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STUDIES IN SUPPORT OF AN SNM CUTOFF AGREEMENT: THE PUREX EXERCISE*

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ABSTRACT

On September 23, 1993, President Clinton, in a speech before the United Nations General Assembly, called for an international agreement banning the production of plutonium and highly enriched uranium for nuclear explosive purposes. A major element of any verification regime for such an agreement would probably involve inspections of reprocessing plants in Nuclear Nonproliferation Treaty weapons states. Many of these are large facilities built in the 1950s with no thought that they would be subject to international inspection. To learn about some of the problems that might be involved in the inspection of such large, old facilities, the Department of Energy, Office of Arms Control and Nonproliferation, sponsored a mock inspection exercise at the PUREX plant on the Hanford Site. This exercise examined a series of alternatives for inspections of the PUREX as a model for this type of facility at other locations. A series of conclusions were developed that can be used to guide the development of verification regimes for a cutoff agreement at reprocessing facilities.

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INTRODUCTION

In September 1993, President Clinton announced a goal of negotiating an international agreement banning the production of special nuclear material (SNM) for nuclear weapons or outside of safeguards. While the exact form of the agreement and its verification provisions remains to be negotiated, some potential options would require the imposition of international inspections at U.S. weapons facilities. Of particular interest are the U.S. DOE reprocessing facilities. It is possible that the F or H canyons or both at Savannah River would be operating to stabilize existing inventory material for some period after the entry into force of an international agreement. In addition, bilateral agreements may start before a full international agreement. Because these facilities, as well as similar ones in other weapons states, have never been under international inspection, it was considered important to understand any issues involved in the implementation of international inspections at these older facilities. The PUREX reprocessing plant at Hanford, Washington, which is currently transitioning to dismantlement, was selected as a model for these types of facilities.

On March 29, 30, and 31, 1994, an exercise was conducted at PUREX and at Pacific

Northwest Laboratory to examine aspects of the imposition of several possible regimes at PUREX to verify nonproduction of SNM for nuclear weapons or outside of safeguards. A follow-up activity to further examine various additional verification regimes was held at Los Alamos National Laboratory on May 10, 1994. This paper describes this exercise and its results.

HISTORY OF PUREX

The PUREX Plant was the last, and by far the largest, of the five reprocessing plants built at Hanford during the 1940s and 1950s. The original plans for the plant were developed during the Korean War when plutonium requirements were in excess of current capacity. Planning criteria determined that a new reprocessing plant with an initial capacity of 200 metric tons (MT) of fuel per month (about 2000 MT/year allowing for shutdown) was necessary to meet military plutonium requirements and to handle the output of the last two large single-pass production reactors (KE and KW). In addition, the plant would be designed to have capacity of up to 400 MT/month with process or equipment changes or both.

Design engineering began in July 1952, construction began in April 1953, and the plant was essentially complete by April 1955. Cold runs began later that year and hot processing began in January 1956. The first year of PUREX operations demonstrated a capacity well in excess of design requirements. During 1956, actual production was over 2500 MT, which increased to nearly 4400 MT in 1957. During the next several years, capacity continued to increase with an actual throughput of over 6200 MT in 1960. Because of the large capacity and economic operation, plans to renovate B-Plant and T-Plant (the first two reprocessing plants dating from the Manhattan Project) were abandoned. Nearly all Hanford-generated irradiated fuel (aluminum-clad uranium metal) was sent through PUREX (REDOX plant continued to process the slightly enriched uranium through 1966).

As the single-pass reactors were shut down in the late 1960s and early 1970s, the plant was modified to allow processing of the zirconium-clad N Reactor fuel and other fuel types. The plant was placed on standby in October 1990 and a final closure order was issued in December 1992. The plant is currently in a transition phase to a decontamination and disassembly "D&D ready" state, at which time it will be periodically evaluated to determine when final D&D will begin.

The PUREX plant was the largest U.S. reprocessing plant. Although it was not the first to use the "PUREX" process (Savannah River facilities were the first large-scale PUREX process facilities), it was the first to use pulse columns in the chemical separations area. PUREX is a good example of a large, flexible chemical reprocessing plant with high capacity that operated reliably for several decades. The present status of PUREX, as well as its extensive history, makes it an ideal laboratory to investigate implementation of international inspections.

OBJECTIVES AND METHODOLOGY

The objectives of the PUREX Exercise were the following:

- To develop a number of alternative approaches to inspections at operating, existing U.S. reprocessing plants under an SNM production cutoff agreement

- To help the U.S. government understand the problems that might be involved in allowing international inspections of operating existing U.S. reprocessing plants

- To understand the effects of operating status on inspection problems at
  - a facility separating direct use material from fission products (spent fuel and targets)
  - a facility processing nuclear material (for example, waste stabilization and plutonium cleanup) but not separating direct use material from fission products
  - a facility that is still capable of operating but not currently operating.

To address these objectives, the exercise used a modified form of a seminar war game. Participants in the exercise were drawn from throughout the DOE complex and included former International Atomic Energy Agency (IAEA) inspectors, members of the LASCAR committee, reprocessing plant operators, and experts on safeguards and arms control. The participants were divided into three teams: a Facility Team, an Inspector Team, and a Control Team. The Facility Team was generally responsible for understanding the workings of PUREX under various operating conditions and discussing the effects of various inspection strategies on facility operations. The Inspector Team was responsible for developing a series of alternative inspection strategies that could be applied at PUREX. The Control Team was charged with facilitating the course of the exercise and capturing the results.

Before the exercise, the Facility Team prepared a Design Information Questionnaire (DIQ), a document required by the IAEA. The DIQ provides the information necessary for the IAEA to design the inspection plan for a facility. This provided a good vehicle during the exercise for the Facility Team to explain the facility to the participants. The DIQ was provided to the Inspector Team to allow them to develop their inspection plan.

Before the exercise, the Inspector Team prepared an inspection plan. The initial plan was based on "Safeguards Criteria, 1991–1995," which is produced by the IAEA Department of Safeguards to cover inspections under INFCIRC/66 and INFCIRC/153. The Inspector Team also considered alternative inspection measures. During the exercise, the inspection plans were explained to the participants, and the Facility Team was allowed to comment on the feasibility and impact of the plans.

The Control Team was responsible for the logistic support of the exercise, collection of results, and the preparation of the final documentation. The Control Team also provided questions for discussion during the exercise.

In addition to the interaction between the participants on the DIQ and the inspection plan, a discussion was held to expand the range of possible inspections options. During the Hanford phase of the exercise, an effort was made to discuss the pros and cons of each measure in isolation. During the Los Alamos phase, the participants further discussed the individual options and jointly worked on combining the alternatives to produce more effective verification schemes. All the single and combined schemes were then rated as to their effectiveness, intrusiveness, and cost.

The final part of the Hanford phase of the exercise consisted of a comparison of PUREX and the lessons learned there with other reprocessing plants. In particular comparisons were discussed with the F and H canyons at the Savannah River Site, the Idaho Chemical Processing Plant, and selected foreign reprocessing plants.

ASSUMED FACILITY OPERATING CONDITIONS

Three different facility operating conditions were examined during the PUREX exercise. They were the plant as it operated just before it was shut down in 1990, the plant doing rework and recycle of nonsafeguarded material, and the plant in a fully shutdown condition with no safeguarded inventory but still in an operable condition while it is awaiting D&D.

Operating Plant

The plant was assumed to be receiving 10.2 MTU/day with a maximum throughput of 900 MTU/year. (The PUREX facility had a significantly lower throughput for zirconium-clad fuel than for aluminum clad fuel.)The plutonium content was assumed to be 0.2% for a plutonium production of 1.8 MTU/year. Excursions of throughput up to the design capacity of 2550 MTU/year were also discussed. These throughputs are appropriate for the Zircalloy-clad N Reactor fuel processed in the latter part of the PUREX plant's operating history. The product of the plant was considered to be plutonium nitrate, but the production of plutonium oxide was also considered. The plutonium nitrate would be assumed to be taken to the Plutonium Finishing Plant for conversion to metal. The uranium product, uranyl nitrate, was considered to be shipped from PUREX to the UO_3 plant for conversion to oxide.

Rework and Recycle of Non-safeguarded Material

Under this condition it was assumed that the headend of the plant that allows for metal (fuel) dissolution was normally shutdown. The feed to the plant is unirradiated nitrate solution, oxide powder, or metal. The feed is assumed to be prepared in new small-quantity (10 kg/day) dissolvers. The typical campaign would be 100 kg of plutonium accumulated over 10 days and processed over a two-day period.

Plant Shutdown with No Safeguarded Inventory But Still Operable

It is assumed that the plant has been cleaned out to the point that it has less than 0.3 SQ in inventory. It is assumed that all major equipment is still in the facility and that it would be possible to restart after some period.

VERIFICATION OPTIONS CONSIDERED

During the exercise a number of alternative verification measures were considered both individually and in combination. Table 1 lists the individual options considered. Tables 2 and 3 present an evaluation of the relative effectiveness, intrusiveness, and costs of these alternatives, individually and in combination.

LESSONS LEARNED

In addition to the evaluations of the options describe above, a number of significant conclusions were drawn from the exercise and its very detailed discussion of verification activities at a PUREX-type reprocessing plant.

- A wide range of verification strategies exist that could be applied at PUREX. The effectiveness, intrusiveness, and cost are highly dependent on the goals of the cutoff agreement and the operating status of the facility. It is easy to tell if a facility is not operating; it is harder to tell if an operating facility is not violating the agreement.
- If information on materials balance is not required for verification, several attractive verification schemes are available. If information on materials balance to detect diversion is a requirement of the agreement, then

TABLE 1. OPTIONS CONSIDERED DURING THE PUREX EXERCISE

Options	Definition
Material Balance Accounting with Interim Inspections	Full material balance accounting supplemented with containment/ surveillance (cameras and seals)[a]
Randomized Inspections to Determine Material Balance	Full material balance accounting except the probability that any specific verification activity will be carried out is less than 100%. Verification scheduling could also be randomized.
Randomized Inspections to Look for a "Smoking Gun"	Detailed forward declarations of facility operations combined with short or no–notice inspections aimed at detection of undeclared activities.
Randomized Inspections Using Only Visual Observation	Unlimited short or no-notice inspections with visual access only.
Portal/Perimeter Monitoring Around the Entire Facility	A perimeter encloses the entire facility and has defined portals for all movement in or out. Provisions are made to ensure that all movements are through defined portals. (In practice some access would be required inside the facility.) Portals have instrumentation capable of detecting SNM. Declared product would be verified.
Portal/Perimeter Monitoring Around the Key Points	A perimeter established around key process areas such as headend and product loadout. Portals are instrumented to detect all movements of SNM in and out.
Running Book Inventory	Verification (by surveillance and sampling) of input accountability tank values and balancing of input values against product values (subject to verification).
Process Monitoring with On–Site Readout	Use of standard current state-of-the-art process instrumentation. Data storage is on–site. Process data supplemented as necessary to compute quantities.
Process Monitoring with Off–Site Readout	Use of current state-of-the-art instrumentation plus necessary authentication procedures to transmit real-time process data, including all data needed to compute SNM quantities, to a remote site.
Zone Approach	Complete, verified material balance accounting at all facilities within the zone (either PUREX/PFP[b]/UO_3 or entire Hanford Site), with simultaneous verified physical inventories at all facilities.
Environmental Monitoring Inside of Facility	Use of swipe samples, air monitors, stack monitors, and waste stream monitors, for example, to detect new dissolution of irradiated material.
Environmental Monitoring Outside of Facility	Collection and analysis of air, water, soil, biota, and utility use from the immediate vicinity of a facility, including visual observation.
Enhanced Information Management	Collection, collation, and analysis of as much open-source and declared data as available.
Enhanced Containment/Surveillance	Use of devices such as cameras, seals, and radiation monitors to provide continuity of knowledge.

[a]This would be a regime essentially similar to current practice in IAEA safeguards.
[b]Plutonium Finishing Plant.

TABLE 2. EVALUATION OF INDIVIDUAL OPTIONS

Options	Effectiveness	Intrusiveness	Cost
Materials Balance Accounting with Interim Inspections	High	High	High
Randomized Inspections to Determine Material Balance	Moderate	Moderate to High	Moderate to High
Randomized Inspections to Look for a "Smoking Gun"	Moderate	Low to Moderate	Low
Randomized Inspections using Only Visual Observations	Low	Low	Low
Portal/Perimeter Monitoring around the Entire Facility	Moderate	Low	High
Portal/Perimeter Monitoring around Key Points	Low	Moderate	Low to Moderate
Running Book Inventory	Moderate	Moderate	Moderate
Process Monitoring with On-Site Readout	High	High	High
Process Monitoring with Off-Site Readout	High	High	High
Zone Approach	High	High	High
Environmental Monitoring Inside of Facility	Moderate	Low to Moderate	Low
Environmental Monitoring Outside of Facility	Low	Low	Low
Enhanced Information Management	Low	Low	Low to Moderate
Enhanced Containment/Surveillance	Moderate	Moderate	Moderate to High

TABLE 3. EVALUATION OF COMBINATIONS OF OPTIONS

Options	Effectiveness	Intrusiveness	Cost
Visual-Only Random Inspections plus Inside Facility Environmental Monitoring	Moderate	Low to Moderate	Low
"Smoking Gun" Random Inspections plus Portal/Perimeter Monitoring around Entire Site	High	Moderate to High	High
"Smoking Gun" Random Inspections plus Running Book Inventory	High	Moderate	Moderate to High
"Smoking Gun" Random Inspections plus Process Monitoring with On-Site or Off-Site Readout	High	High	High
"Smoking Gun" Random Inspections plus Outside Environmental Monitoring	Moderate	Low to Moderate	Low
Visual-Only Random Inspections plus Running Book Inventory	Moderate	Moderate	Moderate
Portal/Perimeter Monitoring around the Entire Facility plus Outside Environmental Monitoring	Moderate	Low to Moderate	High

no available approach improves on classical materials balance accounting with interim inspections of in-process inventories. This option can be further improved with the use of adjunctive measures.

- Verification costs depend on verification goals ("Confidence Costs!")
  - In the absence of significant automation, a continuous inspector presence would be required to achieve the highest levels of confidence (~1000 inspector days/year).
  - Process monitoring can be effective but costly. ($20-$30 million in '87 dollars)
- Design verification at a large, complex, highly radioactive facility such as PUREX is *extremely* difficult. C/S measures can provide some confidence regarding changes in facility configuration.
- Under certain circumstances PUREX may be able to meet the IAEA timeliness goal (detection of diversion of 1 SQ in 30 days). However, it could not meet the goal of detecting a 1 SQ diversion over a year.
- Facility status has a significant effect on ease of verification
  - Shutdown but operable facilities:
    - Quite easy; may be possible to verify remotely with very limited on-site inspection
  - Facilities doing cleanup and rework:
    - Place key areas such as dissolvers under surveillance
  - Operating Facilities:
    - More difficult because they require assurances that material produced is not used for weapons purposes
- While this exercise centered on PUREX, most of the conclusions would apply at Savannah River and other old, large-scale reprocessing plants not currently subject to full-time international safeguards.

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