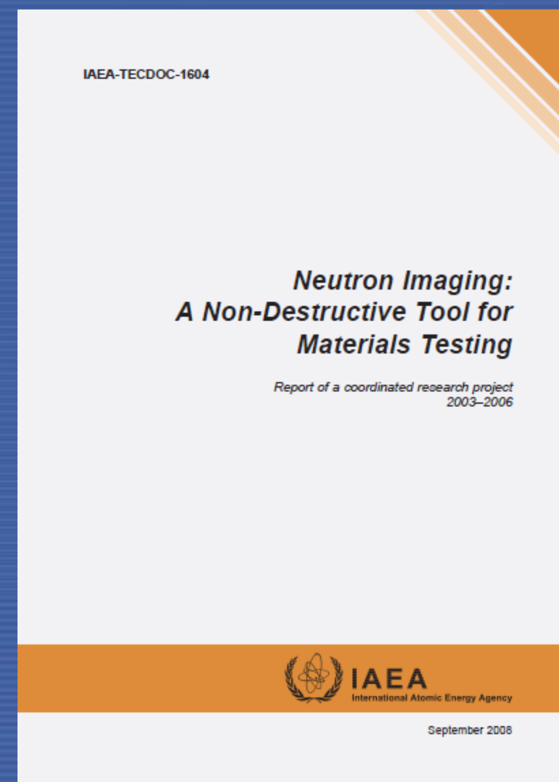
Closed CRP 1309 : (2003-2006)

Development of improved sources and imaging systems for neutron radiography

Main objectives:

- To optimize the neutron beams for imaging purpose using modern simulation techniques.
- To enhance the beam intensity using modern layout principles, neutron optics, like focusing and beam guides and filters.
- To develop a standardized, low cost, neutron image grabber and analyzer for efficient data collection that can be used with low intensity sources.
- To improve signal processing techniques used in neutron imaging applications.

10 Participating Member States



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Active CRP 1575 (2009-2013):

Development, Characterization and Testing of Materials of Relevance to Nuclear Energy Sector Using Neutron Beams (SANS, diffraction and neutron radiography)

Objectives:

- investigation and characterization of materials relevant to nuclear energy applications
- optimization and validation of experimental and modelling methods
- creation of a database of reference data for nuclear materials research
- enhancement of the capacity of research reactors for nuclear materials research

10 Research Contracts + 9 Research Agreements

6 countries out of 18 use neutron imaging technique for this purpose:

1. Brazil
2. Germany
3. Indonesia
4. Korea
5. South Africa
6. Switzerland

Expected output:

- Creation of multilateral network in the field of advanced nuclear materials research
- Creation of an experimental reference database for models and calculations
- Final project publication

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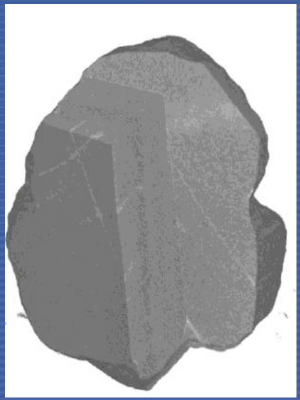
New CRP 1782 (2011-2014):

Application of neutron imaging with focus on cultural heritage research

- **Initiated/discussed during IAEA Satellite meeting of WCNR in October 2010**
- **Designed/drafted during CM in September 2011 in Vienna**
- **Objectives:**
  - Promote NI technology in order to enhance its utilisation in cultural heritage
  - Establish the necessary standardization procedures and methodology to achieve synergy among participating laboratories / facilities.
  - Strengthen collaboration between the NI community involved in cultural heritage research
  - Develop a database of standard NI-services for cultural heritage needs
  - Evaluate available software for data-analysis and simulation.
- **19 Research Contracts and Agreements approved (out of 30 proposals)**
- **Kick of meeting will take place on 7-11 May in Vienna**



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Round Robin related to neutron imaging (1)

- Need of standard approach for facility characterization
- Need of accepted procedures for standardisation
- CM in Vienna in 2009
- Discussions via e-mail and phone conferences
- Round table discussion at WCNR 2010 in South Africa
- Targeted meeting during RCM in China in 2011

→ PSI designed and fabricated samples, developed measurement protocol and data analysis procedure

→ Presently: Brazil, Hungary, Portugal and South Africa
→ Next: Poland, Malaysia, Argentina, Algeria
→ After: Indonesia, Germany, Slovenia, South Korea

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Round Robin related to neutron imaging (2)

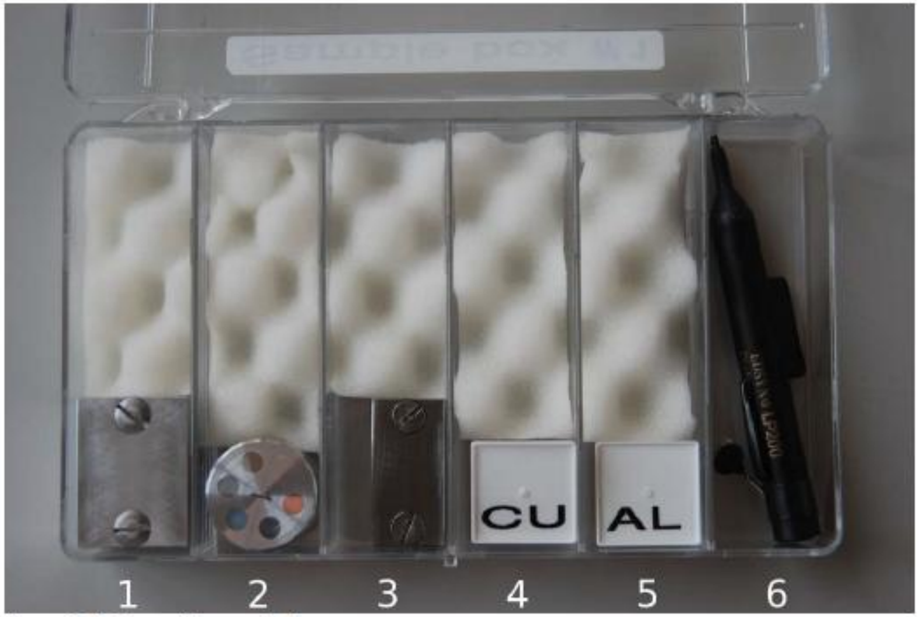

Figure 6: Picture of the sample box.

A.1 Item list

1. Resolution sample of aluminum to be combined with Cu foils.
2. Contrast sample
3. Resolution sample of iron to be combined with Al foils.
4. Box with 20 µm thick Cu foils. Please use the suction device when you handle the foils.
5. Box with 20 µm thick Al foils. Please use the suction device when you handle the foils.
6. Suction device to pick up and position foils for the resolution samples.
7. 8Gb USB memory-stick containing instructions. The experiment data organized as described in section 4 shall be copied to this device upon returning the sample box. A template of the folder structure is provided on the stick. Copy the template and rename according to the instructions.

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TM on Regional Research Reactor Users' Networks (RRUNs): advances in neutron imaging

26 – 30 November 2012 ; Serpong-Jakarta, Indonesia

Topics:

- On-going modernization or new projects of neutron imaging facilities
- Advances in modern neutron imaging, e.g. energy-selective imaging, real-time imaging, computed tomography, relation to neutron scattering techniques, etc.
- Role of neutron imaging in materials research and various industrial applications
- Results of the IAEA Round Robin exercises using standardization samples
- Share of good practices and strategies from international collaborations and networking in the field of neutron imaging; potential creation of users' network on neutron imaging.

Expected Output:

→ Preparation of report on present status and future development of neutron imaging facilities and associated instrumentation

→ Share of good practices and lessons learned from international cooperation and multi-user facilities

→ Critical evaluation of Round Robin results, available by this time

→ Formulation of recommendations and work-plan; potential creation of network

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Summer School on neutron imaging (tentative)

June/October 2013 ; HZB, Berlin, Germany; ~30 students; ~10 days

Topics:

- Introduction to neutron sources: reactor and accelerator based
- Introduction to fundamentals and advances in neutron imaging techniques
- Guidelines on required
  - neutron beam characteristics
  - equipment installation and licensing, including hardware and software
  - experimental setup, data taking, and data analysis
  - standardization of techniques with respect to industrial applications
  - staff training and qualification
- Basic experimental training (hands-on-experiment in small groups) in neutron radiography and neutron tomography
- Experimental case studies (hands-on-experiment in small groups) on specific applications of neutron imaging
- Tutorials on neutrons imaging: demonstration of toolkit on experimental data handling, post-experimental analysis, image reconstruction and examination, finalization of results
- Examples of neutron imaging applications in biology, chemistry, medicine, physics, material sciences, environment, engineering and various industries
- Marketing and industrial opportunities for neutron imaging applications

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PUI supported project on neutron imaging

2012-2014; partial funding granted; full funding requested/resubmitted

Expected Output:

- → Creation of a comprehensive database on neutron imaging facilities and their characteristics in developing countries
- → Transfer of advanced technology and know-how through the installation of modern equipment and software, dedicated training and qualification of involved personnel, and implementation of standardization procedures and protocols
- → At least five digital neutron radiography-tomography facilities installed or modernized, licensed and fully operational in the developing countries
- → Established cooperation between developed and developing countries in the field of neutron imaging research and applications
- → Established contacts and initiated cooperation between neutron imaging facilities and industrial partners; industrial needs evaluated
- → Publication of relevant technical documents, guidelines and promotional material related to industrial applications of neutron imaging
- → Contribution to the enhanced utilization of research reactors, including increased sustainability through additional revenue generation from industrial neutron imaging applications

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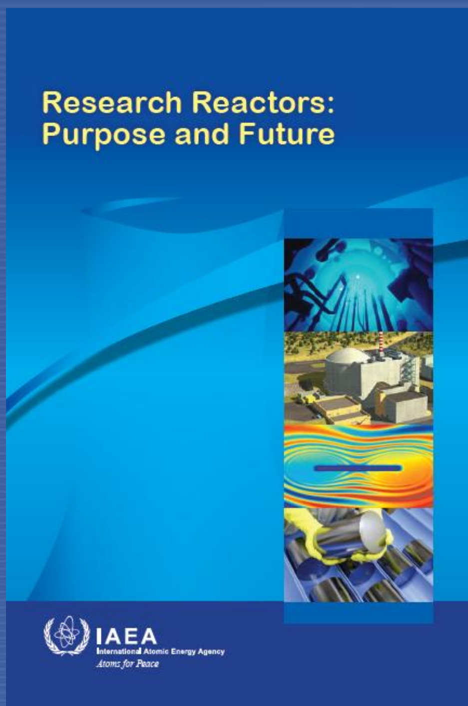
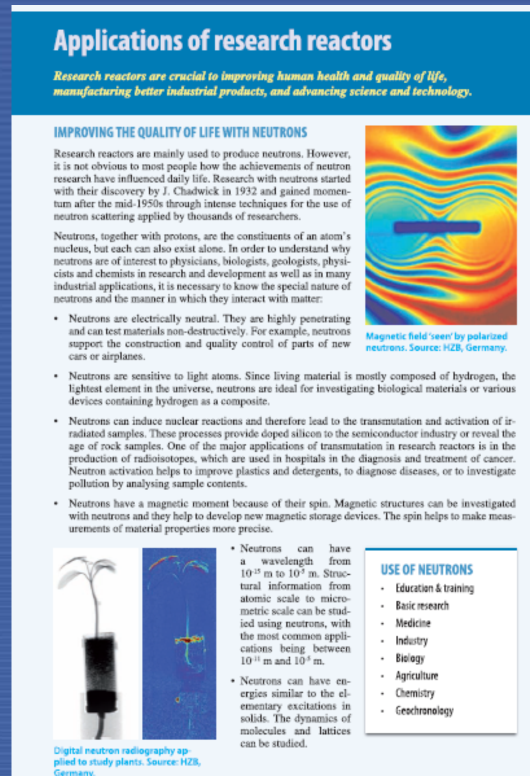
Promotion of neutron imaging

Present

• In addition to CRP, TM, School, Round Robin, PUI project, … neutron imaging featured in IAEA brochure (2010), sent to 151 IAEA Member States





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 hospitals in the diagnosis and treatment of cancer. 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.
- Neutrons can have a wavelength from 10^{-15} m to 10^{-3} 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. The dynamics of molecules and lattices can be studied.

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

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.

Three-dimensional image of brazing connections in a heat exchanger device. 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 a 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 17 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 NCT efficient in killing the tumour cells in only a few sessions without significant collateral damage.

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

Future

Preparation and publication of a dedicated promotional brochure "Advances of Neutron Imaging: from Research to Industrial Applications"

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Thanks for your attention!

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