Nexus of Safeguards, Security and Safety for Advanced Reactors

Dr. George Flanagan
Oak Ridge National Laboratory, USA

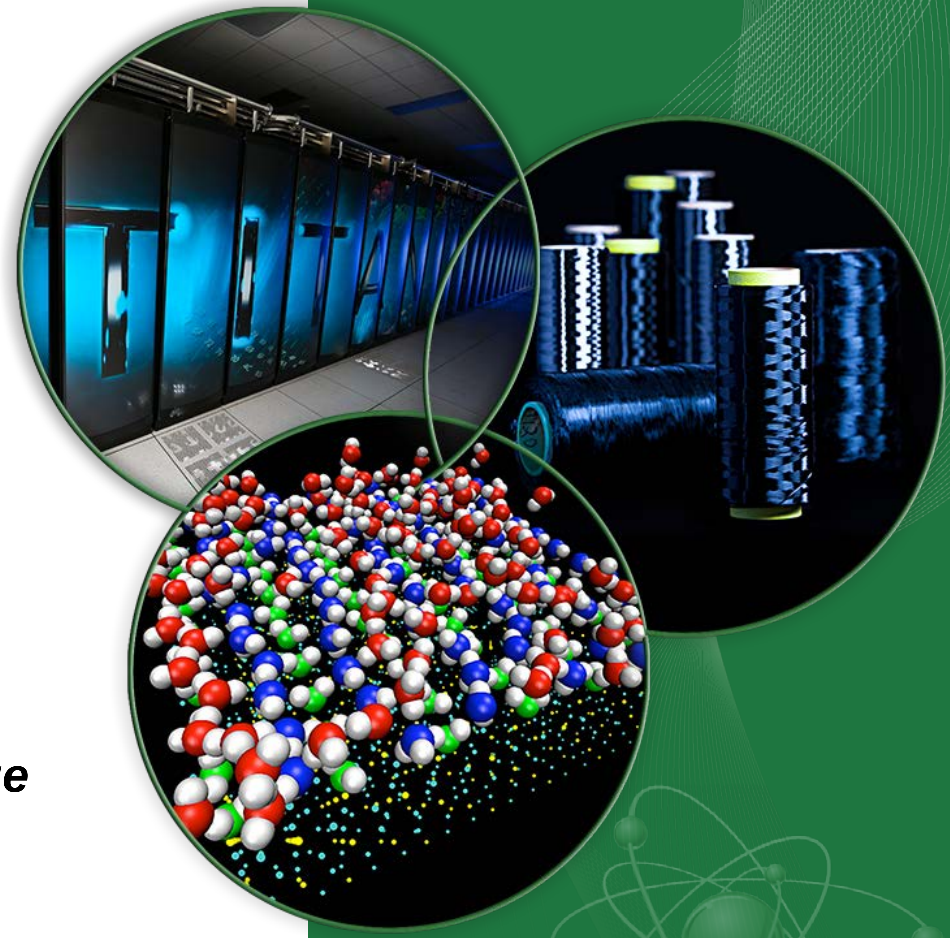
Dr. Robert Bari
Brookhaven National Laboratory, USA

Presentation for the

Global Nexus Initiative

Next Generation Nuclear Power: Value and Challenges of Transitioning to Advanced Technologies

February 23, 2016



ORNL is managed by UT-Battelle
for the US Department of Energy

Oak Ridge National Laboratory

Outline

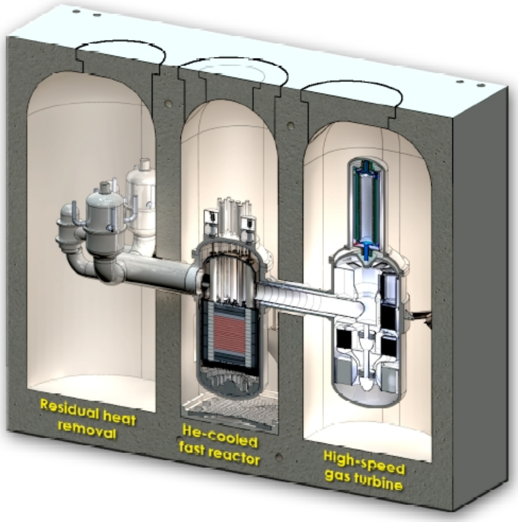
- Safeguards & Proliferation Resistant Designs
- Security Implications of Advanced Reactor Designs
- GEN IV Forum Attempts to Systematically Address Design Issues Related to Both Safeguards & Security
- Design Considerations
- Conclusions

OAK RIDGE National Laboratory

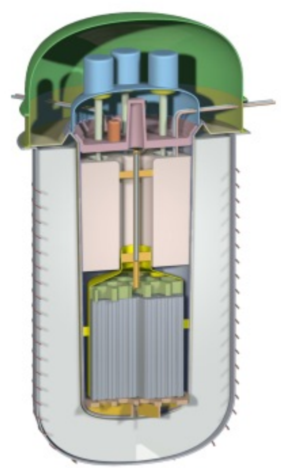
The Wide Variation of Advanced Reactor Designs Impacts Traditional Security, Safeguards, and Safety Approaches

- Generally there are three classes of non-water cooled reactors
  - Liquid metal-cooled reactors (fast neutron spectrum—no moderator to slow neutrons)
    - Sodium-cooled (metal or oxide fuel);
    - Lead-cooled (nitride or carbide fuel); and
    - Lead-bismuth-cooled (nitride or carbide fuel).
  - Gas-cooled reactors
    - Modular High Temperature Gas-cooled Reactors—MHTGR (thermal neutron spectrum, helium-cooled, graphite moderated, using TRISO fuel particles in either a prismatic or pebble bed array)
    - Fast gas-cooled reactors (fast neutron spectrum, helium-cooled, advanced fuel forms)
  - Molten salt reactors
    - Molten Salt Cooled Reactors –FHR (thermal neutron spectrum, fluoride salt-cooled, graphite moderated, TRISO fuel)
    - Molten Salt Fueled Reactors
      - MSR [Thermal neutron spectrum, Fluoride salt fuel (U, Th/U-233, Pu, actinides)]
      - MSFR [Fast neutron spectrum, Fluoride/ Chloride fuel (U, Th/U-233, Pu, Actinide, LWR recycle)]
- Each raises unique issues in the areas of safeguards, security, and safety

OAK RIDGE National Laboratory



Safeguards & Proliferation Resistant Designs



IAEA Safeguards Objectives are Defined in INFCIRC/153

- **Comprehensive Safeguards Agreement (CSA)**

"Traditional Safeguards"

- ***INFCIRC/153 Para. 28: The Safeguards Technical Objective***

- … the objective of safeguards is the *timely detection* of *diversion* of *significant quantities* of *nuclear material* from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and *deterrence of such diversion* by the *risk of early detection*…

- NOTE:

  Current safeguards efforts primarily relate to water-cooled technologies (Materials Control and Accountability – MC&A)

Current Safeguards Approaches May Not be Applicable for all Advanced Reactors

- Accountability currently is based on physical units
  - May still work for LMRs, GCRs, and FHRs (solid fuel) but may be complicated by the small size but large number of TRISO fuel kernels in MHTGRs and FHRs.
  - MSR liquid-fueled reactors may require the development of new methods
    - Homogeneous mixture of fuel, coolant, fission products, actinides
    - Continuous variation of isotopic concentrations in the fuel salt
    - High melting temperature
    - On line reprocessing possible
    - Unique refueling schemes
    - Liquid fuel requires one type of process for safeguards likely that frozen fuel will require another
    - Fuel outside the vessel
    - Difficult to introduce safeguards after the design of an MSR is completed

Impact of Advanced Reactors on Safeguards Needs to be Addressed

- Accountancy tools and measures may need to be modified for non-conventional (liquid) fuel types.
- New fuel loading schemes may present novel accountancy challenges. (pebble bed and MSR)
- Accessibility to the nuclear material, consider:
  - is facility operated continuously;
  - how facility is refueled;
  - location and mobility of fuel (form of the fuel, solid or liquid); and
  - existence and locations of other nuclear facilities- reprocessing or hot cells.

Impact on Safeguards Needs to be Addressed (cont'd)

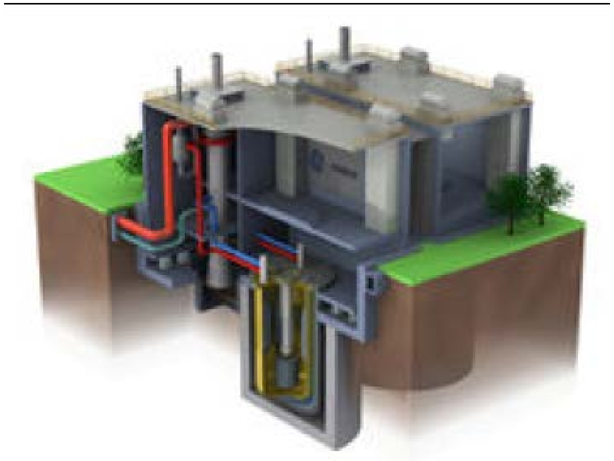
- Will there be a different approach to physical protection and how might that affect the safeguards tools?
- Will the site or nearby sites have more or less ancillary equipment like hot cells, fuel treatment, fuel storage, or nuclear research activities?
- Will the containment features be shared by multiple units? Will there be underground containment?

Impact on Safeguards Needs to be Addressed (cont'd)

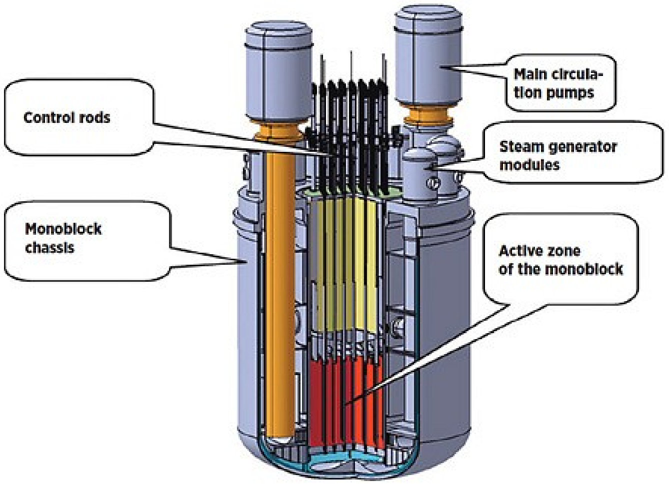
- Fuel leasing or supply arrangements that avoid on-site storage of fresh and/or used fuel or the need to refuel on site
- The isolation of the site or mobility of the reactor (sea or rail). Access issues for both inspectorate and the adversary.
- Remote monitoring: Operator / State / IAEA communication

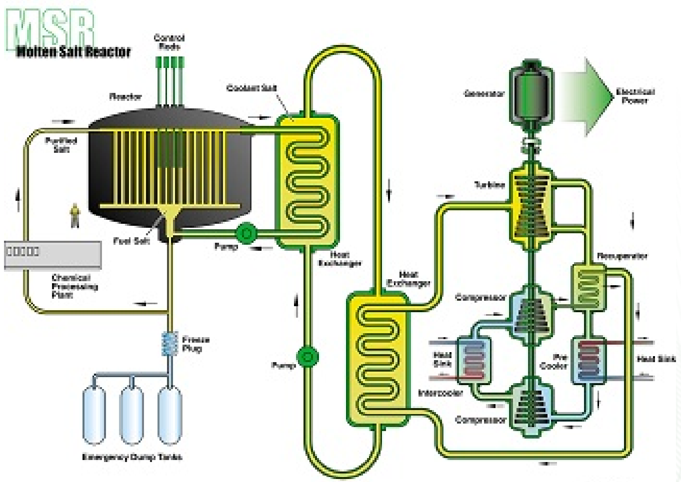
Advanced Reactors Unique Features Imply Designers Should Consider Safeguards as Part of the Design *Safeguards by Design (SBD)*

- **SBD: process of incorporating features to support international safeguards into nuclear facility designs starting in its conceptual design phase.**
  - **Element of the design process for a new nuclear facility from initial planning through design, construction, operation, and decommissioning.**
  - **Similar to the way safety is considered in today's reactor designs**
- **SBD includes use of design measures that make the implementation of safeguards at such facilities more effective and efficient**
  - **Maybe less costly to introduce safeguards at the beginning of the design process**
- **Both DOE/NNSA and IAEA advocate SBD**



Security Implications of Advanced Reactor Designs

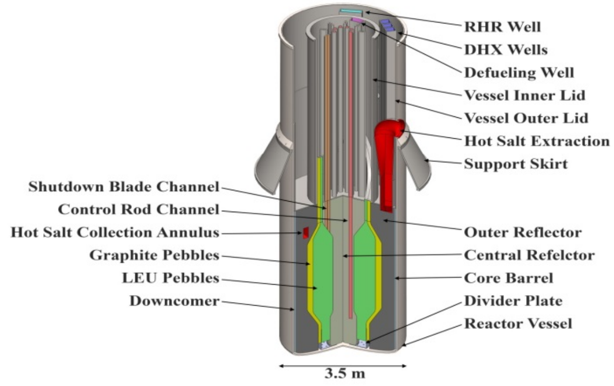




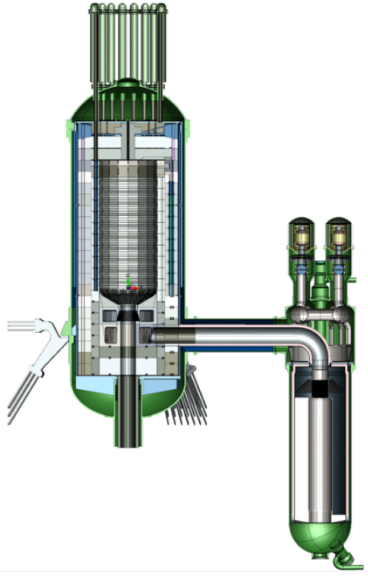
OAK RIDGE National Laboratory

Security Issues Related to Advanced Reactors

- Subject to the same threats as current reactors
  - Theft
  - Sabotage
- Some advanced reactors may have inherent/passive mechanisms that make them less vulnerable to sabotage/theft
  - Inherent shut down (strong negative reactivity feedback)
  - Dump valves to empty the reactor vessel into subcritical passively cooled underground storage tanks (MSR)
  - High operating temperature/liquid fuel/inert atmosphere
  - Passive systems for shutdown and heat removal
- Underground construction
- Fuel outside reactor vessel in some designs may increase sabotage/theft vulnerabilities.



GEN IV Forum Attempts to Systematically Address Design Issues Related to Both Safeguards & Security



GEN IV Proliferation Resistance and Physical Protection Program Looks at Improving Both Through Analysis and Design

- PR&PP Methodology
  - Similar to a Probabilistic Risk Assessment commonly used to address safety (risk triplet)
    - Likelihood of a event?
    - Given an event occurs what is the plant's response?
    - What are the consequences?
- Maybe useful for consideration in advanced reactors other than Gen IV designs … some applications already exist
- Used to focus the issues on high risk issues and reduce cost and time implementing both safeguards and security

The Gen IV Proliferation Resistance and Physical Protection (PR&PP) Methodology

see: https://www.gen-4.org/gif/jcms/c_40413/evaluation-methodology-for-proliferation-resistance-and-physical-protection-of-generation-iv-nuclear-energy-systems-rev-6

CHALLENGES → **SYSTEM RESPONSE** → **OUTCOMES**

Threats

PR

- Diversion
- Misuse
- Breakout
- Clandestine Facility

PP

- Theft
- Sabotage

PR & PP

Intrinsic

Physical & technical design features

Extrinsic

Institutional arrangements

e.g. IAEA Safeguards, Guns/Guards/Gates

Assessment

Measures

PR

- Material Type
- Detection Probability
- Technical Difficulty
- Proliferation Time
- Proliferation Cost
- Safeguards Cost

PP

- Adversary Success Probability
- Consequence
- Security Cost

Courtesy of BNL

Need to Realize There Are Differences Between Proliferation Resistance and Physical Protection

Proliferation Resistance

Host state is adversary
Threats are
- Diversion
- Misuse
- Breakout

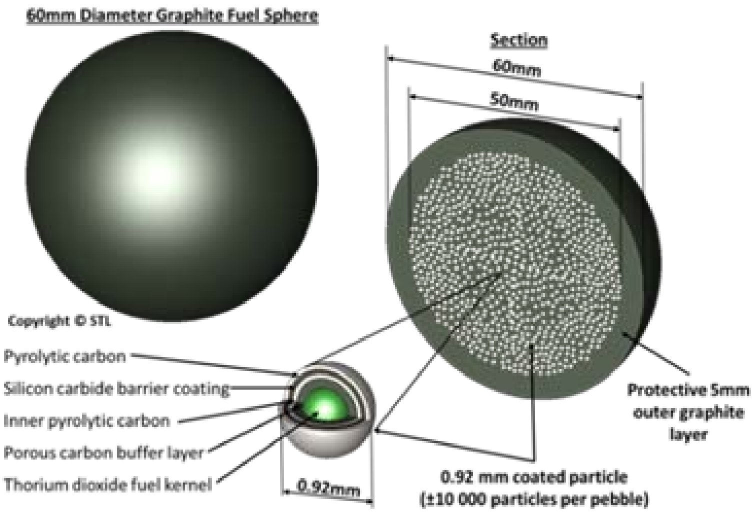
International Safeguards
Usually slow moving events (not always)

Physical Protection

Sub-national is adversary
Threats are
- Theft
- Sabotage

Domestic Safeguards
Fast moving events (sometimes)

Courtesy of BNL



Design Considerations

It Is Important that Advanced Reactors Consider Safeguards & Security Early in the Design

- Difficulty/Expensive to retrofit the design
  - Retrofits may interfere with operations, maintenance, radiation protection, or safety aspects of the design – post design introduction may conflict with safety aspects already existing in design which has been reviewed by regulatory body
- Safeguards
  - Designers/researchers need to work with the regulators to develop methods that make it easier to implement safeguards in the design
    - monitoring - challenging in an advanced reactor (temperature, tritium, high radiation, inert atmospheres, toxic materials)
    - remote sampling capability (counting and visual accountability won't work for MSR)
    - reduce quantities of fuel outside the vessel
    - accessibility for inspections
- Design Security into the advanced reactors
  - Perform vulnerability studies early and as necessary as the design progresses
  - Use modern technology to reduce the need for guard, guns and gates

OAK RIDGE National Laboratory

Security/Safeguards Requirements Are Not Strongly Related to Physical Size and Power Levels

- Security & safeguards requirements are not significantly affected by power level or physical size of the facility
  - Small reactors may have smaller source terms and therefore may affect emergency planning—mostly safety issue may impact sabotage
  - However the requirements for security & safeguards are not directly affected by power level but other aspects of the design may have an impact
    - Below grade reactor placement and incorporation of inherent and passive safety systems, and reduced accessibility may make sabotage and theft more difficult
    - Safeguards are required for any system using Significant Quantities of Special Nuclear Material - even research reactors
  - Incorporation of safeguards and security into the design may have an impact on lifetime costs—Reduce number of security personnel and inspections

Advanced Reactors Vary as to Their Non-proliferation Design Aspects

- Some designs imply the need for associated reprocessing facilities (breeders and burners)
  - Such designs may have ramifications on where they should be deployed
- Some reduce or eliminate the need for refueling—impacting the need for enrichment, fabrication, shipping, and storage facilities
  - Some designs have sealed reactor systems that are never refueled onsite
- Most designs reduce the likelihood of accessibility because of inherent operational conditions such as high temperature, high radiation levels, inert environments, or presence of toxic materials.
- Use of thorium fuel cycle may reduce the risk of proliferation because of presence of strong U 232 photon (requires shielding to access U 233)

Many of the Same Design Issues Associated with Advanced Reactors that Influence Safeguards and Security Also Impact the Safety

- Power level
- Inherent and passive features
- Unique fuel and coolants including liquid fuels
- High temperatures, radiation and power density
- Underground designs, unique containments
- Modularity, transportability
- Unique refueling and storage
- Fuel outside the core

Nexus of PR, PP, and Safety:
some features in common

ACCIDENT INITIATORS → SYSTEM RESPONSE → CONSEQUENCES

THREATS → SYSTEM RESPONSE → OUTCOMES

Safety and PR&PP should be considered from the earliest stages of design

Flow diagrams: preliminary safety hazard and PR&PP target identification and categorization

Physical arrangement: external events shielding, access control

Safety and PR&PP can be complementary (in some ways) and in conflict (in others)

Design to maximize the complementarity
The GIF PR &PP and Risk and Safety working groups coordinate on these issues

Conclusions

- Advanced reactor designs present challenges and opportunities in the areas of safeguards, security and safety
- Since most are in the conceptual design stages, it is important that all three are optimally considered early in the design as the designs progress
- In addition to having robust design characteristics, strong institutional measures are essential to safeguards, security, and safety of advanced reactors