Safeguarding the fuel cycle: Methodologies

by Hans Gruemm

The effectiveness of IAEA safeguards is characterized by the extent to which they achieve their basic purpose – credible verification that no nuclear material is diverted from peaceful uses. This effectiveness depends *inter alia* but significantly on manpower in terms of the number and qualifications of inspectors. Staff increases will be required to improve effectiveness further, if this is requested by Member States, as well as to take into account new facilities expected to come under safeguards in the future. However, they are difficult to achieve due to financial constraints set by the IAEA budget.

As a consequence, much has been done and is being undertaken to improve utilization of available manpower, including standardization of inspection procedures; improvement of management practices and training; rationalization of planning, reporting, and evaluation of inspection activities; and development of new equipment.*

This article focuses on certain aspects of the verification methodology presently used and asks: are any modifications of this methodology conceivable that would lead to economies of manpower, without loss of effectiveness?

It has been stated in this context that present safeguards approaches are "facility-oriented" and that the adoption of a "fuel cycle-oriented approach" might bring about the desired savings.** Many studies have been devoted to this very interesting suggestion. Up to this moment, no definite answer is available and further studies will be necessary to come to a conclusion. In what follows, the essentials of the problem are explained and some possible paths to a solution are discussed.

Model approaches of present methodology

At first glance, the present safeguards methodology seems indeed to be "facility oriented", that is treating facilities as isolated entities without taking into account the characteristics of the national nuclear fuel cycle as a whole.

As a matter of fact, model approaches are designed for each type of nuclear facility. They take into consideration, according to paragraphs 81(a) and (c) of document [153]* in particular, characteristics relevant to safeguards of the facility type in question and the form and accessibility of the nuclear material.

The model approaches are based on model facilities and modified to account for specific features of individual facilities (facility approach). Verification measures foreseen for each facility, and the corresponding estimated actual routine inspection effort (ARIE), are negotiated with the State. The sum of the ARIE of all facilities in the State is the annual effort in man-days of inspection work that should, in principle, be carried out in the State. Adjusted for the expected operational status of the facilities (e.g., shutdowns) these annual efforts serve as basis for manpower allocation. The efforts assigned to each State are reduced proportionally in order to adapt their total to the expected manpower available.

Stipulations of safeguards agreements

The consideration of individual facilities as "building blocks" of the safeguards approach for a State is in conformity with important stipulations of the respective safeguards agreements.

Documents [153] and [66]** describe procedures for facility types or individual facilities, such as those relating to design information, specific measures, and inspection effort. Paragraph 90(b) of document [153], in particular, requests IAEA to draw conclusions from its verification activities in the State with respect to *each* material balance area***. This implies that the overall conclusion drawn by IAEA with respect to a national fuel cycle as a whole must be based on the conclusions with respect to the individual facilities of the cycle.

The prominent rôle of the individual facility when safeguards approaches are designed does not mean, however, that characteristics of the national fuel cycle are neglected.

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* The *IAEA Safeguards Glossary* (IAEA/SG/INF/1) contains definitions and explanations of technical terms used in this article.

** A safeguards approach is a combination of nuclear material accountancy, containment and surveillance, and other measures as considered necessary and sufficient to verify that no nuclear material has been diverted.

* Document INFCIRC/153 (Corr.), the model for safeguards agreements with parties to the Non-Proliferation Treaty (NPT).

** INFCIRC/66/Rev.2. contains guidelines for safeguards agreements other than of the [153] type.

*** A nuclear facility may be structured into several such areas.

There is, for instance, a basic difference between safeguards agreements according to documents [153] and [66], respectively. In the first case, the State submits *all* nuclear material in *all* of its peaceful nuclear activities to IAEA safeguards (full-scope situation). In contrast, [66]-type agreements cover *individually* certain material, services, equipment, facilities, and information, but not necessarily all nuclear activities of the State. In this case, facilities submitted to IAEA safeguards (e.g., a reactor) may be connected to unsafeguarded facilities (e.g., a fuel fabrication plant). This makes it very difficult to verify a complete nuclear material balance at the facility in question.

This circumstance has to be taken into account in designing the safeguards approach to the facility and this can then be different from the approach for a facility of the same type in a full-scope situation. Since most safeguarded facilities operate in full-scope situations, the present discussion will be limited to these.

Other factors considered

Another factor related to certain States or groups of States and their fuel cycle as a whole is the effectiveness of the States' System of Accounting for and Control of Nuclear Material (SSAC) and the extent to which the facility operators are functionally independent of the SSAC (paragraph 81(b) of document [153]). This has been taken into account explicitly in safeguards agreements that include special arrangements for the co-operation between IAEA and the SSAC or its equivalent.

Apart from the differences between the types of safeguards agreements, there also are basic technical differences between national fuel cycles that should be taken into account according to paragraph 6(c) of document [153]. This paragraph requires the concentration of effort of verification procedures at those stages of the nuclear fuel cycle involving the production, processing, use or storage of nuclear material from which nuclear explosive devices could readily be made, i.e., "direct-use material" (highly enriched uranium and plutonium).

This guideline indeed has been used by IAEA in concentrating inspection efforts on "sensitive facilities" such as enrichment plants or reprocessing plants, and other facilities with large amounts of direct-use material, (e.g., fresh fuel in certain reactors, critical assemblies and fuel fabrication plants). As a result, about 35% of the total inspection effort of IAEA in 1983 was concentrated on 14 sensitive facilities and the remaining 65% on more than 400 others. This leads, of course, to considerable inspection activities in States with many nuclear facilities and a highly developed fuel cycle: In 1983 nearly 70% of the inspection effort had to be spent in 5 of the 50 States visited by IAEA inspectors.

The above comments make it clear that the relevant legal requirements and the most important technical characteristics of the national fuel cycles have been taken into account in devising the safeguards approaches presently used.

Apart from this differentiated treatment of national fuel cycles as prescribed explicitly by the safeguards agreements, the same approaches are used and the same inspection efforts are planned for comparable facilities. This policy reflects, according to the present state-of-the-art and in a transparent manner, the principle of non-discrimination among States. Those who propose to emphasize further the fuel cycle orientation of the safeguards approaches have in mind obviously additional differences between national fuel cycles. So doing would imply unequal treatment of the same type of facility in different States depending on characteristics of the surrounding national fuel cycle that are not yet taken into account.

It should be clear that the corresponding modification of the safeguards approaches would have to be developed carefully to make sure that the unequal treatment of the same facility type in different national fuel cycles can be justified in an objective manner acceptable to Member States. In addition, the modified approaches must be demonstrated to be at least as effective as the present ones in attaining the objective of safeguards.

Possible modified approaches

Two criteria are not yet taken into account when analysing the differences between fuel cycles of different States: (1) the non-existence of sensitive facilities; and (2) the existence of many facilities of the same type (e.g., light-water reactors) in a national fuel cycle.

The case of fuel cycles containing sensitive facilities is covered explicitly by paragraph 6(c) of document [153]. It could be asked whether an acceptable modification of the approach for "insensitive" fuel cycles is conceivable that would lead to the desired manpower savings.

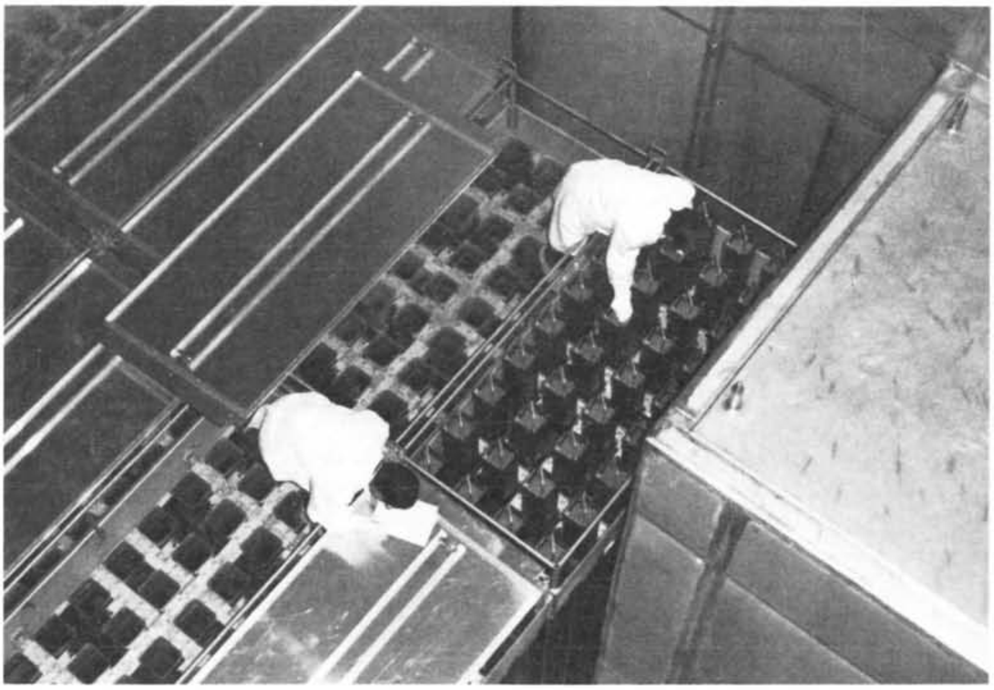
To understand the size of savings that could possibly be expected from taking these differences into account, a simplified method might consist of grouping nuclear facilities into four types according to their individual "diversion risk", i.e., according to the composition and amount of nuclear material present.*

The groupings for facility types would be:

a – Reprocessing or enrichment plants as sources of large amounts of direct-use material

b – Facilities containing large amounts of unirradiated direct-use material, e.g., fresh fuel of certain reactors, critical assemblies, and the associated fuel fabrication plants

* Composition and amount of nuclear material already have been taken tinto account in estimating the ARIE for the standard approach in accordance with paragraph 81(a) of document [153].



Improved use of available manpower for safeguards inspections may be achieved by modifying present methodologies to further emphasize fuel-cycle aspects. However, extensive study would be required to fully assess the effects of such modifications on other factors.

c – Power reactors fuelled with low-enriched or natural uranium and the associated fuel fabrication plants

d – Small research reactors, laboratories, etc. containing in total less than one Significant Quantity (SQ) of direct-use material.

The accompanying table provides approximate percentages of the ARIE for nuclear installations under safeguards or expected to come under safeguards in the next few years in States with full-scope agreements. States with a type-IV fuel cycle are physically not in a position to divert one SQ of direct-use material. The inspection effort in these States is low and sometimes zero. No substantial savings can be expected from a modification of the present approach.

States with a type-III fuel cycle would be in a position physically to divert an SQ or more of direct-use material only after production of the material in a clandestine enrichment or reprocessing plant. The same holds true for a type-II fuel cycle with respect to diversion from facility types-c-and-d.

However, the present safeguards approach is based on the assumption that the existence of clandestine facilities cannot be excluded.* Savings of inspection effort could be effected by a fundamental change in this basic assumption and the adoption of the hypothesis: "No clandestine facilities exist in full-scope situations."

In this case, it also would be physically impossible for type-III States and certain facilities of type-II States to manufacture nuclear explosives, and assurances of non-diversion with respect to the facilities in question theoretically could be given without verification. About 26% of the total estimated effort would be affected by the hypothesis.

However, it is improbable that such a drastic modification of the safeguards philosophy would meet with the agreement of Member States, for several reasons:

- IAEA is legally committed by its Statute and the safeguards agreements to perform verifications at all facilities covered by the agreements and to draw conclusions from the results.
- The discontinuation of verification activities in type-III fuel cycles and at certain facilities in type-II fuel cycles may be considered as discriminatory or otherwise unacceptable by other States.
- The credibility of IAEA safeguards would suffer because certain diversion hypotheses deemed plausible by some analysts would be excluded (the State could, e.g., divert and stockpile nuclear material and use it later on in prohibited ways).

Even if the above hypothesis cannot be accepted, the consequences of a less far-reaching assumption might perhaps be of interest: "The existence of clandestine facilities constitute only a remote possibility." Verification activities then could be made less stringent in appropriate cases. A lower detection probability then might be considered acceptable for type-III-and-IV fuel cycles and certain facilities in type-II fuel cycles.

As a consequence, the standard ARIE of the type-c-and-d facilities concerned could be multiplied by a "reduction factor" (r). There is, however, no scientific way of determining such a factor. The support of external experts would be necessary to select a value that would be technically meaningful and politically acceptable to Member States. A further difficult problem would be the design of a safeguards approach for facility types-c-and-d which ensures optimum (but reduced) verification activities.

To give an example of possible reductions, r = 0.5 is arbitrarily selected. As can be seen from the Table,

Table. Approximate ARIE for nuclear installations under safeguards, or expected under safeguards, in States with full-scope agreements

Fuel cycle type	Percentage of States	Percentage of facility type				Percent of inspection effort
		a	b	c	d	
I	15	18	28	18	9	73
II	8	–	1	15	1	17
III	27	–	–	4	2	6
IV	50	–	–	–	4	4
Totals	100	18	29	37	16	100

13% of the total theoretical inspection effort would be cut.

One could extend the reduction by a factor of r = 0.25 also to type-c-and-d facilities in type-I fuel cycles, assuming that material diverted from these facilities could be detected at type-a facilities, where it has to be processed in order to obtain direct-use material. In this case, the cuts in our example would increase to about 20% of the total theoretical effort.

However, the figure so calculated must be compared to the current efforts: In 1983 only about half of the total ARIE could be "produced" by the staff available, so actual savings from current efforts would be about 10% of the total ARIE. This is not very much compared to a possible credibility cost of the change in the diversion hypothesis. The savings could be used in the first instance for improving safeguards effectiveness at type-a-and-b facilities and also for facilities to come under safeguards in future.

Case Two: similar facilities, one fuel cycle

Next, let us turn to case (2), where many facilities of the same type exist in one fuel cycle. This applies in a few type-I-and-II fuel cycles. In this case a question also arises: Is it possible to reduce the inspection effort in such a way that the resulting effectiveness is still acceptable to Member States?

It has been suggested that the widely used principle of checking random samples of nuclear material could be extended to groups of power reactors of the same type. IAEA inspectors then would present themselves unexpectedly at the facilities selected. It has been claimed that the deterrent effect of such "surprise inspections" would compensate for the loss of effectiveness of material accountancy connected with cancelling inspections at the remaining power plants.

This assumption should be studied very carefully because, with some exceptions, there are certain doubts with respect to the surprise effect of unannounced

* For a previous discussion, see the author's "Safeguards verification – its credibility and the diversion hypothesis", *IAEA Bulletin*, Vol.25, No.4, page 27 (December 1983).

inspections – for instance, in many cases the necessary procedures (visa, availability of accompanying staff of the SSAC, etc.) would give an early warning to a would-be diverter. Most important, however, is the fact that an effective inspection requires careful preparation by the operator (e.g., updating of the files) and proper selection of the appropriate operating phase of the facility (e.g., the core of a power reactor can only be inspected after the vessel lid has been removed).

An example indicates the order of magnitude of the savings that could be expected by "sampling of facilities." At present, seven States have more than five nuclear power plants of the same type under safeguards. The ARIE estimated and agreed for these facilities is about 19% of the total.

As an example, a reduction factor of $r = 0.5$ is assumed again without examination of the associated decrease of effectiveness. Taking the fact in account that only part of the ARIE can be produced at present, only about 5% of the effort could be saved. This is not very much and the savings should be seen in the light of decreased effectiveness.

Finally, how is it possible to comply with paragraph 90(b) of document [153] that requires verification by IAEA of physical inventories for *each* material balance area under safeguards?

Another possibility for saving manpower is an annual simultaneous inventory verification of a whole material stratum of a fuel cycle. This already has been carried out for the fresh material in a natural uranium fuel cycle and led to some savings without loss of safeguards effectiveness. Whether this method can be used for a light-water reactor fuel cycle still is an open question and deserves careful study.

Effects on detection goals

The concepts discussed are connected in most cases with a lessening, at least for certain facilities, of one of the most important parameters determining safeguards effectiveness, the detection probability. It could be asked whether modifications of other detection goals are conceivable, namely detection time and SQ, that would lead to manpower savings with tolerable loss of effectiveness.

As a matter of fact, the manpower situation and practical experience already required a relaxation of detection time from two or three weeks to four weeks for easily accessible direct-use material. However, Member States do not seem prepared to accept a further extension of detection time. Furthermore, it should be borne in mind that the automatic-camera system widely used for surveillance requires film change and maintenance every three months. This commits a considerable part of inspector time at the facility, at least until new camera systems with longer running times and high reliability become available or other advanced safeguards methods are developed.

Finally, the SQ remains. An increase of the values presently used would lead to certain manpower savings because SQ is one factor determining sample sizes and, thus, the necessary effort for verification of the samples selected. Practice shows that the quantity detection goals can be attained in most cases with modest effort. Furthermore, relatively large changes in the values for SQ would result in only small savings in effort. For complex facilities, specific inspection goals that do not necessarily coincide with the SQ have been determined with attainability in mind.

Some savings possible, but more study needed

The rough assessments made in this article indicate that some savings of inspector manpower seem to be possible if the safeguards approaches presently used were to be modified by further emphasizing the fuel cycle aspects – for example, by deletion of certain diversion assumptions and a decrease of the desired detection probability for many nuclear facilities. The effect of such modifications, however, has to be studied very carefully with respect to all of the following:

- Acceptability of a significant change of the philosophy of IAEA safeguards (disregarding some diversion assumptions) may be associated with a decrease in detection probability
- Acceptability of different treatment of the same type of facility in different States
- Real manpower savings that can be expected.

These complicated problems would require extensive study. In addition, tests of modified approaches in practical verification work and, if the results are satisfactory, acceptance of substantial modifications of basic safeguards concepts by Member States would be necessary. The time and effort necessary for such studies and trials should not be underestimated.