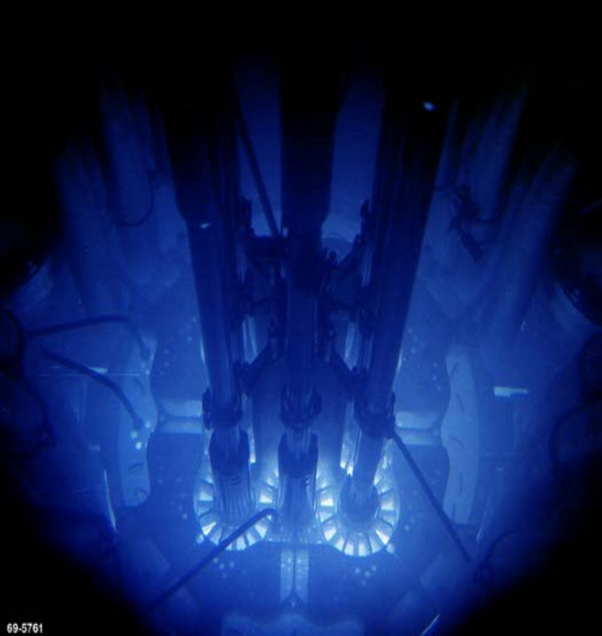

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Nonproliferation Considerations of Advanced Fuel Cycles

Merits and Viability of Different Nuclear Fuel Cycles and Technology Options and Waste Aspects of Advanced Nuclear Reactors

Idaho National Laboratory

INL/MIS-20-60766

Outline

- Nonproliferation dimensions of the current nuclear fuel cycle
- Advanced fuel cycle and reactor options – nonproliferation impacts
- R&D to support advanced fuel cycle and reactor deployment

Nonproliferation Dimensions of the Current Fuel Cycle

- The global nuclear energy enterprise is primarily based on a once-through fuel cycle (no reprocessing), using UOX fuel with U-235 <5% enriched, and large ~1GWe LWR power plants
  - Supporting infrastructure includes uranium mining & milling, conversion & enrichment, fuel fabrication
  - U.S. has mining & milling, conversion, fuel fabrication capacity, commercial enrichment, 95% of uranium imported
  - Safeguards and security entails item accounting at reactors and bulk accounting at enrichment and fuel fabrication
- Some countries have implemented advanced fuel cycles and reactors (e.g., gas or Na cooled) and alternate fuels (e.g., TRISO, MOX) and much R&D has been done over many decades
  - Safeguards are in place by IAEA, often a challenge to resourcees
  - Goal quantities and timeliness may change (e.g., MOX fuel)
  - U.S. is not recycling commercial SNF
  - U.S. experience in advanced fuel cycle and reactor safeguards and security has been largely in support of the international community

Safeguards and Security Requirements Vary

- US NRC regulates commercial nuclear enterprise
  - 10 CFR 73 Physical Protection
  - 10 CFR 74 MC&A
  - 10 CFR 110 Export Control
- DOE regulates their own facilities
  - DOE Order 473.3 Physical Security
  - DOE Order 474.2 MC&A
  - 10 CFR 810 Export Control
- IAEA verifies compliance with Article 3.1 of the NPT
  - INFCIRC 153 Safeguards Agreements
  - INFCIRC 225 Nuclear Security
  - INFCIRC 540 Additional Protocol
  - Other conventions regarding nuclear materials
- Security requirements, goal quantities and timeliness vary somewhat

It is important to consider safeguards and security in a domestic and international context for export and U.S. nonproliferation purposes

Advanced Reactor Concepts

- Numerous AR/SMR/micro designs worldwide (over 70 in the IAEA advanced reactor information system alone)
- Water Cooled
- Gas Cooled
- Liquid Metal Cooled
- Molten Salt Cooled
- Small Modular Designs
- Not all designs have mature safeguards and security concepts and approaches

https://aris.iaea.org

From a technical perspective, all can be secured and safeguarded, some are very challenging, and would require significant resources and/or advances derived from research and development

Departure From Current Fuel Cycle

- Fuel characteristics
  - Enrichments: HALEU, HEU
  - Plutonium, Thorium
  - Composition: oxides, metal, molten salts (U, F, Li, Be)
  - Forms: assemblies, pebble bed/TRISO, liquid
- Coolant/Moderator
  - HW, sodium, lead, graphite, helium, etc.
- Overall characteristics can include
  - Inherent or passive safety features
  - Simplified or modular designs
  - Lower power
  - Enhanced load-following capabilities
  - Thermal and fast neutron spectrums
  - Closed fuel cycle
  - Less frequent/continuous refueling

Categories of Differences (Increasing Departure)

Fuel
- HALEU
- TRISO
- Pu
- Th/U-233
- Molten Salt

Coolant
- LW/HW
- Gas/Graphite
- Liquid Metal
- Molten Salt

- Pu/U-233 have lower significant quantity masses and security category 1 thresholds
- Pebble bed and liquid metal cooled reactors present challenges but some experience
- Molten salt systems are biggest challenge (least experience)

Needs to Support Advanced Reactor Deployment

- Current focus is micro reactor, pebble bed, molten salt, and liquid cooled reactors and associated fuel cycle facilities
- Regulatory challenges, identification of gaps, and providing R&D to support vendors in meeting regulatory requirements
- Developing optimized physical protection systems for advanced and microreactor designs
- Examining unique materials accountancy challenges for designs that use non-traditional fuel assemblies
- A key paradigm is safeguards by design and security by design, where safeguards and security aspects are addressed early in the design process rather than applied after the fact
- Integration of process monitoring data, security data, and other information, including cyber to develop knowledge of facility status in near real time
- Application of data science, AI/ML, digital twins
- Advanced sensors

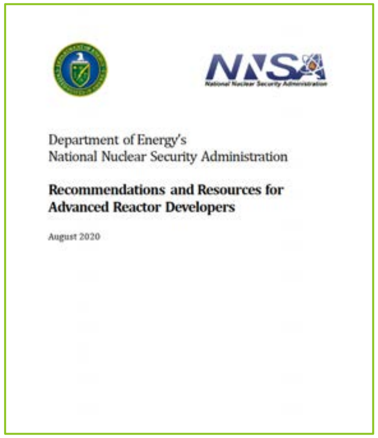
Needs Addressed Under Multiple Initiatives

- DOE/NNSA
  - Advanced Reactor Safeguards (ARS)
  - Material Protection, Accounting and Control Technologies (MPACT)
  - Advanced Reactor Development Program (ARDP)
  - Gateway for Accelerated Innovation in Nuclear (GAIN)
  - Nuclear Reactor Innovation Center (NRIC)
  - U.S. Nuclear Nexus (NNSA engagement with industry)
  - Safeguards & Security by Design Working Groups (SSBD-WG)
  - Safeguards Concepts, Approaches, and Technology Development
  - Vulnerability Analysis, Risk-Informed Security Approaches
- NRC's AR Working Group
- IAEA
  - International Project on Innovative Nuclear Reactors & Fuel Cycles
  - CRP SMR Economic Appraisal project
  - SBD-WG
- NGOs: NEI, NTI, Third Way, WINS

NNSA & IAEA document to designers of advanced reactors

DOE/NNSA

- Over a dozen Guidance Documents, Good Practices Studies, and Safeguardability Assessments



Department of Energy's
National Nuclear Security Administration

Recommendations and Resources for Advanced Reactor Developers

August 2020

IAEA

- Several Nuclear Energy Services Series Guidance Documents published
  - Safeguards by Design for Fuel Cycle
  - Nuclear Security

Questions?