



IAEA

60 Years

Atoms for Peace and Development

TW AUNIRA, MLZ, Garching, Germany, 31 August 2017

IAEA e-learning tools in Research Reactor utilization

Nuno Pessoa Barradas

Physics Section

Division of Physical and Chemical Sciences

Department of Nuclear Applications

N.Pessoa-Barradas@iaea.org

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Research Reactors worldwide

OVERVIEW

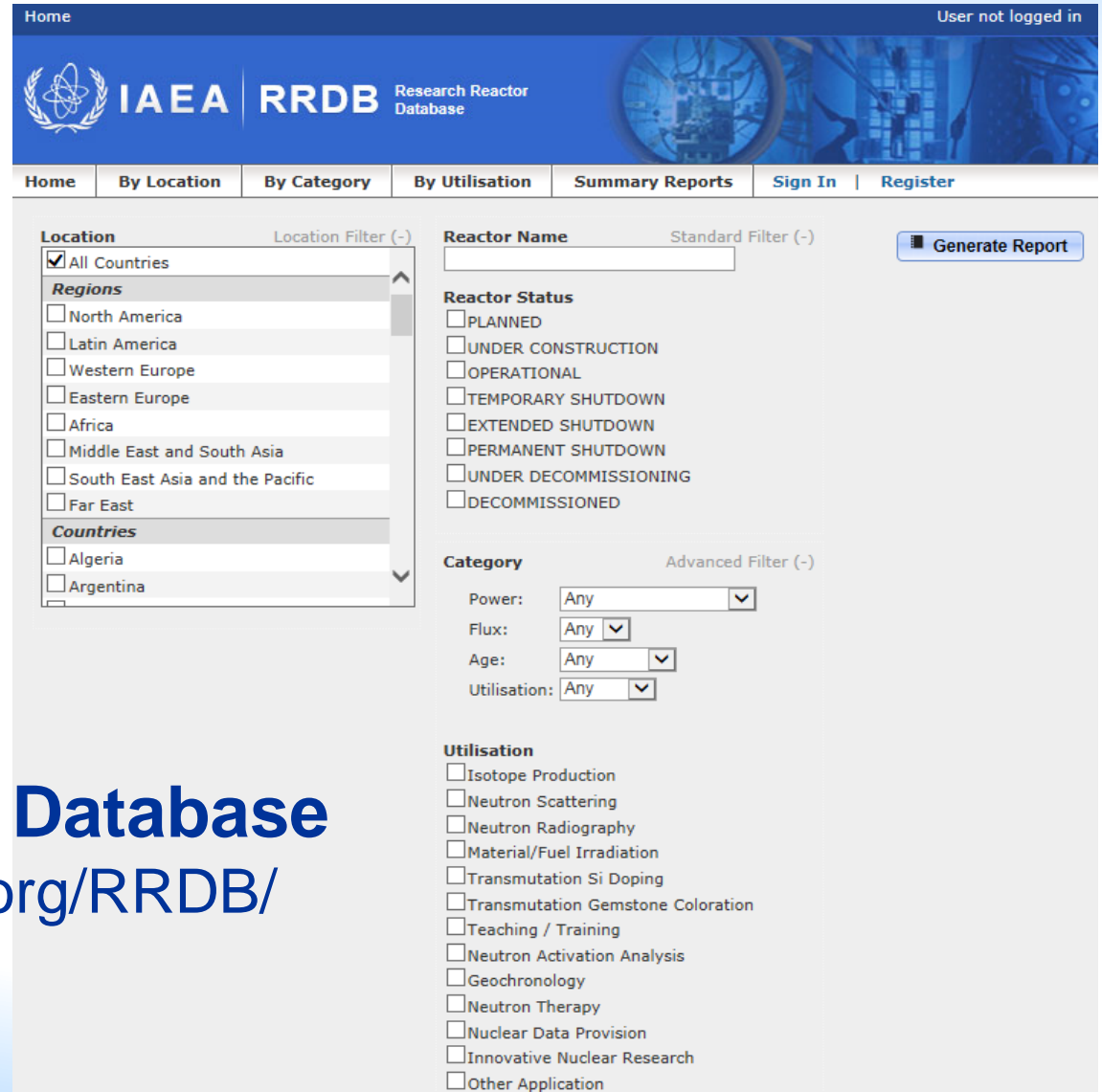
RRs Worldwide - Overview

Includes:


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

Research Reactor Database

<https://nucleus.iaea.org/RRDB/>



Home User not logged in

 **IAEA** | **RRDB** Research Reactor Database

Home By Location By Category By Utilisation Summary Reports Sign In Register

Location Location Filter (-)

All Countries

Regions

- North America
- Latin America
- Western Europe
- Eastern Europe
- Africa
- Middle East and South Asia
- South East Asia and the Pacific
- Far East

Countries

- Algeria
- Argentina

Reactor Name Standard Filter (-)

Reactor Status

- PLANNED
- UNDER CONSTRUCTION
- OPERATIONAL
- TEMPORARY SHUTDOWN
- EXTENDED SHUTDOWN
- PERMANENT SHUTDOWN
- UNDER DECOMMISSIONING
- DECOMMISSIONED

Category Advanced Filter (-)

Power: ▾

Flux: ▾

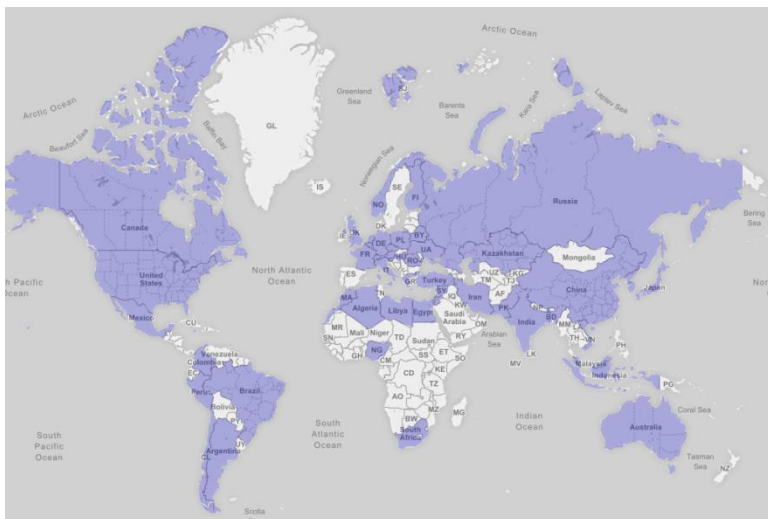
Age: ▾

Utilisation: ▾

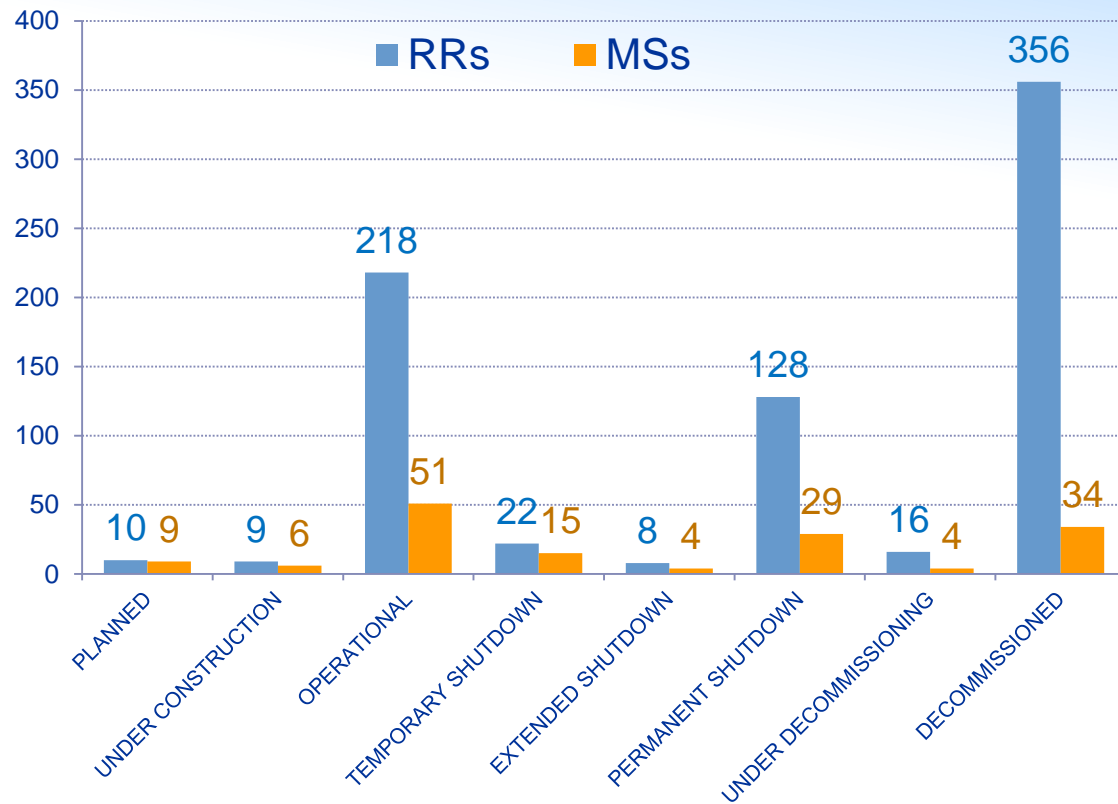
Utilisation

- Isotope Production
- Neutron Scattering
- Neutron Radiography
- Material/Fuel Irradiation
- Transmutation Si Doping
- Transmutation Gemstone Coloration
- Teaching / Training
- Neutron Activation Analysis
- Geochronology
- Neutron Therapy
- Nuclear Data Provision
- Innovative Nuclear Research
- Other Application

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

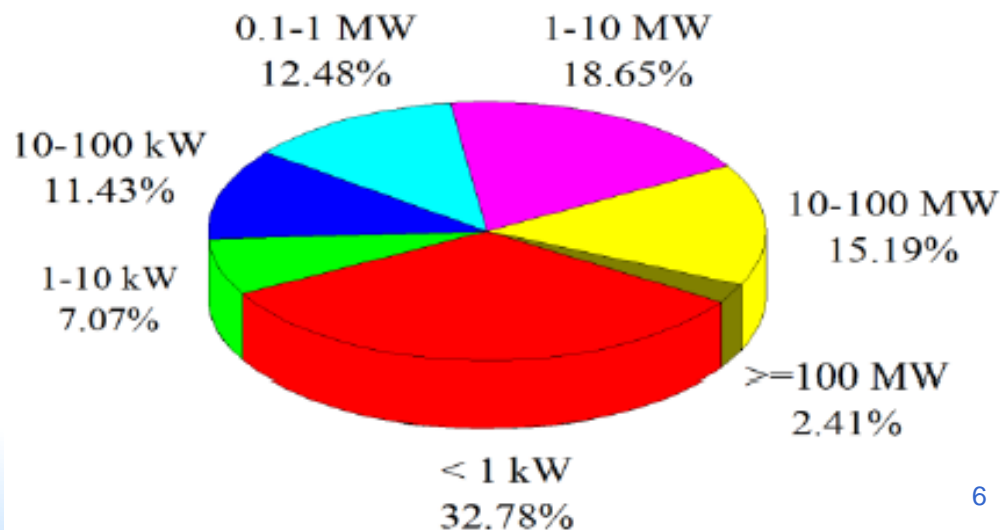


<https://nucleus.iaea.org/RRDB/> (May 2017)

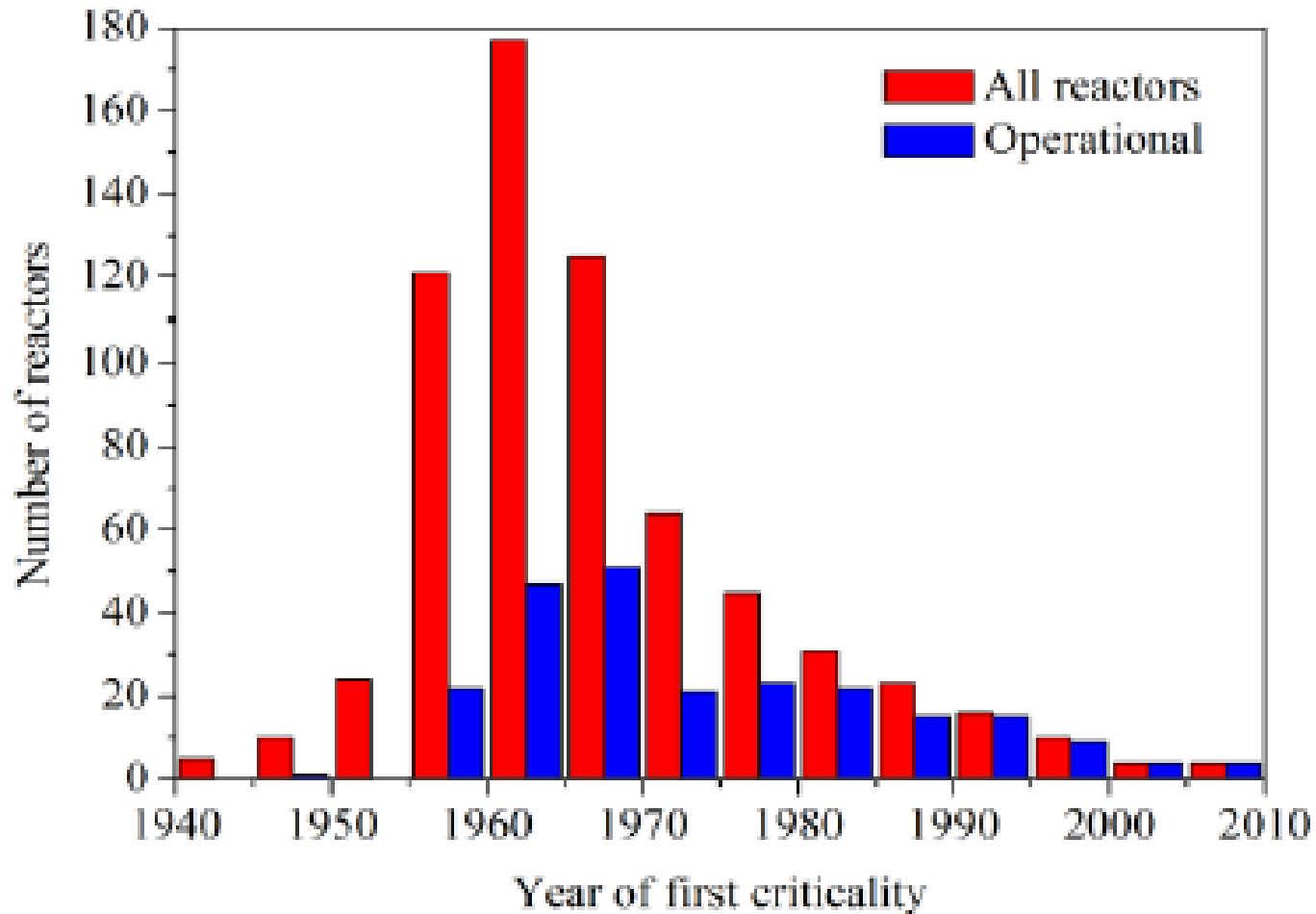
RRs Worldwide - Overview

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

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

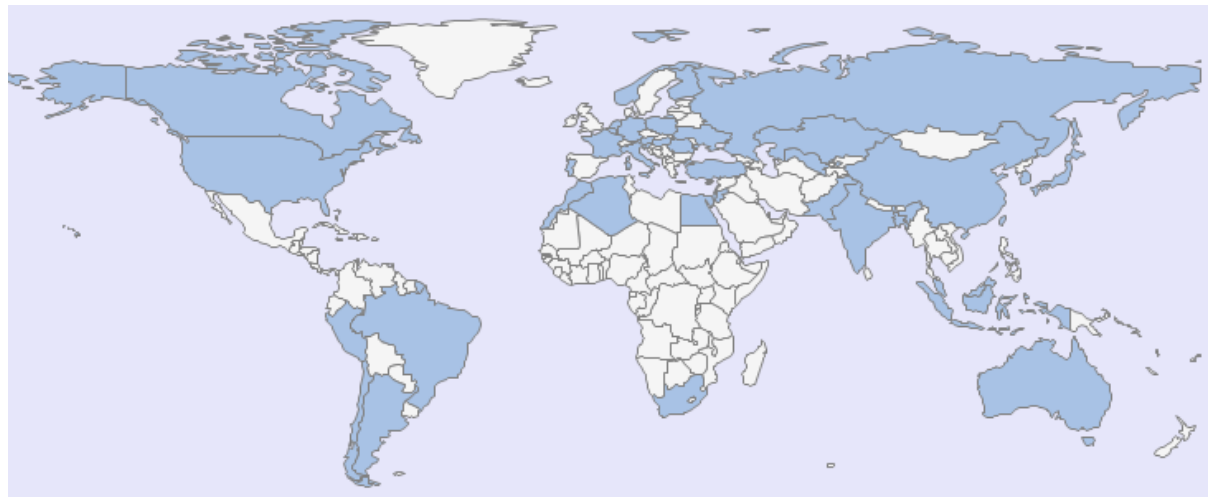
Neutron Imaging – IAEA support

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



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)

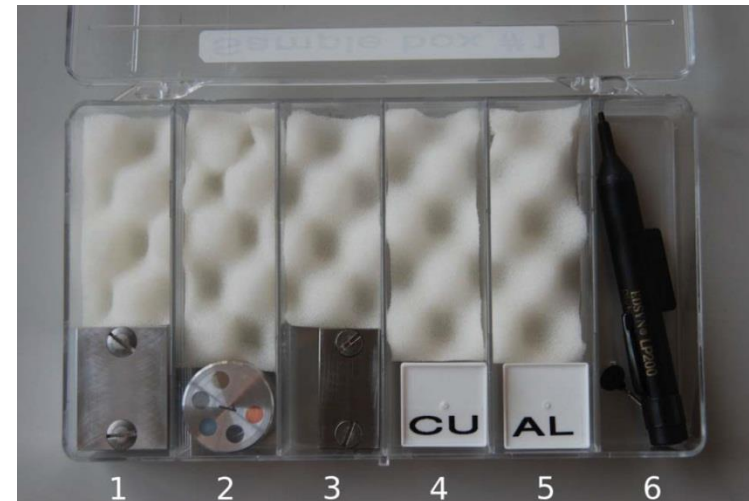
- Finished CRP 1782 (2011-2014, 18 countries):
- Application of Two and Three Dimensional Neutron Imaging with Focus on Cultural Heritage Research

Neutron Imaging – IAEA support

Contrast and precision Round Robin

2012-13, in cooperation with PSI

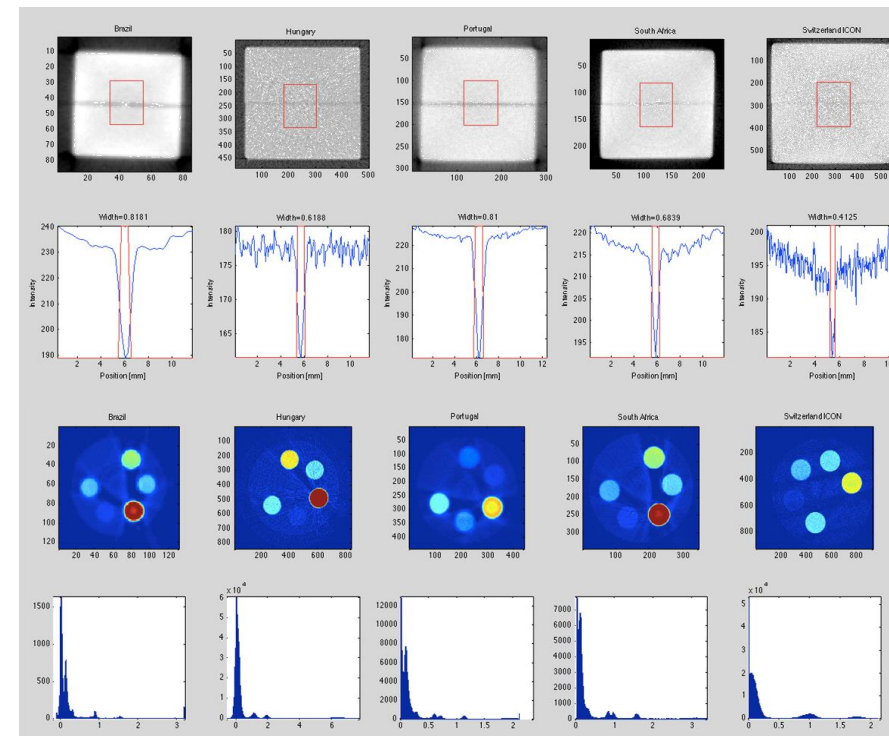
- Objectives:
 - Assist in organisation and implementation of Round Robin exercise
 - Advise on procedures and interpretation in digital neutron imaging
 - Seek for sustainable QA/QC process
 - Offer training workshops/schools
- Means:
 - Guidelines (and deadlines)
 - Samples from PSI: contrast and resolution
 - 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



BIG FIVE ON NEUTRON RADIOGRAPHY
WCNR-9
9th World Conference on Neutron Radiography
3 - 8 October 2010, Kwa Maritane, South Africa

WELCOME TO THE 9TH WORLD CONFERENCE ON NEUTRON RADIOGRAPHY

This is the 9th conference in the series of World Conferences for Neutron Radiography (WCNR-9), that has been scheduled by the International Society for Neutron Radiology (ISNR) to take place every 4 years since 1981, when WCNR-1 was held in San Diego, USA. This is the first opportunity for the event to be held on the African continent with South Africa as the nominated host.

The aim of the series of WCNR is to bring researchers, students and fellows together to share information, build networks and to strengthen relationships between international partners in neutron radiography related research. Topics to be covered at WCNR-9:

- Neutron sources and beams at fast-, thermal- and cold neutron facilities.
- Neutron detectors and techniques for tomographic, phase-, stroboscopic, and other novel imaging practices.
- Industrial neutron imaging applications and its complementary nature to X-ray imaging.

We look forward to your active participation from 3 to 8 October 2010 at the WCNR-9 through oral or poster presentations in the beautiful African wild life setting at Kwa-Maritane Bush Lodge, about 80km north of Pretoria. A scientific visit is also planned to the thermal- and fast neutron radiography facilities at Necsa, located 40km west of Pretoria.

Frikkie de Beer
President: ISNR (2006-2010)

[CLICK HERE TO REGISTER FOR THE WCNR-9](#)
[CLICK HERE TO REGISTER FOR THE SCHOOL OF IMAGING WITH RADIATION](#)

Logos: Proudly South African, International Society for Neutron Radiology, necsa, IAEA, SAINT, VOLUME GRAPHICS



PSI **International Society for Neutron Radiology**

10th World Conference on Neutron Radiography
WCNR-10
Grindelwald, Switzerland, October 5–10, 2014

WCNR-10 will be the global forum to communicate latest developments in the field of Neutron Imaging. It is intended as the international platform to exchange knowledge about methodical improvements, facility installations and upgrade, usage for scientific and industrial related topics and links to related fields like neutron scattering and X-ray imaging. The WCNR-10 will be held to exchange the experience among the facility operators and to bridge between the advanced and the developing laboratories for further improvements.

Topics

- Beamlines
- Instrumentation
- Method development
- Data processing
- Applications

Scientific Advisory Board

M. Arif, USA
L. Bennett, Canada
T. Buecherl, Germany
F. de Beer, South Africa
U. Garbe, Australia
Z. Guo, China
C. Franklin, South Africa
A. P. Kaestner, Switzerland
N. Kardjilov, Germany
Y. Kyanagi, Japan
E. H. Lehmann, Switzerland
B. Schillinger, Germany
N. Takemaka, Japan
R. Tsukimura, USA

Local Organisation Committee

E. H. Lehmann (Chairman)
A. P. Kaestner (Vice-Chairman)
D. Mannes
R. Bercher
G. Frei

Further information on the conference web page:
www.psi.ch/wcnr10
Contact: wcnr10@psi.ch

In cooperation with: IAEA, TRITEC, ESS, VICTORINOX, LOT, VOLUME GRAPHICS

Sponsors: VICTORINOX, TRITEC, SwissNeutronics, LOT, VOLUME GRAPHICS

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

IAEA TECDOC 1715

TECDOC No. 1715

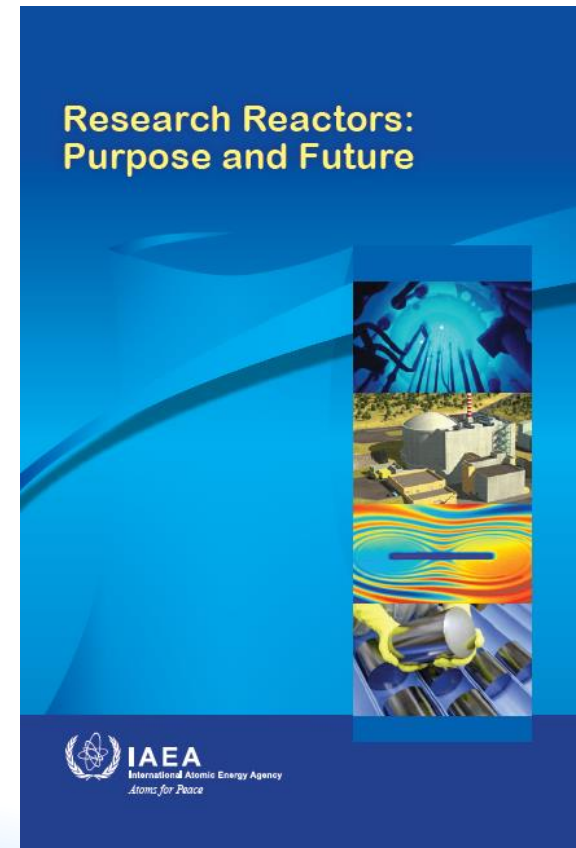
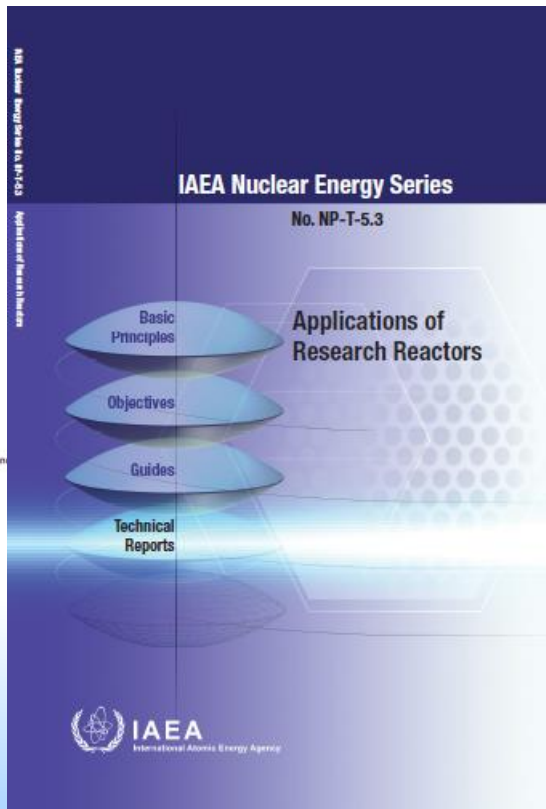
*Use of Neutron Beams for Materials
Research Relevant to Nuclear Energy Sector*

IAEA TECDOC SERIES

IAEA TECDOC 1715

TECDOC No. 1715

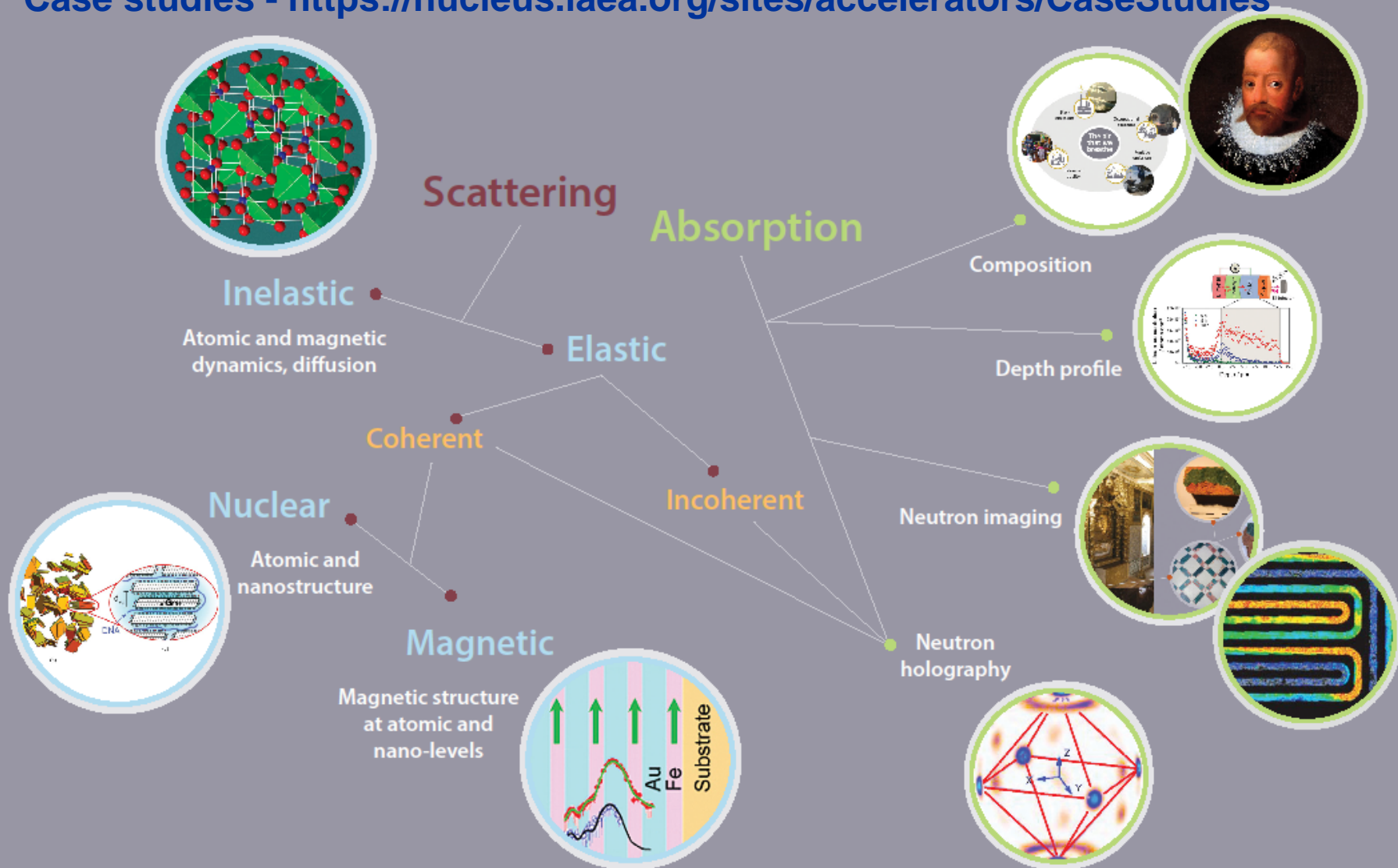
Commercial Products and
Services of Research Reactors



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

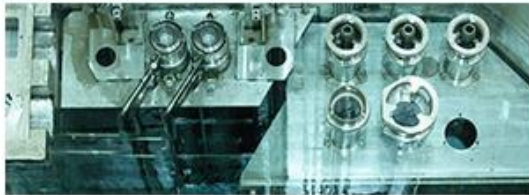
IAEA Learning Management System - <http://elearning.iaea.org/>



IAEA Learning Management System

powered by CLP4NET

Nuclear Technology & Applications



- Nuclear Energy
 - Knowledge Management
- [more...](#)

Nuclear Safety & Security



- Nuclear Security
 - Nuclear Safety
- [more..](#)

Cooperation Partners



Safeguards & Verification



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.**

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

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

Main contributors



Peter Bode

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

Danas Ridikas & Nuno Barradas

IAEA



Sheldon Landsberger

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

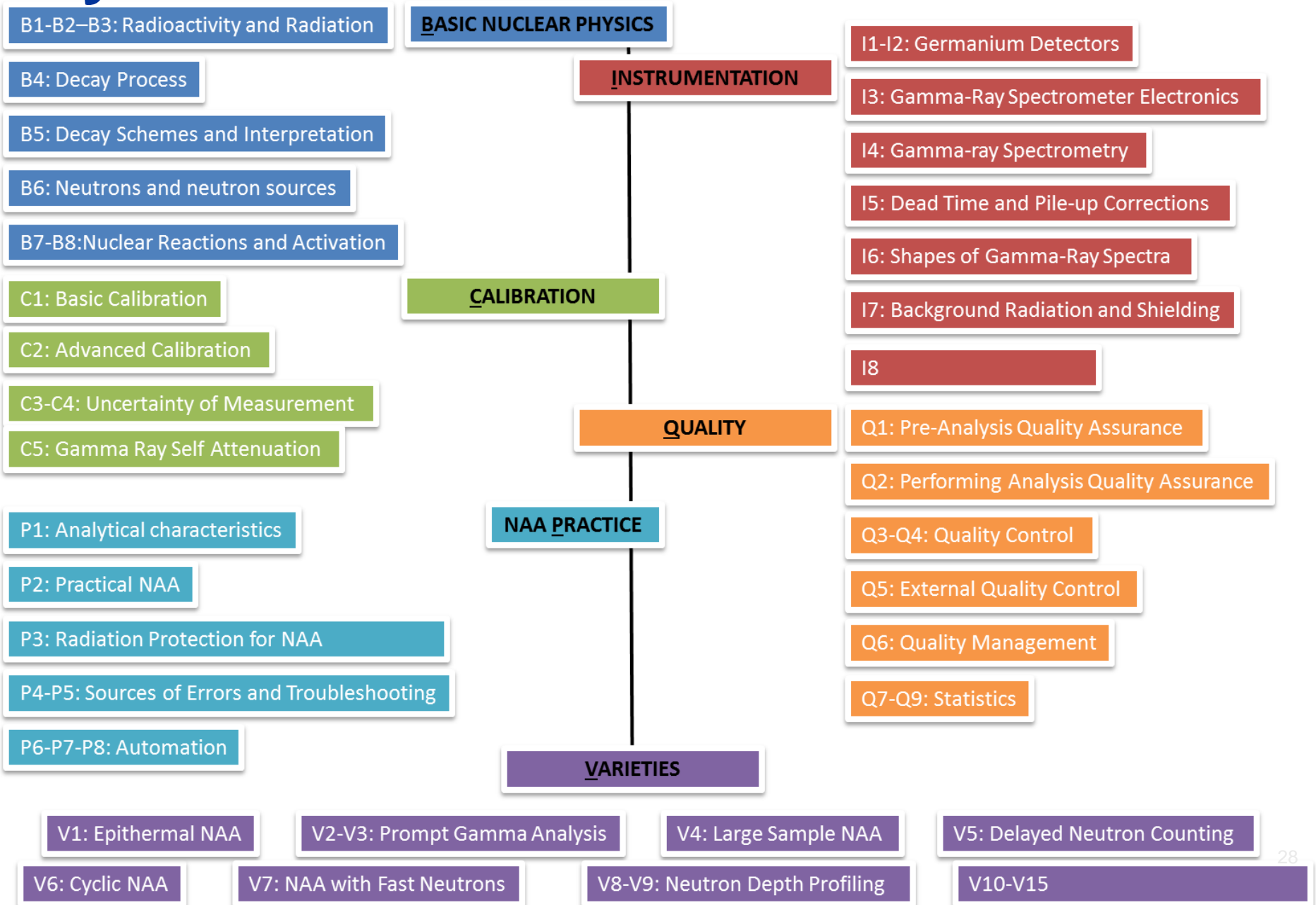
Alesia Iunikova

external consultant, overall
coordination and liaison

IAEA e-learning NAA (Neutron Activation Analysis)

A1-A2-A3: Introduction, History, and Applications

Syllabus



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

E-learning NAA: format

Neutron Activation Analysis

IAEA

Neutron Activation Analysis e-learning

Neutron Activation Analysis

Start

Modules

NAA practice

Varieties

Summary & Exit

Introduction

Basic nuclear physics

Instrumentation

Calibration

Quality

Neutron Activation Analysis

Module 2 - 6: Basic nuclear physics

E-learning NAA

B1: Radioactivity and Radiation

B2: Radioactivity and Radiation

B3: Radioactivity and Radiation

B4: Decay process

B5: Decay schemes and interpretation

B6: Neutrons and Neutron Sources

E-learning NAA

B2: Radioactivity and Radiation

Peter Bode and Sheldon Landsberger

IAEA
International Atomic Energy Agency

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

Neutron Activation Analysis

Results

Your Score: 90% (90 points)

Passing Score: 80% (80 points)

Result:

✓ Congratulations, you passed.

Review Quiz Print Results Retry Quiz

Involved parties and support

- ✓ **Mr Danas RIDIKAS & Mr Nuno Barradas, IAEA**
- ✓ **Mr Peter BODE & Mr Sheldon LANDSBERGER, external experts**
 - ✓ **Main authors and contributors**
- ✓ **Mr Zsolts REVAY & Mr Greg DOWNING, external experts**
 - ✓ **Authors and contributors**
- ✓ **Mr B. Smodis, Mr J. Preston, Ms M. Almeida, et al., external experts**
 - ✓ **Contributors & reviewers**
- ✓ **Ms Alesia YUNIKOVA, external consultant**
 - ✓ **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)**

Contact Information

Research Reactor Section contact point:

Research.Reactors@iaea.org

Research Reactor utilization contact point:

RRAppl.Contact-Point@iaea.org

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!