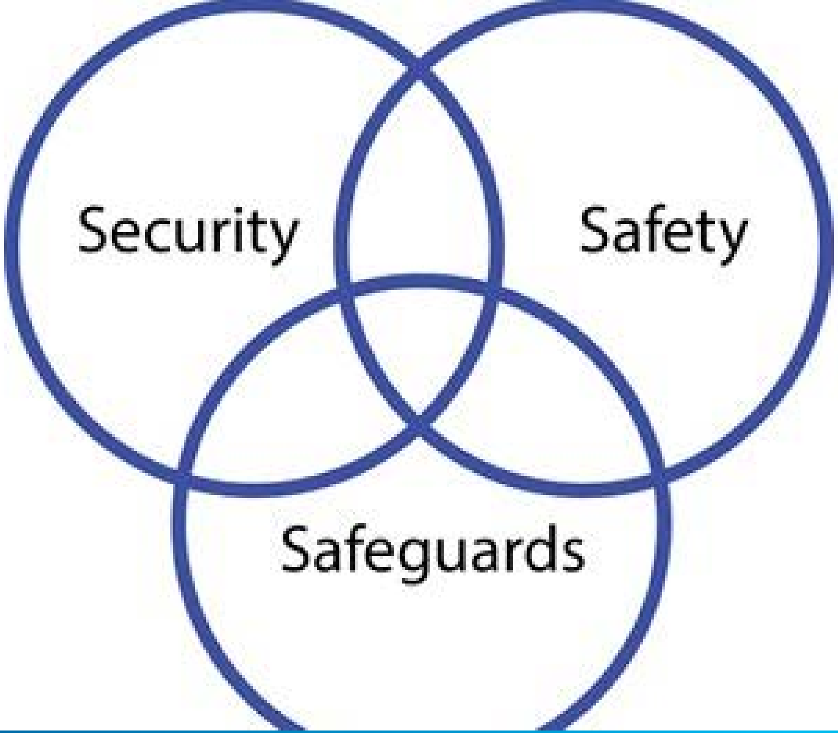

The Interface between Safety, Security and Safeguards for Small Modular Reactors

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WINS Workshop on Security of Small Modular Reactors

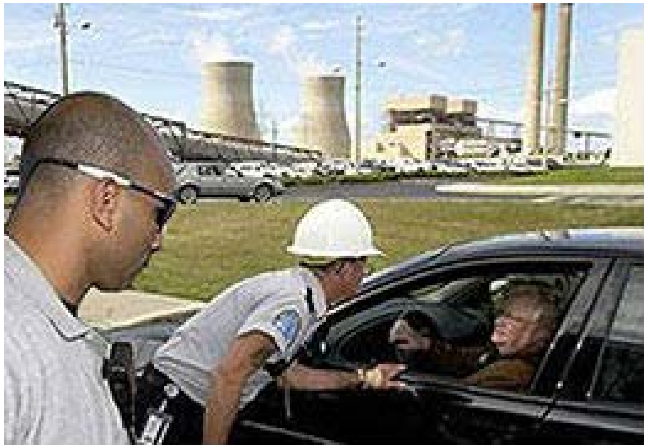
Ottawa, ON 2019 Nov. 21

The Focus of Nuclear Security

- Nuclear security prevents unauthorized actors from theft, sabotage, unauthorized access, illegal transfer or other malicious acts involving nuclear or other radioactive substances or their associated facilities.
- The actors could be

1. Outside adversaries such as criminals, terrorist organizations, and other countries
2. Insider threats, such as employees or persons with inside knowledge

- A design basis threat provides the basis for constructing a physical protection system



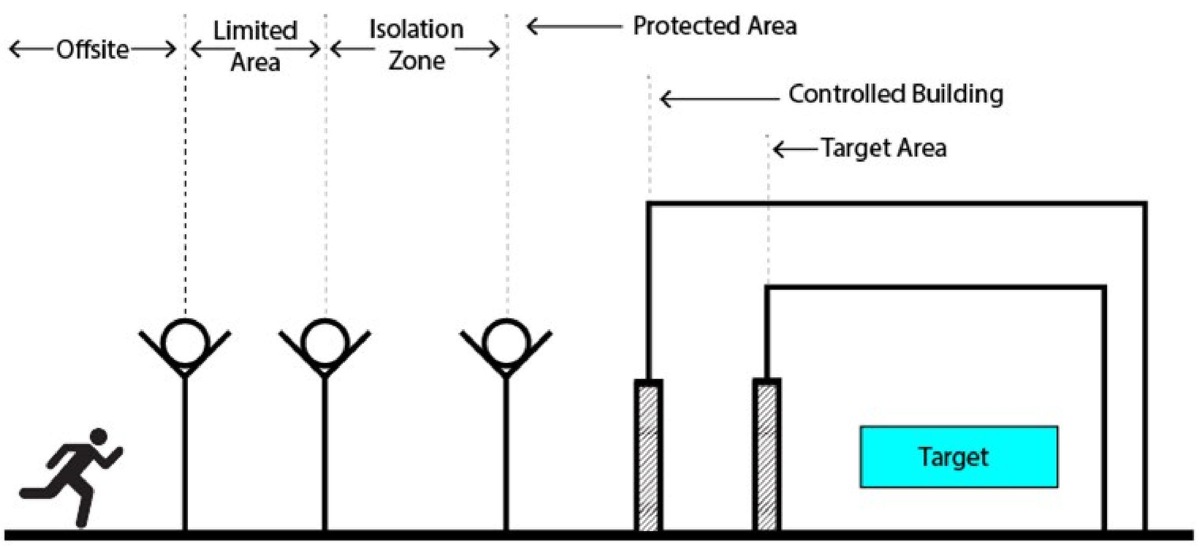
Members of a security team inspecting an individual entering a nuclear facility. (Photo Source: NRC)

Nuclear Security Physical Protection System

A physical protection system (PPS) is designed on a system of five essential elements:

1. Deterrence: an outward show of strength to try and prevent an adversary from attacking.
2. Detection: means to alert the facility of covert or overt actions by the adversary.
3. Delay: means to impede the adversary's progress towards their intended target.
4. Response: actions taken by security personnel to prevent the adversary from succeeding.
5. Recovery: the ability to resume normal operations after an (attempted) incident.

A PPS is usually designed using a defense-in-depth approach, consisting of multiple layers of defense employing various components.



Defense in Depth for a Physical Protection System (Source: Combined Safety and Security Risk Evaluation, Considering Safety and Security-Type Initiating Events, Mohammed Hawila)

The Focus of Nuclear Safety

- Nuclear safety measures are put in place at nuclear facilities to protect people (both workers and the public) and the environment from radiation risks, whatever the cause.
- Threats to nuclear safety can include:

1. Natural disasters
2. Equipment malfunctions
3. Human error

- A design basis accident provides the basis for constructing facility safety measures.

The Fukushima I Nuclear Power Plant after the 2011 Tōhoku earthquake and tsunami. Reactor 1 to 4 from right to left.
Source: Digital Globe

Nuclear Facility Safety Measures

Nuclear facility safety measures are constructed on the basis of the following elements:

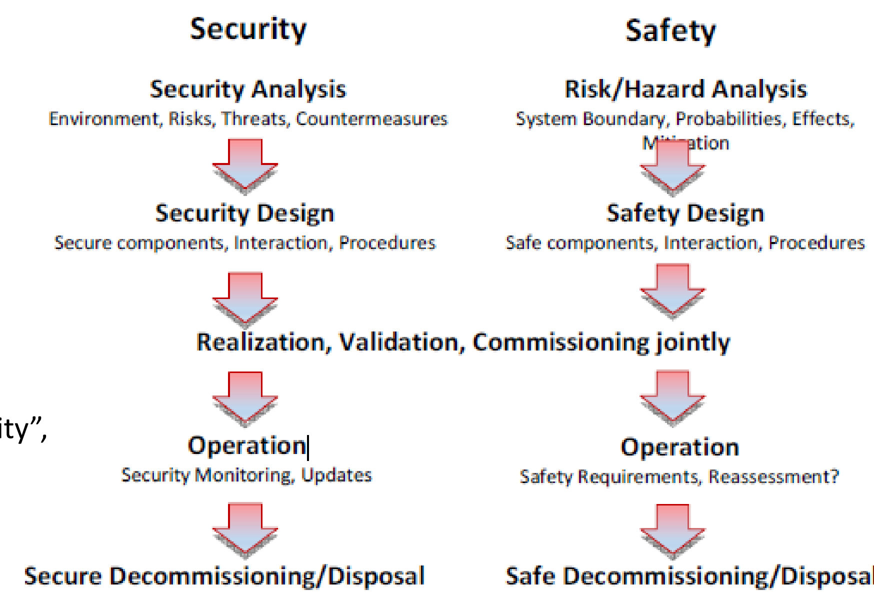
1. Preventing deviations from normal operation.
2. Controlling deviations from operational states.
3. Controlling accidents within the design basis.
4. Mitigating accidents and ensuring confinement of radioactive materials.
5. Mitigating the radiological consequences of radioactive releases.

Safety measures are deployed using a defense-in-depth approach providing successive layers of protection.

Defense-in-depth at Pickering Generating Station
Source: http://hatchstudios.com/opg-defense-depth-now-online/

The Interface between Nuclear Safety and Nuclear Security

1. Safety is necessary, but not adequate to protect nuclear or other radioactive material from theft, sabotage, or other malicious acts.
2. Security is necessary, but not sufficient to protect people or the environment from a radioactive release caused by malicious acts.
3. In most cases, safety and security are not mutually exclusive, and have to be managed in an integrated manner.
4. The acceptable risk to workers, the public, and the environment cannot be different, irrespective of the cause of the initiating event of a radiological release.



One possible unified approach to nuclear safety and security
B. Heinz-Peter, S. Freddy, "Interface between nuclear safety and security", Journal of Polish Safety and Reliability Association, 5 (1) 9-20 (2014)

Probabilistic Assessment of Integrated Safety and Security

A Bayesian network for integrating safety and security probability risk assessments provides:

- Quantitative analysis of impacts of the interaction of safety and security
- Dynamic probability assessment using evidence
- A visual display of specific accident evolution directly initiated from a poor security factor
- Inclusion of physical intrusion processes

This integrated method has been demonstrated to significantly change the occurrence probability of abnormal events in dynamical assessment.

G. Song et al. *Safety Science 113 (2019) 115–125*

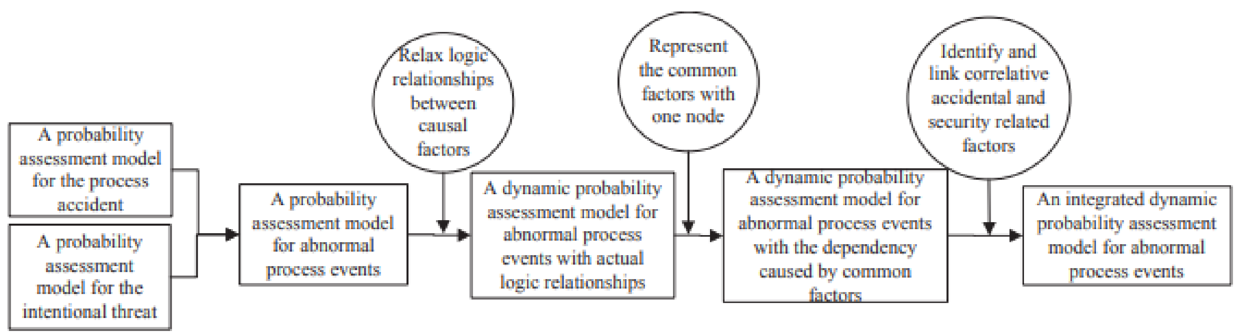


Fig. 2. The approach to obtain the integrated dynamic probability assessment model.

The Focus of Nuclear Safeguards

- Nuclear safeguards is a set of technical measures that are applied on nuclear material and activities to independently verify that nuclear facilities are not misused and nuclear material is not diverted from peaceful uses.
- The intent is deter authorized actor(s) or a State from diverting and misusing nuclear material for military purposes.

IAEA Safeguards inspectors taking a physical inventory of fresh enriched uranium fuel assemblies. (Photo source: D. Calma/IAEA)

Nuclear Safeguards Measures

The implementation of nuclear safeguards involves a number of components:

1. Nuclear Material Accountancy (NMA);
2. Containment and Surveillance (C&S);
3. Design Information Verification (DIV);
4. Reports; and
5. Inspections

- NMA is the principal means used to independently verify the correctness of the accounting information provided by facility operations and the State System of Accounting for and Control of nuclear material (SSAC).

https://www.iaea.org/topics/basics-of-iaea-safeguards

Nuclear Material Accountancy and Control

- Nuclear Material Accountancy includes the following elements:

a) Establishment of accounting areas (MBAs);

b) Record keeping;

c) Nuclear material measurement;

d) Preparation and submission of accounting reports; and

e) Verification of the correctness of the nuclear material accounting information.

- Nuclear Material Control includes:

i. Access and authority restrictions

ii. Tracking/monitoring of materials and processes, possibly remotely

iii. Movement verification

iv. Stock taking

NMAC Supporting Security

- NMAC provides security with a statement of what materials a site holds and where they are located.
- Inventory data are a key component of vulnerability assessment and the site security plan.
- Security personnel rely on facility operators and material custodians to effectively manage access controls and help formulate Vulnerability Assessments (VAs) and mitigate Vital Area risks.

- To create immediate and very localized alarms, the mass balance concept can be applied to each process: individual measurement errors are more manageable than for a large material balance area.

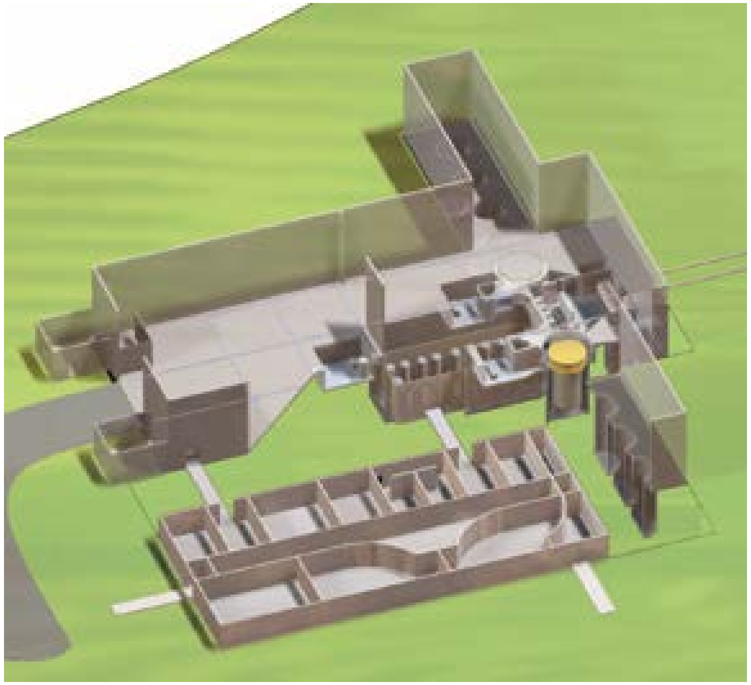
Source: WINS Best Practice Guide, 4.4, Nuclear Material Accountancy and Control in Support of Nuclear Security

SMRs in Remote Locations with Limited Access

<u>*Impact on Safeguards:*</u>

- Benefit: increased cost and difficulty of diversion/covert misuse
- Challenge: difficulty of access for inspections, especially unannounced
- Use reliable year-round off-site monitoring to minimize costs of safeguards visits

http://terrestrialenergy.com/imsr-technology/



SMRs in Remote Locations with Limited Access

Impact on Security:

- Benefit: limited access mitigates likelihood of attack
- Challenge: may be difficult to have enough manpower to ensure full protection against attacks

Impact on Safety:

- Benefit: remote location mitigates impact on populated areas in case of radiological release, further mitigated when the core is a subterranean installation.
- Challenge: may be difficult to have external emergency services present in a timely fashion when needed.

SMRs with Long-life Reactor Cores, Possibly Sealed

<u>*Impact on Safeguards:*</u>

- Benefit: reduced core access and reduced refueling frequency makes diversion more difficult
- Challenge: verifying core inventory
- Reliable monitoring of authenticated sensor data can provide "virtual" access
- Must provide maintenance and materials inspection without need to access core between refueling outages

http://terrestrialenergy.com/imsr-technology/

SMRs with Long-life Reactor Cores, Possibly Sealed

Impact on Security:

- Benefit: reduced core access mitigates success of attack on the core.
- Challenge: maintaining vigilance against attack during the lifetime of the core.

Impact on Safety:

- Benefit: where the core seal provides containment against radiological release.
- Challenge: maintaining safety across the entire range of plant states of the core

Hurdles for Transporting Sealed Cores

Safety and Security Issues:

SMR design must maintain the integrity of core in transport

Other challenges:

- Inspection/evaluation of fitness for transport/service
- Maintaining sub-critical arrangement during transport
- Payload size/weight, encumbered by shielding requirements
- Limitations of local transportation infrastructure
- Maintaining robust security monitoring during transport

Safeguards Issues:

How to implement safeguards from factory to SMR plant (to re-processing plant)?

Potential Large Number of SMR Sites

Safety/Security/Safeguards

- Distributed generation/operation: power generation at point of consumption
- SMRs lend themselves to distributed operation: many sites over a large geographic area, all requiring safeguards inspections, all requiring safety and security infrastructure.
- Capitalize on 3S safe and secure remote monitoring mated with centralized 3S cross functional response capable of responding within a required time period.

http://www.bloomenergy.com/fuel-cell/distributed-generation/

SMRs with Smaller Fissile Inventory

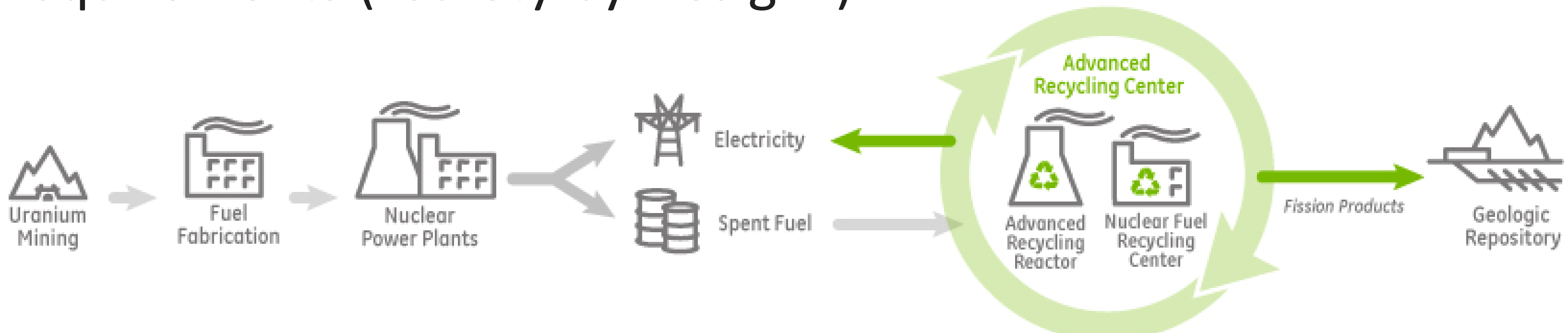
Safety/Security/Safeguards:

- Core loads are small compared to conventional power reactors, reducing source material in accident scenarios, and providing an additional barrier to diversion/misuse.
- However, nuclear devices using supporting materials such as neutron reflectors can achieve critical mass significantly below standard Significant Quantity (52 kg U, or 10 kg Pu)
- It is tempting to reduce security infrastructure and safeguards approaches in a graded approach to individual sites.
- The number of SMR sites deployed over time must be considered.

SMRs with Advanced Fuel Cycles

Safety/Security/Safeguards:

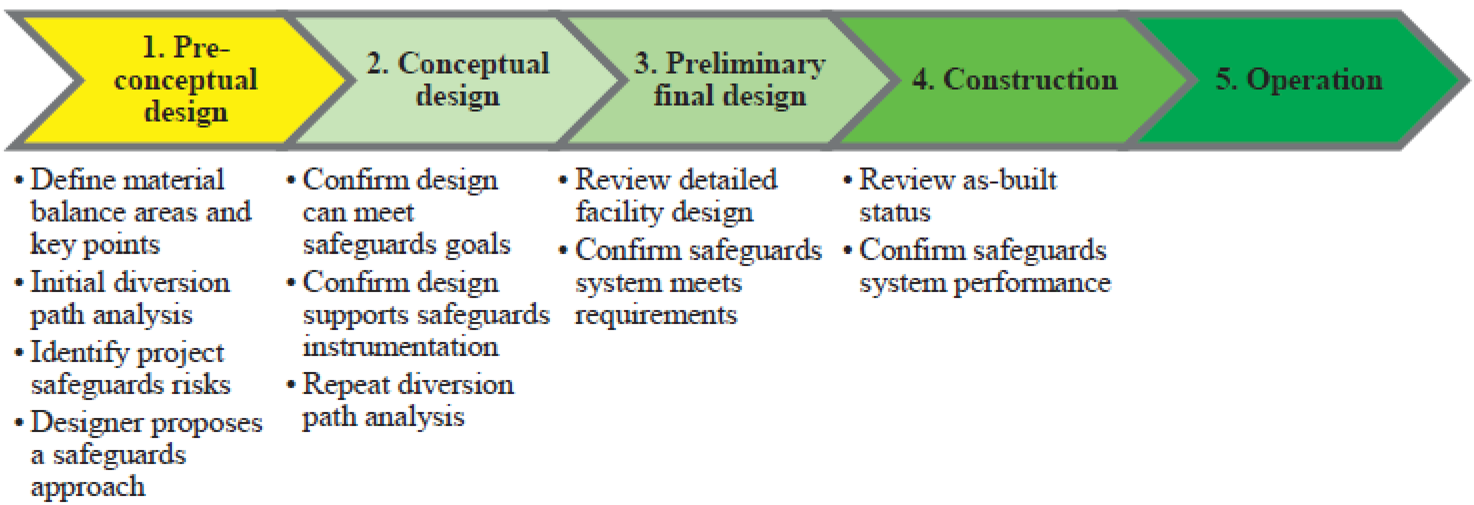
- Requires significant analysis to determine best safety requirements, security recommendations, and safeguards approach
- Important to employ “Safeguards by Design” and “Security by Design” at the earliest design stages, while complying with safety requirements (“Safety by Design”).



http://gehitachiprism.com/what-is-prism/how-prism-works/

Safeguards by Design

- Safeguards by Design was introduced by the IAEA to achieve safeguards goals with limited resources, in light of possible expansion of the nuclear industry
- Desirable and necessary for development of SMR technology: factor in proliferation resistance along with security, environmental, economic, and social acceptance considerations



Options to Enhance Proliferation Resistance of Innovative Small and Medium Sized Reactors, IAEA NP-T-1.11 (2014)

Conclusions

- Nuclear safety, security, and safeguards have strongly overlapping regimes and must be optimally integrated.
- SMRs present unique characteristics with benefits and challenges to each of these regimes.
- The adopted safety requirements, security recommendations, and safeguards approaches must be chosen in an integrated manner, using a balanced, graded approach.