IAEA 60 Years
Atoms for Peace and Development

IAEA e-learning tools
in Research Reactor utilization

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Table of Contents

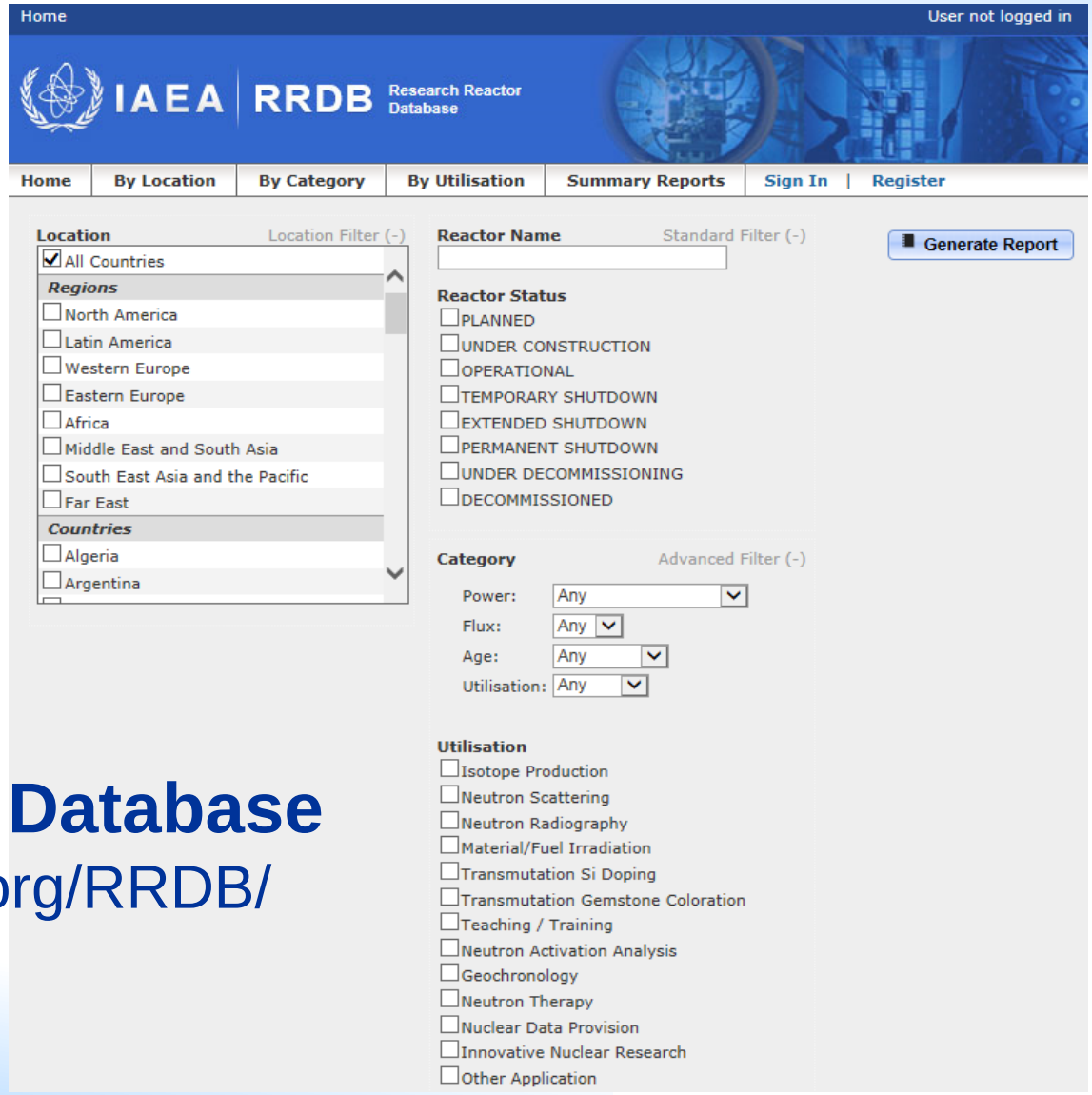
Research Reactors worldwide

OVERVIEW

RRs Worldwide - Overview

Includes:

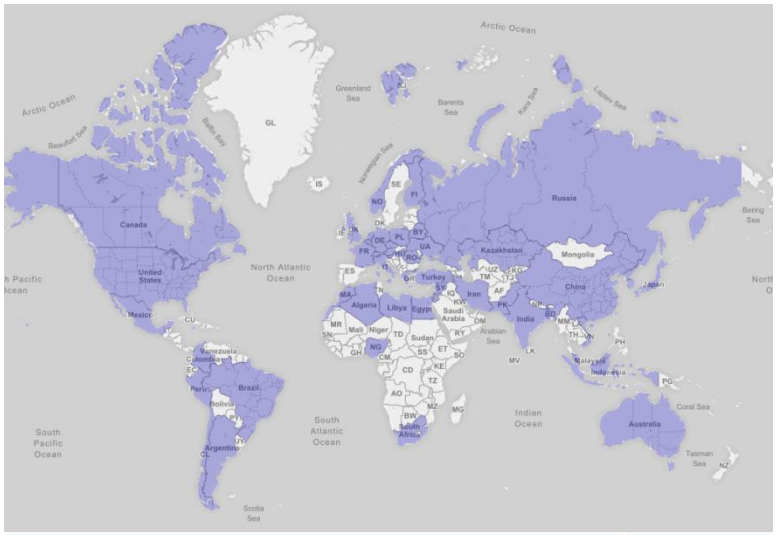
- ✓ **Detailed information of ~700 facilities**
- ✓ **Operational status**
- ✓ **Reactor data**
- ✓ **Fuel data**
- ✓ **Utilization records**
- ✓ **…**



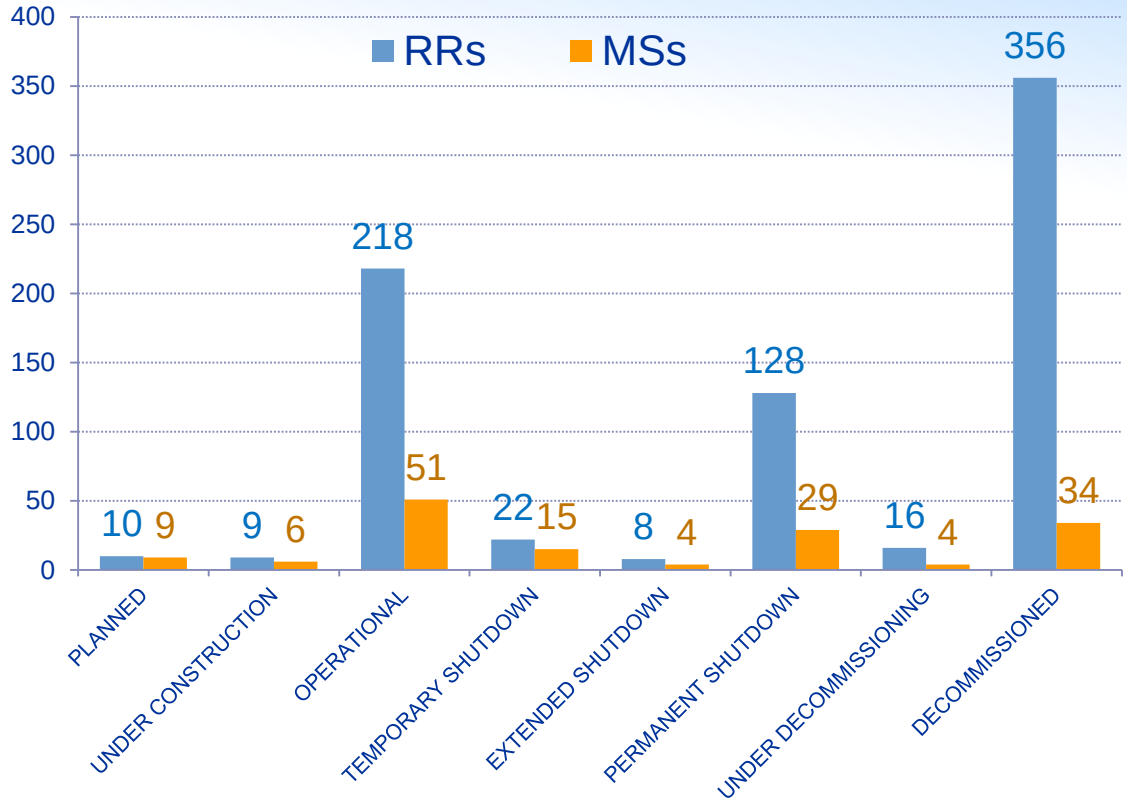
Research Reactor Database

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

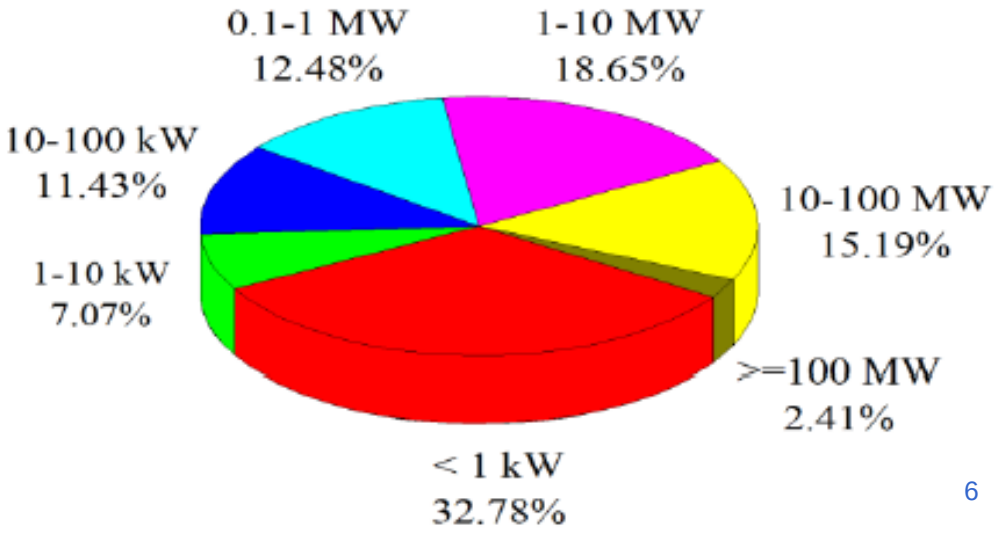


https://nucleus.iaea.org/RRDB/ (May 2017)

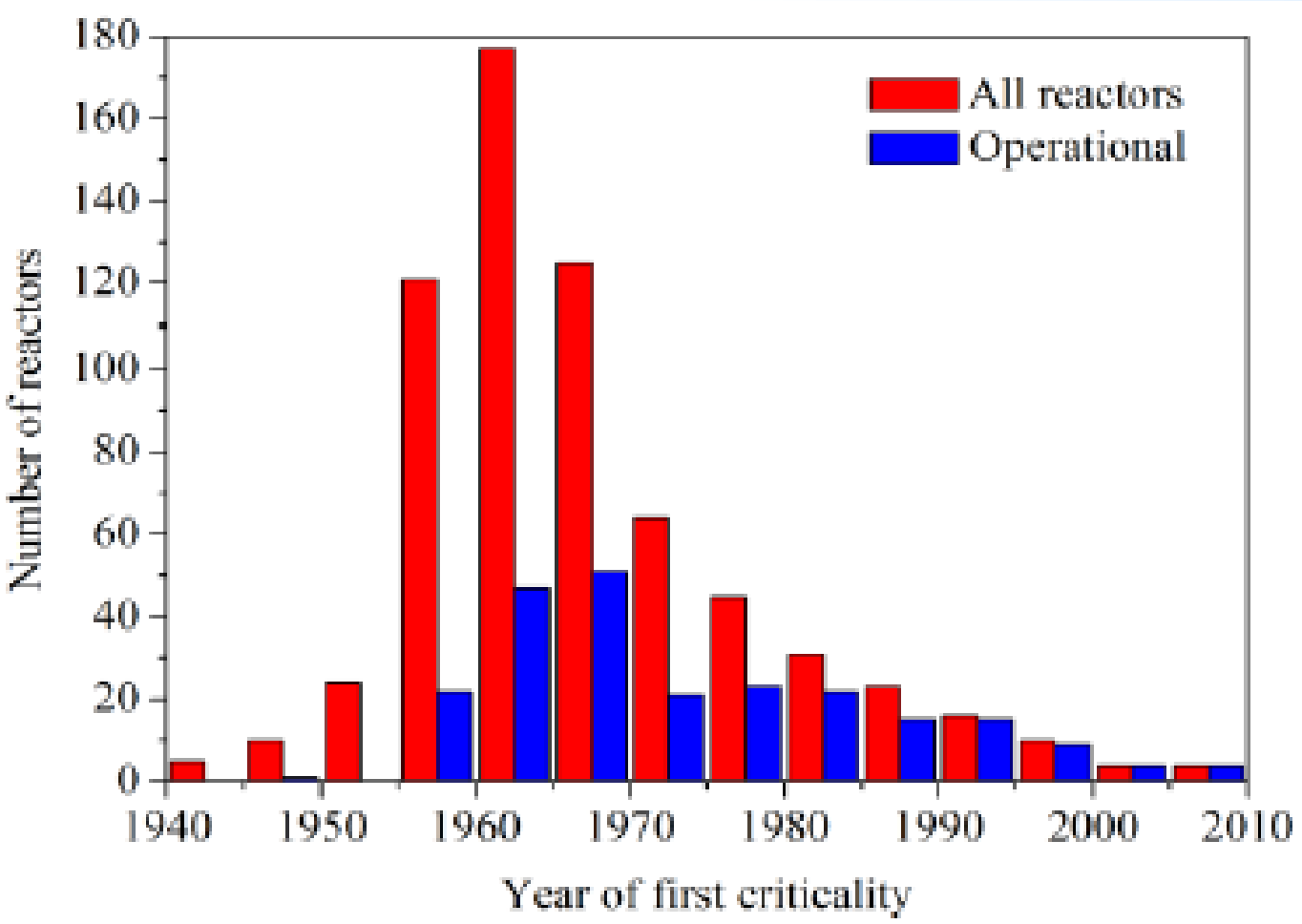
RRs Worldwide - Overview

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

Total power of all RRs in operation is ~2.2 GW (thermal)



RRs Worldwide - Overview



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

Research Reactors - Purpose

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Produce neutrons and provide access to it

Application	Number of RR involved	Number of countries
Education & Training	166	53
Neutron Activation Analysis	120	53
Radioisotope production	97	43
Material/fuel testing/irradiations	80	27
Neutron radiography	**72**	**38**
Neutron scattering	48	31
Si doping	28	18
Geochronology	26	22
Gem coloration	21	12
Neutron Therapy	17	12
Nuclear energy research	16	11
Nuclear Data Measurements	4	4
Other	130	38

IAEA activities in support to

NEUTRON IMAGING

Neutron Imaging – IAEA support

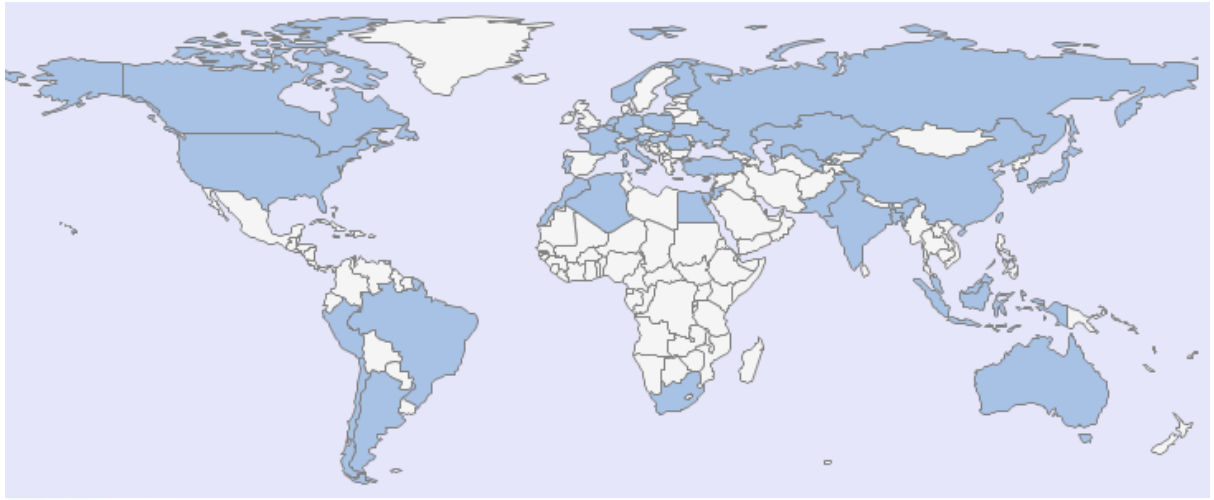
IAEA and ISNR survey of neutron imaging facilities (2015)

- 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



11

Neutron Imaging – IAEA support

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

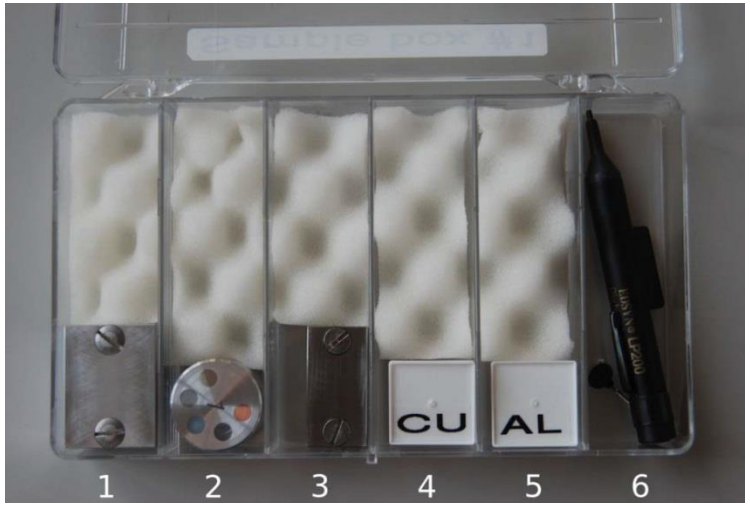
12

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



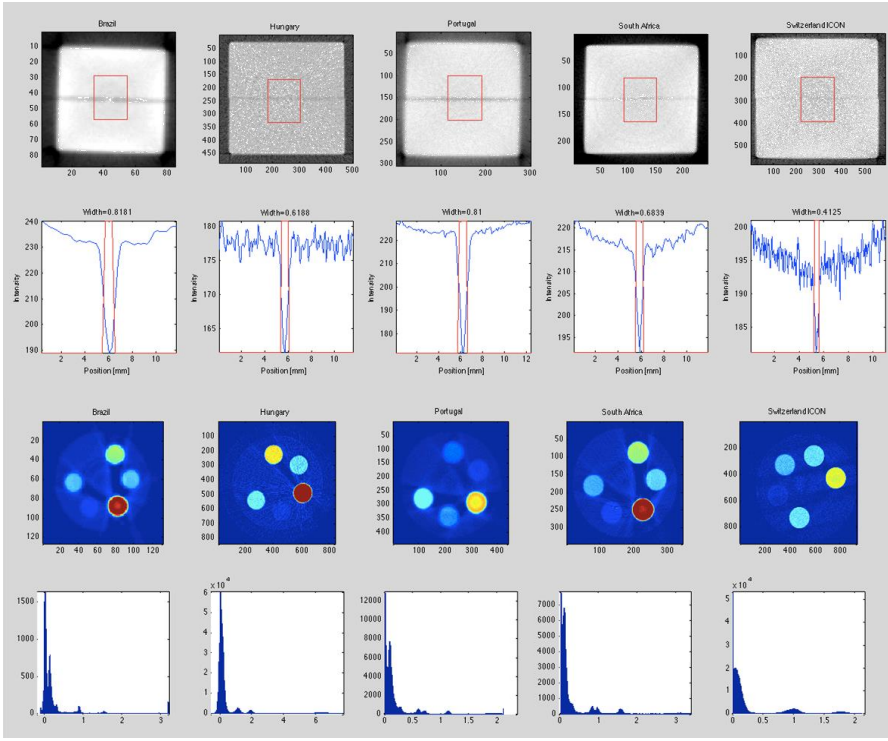
13

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



14

Neutron Imaging – IAEA support

Support to conferences

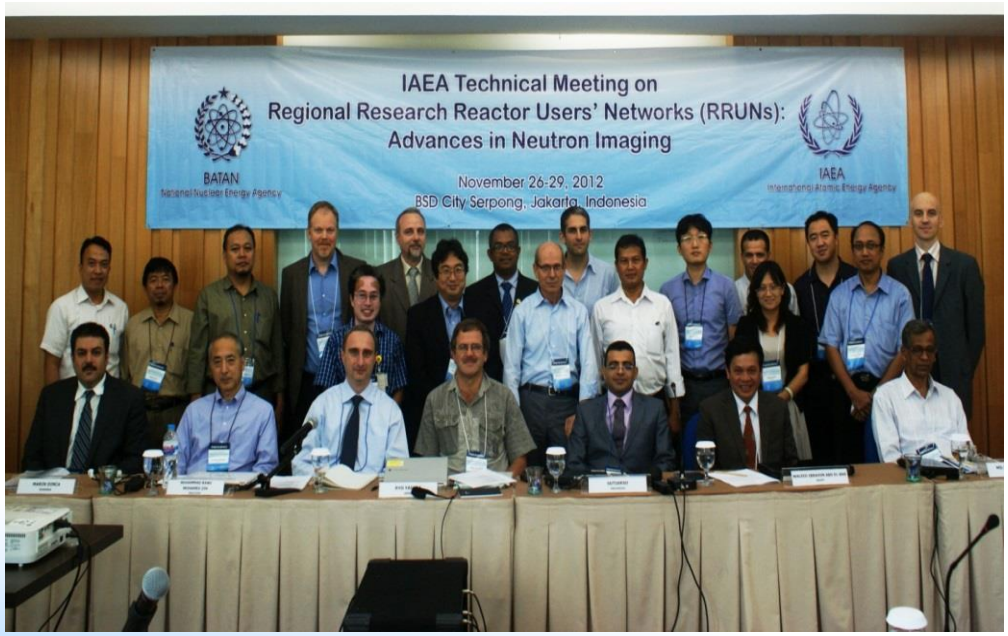
- World Conferences on Neutron Radiography (WCNR 2010 and 2014)
- Neutron Imaging and Neutron Methods in Archaeology and Cultural Heritage (NINMACH 2013 and 2017)
- Other conferences on neutron methods and RRs

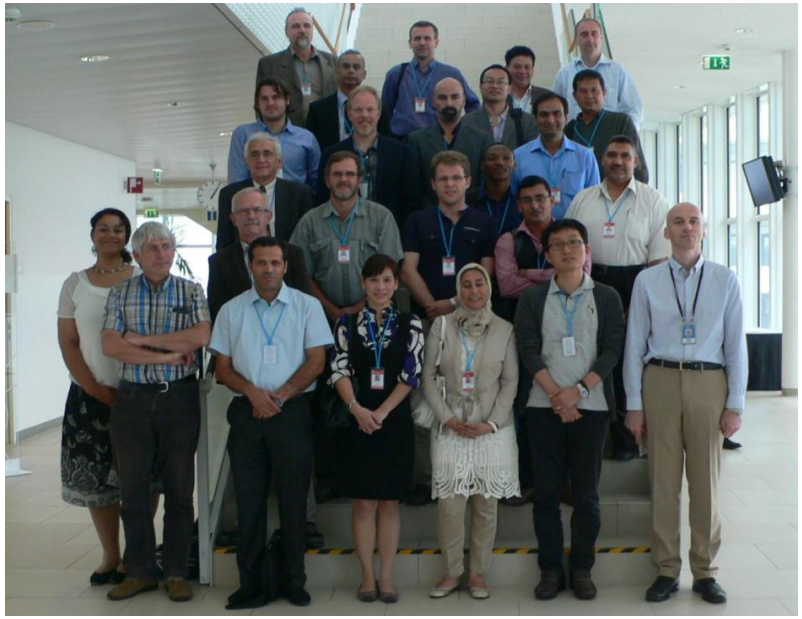
Neutron Imaging – IAEA support

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





16

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

17

Neutron Imaging – IAEA support

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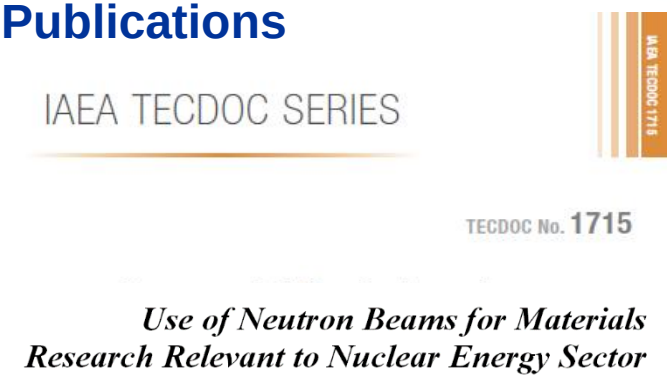
Technical Cooperation

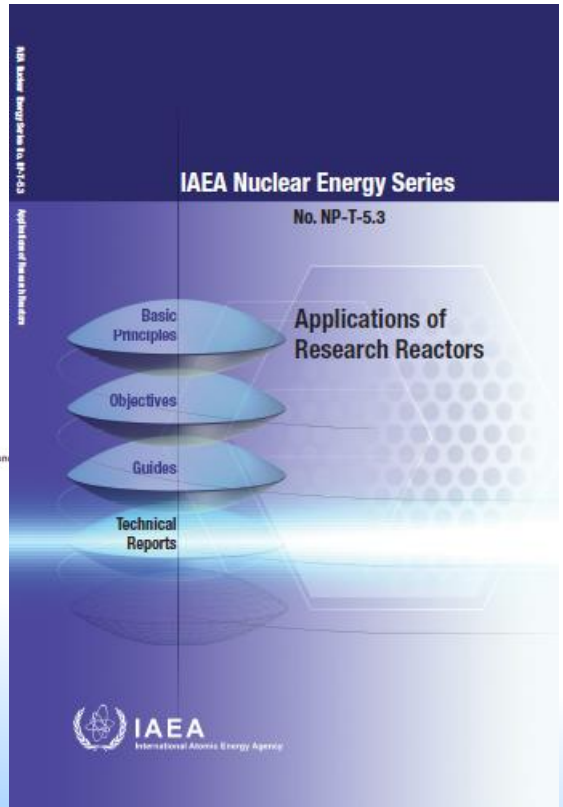
- South Africa: upgrade of neutron imaging station (training, procurements)
- China: development of neutron imaging station (training, procurements)
- Algeria: procurement and expert advise
- Indonesia: support through EMs
- Malaysia: support through EMs
- Morocco: support through EMs
- Jordan: preliminary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

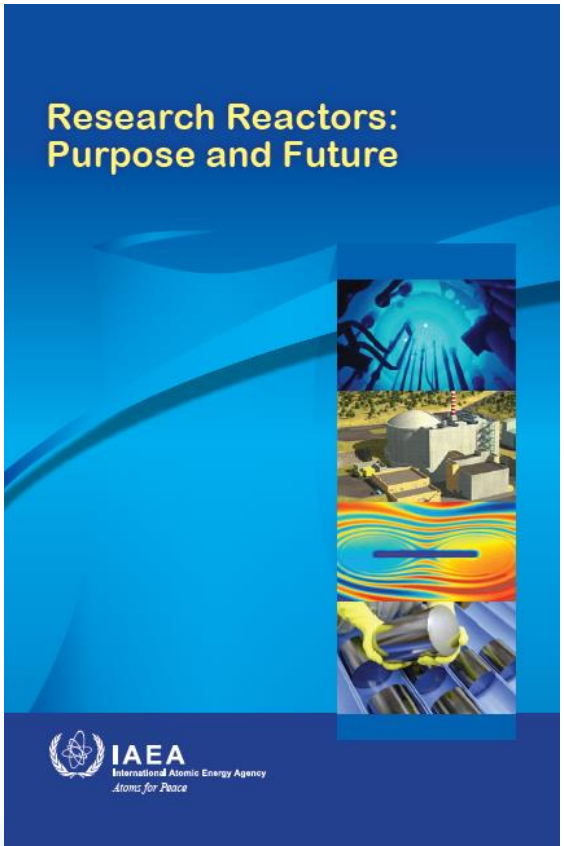
18

Neutron Imaging – IAEA support

Publications



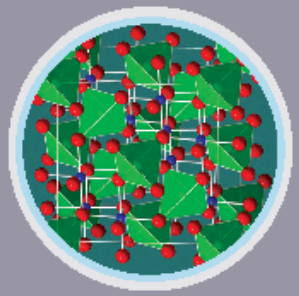




Neutron Imaging – IAEA support

Interaction of (slow) neutrons with matter

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



Scattering

Absorption

Inelastic

Atomic and magnetic dynamics, diffusion

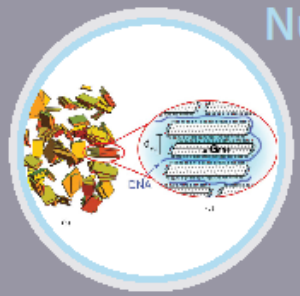
Elastic

Coherent

Incoherent

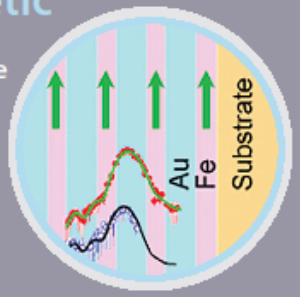
Nuclear

Atomic and nanostructure

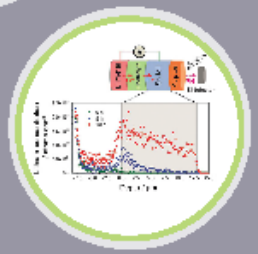


Magnetic

Magnetic structure at atomic and nano-levels



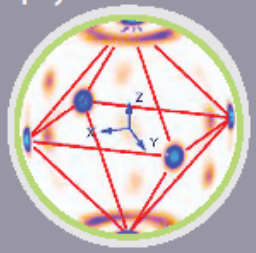
Composition



Depth profile

Neutron imaging

Neutron holography



Research Reactor utilisation

E-LEARNING

E-Learning at the IAEA

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

22

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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Associate Professor (retired) Nuclear Science & Technology Nuclear Security, Quality Management

Sheldon Landsberger
Texas Atomic Research Foundation Professorship Associate Editor, Journal of Environmental Radioactivity

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external consultant, overall coordination and liaison

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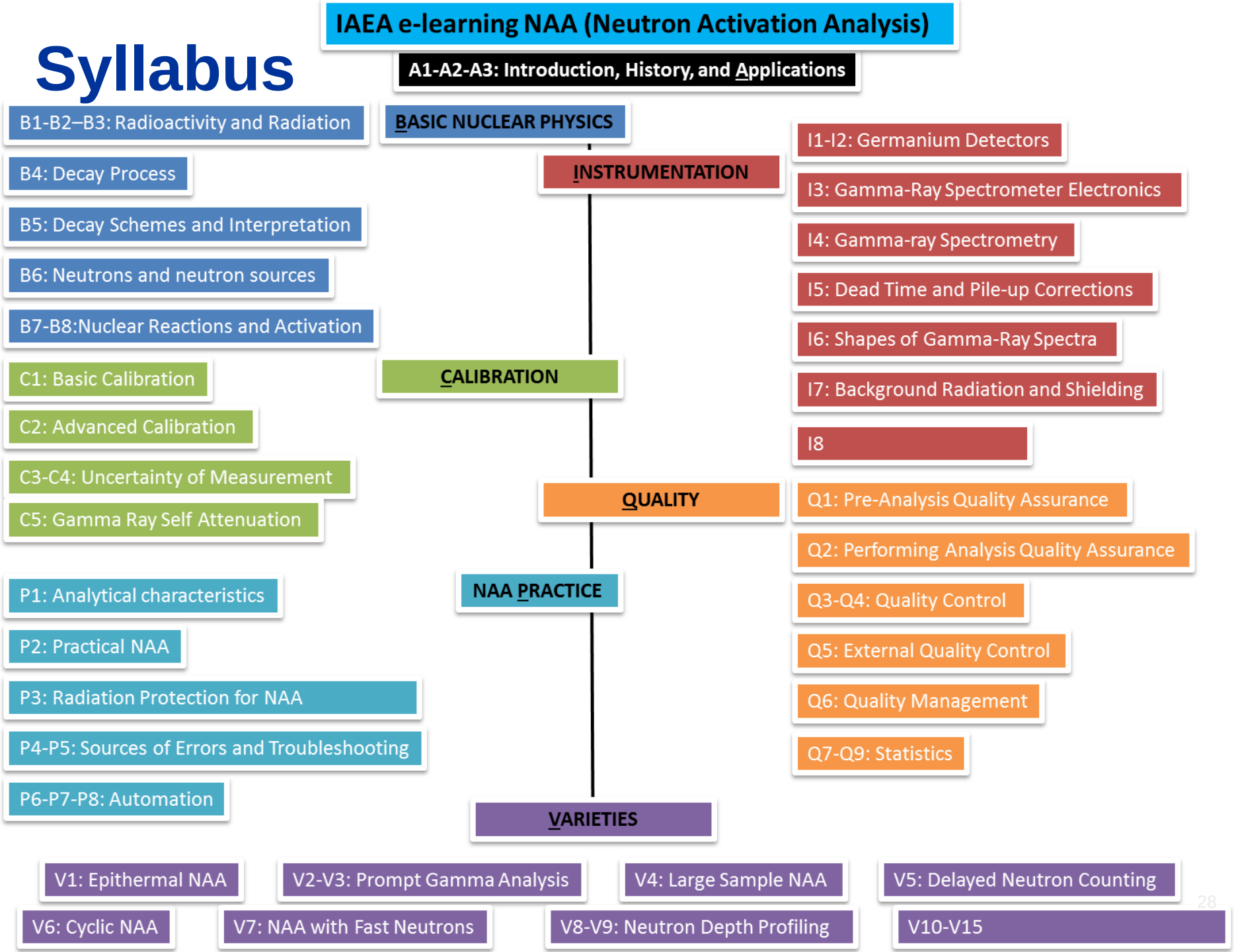
Syllabus


IAEA e-learning NAA (Neutron Activation Analysis)
A1-A2-A3: Introduction, History, and Applications
BASIC NUCLEAR PHYSICS
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
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
C1: Basic Calibration
C2: Advanced Calibration
C3-C4: Uncertainty of Measurement
C5: Gamma Ray Self Attenuation
QUALITY
Q1: Pre-Analysis Quality Assurance
Q2: Performing Analysis Quality Assurance
Q3-Q4: Quality Control
Q5: External Quality Control
Q6: Quality Management
Q7-Q9: Statistics
NAA PRACTICE
P1: Analytical characteristics
P2: Practical NAA
P3: Radiation Protection for NAA
P4-P5: Sources of Errors and Troubleshooting
P6-P7-P8: Automation
VARIETIES
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 2nd year
  - ✓ New modules already foreseen
  - ✓ Feedback from users to be incorporated
- ✓ Similar E-learning tools for other applications of RRs

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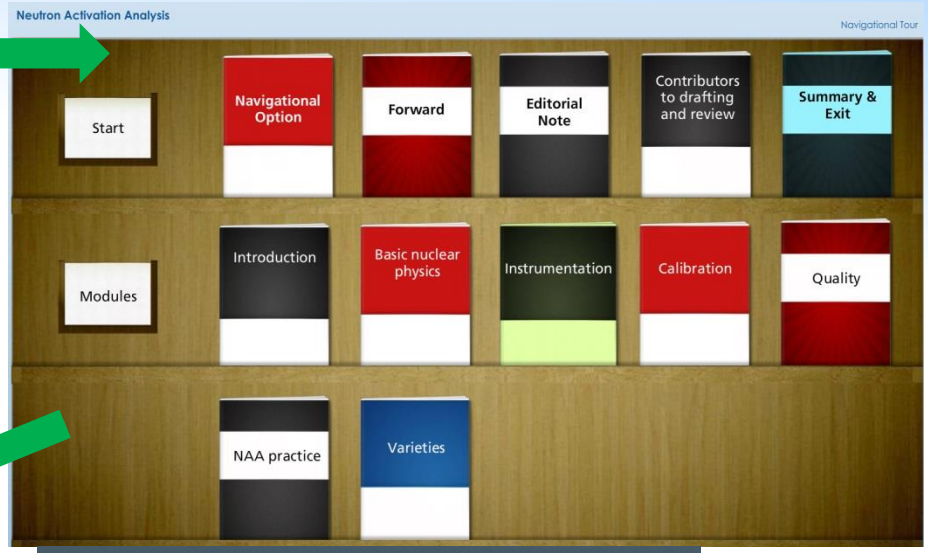
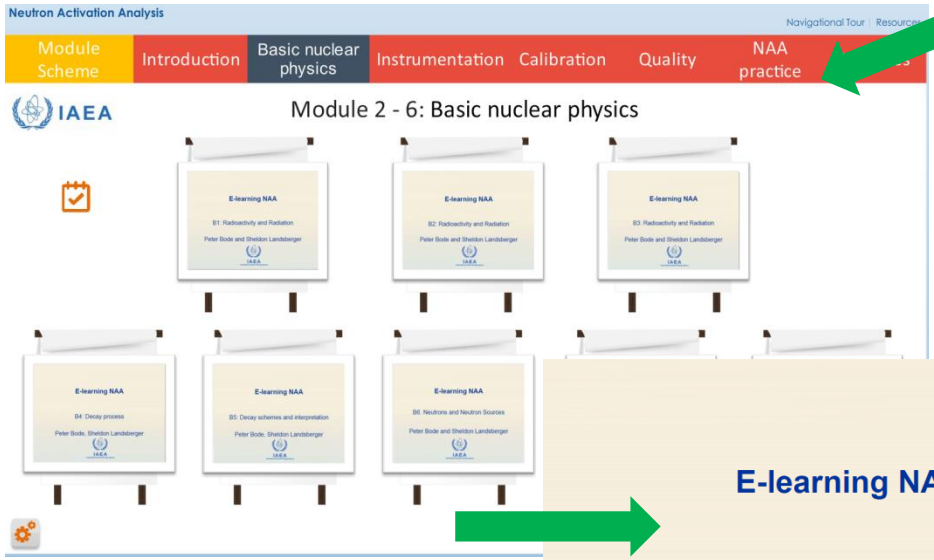
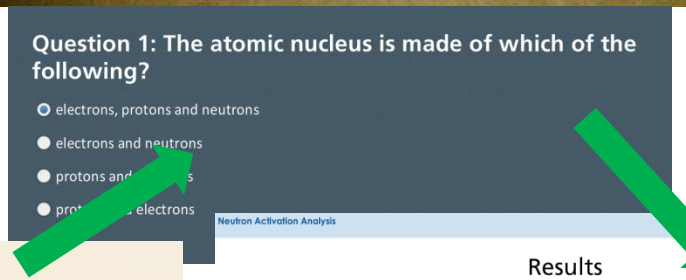
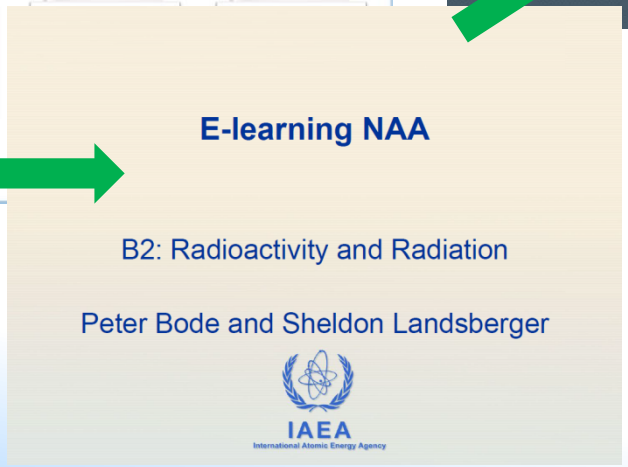
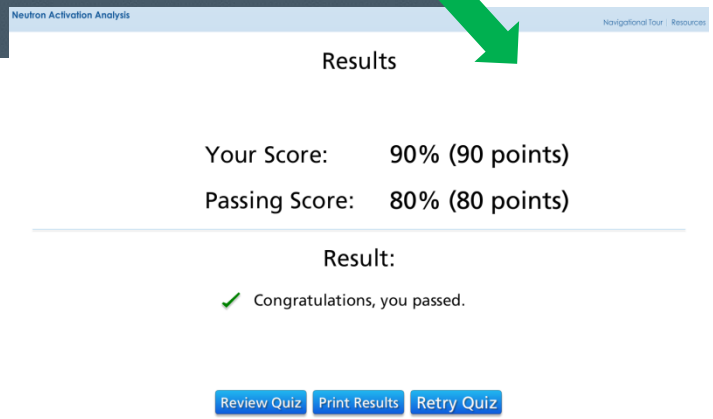
E-learning NAA: format











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Involved parties and support

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  - ✓ Main authors and contributors
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  - ✓ Authors and contributors
- ✓ Mr B. Smodis, Mr J. Preston, Ms M. Almeida, et al., external experts
  - ✓ Contributors & reviewers
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  - ✓ Overall coordination and liaison
- ✓ Technical Cooperation department
  - ✓ RAS0075, PMO Mr Massoud MALEK
  - ✓ RAF1005, PMO Mr Felix BARRIO
  - ✓ 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:
https://www.iaea.org/OurWork/ST/NE/NEFW/Technical-Areas/RRS/bibliography.html

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

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

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Thank you!