Domestic Safeguards & Security Challenges for HALEU

Maia Gemmill, Lap-Yan Cheng, Warren Stern,
Yonggang Cui, Joe Rivers, Tom Grice

BROOKHAVEN NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

Email: mgemmill@bnl.gov
Phone: (631) 599-6231

Project Objectives

- Reduce regulatory uncertainty for prospective licensees of advanced reactors (ARs)
  - Identify areas of regulatory uncertainty associated with the physical protection of High Assay Low Enriched Uranium (HALEU)
  - Provide a neutral analysis of the identified regulatory issues
  - Develop recommendations related to physical protection of HALEU to assist vendors and operators in preparing license applications

Background

- Current NRC regulations prescribe physical protection requirements that are not appropriate for the security of advanced reactors and their associated fuel fabrication facilities
  - Requirements for the physical protection of HALEU fuel have not been updated in over 40 years
  - Reactor security requirements are based on security needs of LLWRs
- Existing performance objectives for reactor security are generally appropriate, but some of the prescriptive requirements likely exceed what would be necessary for the security of an advanced reactor
- Existing regulations focus on protection from sabotage and don't address theft or diversion scenarios, because theft is not considered a credible threat to LWRs
- The business case for most ARs is based on the assumption that physical security needs will be substantially lower due to the inherent safety and security features of the reactor

Nuclear Material Categorization

- NRC divides special nuclear material (SNM) into three main categories, according to the risk and potential for its potential for use in an improvised nuclear device or for its use in the production of nuclear material for use in a fissile explosive. For uranium enriched in the U-235 isotope, the categories are as follows:

Category I - Strategic SNM (SSNM)

5 kgs or more of U-235 (contained in uranium enriched to 20 percent or more in the U-235 isotope)

Category II - SNM of moderate strategic significance

Less than 5kgs but greater than or equal to 1kg of uranium-235 (contained in uranium enriched to 20 percent or more in the U-235 isotope); or

10kg or more of uranium-235 (contained in uranium enriched to 10 percent or more but less than 20 percent in the U-235 isotope)

Category III - SNM of low strategic significance

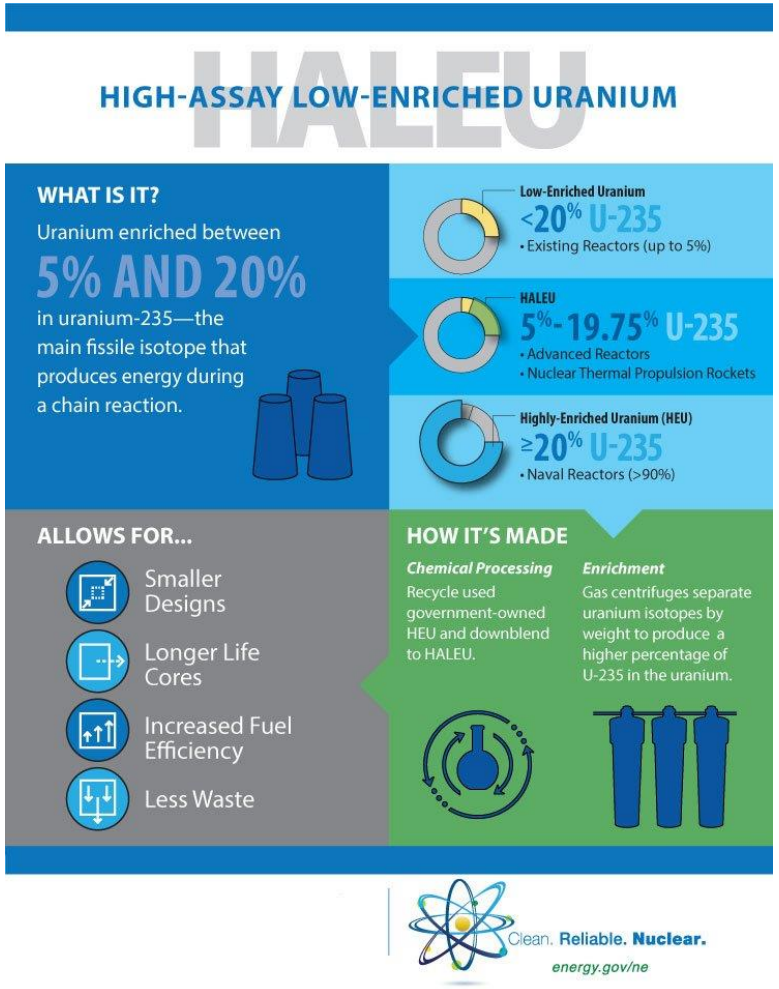
Less than 1kg but more than 15 grams of uranium-235 (contained in uranium enriched to 20 percent or more in the U-235 isotope)

Less than 10kgs but more than 1kg of uranium-235 (contained in uranium enriched to 10 percent or more but less than 20 percent in the U-235 isotope); or

10 kgs or more of uranium-235 (contained in uranium enriched above natural but less than 10 percent in the U-235 isotope)

Current Regulations for HALEU

- HALEU is regulated as Category II special nuclear material
  - Enriched to 10% or more U235 but less than 20% U235
  - Quantities of 10kg or more
- Regulations for protection of Category II SNM (10 CFR Part 73.67) last updated in 1979
- NRC intended to update regulations for Category II as part of rulemaking on Enhanced Security for SNM, but rulemaking was canceled in 2018
  - Licensing decisions for security of facilities using Category II HALEU will be conducted on a case-by-case basis
  - NRC staff have indicated their intent to use the technical basis from this rulemaking to inform decision-making process
- Project is examining regulatory issues for physical protection of HALEU, not MC&A at this time



Regulatory Environment for ARs

- NRC currently undertaking a limited scope rulemaking for ARs
  - Reduce need for vendors to expend resources on processing numerous exemptions
  - Limited scope rulemaking due to desire to complete rulemaking quickly so that the new process for evaluating alternative security approaches prepared by perspective licensees is available as soon as possible
  - Specifically considers requirements for numbers of armed responders and location of secondary alarm station
- Rulemaking on Physical Security for Advanced Reactors focuses on protection against sabotage scenarios, and does not address theft or diversion
  - Technical basis assumed that theft and diversion scenarios would be covered through a separate rulemaking process on enhanced physical security for special nuclear material
- <u>As a result, the rulemaking does not consider differences in security that may be required for advanced reactors using HALEU fuel vs. traditional LEU fuel.</u>

Protection Gap

- Reactor designers may need to consider Category II protection requirements for fresh fuel
- Protection measures appropriate for Category II SNM would apply in the following cases:
  - During construction if unirradiated fuel is present and reactor is assembled on site
  - After initial fuel load, awaiting start up
  - Any times when unirradiated fuel is onsite (refueling, pebble bed reactors)
  - If the fuel is greater than 1 weight percent U-235
- After start-up, reactor security measures included in the “Rulemaking on Physical Protection for Advanced Reactors” and any changes resulting from the Part 53 rulemaking will apply to the reactor itself
- Still need to consider protection of HALEU fuel on site for periodic or continuous refueling

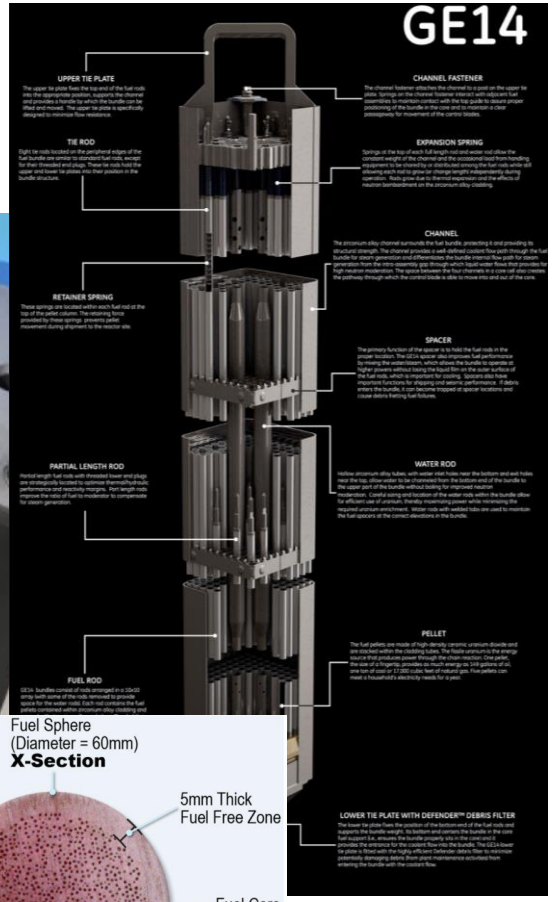
Impact on Advanced Reactors Using HALEU

- Fresh fuel containing HALEU at a reactor may not be adequately protected under the requirements established for the physical security of an advanced reactor during operation
  - Security gains relative to the inherent safety features may not apply to unirradiated HALEU fuel, particularly those which are mostly relevant to sabotage scenarios for the reactor as opposed to theft or division of fuel
- Vendors expect to be able to take credit for characteristics that improve safety for some aspects of security, especially for sabotage scenarios, to justify decreased physical security requirements
- Reliance on inherent design features and smaller reactor size supports reduced sabotage risk
- Theft and diversion risks associated with possible presence of HALEU fuel on site also need to be considered
- Potential concerns are higher for fresh HALEU fuel than spent discharged fuel, though it could become an issue in the future if discharged fuel has a sufficiently long cooling time

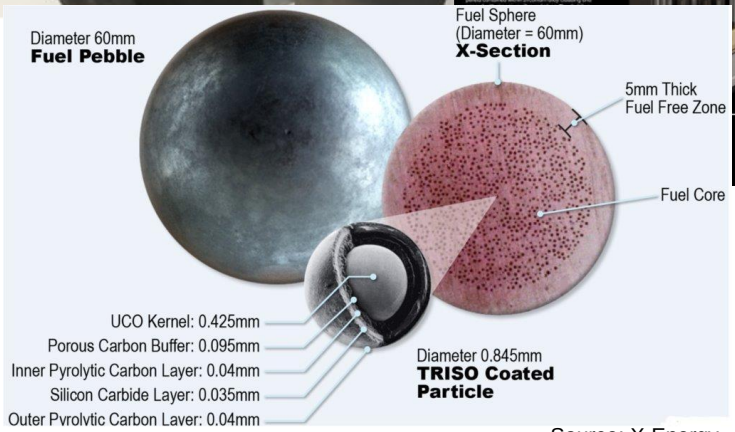
Analytical Approach

- Technical basis for Enhanced Security for SNM will be used by NRC as one of their primary decision-making tools for determining adequate security for HALEU
  - Dilution factor – would have been introduced by this rulemaking as an additional metric for the establishment of protection requirements for SNM
  - Category II Moderately Dilute or Highly Dilute would apply to HALEU
- BNL team is conducting a regulatory gap analysis comparing 10 CFR Part 73.67 with physical protection elements described in the technical basis for Enhanced Security of SNM for Category II Moderately Dilute SNM
- Also considering technical design factors of ARs to aid in developing recommendations tailored to specific reactor design elements

Source: https://doi.org/10.2172/1167529



Source: GE HItachi

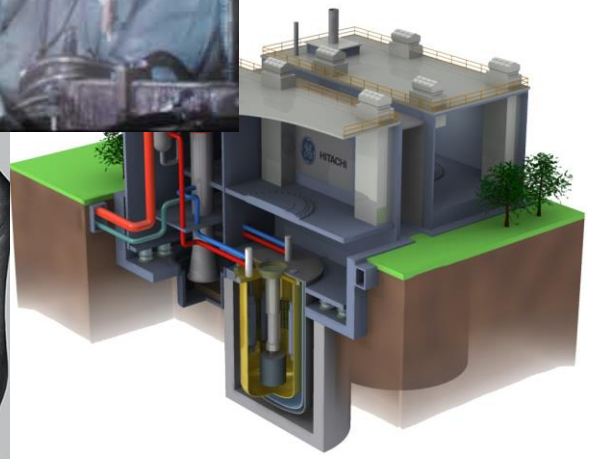


Source: X-Energy

Identifying Relevant Factors

Source: Argonne National Laboratory

Source: X-Energy



Source: GE Hitachi

- Broad variation in advanced reactor designs under development using HALEU fuel means that a single set of recommendations is not feasible
- BNL team conducted a market survey of ARs using HALEU at any point in the reactor's operational lifetime with a focus on fuel-related characteristics
  - Fuel-loading
  - Fuel cycle management
  - Fuel form and composition
  - Enrichment level
  - Other related characteristics, including siting

Relevant ARD Characteristics

Fuel Loading

- Factory loaded or sealed, no refueling
- Rare reloading (initial load plus one or two refueling cycles over reactor lifetime
- Frequent reloading (comparable to current generation LWRs)
- Core shuffling only
- Continuous online refueling
- HALEU present only at start up

Fuel Form

- Monolith/Cartridge
- Fuel rod/assembly
- TRISO-pebble
- TRISO-block compact
- Liquid salt

Fuel Composition

- Metal
- Ceramic (oxide, nitride, etc.)
- TRISO/encapsulated
- Molten salt

Coolant

- Transparent/opaque
- Chemically inert/active
- N/A (heat pipe cooled)

Siting

- In ground/below grade
- Above grade, fixed construction
- Above grade, relocatable/mobile
- Remoteness/near population center
- Access segmentation

Other

- Fuel unit is man-portable/not man-portable
- Containment/confinement
- Fuel burnup/spent fuel decay heat

Engagement with NRC and Industry

- Working with NRC to ensure that recommendations are appropriate and do not conflict with NRC Staff thinking
- Also interested in discussing with industry to ensure that recommendations helpful and relevant

Conclusions

- Existing NRC regulations for physical protection that would apply to HALEU fuel are likely outdated and inappropriate for the needs of regulating ARs
- Need to consider Category II protection requirements for fresh HALEU fuel.
- This issue will not be addressed as part of the Limited Scope Rulemaking on Advanced Reactor Security or Part 53
- Vendor and operators will require exemptions and alternative approaches as part of the licensing process
- Technical basis for Enhanced Security for SNM will inform licensing requirements for adequate security for HALEU.
- Characteristics of AR designs and fuel designs can be used to develop sets of recommendations for appropriate physical protection measures to facilitate this portion of the licensing process and create a common baseline for preparing and evaluating licensing applications

Next Steps and Beyond

- Expect to have sets of recommendations specific to various ARD design characteristics to allow vendors to identify which elements are relevant to their design
- Recommendations will be published and unclassified (potential for some Official Use Only information)
- Potential in the future to develop deeper and more specific recommendations