IAEA e-learning tools in Research Reactor utilization

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Research Reactors worldwide

OVERVIEW
RRs Worldwide - Overview

Includes:

- Detailed information of ~700 facilities
- Operational status
- Reactor data
- Fuel data
- Utilization records
- ...

Research Reactor Database
https://nucleus.iaea.org/RRDB/
RRs Worldwide - Overview

TOTAL 783
Operational 218
Temporary shutdown 22
Extended shutdown 8
Under construction 9
Planned 10
Permanent shutdown 128
Under decommissioning/decommissioned 372

https://nucleus.iaea.org/RRDB/ (May 2017)
RRs Worldwide - Overview

<table>
<thead>
<tr>
<th>Type of reactor</th>
<th>Units built (%)</th>
<th>Power range (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pool</td>
<td>23.6</td>
<td>0.01 k – 100 M</td>
</tr>
<tr>
<td>Critical assembly</td>
<td>16.1</td>
<td>0.01 k – 20 k</td>
</tr>
<tr>
<td>Tank, tank in pool</td>
<td>11.1</td>
<td>0.01 k – 250 M</td>
</tr>
<tr>
<td>Homogeneous (solid and liquid)</td>
<td>11.1</td>
<td>0.01 k – 10 k</td>
</tr>
<tr>
<td>TRIGA</td>
<td>10.2</td>
<td>20 k – 14 M</td>
</tr>
<tr>
<td>Heavy water moderated</td>
<td>5.6</td>
<td>0 – 135 M</td>
</tr>
<tr>
<td>ARGONAUT</td>
<td>4.2</td>
<td>0.01 – 300 k</td>
</tr>
<tr>
<td>Fast</td>
<td>3.9</td>
<td>0 – 6 k</td>
</tr>
<tr>
<td>Graphite moderated</td>
<td>3.3</td>
<td>0.1 k – 120 M</td>
</tr>
<tr>
<td>Subcritical</td>
<td>1.7</td>
<td>0</td>
</tr>
<tr>
<td>SLOWPOKE</td>
<td>1.5</td>
<td>0 – 20 k</td>
</tr>
<tr>
<td>MNSR</td>
<td>1.4</td>
<td>27 k – 33 k</td>
</tr>
<tr>
<td>Other</td>
<td>7.3</td>
<td>0 – 200 M</td>
</tr>
</tbody>
</table>

Total power of all RRs in operation is ~2.2 GW (thermal)
RRs Worldwide - Overview
Currently:

- **30 IAEA Member States** developing or planning new research reactors

  **Phase 1 (Consideration):**
  Azerbaijan, Bangladesh, Ethiopia, Ghana, Kenya, Kuwait, Lebanon, Malaysia, Mongolia, Myanmar, Nigeria, Philippines, Saudi Arabia (Multipurpose RR), South Africa, Sudan, Tajikistan, Thailand, Tunisia, and Tanzania.

  **Phase 2 (Planning):**
  Belarus, Belgium, Bolivia, Brazil, The Netherlands, Saudi Arabia (Low Power RR), United States of America, and Viet Nam.

  **Phase 3 (Construction):**
  Argentina, France, India, Republic of Korea, and Russian Federation

- **13 IAEA Member States** working on their first ever research reactor project
Produce neutrons and provide access to it

<table>
<thead>
<tr>
<th>Application</th>
<th>Number of RR involved</th>
<th>Number of countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education &amp; Training</td>
<td>166</td>
<td>53</td>
</tr>
<tr>
<td>Neutron Activation Analysis</td>
<td>120</td>
<td>53</td>
</tr>
<tr>
<td>Radioisotope production</td>
<td>97</td>
<td>43</td>
</tr>
<tr>
<td>Material/fuel testing/irradiations</td>
<td>80</td>
<td>27</td>
</tr>
<tr>
<td>Neutron radiography</td>
<td><strong>72</strong></td>
<td><strong>38</strong></td>
</tr>
<tr>
<td>Neutron scattering</td>
<td>48</td>
<td>31</td>
</tr>
<tr>
<td>Si doping</td>
<td>28</td>
<td>18</td>
</tr>
<tr>
<td>Geochronology</td>
<td>26</td>
<td>22</td>
</tr>
<tr>
<td>Gem coloration</td>
<td>21</td>
<td>12</td>
</tr>
<tr>
<td>Neutron Therapy</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td>Nuclear energy research</td>
<td>16</td>
<td>11</td>
</tr>
<tr>
<td>Nuclear Data Measurements</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Other</td>
<td>130</td>
<td>38</td>
</tr>
</tbody>
</table>
IAEA activities in support to

NEUTRON IMAGING
Neutron Imaging – IAEA support

IAEA and ISNR survey of neutron imaging facilities (2015)

- 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

- General information, Beam qualification, Beam line layout, Detectors, Advanced neutron imaging features, Involved manpower, Applications, Revenue generation/recovery, Plans for future upgrades, Other relevant information

Neutron Imaging Facilities Survey

Jointly Prepared and Conducted by the ISNR and IAEA
Coordinated Research Projects

• Finished CRP 1575 (2009-2013, 17 countries):
  Development, Characterization and Testing of Materials of Relevance to Nuclear Energy Sector Using Neutron Beams (SANS, diffraction and neutron imaging)

• Finished CRP 1782 (2011-2014, 18 countries):
  Application of Two and Three Dimensional Neutron Imaging with Focus on Cultural Heritage Research
Neutron Imaging – IAEA support

Contrast and precision Round Robin
2012-13, in cooperation with PSI

• Objectives:
  • Assist in organisation 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
  • Advice and evaluation
  • Results analysis, both individual & group
  • Follow up workshops/schools
Neutron Imaging – IAEA support

Contrast and precision Round Robin (2012-13, in cooperation with PSI)

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

• New exercise planned for 2018
  • Use improved samples/methodology
  • Procurement of new samples
  • Analysis and recommendations
  • Follow up workshops
  • Training workshops/schools
Neutron Imaging – IAEA support

Support to conferences

- World Conferences on Neutron Radiography (WCNR 2010 and 2014)
- Neutron Imaging and Neutron Methods in Archaeology and Cultural Heritage (NINMACH 2013 and 2017)
- Other conferences on neutron methods and RRs
Neutron Imaging – IAEA support

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
Neutron Imaging – IAEA support

Training Workshops - AUNIRA
Advanced Use of Neutron Imaging for Research and Applications

Lectures by experts, from the fundamentals to advanced NI
Hands-on-training practical exercises
Typically 25 to 30 students

• 2013 (26-30 August), in cooperation with the Helmholtz-Zentrum Berlin, Germany

• 2015 (28 September–2 October), in cooperation with the Paul Scherrer Institut, Switzerland

• 2017 (28 August-1 September), in cooperation with the Heinz Maier-Leibnitz Zentrum, Germany
Neutron Imaging – IAEA support

Technical Cooperation

• South Africa: upgrade of neutron imaging station (training, procurements)
• China: development of neutron imaging station (training, procurements)
• Algeria: procurement and expert advise
• Indonesia: support through EMs
• Malaysia: support through EMs
• Morocco: support through EMs
• Jordan: preliminary design of neutron radiography station
Neutron Imaging – IAEA support

Publications

IAEA TECDOC SERIES

TECDOC No. 1715

Use of Neutron Beams for Materials Research Relevant to Nuclear Energy Sector

Commercial Products and Services of Research Reactors

IAEA Nuclear Energy Series

No. NP-T-5.3

Applications of Research Reactors

IAEA Nuclear Energy Series

IAEA TECDOC SERIES

Research Reactors: Purpose and Future
Neutron Imaging – IAEA support

Interaction of (slow) neutrons with matter

Case studies - https://nucleus.iaea.org/sites/accelerators/CaseStudies
Research Reactor utilisation

E-LEARNING
E-Learning at the IAEA

IAEA Learning Management System - http://elearning.iaea.org/

Nuclear Technology & Applications
- Nuclear Energy
- Knowledge Management
  more...

Nuclear Safety & Security
- Nuclear Security
- Nuclear Safety
  more...

Cooperation Partners

Safeguards & Verification

Contact Us | Disclaimer
E-Learning

- Milestones
- Human Resources
- Stakeholder Involvement
- Management of NPP
- Construction Management
- SAT
- Feasibility Study
- Management Systems
- Safety Infrastructure
- EPR
- Safeguards
- ...

- Nuclear Technology & Applications
  - Sciences and Applications
    - Human Health
    - Food and Agriculture
  - Applications of RRs
  - Nuclear Analytical Techniques
E-learning: justification

The overall objective:

✓ Disseminate information, knowledge and experience in the area of methodological principles, metrological & practical aspects of nuclear techniques among the laboratories;

✓ Collaborate in development and dissemination of e-learning materials, for nuclear E&T and outreach for the benefit of Member States;

✓ Support the IAEA initiatives in knowledge preservation, sharing and transfer, and developing the expert communities to provide a sustainable future of neutron-based techniques.

Target audience: young specialists or beginners who do not have sufficient experience of conducting experiments independently.

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E-learning NAA: justification

In 2010-2016 the IAEA assisted ~35 NAA laboratories world-wide:

- In assessing their analytical performance through inter-laboratory proficiency exercises
- In implementing a CRP on automation enhancement at NAA laboratories

One of the key gaps identified: lack of knowledge preservation and knowledge transfer due to the retirement and/or departure of experienced staff

Knowledge management in NAA: Large fraction of ageing experienced people

- NAA is not a ‘push-button’ technique
- Limited succession planning
- Lack of time or resources for knowledge transfer in many NAA labs
- New professionals/users often without nuclear/physics background

Often limited access to scientific journals or books

- New generations of scientists familiar with new technologies

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Project development

September 2015: Syllabus (course structure and contents) completed

November 2015: Meeting with main authors and overall coordinator
✓ Action plan and time line. Complete draft package to be ready by end of year.

December 2015/January 2016: Draft versions sent to reviewers
✓ Feedback on content from over 20 international experts incorporated.

10-14 October 2016: Training Workshop on e-learning tool
✓ Demonstration, review & testing;
✓ Feedback on content from over 30 participants from 29 MSs incorporated.

March-May 2017: Final review and corrections

August 2017: Software developed
✓ Testing by experts.

Comprehensive 49 complete modules in 7 topical areas (~2000 slides) with
✓ Lectures and lecture notes
✓ Practical exercises and case studies
✓ Demonstration videos
✓ Tests and quiz exams
✓ References

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Main contributors

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IAEA e-learning NAA (Neutron Activation Analysis)


B1-B2-B3: Radioactivity and Radiation
B4: Decay Process
B5: Decay Schemes and Interpretation
B6: Neutrons and neutron sources
B7-B8: Nuclear Reactions and Activation
C1: Basic Calibration
C2: Advanced Calibration
C3-C4: Uncertainty of Measurement
C5: Gamma Ray Self Attenuation
P1: Analytical characteristics
P2: Practical NAA
P3: Radiation Protection for NAA
P4-P5: Sources of Errors and Troubleshooting
P6-P7-P8: Automation

BASIC NUCLEAR PHYSICS

INSTRUMENTATION
I1-I2: Germanium Detectors
I3: Gamma-Ray Spectrometer Electronics
I4: Gamma-ray Spectrometry
I5: Dead Time and Pile-up Corrections
I6: Shapes of Gamma-Ray Spectra
I7: Background Radiation and Shielding
I8

CALIBRATION
Q1: Pre-Analysis Quality Assurance
Q2: Performing Analysis Quality Assurance
Q3-Q4: Quality Control
Q5: External Quality Control
Q6: Quality Management
Q7-Q9: Statistics

QUALITY

NAA PRACTICE
Q1: Pre-Analysis Quality Assurance
Q2: Performing Analysis Quality Assurance
Q3-Q4: Quality Control
Q5: External Quality Control
Q6: Quality Management
Q7-Q9: Statistics

VARIED

V1: Epithermal NAA
V2-V3: Prompt Gamma Analysis
V4: Large Sample NAA
V5: Delayed Neutron Counting
V6: Cyclic NAA
V7: NAA with Fast Neutrons
V8-V9: Neutron Depth Profiling
V10-V15
Status and further developments

✓ On-line release through the IAEA Cyber Learning Platform for Network Education and Training (CLP4NET) in 2017
   ✓ Access is requested via email

✓ Publication of a dedicated CD-ROM and distribution in 2017

✓ Dissemination and promotion of the tool to the IAEA MSs

✓ **Living tool**: Periodic updates and training events every 2\(^{nd}\) year
   ✓ New modules already foreseen
   ✓ Feedback from users to be incorporated

✓ Similar E-learning tools for other applications of RRs

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E-learning NAA: format

Neutron Activation Analysis e-learning

Module 2 - 6: Basic nuclear physics

Question 1: The atomic nucleus is made of which of the following?
- electrons, protons and neutrons
- electrons and neutrons
- protons and neutrons
- protons and electrons

Results

Your Score: 90% (90 points)
Passing Score: 80% (80 points)

Result:
- Congratulations, you passed.

E-learning NAA

B2: Radioactivity and Radiation

Peter Bode and Sheldon Landsberger

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  - Contributors & reviewers
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  - Overall coordination and liaison
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  - RER1016, PMO Mr Andrej CHUPOV
- Mr Werner MAKOVICKY, external consultant
  - Development of the software
- Ms Any YEMENJIAN, Division of Planning, Information & Knowledge Management
  - On-line release through the IAEA Cyber Learning Platform for Network Education and Training (CLP4NET)

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RR Bibliography:

Research Reactor Database:
https://nucleus.iaea.org/RRDB

Neutron and accelerator based case studies:
https://nucleus.iaea.org/sites/accelerators/CaseStudies/SitePages/Home.aspx
Thank you!