IAEA Activities in support of Neutron Imaging

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Outline

- RR issues and challenges
- Examples of efforts related to neutron imaging
  - ✓ Finished CRP in the area of cultural heritage
  - ✓ Finished CRP on materials R&D for nuclear energy
  - ✓ Round-Robin tests
  - ✓ Support through Technical Cooperation projects
  - ✓ Most recent publications
  - ✓ Future efforts
- This Training Workshop

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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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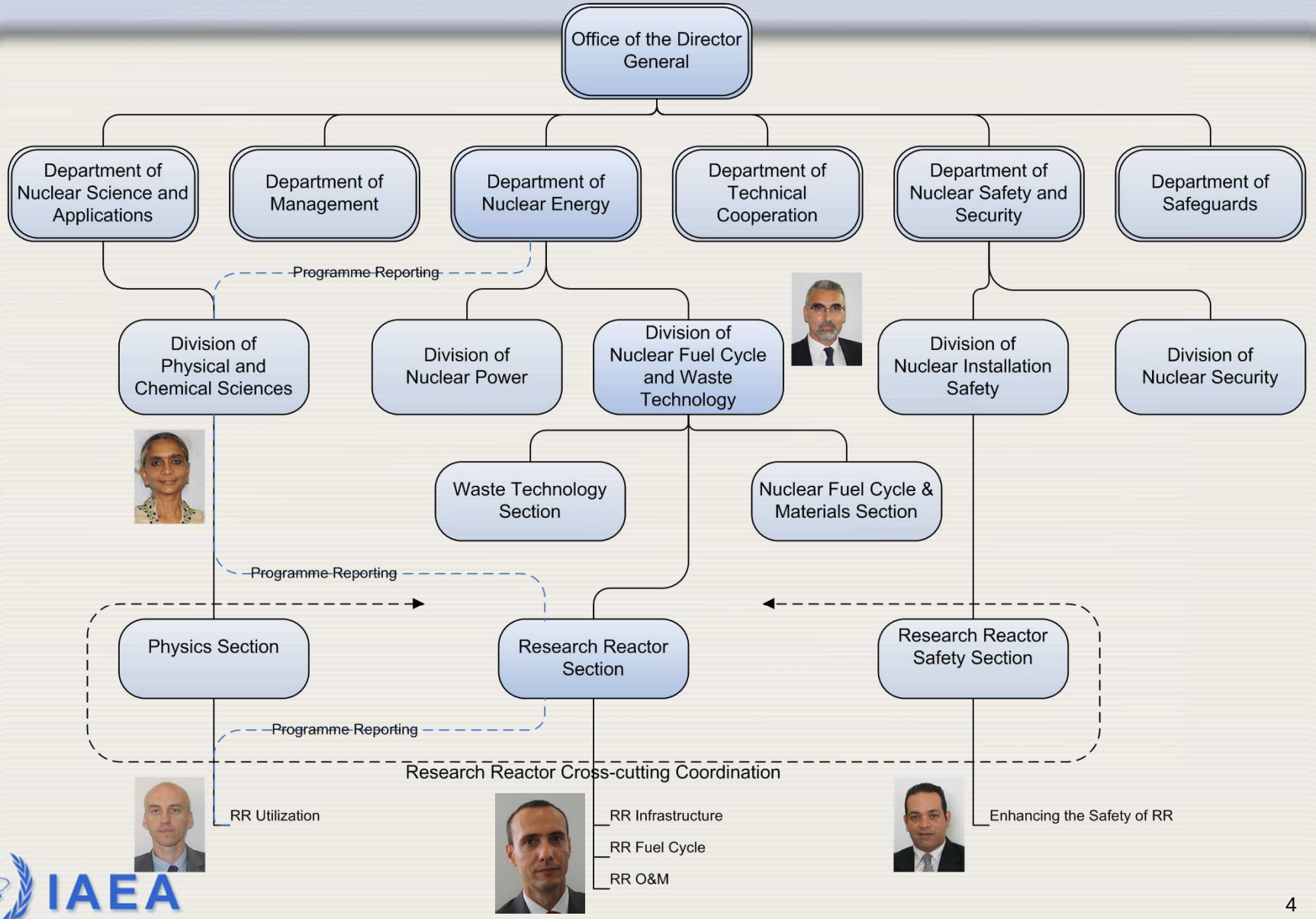
Program/project organisation: x-cutting



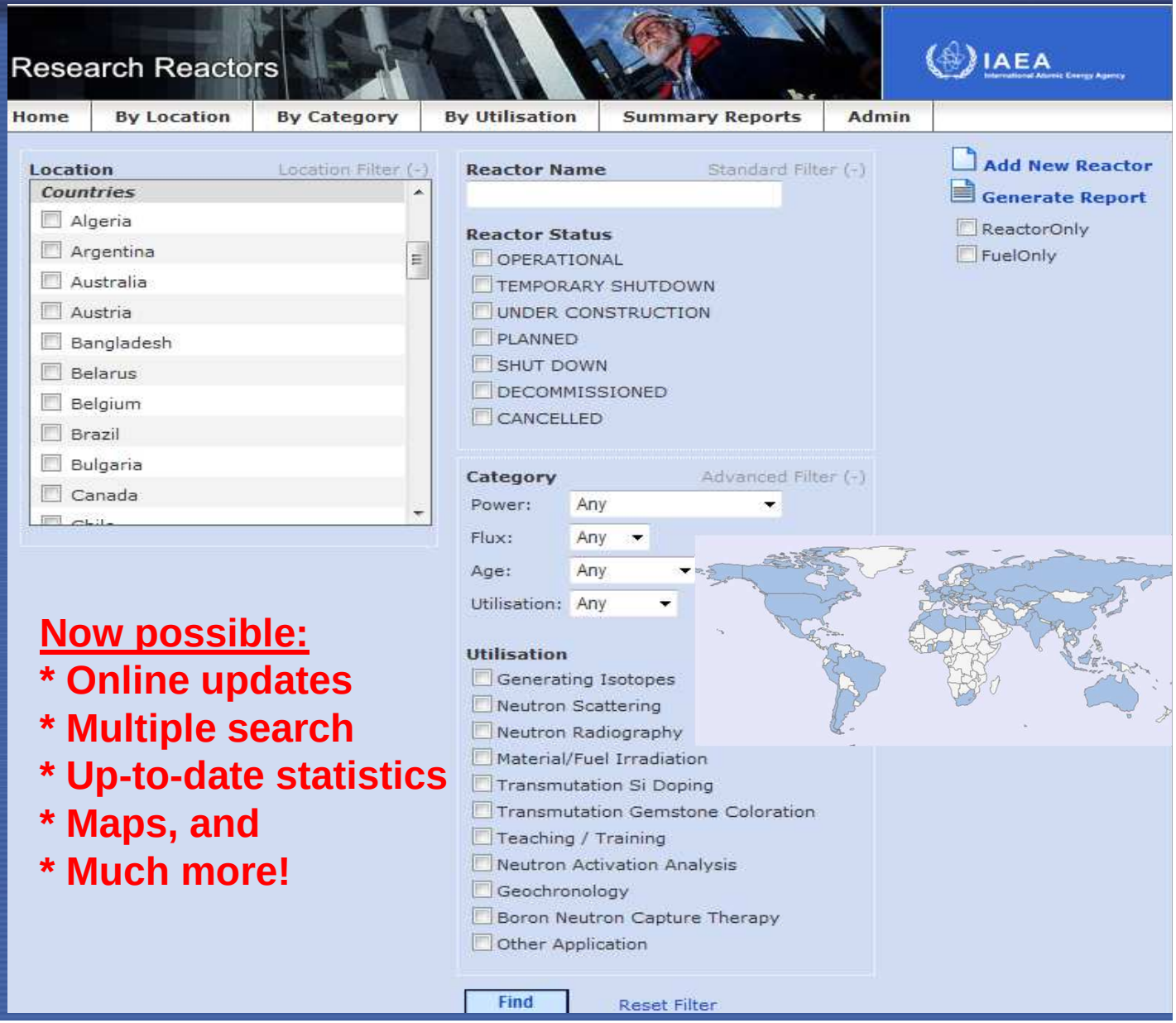
IAEA Research Reactor DataBase (RRDB)

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

Includes:

* Detailed information of ~700 facilities
* Operational status
* Reactor data
* Fuel data
* Utilization records
*…

Jointly coordinated and managed by NAPC & NEFW.



Now possible:

* Online updates
* Multiple search
* Up-to-date statistics
* Maps, and
* Much more!

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RR utilisation: applications

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

Indispensable to define priorities & plan the IAEA activities!

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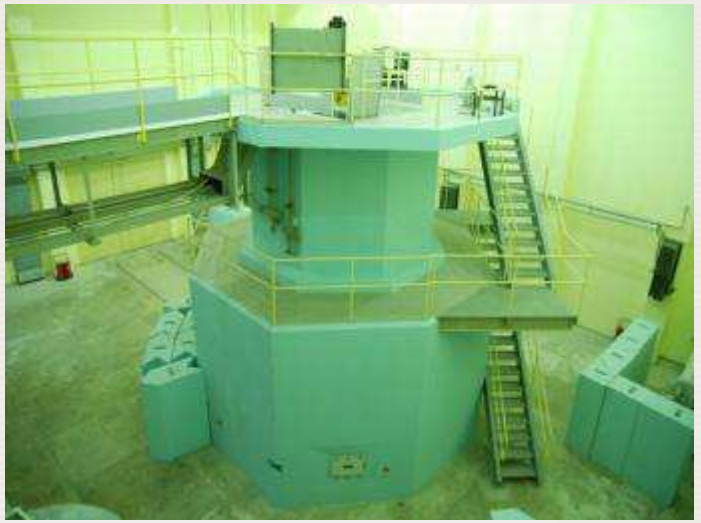
Challenge of Underutilization: affects ~50% of RRs

“Busy”, well utilised RRs; ☺
1st crit. 1965

“Naked”, barely utilised RR; ☹
1st crit. 1979



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Strategic Considerations for a RR facility

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IAEA and ISNR survey of neutron imaging facilities

- 47 entries out of ~60 contacts (~78 %)
- 32 countries represented out of 40 involved (~80 %)
- Both big (>10MW) and small RRs (<1MW) covered , including a few SNSs

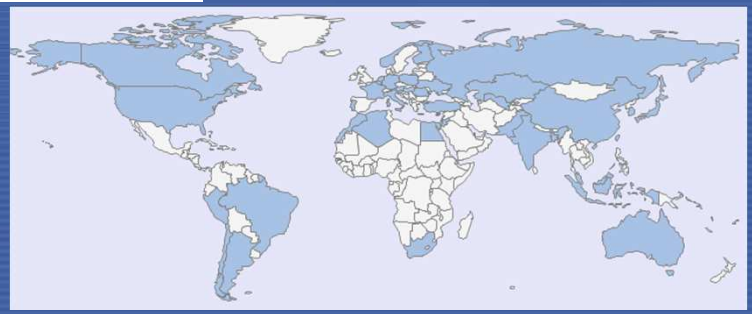
1. Algeria, CRNB, 15 MW 4
2. Algeria, CRND, 1MW 6
3. Argentina, RA-6, 1 MW .....
4. Australia, OPAL, 20 MW .....
5. Austria, TRIGA II Vienna, 0.25 MW .....
6. Bangladesh, TRIGA MARK II, 3MW .....
7. Belgium, BR1, 4 MW .....
8. Brazil, Argonauta, 0 MW .....
9. Brazil, IAE-R1, 5 MW .....
4. Canada, MNR McMaster Univ., 5MW .....
10. China, CARR, 60MW .....
11. China, Peking University AMS Laboratory, 4.5 MeV deuterons on Be and D ..
12. China, Sichuan Reactor, 20MW .....
13. Egypt, ETRR-2, 22 MW .....
14. France, ORPHEE, 14MW .....
15. Germany, BER II, 10 MW (CONRAD Instrument) .....
16. Germany, BER II, 10 MW (PONTO Instrument) .....
17. Germany, FRM-II (ANTARES), 20 MW .....
17. Germany, FRM-II (NECTAR), 20MW, with converter .....
18. Germany, PIAF, 12 MeV Deuterium, 20 μA CW, 2 μA pulsed .....
19. Hungary, DNR , 10 MW .....
20. Hungary, NORMA, 10 MW .....
21. India, Dhruva, 100 MW .....
22. Indonesia, GA Siwabessy MTR, 30 MW .....
23. Israel, IRR-1, 5MW 71
24. Italy, TRIGA RC-1, 1 MW 73
25. Japan, JRR3, 20MW 75
26. Japan, J-PARC, <1MW 78
27. Korea, HANARO, 30 MW 81
28. Malaysia, TRIGA II PUSPATI, 1 MW 83
28. Morocco, MA-R1, 2 MW 86
29. Norway, JEEPII, 2MW 88
30. Poland, Maria, 30 MW 90
31. Portugal, RPI, 1 MW 95
32. Romania, TRIGA 14MW, INUS 98
33. Romania, TRIGA 14MW, INUM 100
34. Russian Federation, IBR-2 pulsed, 2MW average 102
35. Slovenia, TRIGA Mark II, 0.25 MW 104
36. South Africa, SAFARI-1, 20MW 106
37. Switzerland, ICON, spallation neutron source, 0.8 MW 110
38. Switzerland, NEUTRA, spallation neutron source, 0.8 MW 113
39. Thailand, TRIGA Mark III, 1 MW 115
41. USA, NBSR-NIST, 20 MW 122
42. USA, OSTR Oregon State, 1.10 MW 131
43. USA, UC Davis, TRIGA Mark III, 1.0 MW 133
44. USA, ORNL, HFIR, 85 MW 136
45. USA, PSBR PENN ST. UNIV., TRIGA, 1MW 139
46. USA, LANL, LANSCE spallation, 0.08 MW 141
47. Vietnam, Dalat RR, 0.5 MW 145

Neutron Imaging Facilities Survey

Jointly Prepared and Conducted by the ISNR and IAEA

IAEA International Atomic Energy Agency
Atoms for Peace

24 September 2015, Vienna (Austria)



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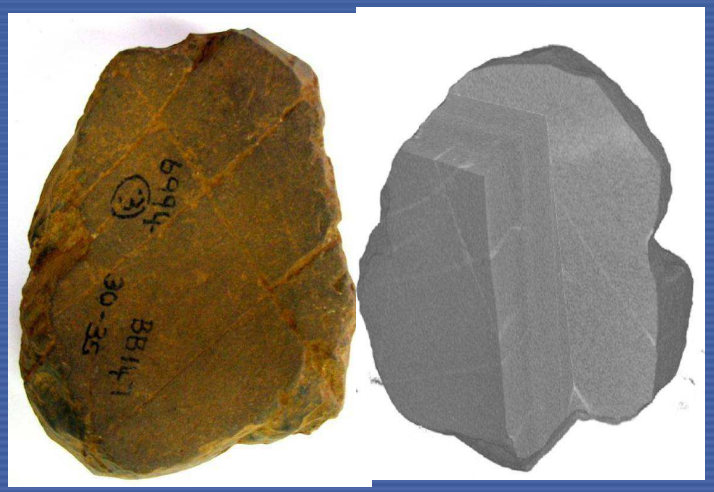
Finished CRP 1782 (2011-2014):

Application of neutron imaging with focus on cultural heritage research

- **Initiated/discussed during IAEA Satellite meeting of WCNR in October 2010**
- **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, ~20 countries**
- **Final publication in print**



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Finished CRP 1575 (2009-2013):

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

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

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Among other achievement, a thematic network on neutron imaging has been created

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Neutron imaging: contrast and precision Round Robin

- **Objectives:**
  - Assist in organization and implementation of Round Robin exercise
  - Advise on procedures and interpretation in digital neutron imaging
  - Seek for sustainable QA/QC process
  - Offer training workshops/schools

- **Means:**
  - Guidelines (and deadlines)
  - Samples from PSI: contrast and resolution
  - IE for advice and evaluation
  - Results analysis, both individual & group
  - Follow up workshops/schools

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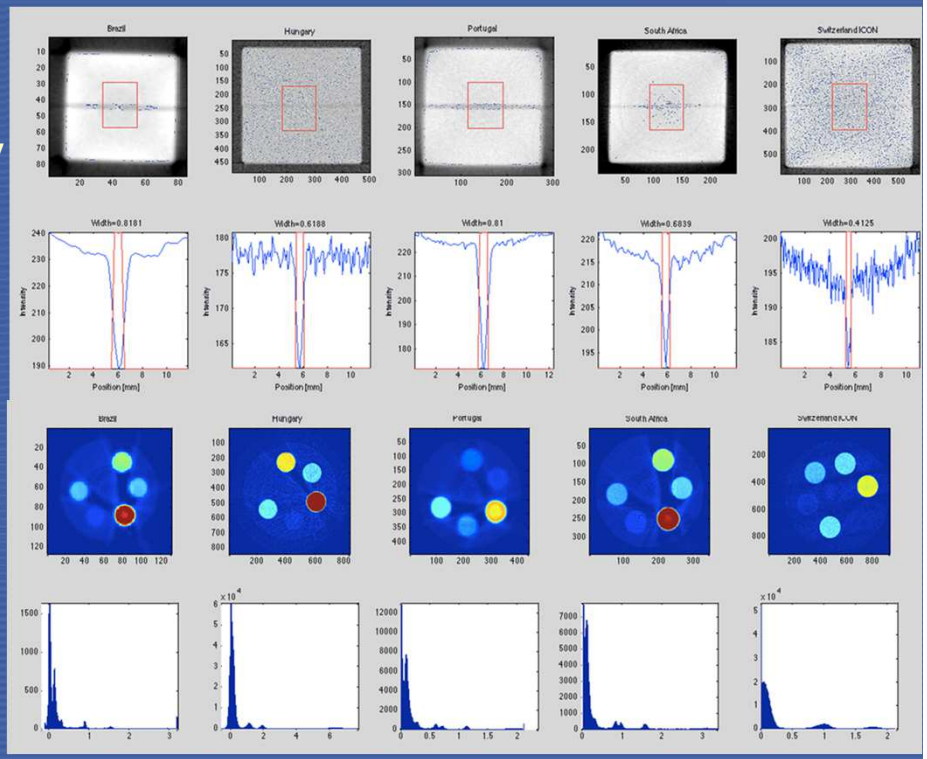
Neutron imaging: contrast and precision Round Robin

- **Results:**
  - Participation from 14 facilities world-wide
  - Good results achieved by 5-6 neutron imaging facilities
  - Deficiencies identified for 2-3 facilities

- **Future:**
  - Continue exercise every two years
  - Use improved samples/methodology
    - Procurement of new samples
    - Analysis and recommendations
    - Follow up workshops
    - Training workshops/schools



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Neutron Imaging: support to WCNR

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Support through the IAEA TC projects

1. South Africa: upgrade of neutron imaging station (training, procurements)
2. China: development of neutron imaging station (training, procurements)
3. Algeria: procurement and expert advise
4. Indonesia: support through EMs
5. Malaysia: support through EMs
6. Morocco: support through EMs
7. Jordan: preliminary design of neutron radiography station (ongoing)
8. Thailand: support through EMs (planned)
9. Bangladesh: support though EMs (planned)
10. Brazil: support through EMs (planned)

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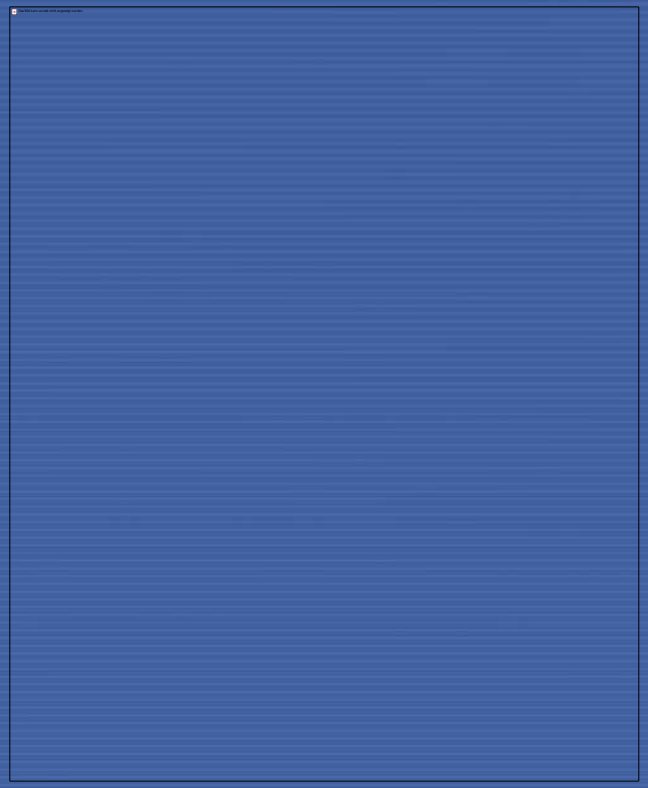
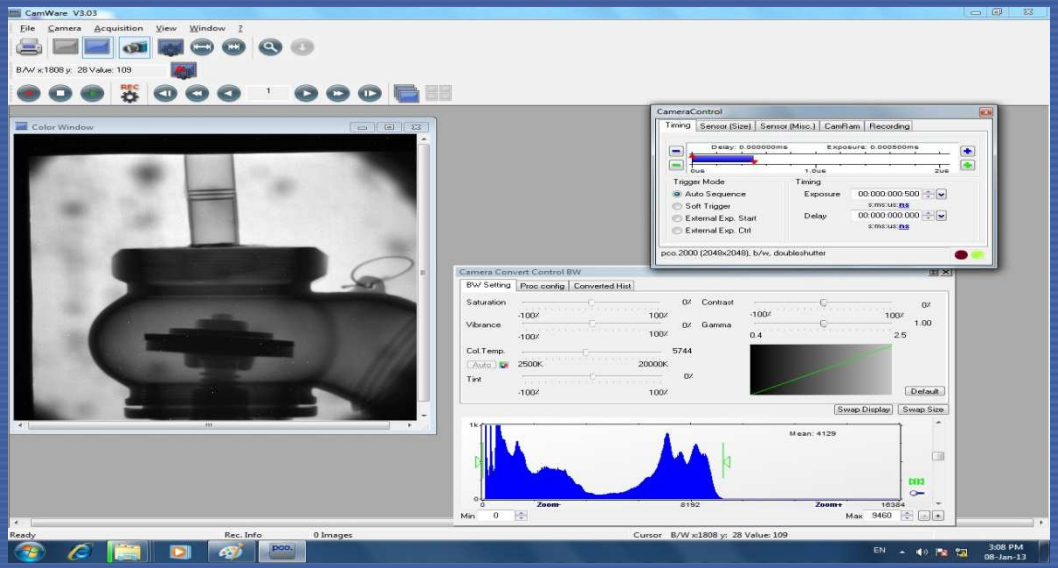
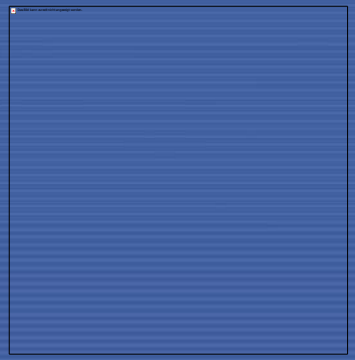
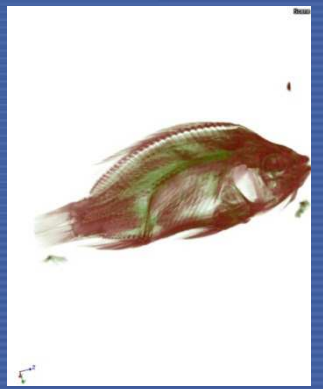
IAEA TC project EGY4048: Development of Neutron Irradiation and Beam Line Facilities for Effective Use of the Research Reactor

Design, procurement and licensing of the complete digital neutron imaging facility at ETRR-2 reactor in of EAEA in Egypt









+ expert missions & training of staff

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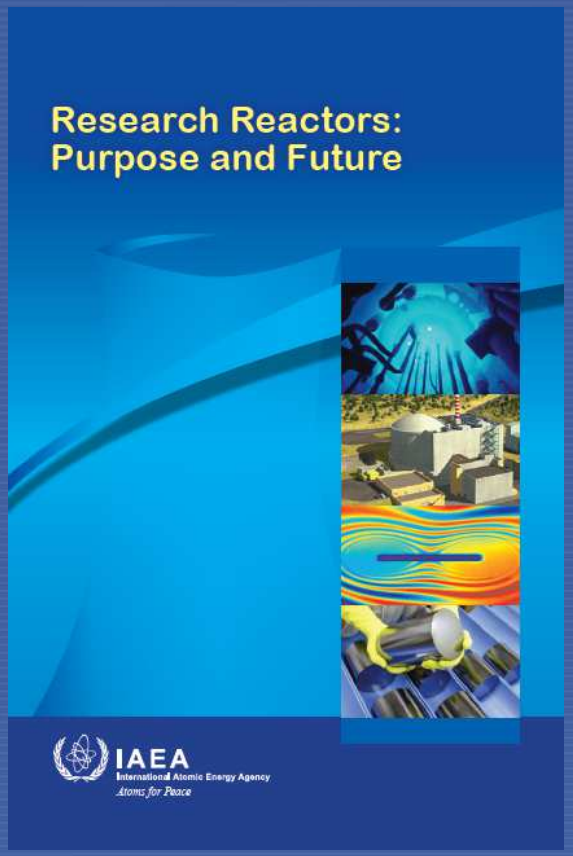
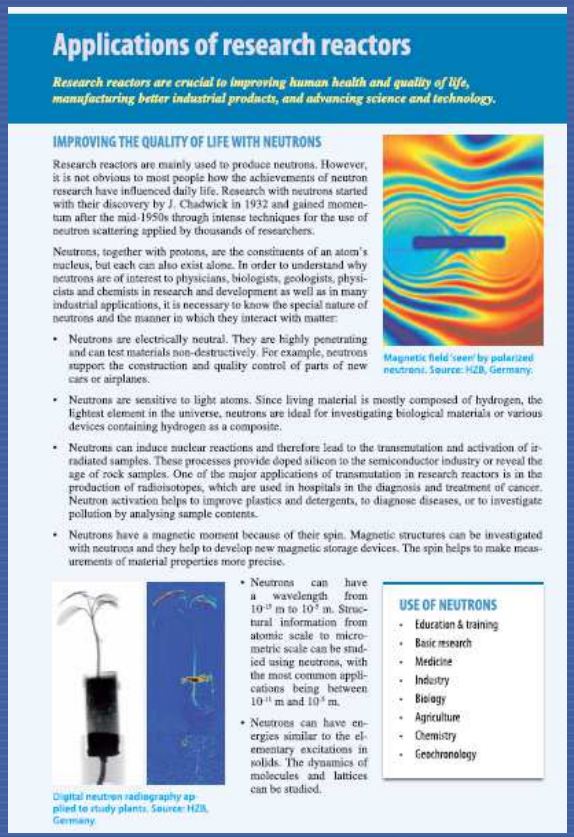
Promotion of neutron imaging

Neutron imaging featured in IAEA brochure (2010, rev. 2015);

sent to ~170 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.

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

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

- 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^{-4} m.
- Neutrons can have energies similar to the elementary excitations in solids. The dynamics of molecules and lattices can be studied.

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.

Three-dimensional image of brazing connections in a heat exchanger device. Source: PSI, Switzerland.

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.

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.

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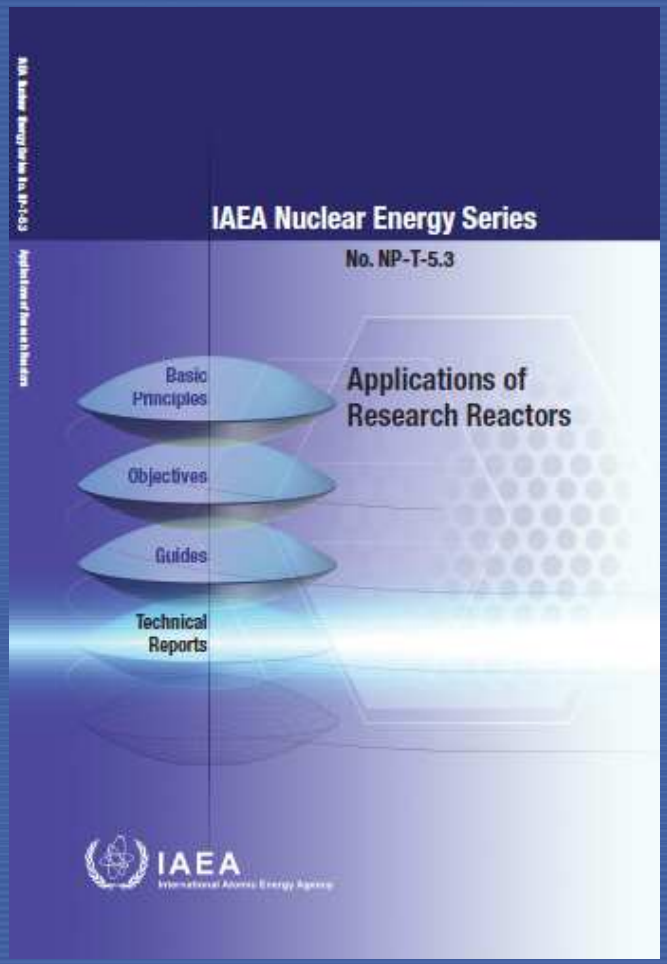
IAEA publication 2014 :
Applications of Research Reactors

- Dedicated Chapter on neutron imaging



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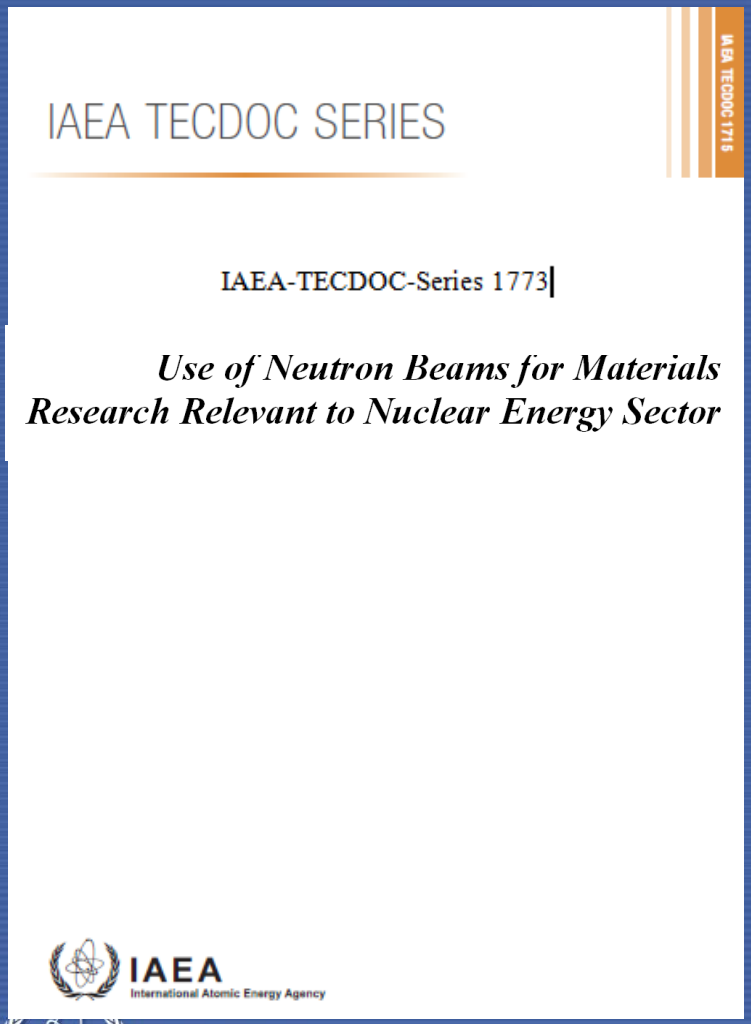
IAEA publication 2015 (in print):

- Dedicated section(s) on neutron imaging



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IAEA Technical Meetings:

- **Networking & advances in neutron imaging**
- **Networking & standardization of neutron imaging**

26-29 November 2012; Serpong, Indonesia; 20 participants from 16 countries.

23-26 June 2014; Vienna, Austria; 25 participants from 20 countries

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Proposal for a new CRP on Development of Standardized Protocols and Samples to Evaluate the Performance of Digital Neutron Imaging for Industrial Applications

Main objectives

→ Develop and publish standardization protocols and guidelines
→ Develop and produce standardized test samples
→ Organize and perform Round Robin exercises
→ Develop a modular E-learning tool for training purposes in digital neutron imaging
→ Develop marketing strategies for industrial applications of neutron imaging
→ Explore and promote neutron imaging using compact neutron generators

Schedule:

- Design of the project 01-2016
- Approval of the project: 03-2016
- Call for research projects: 04-2016
- Deadline for applications: 07-2016
- Evaluation of projects: 09-2016
- Project kick-off meeting: 12-2016

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Neutron imaging: organization of training workshops

- **Results:**
  - Training Workshop, jointly with Berlin Neutron Imaging School, August 2013
  - Attended by 30 students (50% supported by the IAEA)
  - Lectures provided by 10 experts (2 supported by the IAEA)
  - Hands-on-training practical exercises included
  - Technical visits organized

- **Future:**
  - Next Training Workshop in 2015, here at PSI (Switzerland)

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Thanks for your attention!

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