

Nuclear Research Reactors (RR)

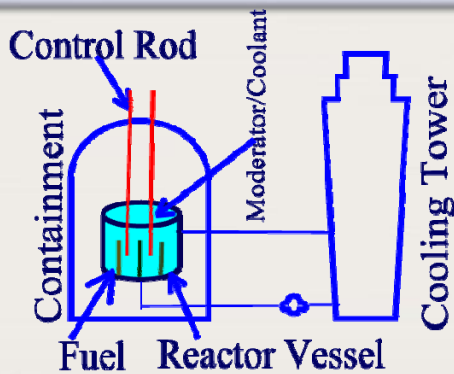
Outline of Presentation

- Introduction to RR principles, components
- RR types and features
- RR utilization: Techniques and Applications
- RR issues & needs: perceptions and concerns
- Agency assistance on RRs
- Some Stories of Success



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Nuclear Reactor



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Nuclear Research Reactors – Typical Features

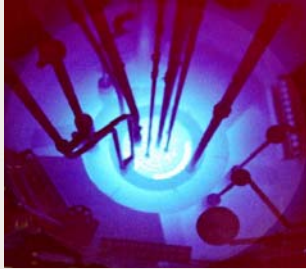
- **Typical power levels 30kW to 10MW**
- **Intense source of neutrons. Typical steady-state neutron flux: 10^{11} to 10^{14} neutrons/cm²s**
- **Vertical and horizontal channels to avail neutrons**
- Various coolants / moderators
 - light water, heavy water, organic liquids
- Various types of fuel
 - plates, rods, tubes, liquid in homogeneous RR
 - metallic, hydrides, silicides
- Natural and forced circulation cooling



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Research Reactors: Some Typical Characteristics

- Small volume cores
- 90% have power level less than 10 MW(t)
- Generally higher enrichment fuel than in power reactors (though some RRs use natural uranium fuel)
- Natural and forced cooling
- May have pulsing capability



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Research Reactor (RR) Types

- Miniature neutron source reactor (MNSR) of 30kW(t) to about 100MW(t) RR (1–10 MW more common)
- Industrial manufacturer supplied RR to custom-built indigenous RR
- Neutron flux ranging from 10^{11} to 10^{14}
 - Neutron beam facilities
 - Sample irradiation facilities (radioisotope production, material testing)
 - Rabbit facility for NAA
 - Analytical and other services facilities



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Research Reactor Data according to the Agency's RR Database (RRDB)

| | |
|-------------------------|---------|
| • Reactors in operation | 242 |
| HEU → LEU converted | 62 |
| HEU → LEU planned | 39 + 28 |
| • Total reactors listed | 671 |
| • Reactors Shut down | 246 |
| • Decommissioned | 172 |
| • Under Construction | 7 |
| • Planned | 4 |

(LEU <20% ²³⁵U; HEU >20 to 93% ²³⁵U)



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Research Reactor Utilization Techniques and Purposes

- Education & Training
- Fuel testing and qualification
- Supporting power reactor programmes
- **Radioisotope Production**
- Neutron Scattering
- Material science investigations
- Neutron Activation Analysis (NAA)
- Neutron transmutation doping
- Neutron Radiography



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Research Reactor (RR) Utilization - Applications

Neutron Irradiation for Radioisotope Production

- *Principle:* Target element's activation in RR for specified period to induce radioactivity
- *Typical Uses:* Production of radioisotopes for a variety of applications in medicine, industry, agriculture, biology and research
- e.g. ANSTO, BARC/Dhruva, HANARO, Safari-1 etc



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Radioisotope Production in RR

- Low n flux: $<10^{13}$
 ^{24}Na , ^{32}P , ^{82}Br
- Medium n flux: $2-8 \times 10^{13}$
 ^{82}Br , ^{99}Mo , ^{125}I , ^{35}S , ^{131}I , ^{153}Sm , ^{177}Lu , $^{186/188}\text{Re}$, ^{192}Ir
- High n flux: $>10^{14}$
 ^{60}Co , ^{192}Ir , ^{75}Se , ^{89}Sr , ^{177}Lu , ^{99}Mo , ^{188}W
- **Medicine**
 - Diagnosis
 - Treatment
- **Industry**
 - Radiography
 - Tracer Techniques
 - Radiation Technology
- **Food and Agriculture**
 - Tracer Techniques
 - Mutants - Productivity
 - Disinfestation – Safety, Shelf-life



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Research Reactor (RR) Utilization - Applications

Neutron scattering

- **Principle:** RR neutrons incident on sample and record the angular and energy distribution of scattered neutrons.
- **Typical Uses:** order and dynamics of atoms and molecules in condensed matter, non-destructive testing of materials – residual stress in engineering components; surface studies - thin films, polymers and biological materials, magnetic specimen
- e.g. ILL, Grenoble; HMI, Berlin; HFIR, ORNL; HFR, Petten etc.



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Research Reactor (RR) Utilization - Applications

Neutron Radiography

- **Principle:** Transmission of neutron through selective absorption and scattering results in photograph with details of material contents and defects in specimen.
- **Typical Uses:** Investigation of bulk materials; explosives,
- e.g. PSI, MIT, IPEN, HMI etc.



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NDT-Neutron Radiography

The diagram illustrates the neutron radiography process and its applications. It is divided into three main sections:

- Take pictures by neutron:** Shows a schematic of a neutron radiography device (JRR-3M) with a neutron source, collimator, and detector.
- Fuels pictures taken by neutron radiography:** Shows two images of fuel rods, one taken by neutron radiography and one taken by X-ray for comparison.
- Inspection of irradiated fuels:** Shows a fuel rod with a crack, labeled "Inspection of space rocket parts and aircraft parts."
- Inspection of space rocket parts and aircraft parts:** Shows a fuel rod with a crack, labeled "Inspection of space rocket parts and aircraft parts."
- Observation of the status of oil flow within engines, etc.:** Shows a fuel rod with a crack, labeled "Observation of the status of oil flow within engines, etc."



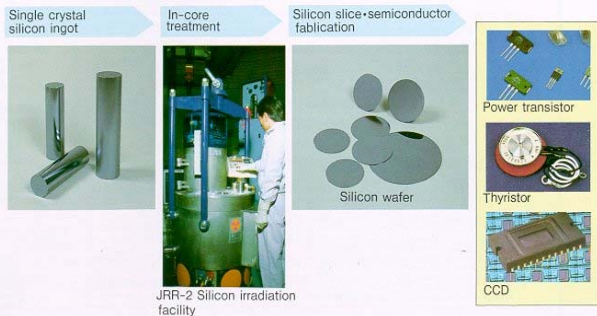
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Research Reactor (RR) Utilization - Applications

Neutron transmutation doping

- **Principle:** Irradiation of Si by neutron transmutes some of the Si atoms to P → change in electrical conduction
- **Typical Uses:** Semiconductor devices
- e.g. Safari-1, HANARO etc.

Neutron Transmutation Doping

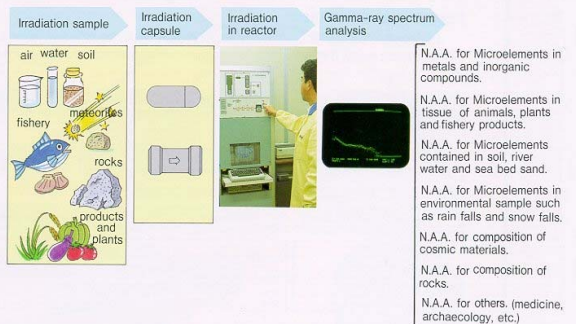


Research Reactor (RR) Utilization - Applications

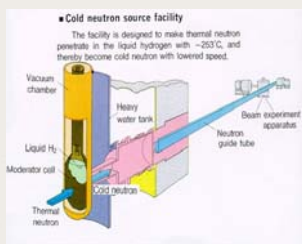
Neutron Activation Analysis *NAA*

- **Principle:** Sample exposed to neutron fluence for a specified time → induced activation products characteristic of the elements and the quantity
- **Typical Uses:** Assessment of elemental composition of chemical, geological, biological, environmental, forensic samples and art objects
- Most centres, even in small reactor e.g. in Ghana, Jamaica and medium size reactor e.g. in Hungary

Neutron Activation Analysis



Cold Neutron Source



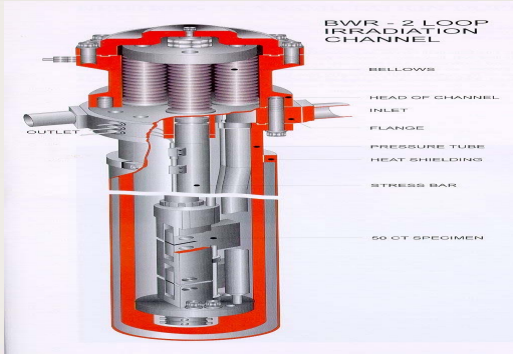
- Useful for large particle sizes / low energy transfers—diffusion of atoms & molecules.
 - Study of Bio-molecules, Polymers, Paints
 - Precipitation, phase separation in alloy synthesis
 - Surface studies, thin films, bio membranes
- e.g. in ILL, Grenoble; HMI, Berlin

Research Reactor (RR) Utilization - Applications

Neutron irradiation for materials testing

- **Principle:** Target material's irradiation by neutrons and exposure to radiation field in RR for specified period leading to changes/damages
 - **Typical Uses:** Understanding and assessment of radiation induced damage
 - Modification to material characteristics, structure
- Utility for new reactor designs and concepts; Data for plant life-extension studies and decommissioning/disposal purposes

Applications – Irradiation Testing



Research Reactor (RR) Utilization - Applications

Post-irradiation examination (PIE)

Principle: Fuel & related material's exposure to RR ambience (radiation, temperature, pressure, neutron flux) for specified period

- *Typical Uses:* Reactor fuel testing and development, validation/qualification, trouble-shooting. Understanding fuel behaviour in various conditions

Research Reactor (RR) Utilization - Applications

Education and Training for HRD

- Science teachers & students
- Engineering teachers & students
- Nuclear power plant operator trainees
- Operational health physicists
- Regulators
- Public awareness
