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Joint ICTP-IAEA School of Nuclear Energy Management

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Nuclear Applications Fundamentals: Research Reactors

Danas Ridikas
IAEA, Vienna
Austria

Strada Costiera 11, 34151 Trieste, Italy - Tel.+39 040 2240 111; Fax +39 040 224 163 - sci_info@ictp.it

Lecture 1

Nuclear Applications Fundamentals:

Research Reactors

10 August 2011

Danas Ridikas

Department of Nuclear Sciences and Applications (NA)
Vienna International Centre, PO Box 100, 1400 Vienna, Austria

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Outline

- Introduction
- Historical background
- IAEA RR Data Base
- Key Issues and challenges
- Latest news on RRs
- (Applications of RRs TECDOC-1234, 2001)

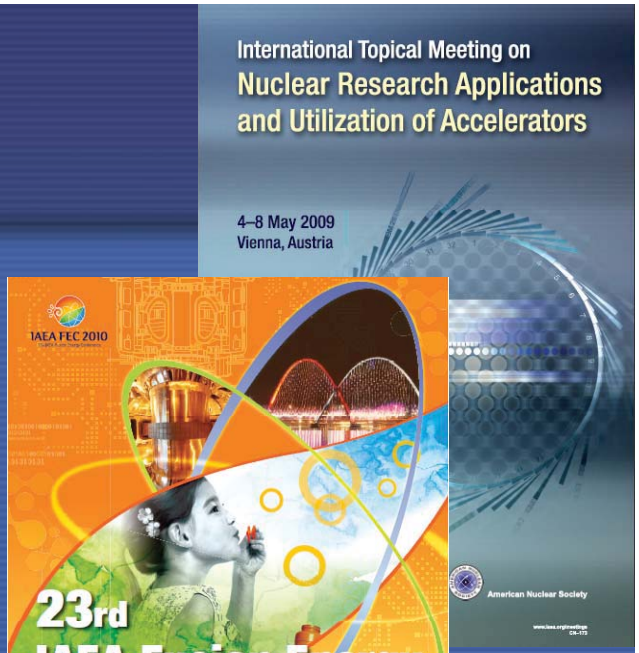
Major Activities within Physics Section

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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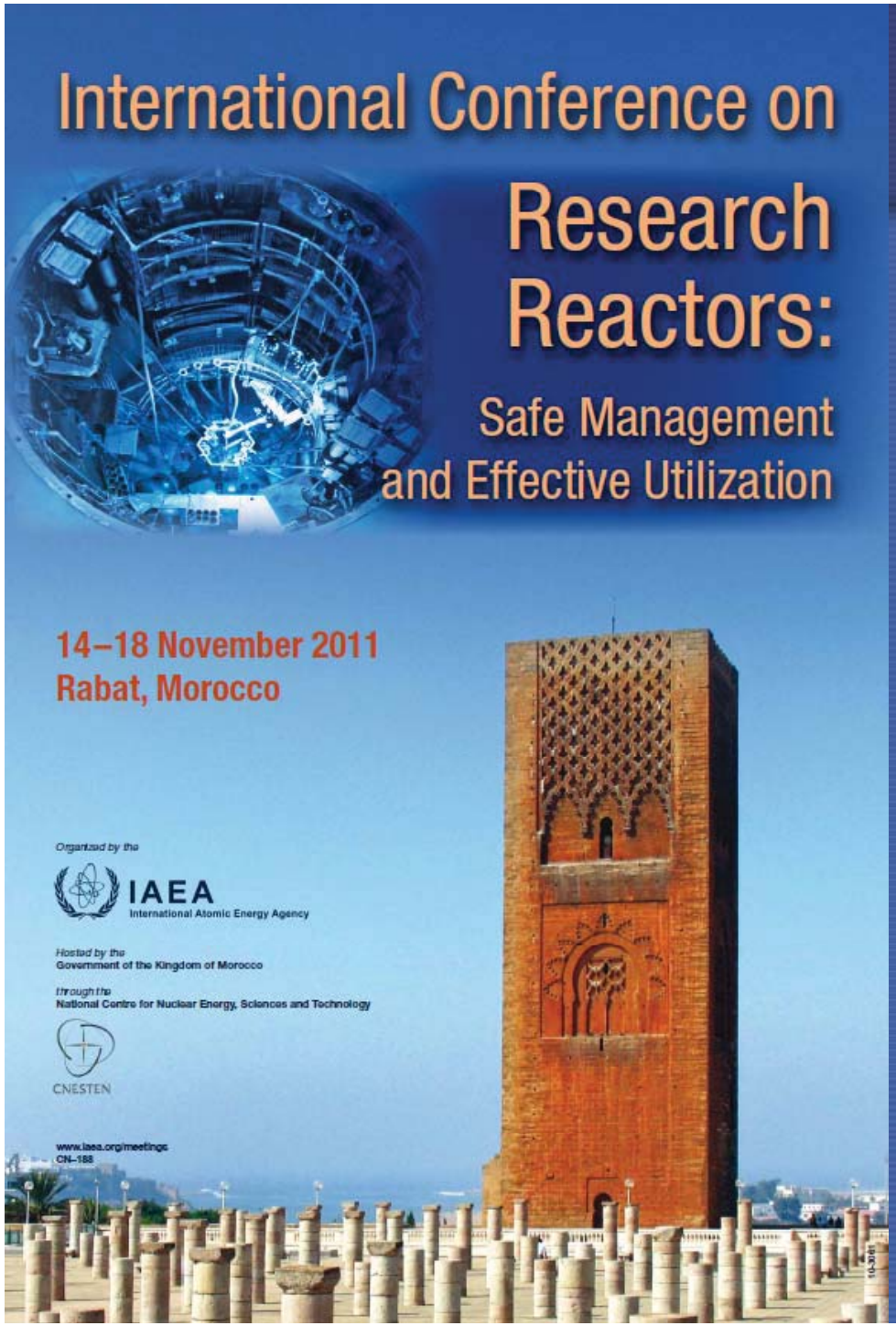

Six main topics to be addressed:

1. **Utilization & Applications of RRs**
2. **Operation & Maintenance**
3. **New RR Projects**
4. **Safety of RRs**
5. **Spent Fuel Management, Waste & Decommissioning**
6. **RR designers/providers**

Jointly by NA, NE, NS and TC

>200 participants expected
>130 papers presented
>50 countries represented

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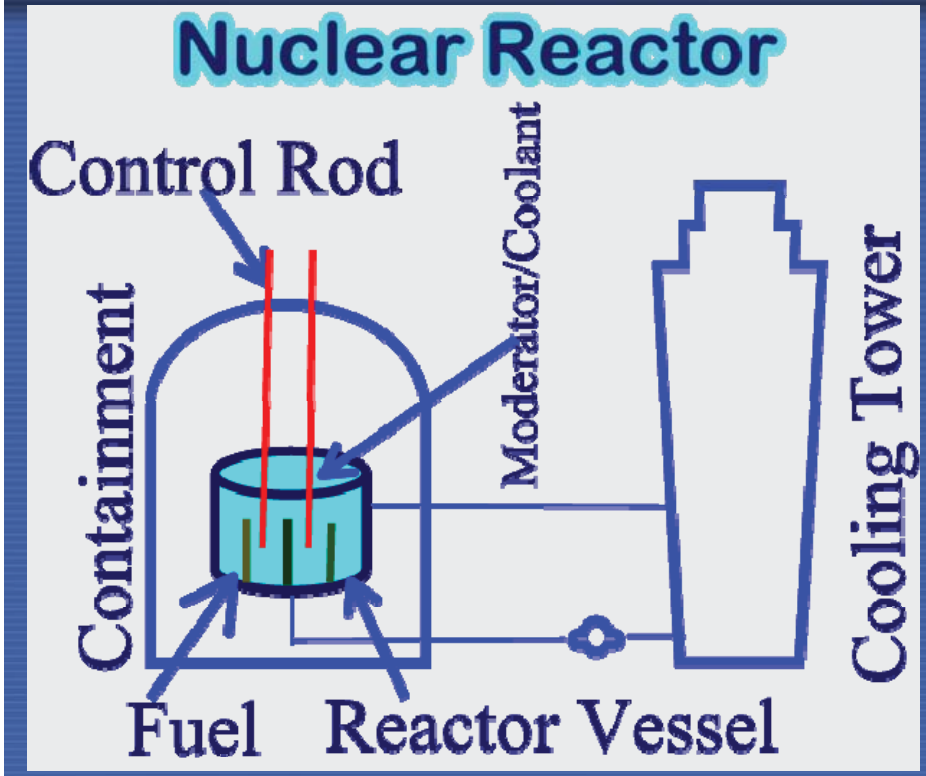
Introduction



Main Components of Research Reactor

FUEL	Natural Uranium / Enriched Uranium
FORM	Metal, Alloy, Oxide, Silicide
CLAD	Aluminium, Zirconium, SS
MODERATOR	H2O, D2O, Graphite, Beryllium
CONTROL	Boron, Cadmium, Nickel
COOLANT	Water, Gas, Sodium, PbBi
VESSEL	to contain all components

Basic Nuclear Physics

Interaction of neutrons with matter (fission, capture, scattering)
Criticality, role of delayed neutrons, radiocative decay
Basics of thermohydraulics

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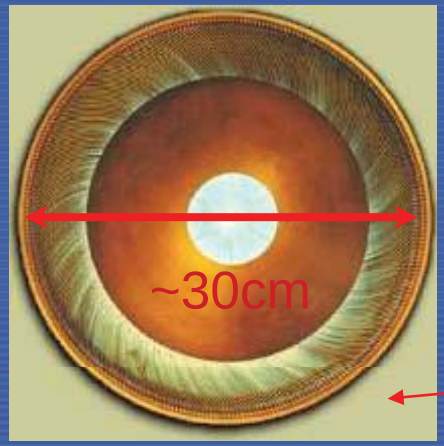
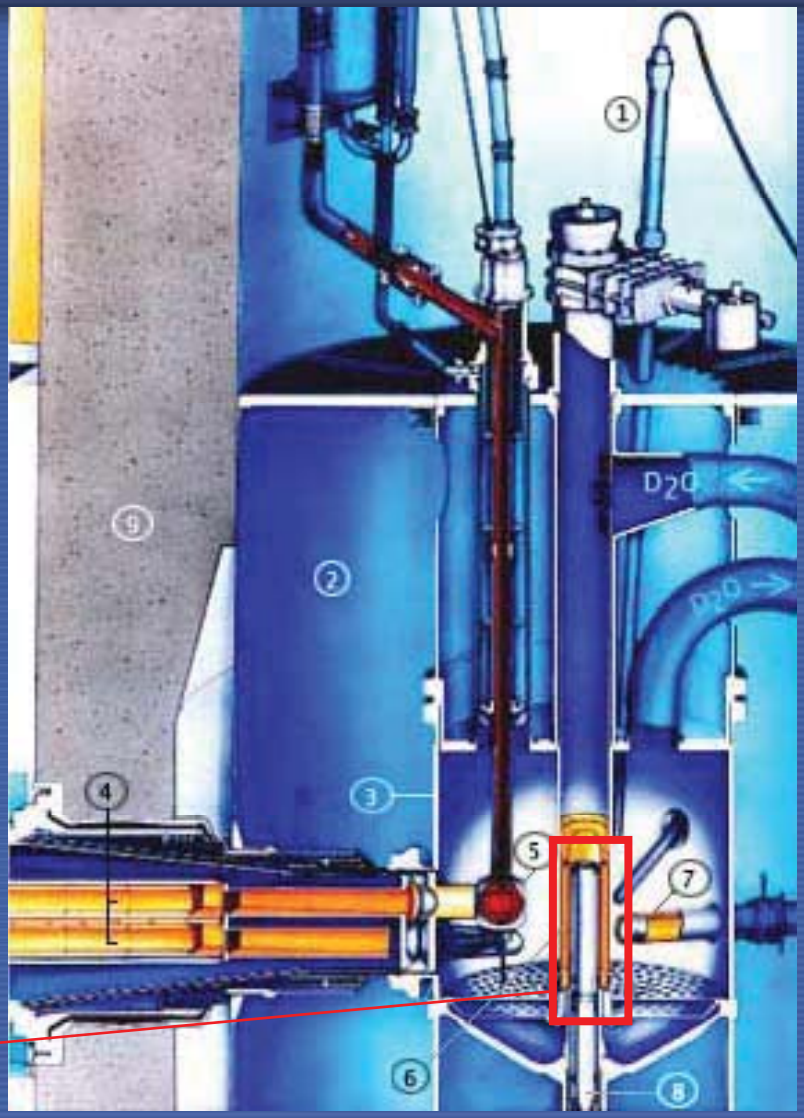
Introduction

Other general information: features

- Typically, RR cores have small volume
- Many have powers less than 5 MW(t)
- Higher enrichments than power reactors
- Natural and forced cooling
- Pulsing capability





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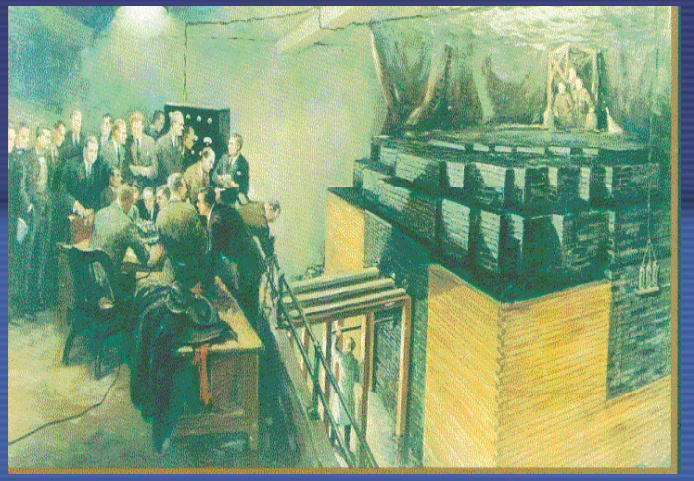
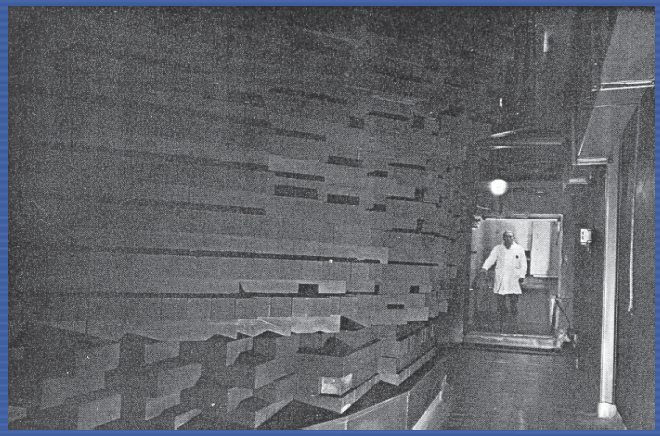
Background

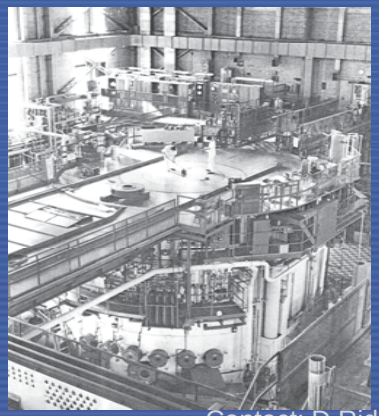
Some historical facts



- USA, Dec. 1942: Chicago Pile (CP1), E. Fermi
  - Objective: neutron source for Pu production



- Russia, Dec. 1946, F-1, I. Kurchatov
  - Objective: excess neutrons for Pu production



- Canada, Jul. 1947, Chalk River Laboratories
  - NRX – National Research Experiment
  - Reached 20MW(t) in 1949
  - Used for basic research
  - Contributed to nuclear x-section data

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Background

Some historical facts (continued)

- **Obninsk, Russia, 1954 APS-1: Institute of Physics and Power Engineering**
  - **First reactor to generate appreciable electric power, 5 MW(e)**
  - **Start of nuclear energy…**

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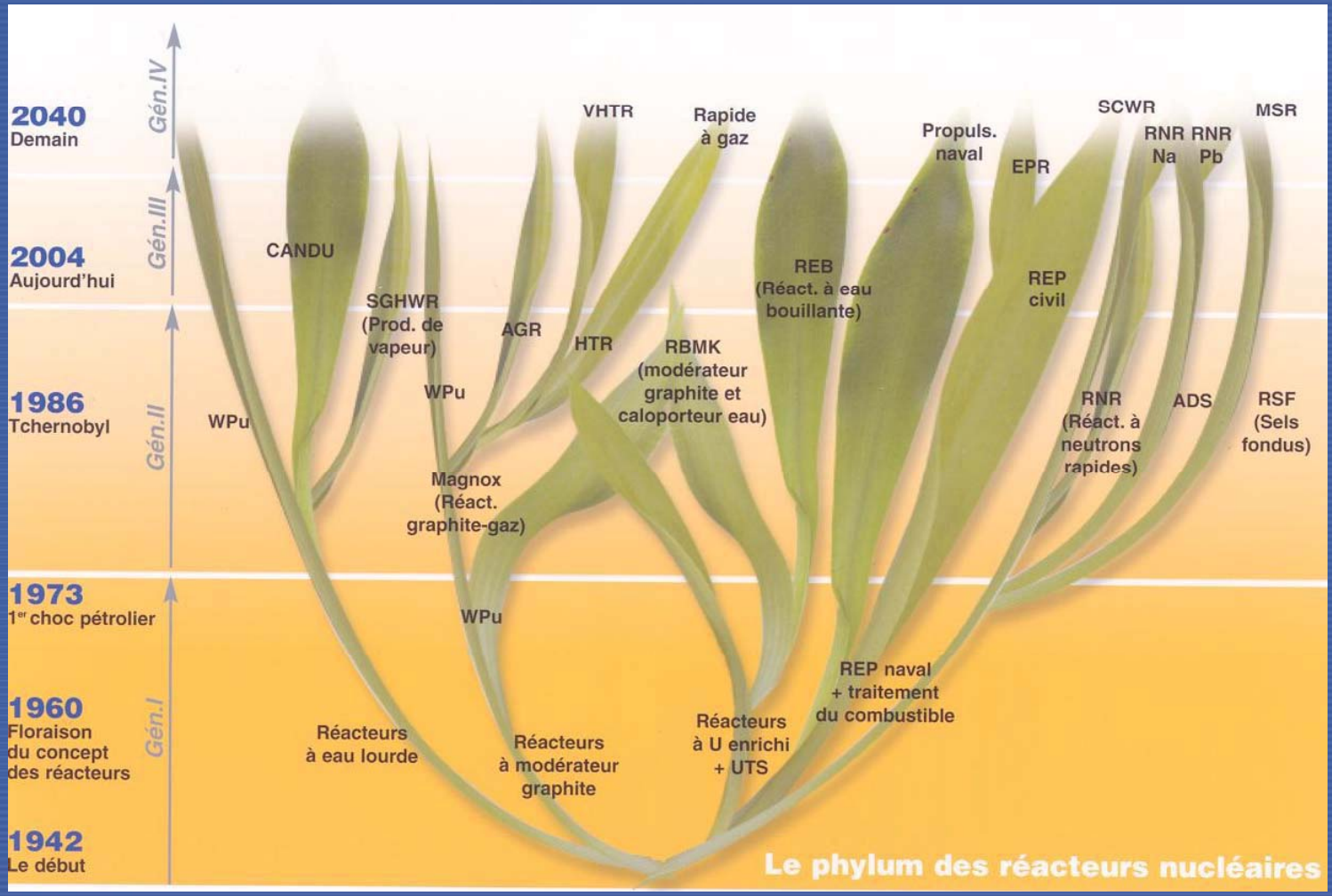
Background

« If any species do not become modified and improved in a corresponding degree with its competitors, it will soon be exterminated » ***Charles Darwin. The origin of species, 1859***



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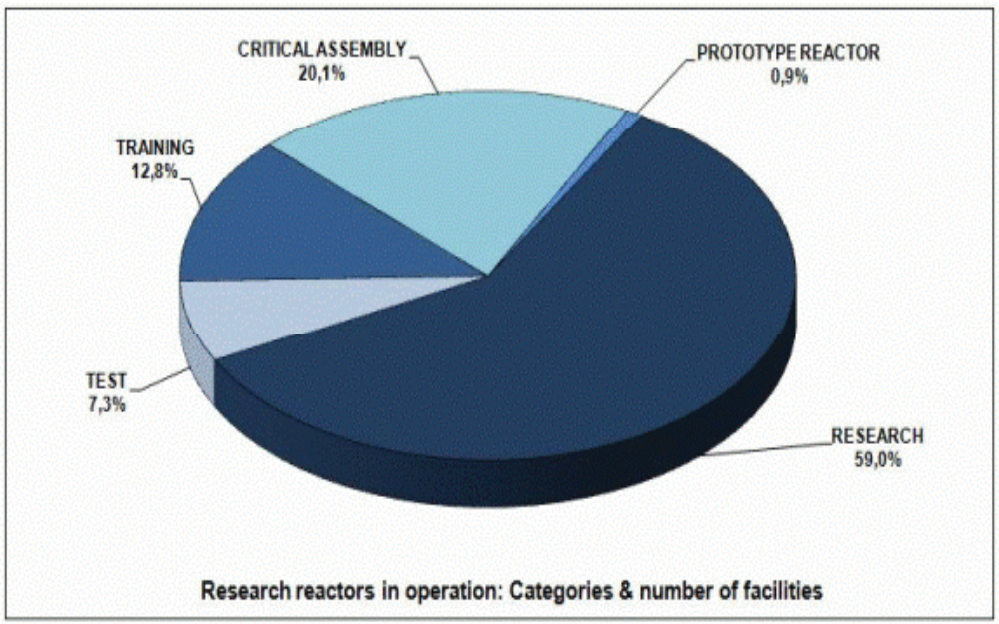
Status of RR as of today (IAEA RR Data Base): type of RRs

- Huge variety, no easy categorization, 26 different types
- Manufacturer types: Slowpoke, MNSR, Argonaut, TRIGA, IRT, WWR
- Coolant/moderator: heavy water, pool, light water, liquid metal, organic
- Fuel: plate, TRIGA, rods, homogeneous
- Purpose: critical assembly, research, test, training, prototype



Research reactors in operation: Categories & number of facilities

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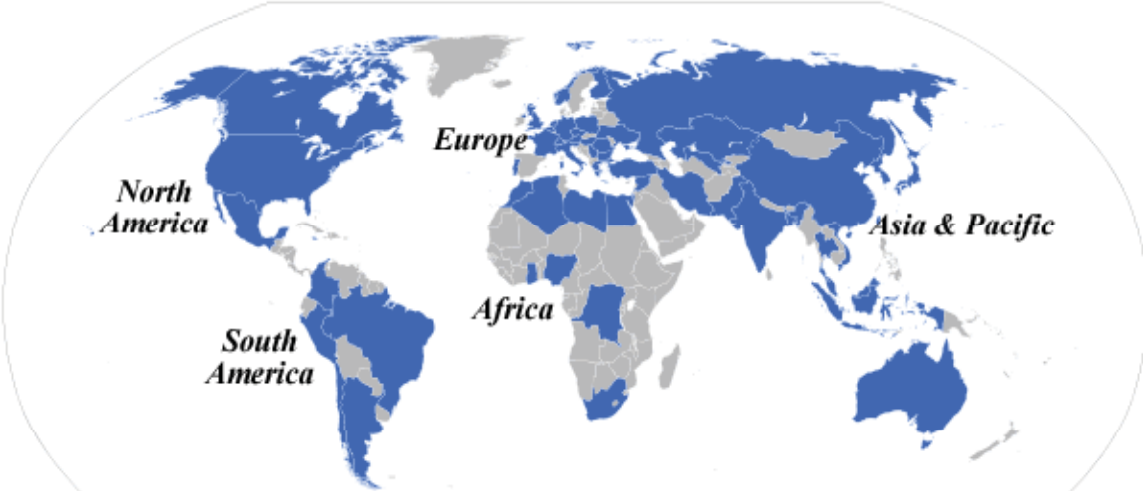
Background

Source: IAEA RRDB, February 2011

TOTAL:	676
Operational	237
Temp. shutdown	12
Under construction	3
Planned	2
Shutdown/Decommissioned	417
Cancelled	5



Number: ~237 operational

Operational RRs are distributed over 56 countries

Russia	~47
USA	~41
China	~16
Japan	~15
France	~11
Germany	~10

Region	Operational RRs
Africa	9
Americas	66
Asia/Pacific	59
Europe (with Russia)	100

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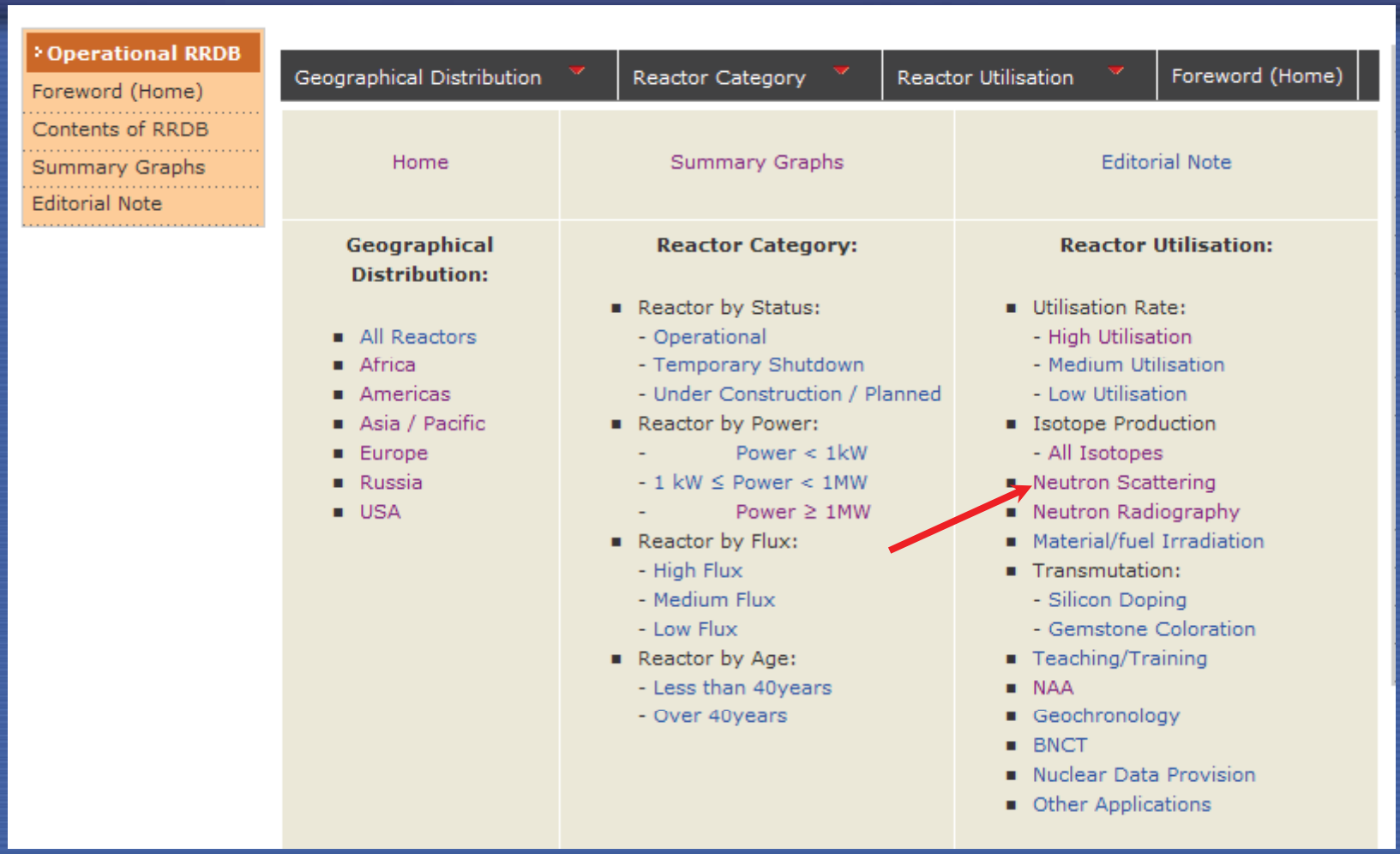
RRDB: Utilization and Application Oriented, new capability

115 RRs data updated in 2010 – nearly 50% of operational facilities



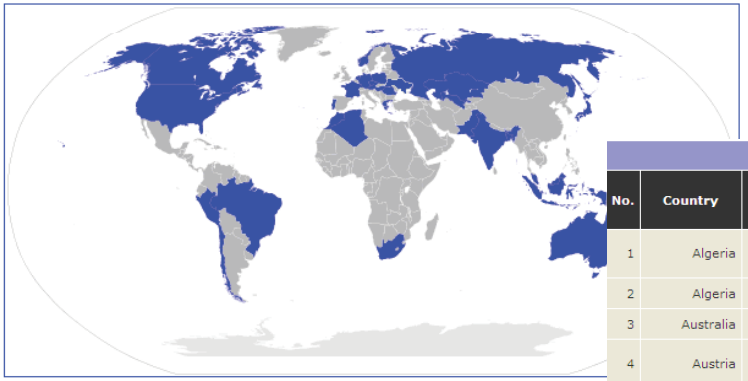
Available at:

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

or USB Memory Stick, <10MB, no internet is needed!

RRDB: Utilization and Application Oriented, new capability

Neutron Scattering Facilities - "Click here for details"



This database contains 44 research reactors performing Neutron Scaterring distributed over 3

44 RRs employ neutron beams; they are distributed over 30 MSs

Neutron Scattering Facilities

No.	Country	Name	Reactor Type	Thermal Power, kW	Thermal Flux, n/cm²/s	Fast Flux, n/cm²/s	Criticality Date
1	Algeria	ES-SALAM	HEAVY WATER	15000	2.1E14	4.2E12	1992-02-17
2	Algeria	NUR	POOL	1000	5.9E12	4.0E12	1989-03-24
3	Australia	OPAL	POOL	20000	3.0E14	2.1E14	2006-08-12
4	Austria	TRIGA II VIENNA	TRIGA MARK II	250	1.0E13	1.7E13	1962-03-07
5	Bangladesh	TRIGA MARK II	TRIGA MARK II	3000	7.5E13	3.8E13	1986-09-14
6	Brazil	IEA-R1	POOL	5000	4.6E13	1.3E14	1957-09-16
7	Canada	MNR MCMASTER UNIV	POOL	3000	1.0E14	4.0E13	1959-04-04
8	Canada	NRU	HEAVY WATER	135000	4.0E14	4.5E13	1957 Temp
9	Chile	RECH-1	POOL	5000	7.0E13	5.0E13	1974
10	Czech Republic	LVR-15 REZ	TANK WWR	10000	1.5E14	3.0E14	1957
11	France	HFR	HEAVY WATER	58300	1.5E15		1971
12	France	ORPHEE	POOL	14000	3.0E14	3.0E14	1980
13	Germany	BER-II	POOL	10000	2.0E14	1.4E13	1973
14	Germany	FRG-1	POOL	5000	1.4E14	4.5E13	1958
15	Germany	FRM II	POOL	20000	8.0E14	5.0E14	2004
16	Greece	DEMOKRITOS (GRR-1)	POOL	5000	1.0E14	4.5E13	1961 Temp
17	Hungary	NUCL. BUDAPEST RES.	TANK WWR	10000	2.5E14	1.0E14	1959

Utilization	
Hours per Day	24
Days per Week	7
Weeks per Year	21
MW Days per Year	2100
Materials/fuel test experiments	NO
Isotope Production	99Mo, 131I,192Ir, 32P
• Total Activity (GBq)	33741
Neutron Scattering	HRPD, NRF, HRSANS, FCD/TD, SANS, PD
• On-line beam hours	2100
Neutron Radiography	On-line beam hours: N/A
Neutron capture therapy	NO
Activation Analysis	INAA
• number of samples irradiated	300
Transmutation	NO
Geochronology	NO
Teaching	Number of students: N/A
Training	Number of operators/experimenters trained: 13
Other Uses	NO

Available at:

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or USB Memory Stick, <10MB, no internet is needed!

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RRDB: Applications of ~240 operational RRs today

Application	Number of RR involved	Involved / Operational, %	Number of countries represented
Education & Training	**149**	**62**	**51**
Neutron Activation Analysis	**114**	**47**	**54**
Radioisotope production	**84**	**35**	**44**
Neutron radiography	**68**	**28**	**40**
Material/fuel testing/irradiations	**60**	**25**	**25**
Neutron scattering	**51**	**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

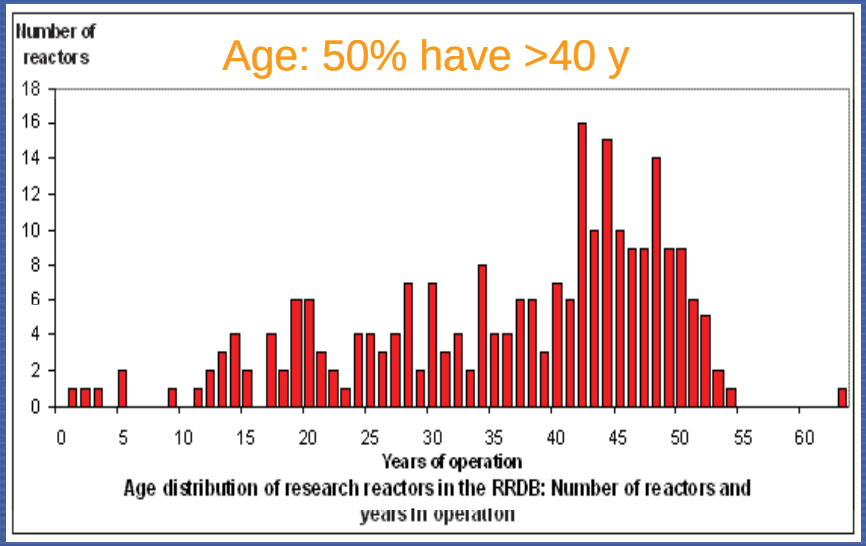
→ **For more information see IAEA-TECDOC 1234 (2001)**

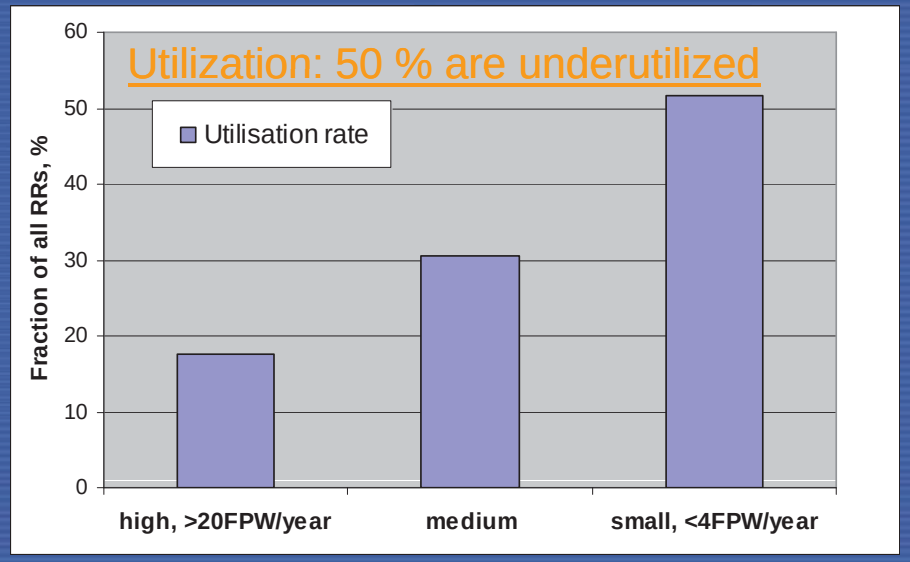
Contact: D.Ridikas@iaea.org

Key issues and challenges

Source: IAEA RRDB, February 2011

- RR underutilization
- Ageing & needs for refurbishment
- Fuel cycle issues
- Requests for new RRs
- Safety & security
- …





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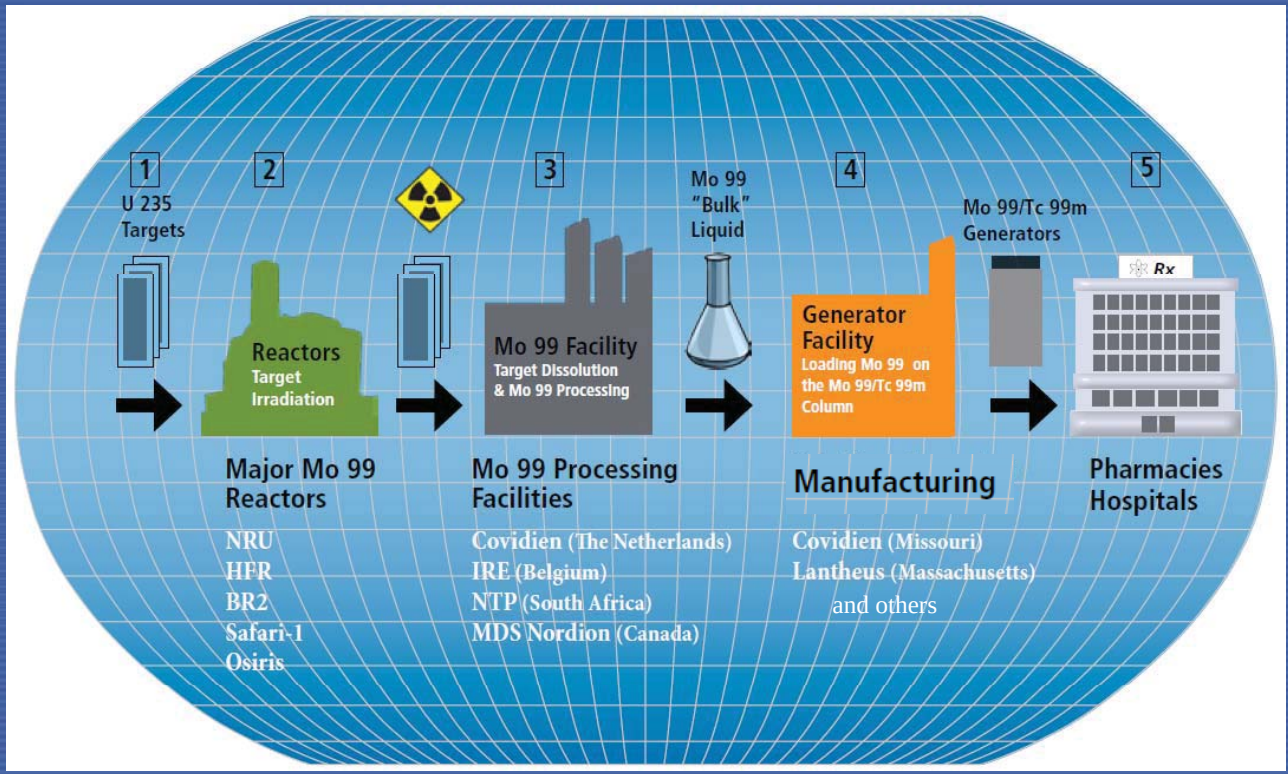
Key issues and challenges: supply of Mo-99

• Over 80% of diagnostic nuclear medical imaging uses radiopharmaceuticals containing technetium-99m (^{99m}Tc), entailing over 30 million investigations per year

• Over 95% of the ^{99}Mo required for ^{99m}Tc generators is produced by the fission of uranium-235 targets in nuclear research reactors

Source: IAEA NTR 2010, Annex



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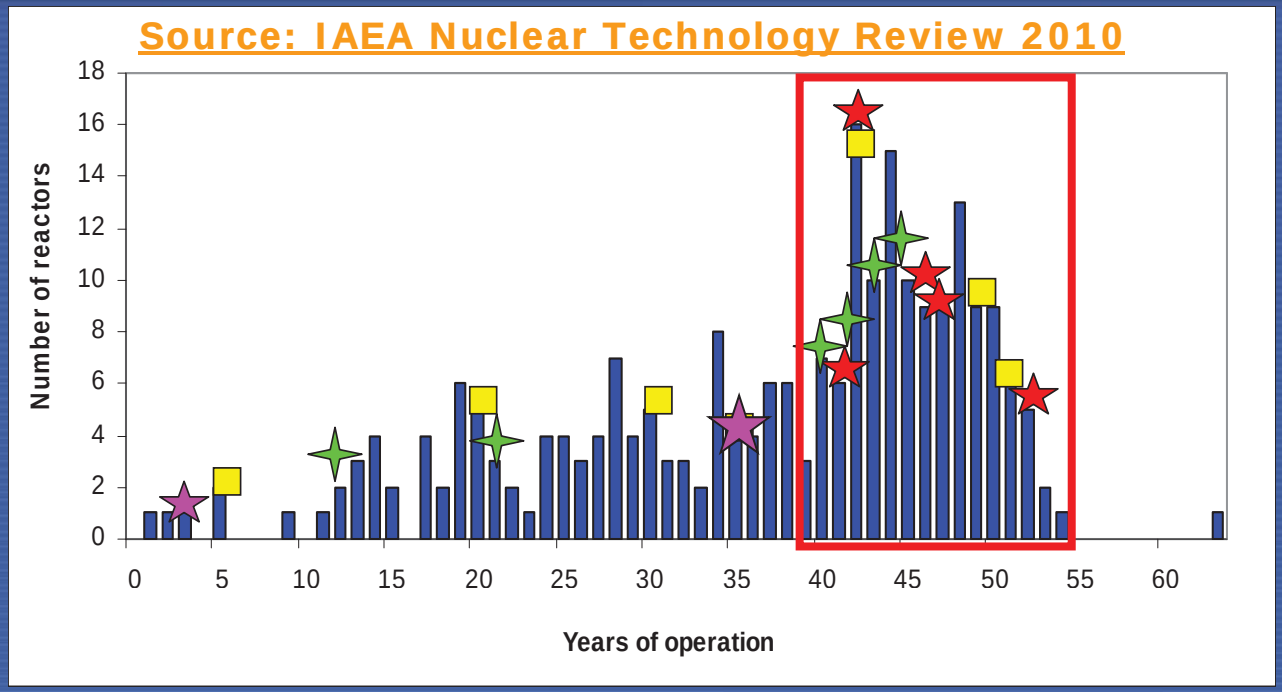
Key issues and challenges: supply of Mo-99



- The five major RR currently producing more than 95 % of ^{99}Mo
- The OPAL (Australia) and Maria (Poland)
- Existing RR that are already used by regional ^{99}Mo producers or for which commissioning is underway
- Existing RR which are now studying the feasibility of providing irradiation services.

Latest news:

NRU (Canada) and HFR (Netherlands) are back to operation!

Maria (Poland) & LVR-15 (Czech) have entered as new important players!

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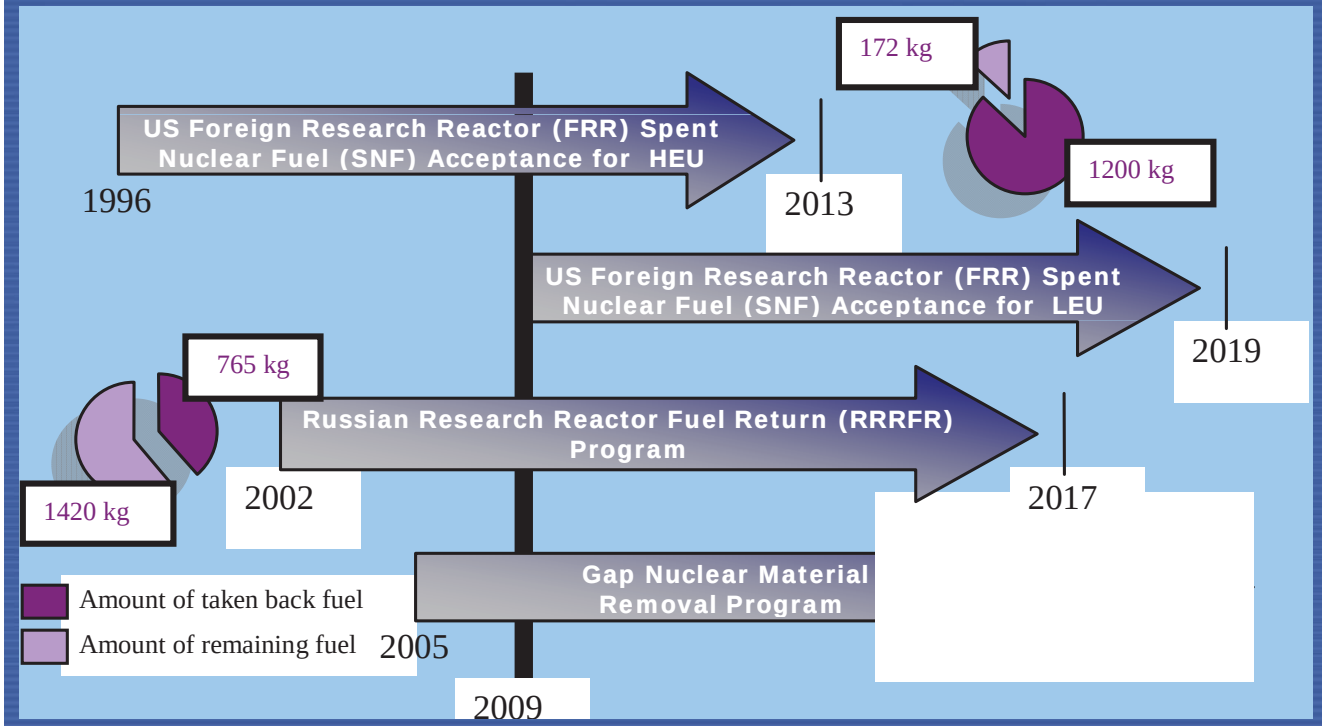
Key issues and challenges: reduction of HEU

- **Reduction of HEU through the Global Threat Reduction Initiative (GTRI)**
  - → **67 RR cores converted to LEU, 27 RR are expected/ongoing**
  - → **Spent and fresh fuel take back programmes**



Latest news:

→74 kg of Russian-origin HEU has been removed from Kazakhstan

→SAFARI-1 is entirely LEU

Other countries, where HEU is being removed:

Bulgaria, the Czech Republic, Germany, Hungary, Kazakhstan, Latvia, Libya, Poland, Romania, Serbia, Uzbekistan and Vietnam.

Contact: D.Ridikas@iaea.org

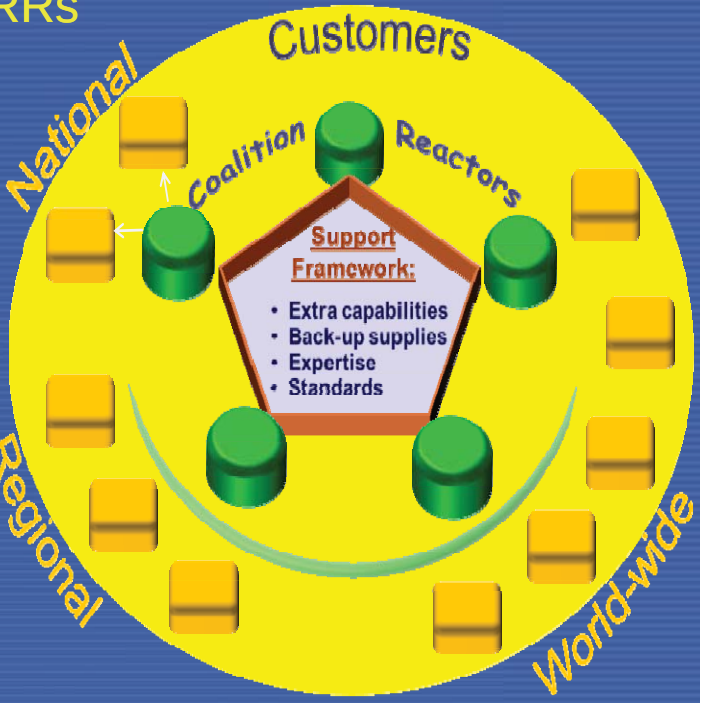
Activity: RR Networks and Coalitions, background

Objectives:

- → increase utilization and sustainability
- → promote regional/international cooperation
- → access to RRs from Member States without RRs

Role of the IAEA

- → Catalyst and facilitator towards self-reliance
- → Preparation of strategic and business plans
- → Initial support via regional TC projects



Performance indicators:

- Number of RR facilities forming networks
- Number of non-RR countries forming networks
- Number of RRs with new/updated strategic plans
- Number of RRs with increased utilization/revenues

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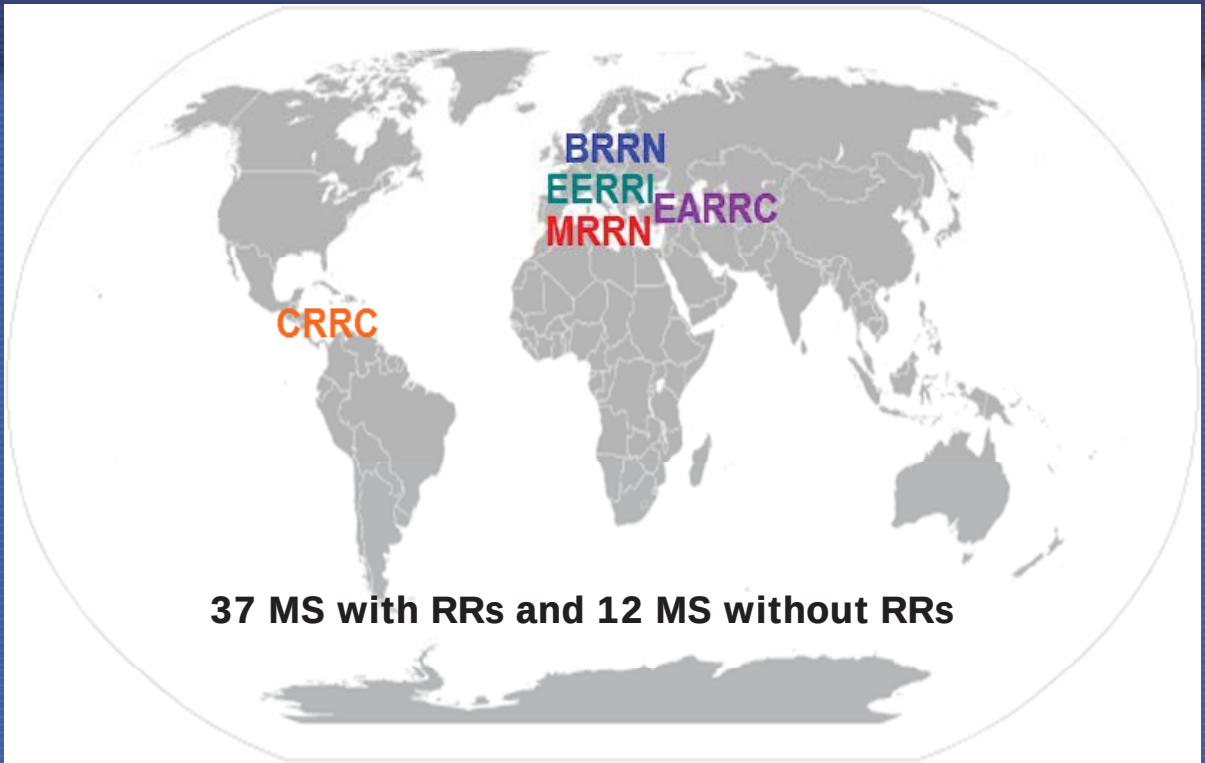
Activity: RR Networks and Coalitions, status



1.	BRRN – Baltic Research Reactor Network,	multipurpose,	10
2.	EARRC – Eurasian RR Coalition,	isotope production,	5
3.	EERRI – Eastern European RR Initiative,	multipurpose,	6
4.	CRRC – Caribbean RR Coalition,	mainly NAA,	3
5.	MRRN – Mediterranean RR Network,	multipurpose,	14

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Activity: TC projects and new RRs

Planned RRs as of today

- **More than 30 ongoing IAEA TC projects related to RR utilization, safety, fuel cycle, refurbishment and modernization, etc.**

- **4 ongoing projects to start the 1st RR in the country**
  1) Azerbaijan: Conducting a Feasibility Study for Planning and Establishing a RR
  2) Jordan: Establishing a RR
  3) Sudan: Sudan Nuclear RR Project
  4) GCC: Developing a Regional Nuclear Training Centre for Capacity Building and Research

- **7 new project concepts submitted and related to the 1st RR in the country**
  - Jordan, Lebanon, Philippines, Saudi Arabia, Sudan, Tunisia, and Tanzania

→ Other countries: Argentina, Brazil, The Netherlands, South Korea, South Africa,...

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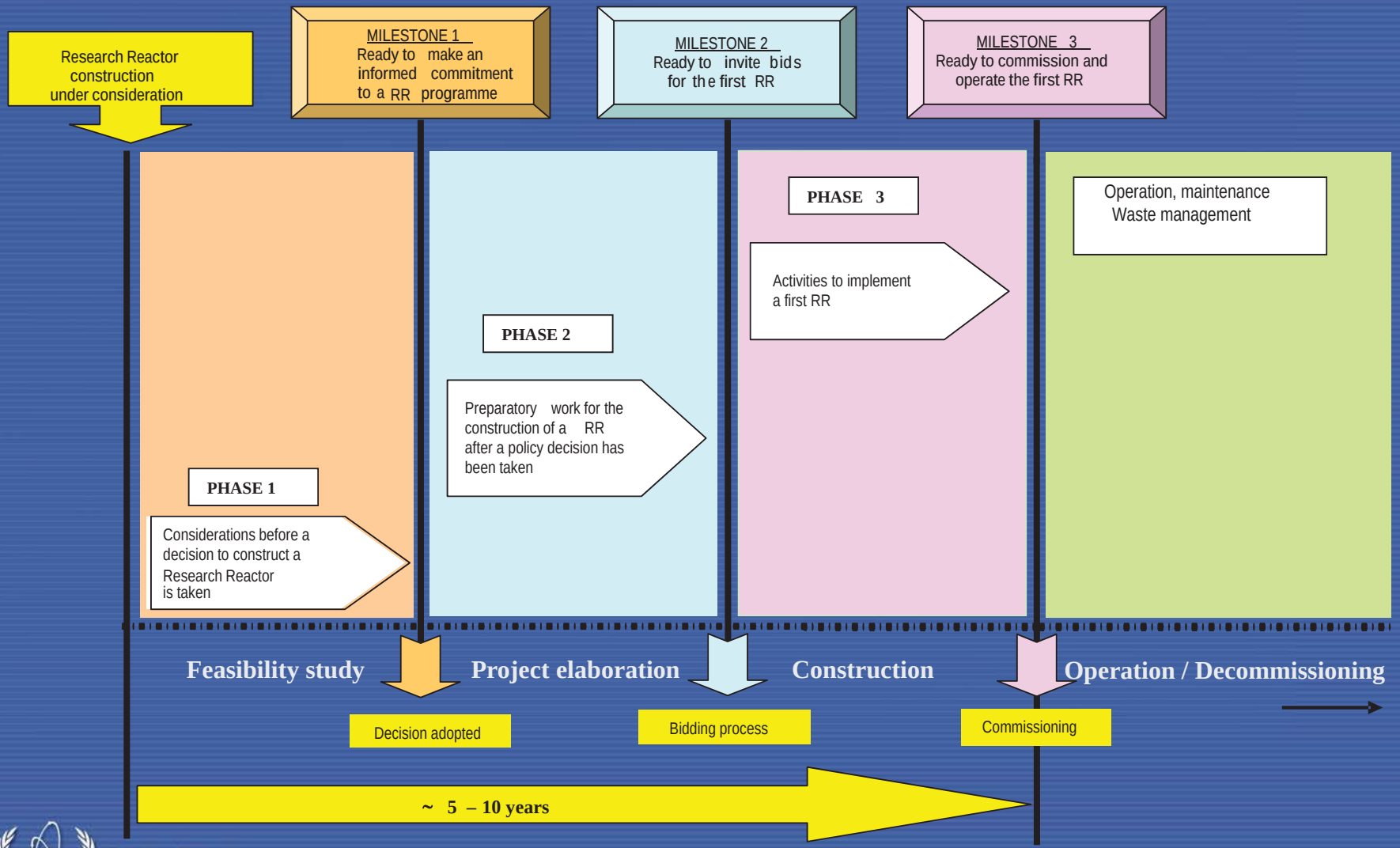
Activity: Newcomer Member States

Planning, Building and Operation of RR: phases/milestones



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Activity: New & old RRs

Preparation/revision of

→ Justification and Demonstrated Needs

→ Strategic & Business Plans

Facility Status
Capabilities
What can I do?

Current Stakeholder
Requirements/Needs
What should I do?

Production of a strategic plan supports an increase in utilization by increasing capabilities and creating new requirements

Support/assistance from the IAEA is dependent on having a demonstrated need, i.e. … a strategic plan

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→ Role of RR in E&T (1)

- Public tours and visits
- Teaching physical and biological science students
- Teaching radiation protection and radiological engineering students
- Nuclear engineering students
- NPP operator training

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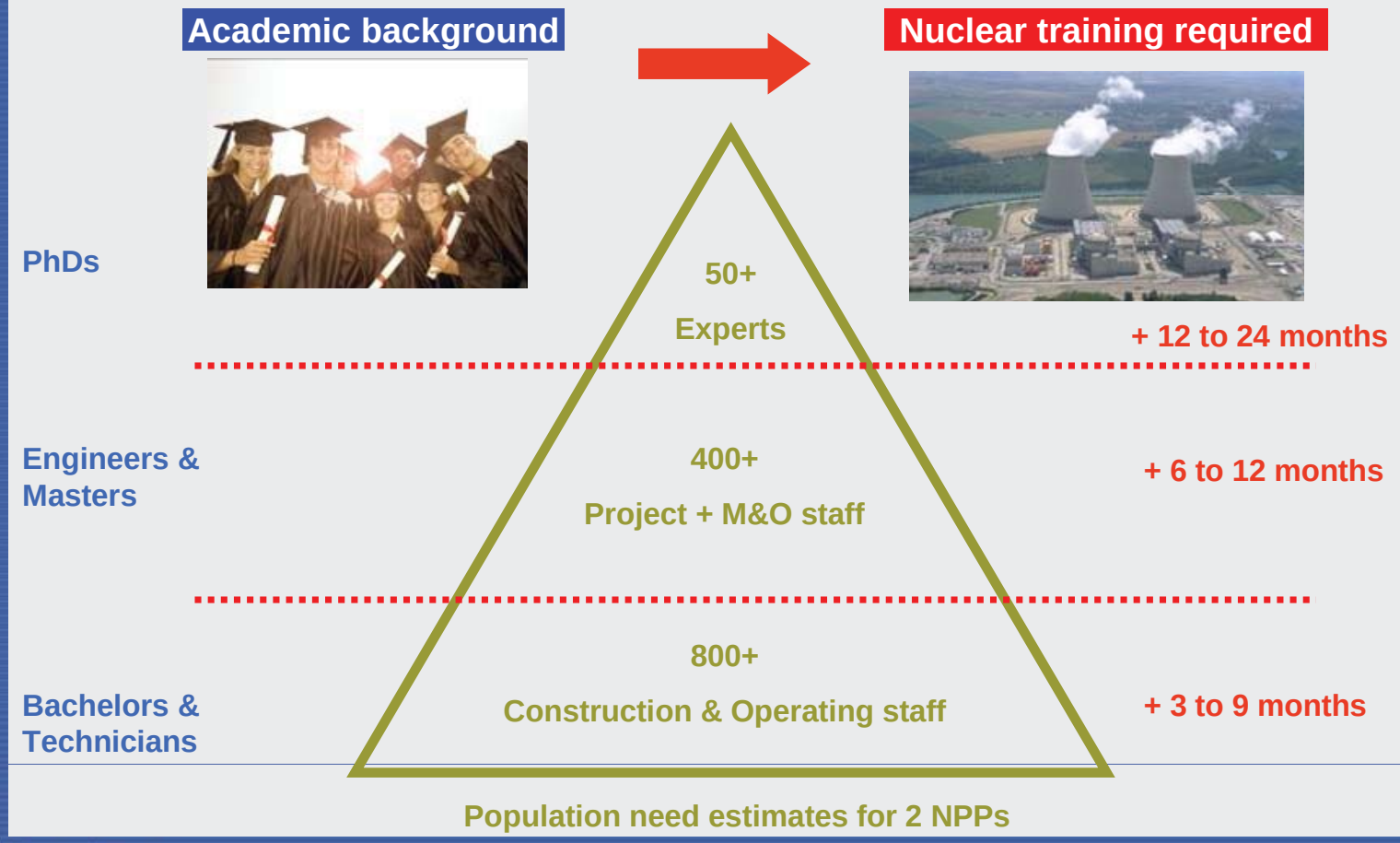
→ Role of RR in E&T (2)

Typical flow from Academics to Nuclear



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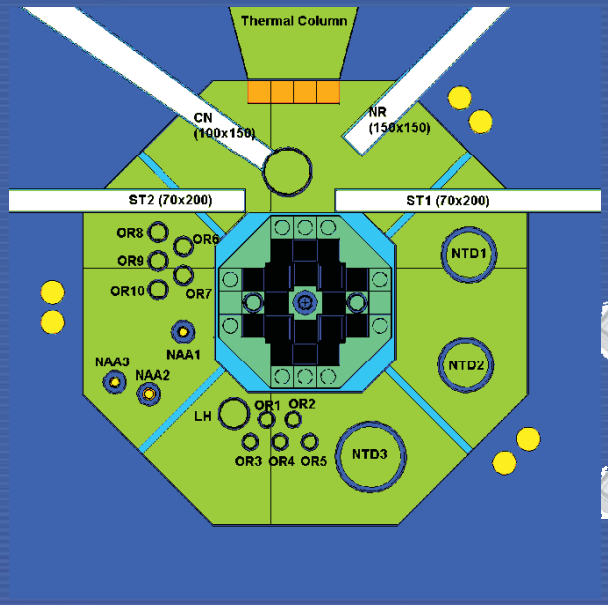
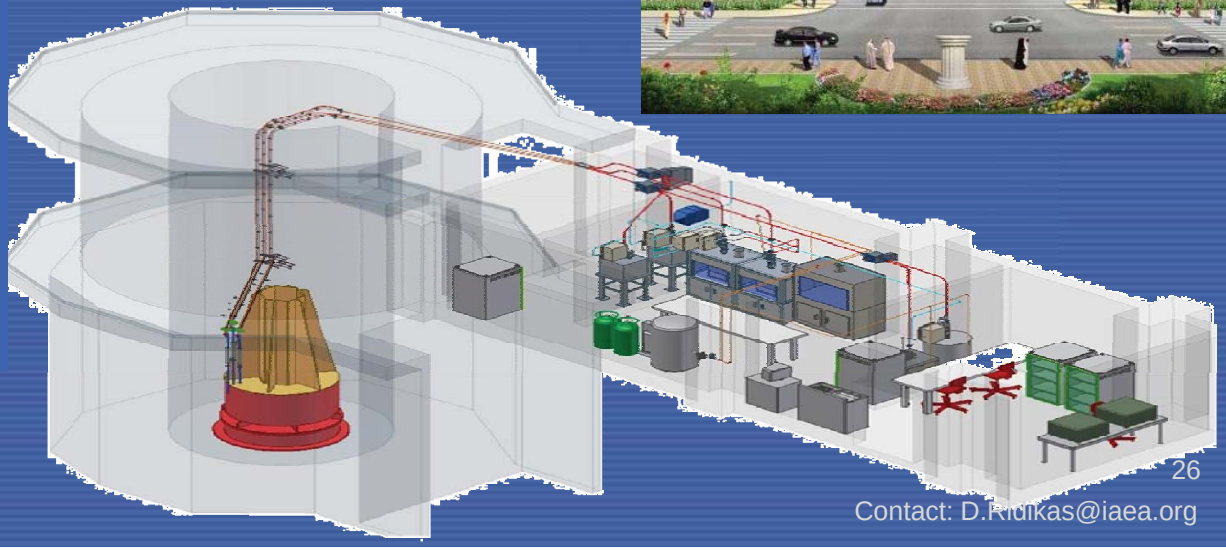
Activity: New RRs

Jordan Research & Training Reactor (JRTR)

In the detailed design stage, construction to start in 2011

- **5 MW (upgradable to 10MW), neutron flux ~1.5*10^{14} n/(s cm^2)**
- **Fuel: ~19.75 % U-235, U_3Si_2-Al, Coolant & Moderator: H_2O, Reflector: Be**
- **Multipurpose RR: radioisotope production, Si doping, neutron beams, NAA, E&T, etc.**
- **1st step to the national NPP programme**





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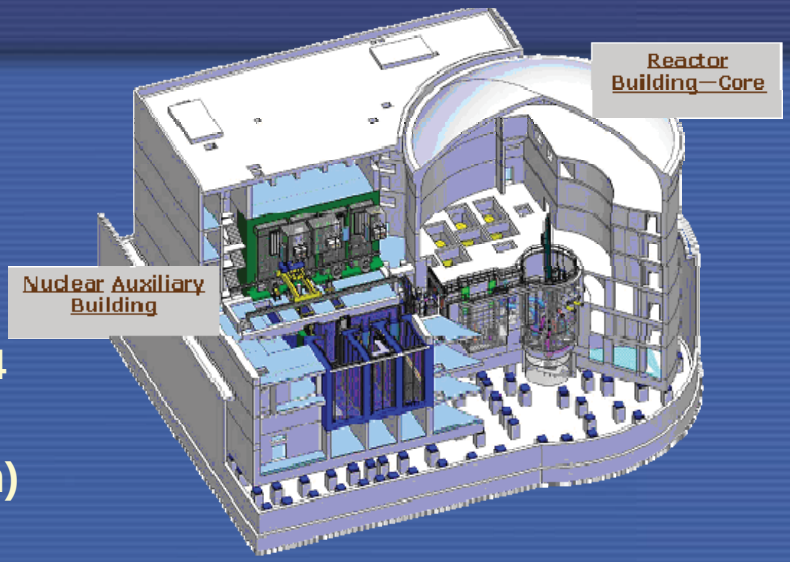
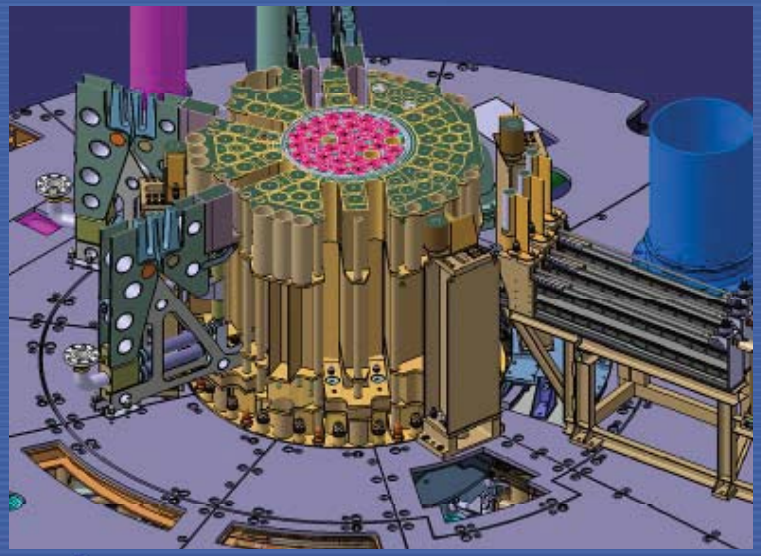
Activity: New RRs

RR under construction

JHR, France, operation expected in 2014



- MTR pool, 100 MW, in core flux ~1*10^{15} n/(s cm^2)
- Fuel: Ref. UMo LEU, Backup: U_3Si_2 27 % U-235
- In support of future nuclear power, Gen3+ & Gen4
- Dedicated for material/fuel irradiation and testing
- Other applications envisaged (isotope production)
- International consortium



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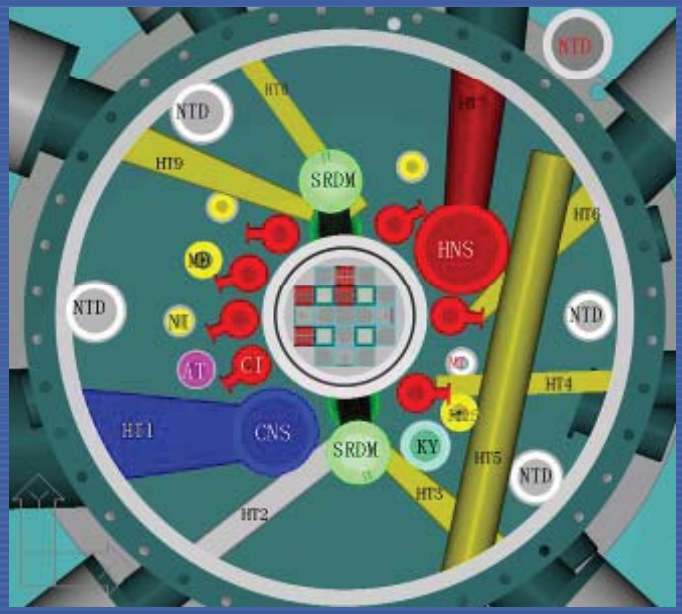
Activity: New RRs

CARR, China

1st criticality in May 2010; full power expected by the end of 2011

- 60 MW, in core flux ~1*10^{15} n/(s cm^2)
- Fuel: 19% U-235, Moderator: H_2O, Reflector: D_2O
- Replacement for 10MW HWRR (2007)
- Multipurpose RR with the main objectives in basic research
- Open to users from universities, governmental laboratories, industry



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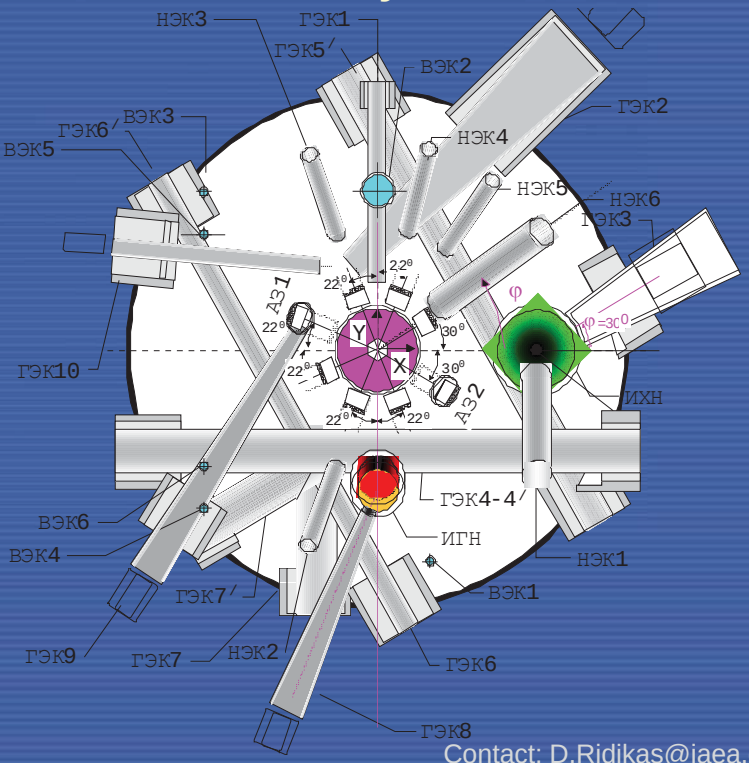
Activity: New RRs

PIK, Russian Federation

1st criticality in March 2011, full power expected in 2013

- 100 MW, in neutron trap flux ~4.5*10^{15} n/(s cm^2)
- Fuel: ~90% U-235, Moderator & Reflector: D_2O
- Replacement for WWR-M (18MW)
- Multipurpose RR with the main objectives in basic research
- Open to users from universities, governmental laboratories, industry



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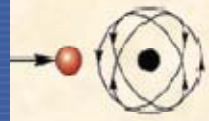
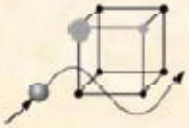
Why Neutrons?

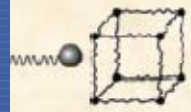
1. Neutrons have the right wavelength



2. Neutrons see the Nuclei



3. Neutrons see Light Atoms next to Heavy Ones



4. Neutrons measure the Velocity of Atoms

5. Neutrons penetrate deep into Matter

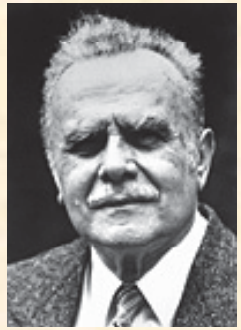
6. Neutrons see Elementary Magnets

Contact: D.Ridikas@iaea.org

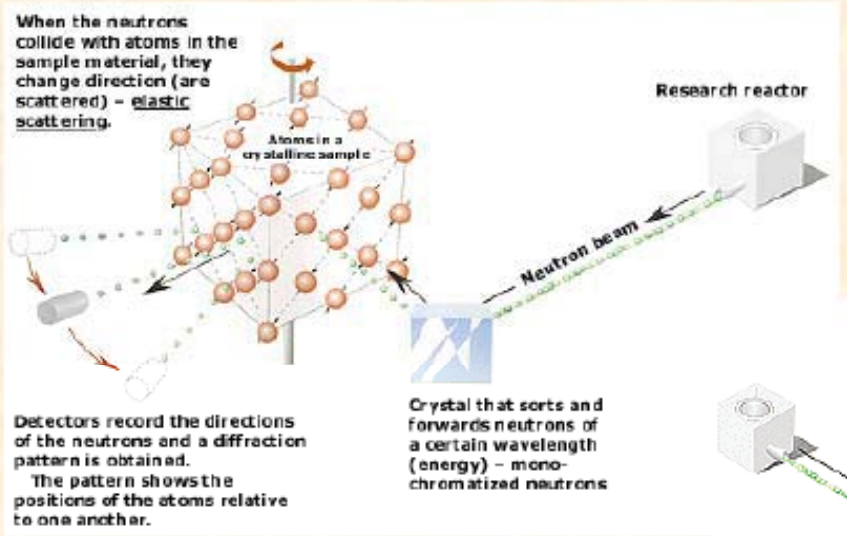
Neutrons in scattering research

What do neutrons do?

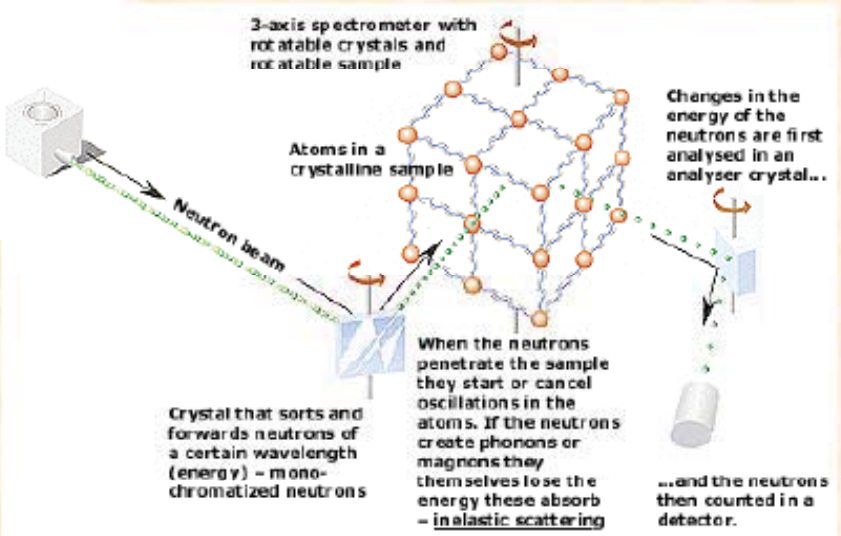
Nobel Prize in Physics 1994 - Shull and Brockhouse



Neutrons show where atoms are…..



… and what atoms do



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How do we produce neutrons?

a) www.ill.fr

a. Fission Reactions

$n^1 + U^{235} \longrightarrow$ 2 fission fragments + $2.5n^1$ + 200 MeV

thermal

- 1 neutron to maintain chain reaction
- 1 neutron escapes & is available for use
- 0.5 neutrons absorbed

1 neutron

2 to 3 neutrons

Example: 20 MW Research Reactor

No. of fissions/sec = $\frac{20 \times 10^6 \text{ watts}}{200 \text{ MeV/fission}}$ = 6×10^{17} fissions/second

generates 1.5×10^{18} neutrons/sec in the whole reactor volume

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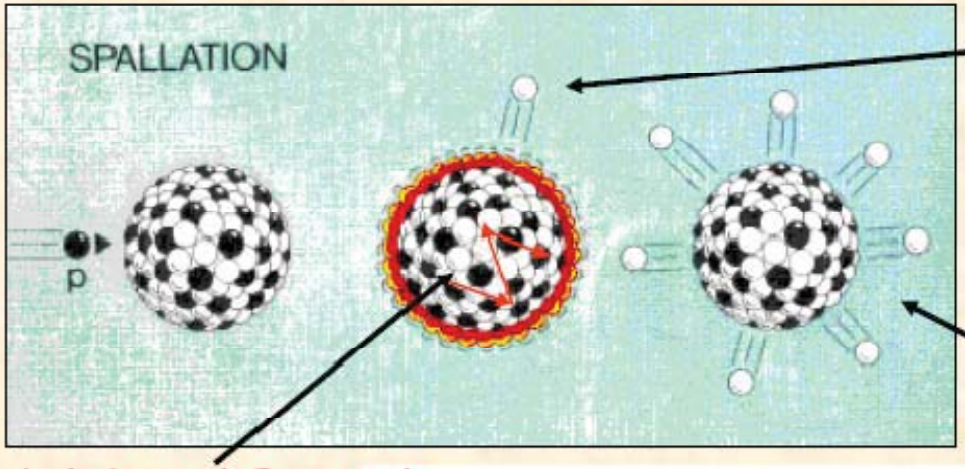
How do we produce neutrons?

b) www.sns.gov

b. Artificially accelerated particles

(iii) Spallation with Protons

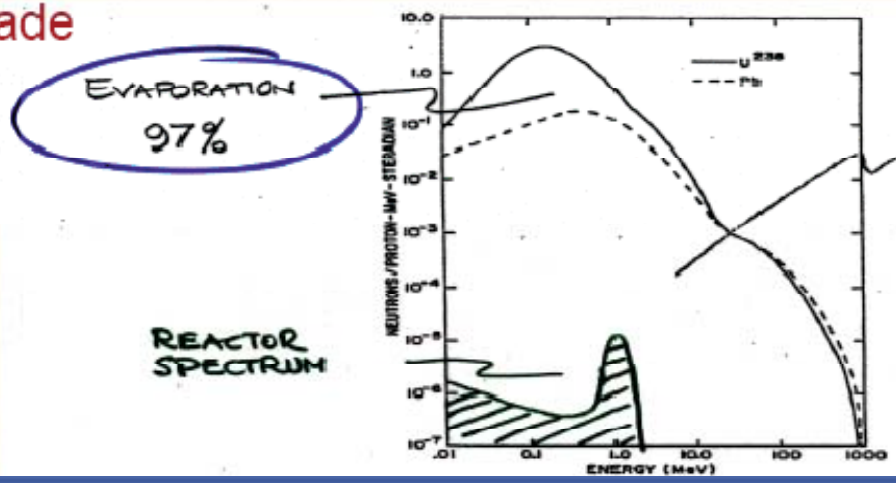


2. Inter Nuclear Cascade

Up to 40 neutrons per incident proton

3. Evaporation

1. Internal Cascade



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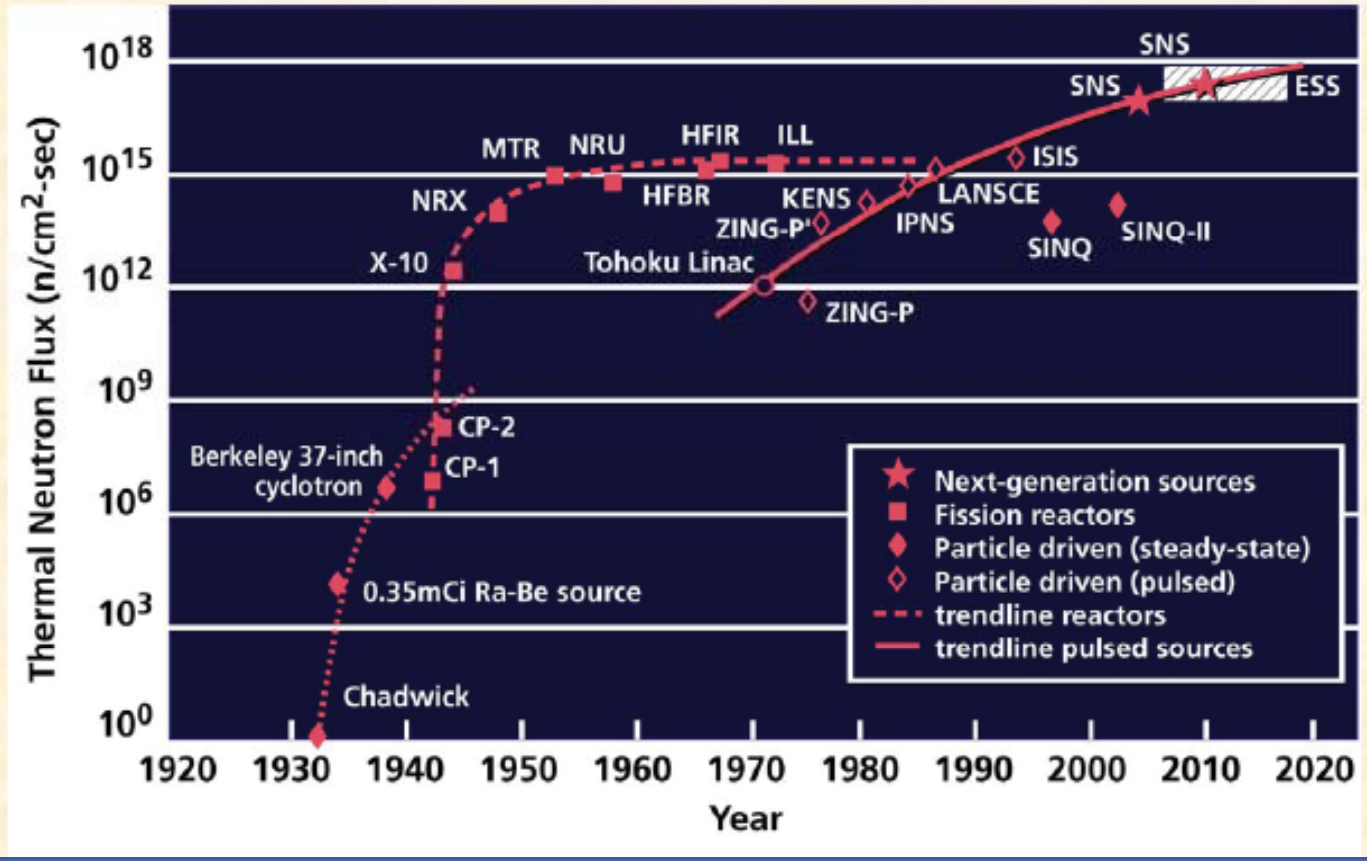
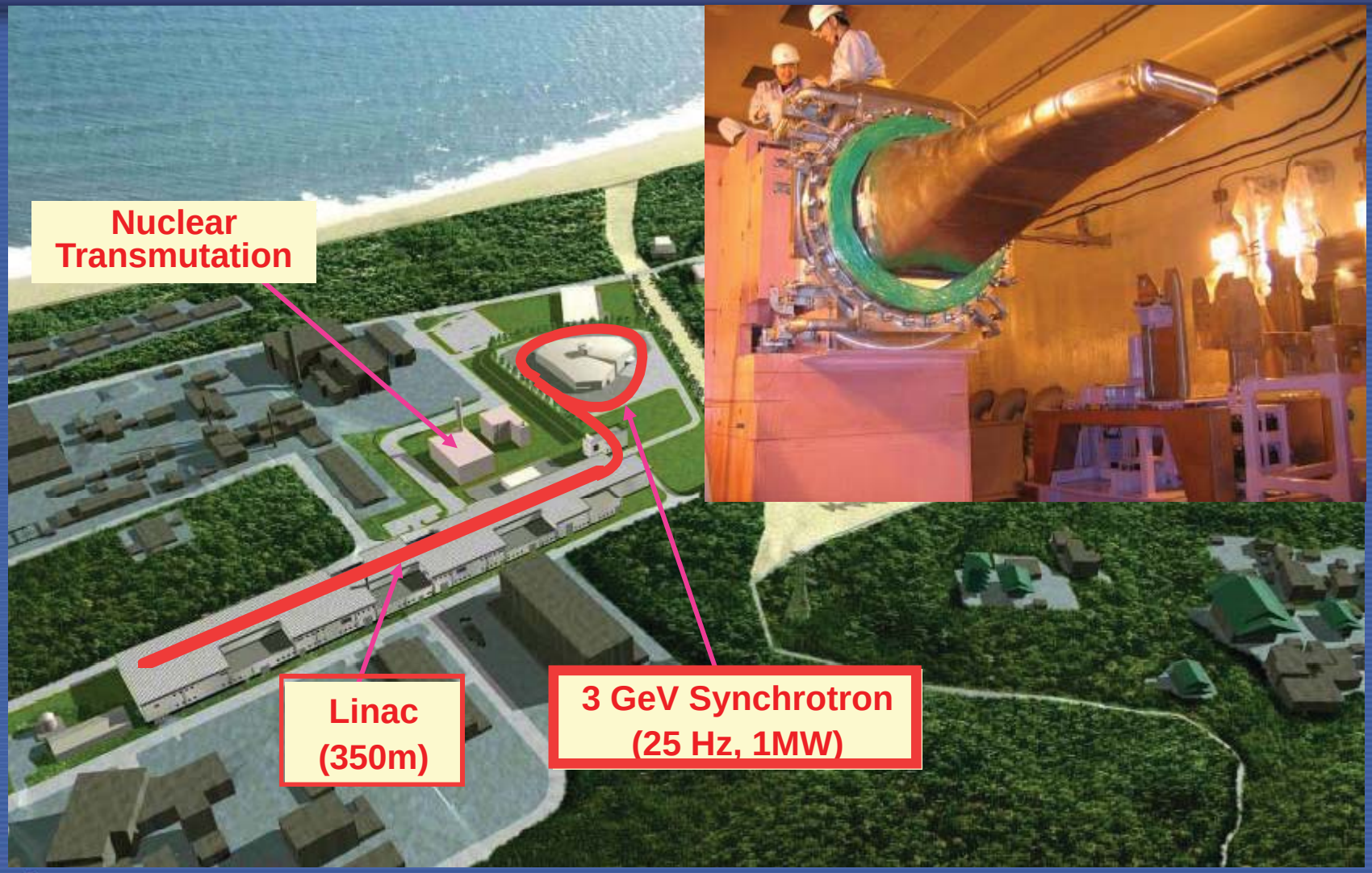
Higher neutron fluxes?

Reactors have reached the limit at which heat can be removed from the core
Pulsed sources have not yet reached that limit and hold out the promise of higher intensities



Contact: D.Ridikas@iaea.org

J-PARC = Japan Proton Accelerator Research Complex



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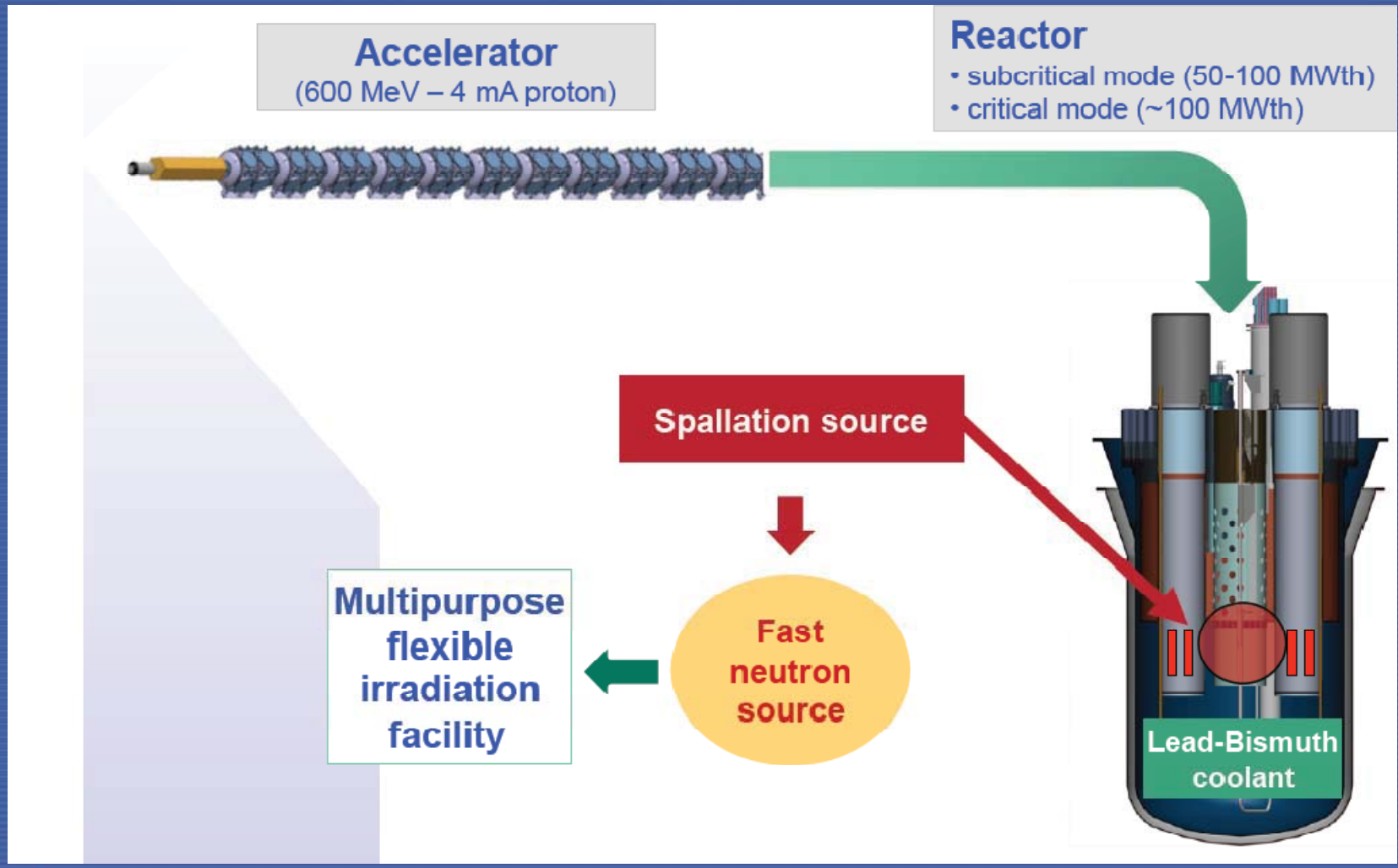
Accelerator Driven System: MYRRHA project in Belgium



Contact: D.Ridikas@iaea.org

Thanks for your attention and...

...we continue with accelerators now…

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Contact: D.Ridikas@iaea.org