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ROUTINE INSPECTION EFFORT REQUIRED FOR VERIFICATION OF A NUCLEAR MATERIAL PRODUCTION CUTOFF CONVENTION

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*Executive Summary**

Preliminary estimates of the inspection effort to verify a Nuclear Material Cutoff Convention are presented. The estimates are based on (1) a database of about 650 facilities a total of eight states, i.e., the five nuclear-weapons states and three "threshold" states; (2) typical figures for inspection requirements for specific facility types derived from IAEA experience, where applicable; and (3) alternative estimates of inspection effort in cutoff options where full IAEA safeguards are not stipulated.

Three options are considered. In Option 1, all peaceful nuclear activities would be declared and verified as in non-nuclear weapons states party to the Non-Proliferation Treaty. In Option 2, declarations and verifications would be restricted to enrichment and reprocessing plants and to facilities storing or processing the produced fissile material. In Option 3, declarations would cover all nuclear facilities but verifications would focus on production at enrichment and reprocessing plants and on the disposition of the produced fissile material. The report does not assess the adequacy of any of these options. "Challenge" or "undeclared site" inspection effort requirements were not considered.

The computed effort values associated with these three options are about 29,000 PDI (person days of inspection effort), 23,000 PDI, and 8,300 PDI, respectively, which can be compared with the total of 8,513 PDI expended by the IAEA Department of Safeguards in 1993. (The 1993 budget of the Department of Safeguards was about $65 million, plus about $6 million in extrabudgetary resources).

Considerable uncertainty must be attached to the effort estimates. About 50 - 60% of the effort for each option is attributable to 16 large-scale reprocessing plants assumed to be in operation in the eight states; it is likely that some of these will be shut down by the time the convention enters into force. Another important question involving about one-third of the overall effort is whether Euratom inspections in France and the U.K. could obviate the need for full-scale IAEA inspections at these facilities. Finally, the database does not yet contain many small-scale and military-related facilities. The results are therefore not presented as predictions but as the consequences of alternative assumptions.

Despite the preliminary nature of the estimates, it is clear that a broad application of NPT-like safeguards to the eight states would require dramatic increases in the IAEA's safeguards budget. It is also clear that the major component of the increased inspection effort would occur at large reprocessing plants (and associated plutonium facilities). Therefore, significantly bounding the increased effort requires a limitation on the inspection effort in these facility types.

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1. Introduction

On 27 September 1993, President Clinton proposed " ... a multilateral convention prohibiting the production of highly enriched uranium or plutonium for nuclear explosives purposes or outside of international safeguards." The UN General Assembly subsequently adopted a resolution recommending negotiation of a non-discriminatory, multilateral, and internationally and effectively verifiable treaty (hereinafter referred to as "the Cutoff Convention") banning the production of fissile material for nuclear weapons. The matter is now on the agenda of the Conference on Disarmament.

The IAEA is expected to play a key role in the verifications required by the Cutoff Convention. It is assumed that existing comprehensive IAEA safeguards arrangements for non-nuclear-weapons states (NNWSs) would essentially meet the verification requirements of the Cutoff Convention, so that the new verification requirements would apply mainly to the nuclear-weapons states and the so-called "threshold states." Thus this paper focuses on eight states: the U.S., Russia, China, the U.K., France, India, Pakistan, and Israel.

This paper provides estimates of the inspection effort that would be required under a cutoff convention for routine verification activities. Three verification options are considered. Some provision for undeclared site inspections is likely to be included in the Cutoff Convention, but this question is beyond the scope of this paper. Effort for such inspections is not addressed here.

The estimates are based on a database of about 650 facilities in the eight states. The inspection effort estimates should be regarded as preliminary for several reasons. First, the verification options themselves are not yet clearly defined. Second, the operational status of some important facilities is uncertain at present and cannot be predicted at the time of the Convention's entry-into-force. Third, the database does not yet contain many small-scale and military-related facilities, which may affect the required inspection effort. Fourth, the facility-type inspection-effort estimates do not take into account the particular features of individual facilities, which can dramatically affect the required safeguards inspection effort.

Continuing efforts are being made to refine the database. The accuracy of the effort estimates will improve as more information is incorporated on the facilities themselves and as the verification options crystallize.

2. Cutoff Convention Options for Routine Verification

Three options for routine verification effort for the Cutoff Convention are considered. One option entails broad inspection activities very similar to those applied under the NPT; a second entails similar activities but restricts their scope to certain facility types; and the third involves less intensive verification.

In Option 1, the verification regime would be based to the greatest extent possible on the NPT safeguards specified in IAEA document INFCIRC/153. The objectives of verification would be the detection of diversion and the detection of undeclared production, particularly from enrichment or reprocessing plants. All peaceful nuclear activities would be declared, including existing inventories of fissile material not for military purposes, and all would be routinely inspected. Shutdown facilities retaining nuclear material would undergo less intensive inspections than operating facilities. Facilities without nuclear material and military facilities would not be declared or be subject to routine inspection.

Option 2 preserves the structure of IAEA safeguards but restricts the application to the facilities most relevant to the Cutoff Convention, particularly enrichment and reprocessing plants. The objectives of verification at operating facilities would be the detection of diversion and the detection of undeclared production. At shutdown facilities, the objective would be verification that production is not possible and that none has occurred since the entry into force of the Cutoff Convention. All (operational or not) enrichment and reprocessing plants would be declared, as would the research and development facilities capable of the same operations. Also declared and verified would be facilities storing or processing the highly enriched uranium (HEU) and plutonium produced after the Cutoff Convention's entry-into-force. Facilities processing only low-enriched uranium (LEU), military facilities, and facilities with subject fissile material produced before the entry into force of the Cutoff Convention ("grandfathered" material) would not be declared.

Option 3 has narrowly focused routine inspections but broad declarations. There would be three objectives of verification under this option. First is the verification of production and the detection of undeclared production at production facilities. Second is the verification of the disposition of subject material at storage facilities and processing facilities. Third is the detection of undeclared production at other processing facilities. All nuclear processing facilities would be declared, excluding only storage and military facilities with subject fissile material produced before the entry-into-force of the Cutoff Convention. Table 1 summarizes the three options.

3. Facility Information

For the current report, entirely unclassified sources of information have been used.

The database contains information about several facility types. These encompass facilities primarily for the production of electric power for civilian needs, those primarily for the production of fissile material for military purposes, and those specializing in research and development. The facility types are listed in Table 1. Regarding military production fuel cycles, only the reactors, enrichment plants, and reprocessing plants are included in the database at present. Associated fabrication and weapons assembly-disassembly facilities are not yet included. Also absent are such small-scale but important research facilities as hot cells and many shutdown research facilities. For each facility included, the database has information about status, gross technical features, and the sources of the information. Facilities currently under construction or decommissioned do not contribute to the inspection effort totals.

Knowledge about several data elements is lacking for some of the facilities in question here, particularly those in states other than France, the U.K. and the U.S. Indeed, even the exact numbers of facilities associated with the military nuclear fuel cycles are not precisely known.

There is no information in the database yet indicating that certain light-water reactors may be utilizing mixed-oxide (plutonium plus uranium) fresh fuel.

Table 1.

Facilities to Be Routinely Verified Under Cutoff Convention Options

Facility Type	*Option 1*	*Option 2*	*Option 3*
Power Reactors	X	X,s	d
Pu Production Reactors	X		p,a
Spent Fuel Storage	X		
Research Reactors and Critical Facilities	X	X,s	d
Reprocessing	X	X	p,a
Enrichment	X	X	p,a
Uranium Fuel Fabrication	X		
Uranium Conversion	X		
Plutonium Conversion	X	X	d
Plutonium Fuel Fabrication	X	X,s	d
Plutonium and HEU Storage	X	X,s	d
R&D Centers (Including Hot Cells)*	X	X	p,a
Recovery, Repurification, Fabrication for Military*			a**

X - Verifications according to IAEA Safeguards Criteria
s - Only if subject fissile material is present
d - Verification of disposition of subject material only
p - Verification of production only
a - Verification of absence of undeclared enrichment or reprocessing
*Very few in database at present
**Not considered in this report

4. Facility Inspection Effort Characterization

Table 2 contains the effort values commensurate with IAEA practice under INFCIRC/153 which were used for the effort calculations. Values listed are for operating and shutdown facilities. The inspection effort estimates derive from values typical of facilities currently undergoing IAEA safeguards, for which the knowledge is adequate and the verification systems generally good. These values characterize Option 1. Values for Options 2 and 3 follow by judgment from the Option 1 values.

Precise predictions of actual inspection effort at nuclear facilities depend on a detailed knowledge of facility characteristics, operational status, and safeguards approach. Additionally important is the State System of Accounting for and Control of Nuclear Material (SSAC), which sets requirements for the measurement and reporting system of individual facilities. However, facility and SSAC characteristics are not known for all situations addressed here. Nor is there experience with an IAEA safeguards approach for some of the facility types. For example, there is no reliable basis for estimating the total

Table 2.
Facility Inspection Effort Values

*Type of Facility**	*Options*	*PIV*	*IIV*	*NIV*	*FV*	*NFV*	*AIE*
Light water reactor	1	3	1	4	1	2	9
	s	-	1	4	-		4
Light water reactor (with mixed-oxide fresh fuel)**	1, 2	6	1	11	1	2	19
	3		1	4			4
On-load reactor	1	7	2	4	1	6	21
	s	-	1	4			4
Production reactor	1	6	-	-	8	8	70
	s	4	1	4			8
Critical facility: Fast	1, 2	15	2	11			37
Critical facility: Thermal	1,2	5	1	11			16
Research reactor: Fast	1,2	1	1	11			12
Research reactor: Thermal	1	1	1	3			4
Research reactor: Training	1	1					1
Reprocessing plant	1, 2	60	25	11	1	600	935
	3	23	7	11	1	200	300
	s	10	4	5			30
Enrichment (centrifuge)	1, 2	25	2	5	4	11	79
	3	10	2	5	2	11	42
	s	6	2	5			16
Enrichment (diffusion)	1,2	50	2	5	4	11	104
	3	20	2	5	2	11	52
	s	6	2	5			10
Fabrication (LEU)	1	60			4	5	80
Conversion (LEU)	1	30			4	5	50
Fabrication (MOX, old) & Pu conversion	1, 2	60	25	11	1	400	735
	3	25	15	5	1	200	300
	s	10	4	5			30
Fabrication (MOX, new)	1, 2	60	15	11	15	11	390
	3	25	15	5	5	11	155
	s	10	4	5			30

"s" denotes shutdown plant in all options, but still with nuclear material or the potential to produce it without extraordinary reconstruction.
**None currently in database
*A few others are not listed here, including pilot-size facilities to which smaller effort numbers apply

inspection effort that would be required at large gaseous diffusion enrichment plants, so the values used are somewhat arbitrary.

Another difficult area is that of facilities in various stages of shutdown; obviously those which are completely inoperable will require less inspection effort than those on "warm standby" or "cold standby," but these distinctions are not yet captured; each plant requiring inspection effort is now designated either operating or shutdown. (Decommissioned means there is no nuclear material.)

Following is a brief description of these inspection effort values for various facility types. They are a combination of known, standard effort values plus estimates derived for this paper.

Total annual facility inspection effort, AIE, satisfies

$$AIE = PIV + NIV * IIV + NFV * FV.$$

Here PIV, IIV, and FV represent the inspection effort in person-days of inspection (PDI) for the annual physical inventory verification, interim inventory verifications, and flow verifications respectively, and NIV and NFV represent the number of IIVs and FVs each year. Facility inspection effort values will be given in terms of these quantities.

The "person-day of inspection" (PDI) is the most easily estimated inspection effort parameter. It is not straightforward to convert values for PDI to numbers of inspectors required because of the co-location of facilities and because one PDI can represent a very short time in a facility on a given day or it could represent an entire shift. A very crude conversion from PDI to dollar cost, which ignores subtleties, some significant, can be derived from the fact that the IAEA Department of Safeguards conducted 8153 PDI in 1993 on a Department budget of $65 million; this yields a ratio of about $8000/PDI.

- For a light water reactor (LWR), 3 PDI are required for a PIV, 4 PDI are required for all quarterly interim verifications (IIVs), and 2 PDI are required for verifications of spent fuel shipments. These numbers are all increased for verifications at on-load reactors (OLRs), which are refueled continuously. Monthly IIVs are required if the LWR has fresh, mixed-oxide (MOX) fuel present. The total under Option 1 is 9 PDI for LWRs and 21 PDI for OLRs.
- Plutonium production reactors with off-load refueling of natural uranium require 6 PDI for a PIV and 8 PDI for each of 8 refueling (plus spent fuel shipment) campaigns. The total effort would be 70 PDI.
- Critical facilities require increasingly large inspection efforts for the PIV and possibly monthly IIVs depending upon the nature of the facility - thermal vs. fast. (A better formulation would depend on the amount of nuclear material present). The effort ranges to 15 PDI for the PIV and 2 PDI at each of 11 monthly IIVs for a fast critical facility, for a total of 37 PDI.
- Research reactors require 1 PDI for the PIV and possibly several IIVs. For example, monthly IIVs would be needed if there is a large amount of fresh HEU fuel. Very small research reactors would require none. As used here, the total effort could range from 1 to 12 PDI and depends on the the natue of the facility -

thermal, fast, or training. A better formulation would depend on the amount of fresh fuel and operational mode.

- Reprocessing plants in operation require 60 PDI for the PIV, 5 PDI for each of 11 IIVs, and 600 PDI for full-time flow verification (given 200 assumed days of operation) for a total of 935 PDI. Note well that this is the largest single facility-specific inspection effort total.
- Centrifuge enrichment plants in operation require 25 PDI for the PIV, 2 PDI for each of 5 IIVs, and 4 PDI for flow verification at each of 11 monthly inspections, for a total of 79 PDI.
- Gaseous diffusion enrichment plants in operation require 50 PDI for the PIV, 2 PDI for each of 5 IIVs, and 4 PDI for flow verification at each of 11 monthly inspections, for a total of 104 PDI.
- Fabrication plants making low-enriched uranium fuel require 60 PDI for the PIV and 4 PDI for each of 5 flow verifications. The total is 80 PDI.
- Conversion plants handling low-enriched uranium require 30 PDI for the PIV and 4 PDI for each of 5 flow verifications. The total is 50 PDI.
- Older fabrication plants making plutonium or mixed oxide fuel without highly automated methods require 60 PDI for the PIV, 25 PDI for each of 11 IIVs, and 400 PDI for two-shift flow verification, given 200 assumed days of operation, for a total of 735 PDI. The same effort breakdown is assumed to apply to plutonium conversion facilities.
- Very modern fabrication plants making plutonium or mixed oxide fuel by highly automated methods require 60 PDI for the PIV, 15 PDI for each of 11 IIVs, and 15 PDI for each of 11 flow verifications, for a total of 390 PDI.
- The inspection effort for other facilities, including small-scale reprocessing plants and storage facilities is given in the complete summary table included as the Appendix.

This information is summarized in Table 2. Note that bulk facilities, particularly those processing plutonium, require substantially more effort than do facilities such as reactors, which handle material in item form.

5. Overall Inspection Effort for Cutoff Convention Verification

For Option 1, the overall inspection effort required is about 29000 person-days of inspection. To put this effort requirement in perspective, we reiterate that the effort expended by the IAEA for routine safeguards verifications, predominantly in states without nuclear weapons and not including effort expended for verifications under UN Security Council resolutions, was 8153 person-days in 1993. For Option 2, the overall inspection effort drops to about 23000 person-days of inspection, because of the narrower scope of facilities subject to routine verifications. For Option 3, the inspection effort required is about 8300 person-days of inspection. This effort is much lower than for Options 1 and 2 because of the narrower scope of facilities and the narrower focus of verifications.

The results are displayed in Table 3. Each facility group in the table lists the number of facilities in the database followed by the PDI value in the three cases. The first value includes shutdown facilities.

For all three options, the effort requirement derives predominantly from facilities handling plutonium and highly enriched uranium. Facilities such as light-water reactors require substantially less inspection effort. Reprocessing plants alone account for 52%, 65%, and 63% of the inspection effort in the three cases respectively.

One large uncertainty in these figures is that civilian facilities in France and the United Kingdom currently undergo Euratom safeguards, and a large effort is expended on the required inspections. This effort has not been applied to reduce the estimates in this paper, but conceivably affects about one-third of the total effort calculated. A second, much smaller uncertainty is that some of facilities encompassed in the present estimation already undergo Agency safeguards under INFCIRC/66 or voluntary offer agreements. These are not taken into account in the estimates.

6. Conclusions

Estimated inspection effort values are very large, about 29000 PDI in the case of the Option 1 safeguards verifications following the NPT model. By the crude cost conversion mentioned in Section 4, this effort estimate leads to a cost estimate of about $230 million. Analogously, the Option 2 effort estimate of about 23000 PDI leads to a cost estimate of $184 million, while the Option 3 effort estimate of about 8300 PDI leads to a cost estimate of $66 million. The range of the inspection effort figures is very large, reflecting the differences in routine verifications among the three options. Note that the the lowest effort scenario, Option 3, results in an approximate doubling of the agency's inspection effort while Option 1, with the highest effort, results in more than four times the current inspection effort.

As stated earlier, it is not straightforward to convert values for PDI per year to number of inspectors required. However, one can obtain a crude estimate of the number of new inspectors that would be needed from the current staffing levels at the IAEA. The current professional staff of the three operations (inspections) divisions of the Department of Safeguards numbers about 200; these inspectors account for a yearly total of about 8100 PDI. Given that the inspection staff size is proportional to the annual PDI, the additional inspection staff needed under the three options are 711, 564, and 204, respectively. In addition to the monetary expense for these additional inspections, bringing these additional inspectors "on line" in a timely manner would be difficult, since there will be a need for recruitment, training and field experience.

It is clear that the PDI totals are mostly driven by the large values of about 900 PDI assigned to each large reprocessing plant. It may well be that many of these facilities will be shut down by the time the convention enters into force. However, note that in Option 1 there are about 14,000 PDI assigned to facilities other than reprocessing plants, a value which by itself is 170% of current IAEA inspection effort. It is also true that small-scale facilities not included in the database may significantly increase the inspection burden.

For reasons cited throughout the report, the effort estimates are subject to large uncertainties; the results therefore are not presented as predictions but as the consequences of alternative assumptions. It is a straightforward exercise to redo estimates for other verification options and for different facility-specific effort requirements. The facility database will undergo further review and expansion based on classified information. Finally, the effectiveness of the IAEA verification procedures may not be the same for military facilities as in modern civilian facilities, for which safeguards verifications are part of the design considerations.

Table 3.
Inspection Effort Estimates for Each Verification Option and Numbers of Facilities*

	Israel	*India*	*Pak.*	*US*	*UK*	*France*	*Russia*	*China*	*Total*
Reprocessing	2	4	3	10	3	3	6	3	34
(1)	395	2805	60	2110	2805	2805	2835	1900	15715
(2)	395	2805	60	2110	2805	2805	2835	1900	15715
(3)	130	900	60	840	900	900	930	630	5290
Enrichment	0	0	1	8	3	2	8	2	24
(1)	0	0	79	304	111	208	360	208	1290
(2)	0	0	79	304	111	208	360	208	1290
(3)	0	0	42	200	74	104	232	104	756
Power/ Prod Reactors	0	17	2	154	48	71	55	8	355
(1)	0	186	21	1102	759	709	863	228	3868
(2)	0	0	0	0	0	0	0	0	0
(3)	0	0	0	0	0	0	0	0	0
Other	3	11	2	117	26	27	43	13	242
(1)	57	240	56	1236	1133	2546	2661	173	8102
(2)	0	26	0	461	793	2290	2245	53	5870
(3)	0	4	0	80	334	920	900	12	2250
Total	5	32	8	289	80	103	112	26	655
(1)	452	3231	216	4752	4808	6268	6739	2509	28975
(2)	395	2833	139	2875	3709	5303	5460	2161	22875
(3)	130	904	102	1120	1308	1924	2062	746	8296

*For each facility type, the first row gives the number of facilities of a given type within the state, and the next three rows indicate the inspection effort at those facilities for the three verification options.

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APPENDIX: Effort Values

Facility Type	Status	Option 1	Option2	Option 3
Light water reactor	O	9	0	0
	S	4	0	0
On-load reactor	O	21	0	0
	S	4	0	0
High temperature reactor	O	21	0	0
	S	4	0	0
Fast breeder reactor	O	21	0	0
	S	4	0	0
Reactor (other)	O	9	0	0
	S	4	0	0
Production reactor	O	70	0	0
	S	8	0	0
Thermal research reactor	O	4	0	0
	S	1	0	0
Fast research reactor	O	12	12	0
	S	4	4	0
University reactor	O	1	0	0
	S	0	0	0
Naval-type reactor	O	12	12	0
Thermal critical assembly	O	16	16	4
	S	4	4	0
Fast critical assembly	O	37	37	8
	S	8	8	0
Natural U conversion	O	32	0	0
	S	10	0	0
LEU conversion	O	50	0	0
	S	15	0	0
HEU conversion facility	O	735	735	300
	S	30	30	30
Plutonium conversion facility	O	735	735	300
	S	30	30	30
Thorium conversion facility	O	32	0	0
	S	10	0	0
Natural/depleted U fabrication	O	52	0	0
	S	10	0	0
LEU fabrication	O	80	0	0
	S	30	0	0
HEU fabrication	O	735	735	300
	S	30	30	30

Facility Type	Status	Option 1	Option 2	Option 3
MOX fabrication (conventional)	O	735	735	300
	S	30	30	30
MOX fabrication (automated)	O	390	390	155
	S	30	30	30
Thorium fabrication	O	735	735	300
	S	30	30	30
Reprocessing (nat. U)	O	935	935	300
	S	30	30	30
Reprocessing plant (LEU)	O	935	935	300
	S	30	30	30
Reprocessing plant (HEU)	O	935	935	300
	S	30	30	30
Reprocessing plant (plutonium)	O	935	935	300
	S	30	30	30
Reprocessing (thorium)	O	935	935	300
	S	30	30	30
Reprocessing plant (pilot)	O	365	365	100
	S	30	30	30
Hot cell (lab scale)	O	30	30	30
	S	12	12	12
Diffusion plant	O	104	104	52
	S	16	16	16
Centrifuge enrichment plant	O	79	79	42
	S	16	16	16
Enrichment plant (other)	O	79	79	42
	S	16	16	16
Sealed storage (spent fuel)	O	24	0	0
	S	4	0	0
Sealed storage (nat. U)	O	12	0	0
	S	6	0	0
Sealed storage (HEU)	O	54	54	6
	S	32	32	6
Sealed storage (plutonium)	O	70	70	10
	S	48	48	10
Unsealed storage (spent fuel)	O	48	0	0
	S	8	0	0
Unsealed storage (nat. U)	O	24	0	0
	S	12	0	0
Unsealed storage (HEU)	O	80	80	6
	S	54	54	6

Facility Type	Status	Option 1	Option 2	Option 3
Unsealed storage (plutonium)	O	120	120	10
	S	70	70	10
Weapons components fabrication	O	735	735	300
	S	30	30	30
Weapons assembly/disassembly	O	735	735	300
	S	30	30	30