The Technical Objective of Safeguards

THE NON-DIVERSION UNDERTAKING AND THE SAFEGUARDS OBJECTIVE

Since the International Atomic Energy Agency was set up in 1957 there has been a growing recognition that the politically acceptable way of implementing safeguards is through agreements between a State or States and the Agency. Such agreements are invariably built around a basic undertaking of the State. Before the Non-Proliferation Treaty came into force this basic undertaking had always been formulated in the agreement itself, in accordance with the requirement of the Agency's Statute that "special fissionable and other materials, services, equipment, facilities, and information" shall not be "used in such a way as to further any military purpose".

A similar undertaking is contained in the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), on which agreement was reached in 1968 and which entered into force in 1970. States party to NPT undertake not to divert "nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices". They also conclude agreements with the IAEA for the application of safeguards. In these agreements the undertaking is not repeated but is incorporated by reference.

All types of safeguards agreements concluded with the Agency contain a supplementary undertaking to accept safeguards for the purpose of ensuring that the basic undertaking is continuously honoured. This means that the safeguarding authority has to establish proof that nuclear materials and equipment are not used for activities which are contrary to the basic undertaking. How to establish convincing evidence that something is not being done has been a subject of debate for many years. Out of this discussion the definition of safeguards objectives has emerged. Particular care was taken by the Safeguards Committee (1970) to formulate the objective of safeguards for incorporation in every safeguards agreement concluded in connection with NPT.

The second part of the agreement, which specifies the procedures to be applied, begins with a definition of the objective of safeguards as "timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection."

The inclusion of the expression "or for purposes unknown" is of great importance for the practical application of safeguards. This expression means that the safeguards authority no longer has to prove manufacturing of specific devices, a difficult task in practice. The disappearance of nuclear material is considered to constitute diversion in itself. The expression "timely detection of diversion of significant quantities of nuclear material" focuses attention on the nuclear material and the requirement that it must be used exclusively for peaceful nuclear activities. Up to this point the objective of safeguards is defined – in general terms – in the agreements between States and the Agency.

Rational planning of safeguards work within the Agency's Secretariat requires translating this general objective into specific practical terms: values have to be selected for "significant quantities", as used in statistical techniques and for other parameters such as detection probability, timeliness, uncertainty and so on. Through this quantification the objective becomes technically defined and can be used as a guideline in routine safeguards work. The quantification is based on numerous panel discussions held with experts from Member States and on the long-standing experience of the IAEA with nuclear material accountancy. The values selected must be understood as reflecting today's performance possibilities; they will be refined and adapted in the light of subsequent technological developments. They are meaningful, moreover, only within the context and structure of the applied accountancy system and verification scheme.

ACCOUNTANCY AND VERIFICATION

Accountancy is established by recording in the facility, and reporting to the IAEA, initial inventories of nuclear material and subsequent inventory changes. Additions to and subtractions from the initial inventory yield the so-called "book inventory", i.e. the amount of nuclear material which *"should be"* in a given facility or a given material balance area. Periodically, the facility operator takes a physical inventory in the material balance area by measuring the nuclear material which *"is"* present. Because of the inherent measurement uncertainty, there is usually some difference between what *"should be"* and what *"is"* – between the book inventory and the physical inventory. There may also be discrepancies for other reasons; failure to measure parts of the inventory or an unmeasured loss of material. The difference between book inventory and physical inventory is called "material unaccounted for", abbreviated to "MUF". As a variable derived from measurements, MUF is, like the measurements themselves, subject to uncertainties. The MUF and its uncertainty make it possible to judge the quality of the material balance; they indicate to the facility operator what the limits of his knowledge are regarding the whereabouts of his nuclear material.

The verification of material accountancy by the Agency's inspectorate is the safeguards measure of fundamental importance. It makes use of statistical techniques to draw conclusions concerning the acceptance or rejection of the material balance and on non-diversion. The numerous components of a material balance, the receipts into a material balance area, the shipments out of it, and all the material batches making up the beginning and the ending inventory are cross-checked by independent measurement or chemical analysis, on the basis of a random sampling plan. Therefore, when the Agency draws its conclusions on non-diversion, these conclusions are subject to the probabilities used for the calculation of the sampling plans. The Secretariat of the IAEA has fixed, on advice of technical panels, the probability of detecting the significant quantity, if missing, at 95%, and the probability that this quantity is correctly established (confidence level) also at 95%. As a result, that significant quantity which, in accordance with the safeguards objective, *must* be detected, if diverted, becomes equal to the significant quantity which *can* be detected, if missing, through the establishment of the material balance by the facility operator as verified by the Agency's inspectorate. The system of measurements used for the material balance accountancy is required by the agreement to conform to the latest international standards. Thus, the state of the art in nuclear material measurement and analysis provides the first basis for defining a quantitative, technical objective of safeguards.

The IAEA has compiled performance data on nuclear material determination using information obtained both from facility operators and from laboratories in Member States that are developing advanced methods. From those data accuracies have been derived to apply to any facility engaged in the same type of operation. They are for:

Uranium enrichment	±0.2%
Uranium fuel fabrication	±0.3%
Plutonium fuel fabrication	±0.5%
Uranium in power reactors	±0.2%
Reprocessing, Uranium line	±0.8%
Reprocessing, Plutonium line	±1.0%

of the material throughput.

These accuracies are expressed as one standard deviation[1] and represent the total error in composing a material balance; its components stem from all types of measurements involved, such as weighing, metering, spectrometer readings and so on, as well as from sampling, equipment calibration, summing up over several batches, and the like. Today, quite a number of facilities actually do somewhat better than these figures indicate, but they have been rounded up to the highest tenable value to avoid discussions over individual performance.

Multiplying the accuracy figures by two gives the quantities, as a percentage of facility throughput, which would and could be detected, if missing, at the end of the lengthy process of establishing a verified material balance. During that process assurance has been gained that the bookkeeping correctly reflects all transactions. Detection of such a quantity with the set probabilities represents the highest technical objective which can be achieved by accountancy measures alone.

EVALUATION AND OPTIMIZATION

At present around three hundred facilities are subject to Agency safeguards. At least a third of them are subdivided into two or more material balance areas. In all of them the technical objective of safeguards work, rooted in the possibilities offered by nuclear material accountancy, is being tested continuously in the light of the aim of the undertaking incorporated in safeguards agreements and in NPT. This means that the significant quantities of nuclear material to be detected are compared with "threshold amounts" of such material needed to manufacture a nuclear explosive device, i.e. a nuclear weapon. As in the case of the significant quantity, it is not possible to quote a single specific figure as the threshold amount. Instead, an evaluation process introducing several new aspects has to be applied.

This process begins with the introduction of the upper limits of a range of threshold amounts recommended by a group of international experts from Agency Member States. These experts considered up to 8 kilogrammes of plutonium per year and up to 25 kilogrammes of contained uranium-235 per year valid for all situations.

As a result of a first rough comparison it becomes apparent that the most critical step

1) One standard deviation of a group of measurements of the same value is calculated by the formula:

$$\sigma = \sqrt{\sum_{i-1}^{n} \frac{(x_i - \bar{x})^2}{n-1}}$$

in the nuclear fuel cycle, from the safeguards point of view, occurs when plutonium is separated out as a clean product from the highly radioactive fission products and the remaining mass of uranium. This is the purpose of chemical reprocessing plants for nuclear fuel. Such a plant may today have a throughput of 1000 kilogrammes of plutonium per year. Clearly, if material accountancy were tested for balance only once a year, the accuracy indicated in the table on p.15 would yield an unsatisfactory ratio of threshold amount over significant quantity. Therefore, in such plants, the taking of physical inventory, its verification, and the closing of the material balance are required four times a year. This is obviously in the interest of the facility operator as well as of the safeguards inspectorate: timeliness of detection is assured and the significant quantity to be detected, if missing, becomes acceptable.

In the next few years reprocessing facilities with capacities five or ten times as large as the throughput of today's plants are expected to commence operation. The question arises whether and how the technical objective of safeguards can be achieved in such facilities.

There are three favourable factors which allow an optimistic prediction to be made. Firstly, plant operators, national laboratories, and safeguards development teams are working hard to improve the accuracy of material balance accountancy and the associated verification procedures. It now seems safe to expect that the accuracy of plutonium accountancy in large plants will be doubled, reaching 0.5% of the throughput. Secondly, a tighter schedule of material balance closing is being considered to assure timeliness of detection. For that purpose, improved methods of physical inventory taking, methods that will have scarcely any effect on continuous plant operation, are being developed.

And, last but not least, particular attention will be paid to all possibilities of protecting the nuclear material by physical containment within the plant. This latter measure is complemented by surveillance, preferably by means of automatic instruments when performed by the international safeguards inspectorate. In addition, measures for the physical protection of nuclear material are provided by the national authorities as required in fulfilling their regulations.

The anticipated rapid growth of nuclear activities in the years to come will require new methods of maintaining optimum cost/effectiveness in safeguards work. The aim is to continue to achieve the objective without increasing expenditure at the same rate as nuclear power production. One novel way of attaining this goal is to adjust the technical objective to the importance of the nuclear material from the point of view of safeguards; this could be done by introducing a classification of nuclear materials according to criteria that define their attractiveness for diversion.

It is obvious, for instance, that plutonium within irradiated power reactor fuel is of little interest from the point of view of diversion in a country where none of the highly specialized facilities for its separation exist. It is virtually impossible for this material to be diverted "in situ" in just the right amount for the construction of a nuclear explosive device. However, the possibility that fairly large amounts might be set aside over relatively long periods, even in irradiated and unseparated form cannot be excluded. Thus, safeguards should be applied continuously to such material as well; but the technical objective of the safeguards, i.e. the significant quantity to be detected, if missing, could be set at a higher value.

Similar considerations are valid for low enriched uranium in a country where no possibility of enrichment exists. It is less easy to take account of the isotopic composition of plutonium. To judge, for instance, the possibilities of a nuclear explosive device being made from ordinary power reactor plutonium is not only a technical problem but also one that involves assumptions regarding the circumstances under which the device might be used. However that may be, a classification of nuclear material with a view to introducing "graded safeguards" – a system that takes account of the content of fissile nuclei in the material and the degree of its contamination with fission products, as well as the characteristics of the State's nuclear fuel cycle – is likely to be one of the important future possibilities of optimization.

Continued efforts will be needed to give practical shape to this concept. The same is true of a number of other promising ideas and techniques, such as the introduction of more accurate measurement systems, the use of isotopic composition and other correlations, trend analysis, and the like. Their timely implementation will be decisive for the Agency's ability to maintain efficient safeguards. The goal can be achieved only if the Agency has the requisite material and intellectual resources at its disposal.

The IAEA seal covering the core of a nuclear power plant.