Proliferation Resistance Assessment Methodology:

Development of a Proliferation Resistance Optimization of Advanced Reactors and Fuel Cycles (PRO-AR&FC) Methodology Using Intrinsic Attributes

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The NNSA PRO-X Program

PRO-Research Reactors (PRO-RR)

- Est. in 2019
- Technical teams at ANL and SRNL
- Leverages over 40 years of reactor conversion experience
- Focused on 3 technical areas of optimization: Core, Fuel, Auxiliary
- Partners in Asia, Africa, South America, and North America



PRO-Advanced Reactors and Fuel Cycles (PRO-AR&FC)

- Est. in 2024
- Technical teams at ORNL and Y-12
- Additional support from ANL, INL, LANL, LLNL, SNL, SRNL
- Applying a novel approach, based on 40 years of reactor conversion experience
- Phase I focused on developing a proliferation resistance assessment methodology; Phase II to focus on an optimization methodology



History of PRO-AR&FC

PRO-X Mission

- The Proliferation Resistance Optimization program maximizes proliferation resistance while optimizing performance for stated peaceful uses in nuclear facility and technology designs

PRO-X Goal

- Reduce nuclear risks while supporting research by helping partners design new reactors and facilities that minimize the production of special nuclear material while maintaining or even improving reactor performance

The Beginning of PRO-AR&FC

- Workshops on advanced reactor and associated fuel cycles were held with lab experts across the DOE complex
- Identified a gap well aligned with PRO-X goals

PRO-AR&FC Proliferation Resistance Definition

PRO-AR&FC *defines* ***intrinsic proliferation resistance*** as the characteristics of a reactor or fuel cycle facility, system, or material that impedes the production, extraction, and/or utility of materials of weapons interest

Materials of weapons interest: Materials that have a potential nuclear function in a nuclear explosive device. These materials include, but are not limited to, special nuclear materials such as enriched uranium, plutonium, uranium-233, and other relevant materials such as tritium, enriched lithium, and minor actinides

Why Proliferation Resistance?

- Proliferation resistance (PR) is a process of norm setting for advanced reactors and associated fuel cycle decisions in its earliest stages
- Modify intrinsic design features to minimize opportunities for non-peaceful fissile material production
- Reactors, including those operating within a fast neutron energy spectrum, can have target irradiation locations

Why PRO-X, Why Now?

- "Proliferation resistance" is a key phrase for advanced reactor designs – sometimes applied with different meaning or context
- Technically-based norms related to proliferation resistance through PRO-AR&FC
- A goal is to provide concrete and objective recommendations for advanced reactor and associated fuel cycle decisions
- Methodology is not intended to compare across or between reactor design types– but to optimize within each design
- Considering reactor facility design and associated fuel cycle decisions
- Complementary with other nonproliferation objectives

PRO-AR&FC

- Provide a framework to integrate proliferation resistance in nuclear system designs to maximize intrinsic proliferation resistance (PR) features while optimizing system performance for peaceful use missions
  - Considering breakout scenarios

- Focused on three technical areas:
  - Methodologies
  - Assessments
  - Engagements

PRO-AR&FC Technical Workflow

Phase I: Develop and Test Methodology for PR Assessment

Tested using 4 Advanced Reactors + 1 Large LWR Non-Proprietary Case Studies

PR Assessment

Assessment Methodology

Advanced Reactor Design = Design Features + Operational Parameters + Associated Fuel Cycle Decisions

PR Assessment Results

Calculate attributes

Convey in visual format

PRO-AR&FC Technical Workflow

Phase II: Develop and Test Methodology for Optimization

Tested using 4 Advanced Reactors + 1 Large LWR Non-Proprietary Case Studies

PR Optimization

Optimization Methodology

Advanced Reactor Design

PR Optimization Recommendations

Optimize PR with other design aspects

Convey design recommendations to increase intrinsic proliferation resistance

Proliferation Resistance (PR) Assessment Methodology Framework

Goal: Develop an objective, technical methodology for assessing advanced nuclear reactor facility PR considering the associated fuel cycle decisions

Identify Intrinsic PR Attributes

Create a list of intrinsic attributes that aim to objectively measure PR of an advanced nuclear reactor facility, including the associated fuel cycle decisions

Procedure for PR Assessments

Develop a procedure to apply the attributes to effectively perform repeatable PR evaluations on different advanced reactor facilities

PR Assessment Result Dissemination

Develop a scheme to interpret and represent the results of a PR assessment

Draft List of Intrinsic PR Attributes

Group 1 Attributes: Nuclear Reactor Features

- **Attribute 1**: Fissile material production capacity of the reactor in kilograms (kg) per year per thermal power (MWth)
  - Evaluates proliferation resistance due to the new fissile material production by the reactor; normalization by the reactor design thermal power (MWth).

- **Attribute 2**: Cumulative amount of all types of fissionable and fertile nuclear material (Pu, U, Th) in number of significant quantities (SQs) present at the reactor facility at the end of each year for ten years, evaluated separately for fresh fuel, fuel in the core, and spent fuel
  - Evaluates proliferation resistance due to the presence of all fissile and fertile nuclear materials at the reactor facility, intended to gauge the ease of obtaining 1 SQ of nuclear material from the reactor facility and is not normalized by the power output of the reactor.

Draft List of Intrinsic PR Attributes
(continued)

Group 1 Attributes: Nuclear Reactor Features (continued)

- **Attribute 3**: Total material mass in kilograms (kg) of removed material that contains 1 SQ of nuclear material
  - Estimates the amount of total material mass that a proliferator needs to remove to obtain 1 SQ of nuclear material and captures the dilution of nuclear material in the removed material, which in turn captures the level of effort associated with removing the material from the reactor facility.
- **Attribute 4**: Volume of the total removed material in cubic meters (m^3) that contains 1 SQ of nuclear material
  - Estimates the total volume of material that a proliferator needs to handle to obtain 1 SQ of nuclear material.
- **Attribute 5**: Number of items to be removed to obtain 1 SQ of nuclear material (number of fuel assemblies or storage containers for bulk material, etc.)
  - Estimates the level of effort associated with removing 1 SQ of nuclear material from the perspective of the number of items that need to be removed.

Draft List of Intrinsic PR Attributes
(continued)

Group 2 Attributes: Fresh and Irradiated Nuclear Fuel

- **Attribute 6**: Time needed in days for converting the removed material from the reactor facility to metallic form (Ref. Table 3 IAEA Safeguards Glossary)
  - Captures the level of effort related to the time needed for a proliferator to convert the removed nuclear material from the reactor facility (e.g., fresh or irradiated low-enriched uranium/high-assay low-enriched uranium oxide fuel, pebble fuel, molten salt reactor salt fuel, mixed oxide fuel) to metallic form.

- **Attribute 7**: What steps are required to convert removed material from the reactor to its pure (U or Pu) metallic form?
  - Assesses the amount of converted material in terms of BCM by considering all the isotopes of the target element present in the removed material.

Potential steps involved in converting fresh fuel nuclear material removed from a reactor facility to its metallic form.	
1. Conversion to UF_6	a) Can conversion to UF_6 be done in steps usually envisaged in current civilian nuclear fuel cycle? (yes/no)
2. Enrichment	b) How many separative work units (SWU) are required to enrich to highly enriched uranium?
3. Conversion to metal	c) Is the material to be converted different than UF_6? (yes/no)
Potential steps involved in converting irradiated nuclear material (or fresh mixed oxide fuel) removed from a reactor facility to its metallic form.	
1. Feed preparation	a) Is mechanical processing needed? (yes/no) b) Is chemical decladding needed? (yes/no)
2. Dissolution	a) Does the removed material dissolve in water? (yes/no) b) Does the removed material dissolve in standard acids? (yes/no) c) Does the removed material need dissolving with specialty reagents/methods? (yes/no) d) Is the material intractable (e.g., due to preconditioning)? (yes/no)
3. Purification	a) Is it a mechanically separable solid? (yes/no) b) Is it a nearly simple mixture (e.g., nearly pure special nuclear material)? (yes/no) c) Is it a complex mixture (e.g., fission product solution)? (yes/no) d) Is it a very complex mixture with dilute special nuclear material? (yes/no)
4. Conversion to metal	a) Is the material to be converted in its chloride or fluoride form? (yes/no)

Draft List of Intrinsic PR Attributes
(continued)

Group 2 Attributes: Fresh and Irradiated Nuclear Fuel (continued)

- **Attribute 8**: Bare-sphere critical mass (BCM) in kilograms (kg)
  - Assesses the amount of converted material in terms of BCM by considering all the isotopes of the target element that are present in the removed material.

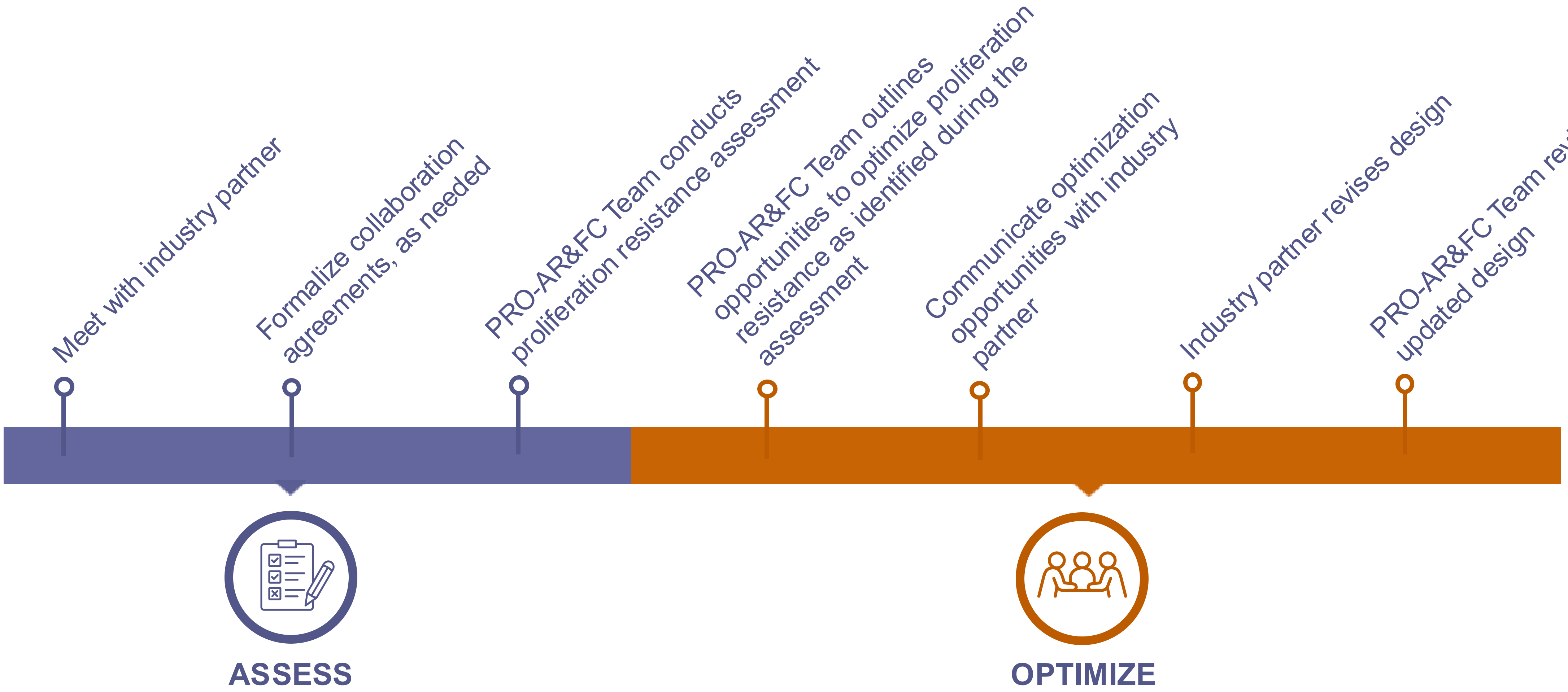
- These three attributes capture the intrinsic proliferation barriers presented by the converted material with respect to the radiation level, spontaneous fission neutron rate, and heat emission rate by one BCM.
  - **Attribute 9**: Radiation level (gamma and neutron radiation) in sieverts per hour (Sv/h) at 1 meter from the surface of a BCM
  - **Attribute 10**: Spontaneous fission neutron rate in seconds per BCM
  - **Attribute 11**: Heat load in watts per BCM

Draft List of Intrinsic PR Attributes
(continued)

Group 3 Attribute: Reactor Facility Features

- **Attribute 12**: Presence of operational modes of reactor design features that could enable proliferation
  - Is there online refuelling provision in the reactor design? (Yes/No)
  - Are there specialized remote tools in the reactor facility to help the operator access and transfer nuclear material? (Yes/No)
  - Is there additional space for target irradiation in the reactor? (Yes/No)
  - Based on the attribute inputs for 1a, 1b, and 1c (i.e., whether a yes or no), there will be additional inputs sought in terms of frequency of refueling, the capacity and availability of remote tools, volume and number of target irradiation locations, respectively.

Expected Engagement Process Flow



Thank you!