

## Methodology for Identifying Optimal Misuse Scenario for Decommissioning Nuclear Power Plants

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### 1. Introduction

The International Atomic Energy Agency (IAEA) utilizes Acquisition Path Analysis (APA) as a key tool for assessing a state's overall nuclear activities under the State-Level Concept (SLC) framework. However, existing APA guidelines focus on identifying macro-level pathways at the national level, limiting their ability to precisely analyze specific physical misuse activities occurring within individual nuclear facilities. Commercial nuclear power plants (NPPs), in particular, hold vast quantities of nuclear material to irradiate undeclared targets, posing a potential risk for plutonium production. This study proposes a methodology to identify the 'optimal misuse scenario' capable of evading the IAEA's timely detection among numerous misuse scenarios derived through identification of facility physical access routes (Phase 1) and scenario structuring (Phase 2). Scenarios typically involve four phases: 1) receipt of undeclared nuclear material, 2) irradiation, 3) cask receipt, and 4) nuclear material shipment. This report aims to engineer the time required for each stage and integrate these to identify a path that minimizes the overall lead time. This will enable future assessments of the Safeguards measures for decommissioned nuclear power plants.

### 2. Development of Misuse Scenarios

#### 2.1 Identification of Physical Access Routes

The first step in developing misuse scenarios is to clearly define the physical boundaries of the nuclear power plant under analysis and identify all physical paths through which nuclear materials or related equipment could be moved. This is performed based on extensive foundational data, including facility design drawings, Design Information Questionnaires (DIQ), and operating procedures. Specifically, to understand the facility's design characteristics, the General Arrangement Drawing (GAD) and the Piping and Instrumentation Diagram (P&ID) must be analyzed in depth. Particularly, the connecting structures between the Fuel Building and Reactor Building, the location and size of entrances and exits, and the elevation

information for each floor are key data determining the movement paths of nuclear material. Furthermore, by identifying the flow and storage locations of nuclear material declared in the DIQ, as well as the rated capacities of major equipment, thereby distinguishing between normal operational ranges and potential misuse scenarios.

#### 2.2 Structuring the 4-Step Misuse Scenario

Once the physical path identification is complete, the process enters the scenario structuring phase, where actions are designed according to the temporal flow. Nuclear power plant misuse is not a single event but consists of a continuous four-step operational process as follows, with the time required for each step determined by the facility's engineering capabilities.

1) Import Phase: This involves moving an undeclared target or fuel from outside the facility to inside, ultimately to the reactor core.

2) Irradiation Phase: The imported material is loaded into the reactor and irradiated with neutrons to produce nuclides. This is the key step that triggers the transformation for the production of weapons-grade plutonium (Pu<sup>239</sup>), a low burn-up strategy is primarily considered.

3) Cask Import Phase: This is the stage where a shielded cask is brought into the facility to remove the irradiated target.

4) Export Phase: This phase involves loading irradiated material into a cask and covertly removing it from the facility.

The next step involves constructing a scenario matrix by cross-referencing the physical pathways identified in the previous step with the four operational processes. For example, various combinations are possible, such as 'import via the conventional route, export via the non-conventional route'. The time required for each combination is calculated and compared. Detailed scenarios should include specific operational procedures, not merely list pathways. For example, in a scenario involving import via a standard pathway, specific actions are described, such as "the operator conceals the target pin inside a declared fuel

assembly while disguised in the new fuel inspection area and imports it." The irradiation phase should include a strategy such as "Expose for only several weeks to several months to maintain Pu-240 content below 7% for weapons-grade plutonium production, then withdraw quickly."

### 3. Identifying Optimal Misuse Scenarios

The core of this study is developing a methodology to identify the 'optimal' misuse scenario among multiple possibilities. From a Safeguards perspective, the optimal scenario refers to the fastest possible path to complete the entire process to evade timely detection of misuse by the IAEA. The function for identifying the optimal misuse scenario is to minimize the total time required across all four phases.

$$T_{total} = T_{import} + T_{irradiation} + T_{cask\_in} + T_{export}$$

#### 3.1 Determination of Import Time ( $T_{import}$ )

The delivery time depends on the readiness of the selected route and the speed of the transport equipment. Using the standard route requires minimal preparation time since existing fuel handling facilities are utilized as-is. However, using the non-standard route through the equipment entrance requires significant lead time for hatch opening and temporary crane installation.

#### 3.2 Determination of Irradiation Time ( $T_{irradiation}$ )

The irradiation time is the net time a reactor must operate to produce 1SQ (8kg) of Pu<sup>239</sup>. It is inversely proportional to the reactor's neutron flux and the quantity of the target material. For a commercial light water reactor (1000 MWe), placing the target in the high-power region at the core center enables annual production of tens of kilograms. Therefore, the optimal irradiation period to obtain 8 kg is calculated to be approximately 2 to 3 months (60 to 90 days). [1] To increase production rate, operators can perform maneuvers such as raising reactor power or adjusting the position of neutron absorbers (e.g., control rods).

#### 3.3 Cask Import and Export Time ( $T_{cask\_in}, T_{export}$ )

These steps are determined by the efficiency of logistics operations. Moving a 85–110 ton Cask from the truck bay to the pool is constrained by the crane's hoisting speed and traverse speed. According to on-site transfer process data using transport cask like CASTOR KN-12, a single turnaround (inbound-loading-outbound) takes an average of 5 days. [2] Optimization requires linearizing the crane's path and

eliminating bottlenecks occurring during loading and decontamination processes.

Scenario	In	Out	$T_{import}$	$T_{irra}$	$T_{cask}$	$T_{total}$
S-01	A	A	2	70	7	79
S-02	B	B	15	70	12	97
S-03	A	B	2	70	12	84

Fig.1. Scenario Time Comparison (Example)

“A” in Fig.1 means normal physical route for nuclear material receipt and shipment while “B” is the abnormal route such as temporary opening in decommissioning facility. Based on the matrix analysis above, Scenario S-01 is identified as the most 'optimal misuse scenario' capable of neutralizing the IAEA's three-month (90-day) timely detection objective which is set for irradiated direct-use nuclear material. [3]

### 4. Conclusions

This paper establishes a standardized framework for identifying the 'optimal misuse scenario' that enables the fastest execution of the four-phase process for misusing a nuclear power plant. This was achieved by concretizing the IAEA's state-level acquisition pathway analysis methodology at the facility level. The time required for each stage and the performance capability data of essential equipment derived through engineering analysis contribute to quantitatively identifying blind spots in safeguards. This methodology could be useful tool for the IAEA to determine whether the decommissioning facility has been completed from Safeguards perspective.

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### REFERENCES

- [1] World Nuclear Association, Plutonium, <https://world-nuclear.org/information-library/nuclear-fuel-cycle/fuel-recycling/plutonium>, 16 August 2023.
- [2] S. H. Chung et al., Operational Experiences of On-Site Transport of Spent Nuclear Fuels in Korea, PATRAM 2004, Paper #073, 24 September 2004.
- [3] IAEA, Safeguards Glossary, 2022 Edition.