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# *Proliferation Risk Reduction Study of Alternative Spent Fuel Processing*

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**Proliferation Risk Reduction Study of Alternative Spent Fuel Processing Technologies**

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## ABSTRACT

This paper presents the results of an evaluation of the relative proliferation risks of particular reprocessing technologies of current interest. The assessment focuses on determining whether three alternative reprocessing technologies – COEX, UREX+, and pyroprocessing – provide nonproliferation advantages relative to the PUREX technology because they do not produce separated plutonium. This study considers how a facility may be threatened under various proliferation scenarios. For each alternative, the measures of proliferation risk considered include the relative difficulty of achieving the objective, the time required, the cost to the adversary, the likelihood of detection, the cost of safeguards and physical protection, and the characteristics of the material acquired. This evaluation found only a modest improvement in reducing proliferation risk over existing PUREX technologies and these modest improvements apply primarily for non-state actors.

## INTRODUCTION

As global interest in nuclear power generation increases, options are being developed that promote expanded use of nuclear power worldwide and at the same time reduce the risk of proliferation. One way do so is to offer non-fuel cycle nations the reliable supply of nuclear fuel cycle services as an attractive alternative to developing indigenous enrichment and reprocessing capabilities. This paper presents the results of an evaluation of the relative proliferation risks of particular reprocessing technologies of current interest. The assessment focuses on determining whether three alternative reprocessing technologies – COEX, UREX+, and pyroprocessing – provide nonproliferation advantages relative to the PUREX technology because they do not produce separated plutonium. Detailed descriptions of the three alternative reprocessing technologies can be found in References [1] and [2]. The results of this paper are included, with more detail, in Reference [2].

## METHODOLOGY

The methodology [3] developed by the Gen-IV Proliferation Resistance and Physical Protection Working Group was used for this evaluation. The methodology considers how a facility may be threatened under various proliferation scenarios. For the host-state, diversion of material, facility misuse, and breakout from treaty agreements are evaluated. For the non-state entity, theft of nuclear material is evaluated. For each alternative, the measures of proliferation risk considered include the relative difficulty of achieving the objective, the time required, the cost to the adversary, the likelihood of detection, the cost of safeguards and physical protection, and the characteristics of the material acquired.

The methodology makes the distinction between proliferation resistance and physical protection according to the following definitions.

***Proliferation resistance (PR)*** is that characteristic of a nuclear energy system (NES) that impedes the diversion or undeclared production of nuclear material or misuse of technology by the Host State seeking to acquire nuclear weapons or other nuclear explosive devices.

***Physical protection*** ***(PP)*** is that characteristic of an NES that impedes the theft of materials suitable for nuclear explosives or radiation dispersal devices (RDDs) and the sabotage of facilities and transportation by sub-national entities and other non-Host State adversaries.

The measures are assessed through a pathway evaluation process for each threat under consideration according to the algorithm:

**Threat → Response (Pathways) → Outcomes (Measures).**

The measures are defined as follows.

For PR, the measures are:

- *Proliferation Technical Difficulty* (TD) – The inherent difficulty, arising from the need for technical sophistication and materials handling capabilities, required to overcome the multiple barriers to proliferation.
- *Proliferation Cost* (PC) – The economic and staffing investment required to overcome the multiple technical barriers to proliferation including the use of existing or new facilities.
- *Proliferation Time* (PT) – The minimum time required to overcome the multiple barriers to proliferation (i.e., the total time planned by the Host State for the project).

- *Fissile Material Type* (MT) – A categorization of material based on the degree to which its characteristics affect its utility for use in nuclear explosives.
- *Detection Probability* (DP) – The cumulative probability of detecting a proliferation segment or pathway.
- *Detection Resource Efficiency* (DE) – The efficiency in the use of staffing, equipment, and funding to apply international safeguards to the NES.

For PP, the measures are:

- *Probability of Adversary Success* – The probability that an adversary will successfully complete the actions described by a pathway and generates a consequence.
- *Consequences* – The effects resulting from the successful completion of the adversary's action described by a pathway.
- *Physical Protection Resources* – the staffing, capabilities, and costs required to provide PP, such as background screening, detection, interruption, and neutralization, and the sensitivity of these resources to changes in the threat sophistication and capability.

Reference [3] elaborates on the details of the evaluation process including discussion of identification of the targets of the threats, methods for constructing pathways, and how to present results.

## ASSUMPTIONS

The evaluation for each alternative begins with receipt of spent fuel and ends with the final material product that would be transferred to a fabrication facility. The spent fuel received as input to the facilities examined in this study can be received from light water reactors and/or from fast reactors. COEX and pyroprocessing plants each produce their own distinct type of product stream that contains plutonium. Specifically, COEX produces a plutonium oxide product mixed with uranium, while pyroprocessing produces a metal product containing plutonium mixed with uranium, americium, neptunium, curium, and some rare earth fission product impurities. The UREX+ technology offers a suite of options that each produce different plutonium-bearing product streams. UREX+ results in a plutonium product mixed with various combinations of uranium, americium, neptunium, curium, and possibly rare earth fission products.

This assessment evaluates proliferation threats by both states and non-state actors. It considers the possibility that the processing facility being evaluated is located in a non-nuclear weapon state (NNWS) and considers the risk that the state might remove plutonium-bearing materials from the facility either clandestinely or after withdrawing from or violating its NPT obligations. The NNWS is assumed to be under full-scope IAEA safeguards with an Additional Protocol in force. It also considers the risk that a non-state actor might gain access to plutonium-bearing materials, whether in a nuclear weapon state or a non-nuclear weapon state.

It is assumed that the objective of the threat is to obtain, ultimately, enough plutonium (termed "one significant quantity"). Details of weapon manufacture or use are not assessed in this study; instead, the analysis is concerned with acquisition and processing of the material, not the follow-on activities. For each option, the measures of proliferation risk considered include the relative difficulty of achieving the objective, the time required, the likelihood of detection, and the characteristics of the material acquired. This enables comparison of the proliferation risk between each reprocessing technology and the PUREX technology.

## RESULTS

The analyses resulted in natural groupings among the process alternatives based on product form. They are presented here in order of increasing proliferation risk relative to PUREX. We refer the reader to References [1] and [2]

**Group W** Pyroprocessing is grouped with UREX+1b since both produce plutonium that is not separated from uranium, americium, neptunium, and curium in the final product.

**Group X** UREX+1 and UREX+1a produce a grouped transuranic product of plutonium, neptunium, americium, and curium. UREX+1 adds the lanthanides, which would be removed prior to fuel fabrication. UREX+1a produces the same transuranic material product but without the lanthanides. The mixing in of multiple isotopes makes this product less useful than those listed below as a potential weapons material.

**Group Y** COEX and UREX+2a, UREX+3a, and UREX+4a all produce similar products: a mixture of uranium with either plutonium or a combination of plutonium and neptunium. The degree of dilution with uranium affects their potential use as weapons material; the smaller the fraction of plutonium in the product stream, the lower the proliferation concern. The fact that the latter three products include neptunium as well as plutonium does not reduce their proliferation risk relative to COEX.

**Group Z** In the UREX+ suite, UREX+2, UREX+3, and UREX+4 produce plutonium that is not separated from neptunium. All of the uranium from the spent fuel is recovered separately from this product. The proliferation risk of these processes is essentially equivalent to that of the PUREX process. This applies to both state-level and non-state threats.

The study concluded that for state-level threats, the differences among the technologies in these three groups – W, X, and Y – are not very significant. Further, the additional proliferation resistance of these alternative processes over Group Z – and over PUREX in particular – is small. The reason is the ease, given the resources available to a state, with which the various plutonium-bearing materials or the reprocessing process itself could be converted to produce separated plutonium. The remaining nonproliferation advantages and disadvantages depend on factors other than physical form, such as transparency and ease of inspection by the IAEA, and the detectability of clandestine misuse of the plant to produce separated plutonium or diversion of the product to a clandestine facility where the plutonium could be separated. The distinctions among these four groups may be more significant with respect to non-state actors, due to their smaller resource base and lesser ability to hide and control access to clandestine facilities.

While an attempt by the state to separate pure plutonium in facilities using these technologies might be readily detected, once the state has withdrawn or broken out from its nonproliferation obligations, estimates of the time to convert the facility to separate pure plutonium ranges from a few days to a few weeks, depending on the technology and assuming the state has prepared for the breakout by becoming sufficiently familiar with any additional required separations. The significance of the time needed to accomplish this task should be considered in the context of the time needed for the international community to detect and respond to such an event. It could well take the IAEA or the UN Security Council that long (or longer) to negotiate a response to any withdrawal or breakout from nonproliferation obligations.

In sum, for a state with pre-existing PUREX or equivalent capability (or more broadly the capability to design and operate a reprocessing plant of this complexity), there is minimal additional proliferation resistance to be found by introducing Group W, X, or Y processing technologies when considering the potential for diversion, misuse, and breakout scenarios.

In a nuclear material theft scenario involving non-state actors, Groups W, X, and Y provide some advantage over Group Z (whose product is plutonium or plutonium not separated from neptunium). These advantages arise from the additional cost, time, and technical difficulty that would be entailed in further processing by a non-state actor of any Group W, X, or Y products to obtain pure plutonium. The proliferation significance of these advantages depends heavily on assumptions about the capabilities (including both physical facilities and the knowledge and experience of the personnel involved), motivations, and strategies of the adversary. It has been presumed that all Group W, X, Y, and Z products (all of which are considered to be Category I nuclear material under current DOE Directives as well as Nuclear Regulatory Commission and international guidelines for nuclear material categorization) present comparable proliferation risks. The main difference is in stored product packaging resulting from differences in volume, mass, radiation, and heat load. Group Z products are likely to be more compact and stored in smaller, more easily transportable packages. Next in ease for storage and transportation are Group Y products. Groups W and X have larger radiation and heat loads and would be more difficult to handle for health and safety reasons. However, even with the lanthanides present the total dose is not very high and would be unlikely to deter an adversary who was willing to accept injury (or self-sacrifice).

Groups Y and Z produce secondary streams of materials that contain americium and curium, either with or without neptunium. Further, for UREX+4 and UREX+4a, americium is chemically separated from curium. In all cases, these secondary streams would be either stored for waste disposal or for burning in a reactor. Consequently, for these potentially attractive materials, for the state there is the opportunity for diversion and for a non-state actor there is the opportunity for theft.

## CONCLUSIONS AND DISCUSSION

This evaluation found only a modest improvement in reducing proliferation risk over existing PUREX technologies, and these modest improvements apply primarily for non-state actors. This study reinforces the importance (1) limiting reprocessing activities to a small number of states with strong nonproliferation credentials and (2) developing effective and transparent international safeguards for any reprocessing technologies selected for use in a comprehensive program.

Several of these processes introduce challenges for nuclear materials measurement systems not found in PUREX, in addition to the challenges involved in safeguarding any large throughput bulk processing facility. Improvements in measurement capabilities are needed to mitigate or eliminate these challenges, as well as improvements in compensatory measures. In some cases, considerable effort would be required to develop new safeguards approaches that are tailored to the novel characteristics of the suggested processes. See References [4] and [5] for discussions of advanced safeguards needs. Currently, there is a U.S.-based program, the Next Generation Safeguards Initiative [6], which aims to address many of the challenges for future safeguards.

Since the nonproliferation differences are small between the alternatives analyzed here, any future selection of spent fuel reprocessing technologies should consider the benefits of that particular technology in enabling back end fuel services and the long term management of nuclear waste.

## REFERENCES

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[6] For an overview of the Next Generation Safeguards Initiative, see http://nnsa.energy.gov/nuclear_nonproliferation/nuclear_safeguards.htm.