

LA-UR- 97-2676

Approved for public release;
distribution is unlimited.

Title:

SAFEGUARDS CONSIDERATIONS IN THE STUDY
OF PROLIFERATION RESISTANCE OF PLUTONIUM
DISPOSITION OPTIONS

CONF-970744--

Author(s):

E. A. Hakkila and T. Burr

Submitted to:

38th Annual Meeting of the Institute of
Nuclear Materials Management, Phoenix,
July 20-24, 1997

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED ^{ph}

Los Alamos
NATIONAL LABORATORY

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. The Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

**Portions of this document may be illegible
in electronic image products. Images are
produced from the best available original
document.**

SAFEGUARDS CONSIDERATIONS IN THE STUDY OF PROLIFERATION RESISTANCE OF PLUTONIUM DISPOSITION OPTIONS

E. A. Hakkila and T. Burr

Los Alamos National Laboratory, Los Alamos, New Mexico 87545

RECEIVED

NOV 03 1997

OSTI

ABSTRACT

Domestic and international safeguards considerations of the various plutonium disposition program options were studied. The options included immobilization in either glass or ceramic; deep borehole disposal, either directly as oxide or after immobilization in ceramic pellets; and nine options of burning in reactors as mixed oxide (MOX) fuel. Two of the MOX options considered burning in CANDU (Canadian deuterium uranium) reactors in Canada; the remaining options used either existing or new reactors in the US.

A facility for conversion of weapons-grade Pu metal to plutonium oxide is common to all options. Although domestic safeguards are applied for all material in the facility, international verification probably will not be possible until weapons design information from material form can no longer be inferred. Assuming that the facility processed 5 tonnes of Pu/year and all measurements are made to meet 1993 ESARDA (European Safeguards Research and Development Association) Target Values, the best annual detection limit (false alarm probability = 0.05, detection probability = 0.95) for loss of Pu can be no smaller than 16.5 kg, and probably will be higher.

A MOX fuel fabrication facility is required for all of the reactor options, and location of the facility either in the US or in a EURATOM country was considered. Assuming that the facility processes 3.2 tonnes of Pu/year, and all measurements are made to meet ESARDA Target Values, the best annual detection limit for loss of Pu can be no smaller than 24 kg. Location in Europe adds an additional international safeguards burden.

Impact of the various disposal options on domestic and international safeguards will be reviewed.

I. INTRODUCTION

In 1996, a Proliferation Vulnerability Red Team was tasked to study the proliferation resistance of the various plutonium disposition options.¹ The options studied were as follows:

Case R2.0, (base case) burning in existing light water reactors (LWRs).

Case R2.1, same as R2.0 but with federally owned, collocated Pu processing and fuel fabrication.

Case R2.2, same as R2.0 but with privately owned European fuel fabrication facility.

Case R3.0, same as R2.0 but with two privately owned reactors in southeast US.

Case R3.1, same as R3.0 but four reactors.

Case R3.2, same as R3.0 but federally owned, collocated Pu processing and fuel fabrication facility.

Case R6.0, same as R2.0 but two CANDU (Canadian deuterium uranium) reactors; spent fuel to Canadian repository.

Case R6.1, same as R6.0 but hybrid mixed oxide/CANFLEX fuel loading.

Case R2A.0, same as R2.0 but two federally owned reactors.

Case I1.0, vitrification.

Case I2.0, Ceramic form disposition.
Case D1, borehole, direct emplacement.
Case D2, borehole, immobilized emplacement.

Included in the study was the consideration of vulnerability from both domestic safeguards (Criterion 1) and international safeguards (Criterion 2).

II. LEGAL REQUIREMENTS

A. Criterion 1, Resistance to Theft or Diversion by Unauthorized Parties

For Criterion 1, Resistance to Theft or Diversion by Unauthorized Parties, it is assumed that material in the US will be subject to material control and accounting and physical protection to meet applicable US government regulations. For the various plutonium disposal options, facilities may be owned by either the US government and safeguards are applied under Department of Energy regulations² or by private corporations and safeguards are applied by the Nuclear Regulatory Commission (NRC).³

Both the DOE and NRC regulations use graded safeguards, where the severest requirements are applied to material of greatest strategic value.

Material in Canada will be under Canadian domestic safeguards applied by the Atomic Energy Control Board. Material in Europe will be under EURATOM safeguards per the EURATOM Treaty.

B. Criterion 2, Resistance to Retrieval, Extraction, and Reuse by the Host Nation

For all of the disposal options being studied, all of the States that may be involved (the US, Canada, the UK, and France) are Nuclear Non-Proliferation Treaty signatories, and therefore subject to International Atomic Energy Agency (IAEA) safeguards as described in INFCIRC 153 (Corrected).⁴

The objectives of safeguards are reviewed in Paragraphs 28, 29, and 30 of INFCIRC 153 (Corrected). These state that detection and deterrence of diversion is attained using material accountancy to obtain a statement of MUF (material unaccounted for) and limit of error of MUF equal to $2 \sigma_{\text{muf}}$, where σ_{muf} is the measurement error standard deviation of MUF. We define the annual detection limit to be $3.3 \times \sigma_{\text{muf}}$. The factor 3.3 arises from assuming MUF is approximately normally distributed and then requiring a 0.05 false alarm probability with a 0.95 detection probability. Therefore, in each of the proposed disposal schemes, material balance areas (MBAs) must be defined and measurement methods and measurement uncertainties for transfers of all nuclear material across MBA boundaries and material in the process must be identified. Containment and surveillance (C/S) is used to verify the integrity of the materials accountancy system by assuring that critical diversion paths in the system cannot be bypassed.

Until the information outlined in Paragraphs 28–32 is more clearly outlined in the Alternative Technical Summary Reports, it is difficult to determine if Criterion 2, with respect to detection of diversion by the host nation, can be evaluated for the different options.

1. IAEA Inspection Procedures. IAEA inspection procedures for various types of facilities have been defined by the IAEA.⁵ The IAEA uses three levels of measurement quality in its inspection procedures. Attributes measures, also referred to as gross defect measures, are generally a gross test, for example, to test if radiation from a sample is consistent with the declared content such as Pu. Variables tests generally are the most precise and are sometimes referred to as bias defect measurements. These measurements usually are expected to meet ESARDA (European Safeguards Research and Development Association) Target Values. Variables tests in attribute mode, referred to as partial defect

measurements, are somewhere between the two and are used as a rough measure of the declared contents of an item. These tests are generally nondestructive assay (NDA) measurements and are designed to measure content to within approximately 5% of the declared value.

2. *Quality of Measurements.* Paragraph 55 of INFCIRC 153 requires that the system of measurements on which the records used for the preparation of (material accounting) reports shall either conform to the latest international standards or be equivalent in quality to such standards. It is assumed in this review that the 1993 ESARDA Target Values will be used at facilities and by IAEA inspectors.⁶ Throughout this paper, we follow the convention of Ref. 6: both the random (σ_R) and systematic (σ_S) error standard deviations are for relative error models.

III. LIMITATIONS IN CAPABILITIES TO MONITOR AND ACCOUNT FOR PLUTONIUM IN VARIOUS FORMS AND PROCESSES FOR THE VARIOUS PROPOSED PLUTONIUM DISPOSITION ALTERNATIVES

The following summarizes information from the Alternative Technical Summary Reports on the various options and draws some preliminary conclusions on the ability to meet Criteria 1 and 2.

A. Disassembly/Conversion Facility

This facility is common to all disposal options except D1, Borehole Direct Emplacement. The facility receives 5 tonnes of Pu/year, with approximately 3.5 tonnes (70%) as clean metal from pits and 1.5 tonnes (30%) as oxide, alloy and oxide reactor fuels, and various forms of scrap. The percentage of pure oxide relative to the other more difficult to measure materials is not specified. Input metal and clean oxide and product PuO₂ should be measured to meet ESARDA Target Values of $\sigma_R = 0.15\%$ and $\sigma_S = 0.10\%$, respectively. Measurement uncertainty for other types of material will depend on purity and may be as poor as 5% for some forms of scrap.

If we assume that all input material is clean metal or oxide and the product is clean oxide, the annual throughput contribution to σ_{muf} is estimated to be approximately 5.0 kg/year. Assuming that the detection limit is $3.3 \times \sigma_{muf}$, the best detection limit that can be expected for this process is approximately 16.5 kg/year. The value for σ_{muf} is sensitive to input and output batch size and instrument calibration frequency as well as to the amount of material in the process.

It is not clear if this facility will be open to IAEA inspections. If it is not, international safeguards will begin on the output PuO₂ product.

B. Reactor Options

It is assumed that plutonium metal or compounds will not be subject to international inspections until material has been blended and converted to oxide in the conversion facility where classified information will not be divulged from inspection operations. International inspections may start at the output of the conversion process.

It is assumed that all of the reactor options will have the following three MBAs:

- (1) Fuel Fabrication. This MBA receives 5 tonnes of unirradiated, direct use PuO₂ from the conversion process and ships unirradiated, direct-use material in the form of mixed oxide (MOX) fuel bundles to the reactor. For the non-CANDU options, the facility produces MOX fuel containing 3.2 tonnes/year of Pu, with the other 1.8 tonnes of Pu going into lag storage. We assume this storage continues to accumulate MOX at a rate of 1.8 tonnes of Pu

per year. If the facility is under INFCIRC 153-type safeguards, the IAEA will perform verification inspection activities with a period no greater than one month plus one week between inspections, with an annual physical inventory verification (PIV).

During inspections, PuO₂ and MOX powder, pellets, and scrap are verified for gross, partial, and bias defects. Bias defect measurements by the operator shall conform to the following 1993 ESARDA Target Values: for Pu in PuO₂, $\sigma_R = 0.15\%$ and $\sigma_S = 0.10\%$; for Pu in MOX, $\sigma_R = 0.55\%$ and $\sigma_S = 0.2\%$. Based on an annual throughput of 3.2 tonnes/year, the smallest throughput contribution to MUF is estimated to be approximately 24 kg/year.

- (2) Reactor. This MBA receives unirradiated, direct-use material in the form of MOX fuel assemblies and produces irradiated direct use material in the form of spent fuel. The irradiated fuel assemblies may be stored on site for 10 years for the LWR options. A PIV is performed annually.

Fresh MOX fuel received at the reactor under seals is verified either by detaching and verifying all of the seals, or seals may be verified in place with a medium (50%) detection probability.⁵ Assemblies received not under seal are verified by item counting, serial number identification where applicable, and measurement for gross and partial defects with a 90% detection probability. Fresh MOX fuel stored on site is verified monthly.

Spent fuel stored at the reactor is under C/S, preferably dual C/S. The period between consecutive verifications should not be more than three months plus three weeks. Inspection activities may include item counting and gross defect radiation measurements.

Spent fuel shipments from the reactor are verified by item counting as shipping casks are filled and by gross-defect measurement with a medium (50%) detection probability. Loaded casks are placed under seal, the seals are verified, and spent fuel items are counted at the receiving facility.

All areas of the reactor are item accountability areas and should have zero MUF.

- (3) Spent Fuel Repository. Casks received at the spent fuel repository are verified through seals placed at the reactor. Item accountability applies, and MUF should be zero. There is one PIV of the operator's physical inventory taking during each calendar year. For spent fuel under dual C/S, seals are verified with a low (20%) detection probability. For spent fuel under single C/S, the spent fuel is item counted or a spent fuel inventory check is performed. Spent fuel not under C/S is item counted and verified with a medium (50%) detection probability for gross defects.

Item counting or spent fuel inventory checks do not apply to spent fuel that is designated difficult to access.

C. Disposal Options

1. *Case R2.0, R2.1, R2A.0*. Each reactor can be treated as an item-control MBA. Collocated reactors may be treated as a single MBA. Spent fuel is stored in the spent fuel pool for approximately 10 years. All shipments from the reactor to the storage facility are accounted for as items.

Because all material is treated as items, if all material is under successful dual C/S and verification activities are performed monthly, there should be zero MUF.

2. *Case R2.2.* After Pu processing to PuO₂, the product is shipped to a lag storage facility prior to shipment to Europe for MOX fuel fabrication. It is assumed that international safeguards start at the output of the oxide conversion facility prior to shipment to the lag storage facility. If the lag storage facility is treated as an item accountability area, the facility should have zero MUF. The IAEA may wish to randomly sample cans of PuO₂ for analysis or perform NDA measurements on a randomly selected number of cans.

Shipment of PuO₂ to the European MOX facility and shipment of MOX fuel to the US involve international transfers, and the IAEA must verify shipper/receiver differences.

It is assumed that international safeguards considerations for the MOX fuel fabrication facility are the same as for Case 2.0.

Finished MOX fuel assemblies are returned to the USA through the lag storage facility. Verification activities would be by item counting, seal identification, and measurement for gross defects.

It is assumed that international safeguards considerations for the reactor(s) are the same as for Case R2.0.

3. *Case R3.0, R3.1, R3.2.* It is assumed that international safeguards considerations are the same as for Case R2.0 except that where reactors are not collocated, each must be treated as a single MBA.

4. *Case R6.0, Same as R2.0 but two CANDU reactors; spent fuel to Canadian repository.* The MOX fuel fabrication facility receives 3.5 tonnes of direct-use material as PuO₂/year and produces direct-use material as CANDU MOX fuel containing 2.13 tonnes of PuO₂/year. The extra PuO₂ is stored in lag storage for future use. Approximately 20% of the PuO₂ is considered dirty and is mixed with dirty, recycled PuO₂; it is purified through an aqueous process. Transfer of fresh fuel from the fabrication facility in the US to the reactor in Canada involves an international transfer, and shipper/receiver differences must be verified by the IAEA.

The CANDU facility has four process sections: fresh MOX storage and handling, two reactors, spent fuel cooling pond, and dry spent fuel storage; the facility can be treated by the IAEA as a single MBA.

The spent fuel will be stored at the reactor spent fuel storage pool for 10 years. The amount of Pu discharged to the pool is 694 kg/year, with a maximum capacity of 6,940 kg. The material is irradiated, direct-use material and subject to verification activities every three months. Material control and accountability is by item counting and identification. The IAEA verifies seals with low (20%) detection probability.

After 10 years the spent fuel is transferred to dry storage containers on the reactor site and is still considered as irradiated, direct-use material. Canada has designed dry-storage containers and a safeguards approach that is intended to meet requirements of Ref. 5.⁷

5. *Case R6.1, Same as R6.0 but hybrid MOX/CANFLEX fuel loading.* The first five years of operation are as for case R6.0, and the same international safeguards considerations apply.

After five years the two reactors and two additional reactors at the same site will be converted to burn CANFLEX fuel containing 2.7% Pu. The transition time to convert the reactors to CANFLEX fuel is estimated to be three to six months.

The shipment of MOX fuel assemblies from the US to Canada is an international transfer and must be verified by the IAEA.

The reactor facility has four process sections similar to Case R6.0, and safeguards are as described for Case R6.0

6. *Case I1.0, Vitrification.* Several vitrification processes were considered. The PuO_2 is vitrified with glass to form a product containing from 2 to 10% Pu. The glass may also contain neutron absorbers and ^{137}Cs . The processes were not sufficiently well described to draw conclusions about Pu detection sensitivity.

7. *Case I2.0, Ceramic Form.* The processes receive material as 25% metal in the form of ingots and 75% as oxide. The input material is considered irradiated, direct-use material and should be verified to meet ESARDA Target Values for both metal and oxide. The product is a titanium-based ceramic known as SYNROC. There is insufficient information on the process and the form of material in inventory to estimate measurement uncertainties for the process.

8. *Case D1.* The direct emplacement of fissile material in boreholes uses minimal processing of input material in the disassembly/conversion facility. Material is received as Pu metal, PuO_2 , or other Pu compounds. The processing and types of measurements are not well defined, and conclusions on detection sensitivity of Pu could not be assessed.

If material is received and disposed of as metal, it is not clear if IAEA safeguards can be applied without disclosing classified information. In this case it is not clear if Criterion 2 can be met.

9. *Case D2.* The disassembly/conversion facility throughput is 5.0 tonnes of Pu/year. The PuO_2 is converted in the same facility to ceramic pellets using an aqueous batchwise process. The Pu in solution should be measurable to meet ESARDA Target Values of $\sigma_R = 0.4\%$ and $\sigma_S = 0.25\%$. The plutonyl nitrate solution is mixed with a slurry of ceramic precursors and gadolinium in tanks containing 12.5 kg of Pu at a concentration of 3 g/L. The ceramic product contains 98.3% ceramic, 0.7% Gd, and 1.0% Pu. Depending on homogeneity, Pu in the ceramic may be measured to meet ESARDA Target Values for Pu in MOX of $\sigma_R = 0.55\%$ and $\sigma_S = 0.2\%$, or ESARDA Target Values for Pu in scrap of $\sigma_R = 5.1\%$ and $\sigma_S = 0.5\%$. The pellets are considered by the IAEA as unirradiated, direct-use material, and the IAEA would perform monthly verification activities, with an annual PIV. If the final measurement is on the ceramic and the ceramic is considered the same as LWR MOX, the contribution to σ_{muf} should be the same as for a MOX fuel fabrication plant with an equal annual throughput. Maximum inventory of the conversion/ immobilization facility is 2 tonnes.

The ceramic pellets are placed in 55-gallon drums with 510 kg of pellets containing 5.1 kg of Pu per drum. The drums can be considered as items for accountability purposes. The drums are shipped to the borehole site with five drums (25.5 kg of Pu) per shipment.

At the borehole site, the drums containing the 1% Pu pellets are opened and mixed with an equal weight of pellets without Pu, for a final product containing 0.5% Pu. The pellet mixture is mixed with approximately 40%-by-volume grout and poured down the borehole. For safeguards accountability the shippers value of drums may be accepted as the receipt value. It is not clear how the IAEA would verify the Pu content of the pellet/grout mixture transferred to the borehole.

IV. SUMMARY

Following are some observations/deficiencies concerning materials accounting in the various Pu disposition alternatives.

- 1) The disassembly/conversion facility is common to all of the disposition options studied and receives 5 tonnes/year of Pu. Because it handles weapons parts, it is not clear that it can be subject to IAEA inspection. For domestic safeguards the smallest throughput contribution to σ_{muf} is approximately 5 kg of Pu, so the annual detection limit is approximately 16.5 kg of Pu. The inventory contribution cannot be estimated.
- 2) The fuel fabrication facility is a bulk handling facility and is common to all of the reactor options. It receives 5 tonnes of Pu/year as the oxide and for all but the CANDU options produces MOX fuel containing 3.2 tonnes of Pu. The value for σ_{muf} has throughput and inventory components. The contribution to σ_{muf} from throughput is estimated to be approximately 7.2 kg for a 3.2-tonnes/year facility so the annual detection limit is approximately 24 kg of Pu; the inventory component cannot be estimated without more detailed knowledge of the process.
- 3) For reactor options R2.2 and R1.0 fuel fabrication is in Europe, and EURATOM and IAEA safeguards apply. A lag storage facility is required to buffer shipment of material to Europe, and for option R2.2, receipt of fuel assemblies from Europe.
- 4) For reactor options R6.0 and R6.1, fabricated fuel assemblies are shipped to Canada and fall under Canadian and IAEA safeguards.
- 5) All of the reactors can be considered as item-control facilities and for accounting purposes should have zero MUF. Fresh MOX fuel is verified monthly by the IAEA using item counting, item identification, and defect testing.
- 6) The vitrification options, Case I1.0 and I2.0, and the borehole options, Cases D1 and D2, are not well enough described to estimate MUF and assess the effectiveness of IAEA safeguards.

REFERENCES

1. J. P. Hinton et al., "Proliferation Vulnerability Red Team Report," Sandia National Laboratories report SAND97-8203 (October 1996).
2. U. S. Department of Energy, DOE Order 5633.3B (September 7, 1994).
3. U. S. Code of Federal Regulations, Volume 10, Parts 70-75.
4. "The Structure and Content of Agreements Between the Agency and the States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons," INFCIRC/153 (Corrected), International Atomic Energy Agency, Vienna (November 18, 1977).
5. Safeguards Criteria 1991-1995. International Atomic Energy Agency, Department of Safeguards, Vienna (November 1990).
6. S. Deron et al., "1993 International Target Values for Uncertainty Components in Fissile Isotope and Element Accountancy for the Effective Safeguards of Nuclear Material," International Atomic Energy Agency, Vienna, STR-294, Rev. 1 (February 1994)
7. C. R. Frost et. al., "Proposed Safeguards Provisions for Pickering NGS Dry Storage Facility," in Proceedings of the 15th Annual Symposium on Safeguards and Nuclear Material Management, ESARDA, Rome, Italy, 11-13 May 1993, pp. 215-221.