SAND2011-3213C

Safety, security, and Safeguards (the3S's) at Research Reactors

Lecture 4, Research Reactor Workshop
Rabat, Morocco

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SAND#

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Acknowledgment

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* *Abby Doll and Roushan Ghanbari, "Safety, Security, and Safeguards Integration in US Nuclear Power Plants ", Sandia National Laboratories, December 2010.*

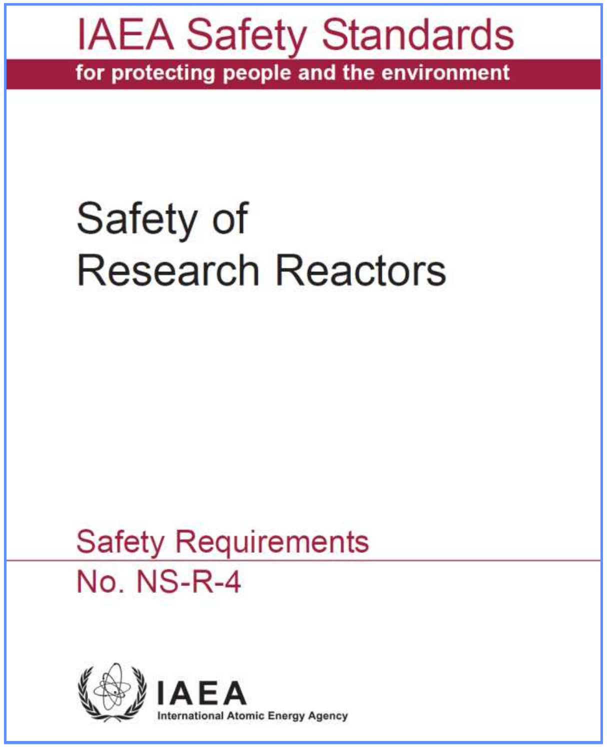
Overview

- IAEA’s Definition of Research Reactor
- IAEA Safety Standards
- IAEA’s Research reactor Safety Objectives and Standards
- Nuclear Security Culture
- IAEA’s Research Reactor Security Goals
- Research Reactor Safeguards
- Integration of Nuclear Safety, Security, and Safeguards (3S)

Research Reactor Safety

Definition of Research Reactor – Per IAEA Safety Standard*

"A research reactor is a nuclear reactor used mainly for the generation and utilization of the neutron flux and ionizing radiation for research and other purposes. In the context of this Safety Requirements publication, the term research reactor also includes associated experimental devices and critical assemblies."


IAEA Safety Standards
for protecting people and the environment

Safety of
Research Reactors

Safety Requirements
No. NS-R-4

IAEA
International Atomic Energy Agency

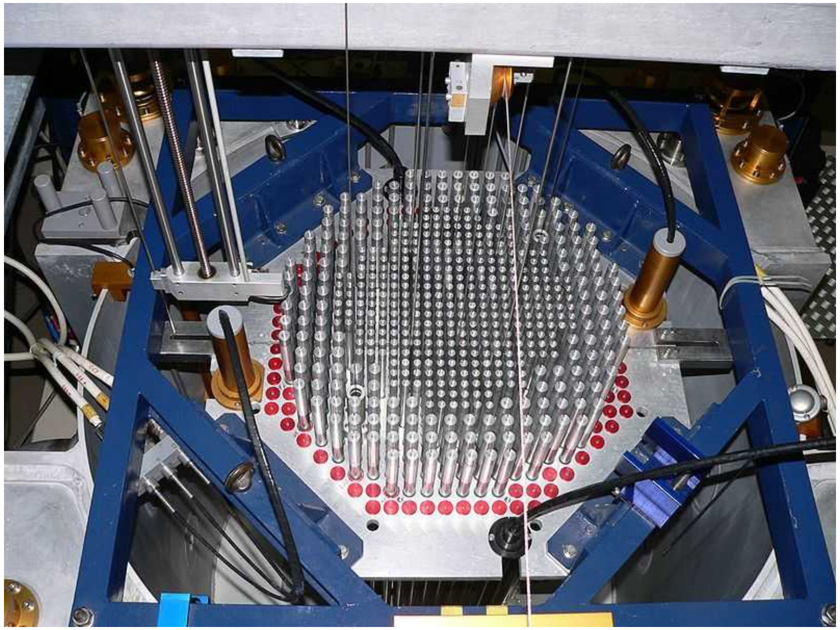
* **IAEA SAFETY STANDARDS SERIES No. NS-R-4, "SAFETY OF RESEARCH REACTORS, SAFETY REQUIREMENTS," June 2005.**

Research Reactor Safety Elements

RR safety elements must include:

- **nuclear safety,**
- **radiation safety,**
- **transportation safety, and**
- **radioactive waste safety**
  - Spent fuel and use products

Reactor Type	CRIT ASSEMBLY
Thermal Power, Steady (kW)	0.10
Max Flux SS, Thermal (n/cm2-s)	7.50E8
Max Flux SS, Fast (n/cm2-s)	1.75E9



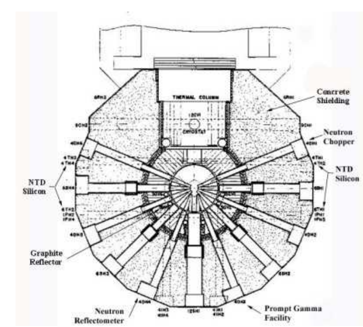
Core of CROCUS, a small nuclear reactor used for research at the EPFL in Switzerland
“zero Power”; 100Wt.

Reference: http://www-naweb.iaea.org/napc/physics/research_reactors/ database/database.html

Research Reactor Safety Objectives

- **Three safety objectives:**
  - **A General (in nature) Safety Objective**
  - **Two complementary - dealing with radiation protection and the technical aspects of safety**

Reference: http://web.mit.edu/nrl/www/photos.htm



MIT Reactor (MITR-II)
Reference:
http://www.trtr.org/Links/TRTR_February.html

Research Reactor Safety Objectives

General Nuclear Safety Objective:

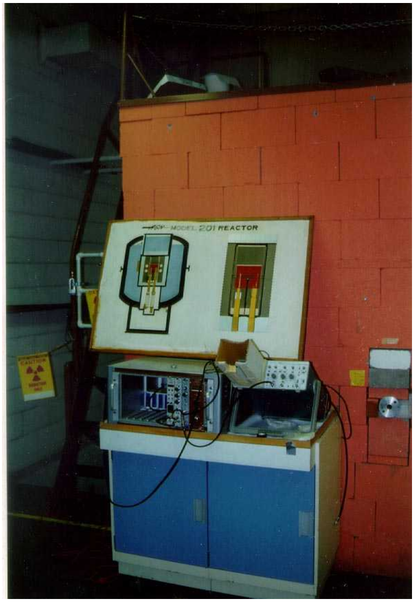
"To protect individuals, society and the environment from harm by establishing and maintaining in nuclear installations effective defenses against radiological hazards."

INTERNATIONAL ATOMIC ENERGY AGENCY, The Safety of Nuclear Installations, Safety Series No. 110, IAEA, Vienna (1993).

Research Reactor Safety Objectives

Radiation Protection Objective:

"To ensure that in all operational states radiation exposure within the installation or due to any planned release of radioactive material from the installation is kept below prescribed limits and as low as reasonably achievable, and to ensure mitigation of the radiological consequences of any accidents."



University of New Mexico's AGN-201M reactor
Ref: http://www.trtr.org/Links/TRTR_February.html

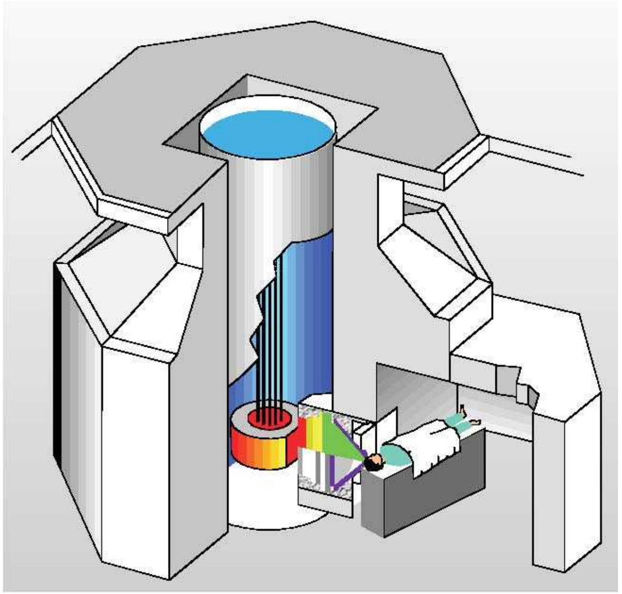
INTERNATIONAL ATOMIC ENERGY AGENCY, The Safety of Nuclear Installations, Safety Series No. 110, IAEA, Vienna (1993).

Research Reactor Safety Objectives

Technical Safety Objective:

"*To take all reasonably practicable measures to prevent accidents in nuclear installations and to mitigate their consequences should they occur; to ensure with a high level of confidence that, for all possible accidents taken into account in the design of the installation, including those of very low probability, any radiological consequences would be minor and below prescribed limits; and to ensure that the likelihood of accidents with serious radiological consequences is extremely low.*"

INTERNATIONAL ATOMIC ENERGY AGENCY, The Safety of Nuclear Installations, Safety Series No. 110, IAEA, Vienna (1993).



The VTT FiR-1 reactor in Otaniemi, FiR-1 has been converted for experimental Boron neutron capture therapy
Reference:
http://www.vtt.fi/research/technology/nuclearenergy/triga_research_reactor_.jsp?lang=en

Important Areas of Research Reactor Safety – per IAEA

- **All activities performed to achieve the purpose for which the nuclear research reactor was designed and constructed or modified; including**
  - **Maintenance, testing and inspection, fuel handling and handling of radioactive material (including the production of radioisotopes), the installation, testing and operation of experimental devices, the use of neutron beams, research and development work and education and training using the research reactor systems, and other associated activities.**

IAEA SAFETY STANDARDS SERIES No. NS-R-4, "SAFETY OF RESEARCH REACTORS, SAFETY REQUIREMENTS," June 2005.

Important Areas of Research Reactor Safety – per IAEA

- The important areas also include:
  - the geographical area that contains an authorized facility, and within which the management of the authorized facility may directly initiate emergency actions. The site boundary is the boundary of the site area.
  - Siting (site evaluation): the process of selecting a suitable site for a facility, including appropriate assessment and definition of the related design bases.

IAEA SAFETY STANDARDS SERIES No. NS-R-4, "SAFETY OF RESEARCH REACTORS, SAFETY REQUIREMENTS," June 2005.

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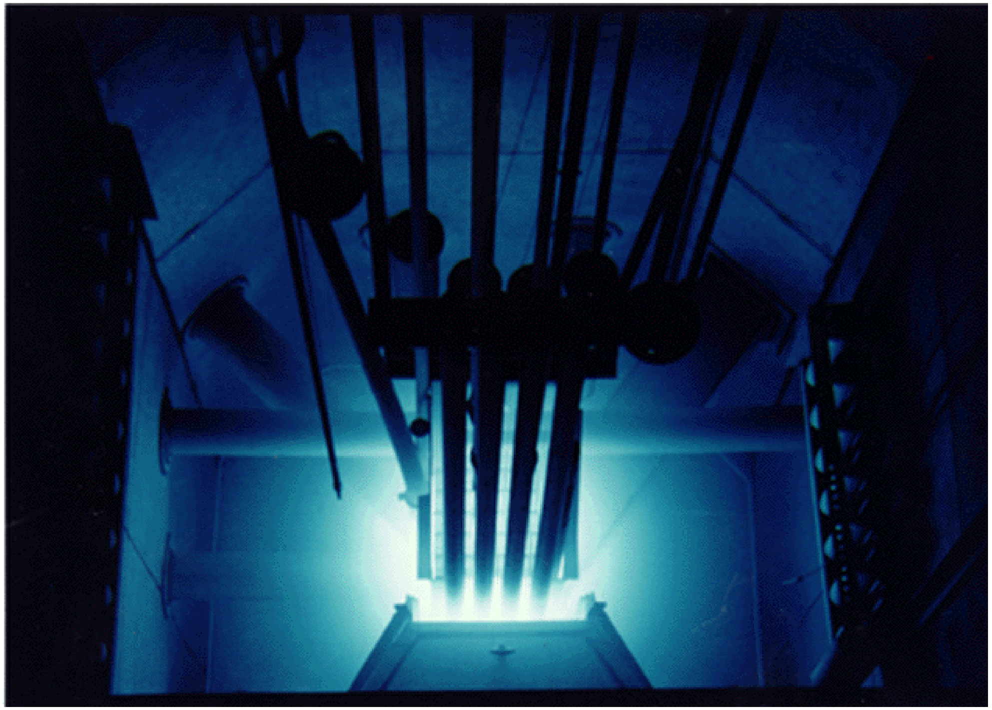
IAEA Research Reactor Safety Requirements

Many of requirements for the safety of nuclear research reactors are the same as or similar to those for nuclear power reactors

IAEA SAFETY STANDARDS SERIES No. NS-R-4, “SAFETY OF RESEARCH REACTORS, SAFETY REQUIREMENTS,” June 2005.



PULSTAR reactor at North Carolina State University (http://www.trtr.org/Links/TRTR_February.html#NCSU)

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IAEA Safety Research Reactor Safety Standards

- Reflect international consensus on what constitutes a high level of safety, and form the basis for the IAEA safety review services and assistance;
- Cover all areas important to the safety of research reactors and provide support for effective application of the IAEA Code of Conduct on the Safety of Research Reactors;
- Intended for use by all organizations involved in research reactors, including operating organizations, regulatory bodies, users, designers, and suppliers.
- Use regulatory language to allow for their incorporation into national safety regulations, and in developing national regulatory guides.

Graded Safety Approach

- Research reactors are used for special and varied purposes, such as research, training, radioisotope production, neutron radiography and material testing.
- These purposes call for different design features and different operational regimes.
- Design and operating characteristics of research reactors may vary significantly since the use of experimental devices may affect the performance of reactors.
- Hence, there is a need for flexibility in the approach to achieving and managing safety.

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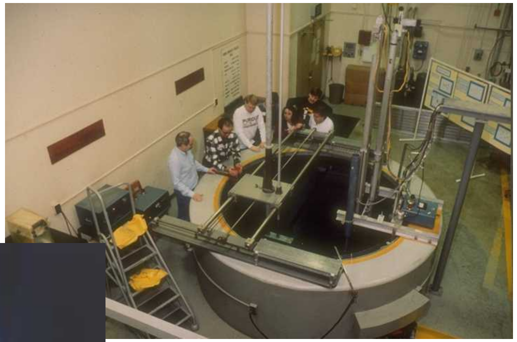
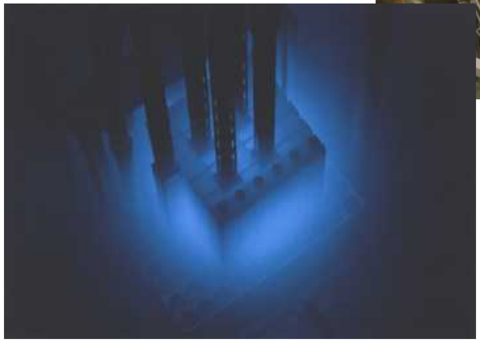
Graded Safety Approach is Based on

- The reactor power;
- The source term;
- The amount and enrichment of fissile and fissionable material;
- Spent fuel elements, high pressure systems, heating systems and the storage of flammables, which may affect the safety of the reactor;
- The type of fuel elements;

Graded Safety Approach is Based on

- The type and the mass of moderator, reflector and coolant;
- The amount of reactivity that can be introduced and its rate of introduction, reactivity control, and inherent and additional safety features;
- The quality of the containment structure or other means of confinement;
- The utilization of the reactor (experimental devices, tests and reactor physics experiments);
- Siting;
- Proximity to population groups.





Purdue University Reactor Number One (PUR-1)
Reference:
https://engineering.purdue.edu/NE/Research/Facilities/reactor.html

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Safety Culture – IAEA Definition

- **IAEA Defines Safety Culture as**

"that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, protection and safety issues receive the attention warranted by their significance"

References:

1. INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for Facilities and Activities, IAEA Safety Standards Series No. GS-R-3, IAEA, Vienna (2006).
2. INTERNATIONAL ATOMIC ENERGY AGENCY, Application of the Management System for Facilities and Activities, IAEA Safety Standards Series No. GS-G-3.1, IAEA, Vienna (2006).

Research Reactor Security

IAEA Nuclear Security Goals

- One of the goals of the IAEA nuclear security program is to provide guidance and assistance to help Member States establish a strong nuclear security culture
  - Facilitate and optimize human aspects in national nuclear security programs of Member States
- Enhanced nuclear security culture
  - Provide greater assurance that the entire nuclear security system will accomplish its functions
    - Prevent, detect, delay and respond to
      - theft, sabotage, unauthorized access, illegal transfer or other malicious acts

Reference: IAEA NUCLEAR SECURITY SERIES No. 7; Nuclear Security Culture, Implementing Guide; September 2008.

Security Culture

- IAEA Guide explains the basic concepts and elements of nuclear security culture and how they relate to arrangements and policies for other aspects of nuclear security
  - Provides an overview of the attributes of nuclear security culture,
  - Emphasizing that nuclear security is ultimately dependent on individuals: policy makers, regulators, managers, individual employees and - to a certain extent — members of the public.

http://www.canberra.com/products/730.asp

Reference: IAEA NUCLEAR SECURITY SERIES No. 7; Nuclear Security Culture, Implementing Guide; September 2008.

Nuclear Security Culture - Definition

- **IAEA Guide Definition**

"The assembly of characteristics, attitudes and behavior of individuals, organizations and institutions which serves as a means to support and enhance nuclear security."

Nuclear security: The prevention and detection of, and response to, theft, sabotage, unauthorized access, illegal transfer or other malicious acts involving nuclear or other radioactive substances or their associated facilities. It should be noted that 'nuclear security' includes 'physical protection', as that term can be understood from consideration of the Physical Protection Objectives and Fundamental Principles, the CPPNM* and the Amendment to the CPPNM.

* CPPNM: Convention on the Physical Protection of Nuclear Material

Reference: IAEA NUCLEAR SECURITY SERIES No. 7; Nuclear Security Culture, Implementing Guide; September 2008.

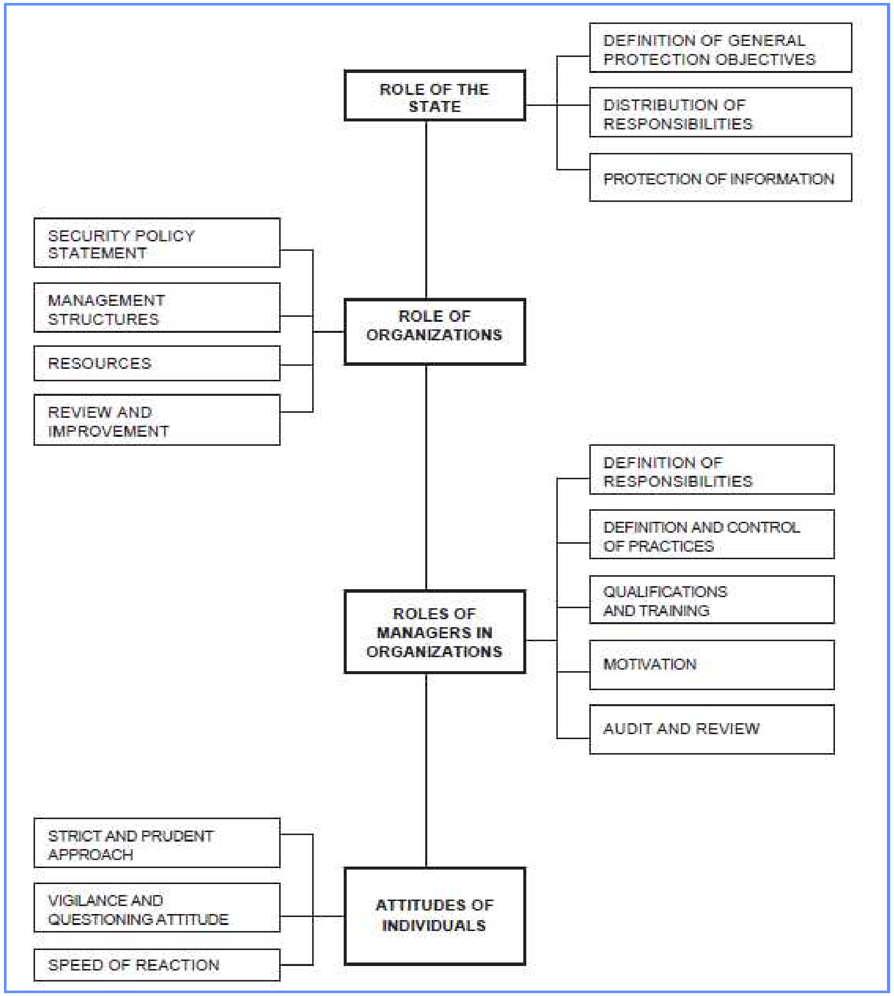
Relationship Between Nuclear Security and Nuclear Safety Culture

- "both nuclear safety and nuclear security consider the risk of inadvertent human error.."
- "The principal shared objective of security culture and safety culture is to limit the risk resulting from radioactive material and associated facilities."
- "This objective is largely based on common principles, e.g. a questioning attitude, rigorous and prudent approaches, and effective communication and open, two way communication."

Reference: IAEA NUCLEAR SECURITY SERIES No. 7; Nuclear Security Culture, Implementing Guide; September 2008.

Features of Nuclear Security Culture

Universal Features of Nuclear Security Culture



Reference: IAEA NUCLEAR SECURITY SERIES No. 7; Nuclear Security Culture, Implementing Guide; September 2008.

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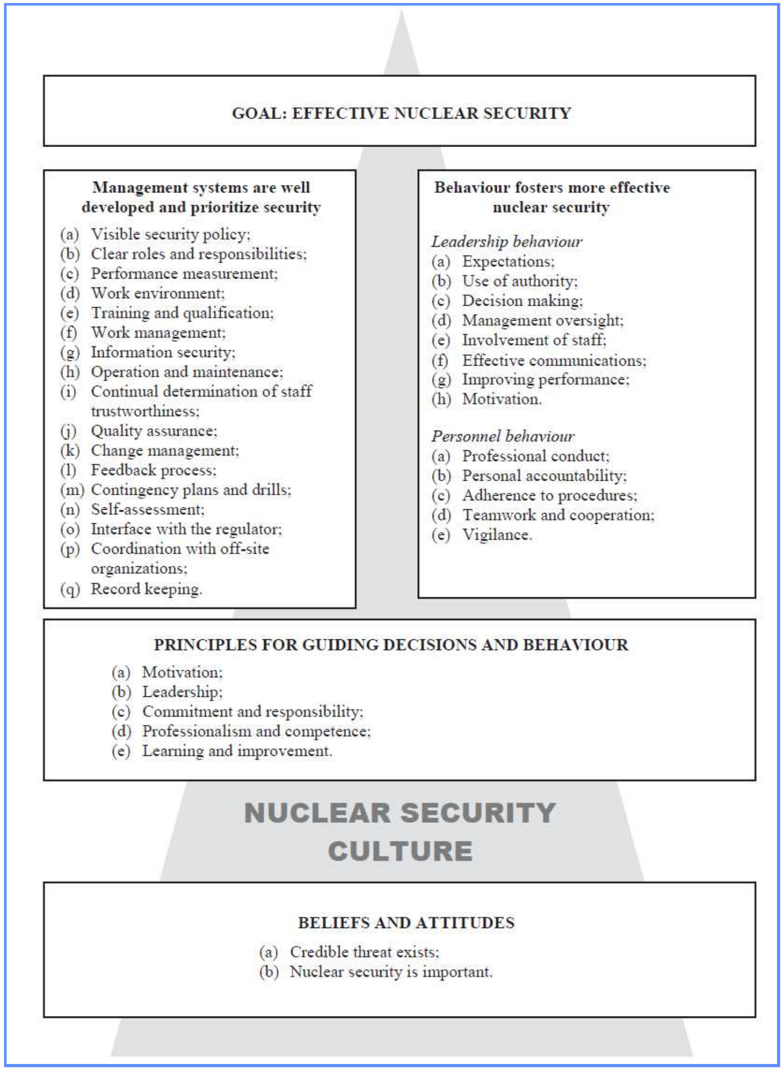
Characteristics of Nuclear Security Culture

Characteristics of Nuclear Security Culture



Reference: IAEA NUCLEAR SECURITY SERIES No. 7; Nuclear Security Culture, Implementing Guide; September 2008.

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Research Reactor Safeguards

IAEA Safeguards Standard / Guidelines

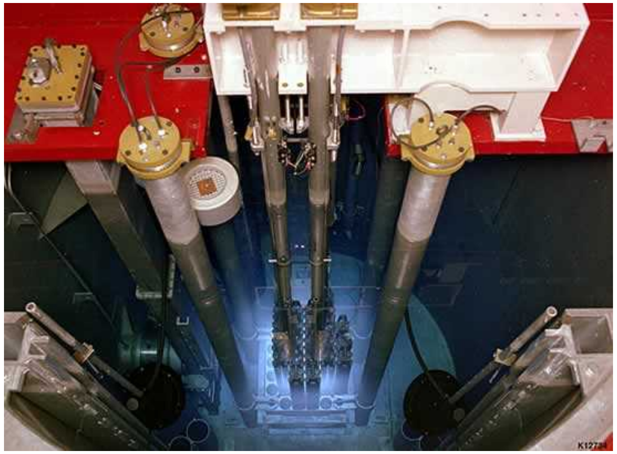
- No IAEA Specific Safeguards “Standard” (like those cited for safety) for research reactors
- Research reactor safeguards are dependent on the:
  - Reactor power
  - Fuel Type
  - Enrichment of Fuel

http://www.canberra.com/pdf/Literature/C27337%20UPu%20Application%20Note%20Update.pdf

Reference: Safeguards at research reactors: Current practices, future directions. IAEA BULLETIN, 4/1996

Safeguards – and Research Reactor Type

- "Pool" Type
  - Power level below 10 MW_{th}
  - Fuel HEU (20% U-235 or more) or LEU (less than 20% U-235)
    - Fuel assemblies are accessible for safeguards measurements



A TRIGA pool-type reactor
Ref: http://en.wikipedia.org/wiki/TRIGA

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Safeguards – and Research Reactor Type

- Other Types:
  - Operate at power levels exceeding 10 MW_{th}
  - Core normally enclosed in core vessels
  - Fuel elements in the reactor core
    - usually not visible or accessible for safeguards measurements.

IAEA Safeguards Objectives and Member State Obligations

- **IAEA has the right and obligation to verify that no nuclear material is diverted from peaceful use**
- **Member States conclude Safeguards Agreements with the IAEA**
  - pursuant to their obligations under the Treaty on the Non-Proliferation of Nuclear Weapons (NPT)

http://www.canberra.com/products/734.asp

Reference: Safeguards at research reactors: Current practices, future directions. IAEA BULLETIN, 4/1996

Diversion Scenarios of Concern to IAEA

Diversion of fresh or slightly irradiated fuel for clandestine chemical extraction of fissile material

- Of particular safeguards attention at facilities where the fresh fuel contains HEU or plutonium,
- A number of research reactors under IAEA safeguards are currently using such direct-use fissile material in amounts equal to more than one significant quantity (SQ)*.
- International efforts are under way to use LEU instead of HEU fuel in research and test reactors without significant degradation in their performance for experiments, costs, or safety aspects.

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* *For safeguards purposes, one SQ is currently defined as 8 kilograms plutonium or uranium-233 or 25 kilograms of uranium-235 in HEU.*

Reference: Safeguards at research reactors: Current practices, future directions. IAEA BULLETIN, 4/1996

Diversion Scenarios of Concern to IAEA

Diversion of spent or extensively irradiated fuel for clandestine chemical extraction of fissile material in a reprocessing facility

- Technically more demanding and time-consuming than the one mentioned on the last slide;
- Of particular concern at research reactors under IAEA safeguards where large quantities of spent fuel have been accumulated
- Of importance at many other reactors with high power and/or ability to produce one SQ of Pu or U-233 per year

Reference: Safeguards at research reactors: Current practices, future directions. IAEA BULLETIN, 4/1996

Production Scenarios of Concern to IAEA

Clandestine production scenarios

- Possibility for clandestine production of plutonium or uranium-233 through irradiation of undeclared fertile material
- Of special concern at high flux reactors; greater than 25 MW_{th}; and/or capability to produce at least one SQ of plutonium (or uranium-233) per year

http://www.canberra.com/pdf/Products/Hybrid-KEdge-SS-M3849.pdf

Reference: Safeguards at research reactors: Current practices, future directions. IAEA BULLETIN, 4/1996

IAEA Safeguards at Research Reactors

- “Classical" IAEA Safeguards
- Strengthened IAEA Safeguards

From: http://www.canberra.com/pdf/Literature/can0019.pdf

From: http://www.canberra.com/pdf/Products/JCC-51-SS-C36907.pdf

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Elements of "classical" IAEA safeguards at Research Reactors

- Annual physical inventory verification (PIV);
- Inspections serving timely detection purposes for
  - fresh (unirradiated) fuel, core fuel, and spent fuel;
- Auditing of records and reports;
- Verification of specific types of fuel transfers;
- Verification activities to confirm the absence of clandestine irradiation of fertile material.

Reference: Safeguards at research reactors: Current practices, future directions. IAEA BULLETIN, 4/1996

Elements of "classical" IAEA safeguards at Research Reactors

- At the PIV, the fresh fuel and spent fuel are verified using non-destructive assay (NDA) methods
- Core fuel is verified by NDA methods or by a criticality check corroborated by other reactor data
- Interim inspections are performed at research reactors at intervals determined by the safeguards timeliness requirements for specific inventories of different material types.

Reference: Safeguards at research reactors: Current practices, future directions. IAEA BULLETIN, 4/1996

Elements of "classical" IAEA safeguards at Research Reactors

- Transfers of fuel and experimental material containing HEU, plutonium, or uranium-233 into or out of a facility are verified either at the shipping or receiving facility, or at both;
- Procedure are performed to check that there has been no unrecorded production at high-power research reactors (greater than 25 megawatts-thermal) of one SQ of plutonium or uranium-233;

Reference: Safeguards at research reactors: Current practices, future directions. IAEA BULLETIN, 4/1996

Elements of "classical" IAEA safeguards at Research Reactors

- Information of relevance to safeguards about the design of the research reactor is provided to the Agency by the State.
  - The information is examined and verified according to established Agency procedures and is re-examined at least once a year.
- Modifications or changes in design information relevant to safeguards are verified to establish the basis for adjustment of safeguards procedures

Reference: Safeguards at research reactors: Current practices, future directions. IAEA BULLETIN, 4/1996

Elements of strengthened safeguards at research reactors

- Endorsed in June 1995, the IAEA Board of Governors under Part 1 of "Program 93+2"
- Some measures were designed to increase the efficiency and improve the effectiveness of aspect of safeguards that are general in nature
  - For example, they include early provision of design information; and description of the State's nuclear fuel cycle
- Other measures are more specific to particular facilities
  - environmental sampling
  - unannounced routine inspections
  - remote transmission of safeguards information

Reference: Safeguards at research reactors: Current practices, future directions. IAEA BULLETIN, 4/1996

Elements of strengthened safeguards at research reactors

Unannounced inspections

- Unannounced inspections are those where the State and the operator are first informed of the Agency's intention to carry out an inspection at the time when the IAEA inspector arrives at the entrance of the site
  - requires that the State grant multiple-entry visas
  - requires the operator to grant access to the Agency inspector to the facility in a short time

Reference: Safeguards at research reactors: Current practices, future directions. IAEA BULLETIN, 4/1996

Elements of strengthened safeguards at research reactors

Remote monitoring: **These types of systems include:**

– *Video surveillance:* Installation of cameras which can be operated remotely would allow continuous surveillance of facility operations

– *Measurement and accountancy data:* Remote transmission of inspection data would provide additional assurance that no undeclared activities have taken place

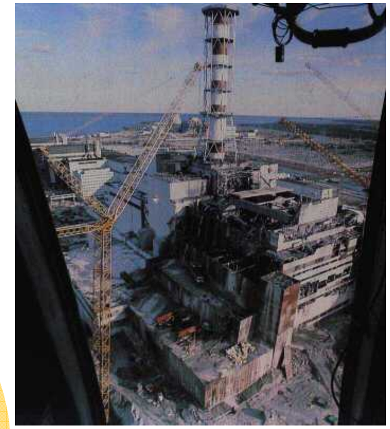
From: http://www.canberra.com/products/438091.asp

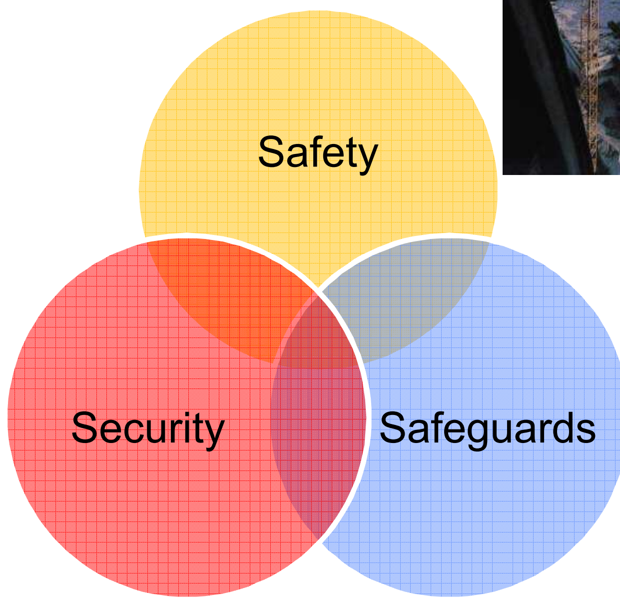
Reference: Safeguards at research reactors: Current practices, future directions. IAEA BULLETIN, 4/1996

Promotion of Integrated Safety, Security, and Safeguards - 3S Integration

- **Promote Sustainability**
  - Reduction in operating cost
- **Increase Reliability**
  - Increase the collective focus on development, implementation, and improvement of 3S
- **Opportunity for Cross Training of Workforce**
  - Enhances worker morale and retention
- **Promotes "System" analysis and solution approach**
  - Results in effective and efficient outcome

Feasibility of 3S Integration





“3S” in Context

Nuclear Safety

Operating conditions, prevention of accidents/mitigation of consequences, resulting in the protection of workers, the public, and the environment from undue radiological hazards.

Nuclear Security

Prevention and detection of, and response to sabotage, unauthorized access, or other malicious acts involving nuclear material, other radioactive substances or their associated facilities.

Nuclear Safeguards

Prevention and detection, through the use of material control and accountancy, of theft or diversion of special nuclear material from civilian facilities.

What must be addressed?

Safety	Security	Safeguards
• Prevention • Detection • Assessment • Mitigation	• Deterrence • Detection • Assessment • Delay • Response	• Deterrence • Detection • Assessment • Response?

Culture Comparisons

Safety	Security	Safeguards
Transparency	Need-to-know	Graded Transparency
Ease of Movement	Restricted Movement	Restricted Movement
Human/Equipment Failure	Deliberate Acts	Deliberate Acts
Facility Environment	Facility Environment	Facility Environment

From: Abby Doll and Roushan Ghanbari, "Safety, Security, and Safeguards Integration in US Nuclear Power Plants ", Sandia National Laboratories, December 2010.

Processes for Addressing 3S

Safety	Security	Safeguards
Prevention	Deterrence	Deterrence
Detection	Detection	Detection
Assessment	Assessment	Assessment
Mitigation	Delay	Response?
	Response	

From: Abby Doll and Roushan Ghanbari, "Safety, Security, and Safeguards Integration in US Nuclear Power Plants ", Sandia National Laboratories, December 2010.

Goals and Methods Safety, Security, and Safeguards

	Safety	Security	Safeguards
Information Flow	Transparency	Need-to-know	Graded Transparency
Personnel Flow Threat	Ease of Movement Human/Equipment Failure	Restricted Movement Deliberate Acts	Restricted Movement Deliberate Acts
Implementation	Facility Environment	Facility Environment	Facility Environment
Authority	State	State	IAEA

Derived from the following sources:

1. "Nuclear Security Culture." IAEA Nuclear Security Series No. 7, 2008; International Atomic Energy Agency.
2. "Safety culture in nuclear installations: Guidance for use in the enhancement of safety culture." IAEA-TECDOC-1329, 2002.

Feasible Opportunities for Integration

- Human Factors/Training
- Cyber Security
- Deterrence/Prevention
- Procedures for Abnormal Operations
- Layout of Plant
- Material Control and Accountancy

References

- IAEA, *Milestones in the Development of a National Infrastructure for Nuclear Power*, NG-G-3.1, 2007
- IAEA, *Evaluation of the Status of National Nuclear Infrastructure Development*, NG-T-3.2, 2008
- IAEA, *Maximizing the Contribution of Nuclear Technology to Society While Verifying its Peaceful Use*, IAEA Primer, 08- 34361/Fact Sheets / November 2008 / E
- Kovacic, Donald N., et. al., *Nuclear Safeguards Infrastructure Development and Integration with Safety and Security*, Pub. 20268
- U.S. Nuclear Regulatory Commission, *Safety and Security Improvements at Nuclear Plants –Fact Sheet*, 2005
- *IAEA, World Research Reactors: http://nucleus.iaea.org/RRDB/RR/ReactorSearch.aspx?rf=1*