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Fuel Cycle Based Safeguards

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Abstract

Although the guidelines for NPT safeguards specify that the State's fuel cycle and degree of international interdependence are to be taken into account, the same model approach and absolute-quantity inspection goals are applied at present to all similar facilities, irrespective of the State's fuel cycle, and the findings are reported in those terms. There is a continuing interest and activity on the part of the IAEA and its advisory bodies in new NPT safeguards approaches that more directly address a state's nuclear activities as a whole, and which are at the same time non-discriminatory.

Some background information prepared for developing such an approach, has been collated and presented in this report. This fuel cycle based safeguards system is expected to

a) provide a statement of findings for the entire State rather than only for individual facilities
b) allocate inspection efforts so as to reflect more realistically the different categories of nuclear materials in the different parts of the fuel cycle and
c) provide more timely and better coordinated information on the inputs, outputs and inventories of nuclear materials in a State.

The consolidated concept for such a fuel cycle based safeguards system is expected to be presented in subsequent reports.

*The contributions collected in this report do not necessarily reflect the positions of the respective governments or the organizations.

Brennstoffzyklusbezogene Kernmaterialüberwachung

Beiträge von *

J.M. de Montmollin, W.A. Higinbotham, D. Gupta

Zusammenfassung

Entsprechend den Richtlinien für die Kernmaterialüberwachung nach dem NV-Vertrag sollen bei der Durchführung der Überwachungstätigkeiten in einem Staat u.a. die Eigenart und internationalen Verflechtungen des Brennstoffzyklus in diesem Staat berücksichtigt werden. Bisher wurden jedoch die gleichen Überwachungsmodelle mit den gleichen absoluten Mengen als Überwachungsziele für Inspektionstätigkeiten für alle Kernanlagen eines Typs angewendet, und zwar unabhängig von der Art des Brennstoffzyklus in einem Staat. Entsprechend waren auch die überwachungsrelevanten Aussagen.

Es besteht jedoch ein ständiges Interesse der IAEO und ihrer Beratungsgremien an neuen Überwachungsvorstellungen nach dem NV-Vertrag, die die gesamten nuklearen Tätigkeiten in einem Staat als Ganzes betrachten und gleichzeitig nicht diskriminierend sind.

Einige Grunddaten, die für die Entwicklung eines solchen Konzeptes erarbeitet worden sind, sind in diesem Bericht zusammengestellt. Das angestrebte brennstoffzyklusorientierte Überwachungssystem soll in der Lage sein,

a) eine Aussage für das gesamte Kernmaterial in einem Staat (statt nur für einzelne Anlagen) zu treffen
b) eine realistischere Verteilung des Inspektionsaufwandes unter Berücksichtigung der überwachungsrelevanten Eigenschaften des Kernmaterials in verschiedenen Teilen des Brennstoffzyklus zu ermöglichen und schließlich
c) besser koordinierte und rechtzeitige Informationen über Eingänge, Ausgänge und Inventar an Kernmaterialien in einem Staat zu erzeugen und zu liefern.

Das Gesamtkonzept für das auf dem ganzen Brennstoffzyklus eines Staates aufgebaute Überwachungssystem soll in einigen nachfolgenden Berichten dargestellt werden.

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*Die in diesem Bericht zusammengestellten Beiträge geben nicht notwendigerweise die Meinungen der jeweiligen Regierungen bzw. der Organisationen wieder.

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Fuel Cycle Based Safeguards

Contributions by

J.M. de Montmollin[1], W.A. Higinbotham[2], D. Gupta[3]

1. General Remarks

During the period July 1984 - April 1985, a number of contributions were prepared on the subject of fuel cycle based safeguards which have been used as a basis for developing some ideas on the possibilities of international safeguards in the frame of NPT, for the fuel cycle as a whole in a State. These contributions are collated and compiled in the present report. The consolidated concept for fuel cycle based safeguards will be presented in subsequent reports. The ideas presented in this report do not necessarily reflect the positions of the respective governments or the organizations.

Until now safeguards have been applied to facilities where the materials are located, and safeguards approaches, detection goals, and reported findings have been with regard to each facility. Under the NPT, States agree not to acquire nuclear weapons from any source, and to submit all their nuclear activities to IAEA safeguards, however, the basis is still the individual facility. Although the guidelines for NPT safeguards specify that the State's fuel cycle and degree of international interdependence are to be taken into account, the same model approach and absolute-quantity inspection goals are applied to all similar facilities, irrespective of State's fuel cycle, and the findings are reported in those terms.

There is a continuing interest and activity on the part of the IAEA and its advisory bodies in new NPT safeguards approaches that more directly address a State's nuclear activities as a whole, and which are at the same time non-discriminatory. However, the fuel cycle basis is somewhat different from the facility basis and it leads to a re-examination of the entire

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concept of inspection goals, allocation of resources and the nature of the reported findings.

The contributions in the present compilation deal with the possibilities of a fuel cycle based safeguards, which may meet one or more of the following objectives:

1. To provide a statement of findings for the entire State besides providing statements for individual facilities.
2. To allocate inspection efforts so as to reflect more realistically the relative importance of the different categories of nuclear materials in and the specific characteristics of the different parts of the fuel cycle and
3. To provide more timely and better co-ordinated information on the inputs, outputs and inventories of nuclear materials in a State.

On the basis of the contributions, it appears that a fuel cycle based safeguards system could have the following principal features:

1. Division of the complete fuel cycle into three zones, each containing materials having a different degree of significance for safeguards.

   Any commercial nuclear fuel cycle based on light-water reactor systems with or without recycled plutonium and with the corresponding R+D facilities, would have, in principle, 3 categories of nuclear materials based on their safeguards significance; namely:
   - natural or low-enriched uranium (LEU having $\leq$ 20 % U-235)
   - irradiated fuel elements
   - separated plutonium or high enriched uranium.

   It is to be noted that in anticipation of such distributions, the INFCIRC/153 recommended 3 different levels of inspection efforts in such a fuel cycle (Article 80). In implementing its safeguards measures, the Agency considers the natural uranium and LEU up to $\leq$ 20 % U-235 concentration, to have the same safeguards significance. This is reflected by the fact that these two categories of materials have the same significant quantity SQ of 75 kg of contained U-235 and the same detection time of 1 year. The Agency considers the plutonium contained in irradiated fuel elements to be of different safeguards significance than separated plutonium. This is reflected by the different detection times considered for these two types of materials (3 months for plutonium in irradiated fuel elements and 3-4 weeks for separated uranium in oxide or nitrate form).

The contributions by de Montmollin and Gupta (2.10, 3.4) indicate that the ratio IMD/WSQ in a facility could be used for considering the allocation of inspection efforts in the different zones of a fuel cycle based safeguards system. Besides SQ, this ratio is sensitive to other safeguards criteria such as the detection time and the containment possibilities in reactors irradiated fuel elements.

2. Closing a verified material balance around each zone, supplementing the present MBA balances for more sensitive facilities and replacing them for others.

A model fuel cycle has been defined (2.6, 3.4, 4.3) for the purpose of developing the concept of fuel cycle based safeguards and to investigate the possibilities of establishing verified material balances around each zone. The reference fuel cycle comprises of a number of LWR's supported by conversion and fabrication facilities, spent fuel storages, reprocessing, MOX fabrication, and LWR recycle facilities as well as some R+D activities. The zones about which material balances are closed are those containing natural uranium and LEU, spent fuel, and separated plutonium.

All flows in and out of zones are verified, and PIV's are made and balances closed annually around each zone. In the third zone with separated plutonium, balances are also verified around each MBA at intervals governed by the present timeliness criteria. In the second zone with the reactors and spent-fuel storages C/S measures and inspections verify the presence of material at three monthly intervals and the occasional transfers between facilities. In the first zone with LEU, no internal flows are verified.

Provision is made for other facilities that are not included in the three zones. Any enrichment plants would be covered individually, with separate, verified material balances. R+D facilities, including those involving plutonium fuel developments, would also be outside the zonal boundaries. Provision can be made for verification of flows associated with all MBA's, both facility and zonal.

The preliminary investigations by de Montmollin and Gupta show (2.6, 3.4) that verified material balances can be drawn around each zone without increasing any of the present-day inspection activities at the facilities. Some marginal additional computer calculations might be necessary at the IAEA headquarters. The investigations of Higinbotham (4.2) indicate that, it would be useful to retain the facility base structure for the zone 3 materials, since it might permit a better resolution of anomalies by the Agency with regard to location, amount and time of a possible loss or a diversion of nuclear materials.

3. Maintenance by the Agency of a current book inventory for each facility location by means of immediate, abbreviated reporting of interfacility transfers.

The contributions of de Montmollin and Gupta (2.4, 2.5, 2.6, 3.4, 3.5) in particular, the detailed analysis of de Montmollin on the possibilities of material balance closings in a fuel cycle based safeguards system, indicate that an inspector validated accounting system for the flow and inventory of nuclear materials for all the three zones, is possible on a near-real-time fashion. The present-day practice of the Agency generates virtually all the necessary information for this purpose. The near-real-time treatment of the information flow from a state to the Agency may improve the timeliness and transparency of the reporting system of the state. The time required by the Agency to report formally to its Board on a diversion after it has been definitely detected by the Agency, is not expected to be shortened by a fuel cycle based safeguards approach (3.5).

4. A modified set of inspection criteria which reflect what can be attained for each material-balance closure.

The inspection activities for individual facility types had been analysed in detail in the frame of SAGSI activities. They were specially compiled and extended where necessary for the purposes of fuel cycle based safeguards by Gupta (3.4). The types of actual inspection activities at the facilities under the conditions of fuel cycle safeguards, are not expected to be altered much, although the intensity and frequency of inspections may be different. However, the inspectors would be required to recognize the important cross linkages, correlations and interdependences of the flows and inventories of nuclear materials amongst the different facilities and zones in the fuel cycle in a State as well as those of the fuel cycle and the outside world. The overall effectiveness and credibility of fuel cycle based safeguards can be improved if the capabilities of the Agency inspectors to recognize the normal flow and inventory patterns and their deviations on the one hand and their capability to verify these flows and inventories on the other, could be combined properly. Further investigations under practical conditions would be required in this area.

5. A periodic statement of findings for the entire State that takes the form that there is assurance that all nuclear materials under safeguards are accounted for to some stated degree of uncertainty.

It was mentioned earlier that a fuel cycle based safeguards would require in all probability, a different concept for inspection goals and the safeguards relevant statements. De Montmollin has investigated this problem in his Working Paper V (2.8). It is found that in a fuel cycle based safeguards, the presently accepted (eventhough provisionally) fixed goal quantities per facility would put the Agency in an untenable position. The total quantity that might be diverted below the detection threshold is a function of the number of facilities in the State. If the threshold for the State is raised proportionate to the number of facilities, there is no longer any justification for the present values.

If the present values based on a one-bomb quantity are applied to the entire State , that would require that more intensive measures be applied to the same kind of facility in a State with a large fuel cycle than one with a small one, which would in no way reflect the relative needs for the assurance that safeguards are intended to provide. The investigations show that the Agency could make reasonable safeguards relevant statements with a different type of inspection goals, e.g. variable inspection goals for individual facilities and a fixed threshold for the State as a whole or vice versa. "Fixed" in this connection does not mean an absolute amount but a fixed criterion.

This possibility needs further investigations.

The main purpose of the contributions which follow is to present ideas for more basic concepts by which IAEA safeguards might be made more effective and efficient within the basic structure that was adopted for the NPT safeguards.

The contributions of Messrs. J.M. de Montmollin, D. Gupta and W.A. Higinbotham on the various aspects of a fuel cycle based safeguards system are presented in the following pages. The contributions under the name of the author are arranged chronologically.

2. Contributions by James M. de Montmollin, Sandia Laboratories, Albuquerque, N.M., USA.

2. Contributions by James M. de Montmollin
Sandia Laboratories, Albuquerque, N.M., USA

2. 1	A Suggested Concept for Improved IAEA Safeguards	Aug. 6, 1984
2. 2	Further Thoughts on a Suggested Fuel-Cycle Safeguards Concept	Aug. 23, 1984
2. 3	Working Paper I : Extended MBA's	Nov. 1, 1984
2. 4	Working Paper II : Zone-1 Accounting	Nov. 28, 1984
2. 5	Working Paper III: Zone 2 Accounting	Dec. 13, 1984
2. 6	Working Paper IV : Zonal Flows	Jan. 11, 1985
2. 7	Excerpt from a letter of J. de Montmollin to W. A. Higinbotham with comments on extended-MBA approach for Zone 3	Jan. 11, 1985
2. 8	Working Paper V : Goals for Fuel Cycle Safeguards	Feb. 1, 1985
2. 9	Zone 1 Flow and the Neutron Collar (Excerpt of a letter from J. M. de Montmollin to D. Gupta dated 19th April 1985	Apr. 19, 1985
2.10	Distribution of Safeguards Inspection over the Fuel Cycle	Apr. 23, 1985

2.1 A Suggested Concept for Improved IAEA Safeguards

Following recent discussions at Brookhaven, this paper is intended to document my understanding of a concept for improved safeguards suggested by Dipak Gupta, which we intend to explore and develop.

We seek to improve the IAEA safeguards system in two respects: the timeliness of findings derived from each inspection activity, and more efficient use of inspector resources, measured in terms of the contribution of inspection effort to the safeguards objectives.

With regard to timeliness, the usual consideration of inspection interval is overshadowed by the total time required to generate, receive, and analyze all information and arrive at a conclusion for each separate facility. The system would better meet the purposes for which it is intended if more current information on a State's entire nuclear-material holdings could be obtained, thereby providing more up-to-date assurance that all were accounted for. At the same time, if the safeguards system were coordinated to verify the flow of materials through the State's nuclear cycle the information obtained from each facility could be used more efficiently in providing assurance regarding the State as a whole - the ultimate purpose of safeguards - than if each facility is considered in isolation.

There is an inherent conflict between timeliness, to the degree that safeguards designers have sought, and the completeness of verification. If both objectives are to be accomplished, it is necessary to recognize that safeguards operations are applied in two stages, as with interim and annual inspections of power reactors, or continuous inspections and cleanout inventory-takings of some bulk plants. One dimension of assurance derives from the more complete verification at longer intervals; another from the more frequent verification of some part of that information so as to maintain more current accounting of all of the State's safeguarded materials. It is for the latter purpose that improvements might be made.

Figure 1 is a simplified representation of an advanced State fuel cycle. Any State fuel cycle would include some, but not necessarily all, of the same elements. A significant point is that in all transfers between facilities

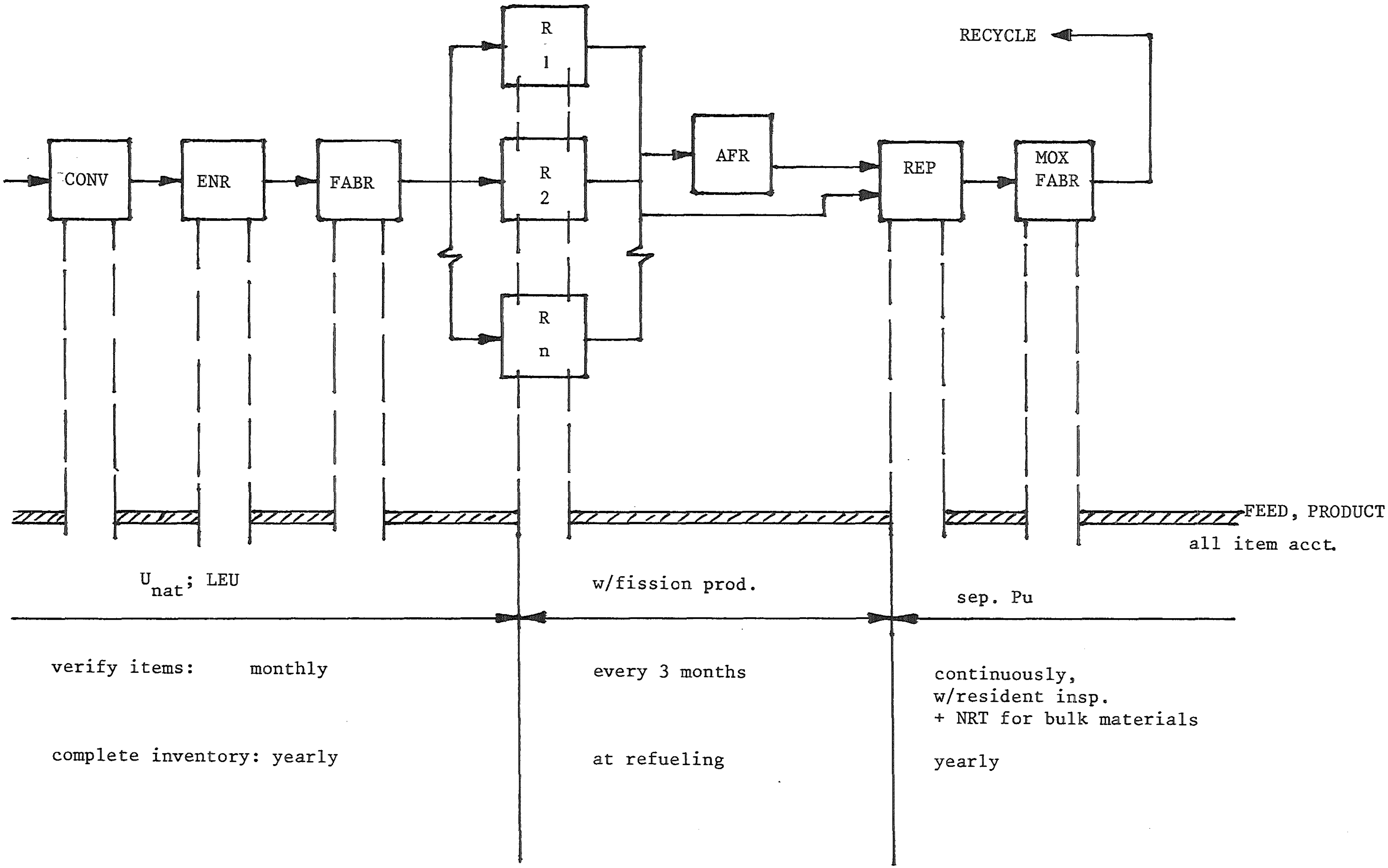

FIG. 1: Concept for Fuel-Cycle Safeguards

material is in the form of discrete items, such as fuel assemblies or individual containers of bulk material. The same is true of those materials held at each terminal point, which could be defined generally as feed and product.

Another point indicated in the figure is that the cycle can be divided into three phases that reflect the sensitivity of the nuclear material, wherein the forms are LEU, Pu associated with fission products, and separated Pu. The differing importance of materials in the three phases is reflected in the intervals between inspection verifications.

The suggested new concept includes the following:

1. The first step in an inspection cycle would be on-site inspections, to verify discrete items, that are conducted on scheduled dates jointly by the Agency and the State. Such verification might include item identification, seal checks, and sampling of contents as appropriate.

   Each party would thereby obtain a verified listing of the item inventory. That would cover all material not in process, ranging from perhaps 60 percent to 100 percent of the total material inventory at each facility, and the portion that is in the form most readily available for diversion or seizure by the State. Those inspections would be done at the same intervals as the present interim inspections: monthly for LEU, every three months for irradiated fuel, and continuously by resident inspectors for separated Pu. (For fresh LEU fuel at the reactor the logic falls down; it might be more appropriate to continue to include it in the schedule for irradiated fuel, as at present. Also, MOX fuel after it leaves the fabricator requires further thought.)

2. Where separated Pu is present, as at reprocessing and MOX plants, the bulk material in process would be monitored by resident inspectors by means of NRT accounting, using operator information, partially but independently verified by appropriate sampling, C/S, or other such measures.

3. Complete physical-inventory taking would be done annually (or at LWR refueling) jointly by operator, State, and Agency.

4. Inventory change reports would be submitted periodically, as at present, to allow the Agency to update its book-inventory records. Preferably, abbreviated ICR's covering transfers between facilities would be submitted within 24 hours, so that the Agency's records by facility would not be subject to the delays now experienced with the State reports, ranging from a nominal 45 days to several months or more.

The suggested concept could provide the Agency with continually-updated book inventories by facility location, with most of that verified by inspection as frequently as is done now, but with much quicker availability of results; a reduction in accounting and analysis effort through joint inspection with the State rather than later verification of outdated book-inventory information; and the basis for conclusions regarding the State's entire inventory rather than by individual facilities. The appropriate intensity of complete inventory verification as a function of the significance of the forms of materials would be unchanged.

In evaluating the suggested concept, it is important to retain as a reference point the proper understanding of the purpose of safeguards. As set forth in the NPT, INFCIRC/66, and INFCIRC/153, it is the verification of accounting for nuclear materials, and not the detection or deterrence of diversion as the primary function. The objective in seeking to improve safeguards should therefore be in the direction of more complete and timely verification of the Agency's book-inventory records rather than to block more hypothetical diversion paths.

2.2 Further Thoughts on a Suggested Fuel-Cycle Safeguards Concept

In a working paper dated August 6, I described a concept for State-wide integrated safeguards that had been suggested by Dipak Gupta for further consideration. In this paper I explore certain aspects of the concept in greater detail.

A central feature of the suggested concept is the joint verification by the State and Agency of feed and product book inventories at each facility at interim inspections. Book inventories of materials in process are updated and partially verified thereby, at appropriate intervals depending on the sensitivity of the material. Feed and product stocks are essentially all discrete items, and in-process inventories are normally held within nominal limits. Since a large fraction of a State's total inventory is in the form of feed, product, and inactive stocks, essentially all in the forms of discrete items, a large part of a State's nuclear-material inventory can be verified in a timely manner. How large a part?

I have made estimates of the fractions of a hypothetical State inventory that would be in discrete and in bulk form. The model cycle was defined by Avenhaus and Gupta in a paper presented at the 1970 IAEA Symposium on Safeguards Techniques, Vol. 1, p. 345, "Effective Application of Safeguards Manpower and Other Techniques in Nuclear Fuel Cycles." The fuel cycle consists of 12 LWR's (6 GW_e), enrichment, LEU fabrication, storage of Pu, U recycle, and conversion. Quantities for input, holdup, output, and waste are given for each facility in terms of absolute chemical-compound weights and effective kilograms. I made the following assumptions regarding inactive quantities, which were not covered in the model cycle:

1. A two-year stockpile of yellowcake.

2. An accumulation of spent fuel equal to five years of discharge from each reactor, not including an additional one-year discharge stored at each reactor and considered as active stock.

3. An accumulation of separated plutonium equal to five years' production of the reprocessing plant.

Table 1 shows the percent of material in the form of discrete, packaged items broken down by facility type and type of inactive stock, by absolute weight of the chemical compound in which it is contained and by effective kilogram. Absolute weight is significant in terms of the inspection effort required to verify the inventory, and effective kilogram reflects the safeguards sensitivities. It turns out that the percentage of material in discrete form is essentially the same in either case.

As mentioned elsewhere, the concept envisions:

1. Periodic, joint State/Agency verification of feed, product, and inactive inventories at intervals generally corresponding to present interim inspections. As the table indicates, that could cover more than 95 percent of the State's total inventory, generally that which is in discrete form. Assurance would be further strengthened by correlation of shipper/receiver transactions between adjacent facilities in the fuel cycle. By that means, over 95 percent of the State's total book inventory would be verified.

2. Input/output correlations would partially verify the in-process book inventories of holdup-material, which would be generally in bulk form. C/S, NRT accounting, and resident inspectors as appropriate would provide further assurance between cleanout inventories, at which time complete material-balance closure would be attained. That would be nominally at yearly intervals, adjusted to conform with reactor refueling or shutdown between campaigns.

Thus, more than 95 percent of the Agency's book inventory of a State's nuclear material holdings would be verified at each minimum inspection interval, and limits would be set on the possible discrepancy in the remaining (holdup) inventory).

Table 1 Percent of Nuclear Material in Discrete-Item Form

	Active Stocks	By Absolute Weight	By Effective kg
Plant:			
	Conversion to UF_6	88	84
	Enrichment	75	77
	Conversion to UO_2	87	83
	Fabrication	79	77
	Reactors	100	100
	Reprocessing	86	82
Aggregate		96	96

	Inactive Stocks	By Absolute Weight	By Effective kg
	Yellowcake	100	100
	Spent Fuel	100	100
	Separated Pu	100	100
Aggregate		100	100
Grand Aggregate		97	99

How much assurance would be provided depends on the beholder. There are those who will immediately point out, taking the conventional view of safeguards objectives, that there are many significant quantities of material in the only-partially verified in-process material, regardless of the overwhelming fraction of the State's holdings that had been verified. To that, there are several counter arguments:

1. The conventional view of safeguards objectives--the "timely" detection of a diversion of one bomb's worth--does not deal realistically with the proclaimed timeliness objective, and it does not address at all the possibility of aggregate diversion from a number of separate facilities within a State.

2. A more fundamental argument is that the purpose of safeguards is to provide reasonable assurance that the State's entire inventory of nuclear material is verified by the Agency. That position is solidly grounded in the IAEA Statute, the NPT, INFCIRC/66, and INFCIRC/153. Measured against that criterion, and considering the resource limitations and the other constraints under which the Agency must operate, the suggested concept should appear to an objective observer to provide considerably more assurance than the present concept.

3. For those who are unwilling to judge safeguards by that standard, the suggested concept offers at least as much as the present one: the information available on each facility taken in isolation is no less than that which is now available. For those who would gain further assurance from the degree of verification suggested by Table 1, the new concept should provide much more confidence in safeguards. What that suggests is the need for a reorientation of thinking, and public indoctrination, on the purpose of safeguards as defined in the Statute and the Treaty. The differences between the two views of safeguards purposes assumes much greater significance when the entire fuel cycle rather than individual facilities in isolation are addressed.

2.3 Working Paper I: Extended MBA's

It seems worthwhile to reflect on the reasons why fuel-cycle rather than isolated-facility safeguards may offer advantages. Depending on how much relative value we may put on each particular objective, it may help clarify our thinking in developing the concept.

Some potential advantages are:

1. Findings from inspection activities relate more directly to the purpose of safeguards, which is with regard to the entire State and not individual facilities.

2. Analysis of coordinated information from all the activities in the State should produce more meaningful results than analysis of each facility in isolation.

3. Safeguards resources can be better allocated to each facility in the context of the entire State fuel cycle, because the relative significance of a particular kind of facility depends on its function in the overall State fuel cycle.

4. Closing of material balances requires verification of both flows and static inventories. Flow verification requires much more frequent inspection at some types of facility than is necessary solely to meet timeliness objectives. MBA's extended to include more than one facility allow the selection of KMP's where flows can be more efficiently and effectively verified.

There may be other advantages that might become apparent as we examine the problem in greater depth. With these possible advantages taken to be objectives, we can investigate various alternatives to see how well they might be accomplished.

Les Fishbone and Willy Higinbotham are working independently on a study with a similar objective, although it is stated in somewhat more restrictive terms (1). While their work explicitly addresses the question of optional allocation of inspection resources over the fuel cycle, other of the above objectives might also be served. They are studying one approach, based on dividing a hypothetical State fuel cycle into "extended MBA's". Three extended MBA's, or zones, are envisioned: Zone 1, with only LEU or natural U; Zone 2, irradiated fuel; and Zone 3, Pu separated from fission products. The boundary between Zones 1 and 2 is the loading of fresh fuel into the reactors and between Zones 2 and 3, the disolution of spent fuel at the reprocessing plant. The intensity of safeguards measures in each zone would reflect present inspection goals, and "sub-MBA's", or MBA's similar to those used at present, would not be precluded.

For our purposes, we should consider the idea of extended MBA's as one alternative approach to meeting the more general objectives listed above. I start with the assumption that a more optimal allocation would be a reduction in Zone 1, and that measures heretofore considered for Zone 3 would be at least the minimum that should be considered. For now, I will limit the discussion to Zone 1.

The input to Zone 1 is the importation of enriched uranium in any of several chemical forms, or, if the State has an enrichment plant, the shipment of enriched uranium to a conversion or fabrication plant within the country (2). Since international transfers are of primary importance to safeguards, each shipment will be verified in any case. The output KMP for Zone 1 is at reactor refueling. That flow could be verified, as is presently done, by the inspector at refueling. Unless additional inspector visits were made at all reactors at the same time, the PIV for Zone 1 could not be taken simultaneously at all locations. (Electrical demand would preclude the shutdown of all reactors for refueling at the same time.) At the time the annual PIV was taken at the conversion/fabrication plant, fresh-fuel stocks at reactors might be verified on a random-inspection basis. Or, the actual presence of assemblies reportedly shipped to reactors but not yet loaded into cores might be assumed for purposes of timely closing of the material balance, to be verified at the next inspector visit to the reactor.

If a State has more than one conversion or fabrication plant, simultaneous PIV's there would also present a problem. Plant schedules would not necessarily coincide, and the demand for inspector services (both State and IAEA) would peak. Considering all of Zone 1, which contains numerous reactors as well, simultaneous inspections would create a problem for efficient scheduling of inspectors. We should look very critically at any arguments that are advanced in justification of simultaneous PIV's.

One argument might be that the material balance must be closed at a particular date, at the end of an inspection interval, wherein all inputs, outputs, and static inventories are brought together. Heretofore, with static inventories at individual facilities the timing was no problem. It is necessary in principle that a material balance be related to some time period. However, there is a distinction between the material balance on the basis of operator's data and the verification of that data by the Agency. Although an idealized concept envisions a material balance computed from measurements reported by the operator which is compared with a corresponding balance determined by the Agency on the basis of independent measurements, the actual practice usually falls short of that, especially with respect to facilities having less-sensitive material. All flows are not independently measured or verified, and the material balance determined by the Agency, when it is done at all, includes some unverified flows (3).

The reason why all flows are not verified is that, for LEU, the timeliness goal is one year, and the PIV needs be done only at that interval. (If a plant conducts its own PIV at a semi-annual shutdown, which is often the case, the Agency may do so at the same time.) Because inspector visits annually or semi-annually are too infrequent to verify flows, the Agency also conducts monthly inspections, on the basis that a least some of the receipts and shipments will still be available for inspection in verifiable form. In effect, the Agency makes 10 or 11 PIV's per year in addition to the annual or semiannual PIV during shutdown. While the justification for monthly inspections is to verify flows, the objective appears to be a complete PIV (4).

While each monthly inspection requires less manpower than the annual PIV, the total required is substantially more -- at least five times as much (5). The actual effort required may be even greater than estimates based on hypothetical model plants. Depending on the size of feed and product stocks relative to throughput, monthly snapshots would vary as representations of actual flows. If the stocks were small, corresponding to much less than a month's flow, a relatively smaller portion of the flow would be available for verification. If they were much larger the monthly inspection would have a higher probability of verifying a flow that would have occurred in the past, or would occur in the succeeding period. However, the larger the stocks the greater the inspection effort required for what is essentially an interim PIV.

The model plant that we have considered is defined in the SAGSI-WG-2 report. The UF_6 feedstock is about a 36-day supply, assuming a 300-day operating year. The product stock is about 31 days production, or about one fuel reload. The assumption is made that there is only one enrichment.

It appears that actual plant inventories would be substantially greater, something that we should examine carefully because it may be important to our investigations in other respects. Based on conversations with a middle manager at a US fabrication plant, a number of factors suggest that the model plant is unrealistic.

1. The UF_6 (or UO_2) feedstock should be on the order of a six-month supply, rather than 36 days, to ensure steady operation.

2. The assumption of a single enrichment is not realistic, because it leads to underestimation of inventory quantities. The model plant shows

average pellet and rod inventories of about five days respectively, which seems somewhat small for even one enrichment line. In most cases individual reloads will require several enrichments, which would be fabricated in separate, parallel process lines. It appears that the rod and pellet inventories should be greater by a factor equal to the number of process lines, typically 3 or 4.

3. Each of the many different enrichments -- for all reactors, there is on the order of 20 -- is obtained by the utility customer from the diffusion plant. (With centrifuge enrichment, some blending may be necessary, possibly in the conversion or LEU plant.) The utility retains ownership of the material throughout, and it must be ordered and accepted in accordance with the long lead times between enrichment and reactor loading. While it may be stored elsewhere, the fabrication-plant operator would require that it be shipped to his plant at least early enough to ensure a 6-month supply.

4. The uranium is not fungible (except for recovered scrap and waste, about six percent of the plant inventory). A single reactor reload would be built from a separate streams of material that are kept separate throughout the plant. The uranium is owned by the utility customer, and hence is kept separate for financial accountability reasons as well as to preserve the unique enrichment.

5. Because the uranium (and the complete assembly, after acceptance) is owned by the customer and not the fabricator, the associated inventory costs are not borne by the fabricator. Consequently, he has no incentive to move products out of the plant to reduce inventory costs. He may hold it for a considerable time for the convenience of the customer. Regardless of ownership, the material is covered by the plant's safeguards inspection.

6. Because of the long lead time between enrichment and fuel loading, there is uncertainty as to the date that the customer will want a

reload to be shipped. The initial schedule is fixed by the nominal refueling date, sometimes before the reactor is even completed. Any delay in refueling date, whether due to construction and licensing problems, accidents, or low capacity factor, extends the date at which the utility will want the fuel shipped. It is likely that those delays would be after fabrication is complete, because the fabricator would want to maintain his schedule and cash flow. The likely result is that when refueling is delayed more than one interval the fabricated fuel will be stored by the fabricator, thereby further increasing the inventory to be safeguarded. In one case the fabricator is storing a first reload indefinitely, because the reactor was cancelled before it was even finished.

I point out these things because it appears that we need to look critically at model plant specifications, which are the basis for inspection-effort estimates. As for the extended-MBA concept for Zone 1, it appears that much more effort would be required for the present approach than is indicated in the WG-2 report, if the safeguards approach were actually implemented as defined. According to the 1983 SIR, the average inspector man-days spent at fabrication and conversion plants was only about half the WG-2 estimate of what is required (6).

When we compare the extended-MBA concept for Zone 1 with the present concept, we need to look at them both realistically instead of in terms of hypothetical model plants and safeguards approaches. Flows at the KMP's bounding Zone 1 can be verified adequately by means that are already in place. Even though 80 percent or more of the inspection effort at LEU fabrication plants is estimated to be spent in the attempt to verify flows, and probably much more if the approach is actually implemented, the interim PIV's cannot actually verify all flows. Material could be deliberately passed through the feedstock or product inventories between interim inspections. A much more rigorous and verifiable material balance can be struck around Zone 1, using flow verifications that are already in place, than can be obtained around a single conversion or fabrication plant.

Another question, addressed at some length by Les and Willy, is the possibility of shuffling fuel assemblies between facilities to defeat the Zone 2-3 flow measurement. I don't believe that a feasible solution is simultaneous PIV's. However, I think the concern is exaggerated. Fuel-assembly identification counters that strategy. Identification is more than the serial number; only some of the assemblies in the pipelines from fabrication to reactor are identical, and so it is more than a matter of altering serial numbers. We should give it further thought, but simultaneous PIV's do not seem to offer a feasible solution.

Aside from the possibility of fuel shuffling, simultaneous PIV's are not necessary in order to close the material balance around Zone 1. For the particular time interval covered by the balance, different parts of the inventory will have been verified at different times. It is not necessary that all verifications coincide in time, as long as there is reasonable assurance that verifications previously made remain valid. If appropriate, seals might be used in some way to provide that assurance.

To summarize, I have tried to make five points:

1. To bring the safeguards coverage into better balance, we need to substantially reduce the effort allocated to the LEU portion.

2. The extended-MBA idea is worth careful study as a means of doing that.

3. The simplified model-plant specification for LEU fabrication plants is unrealistic. It understates the facility inventory and consequently the inspection effort needed for interim inspections.

4. The justification for monthly interim inspection -- to verify flows -- is overstated. While material-balance-closure around an LEU plant seems necessary on a facility-safeguards basis, adequate verification of flows requires an unreasonable proportion of inspection resources available for the fuel cycle as a whole.

5. The extended-MBA concept is entirely consistent with INFCIRC/153.

NOTES

1. L.G. Fishbone and W.A. Higinbotham, "A Study of Fuel-Cycle Approaches to IAEA Safeguards; ISPO Task C.55, draft report ISPO-196, July 1984.

2. If an enrichment plant is included in the State's fuel cycle it probably should be considered a separate zone, although nominally it contains only Zone 1 materials. For now, as with the ISPO project, we will assume that the State imports all its enriched uranium.

3. Although numerous papers over the last 15 years have described the determination of MUF on the basis of separate and idenpendent material balances by the operator/State and the Agency INFCIRC/153 does not require it. While par. 30 states that the Agency should determine material balances for each MBA, it does not say that all measurements that go into it must be independently verified. In a description of the process, the Agency says, with regard to the verification of flows, only that "Routine IAEA inspections may be carried out to verify these changes, and the records are examined and compared with the reports sent to the State". (IAEA Safeguards, An Introduction, IAEA/SG/INF/3, 1981, p.21)

4. IAEA draft paper, "Safeguarding Low Enriched Uranium and Fuel Fabrication Facilities", STR-157, August 1984, p. 46. Because of the problems of measuring the content of complete fuel assemblies, even if the inspector were available before they were shipped, inspection of material at various stages of fabrication is thought necessary. Since material actually in process is not generally available for inventory verification, in one plant material in buffer interim storage, in the form of pellets and rods, is inventoried monthly by safeguards inspectors -- A. Rota, et. al, "International Safeguards Verification Capabilities and Constraints in an LEU Fabrication Plant", ESARDA.

5. Draft, "Report of WG-2 of SAGSI on Safeguards Approaches", 5th August 1983, Table 3.1.1, p. 6. Conversion plants, shown in Table 3.1.2 on page 7, show also that about 5 times as much inspector effort is spent on the interim inspections.

6. The SIR lumps conversion and fabrication, use and direct use material into one figure, so it is not clear what was spent at LEU fabrication plants. In any case, it was substantially less than the WG-2 estimate.

2.4 Working Paper II: Zone-1 Accounting

In Working Paper I I discussed extended MBA's as an approach to fuel-cycle safeguards, with particular reference to the LEU part of the fuel cycle, referred to as Zone 1. In this paper I consider an accounting scheme for Zone 1 which is intended to provide a degree of assurance commensurate with the relative proliferation concerns in that part of a State's fuel cycle.

The scheme would provide (a) an annual material balance around each enrichment stream, with Zone-1 inputs, outputs, and inventories verified annually by Agency inspection, and (b) a current book inventory listing the U-235 holdings, by enrichment, at each facility and fuel assemblies by serial number and U-235 content at each reactor. The information in the Agency's current book inventory would be up to date to within 48 hours.

The suggested system would operate at two complementary levels that adress timeliness and verification respectively. Timeliness and full verification are conflicting objectives; completion of the verification process and the resolution of any anomalies may be as much as several month beyond the end of an inspection interval during which a diversion may have occurred. Information on changes in the quantities and locations of materials for which the State is accountable under safeguards can be reported as interfacility transfers occur, thereby providing the Agency with a current book inventory. The information can be partially verified by means of accounting cross-check, and periodically by inspection.

The present system for LEU and Natural U

The timeliness goal for natural and low-enrichment uranium is one year. At that interval the Agency intends to make statements, fully verified to the extent that available resources permit, assuring that all material under safeguards in each facility is accounted for. While one year has been accepted as satisfactory for a fully-verified statement, confidence in safeguards would be enhanced if the Agency could maintain current knowledge on the location of all material for which the State is held accountable.

That objective, while not stated so explicitly, is nevertheless implicit in the present system wherein Inventory Change Reports are required for the purpose of reporting any transfers from one MBA to another. They are to be submitted within 30 days of the end of each 30-day period during which transfers take place, but many do not arrive until considerably later. They report a level of detail that is needed at the PIV, and beyond what is needed to provide the more basic information on the total amount of material that is at that facility location. The information now provided by ICR's is more relevant to verification than timeliness.

Under present concepts for safeguarding LEU or natural U facilities, in principle a material balance is to be struck around each MBA. The model approach defines three MBA's for a conversion/fabrication plant (1). The material balance requires that flows into and out of each MBA be balanced against beginning and ending inventories. Thus, to verify the balance, the Agency must verify flows as well as inventories. The latter can be verified at the annual PIV, but flows occur continually while the plant is operating. Interim inspections are held every 30 days, for the purpose of at least partially verifying flows (2). However, flows are intermittent events, and the related inventories can give some indication of flows only by changes in stocks of identifiable, sealed items between inspections (and only if the item was present at at least one inventory-taking). Hence, flows are not very well verified in relation to the PIV. What is called a verified material balance is more accurately described as a verified annual inventory, which, combined with declared flows, produces a partially-verified material balance. Nevertheless, more than 80 percent of the nominal inspection effort is estimated to be required for interim inspections for the sole purpose of verifying flows (3). Furthermore, the Inventory Change Reports, being typically outdated, do not provide the declared value of the flows to be verified over the 30 days preceding an interim inspection. They serve little purpose other than provide the Agency with delayed information with which to update its book inventory.

As noted in STR-96 (2), when a plant receives shipments from an out-of-country enrichment plant or ships products to other countries those flows would be verified by the ad-hoc inspections required for international transfers under par. 91-97 of INFCIRC/153. However, transfers between MBA's within the plant or State would not be covered in that way.

Suggested Verification Scheme

Under the extended-MBA concept suggested for Zone 1 input, flows would be verified at the receipt of imported LEU and the output of a domestic reprocessing plant (if any), and the output would be verified upon loading into a power-reactor core or any exporting of fuel assemblies. The ad-hoc inspections would verify all flows involving international transfers. We will assume for now, that, if there is a domestic enrichment plant, all products will be verified before shipment. In the general case, outflows from Zone 1 will be at loading into reactor cores within the country. Since that is done in the presence of inspectors, all flows out of Zone 1 can be verified with existing, or only marginally increased, inspector resources.

The PIV at each bulk-handling plant in Zone 1 would be conducted essentially as now, to provide the inventory component of the verified material balance. Since there may be more than one such plant, as well as several reactors, the question of shuffling inventories as a cover for diversion arises. Simultaneous inventories should not be considered, because the Agency should not assume that it can dictate plant operating schedules, because electrical demand would preclude it for power reactors in any case, and because of the peaking of demand in IAEA inspection effort. Some other solution is needed, one that is commensurate with a realistic appraisal of the risk of diversion by that means.

In addition to the assurance afforded by the periodic verified material balance, the accountability trail through Zone 1 can be enhanced if it is divided into separate enrichment streams. There are many different enrichments, on the order of 20, used in LWR fuel. A material balance can be closed around each enrichment stream, with the qualification that several streams may merge, insofar as verification is concerned, when different enrichments go into a single fuel assembly. (An exception is that some part of the flow may be blended to new enrichments during processing. That is discussed below).

Fuel assemblies are uniquely identifiable items, and comprise many different groups that differ in mechanical details and enrichment. The outer rods can be easily assayed nondestructively. Each group of identical assemblies is used only in a particular model reactor, although there may be the same model reactor in more than one location. Bulk feed material is packaged in discrete containers before it enters the process stream. The package can be sealed and be made securely identifiable. Feedstocks comprise the major part of the bulk-plant inventories, and the identification of containers is associated with operating records and reports to the Agency. Thus, bulk material not in the process line, like fuel assemblies, is not fungible, and both are held accountable at the proper facility.

As noted elsewhere, shuffling scenarios require continuing actions to conceal a single diversion. Taking all these factors into consideration, I suggest that adequate assurance for Zone 1 could be provided even if the annual PIV's were not concurrent. The Zone-1 material balance could cover the period following the PIV at the principal bulk-handling plant in the State. The verified inventories at other plants and reactors could be adjusted on the basis of reported transfers, which would be verified during the next time interval. For the relatively lower diversion concerns of Zone 1, the objective should be reasonable assurance, not the covering of every less-likely diversion path. To keep things in perspective, we should not forget that the present facility-oriented approch does not address shuffling strategies at all. It can hardly be a serious criticism of any new fuel-cycle approach that it does not provide absolute protection against a diversion strategy that is not even considered with the present system.

The principal outflow from Zone 1 is reactor loading. The material balance for each enrichment stream would use reported values for the quantity of each enrichment. Those values would be checked individually for conformance with fuel-assembly specifications. The independent verification would be measurement of the average enrichment at the reactor, by means of the neutron collar. The verified material content of each assembly, identified by serial number, would be entered into the Agency's book inventory carried over into Zones 2 and 3.

Whenever verification is mentioned, some sampling level is assumed. The essential point is that the entire stratum be available for sampling at the time and place. That requirement would be met without additional inspector visits if the neutron-collar assay is done in connection with reactor refueling. That, and the importance of adequate flow verification at the KMP joining Zones 1 and 2, justify strong efforts to solve any problems that may arise. Fuel-assembly handling at that point may complicate refueling operations, and may necessitate inspector presence over a longer span of time. It may be desirable to adapt the neutron-collar for underwater operation, if that would help relieve those problems. Since refueling within a particular State or region will not generally be concurrent for more than a small number of the total reactors, neutron-collar instruments might be designed to facilitate movements between reactor locations.

The problem of calibration standards for the neutron-collar may pose difficult choices. I don't know enough about it at this point to do more than speculate. Does the calibration hold over time, or is it necessary to recalibrate at each use? If the former, it might be calibrated at the fabrication-plant assembly point, using an assembly containing rods verified by the inspector using a rod scanner. That might require additional inspector visits in order to calibrate for each assembly type, although at least some might be done at the annual PIV. If the instrument requires recalibration with time, and hence at the reactor point of use, maybe a cheaper, secondary standard could be calibrated at the fabrication plant as above, and used at the reactor for recalibration at use. If the calibration problems are as difficult as had been indicated, and in view of the importance of an NDA measurement at the outflow KMP of Zone 1, the system designers should work closely with the developers of the neutron collar to resolve any problems of calibration and impacts on refueling operations.

Enrichment streams are generally segregated throughout Zone 1, with two exceptions. One is the material recovered from recycled scrap, wherein the scrap from different enrichments is consolidated for recovery, blended as necessary , and fed back into the production line. Typically that is done entirely within a single facility, and so the individual enrichment accounting would not balance.

The amount of scrap on storage and process, where enrichments might be intermixed, is on the order of 3 or 6 percent of a conversion/fabrication plant's nominal inventory (4). The effect would be that the balance around the plant would show discrepancies in some enrichment streams, but they would compensate, so that the total U-235 flow would balance.

The other situation leading to imbalances in individual enrichment streams arises if feed material is not received at the exact enrichment needed, and blending is done within Zone 1 to obtain a new enrichment. That might be a common practice with centrifuge enrichment, where it is more difficult to provide separate custom enrichments. As with recycled scrap, the individual enrichment imbalance should be compensated in the complete U-235 balance. While custom blending might lead to changed enrichments covering a much larger part of the total flow, the correlation of individual-enrichment and total U-235 balance should provide adequate overall accountability, while preserving the assurance given by separate-enrichment material balances.

Current Book Inventory

The proposed scheme will provide a completely-verified material balance covering Zone 1, something that the present facility-oriented approach does not do. An objection might be that, since a part of the State's fuel cycle included in Zone 1 is not subject to interim inspections, it is less visible to the Agency and hence the continuing assurance is less timely, although it meets the timeliness criterion. The complementary part of the system is intended to meet those objections, by closer reporting ties with the State to enable the Agency to maintain a simplified book inventory that shows at all time the locations and quantities of material for which the State is held accountable. That information enables the Agency to state at any time how much material is where. In the event of any unexpected international development in which the State was under suspicion, the Agency would not be dependent on the State for information after the fact in order to be able to make a statement as to the current accounting.

The Agency's book inventory would maintain accounts of quantities of U-235 by facility and by enrichment, and of fuel assemblies by serial number. The accounting would be in units of U-235, with separate accounts for each enrichment. Information would be reported by the facility receiving or shipping material, by electronical message within 24 hours of receipt or shipment. The report would contain the following information, coded for abbreviation:

Reporting facility
Receipt (shipment)
Shipping (receiving) facility
Date received (shipped)
Total U-235 quantity in kilograms:
enrichment a
enrichment b
etc.
Container identification numbers e to f inclusive

For fuel assemblies, the following additional information would be included:

Type x:
serial numbers i to j inclusive
Type y:
serial numbers k to l inclusive
ect.

The Agency's book inventory would include separate accounts for fuel assemblies identified by type and serial number, for identified, filled containers transferred between facilities, and for the contained U-235. The item accounting would establish fuel-assembly accountability for Zone 2 and 3, through irradiation and the resulting changes in fissile content, to the point of final disposition.

For accounting purposes, U-235 would be considered fungible within each enrichment group. The Agency's requirement would be that it maintain current information on the quality at each enrichment level at each facility, for which the State is to be held accountable. For fuel assemblies, the primary accounting unit is the individual assembly, which is not fungible. The accounting trail for each assembly begins in Zone 1 when it is shipped from the fabricator, and continues until it is dismantled at the reprocessing plant (or safeguards are terminated at final disposal). After initial fabrication, the fuel assembly is the unit of accounting; it is treated as a sealed unit containing a declared quantity of U-235 at each enrichment level, subject to verification of the aggregate U-235 quantity by NDA and by analysis at dissolution.

Summary

The suggested accounting scheme for Zone 1 would provide a verified material balance in conformance with the timeliness goal of one year, with a partially verified, continually-updated book inventory by which the Agency has available current information on the quantities and location of all material for which the State is held accountable. It would provide more current information and more rigorous verification than the present system, along with a substantial reduction in inspection effort.

The scheme would establish the item-accountability trail for fuel assemblies, which would be the principal basis for accounting in Zone 2, from which the material enters Zone 3 at the reprocessing-plant accountability tank.

NOTES

1. S. Ermakov, Safeguards Approach for Low Enriched Uranium Conversion and Fuel Fabrication Plant (LWR Fuel), IAEA/STR 96, draft, August 1980.
2. STR-96, p. 28.
3. Report of WG-2 of SAGSI on Safeguards Approaches, draft, Aug. 5, 1983, Table 3.1.1
4. STR-96 indicates about 3 percent; in one U.S. fabrication plant producing a variety of fuel types the estimate is 6 percent.

2.5 Working Paper III: Zone-2 Accounting

In Working Paper II, dated November 28, a concept for materials accounting in Zone 1 was suggested. Zone 1 comprises the LEU and U_{nat} parts of an LWR fuel cycle, except for enrichment plants. The input is the receipt of imported uranium, natural or enriched, and the shipments from any domestic enrichment plants; the outputs are loading of fuel assemblies into the cores of in-country reactors and any export of fuel assemblies to other states. Under the zone concept internal flows would not be verified.

Zone 2 is defined as all activities within a state that involve irradiated fuel. The Zone 1-2 boundary is at reactor refueling, and a fuel assembly moves from Zone 1 to Zone 2 when the reactor head is closed. All accounting in Zone 2 is by discrete items, nominally identifiable fuel assemblies. When items are consolidated within Zone 2, as when multiple fuel assemblies are sealed into a single storage cask or the item identity is otherwise transformed, the transition must be verified. It is assumed that any subsequent form that fuel assemblies take within Zone 2 will be discrete and identifiable as an accountable item.

Although accounts may be kept of the material content of items in Zone 2 for other purposes, that is not the basis for accountability. Such other purposes might be annual reporting of safeguard operations by the IAEA or for verification of inputs to Zone 3 by assay at the reprocessing-plant accountability tank.

The figure shows possible flows among Zone 2 facilities. Different states would have some, but probably not all, of those shown. Possible flows out of Zone 2 are (1) at the dissolver of an in-country reprocessing plant, (2) at the point of transfer to another state of fuel assemblies are exported, and (3) with geologic disposal, when safeguards are terminated. The corresponding key measurement points are (1) the reprocessing-plant accountability tank, (2) the storage pool of a reprocessing plant or other facility in another state, and (3) the final inventory inspection by which the Agency verifies that safeguards may be terminated. The case of permanent geologic disposal may be only hypothetical; it is included for completeness and consistency.

Timeliness

For the material in Zone 2 the timeliness objective is three month. "Timeliness" is generally understood to mean the determination of MUF: the closure of the material balance. That would require PIV's at each facility every three months. As with Zone 1, it would be desirable to reduce the inspection effort in Zone 2, if it could be justified on rational grounds.

Under the present approach for LWR safeguards, described in STR-80[1], PIV's are conducted annually (or at refueling) and interim inspections every three months. The interim inspection is stated to be for the purpose of examining surveillance information. Although a PIV of the spent fuel may be taken at the same time, for example to investigate any anomaly in the surveillance record, the timeliness objective is met if it is verified that there were no spent-fuel shipments. Closure of the material balance at intervals shorter than one year is not a requirement.

STR-80 did not explore the possibility of longer interim inspection intervals because the recording capacity of surveillance cameras was only three months (sometime two) and a visit was necessary to service the cameras. That is no longer a constraint; capabilities up to a year are technically feasible. However, the point is that the timeliness objective is now met on the basis of surveillance of transfers and not closure of the material balance. Under the zone concept the material balance is closed around the entire zone, not each facility. Flows into and out of the zone are verified as they occur. If PIV's are done annually, the timeliness objective is met on the same basis as now, except that inflows and outflows are verified more directly, as they occur. Hence, if interim inspections at the reactor were omitted, the timeliness goal would be met on the same basis as now: an annual PIV with material-balance closure, and interim verification of flows in and out of the MBA. Beyond that, the flows would be verified more effectively than under the present approach.

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1) Lovett and Tolchenkov, "Safeguarding Light Water Reactors", STR-80, IAEA, May 1979.

AFR Problems

Shipments to AFR storage will be a common activity in at least some countries. If the individual assemblies retain their integrity and identity in the AFR storage configurations, they could be verified at the PIV. However, in at least one case it is planned that transport/storage casks would be loaded at the reactor pool and remain closed thereafter, with no provision for opening them at the AFR. There is a need to verify the identities of the fuel assemblies loaded into each identifiable cask, in order to maintain the accountability trail, and that must be done at the reactor, at the time of loading. The annual discharge from a typical large reactor will require about 20 cask shipments, and a larger number would be required for some time to reduce the backlog. To have an inspector present at each cask loading would require a substantial increase in inspector effort.

The problem is the same, whether the present approach or the zone concept is adopted. It is not the verification of a flow internal to Zone 2 that is the problem; it is the verification of cask contents. Possible solutions are discussed in another paper[1].

A similar problem is the consolidation or reconstitution of fuel assemblies for more compact storage, if that is done at the reactor. Here also, the problem is not affected by the zone concept; it must be addressed in any case.

Summary

A general concept for Zone-2 accounting has been outlined, following the same approach that has been considered for Zone 1. The concept would meet the same criteria as with the present approach, but with more effective verification of flows.

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1) J.M. de Montmollin, "The problem of Material-Balance Closure with Certain Reactor/AFR Spent-Fuel Transfers", Working Paper, December 12, 1984.

Spent-fuel transfers from the reactors to AFR's are internal to Zone 2 and, applying the same criteria as under the present approach, a logical case can be made that camera surveillance at reactor pools is not necessary. That argument rests on the principle, as in Zone 1, that the materials within the zone would not be under continous surveillance between material-balance closures. However, the greater sensitivity of spent fuel may make it politically expedient to retain pool surveillance.

The problem of maintaining item identity through the transition from individual assemblies to closed AFR storage casks is independent of the choice between the present approach and the zone concept. It must be addressed in either case.

2.6 Working Paper IV: Zonal Flows

In earlier working papers I considered the fuel-cycle material flows associated with Zones 1 and 2. In this paper I include certain additional flows that may exist in some States' fuel cycles, and I define the zone boundaries for Zone 3.

In a recent working paper (5.7.44) Willy examined safeguards alternatives for Zone 3, comparing facility safeguards with an extended MBA. My tentative conclusion is that the principal basis for Zone 3 safeguards should continue to be on a facility basis, incorporating all such measures as near-real-time accounting and resident inspectors that have been considered, as may be appropriate. The reason is that Zone 3 covers all parts of the fuel cycle where separated plutonium is present, and the political acceptability of the entire safeguards system is dominated by perceptions of the adequacy of plutonium safeguards.

However, applying safeguards to each facility in Zone 3, including the closing of material balances around each, does not preclude also closing a balance around the entire zone. The objective is to make a comprehensive statement concerning a State's entire fuel cycle, which, because of the differing concerns regarding materials in the different zones, should logically be in three parts, with appropriate criteria for each. In Zone 3 the material balance can be determined from the information available from each facility, adjusted as necessary for different dates when PIV's were made at each facility. The zone material balances provide a quantitative basis for the statement of findings for the entire State, and they integrate the material balances from each facility, an important improvement over the present system. Whether the PIV's in each facility are simultaneous or not, the zone balance must be referenced to a particular time, and so it is necessary to at least implicitly address the question of material shuffling as a diversion strategy.

Willy did not include MOX fabrication and the subsequent disposition of the fuel in his analysis. Here, my purpose is to include all flows that might be encountered in any of the three zones. In developing a concept for fuel-cycle safeguards it is necessary to include all flows, in order to close the zone material balances. That is especially true in Zone 3, where plutonium and MOX fuels will continue for a long time to be involved mainly in R&D programs for thermal recycle and breeders.

Besides the separate facilities within Zone 3, facility safeguards should continue to be applied to enrichment plants and R&D facilities. The former is nominally within the definition of Zone 1. However, the potential for clandestine production and higher enrichments, as well as the general perception that enrichment is a particularly sensitive activity, justifies continuation of the present facility-based approach.

Until plutonium-fuel use has reached a stage of maturity, as LEU fuels have, Zone 3 will continue to be complicated by R&D activities and special situations. One aspect is that, in Zone 3, a State's "fuel cycle" is much less integrated than may be the case with the other zones. Development programs are often multinational, and Zone-3 materials are transferred to other States in various forms. Materials do not pass through a well-defined sequence, as in a mature fuel cycle.

At the same time, the nominal fuel-cycle sequence in Zone 3 should be the basis for fuel-cycle safeguards, anticipating the eventual operational use of plutonium-bearing fuels. Both situations can be accommodated in terms of a model fuel-cycle sequence, with provision for the inflows and outflows that are encountered during the R&D phase.

The figure shows a diagram of such flows for all three zones. It is intended to include essentially all the flows that may be encountered in a complete fuel cycle, including thermal recycle. Although no distinction is made between thermal and breeder reactors, it represents a combined thermal and breeder cycle as well. It provides also for R&D material flows that are associated with the operational fuel cycle. A particular State's activities may include only some of the flows that are shown, but the basic concept is unaffected if some of the flows are not encountered. Minor variations of those shown may also occur, but they are complete enough to illustrate what must be provided for.

The areas wherein material balances would be verified are enclosed by double lines. Those are: Zones 1, 2, 3; each facility in Zone 3; enrichment plants; and R&D facilities that interface with the fuel cycle, but are not part of it. Various export and import flows join the fuel cycle with those of other States because of such things as source-material imports, fuel fabrication for export, reprocessing services for others and by other States, trade in plutonium, and multinational recycle and breeder programs. All such flows must be included in the zone material balances. MOX fuel fabrication involves flows of U-Nat and LEU, which must be included in the Zone-1 material balance.

The zonal flow measurement points are numbered in the figure. Interzonal flows within the State, such as 7, 8, 9, 12, 13, 14, 15, 16, 18 and 19, could be verified at single points. Since both shipping and receiving flows are under the control of the same State, the credibility of the safeguards findings would not be enhanced by separate verifications.

The zonal boundaries shown in the figure are operational, and do not necessarily indicate physical location. For example, KMP's 15 and 16 would logically be at the MOX fabrication plant.

The KMP's for verification of international transfers (1, 2, 3, 4, 5, 6, 10, 11 and 17) involve more than one State. In principle, additional confidence could be gained by separate shipper/receiver verification. INFCIRC/153 provides for that (par. 71(c), 93, 96). However, a single verification at either the shipping or receiving end may be adequate, for several reasons. LEU is imported mostly from weapon States, and there should be little concern that they would be in collusion with safeguarded States in a conspiracy for the latter to divert. In few cases where non-weapon States may export LEU the concern should also be minimal.

If only one verification of international transfers is needed, should it be in the shipping or the receiving country? The safeguards concern is that imports are not understated and that exports are not overstated. Where a weapon State is the other party, it may be sufficient to accept their reported values as independent verification.

That would require that the safeguarded State also accept those values in the determination by the Agency of the quantity for which the State is held accountable (subject to minor adjustments when shipper and receiver disagree on measured values). Independent verification by the Agency at the weapon-State end has the practical disadvantage of requiring additional inspector presence in weapon States to verify shipments. Generally, it would appear that direct verification by the Agency, where necessary, should be at the facility within the safeguarded State where the material is accepted; for example, KMP's 1, 3 and 4 should be at the enrichment, conversion, and storage sites respectively.

The transactions covered by KMP'a 5, 6, 10, 11 and 17 will generally involve other non-weapon States. For 10 and 11, and particularly 17, the greater concerns over those materials should probably require independent verification at both the shipping and receiving ends. That would be necessary in any case for KMP 11, since the scheme requires closing a material balance around each separate facility in Zone 3, and perhaps for Zone 2 as well.

General Summary of System Concept

The figure diagrams the entire fuel-cycle safeguards concept, with appropriate differences among the zones. The Zone-3 scheme is the present facility-based approach, upon which is superimposed the closing of the material balance around the entire zone. The characteristic flows and inventories for the zone as a whole convey additional information on a timely basis that is relevant to verification of the State's compliance with its obligations. A principal objective of the current systems -- to keep all material continously visible by means of surveillance, inspector presence, and NRT accounting -- is retained. The location of all materials by facility is kept current in the Agency's book inventory by means of prompt, abbreviated facility-transfer reports to the Agency.

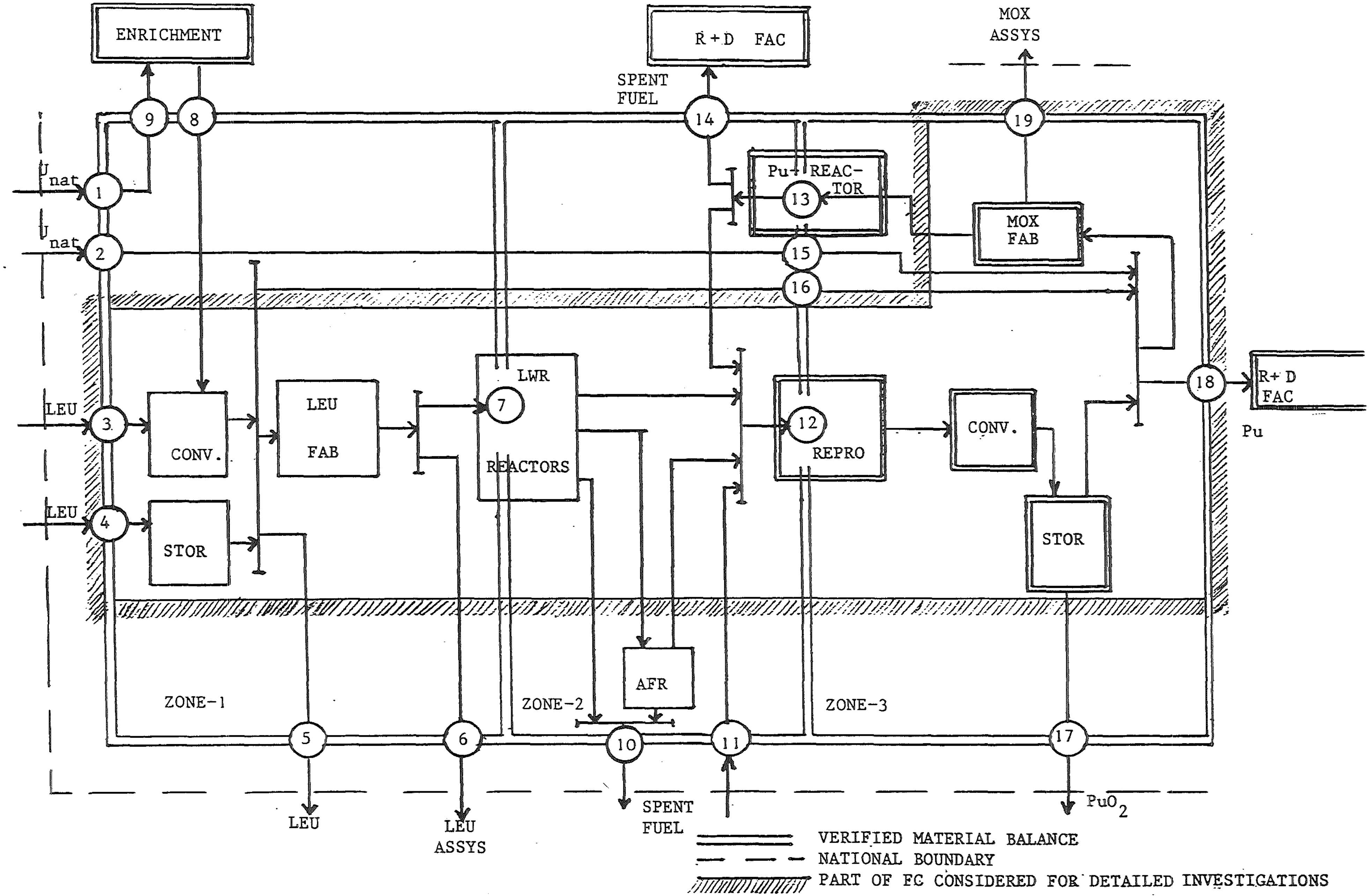
For Zone 1 the approach is fundamentally different. All flows in and out of the zone are reported and verified, providing the Agency with a current book inventory of the material for which the State is held accountable. Prompt interfacility transfer reports provide information on the reported locations of the material, to be verified at annual intervals. The essential difference from Zone 3 is that there is no attempt to maintain continous visibility of the State's Zone-1 inventory. It is verified only as required by the timeliness goal -- annually. At that time, only, is the material balance closed to verify that all the materials for which the State is held accountable are there. The Zone-1 approach meets the present objectives, may be, at a considerable saving of inspection effort, which is now largely applied to the verification of flows at each MBA in each facility.

The Zone-2 approach takes a middle ground, commensurate with the relative concern over Zone-2 materials. It takes advantage of the discrete nature of the material and the relative infrequency of interfacility transfers. Material balance are closed annually, as at present. Because the timeliness goal is 3 months, assurance is needed at more frequent intervals to verify that the material is still present. That is done, as under the present approach, by continuous instrumental surveillance to detect unreported transfers out of the facilities. Interfacility movements are relatively infrequent, and to the extent it deems necessary the Agency can verify them by ad-hoc inspections. The essential difference between the Zone-1 and Zone-2 approaches is that internal, interfacility flows are verified in Zone 2, responsive to the 3-months timeliness objective.

The product of the system in an annual material balance closure around each zone. That provides the basis for a statement of findings regarding the State that takes the following form:

> The Agency finds no evidence of diversion of nuclear materials from declared peaceful uses. All natural and low-enriched uranium is accounted for with a limit of error of ___% of the U-235 inventory with a ___% confidence level; all fuel assemblies are accounted for; and all direct-use material is accounted for with a limit of error of ___% of the inventory with a ___% confidence level.

The limit values and confidence levels would be the same for all States, and would be based on technical feasibility and not weapon capability. The values for Zones 1 and 3 might be different, but it may be politically expedient to make the limit of error for Zone 3 no larger than for Zone 1.



MATERIAL FLOWS —— ZONE CONCEPT

2.7 Excerpt from a letter of J. de Montmollin to W. A. Higinbotham which comments on extended-MBA approach for Zone 3, Jan. 11. 1985

The paper compares the extended-MBA approach for Zone 3 with the present facility-based approach. My conclusion is that, while the extended-MBA approach would provide most of what the present approach does, it appears to be a less intensive system. The biggest problem that IAEA safeguards face is the perception, mainly in the US, that safeguards for separated plutonium are inadequate or even infeasible. Any new approach that seems to be less effective would appear to those critics to be a copout and an admission that their objections had merit.

The closure of the material balance around each entire zone is the basis for the safeguards statement with regard to the State: that the presence of all the State's materials has been verified. I believe that the present approach for Zone 3 should be retained, and in addition the balance should be closed around the entire zone. The latter is largely an accounting step, since the facility balances provide all the field information that is needed. What the zone approach would add is the coordination of verification activities at the facility level and the integration of the facility results into a statement that goes into the Statewide findings with those from the other zones.

A statement on the zone balance addresses, at least implicitly, the problem of material shuffling. Whatever assessment of the risk and specific measures that the Agency may take, the statement would cover it. Material shuffling now is ignored altogether, providing one more contention for the critics.

A State's entire inventory cannot be covered anyway by the complete substitution of the zone approach for the facility approach. Enrichment plants are too sensitive to cover them on the same basis as other Zone-1 activities.

It will be a long time before separated plutonium is restricted to neatly-closed and balanced fuel cycles; meanwhile, R&D activities will continue to be an essential part of the Zone-3 safeguards problem. What is needed is a Zone-3 approach that anticipates a mature plutonium cycle, but which provides for the transitory R&D phase.

I agree with your other points also. I have already responded to your comments on Zone 1; your points are well-taken on Zone 2 also. In the enclosed paper I have brought all these things together, explaining some thoughts on Zone 2 and 3 and describing the system as a whole.

There is a subtle, but I believe fundamental distinction between the approaches for Zones 1 and 2 and for Zone 3. In Zone 1 and 2 the approach is to maintain a book inventory, updated by verified flow reports, that states what material the State is held accountable for. There is no attempt to keep the material continuously visible or to verify internal flows; the presence of the material is verified only at the annual PIV. The one exception is necessitated by the 3-month timeliness requirement for Zone-2 material. Since any spent-fuel movements are both infrequent and conspicuous, optical surveillance can be used to detect any transfer.

For Zone 3 there is a fundamental difference. In addition to verifying the presence of all materials periodically, an objective is to maintain continuous visibility of all materials and activities, to the extent practicable and feasible. One of the faults of the present system is that it attempts to do that indiscriminately to all safeguarded material, and not just in Zone 3. Under the proposed concept we would have:

1. A periodic statement covering all the State's holdings, based on the material balance for each zone,

2. For Zone 3 and other sensitive facilities, continuous observation by means of C/S, resident inspectors, NRT accounting, and the like, in order to provide further assurance by making those activities more visible and to provide more timely detection of anomalous events.

2.8 Working Paper V: Goals for Fuel-Cycle Safeguards

Much of the work on the fuel-cycle approach to safeguards has been constrained by a requirement that the present inspection goals are to remain unchanged. In view of the wide disparities in the numbers of facilities in the fuel-cycles of various States, it appears the present set of goals would be unworkable in any sort of fuel-cycle-based safeguards. An unresolved and generally-ignored problem is that the present absolute-quantity goals that are applied to individual facilities are based on the external consequences of diversion; hence, being applied to separate facilities in isolation, they have no relevance to the purpose of safeguards, which is assurance regarding the entire State. There is correspondingly less assurance the greater the number of facilities in the State. At the same time, a State with a larger number of facilities is likely also to have more sensitive materials in bulk form in some of them. Because the quantitative goals are not even technically feasible in some facilities, they are relaxed in the name of expendiency, but at the cost of undermining the entire rationale upon which they are based. For fuel-cycle-based safeguards, the present rationale puts the Agency in an untenable position. The total quantity that might be diverted below the detection threshold is a function of the number of facilities in the State. If the threshold for the State is raised proportionate to the number of facilities, there is no longer any justification for the present values. If the present values based on a one-bomb quantity are applied to the entire State, that would require that more intensive measures be applied to the same kind of facility in a State with a large fuel cycle than one with a small one, which would in no way reflect the relative needs for the assurance that safeguards are intended to provide. Beyond that, the more stringent goals apportioned to each facility would be infeasible as is now the case with a few large bulk plants, and the last remaining shred of justification would vanish.

The question of inspection goals seems to be inherent to fuel-cycle-based safeguards, regardless of how desirable it might be to address those two issues separately. In the case of the zonal concept, which is the principal approach to fuel-cycle safeguards that has been considered, what is to be the criterion for closing the zonal material balance? It would appear that that question is fundamental.

The problem of goals should be addressed concurrently with the development of a concept. Better, we should begin with the purpose of safeguards, working from that to the product needed from safeguards operations, to the details of the suggested concept. The following ordered description follows that sequence. It might provide the framework for the report. It could be prefaced by a statement that the work discusses a hypothetical concept that is based only on the NPT and INFCIRC/153, and does not address the merit or historical precedent established by the present set of goals. The following set of statements is a logical ordering of the problem defination, and it provides the basis for the sequential development of a solution.

1. The purpose of safeguards is to provide assurance that a State is complying with its obligations to use nuclear energy only for peaceful purposes.
2. As explicitly provided in the NPT and as practiced by the Agency in all its safeguards activities, that assurance is provided by a determination that all the State's materials that are under safeguards are verified as being in peaceful use (or storage).
3. "Material under safeguards" means, for NPT parties, all the State's nuclear materials as declared by the State, or as determinded by the Agency to have been exported to the State. For others, it means all material specifically covered by agreements with the Agency or another country. For present purposes, the discussion is limited to NPT States.
4. The Agency provides assurance by means of periodic statements that the State's material under safeguards is accounted for to the degree that it concludes that there is no reason to believe that any of it has been diverted to non-peaceful use. Routinely such statements are made annually. (Under abnormal circumstances, the Agency would report any situation whenever it deemed it appropriate to do so.).

5. The Agency statement that is most directly responsive to the purpose of safeguards is to the effect that all the State's material under safeguards has been accounted for by the Agency, qualified by a stated degree of uncertainty as to the quantity verified. In the design of the system the Agency strives for the lowest level of uncertainty that it can achieve, subject to limitations imposed by negotiated arrangements, available resources, and the technical state of the art. The same design goal will be applied to the same classes of material in each State.

6. Because of the differing degrees of importance of various materials for direct use in explosives, it is appropriate to extend the principal finding by subordinate, supporting statements covering the major classes of material: natural U and LEU, irradiated fuel, plutonium separated from fission products, including HEU.

7. Normally, the first three classes of material cover the complete fuel cycle, some or all of which may be involved in a particular State. Statements covering each are developed from information relating to the flow of materials through the cycle, among other.

8. Quantitative statements as to the degree that the material is accounted for by the Agency take the form of the closure of a material balance around the State's holdings of each class of material.

9. As appropriate, the Agency's statement as described above will be further supported by material balances closed around each facility and internal MBA, and by information obtained from containment and surveillance measures.

10. Periodic statements of assurance, as described above, are made annually, requiring that verified material balances be obtained at intervals no longer than that. Depending on the class of material, interim assurance may be obtained more frequently by means such as more-frequent balance closure,

C/S, NRT accounting, and resident inspection. Any unresolvable discrepancies will be reported by the Agency as early as it deems appropriate, without regard to the annual cycle.

The implied conclusion would be that present goals will have to go if we are to move to fuel-cycle safeguards with a rational basis. A second implication would be that the inspection goals for individual facilities would vary as a function of the quantity of material held by the State and the number of facilities over which it was distributed. One or the other alternative must be chosen: either a fixed threshold for each facility and consequently a variable threshold for the States, or vice versa. ("Fixed" does not necessarily mean an absolute value; it means a fixed criterion). There should be no question that the purpose of safeguards is with respect to the State and not facilities in isolation.

The sequential development described above would establish criteria for the entire State fuel cycle; it would allocate tolerances to each zone, taking account of the differing safeguards importance of each zone; and it would further allocate to individual facilities in each zone. The development of the goal structure would be the driving element; the zone concept and other features would follow from that. There appears to be an important function for the zonal material balances, in order to segregate the different classes of material as component parts of the final statement.

2.9 Zone 1 Flow and the Neutron Collar (Excerpt of a letter from J. M. de Montmollin to D. Gupta, April 19, 1985)

I have studied your March 18 letter and tables carefully. IMD/WSQ certainly seems to be a logical measure for the distribution of inspection effort. GOV/1982 does not explain how the values for WSQ were selected, and they might be improved upon, but for our present purposes it is better to stay with values that others have chosen rather than open more issues.

As your Table 7 indicates, the problem remains with Zone 1, unless something else is done to reduce the interim inspections at LEU fabrication plants. Most of the inspection there is to verify flows: 123 + 324 = 447 IMD vs. 33 for PIV. Since the model fuel cycle includes only LEU fabrication, and would not in any case be more than that plus separate conversion plants, the Zone in/out flows are essentially the same as the LEU-fabrication-facility flows. The PIV alone requires about two IMD/WSQ for the Zone, leaving little for flow verification. If the neutron collar is to be used, those measurements proper require about 1.3 times as many IMD's (Table 2) as the entire PIV. More than that, since each inspector visit requires more time than the actual measurements.

I suggest that we eliminate interzonal flow verifications entirely as separate verifications within Zone 1. The rationale is partly based on a point I made earlier: for Zone 1, the State is charged with the responsibility of accounting for materials that flow into the Zone, and the Agency verifies it with an annual material balance. That contrasts with the present concept of maintaining continuous visibility of each facility (Working Paper IV, p. 7). The two possible inflows to Zone 1 are imported LEU and the product of a domestic enrichment plant. For the latter, shipments would be verified by the Agency as part of the more intensive safeguards for enrichment.

The same would be true for any other enrichment plant under safeguards. However, much LEU comes from weapon States, where the availability of IAEA inspectors is unlikely. My idea is that the State would accept the responsibility of accounting for the quantity of LEU reported by the exporting State, without independent verification by the Agency. That would be the same quantity that it was paying for, and it would merely be accepting safeguards responsibility for it. Any S/R differences due to measurements would have to be resolved for financial reasons, and the adjusted values would be reported to the Agency. The outflow from the zone is more important to verify. For the State to be relieved of responsibility for a quantity of material, the Agency should independently verify the transfer. That does not require separate verification, since the interzonal KMP is the loading into the reactor core, which is an essential verification from Zone 2. Thus, interzonal flows in connection with Zone 1 could by verified entirely outside the Zone, by measures that would be necessary in any case.

As we have noted, fresh fuel assemblies are unique items with a very high unit value, both direct and in terms of the impact on reactor operations. The State would have every incentive to account for each assembly, ensuring that it would move into the reactor on schedule, whereupon the Agency could verify the movement from Zone 1. The State would also be motivated to help verify all inventories and waste streams in order to close the balance, thereby accounting for what it had been charged with. For the inflow of LEU imported from a weapon State, we can rely on the assumption of no collusion. That is certainly sound, since any collusion would be a most fundamental violation of the NPT Article I by the weapon State. Surely no one would contend that the safeguards scheme should cover such a possibility; if so, they would safeguard weapon States against Article-I violations!

We still have the problem of using the neutron-collar. Although everyone seems to think it is useful and needed, it should be rationalized in some way that is consistent with the Zone-1 strategy. Could a significant amount of material be taken from the inner rods of an assembly, without an unreasonable penalty to reactor operation? Would such a diversion be detectable at dissolution? Would that be too late? What is the difference in the detectable diversion quantity using the neutron collar and external gamma scan, and what is the effect of the diversion on reactor operation? Is the neutron-collar verification useful in connection with the reprocessing accountability-tank verification?

Assuming that the neutron-collar measurement is needed, the cost in IMD's must be held at a low level if the desired IMD/WSQ distribution among the zones is to be achieved. We might consider allocating 5 IMD/WSQ to Zone 1. With 2 for the PIV, that leaves 3 for the neutron collar, or about 50 IMD. In order for any sample testing to be valid for the whole population of a year's production of assemblies, each assembly must have an equal chance of being tested, and there must be assurance that none of the assemblies in the population is altered after the sample is taken. Judging from the activities listed in Table 2, an interim inspection to test a sample group of assemblies might require 40 MH, or about 7 MD. There could therefore be about 3 or 4 such visits in a year with 50 IMD, (assuming two inspectors), sampling a total of about 75 assemblies of population of 2160 in the reference fuel cycle. For valid sampling, the inspector visits would have to be randomized in time, and all assemblies on hand for a particular inspection would have to be made available. That would necessitate moving the assemblies for testing. All assemblies would have to be sealed, including those not in the facility at the time of the inspector visit, in order to ensure that no assembly was altered after the risk of being sampled had passed. That would require the application of some kind of seal by the operator at the completion of manufacture, the seal being valid for IAEA purposes. It is not clear that there is a solution to the sealing problem.

All of this seems to me to raise serious questions as to how the neutron collar can be used at the fabrication plant. The problem is already there under the present concept, and SAGSI has tried to deal with it, without success. My present opinion is that there is no way to use it there without a substantial further imbalance in the IMD/WSQ, we should not try to make a place for it in our concept. The remaining question is, could the neutron collar contribute something that is important to overall fuel-cycle safeguards, going beyond the individual facility or zone for which it has been envisioned thus far?

The problems that I have posed are inherent also in the present approach of trying to verify flows at LEU plants without excessive IMD/WSQ. Presently, neither is accomplished adequately. It appears to me that the neutron collar is a casualty, along with the other flow verifications in Zone 1.

That bring us back to my suggestion that no interzonal-flow verifications and no neutron-collar measurements be done in Zone 1. That would result in 2 IMD/WSQ for Zone 1, all for the PIV. That is not out of line with Zone 3 and with the U-nat cycle. As we have noted, Zone 2 is a special case, with no bulk materials and heavy coverage by C/S, and hence a different figure is justified. Maybe the neutron collar will find a home with MOX fabrication, where the stakes are a lot higher.

2.10 Distribution of Safeguards Inspection over the Fuel Cycle

NPT safeguards, unlike the earlier INFCIRC/66 safeguards that established the precedent for safeguards concepts, are concerned with a State's nuclear activities as a whole, rather than individual facilities in isolation. INFCIRC/153 calls for the concentration of verification procedures on the more sensitive stages of the fuel cycle (1). It also specifies the criteria for a differentiation of inspection effort, as a function of the characteristics of a particular State's nuclear establishment (2).

Those two sections of INFCIRC/153 are often mentioned in connection with fuel-cycle safeguards, and the Agency has contended that present safeguards meet those objectives to a considerable degree. However, much more can be done, leading to payoffs in effectiveness and efficiency.

Paragraph 81(a,b,c,d) calls for differentiation of routine inspection effort on the basis of material forms, the fuel cycle including the degree of international interdependence, and the SSAC. Only the first has been addressed explicitly, except possibly in the negotiation of individual facility attachments.

The form of the nuclear materials, except for different SQ's for LEU and HEU, is differentiated only in terms of inspection frequency, which is rationalized from conversion time. The diversion scenarios for various material forms postulate the existence of clandestine facilities of major significance, such as reactors, enrichment, fabrication, and reprocessing plants.

The assumed conversion times for running materials through those plants are a poor estimator of the risk that the plants exert, and hence timeliness, even as a relative measure, does not adequately represent safeguards concerns.

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1. INFC/153, 6c
2. INFC/153, 81

Material quantities are incorporated in inspection criteria only on the basis of "the quantity of fissile material in respect of which.... the possibility of manufacturing a nuclear explosive device cannot be excluded" (3). Since the same quantity of contained fissile material defines SQ (except for the two levels of enriched U), SQ does not reflect the relative risks of the different chemical and physical forms, nor the item or bulk configuration, nor its accessibility. SQ is merely an extreme limit rationalized on the basis of the consequence of an assumed diversion. Being a fixed, absolute quantity, it does not take account of the relative utility to a diverter of the great differences in material forms, and hence the risk, in relation to the size of a State's total fissile inventory.

The present rationales for both timeliness and quantity, questionable as they are for individual facilities, lose even that shred of credibility as measures of relative safeguards concerns when applied to the fuel cycle of a State as a whole. Consequently, they do not provide a suitable basis for the allocation of inspection effort over the fuel cycle.

With regard to quantity, SQ could be weighted by arbitrary factors reflecting the accessibility and other things that define the relative attractiveness, and hence the assumed risk of diversion. As long ago as 1980 the Agency arrived at the same conclusion, in categorizing bulk-material plants containing a variety of materials in terms of a single index of safeguards significace (4). SQ is adjusted by weighting factors to Weighted Significant Quality, as follows:

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3. IAEA/SG/INF/1, Item 89
4. GOV/1982, para 89

TABLE I

Weighting factors for converting SQ to WSQ

Type of nuclear material	Material form	Weighting factor
Plutonium and Uranium-233 and Uranium enriched to ≥ 20 % in uranium-235	metal or pure material compounds	1
	non irradiated mixtures and impure compounds	0.33
	irradiated	0.1
Uranium enriched to ≤ 20 % in uranium-235 Natural uranium Depleted uranium Thorium	all forms	0.02

There is an inconsistency in using as the basis for the verification threshold, and hence the allocation of inspection efforts, and WQS as a measure of safeguards significance. For parts of the fuel cycle with lower weighting factors, inspection designed on the basis of SQ are disproportionately large relative to the presumed need for verification reflected as WQS.

The basis for the values of weighting factors selected by the Agency is not available, but apparently it only covers the chemical form and the presence or lack of fission products. Other differences in material characteristics stated in par. 81(a), such as bulk or item form and accessibility in terms of the kinds of chemical processing to convert to direct-use material, might also be accomodated by appropriate weighting factors.

Par. 81(c), in part, and 81(d) provide for differences in inspection effort on the basis of the State's fuel cycle. As with 81(a), those differences are more logically related to WQS than to timeliness. Separate weighting-factors could be applied to further adjust the inspection-effort allocation on the basis of interactive flows among facilities internal to the State. International interdependence (81(d)) is a separate factor, and the inspection allocation can be further adjusted because it is assumed that separate States are not acting in collusion.

Par. 81(b) and the remaining parts of 81(c) cover differences that are unique to individual States, and hence they cannot be applied through universal criteria. However, guidelines might be developed for the application of quantified weighting factors in the negotiation of individual facility attachments.

The above suggests that the allocation of inspection effort as directed by par. 81 should be done by adjusting the SQ rather than timeliness. Timeliness criteria can always be applied on an arbitrary basis, and that is essential what is done now. There are two problems with using timeliness as the sole weighting factor. First, it is too crude a criterion to account explicitly for all the variables covered by par. 81. There are presently three levels of timeliness; one is constrained by the operational impact of PIV and another, one year, is merely an arbitrary outer limit. The third has no more real basis in terms of the proclaimed rationale of conversion time than the other two. What we have is merely a set of inspection intervals that reflect nothing more than relative, unquantifiable degrees of safeguards concern. As such, there is no reason to think the values are inappropriate, but they do not provide the scope for accomodating the factors covered by par. 81.

The other problem with timeliness as the variable for applying par. 81 is that the nominal values of one, three and twelve months are grossly distorted by the time required for the Agency to arrive at findings. An inspection at the end of the interval is followed by perhaps one month or more to analyze the results. The outcome is either that the State's reports are verified or that there are anomalies that must be investigated. Further analysis and possibly reinspection is necessary, requiring weeks or months. The final conclusion of the safeguards inspectorate is either that the State's accounting is verified, any anomalies having been concluded to be unrelated to diversion, or that the Agency is unable to verify the State's accounting. That result, reported to the Board, is the end of the safeguards inspection activity. The total time required, from the date of the last previous inspection to any report to the Board of an inability to verify, is on the order of three months in addition to the nominal 1, 3, or 12-month inspection interval. Thus, the differentiation in inspection effort on the basis of timeliness is not by factors of 1, 3, and 12; it is more like 4, 7, and 15. That range does not reflect the range of safeguards concern spanning separated Pu and HEU to depleted uranium.

The problem of fuel-cycle safeguards is essentially the allocation of inspection effort on the basis of par. 81. The factors specified in par. 81 are in effect indicators of relative safeguards concerns, and hence the problem is to match allocation with relative concerns. Resources are always limited, and consequently the inspection effort allocated to one type of facility is necessarily constrained by the need for balanced coverage. It follows that inspection goals in absolute, quantitative terms and based on multiple diversion scenarios cannot provide the basis for optimum allocation, unless the resources are at least sufficient to cover all scenarios to the degree deemed necessary. INFCIRC/153, par. 6 and 81 recognize that, and hence specify a basis for allocation beginning with the State's entire nuclear establishment and working toward the inspection of individual facilities.

Inspection goals must be in relative terms, so that they are adaptable to the resources allocated to each facility in the context of all the State's nuclear activities. The adjustments called for in par. 81 lead to differing levels of inspection activity for similar facilities in different fuel-cycle contexts, and therefore fixed-value goals cannot be applied to individual facilities. The necessary differentiation needed to cover the wide range of relative safeguards concerns cannot be obtained from timeliness alone; weighting more directly based on material forms is necessary, for the same reasons that the Agency uses WQS to categorize types.

3. Contributions by Dipak Gupta,

Kernforschungszentrum Karlsruhe, F. R. of Germany

3 . Contributions by Dipak Gupta
Kernforschungszentrum Karlsruhe, FR Germany

3.1	Draft Outline for a Joint Paper on Fuel Cycle Safeguards	Juli 31, 1984
3.2	Points to be Considered for the Joint Paper on Fuel Cycle Safeguards	Jan. 22, 1985
3.3	Telex to J. de Montmollin on Preliminary Analysis of Allocation of Inspection Efforts in the Reference Fuel Cycle	Jan. 24, 1985
3.4	Comments on - SQ (Significant Quantity) and WSQ (Weighted Significant Quantity) - IMD/yr; IMD/WSQ.yr - LE, LMUF in the Reference Fuel Cycle in Connection with Fuel Cycle Based Safeguards	March 18, 1985
3.5	Comments on - Nature of the Information System in a Fuel Cycle Safeguards System - Reporting System of the State - Pattern Recognition Methods - Timeliness of Agency Actions - Different Types of Fuel Cycle in Connection with Fuel Cycle Safeguards	April 12, 1985

3.1 Draft Outline for a Joint Paper on Fuel Cycle Safeguards
Structure and Content and the Necessary Investigations to be Carried Out

1. In this paper the following aspects of a fuel cycle of the safeguards approach could be investigated:

   1.1 How this approach could improve the robustness of the safeguards data base by improving the verification capability of inspections at the facilities.

   1.2 How the credibility and timeliness of the same data base could be improved by using the in-situ inspector validated material balance data base for a State's Reporting System.

   1.3 As a secondary result the investigations could also indicate how such an approach could open up possibilities of improved allocation of safeguards resources.

2. As a reference case , the fuel cycle studied by the SAGSI WG-2 or a modified version of it could be used for these investigations (3 LEU fabrication facilities, 20 light water reactors, 1 reprocessing 1 MOX and the associated storage facilities).

3. Some calculations would be necessary for the points 1.1 and 1.3. These investigations could preferably be carried out at BNL. They would involve the following types of calculation:

   3.1 Calculate the optimun allocation of inspection efforts with increasing number of inspection mandays per year for the following two levels, using the computer program for allocation of inspection efforts by Les Fishbone:

   i) Level two
   Full coverage as foreseen in WG-2 report for full allocation of inspection efforts.

   ii) Level one
   Inspection coverage without all redundant flow verification activities in the reference fuel cycle (e.g. input LEU fabrication facilities; input reactors; input MOX facility and any other activities found to be redundant in the reference fuel cycle).

3.2 Calculate the corresponding MUF and LMUF for the two levels using the operater's data for the individual facilities as well as for the super MBA one (consisting of reprocessing and MOX facilities with the corresponding storage areas) and the super MBA two (consisting of the three LEU fabrication facilities) by esablishing a material balance on the basis of the operater's data. MUF and LMUF need not be established for reactors since the material balance in these facilities are based on digital accountancy.

3.3 Investigations in connection with the possibilities of increasing the credibility of the data generated at the State's level by using in-situ inspector validated data base in connection with the relevant safeguards activities. They could be carried out by Jim de Montmollin and myself.

4. The proposed paper could be structured in the following way:

4.1 Introduction indicating the necessity and the expected results out of such investigations.

4.2 Short description of the base case consisting of the facilities in the fuel cycle as well as the relevant safeguards activities.

4.3 Parametric investigations to assess the influence of the proposed changes in safeguards activities for the fuel cycle as a whole on the robustness and credibility of the safeguards relevant data base.

4.4 Analysis of the results and concluding remarks.

3.2 Points to be Considered for the Joint Paper on Fuel Cycle Safeguards

1. Possibilities for readjusting the relative importance of the different categories of nuclear materials after taking into consideration the characteristics of the fuel cycle as a whole and subsequent possibilities of improving allocation of safeguards resources.

2. Timeliness of inspector validated safeguards information and the reporting system of the State.

3. Possibilities of improving the verification capability of inspectors at the facilities.

4. Alternative concept for inspection goals, and safeguards relevant statements.

3.3 Preliminary Analysis of Allocation of Inspection Efforts in the Reference Fuel Cycle

(Telex from Dr. D. Gupta, EKS to Dr. J. de Montmollin, Sandia Laboratories, Albuquerque, USA, Jan. 24, 1985)

Re. : Joint paper on fuel cycle safeguards in a State

Here : Preliminary analysis of allocation of inspection efforts in the reference fuel cycle

Basis: Estimates of inspection activities in IMD/yr for reference fuel cycle with neutron collar measurement system in LEU fabrication facility as considered by SAGSI WG-2.

Further assumptions for IMD/yr for other facilities:

- Enrichment facility 100
- Pu research facilities for fresh and irradiated fuel elements 100
- Pu recycle reactor 54
- Conversion facility in Zone one 16
- Storage facility in Zone one 4
- AFR in Zone two 10

Total IMD/yr in

- Zone one (1 conversion, 1 storage, 3 LEU fabrication facilities)	500 (18 % of total)
- Zone two (20 LWR's plus 2 AFR storages)	300 (11)
- Zone three (1 reprocessing plus 1 MOX)	1697 (61)
- Outside Zone facilities (1 Pu recycle LWR, 1 enrichment facility, Pu R&D facilities)	274 (10)
- Total IMD/yr for the reference fuel cycle	2771 (100)

Analysis:

1. Out of a total of about 2770 IMD/yr in the reference fuel cycle 1970 IMD/yr (70 %) are fixed (Zone 3 and outside Zone facilities). They are independent of zonal or MBA approach since material balances are to be closed around each MBA.

2. Out of the rest of 800 IMD/yr in Zones 1 and 2, only those IMD/yr which involve a coverage of material flows from conversion and storage to LEU fabrication in Zone 1 and from reactor to AFR in Zone 2 could be eliminated while changing from an MBA-based approach to a zone-based approach.
Preliminary analysis indicate that they would be in the range of 20 - 30 IMD/yr., i.e. less than 1 % of the total inspection efforts in the reference fuel cycle.

3. Out of 500 IMD/yr in Zone 1 about 240 IMD/yr are required for fuel assembly flow verification at the LEU fabrication which includes 160 IMD/yr for n-collar measurements. If n-collar measurements are to be transferred for those fuel elements which are sent to the reactors to the input KMP of the 20 reactors in the zonal approach, 104 IMD/yr will have to be transferred to the reactor input storage. This means increasing by 5 IMD/yr per reactor over the MBA approach. The rest of the 56 IMD/yr for n-collar measurements and 80 IMD/yr for the product end activities have still to be carried out at the LEU fabrication because fuel assemblies which are to be exported have to be n-collared in LEU fabrication. Sealing of all the fuel assemblies and other product end activities will also have to be maintained there. In other words, there would be no net reduction of IMD/yr in the zonal approach against an MBA approach in the first two zones because of the shifting of n-collar measurement activities from LEU fabrication to reactor inputs.

4. The main improvement of the zonal approach as discussed in our joint paper will therefore, not lie in a reduction in the inspection efforts. It will be more in the following directions:

i) Enabling the Agency to have a more objective basis for obtaining safeguards relevant statements for the State as a whole.

ii) Having a more effective and credible safeguards system which can achieve its goal with the technical means available to the Agency. However, this achievement of goals is obtained not by the zonal approach as such but by changing the nature of the goal, i.e. instead of trying for a statement for an absolute amount and the associated probability of detection, using a statement as you have indicated in your working paper no. 4 page 8.

3.4 Working Paper I: Comments on SQ; WSQ; IMD/WSQ.yr; LMUF in Connection with Fuel Cycle Based Safeguards

(sent in the form of a letter to J. de Montmollin and W.A.Higinbotham on March 18, 1985)

Enclosed herewith is the first series of my calculations in connection with fuel cycle safeguards. The main results are incorporated in the 8 tables included with this working paper. The first 4 tables include all the relevant data for calculating the distribution of inspection efforts in the individual facilities in the reference fuel cycle. The next 4 tables, i.e. tables 5-8, include data on throughput, inventories and inspection effort distributions for the reference fuel cycle as a whole based on the data for individual facilities. The last 4 tables actually form the basis of the preliminary analysis which follows in this working paper. I would suggest that you take the necessary material out of this information and prepare the joint paper as you may deem suitable.

As a reference fuel cycle I could use only such data which were available to me in connection with our work on WG-2 of SAGSI.[1] The data base for this reference fuel cycle is slightly different to that used by Willy for his analysis. However, this data base can be quite easily changed to the data base of Willy and the major conclusions or analysis are not influenced by the type of data base used.

I would like to restrict my comments in this paper to the following three subjects:

- Significant quantities (SQ) and weighted significant quantities (WSQ) in the three zones of the reference fuel cycle.

- IMD/yr; IMD/WSQ.yr; diversion scenarios.

- LE, LMUF in the fuel cycle.

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[1] Report of WG-2 of SAGSI on Safeguards Approaches Sept. 1983 (unpublished)

1. Significant quantities, weighted significant quantities in the three zones

Willy in his letter of February 25 had used IMD/SQ in the input or output stream in a facility to determine the adequacy of the distribution. As I had indicated in my telex of March 11, 1985, this ratio has been considered by many to be somewhat inadequate and rather insensitive to the influence of the distribution of inspection efforts in different facilities with different categories of nuclear materials. The SQ alone does not reflect the inaccessibility of nuclear materials (e.g. Pu in irradiated fuels) or the influence of detection time on the inspection efforts (e.g. in LEU fabrication facilities or facilities handling separated Pu). As a result, the Pu contained in irradiated fuel elements is given the same weightage as the separated Pu in a reprocessing facility although in actual practice these two types of materials are treated differently by the Agency. Similarly, the ratio IMD/SQ alone does not take into account those activities which are influenced by the detection time considered by the Agency for the different categories of nuclear materials. Besides, the ratio IMD/SQ in either the input or the output stream of a facility does not reflect adequately the activities which are carried out by the Agency in safeguarding materials in inventories or in the other stream which is not considered for arriving at SQ for the throughput. As a consequence, the Agency had been using the WSQ as an indicator for assessing the relative importance of the different categories of materials which may be present in a fuel cycle for the last five years. This quantity for a given category of material is obtained by dividing the actual amount of material in a stream or in inventory by the amount required for one significant quantity for that category of material and by the approximate detection time expressed in weeks. This is explained and defined in GOV/1982, para 95. The WSQ in a facility expresses in a more adequate fashion the relative importance of the materials from the point of view of safeguards since it takes into account the inaccessibility of the nuclear material as well as the timeliness factors. I have, therefore, used the ratio IMD/WSQ.yr for a large part of my analysis. You will, however, note that I have also included the corresponding SQ and the IMD/SQ in the relevant tables. Another point to note is that I have used as an indicator the sum of the input plus output plus the inventories expressed in WSQs. This is because of the fact that the inspection activities are carried out for inventories and for both the input and the output streams in a facility. Particularly these streams are relevant from the point of view of fuel cycle safeguards. They form the interface between the two consecutive zones in a fuel cycle.

You will note from Table 6 that the amounts of WSQ in zone 1 with 3 LEU fabrication facilities are 16, in zone 2 with 20 LWR 609, and in zone 3, in the reprocessing facility 254 and in the MOX facility 58. From this distribution one establishes the fact that the maximum amount of WSQs is present in zone 2 in the cores and wet storage facilities for spent fuels in the 20 reactors followed by a total of 437 in zone 3 and 16 in zone 1. If one now compares the different inspection efforts spent in these zones one sees that zone 1 gets a coverage of a total of 480 IMD/yr, zone 2 with the 20 reactors a coverage of 280 IMD/yr, and zone 3 with reprocessing and MOX facilities a total coverage of 1697 IMD/yr. This distribution of inspection IMD/yr brings out among others three interesting points. Firstly, about 70 % of the total inspection efforts are concentrated in zone 3 although only 33 % of the WSQs are used in this zone. Zone 2 contains 65 % of the total WSQs in the fuel cycle but receives 11 % of the inspection coverage, and lastly, the zone 1 receives 20 % of the inspection coverage although only 2 % of the WSQs are handled in this zone. These observations permit one to conclude that the zone 2 with the reactors receives an unusually low coverage whereas in zone 1 with the LEU fabrication facilities the materials receive unusually high coverage through inspections. This is indicated in a more clear fashion if one considers the ratios IMD/WSQ.yr or IMD/NMI.

2. IMD/yr; IMD/SQ.yr; IMD/WSQ.yr; IMD/NMI (WSQ and NMI explained in Table 6)

I have extracted a few relevant numbers from Table 6 and reproduced below for ready reference:

Zone	IMD/SQ.yr	IMD/WSQ.yr	IMD/NMI
1	0.6	30	51
2	0.04	0.46	0.46
3	1.03	5.43	6.41
U-Nat-fab*	0.05	2.6	4.8
Repro (Zone 3a)	0.97	5.64	6.37
MOX (Zone 3b)	1.44	4.53	4.62

*The values for U-Nat fabrication are included in this table for comparison.

It can be quite easily seen from this table that if one considers the ratio IMD/SQ.yr as the main indicator, the values for the bulk facilities excepting U-Nat-fab range between 0.6 to 1.5 approximately whereas the values for the reactors (zone 2) and the U-Nat-fab are in the region of 0.05. If one, on the other hand, considers the ratios IMD/WSQ.yr or IMD/NMI as the indicator then one sees that for all the bulk facilities excepting LEU fabrication, these ratios range between 2.5 and 5.5. The corresponding values for the zone 2 are in the range of 0.5. In view of the considerations which I have made above in connection with the ratio IMD/WSQ.yr, I will concentrate my considerations on this ratio. One sees that all the bulk facilities (except the LEU fabrication) indicate approximately the same range of coverage of 2.5 to 5.5 IMD/SQ.yr. The reduction by a factor of about ten for the zone 2, i.e. the reactors, can be explained by the fact that the inspection coverage takes into account the particular characteristics of the reactors, i.e. the containment possibilities in the form of reactor cores and wet storages for the radioactive spent fuels, and the coverage with seals and other surveillance techniques. The possibility of utilization of the special characteristics of this part of the fuel cycle enables the Agency to reduce its inspection efforts in such facilities by approximately a factor of 10.

I feel that the very high coverage in LEU fabrication facilities, which is higher by about a factor of 10 than in the other bulk handling facilities like U-Nat fabrication or the reprocessing and MOX, can be explained simply by the fact that inspection efforts in LEU facilities have been determined up to now in isolation. As a result, the importance of the nuclear material handled in this zone has been considered to be the same as that in reprocessing or in MOX. Only then can one justify almost a full coverage for the input and output streams, which naturally increases the total inspection efforts in such facilities. One will be in a position to reduce the intensity of coverage of this material and bring it down to approximately the same level of coverage provided in the other zones with bulk handling facilities, that is in the range of 2-5 IMD/WSQ.yr, if the safeguards relevance of this material in this zone be considered in relation to the materials in reprocessing and MOX facilities. Another reason for providing a lower coverage for fabrication facilities handling LEU lies in the fact that LEU and U-Nat belong to the same category of materials. They both have the same values for significant quantities, i.e. 75 kg of U-235 contained and the same detection time of one year.

Such considerations in connection with the fuel cycle safeguards as a whole could therefore, enable the Agency to relativate the safeguards importance of the materials of different categories and reassess the possibility of distribution of efforts in the different zones of the fuel cycle. The natural categorization of nuclear materials (U-Nat, LEU and Pu on the one hand and Pu in irradiated fuels on the other) in the fuel cycle as well as the utilization of the safeguards relevant characteristics of the facilities when considered in the frame of the fuel cycle as a whole leads one to the fact that the specific inspection efforts, expressed as IMD/WSQ.yr, spent on nuclear materials handled in such a fuel cycle can broadly be divided into two categories. One for all types of nuclear materials in bulk handling facilities handling natural Uranium, LEUs, and Pu with a coverage of about 2-5 IMD/WSQ.yr, and the other, for all materials used, stored or handled in LWR type reactors. In such reactors because of the prevailing containment possibilities, the inspection mandays can be reduced by a factor of ten against those for the bulk handling facilities and kept in the range of 0.5 IMD/WSQ.yr.

The very high coverage in the LEU fabrication facilities can also be explained by the fact that the diversion possibilities considered for nuclear materials in these facilities, have been given the same weightage as those in reprocessing and MOX facilities. Therefore, these materials in the input as well as in the output, are covered through very intensive inspection activities. If one considers diversion possibilities for the fuel cycle as a whole, one is in a position to place different weightage for the same diversion possibilities in the different parts of the fuel cycle. This fact is implicitly implied in Art. 6, INFC 153. According to my opinion, the fabricated fresh fuel elements pose the lowest diversion risk in a fuel cycle of this type. The material is extremely costly (appxly. DM 1 Mio/FE) and the material contained in the fuel rods is relatively more inaccessible than those for example in the UF_6 cylinders or in the birdcages containing Pu. The uranium oxide pellets inside the fuel rods are sintered at about 1100^{o}C. It will be difficult to recover uranium from such sintered material without excessive chemical processing. The oxide has to be reconverted into uranium hexafluoride for higher enrichment if an enrichment path is considered; or the fresh fuel elements after diversion, have to be irradiated in a clandestine reactor and then reprocessed in a clandestine facility if the Pu path is considered. Both of these paths are much more complicated than those involving Pu or UF_6 which may be readily available in other parts of the same fuel cycle. Following this trend of thought I feel that the weightage factors for the diversion possibilities should have the lowest value (in a fuel cycle of the sort we are considering) for the fresh fuel elements followed by the UF_6 and other bulk materials in the LEU or U-Nat zones, then the irradiated fuel elements followed by the fresh fuel elements containing MOX fuels, and finally followed by separated and accessible Pu contained in birdcages or in other types of containers. Also, the importance of the diversion possibilities through borrowing or shuffling in such a fuel cycle reduces considerably because of the fact that very seldom similar types of materials are handled in different facilities in the same zone (as Willy has already pointed out) and because of the fact that these nuclear materials can be given different types of coverage at the different parts of the fuel cycle as we have considered in the zone approach. The question of shuffling in the zone 1 arises only during the physical inventory taking which happens only once in a year. Since the fuel elements may be either of the BWR or of the PWR type the shuffling may not be that easy and the possibilites of shuffling can quite simply be eliminated by having very simple type of seals during the physical inventory taking in this zone. In zone 2 also, the problem of shuffling poses according to my opinion, a very minor problem, eventhough the reactors are not inventorized simultaneously in our concept. The facts that the fuel elements can be properly sealed or that the fuel elements are in active form or that the transport of such fuel elements is always associated with a considerable amount of multi-organizational activities (involving independent transport organizations, licensing authorities, insurance companies, plant operators, electrical companies etc.) such reshufflings cannot be carried out secretly. Therefore, for zone 2, the threat of reshuffling, does not exist under practical conditions. This fact has also been recognized by the Agency in designing its facility based approach. In zone 3, the problem of shuffling does not arise at all because of the very heavy coverage through continuous inspections in reprocessing and bi-weekly to monthly inspection in the MOX facilities. The fuel cycle safeguards provide therefore, a more realistic rationale for allocating different weightage for different categories of material and for the diversion possibilities in different parts of the fuel cycle.

If one considers these two factors i.e. the relative importance which can be allocated to the different categories of nuclear materials handled in a fuel cycle and the weightage which can be given to the different diversion possibilities, one comes to the conclusion that with about 30 IMD/WSQ.yr the specific coverage for LEU is very high and that there is a strong justification for investigating the possibilities of reducing the inspection coverage in the LEU part of the fuel cycle. On the other hand, the distribution of inspection activities in the other two zones appears to be quite reasonable.

3. IMDs at the interface of the reference fuel cycle

In Table 7, I have indicated the annual throughputs of nuclear materials under safeguards and the inspection efforts spent on them at the interface of the three zones of the reference fuel cycle. I have included some data on the LWR system with recycled Pu also, which Willy had presented in his data base. It can be seen that the major part of the inspection activities is concentrated at the interface of each of the zones. Of special interest are the activities at the input of zone 1, that is for the LEU fabrication facilities, then the activities at the output of this zone and the input of zone 2 with reactors, and thirdly the activities at the output of reprocessing and the input of the MOX facilities. You will note that most of the activities in zone 1 at the input and output, are required to establish independently and with virtually full coverage, the amounts of nuclear materials coming into the or out of the zone. If we accept the argumentations provided above on the relative importance of the nuclear materials and the corresponding diversion strategies, then there appears to be sufficient room for reassessing the inspection activities for these two streams in the zone. For example, if the measurement data base are accepted from the shipper's data by the Agency, more than half of the inspection activities can be reduced at the input. If the probability of detection for the fresh fuel subassemblies were to be reduced from 95 % to 75 % or the frequency of verification activities could be expanded from 1 month to 2 months period or the detection amount for significant quantities could be increased by a factor of two, the amount of inspection efforts for the output stream would also be reduced by more than half. The very high coverage at the input of a reprocessing facility at interface reactor reprocessing is fully justifiable because at this point, the fuel elements lose their identity and a direct measurement of Pu content in these fuel elements takes place. On the other hand, the output of the reprocessing and the input of the MOX for Pu in birdcages could be a point for further considerations. In most of the modern reprocessing and MOX facilities which are being designed, planned or constructed, the MOX fuel fabrication forms an integral part of the reprocessing facility. The Pu and U at the reprocessing end are stored mainly in the form of nitrates to simplify the separation of americium which builds up with time. They are then mixed in certain proportions in liquid form and precipitated simultaneously to form the mixed oxide which then forms the input to the process area of the MOX facility. In such a combined process, the particular strategic point of Pu nitrate storage at the interface between reprocessing and MOX, may be considered to be a single key-measurement point where some of the duplicating activities, as foreseen in the present reference case, can be eliminated. Another point of interest is the fact that a major part of all the interface inspection activities is carried out for descrete items. At the input and output of each of the zones we have considered, we do not have any material in bulk form. All the material is contained either in UF_6-cylinders or finished fuels are birdcages and other types of containers. This fact points to a possibility of pattern recognition by repetative measurements on these items. Excepting in zone 2, the activities on these interface materials are carried out mostly in a cyclic fashion repeating the same type of activities on a monthly basis. In zone 2 this happens on a three-monthly basis. This type of repetative activities on same or similar type of containers all through the balancing period, can be used as a basis for pattern recognition. As you know, a pattern recognition method has been used in the NRTA system in a reprocessing plant. This is only an idea but which I think could be developed to the advantage of safeguards.

If one considers the ratio IMD/WSQ.yr given in Table 7 one finds that there is a jump from 19 to 50 when one goes from the input to the output stream of zone 1 and a jump of 0.8 to 20 when one transfers material from zone 2 output to zone 3 input. In the first case it is because of the intensive use of NDA at the output in the second case it is the coverage of nuclear material at the reprocessing input through the actual presence of inspectors. It is interesting to note in this connection that a major part of inspection activities at this point as well as at the output of this zone (zone 3), is concerned with activities which do not involve measurements or containment/ surveillance measures but sheer physical observation of the movement of materials through inspectors. This is an important point in itself because it indirectly brings out one fact into focus involving the continuity of knowledge. As opposed to seals or camera surveillance, observation by inspectors enables the Agency to retain and maintain in an active fashion,the continuity of knowledge for the time for which the inspectors observe the movements. The inspectors decide on a continuous basis through such observations about the presence or absence of materials at these particular points. One could also say that the inspectors know through experience the normal flow and inventory patterns of nuclear materials at these points. Through observations they could recognize a departure from or the maintenance of the normal pattern. This becomes of importance when we come to the consideration of the LEs and LMUFs in the different zones.

4. LE and LMUF values for the different zones in the reference fuel cycle

I have included some very rough estimates of the variances and LMUF values for the different streams, inventories and the zones as a whole in Table 8. It is to be noted that in zone 1 as in the case of zone 3 the largest fraction of the LMUF values is obtained from the throughput measurements. In zone 1 the uncertainties in the throughput measurements are of the same order of magnitude as the amount of bulk materials in the process area of that zone. The variance analysis in this zone also indicates that there will be a room for improvements in the inventory management in this zone. For example, the extremely large inventories of rods and finished fuel assemblies could probably be reduced under normal operating conditions. The total uncertainty of the MUF for the annual material balance in the zone 1 comes to approximately two tons of uranium. This is slightly less than 1 significant quantity. Considering the fact that in this zone with the 3 LEU fabrication facilities approximately 1800 tons of materials are measured yearly, the uncertainty caused by the balance is in the order of 0.1 % of the total amount measured (or approximately 0.2 % if one considers only the input and the inventories). In other words, one sees through this variance analysis that the book inventory values which are generated on a monthly or a bi-monthly basis provide a fairly accurate indication of the flow and physical inventories of materials in this zone. One also sees that the total amount of material in this zone is covered by the material balance measurements with an uncertainty of approximately 0.1 % (2 sigma value corresponding to 95 % confidence). This fact, coupled with the absolute value of the uncertainty of 2 tons of U (which is less 1 significant quantity) in this zone, could easily be used as a basis for making safeguards relevant statement on the basis of the percentage of the total amount of material covered instead of on the basis of absolute numbers. Besides, even if the absolute numbers were to be larger than 1 significant quantity the importance of this uncertainty can be regarded to be much lower than the corresponding uncertainty in the zone 3 of the fuel cycle.

In zone 2 involving only reactors we do not have any MUF since we assume digital accountancy and coverage of flow and inventories in this zone through activities which can detect in each reactor, one significant quantity of material. This capability is independent of the number of reactors or the size of reactors. Therefore, for the fuel cycle safeguards concept zone 2 provides the basis for a safeguards relevant statement both for a relative and an absolute amount with regard to the presence of nuclear materials.

In zone 3, we have a very interesting situation. About 90 % of the total LMUF of 24.6 kg Pu in this zone stem from the input of the reprocessing facility. Also out of this total, 24.1 kg Pu come from the reprocessing facility alone, and 4.53 kg Pu from the MOX facility. These variances have been calculated on the basis of the worst situation, i.e when all the uncertainties are accumulated and one balance is carried out per year per facility. If we consider the possibilities of using NRTA measures in these two facilities, the LMUF values for the reprocessing facility as well as for the zone as a whole are expected to be reduced by a factor of 5 to 10. Irrespective of the absolute numbers which one can get on the basis of the variance analysis the most important point is the fact that the major source of the variance is the measurement at the input of the reprocessing facility. And particularly at this key-measurement point and at the output of the process area the Agency has concentrated its efforts on different safeguards activities. At these points the Agency tries to ensure through a combination of observation and measurement activities that the materials follow a preset pattern in the facility and leave also in a preset pattern the facility. After having detailed discussions with the Agency's inspectors and observing their activities at our reprocessing facility I come to the conclusion that the inspectors in this particular zone, zone 3, utilize two distinct types of capabilities in generating the safeguards relevant data base and in enabling the Agency for making a safeguards relevant statement.

The first capability is in the actual measurement, sampling and evaluation of the measured data. The second type of capability is to recognize the underlying pattern of flows and inventories in the facilities in this zone which may be considered to be normal and the capability of recognizing a departure from the normal pattern in case it so happens. The departure is considered as an anomaly which is then followed up by inspectors and resolved. Only a combination of these two capabilities can enable the Agency to arrive at the required statement. In other words, even if the measurement uncertainty in a facility happens to be such that the LMUF exceeds a certain amount of value, the inspectors can still make a statement with regard to the normal flow and inventory pattern in a facility and come to the conclusion that all the materials have been accounted for. This has been the practice of the Agency in the past. This fact leads me to the conclusion that in this zone also, a statement with regard to the percentage of the total amount of material covered can be made. The variance analysis shows that for the total amount of materials covered approximately 0.8 % uncertainty exists (LMUF) which can be reduced to approximately 0.2-0.3 % by the NRTA method. In other words, the entire amount of material in this zone can be covered with the uncertainty of approximately 0.3 % (at the level of 95 % confidence) if NRTA method is used.

The preliminary analysis of the variances in the different zones in the fuel cycle safeguards indicate, therefore, that the safeguards relevant statement in the sense which you had formulated in your last paper can be made without any difficulty. Summarizing my thoughts in this paper, I have first tried to show that the fuel cycle safeguards provides a rationale for reassessing the relative importance of the nuclear material and the corresponding diversion possibilities. The specific inspection activities IMD/WSQ.yr could provide a basis for such reassessment. The facility based approach allocates undue importance to LEU materials. The maximum uncertainty in knowledge through measurement errors comes from the input of a reprocessing facility. The Agency inspectors could overcome the effect of this uncertainty by recognizing normal flow and inventory patterns in this zone as well as in the fuel cycle as a whole. A safeguards relevant statement in the line you have suggested can be made.

I will end the present working paper at this point and provide some further information in the next.

Table 1: Total Yearly Inspection Activities (IMD/yr) at an LWR* +)

*A=Fresh Fuel (FF) KMP; B=Core (CF) KMP; C=spent fuel (SF) KMP

ABC	Interim (3/yr) Inspections (MH)		PIV (1/yr) Inspections (MH)		Concealments expected to be covered
1. Discussion		0.75		0.75	
2. Identify outst. Items		0.75		0.75	Falsification of:
3. Compare S/R - ICRs		-		-	- S/R differences
4. Comp. Acc. Records/Reports		0.75		2.00	- Record/Report data
5. Update Agency BI		0.75		1.50	- Records
6. Check int. cons. Records		0.75		3.50	
7. Determine Inv. Listing		0.75		3.00	
8. Examine power Records		0.50		0.50	
9. Comp. Crane + Transfer Records		0.75		1.50	
10. Discussion	ΣABC=	0.75	ΣABC=	0.75	
11. Identify outst. Items	7.25	0.75	15.0	0.75	
A.1. FF item count		-		1.50	Falsification of Records
2. FF identification		-		1.50	(No. of items; id. no's;
3. FF NDA attributes		-	ΣA=	4.00	Concn.; Amount)
4. FF NDA variables		-	7.0	-	
B.1. CF item count		-		1.50	
2. CF identification		-		3.00	As in A and
3. CF NDA attributes		-		-	misuse of neutrons
4. CF NDA variables		-	ΣB=	-	
5. CF guide tube exam.		-	6.0	1.50	
C.1. SF item count		-		2.50	
2. SF idenfification		-		3.00	As in A and
3. SF NDA attributes		-		8.00	radioactivity level
4. SF NDA variables		-	ΣC=	-	
5. SF guide tube exam.		-	13.5	-	
BC.1. Service cameras/TV		2.25		2.25	- unreported removal
2. Review film		-		-	or replacement of
3. Attach seals to cameras		0.75		0.75	materials
4. Attach seals to m. shield		1.50		1.50	- tampering with
5. Attach seals to ship. casks	ΣBC=	-	ΣBC=	-	C/S systems
6. Return removed seals to HQ	4.5	-	4.5	-	
Totals (MH)	11.75		46.0		

Int. IMD/yr =	3 x 11.75 ÷ 7	5.0
PIV IMD/yr =	46 ÷ 7	6.6
plus one inspection (IMD) to install core seal		1
Total IMD/yr		13
Training		1
Total IMD/yr		14

+) Data presented in Tables 1-4B were extracted from the SAGSI WG-2 report of Sept. (1983).

Table 2: Inspection Activities at a LEU Fuel Fabrication Facility (with Neutron Collar)

I. Flow Verification (12/yr including at PIV)	No. items/ Inspection	Sample Size	MH/ Activity	MH/ Inspection
A. UF_6 receipts (18/month)				
1. Count cylinders + verify id. no's	18	all	0.5	0.5
2. Attribute test (NDA + gross wt.)	18	15	40 min	10
3. Variable test (UF_6-sample+net wt.)	18	2	2	4
4. Calibrate scales	-	-	-	0.5
				Σ 15
B. Production of rods + assemblies (60/month)				
1. Count assemblies + verify id. no's	60	all	1.5	1.5
2. n-collar measurements	60	22	1	22
3. Establish calibration standards	-	-	-	3
4. Seal assemblies	60	all	5 min	5
5. Variable test for rods	13500	27	5 min/sample + 4 MH	6
				Σ 37.5
C. Auditing Activities				
1. Compare acctg. records with supporting documents	-	-	-	3
2. Update BI	-	-	-	1
3. Examine op. records + Collect op. data	-	-	-	2
				Σ 6
D. C/S				
1. Seal/unseal NDA standards				0.5
2. Seal samples				-
				Σ 0.5
E. Quality Control				
1. Examine op. measurement results	-	-	-	0.5
				Σ 0.5
F. Shipment of Waste				
1. Count and tag check				0.5
2. NDA				2
				Σ 2.5
G. General				
1. Meetings				1
2. Investigations				-
3. Sampling plan calculation				0.5
4. Packaging of samples				0.5
				Σ 2

Table 2 (contd)

II. PIV Inspection (1/yr)*	MH
A. Audit activities	8
B. Inventory changes	(included under I)
C. Verification of NM	
1. UF_6	
2. UO_2 powder	4
3. UO_2 pellets	4
4. Pins	8
5. Assemblies	5
6. Wastes	2.5
7. Scrap	2.5
8. Archives, samples etc.	1
	Σ 27
D. Sealing	
1. Sealing/unsealing standards	2
2. Misc. sealing/unsealing	2
	Σ 4
E. Calibration/Quality Control	
1. Scales	4
2. Examine operator's evaluation of measurement results	3
	Σ 7
F. General activities	
1. Meetings	3
2. Sampling plan calculation	6
3. Packaging of samples	1
	Σ 10

* Activities listed above are in addition to those foreseen for flow verification

Table 2A: Total Yearly Inspection Activities (IMD/yr) at a LEU Fuel Fabrication Facility with Neutron-Collar

Inspection Activities (See Table 2 for details)		Flow, I (12/yr) MH		PIV II (1/yr) MH	
I.A.1			0.5		
2			10.0		
3		Σ IA=	4.0	Σ IIE1=	
4	(II.E.1)	15	0.5	4.0	4.0
I.B.1			1.5		
2			22.0		
3			3.0		
4		Σ IB=	5.0		
5		37.5	6.0		
I.C.1			3.0		
2			1.0		
3		Σ IC=	2.0	Σ IIA=	
4	(II.A)	6.0	-	8.0	8.0
I.D.1	(II.D.1)		0.5		2.0
2		Σ ID=	-	Σ IID1,2	-
3	(II.D.2)	0.5	-	4.0	2.0
		Σ IE=		Σ IIE2=	
I.E.1	(II.E.2)	0.5	0.5	3.0	3.0
I.F.1	(II.C.6)	Σ IF=	0.5	Σ IIC6=	0.5
2	(II.C.6)	2.5	2.0	2.5	2.0
I.G.1	(II.F.1)		1.0		3.0
2			-		-
3	(II.F.2)		0.5		6.0
4	(II.F.3)	Σ IG=	0.5	Σ IIF=	1.0
5	(II.F.4)	2.0	-	10	-
II.C.1					-
2					4.0
3					4.0
4					8.0
5					5.0
6	(incl. above)				-
7				Σ IIC=	2.5
8				24.5	1.0
Totals		64		56	

Flow IMD =	64 x 12 ÷ 6 = 128
PIV IMD =	56 ÷ 6 = 9
Flow + PIV IMD/yr	137
Training IMD/yr	23
Total IMD/yr	160

Table 2B: Concealment Methods expected to be covered by Inspection Activities in a LEU-Fabrication Plant

Location	Diversion Possibility	Concealment Methods
1. UF_6-Storage	- Removal of UF_6-Cylinders	1.1 Falsification of S/R data 1.2 Falsification of Report/Record 1.3 Falsification of Measurement and Calibration systems 1.4 Borrowing from other Locations
2. Process Area	- Removal of enriched U. in bulk form - Removal of scrap	2.1 Falsification of Record/Report 2.2 Falsification of Measurement and Calibration systems 2.3 Wrong Measurement Uncertainty data in DI 2.4 Diversion into MUF 2.5 Substitution with inert material; natural or depleted U. 2.6 Borrowing from other Locations
3. Product Storage: Rods and Fuel Assemblies (FA)	- Removal of U. from rods and FA's	3.1 Falsification of Reports/Records 3.2 Changing serial numbers and presenting for reinspection 3.3 Substitution with inert, natural or depleted U. 3.4 Borrowing from other Locations

Table 3: Inspection Activities at a 240 t HM/yr Reprocessing Facility

I. Flow measurement	No/yr	MH/ Activity	MH/yr
A. Spent fuel receipt and transfer			
1. Observe cask opening/closing and count assemblies	72	2	144
2. Check assembly identification numbers	72	4	288
3. Assembly NDA	72	4	144
4. Surveillance of spent fuel storage	4	2	8
5. Verify transfer and start of chopping	576	1	576
6. Surveillance of transfer route	4	2	8
			ΣA 1168
B. Accountability tank			
1. Observe calibration	2	16	32
2. Measure solution volume prior to feed	288	0.5	144
3. Measure solution volume after feed	288	0.5	144
4. Observe sample taking including dilution	288	3	864
5. Observe sample packaging	36	4	144
6. Analysis of sample (HQ)	–	–	–
7. Verify hulls	144	2	288
			ΣB 1616
C. Uranium product			
1. Observe calibration of U product scale	4	0.5	2
2. Weigh container	87	0.5	43
3. Sample container	87	0.5	44
4. Sample packaging and shipment	10	2	20
5. Install seal	600	5 min	50
			ΣC 159
D. $Pu(NO_3)_4$ output			
1. Tank calibration	2	8	16
2. Tank measurement before and after	300	1	300
3. Tank sampling	300	3	900
4. Sample packaging and shipment	40	4	160
5. Sample analysis (HQ)	–	–	–
			ΣD 1376
E. PuO_2 powder output			
1. NDA attribute measurement	239	0.5	120
2. NDA variables measurement	281	1	281
3. Sample and weigh for variables measurement	98 + 14	3, 4	350
4. Seal birdcage	1200	5 min	100
5. Calibrate scale	4	0.5	2
6. Calibrate NDA (incl. E.1,2)	–	–	–
7. Package and ship samples	20	4	80
8. Sample analysis (HQ)	–	–	–
			ΣE 933
F. Waste			
1. Medium active waste	~1100	–	32
2. Low acitve waste	~1000	–	16
			ΣF 48

Table 3 (contd): Inspection Acitvities at a 240 t HM/yr Reprocessing Facility

II. Physical inventory taking (2/yr)	No/yr	MH/ Activity	MH/yr
G. Spent fuel pond			
1. Item count	2	8	16
2. Identification number check	2	8	16
3. Cerenkov glow	2	32	64
			ΣG 96
H. UO_3			
1. Item count	2	16	32
2. Check seals and identification numbers	2	-	incl. in H.1
3. Replace seals (45/PIV)	2	5 min	8
4. NDA remeasurement (42/PIV)	2	0.25	21
			ΣH 61
I. PuO_2			
1. Item count	2	16	32
2. Check seals and identification numbers	2	-	incl. in I.1
3. Replace seals and examine contents (242)	2	5 min	47
4. NDA remeasurement (351)	2	20 min	234
			ΣI 313
J. Miscellaneous			
1. Verify miscelllaneaous material	2	32	64
2. Verify completeness of inventory	2	32	64
			ΣJ 128
K. Additional partial physical inventories (NRTA)			
1. Item count PuO_2 cans	22	16	352
2. Check seals on PuO_2 cans	-	-	incl. in K.1
3. Replace seals on PuO_2 cans (34)	22	5	66
4. Reverify contents of PuO_2 cans with NDA	22	20 min	59
5. Verification of in-process material at other strategic points	22	8	176
6. Other verification activities	44	2	88
			ΣK 741
III. Other inspection activities			
1. Health physics and access	-	-	-
2. Comparison of records and reports	12	2	24
3. Comparison of accounting records with supplementary documents	12	6	72
4. Examination of operating records	250	1	250
5. Updating of book inventory	12	2	24
6. Other auditing activities	-	80	80
7. Other tank calibrations (4)	1	8	32
8. Other weighing system calibration (4)	4	2	32
9. Quality control of chemical measurement	2	8	16
10. Other calibrations and quality control	-	-	100
11. Meeting with operating staff for discussions, clarifications, etc.	50	2	100
			ΣIII 730

Table 3A: Total Yearly Inspection Activities (IMD/yr) at a 240 t HM/yr Reprocessing Facility

Inspection Activities for details see Table 3	Flow MH/yr	NRTA MH/yr	PIV 2/yr MH/yr
A. 1 (G.1)	144		16
2 (G.2)	288		16
3 (G.3)	144		ΣG 64
4	8		
5	576		96
6	ΣA 8		
	1168		
B. 1	32		
2	144		
3	144		
4	864		
5	144		
6	-		
7	ΣB 288		
	1616		
C. 1	2		
2	43		
3	44		
4	20		
5	ΣC 50		
	159		
D. 1	16		
2	300		
3	900		
4	160		
5	ΣD -		
	1376		
E. 1	120		
2	281		
3	350		
4	100		
5	2		
6	-		
7	80		
8	ΣE -		
	933		
F. 1	32		
2	ΣF 16		
	48		

Table 3A (contd): Total Yearly Inspection Activities (IMD/yr) at a 240 t HM/yr Reprocessing Facility

Inspection Activities for details see Table 3	Flow MH/yr	NRTA MH/yr	PIV 2/yr MH/yr
(H.1)			32
(H.2)			-
(H.3)			ΣH 8
(H.4)			61 21
(K.1) (I.1)		352	32
(K.2) (I.2)		-	-
(K.3) (I.3)		66	ΣI 47
(K.4) (I.4)		59	313 234
J.1			ΣJ 64
2			128 64
(K.5)		ΣK 176	
(K.6)		741 88	
III. 1	-		
2*	24		
3*	72		
4*	250		
5*	24		
6*	80		
(III.7)		ΣIII NRTA 32	
(III.8)		64 32	
9	16		
10*	ΣIII Flow 100		
11*	666 100		
Total Manhours (MH)	5966	805	598

IMD = mhrs/6 = (5966 + 805 + 598)/6

=	1228	IMD/yr
Training =	205	IMD/yr
Total	1433	IMD/yr

* These activities are associated with the measurements of flows and inventories for verifying the 6-months material balances

Table 3B: Concealment Methods expected to be covered by Inspection Activities in a Reprocessing Facility

Location	Diversion Possibility	Concealment Methods to be covered by Inspection Activities
1. Spent Fuel (SF) Storage	Spent Fuel: - Diversion - Removal during transfer to process - unrecorded transfer to process	1.1 Substitution and Borrowing 1.2 Falsification of Records/ Reports 1.3 Tampering with surveillance systems
2. Dissolver	- Chopped pieces removed - U + Pu not fully dissolved	2.1 Diversion into MUF 2.2 Falsification of Hulls/ Ac. Tank measurements 2.3 Falsification of Records
3. Feed: Ac.-Tank	- Ac.-Tank by-passed from dissolver - unrecorded transfer to process	3.1 Falsification of op. records 3.2 Wrong measurement uncertainties in DI 3.3 Falsification of measurement and calibration systems 3.4 Falsification U/Pu data in Recycle Acid
4. Process Area	- Solution removal through non process pipework - Solution removal by by-passing product Ac.-Tank	4.1 Falsification of op. records (for Wastes and Processing Inventories) 4.2 Wrong measurement uncertainties in DI 4.3 Falsification of measurement and calibration systems 4.4 Falsification U/Pu data in Recycle Acid 4.5 Diversion into MUF
5. PuO_2 Storage	- Removal of Pu from sealed cans - Removal of sealed cans	5.1 Falsification of Records/ Reports 5.2 Falsification of measurement and calibration systems 5.3 Substitution by inert or active materials 5.4 Borrowing 5.5 Tampering + counterfeitung of seals

Table 4: Inspection Activities at a MOX Fuel Fabrication Facility
(MBA 1: PuO_2-storage; MBA 2: Process; MBA 3: Rod + Assembly storage)

I. PIV (2/yr) Inspection Activity	Total Items at PIV	Sample Size	MH/ Activity	MH/ PIV	
A. MBA 1					
1. Item count PuO_2-cans, check seals + id. numbers	110	all	2	2	
2. Replace seals + examine contents	100	24	5 min	2	
3. Remeasure sealed cans with NDA	100	29	20 min	10	
4. Quick NDA: unsealed cans	10	3	20 min	1	
5. Long NDA: unsealed cans	10	2	1	2	
6. Seal unsealed cans	10	10	5 min	1	
7. Weigh sample + analyse unsealed cans	10	1	2	2	ΣIA = 20
B. MBA 2					
1. Weigh PuO_2 lot	1	1	1	1	
2. Sample PuO_2 lot	1	1	1	1	
3. Weigh MOX lot	1	1	1	1	
4. Sample MOX lot	1	1	1	1	
5. Count pellet stacks	108	all	0.5	0.5	
6. Weigh pellet stacks	108	4	15 min	1	
7. NDA pellet stacks	108	4	1	4	
8. Count rods	110	all	0.5	0.5	
9. NDA rods	110	2	1	2	
10. Count waste drums	60	all	0.5	0.5	
11. NDA waste drums	60	1	0.5	0.5	
12. Count scrap drums	3	all	-	-	
13. NDA scrap drums	3	1	0.5	0.5	ΣIB = 13.5
C. MBA 3					
1. I. C. rods in partial assemblies	50	all	0.5	0.5	
2. NDA partial assembly	1	1	1	1	
3. Quick NDA unsealed assembly	5	3	0.5	1.5	
4. Long NDA unsealed assembly	5	1	1	1	
5. Seal unsealed assembly	5	5	5 min	0.5	
6. I. C. sealed assembly + check id. no's + seals	40	all	1	1	
7. Replace seals	40	11	5 min	1	
8. Remeasure sealed assembly, Quick NDA	40	20	0.5	10	ΣIC = 16.5

Table 4 (contd): Inspection Activities at a MOX Fuel Fabrication Facility

I. PIV (contd) Inspection Activity	No. of items per 2 weeks	Sample Size	MH/ Activity	MH/ Inspection	
D. General					
1. Set up, calibrate, dismantle NDA equipmt.				18	
2. Prepare, package + ship samples				4	
3. Update BI + compare PIL				1	
4. Compare records/reports				4	
5. Meetings with operators				6	
6. Calibration + quality control measurements				8	
7. Exam. operating records				2	ΣID = 43
II. Flow Verification: every 2 weeks (18 times per year)					
A. 1. Receipt PuO_2 cans	10				
i. I.C. + id. check		all	0.5	0.5	
ii. Quick NDA		2	20 min	1	
iii. Long NDA		2	1	2	
iv. Weigh/Sample		1	2	2	
v. Seal		all	5 min	1	
A. 2. Sample MOX blend or pellet		1	1	1	
A. 3. Scrap recovery/recycle	3/4	2/4	0.5	0.25	
A. 4. Fuel rod to assembly area	415	8	20 min	3	
A. 5. FA production:					
i. NDA Quick	5	3	0.5	1.5	
ii. NDA Long	5	0.5	1	0.5	
iii. Apply seal	5	5	5 min	0.5	
A. 6. FA shipment (10/yr)	all	all	1.5/2	0.75	
A. 7. Waste shipment	all	all	0.5/5	0.1	ΣIIA = 14.10
B. General					
B. 1. Set up, calibrate, dismantle NDA equipmt.				18	
B. 2. Prepare, package + ship samples				4	
B. 3. Compare records/reports				2	
B. 4. Meeting with operators				1	
B. 5. Exam. accounting and operating records				1	
B. 6. Calibration + QC of measurements				1	ΣIIB = 27

Table 4 (contd): Inspection Activities at a MOX Fuel Fabrication Facility

III. Verification at Str. Pts. (24/yr)

Inspection Activity	No. of items per 2 weeks	Sample Size	MH/ Activity	MH/ Inspection	
1. IC PuO_2 cans + check seals	100	all	2	2	
2. Replace seals	100	5	5 min	0.5	
3. Reverify content via NDA	100	2	20 min	1	
4. Verification of in-process PuO_2 inventory (50 kg)	-	-	-	4	
5. IC FA, check seals + id. no's	40	all	1	1	
6. Replace seals	40	4	5 min	0.5	
7. Reverify FA via NDA Q	40	2	0.5	1	
8. Others	-	-	-	8	ΣIII = 18

Table 4 A: Total Yearly Inspection Activities (IMD/yr) at a MOX Fuel Fabrication Facility

Inspection Activity for details see Table 4			Flow (II) MH/Insp.	Int. Verification at Str. Pt. (III) MH/Insp.	PIV (I) MH/PIV
I.A. 1	(II.A.1.i.)	(III.1)	0.5	2	2
2		(III.2)		0.5	2
3		(III.3)		1	10
4	(II.A.1.ii.)		1		1
5	(II.A.1.iii.)		2		2
6	(II.A.1.v.)		1		ΣIA= 1
7	(II.A.1.iv.)		2		20 2
I.B. 1					1
2					1
3					1
4	(II.A.2)		1		1
5 - 7					5.5
8 - 9	(II.A.4)		3		2.5
10 - 11	(II.A.7)		0.1		ΣIB= 1
12 - 13	(II.A.3)		0.25		13.5 0.5
I.C. 1					0.5
2					1
3	(II.A.5.i.)		1.5		1.5
4	(II.A.5.ii.)		0.5		1
5	(II.A.5.iii.)		0.5		0.5
6		(III.5)		1	1
7		(III.6)		0.5	ΣIC= 1
8		(III.7)	ΣIIA=	1	16.5 10
	(II.A.6)		14.1 0.75		
		(III.4)		4	
I.D. 1	(II.B.1)		18		18
2	(II.B.2)		4		4
3					1
4	(II.B.3)		2		4
5	(II.B.4)		1		6
6	(II.B.6)		ΣIIB= 1		ΣID= 8
7	(II.B.5)		27 1		43 2
8	(II.B.7)		–		–
		(III.8)	ΣIIA+B	ΣIII 8	ΣIA-D
Totals (man-hours)			= 41.1	= 18	= 93
Man-days:			x 18/6	x 24/6	x 2/6
			= 123.3	= 72	= 31

Inspection man-days (IMD/yr)	=	226
Training (IMD/yr)	=	38
Total Inspection man-days (IMD/yr)	=	264

Table 4B: Concealment Methods expected to be covered by Inspection Activities in a MOX-Fuel Fabrication Facility

Location	Diversion Possibilities	Concealment Methods expected to be covered by Inspection Activities
1. Feed Storage PuO_2-Cans	- Removal of Pu from sealed cans - Removal of sealed cans	1.1 Falsification of Records/Reports 1.2 Falsification of Measurement and Calibration systems 1.3 Substitution with inert or active materials 1.4 Borrowing 1.5 Tampering and counterfeiting of seals
2. Process Area	- Removal of Pu from different batches - Removal of complete batches	2.1 Falsification of Records/Reports 2.2 Diversion into MUF 2.3 Wrong measurement uncertainties in DI 2.4 Falsification of Measurement and Calibration systems 2.5 Substitution with inert or active materials 2.6 Borrowing from other Locations
3. Product Storage: Rods and Fuel Assemblies (FA's)	- Removal of Pu from rods and FA's - Removal of complete rods and FA's	3.1 Falsification of Records/Reports 3.2 Changing serial numbers and presenting for reinspection 3.3 Falsification of Measurement and Calibration Systems 3.4 Substitution with inert or active materials 3.5 Borrowing from other Locations

Table 5: Inventories and Annual Flows in each Facility Type in the Reference Fuel Cycle

Facility type	Throughput Amount	Throughput WSQ^+	Throughput No. of items	Inventories Amount	Inventories WSQ^+	Inventories No. of items
1. LEU-Fabricatn.Facility						
1.1 Input:UF_6 Cylinders	273 tU/yr	2.18	215	33 tU	0.26	26
1.2 Process						
a) UO_2-Powder Buckets	-	-	-	4.8 tU	0.04	240
b) UO_2-Pellet-Trays	-	-	-	4.7 tU	0.04	943
c) Fuel Rods	-	-	-	47 tU	0.38	9300
1.3 Output						
a) Fuel Assemblies(FA)	270 tU/yr	2.16	720	28 tU	0.22	75
b) Misc.+Wastes	3 tU/yr	0.02	-	4 tU	0.03	-
1.4 Total Safeguarded Amount/Items	546 tU/yr	4.36	935	121.5	0.97	10584
1.5 Nuclear Material* Index (NMI)			3.15			
2. LWR						
2.1 Input:Fresh Fuel(FA)						
a) U	27 tU/yr	0.22	72	27 tU	0.22	72
b) Pu	-			-		-
2.2 Core Fuel (CFA)						
a) U	-		-	81 tU	0.65	216
b) Pu				625 kgPu	7.81	
2.3 Output:Spent Fuel(SFA)						
a) U	27 tU/yr	0.22	72	135 tU	1.08	360
b) Pu	270 kgPu/yr	3.38		1350 kgPu	16.88	
2.4 Total Amounts/Items						
a) U	54 tU/yr	3.82	144	243 tU	26.64	640
b) Pu	270 kgPu/yr			1975 kgPu		
2.5 Nuclear Material Index (NMI)			30.24			
3. Reprocessing						
3.1 Input SFA:						
a) U	216 tU/a	1.73	576	216 tU	1.73	576
b) Pu	2160 kgPu/a	27		2160 kgPu	27	
3.2 Process						
a) U	-	-	-	negligible	-	-
b) Pu	-	-	-	65 kgPu	2.71	
3.3 Product						
a) U	214 tU/a	1.71	535	240 tU	1.92	600
b) Pu	2140 kgPu/a	89.17	1.070	2400 kgPu	100	1200
3.4 Wastes						
a) U	2 tU/a	0.02	-	-	-	-
b) Pu	20 kgPu/a	0.83	-	-	-	-
3.5 Total Amounts/Items Safeguarded						
a) U	432 tU/a	120.46	2.181	456 tU	133.36	2376
b) Pu	4320 kgPu/a			4625 kgPu		
3.6 NMI *			225.			

Table 5 ctd.

Facility type	Throughput Amount	Throughput WSQ+	Throughput No. of items	Inventories Amount	Inventories WSQ+	Inventories No. of items
4. MOX-Fuel Fabr.						
4.1 Input						
a) U	16 tU/yr	0.13	40	8 tU	0.07	20
b) Pu	440 kgPu/yr	18.33	220	220 kgPu	9.17	110
4.2 Process: Inventory						
a) U	-	-	-	negligible	-	-
b) Pu	-	-	-	74	3.08	100
4.3 Output: Fuel Assemblies						
a) U	15.68 tU/y	0.12	78	7.8 tU	0.06	39
b) Pu	433 kgPu/yr	18.03		217 kgPu	9.02	
Wastes						
a) U	0.32 tU/y	0.01	not considered	not present	-	-
b) Pu	7 kgPu/yr	0.3			-	-
Total Safeguarded Amounts/Items						
a) U	32 tU/yr	0.26	338	15.8 tU	0.13	269
b) Pu	880 kgPu/yr	36.66		437 kgPu	21.28	
NMI*			39.9			

+WSQ: Weighted Significant Quantity, calculated as follows (Ref. 1):

Separated Pu: $\frac{Pu\ [kg]}{8 \times 3}$

Pu in Spent Fuel Assemblies: $\frac{Pu\ [kg]}{8 \times 10}$

LEU: $\frac{U\ [t]}{2.5 \times 50}$

*NMI: Nuclear Material Index for a Facility, calculated as follows (Ref. 1):

NMI: WSQ (Inventory) + WSQ (Input or Output whichever is greater)

Ref. 1: SIR for 1979 (Gov/1982, para 95)

Table 6: Inspection Activities, SQs, WSQs and NMI in the Reference Fuel Cycle

Zone 1: Three LEU Fabrication Facilities	Per Zone	Input	Output	Inventory
Significant Quantities Safeguarded	800	327	327	146
Weighted SQ	16	6.55	6.55	2.91
NMI	9.46			
IMD/yr	480	123	324	33
IMD/SQ yr	0.6	0.38	1.0	0.23
IMD/WSQ yr	30	18.78	49.5	11.34
IMD/NMI	51			
Zone 2: Twenty LWRs				
Significant Quantities	7988	216	891	6881
Weighted SQ	608.7	4.32	71.82	532.6
NMI	604.4			
IMD/yr	280	60	60	160
IMD/SQ yr	0.04	0.28	0.07	0.02
IMD/WSQ yr	0.46	13.9	0.84	0.3
IMD/NMI	0.46			
Zone 3A: One Reprocessing Fac.*				
Significant Quantities	1472	356.4	356.4	760
WSQ	254	28.73	91.73	133.36
NMI	225			
IMD/yr	1433	600	543	290
IMD/SQ yr	0.97	1.68	1.52	0.38
IMD/WSQ yr	5.64	20.9	5.9	2.2
IMD/NMI	6.37			
Zone 3B: One MOX Facility*				
Significant Quantities	183	61.4	61.4	70.2
Weighted SQ	58.33	18.46	18.46	21.41
NMI	39.9			
IMD/yr	264	73	71	120
IMD/SQ yr	1.44	1.19	1.16	1.71
IMD/WSQ yr	4.53	3.95	3.85	5.6
IMD/NMI	6.62			

Table 6 (ctd.)

	Per Zone	Input	Output	Inventory
Zone 3 Total				
Significant Quantities	1655	417.8	417.8	830.2
Weighted SQ	312.33	47.19	110.19	154.77
NMI	264.9	-	-	-
IMD/yr	1697	673	614	410
IMD/SQ yr	1.03	1.61	1.47	0.49
IMD/WSQ yr	5.43	14.26	5.57	2.65
IMD/NMI	6.41	-	-	-

Comments on Table 6

1. Significant Quanties are calculated for

$$SQ\ U = \frac{tU}{2.5}$$

$$SQ\ Pu = \frac{kg\ Pu}{8}$$

2. The value of WSQs and NMIs are taken from Table 5. The values for LEU Fab. are multiplied by 3 to obtain values for zone 1 and those for LWR are multiplied by 20 to obtain values for zone 2. The values for Repro. and MOX facilities are given separately for zone 3.

3. The IMD/yr values for the respective facilities are obtained from Tables 1 (LWR), 2A (LEU Fab.), 3A (Repro.) and 4A (MOX),and corrected to zone values by multiplying them with the relevant number of facilities in the different zones. The IMD/yr for general activities and training are proportionally distributed among the input/output/inventory values for IMD/yr.

4. IMD/WSQ yr is a more relevant ratio for fuel cycle safeguards analysis than IMD/NMI since the latter takes into account only <u>one</u> flow stream (input or output whichever is greater), although IMD/yr are spent on both the streams.

*The values per zone correspond to the reprocessing or the MOX facility respectively.

Table 7: Interface Activities between FC-Zones

	Zone 1 In	Zone 1 Out	Zone 2 In	Zone 2 Out	Zone 3A (Repro) In	Zone 3A (Repro) Out	Zone 3B (MOX) In	Zone 3B (MOX) Out	Reactors (3 LWR with Pu) In	Reactors (3 LWR with Pu) Out
U t/yr	819	819	540	540	216	216	16	16	16	16
Pu kg/yr	-	-	-	5400	2160	2140	440	433	433	433
SQ/yr	327	327	216	891	356	356	61	61	61	61
WSQ/yr	6.5	6.5	4.32	71.82	29	92	18	18	18	6
IMD/yr	123	324	60	60	600	543	73	71	12	7
IMD/SQ yr	0.38	1.0	0.28	0.07	1.68	1.52	1.19	1.16	0.2	0.11
IMD/WSQ yr	18.78	49.5	13.9	0.84	20.09	5.9	3.95	3.85	0.67	1.17

Comments to Table 7

1. The differences between the output/input at the interface of two consecutive zones are caused by
   - export or } both of which leave the zone
   - waste streams } boundaries.

2. The SQ, WSQ and all the IMD values are taken over from Table 6.

3. Values for 3 LWRs with recycled Pu are estimated from Willy's data conveyed through his letter of 25th February 1985.

Table 8: Approximate LMUF Values (Operators' Data) for the Zone 1 and different MBAs in Zone 3 (LMUF Zone 2 = 0)

Zone/Facility	σ_{syst} %	Amount	Variance($\sigma^2 s$)	LMUF (σ_s) Act.Amount	SQ	WSQ
Zone 1						
LEU Fab.						
Input	0.3	273 tU	0.67 $[tU]^2$			
Output	0.2	270 tU	0.29 $[tU]^2$			
Waste	5.0	3 tU	0.02 $[tU]^2$			
Inventory						
Powder	0.2	4.8 tU	~0.0 } x2			
Pellets	0.2	4.7 tU	~0.0 } x2			
Rods	1.0	47 tU	0.22 } x2 $(tU)^2$			
Total Fac.			1.42	1.2 tU	0.48	0.01
Total Zone 1			4.26	2.0 tU	0.83	0.017
Zone 3						
Reprocessing						
Input	1.0	2160 kgPu	466.56 $[kgPu]^2$			
Output	0.5	2140 kgPu	114.49 $[kgPu]^2$			
Waste	5.0	20 kgPu	1.0 $[kgPu]^2$			
Inventory	1.0	65 kgPu	0.42x2 $[kgPu]^2$			
Total Fac.			582.9 $[kgPu]^2$	24.1 kgPu	3.02	1.01
Zone 3						
MOX						
Input	0.25	440 kgPu	1.21 $[kgPu]^2$			
Output	1.0	433 kgPu	18.75 $[kgPu]^2$			
Waste	10.0	7 kgPu	0.49 $[kgPu]^2$			
Inventory	0.25	74 kgPu	0.02x2 $[kgPu]^2$			
Total Fac.			20.49 $[kgPu]^2$	4.53 kgPu	0.57	0.19
Total Zone 3			603.4 $[kgPu]^2$	24.6 kgPu	3.07	1.02

Comments to Table 8:

1. UF_6 and fresh fuel assemblies have not been considered for inventory-variance calculations since they have been assumed to be covered during throughput measurements.

2. Only process inventories in Repro. and MOX are considered for MUF-variance calculations, the rest of the stored materials (PuO_2 and assemblies)has been considered to be under seal and assumed to be measured during throughput measurements.

3. The inventory variance is multiplied by two to account for the beginning and ending inventories.

4. All the measurements are assumed to be independent of each other. For simplification, only systematic measurement errors have been considered.

3.5 Working Paper II: Comments on Information System, Pattern Recognition Methods, Timeliness

(sent in the form of a letter to J. de Montmollin and W.A.Higinbotham on April 12, 1985)

In this working paper I have presented some ideas on the information system for the fuel cycle safeguards. In addition I have also discussed some points on other types of fuel cycles as well as on the timeliness of safeguards activities. For simplifying the analysis I have included table 9 with this letter. It contains information on the number of items and amounts which are expected to be under safeguards in the reference fuel cycle.

1. Nature of the information system

In principle, the material flows and inventories in the different zones of the reference fuel cycle can be considered to be sequentially converted into an inspector validated information flow. This conversion takes place in all the three zones of the reference fuel cycle in a near-real-time fashion. In zone 1, for example, 54 new UF_6-cylinders are verified by the inspectors on a monthly basis, i.e. repeating the activities 12 times per year for the oncoming new cylinders. All these cylinders are counted and identified by the inspectors who are present during the verification activities and about 45 of these cylinders are measured through NDA. At the same time 180 finished fresh fuel elements are individually counted and sealed every month, 12 times a year. Besides, 66 fuel elements are n-collared over the year. The sampling plan is designed in such a way that every month, a loss of one significant quantity can be detected with 95 % probability for both the input and the output flows. The total material in the zone is verified at least twice, that is at the time when it enters the zone as well as at the time when the material leaves the zone in the form of finished fuel elements.

In zone 2 the total number of fuel elements present in each of the reactors is counted and identified once a year. The identification takes place in such a way that at least one fuel element can be detected in case it is lost. Besides these annual inventory verification activities, the Agency inspectors come in addition, three times a year to each of the reactors and ensure the presence of the fuel elements at the fresh fuel and the wet storages and in the core with the use of C/S-measures. In zone 3 a full coverage for all the material entering and leaving the zone or the facility is provided on a semi-continuous basis. In the reprocessing facility in particular, each and every batch of accountability tank solution is correlated with the relevant fuel elements, is verified with regard to its Pu content, and is ensured through observation that the material in the batch enters the process area. A material balance is struck around the process MBA in this facility on a bi-weekly basis. This data base is used on a near-real-time fashion to have an idea on the actual flow and inventory of materials in this MBA and to enable the Agency to detect a loss of a given amount of nuclear material in a timely fashion. The timeliness in this context has to be seen with reference to the type of diversion scenarios which one considers from the point of view of international safeguards. If the given amount is diverted over a short period of time (abrupt diversion) the near-real-time accountancy enables the Agency to detect such a diversion almost immediately after the diversion of the whole amount has taken place, i.e. within approximately 2-3 weeks time. On the other hand, if the diversion takes place over a longer period of time, i.e. over the whole year (protracted diversion), the detection can take place after the whole amount has been diverted. The sequentially generated information in the reprocessing (as well as in the MOX facility) provides a fairly powerful data base for recognizing the normal flow and inventory patterns in the facility and a deviation from it. For example, in the 240 tons/year reprocessing facility in the reference fuel cycle, such sequentially generated data base could provide, under suitable operation conditions, a detection capability of less than 8 kg with a high probability of detection almost immediately after such a diversion has taken place.

2. Reporting system of a State

The information system which is assumed to be generated in a sequential fashion in the reference fuel cycle, can also provide another important advantage. Any state which has a reference fuel cycle of the type we are considering, will also have a properly developed state's system of accountancy and control. Such a state may send their own inspectors to a facility during the time when the Agency inspectors carry out their activities. This is the normal case at present. If the state's inspectors could accept the Agency validated information system generated by the Agency inspectors during their activities at the facility, then this validated system could form the basis for the reporting system of that particular state. Such a system can provide almost all the data necessary for the inventory change reports and the material balance reports from a state to the Agency. The Agency, after receiving these reports from the state at the headquarters, would not have to validate the information contained in these reports since it has already been validated by its own inspectors some time back. This would mean that the actual verification activity of the Agency inspectors will be concentrated in validating mainly the operator's data at the time of their visits to the different zones. This particular procedure could simplify a part of the verification procedure of the Agency, a part of the reporting procedure of the states and improve the transparency of the overall information system. It could also improve the credibility of the data base produced by the operators and sent by the state to the Agency. The detailed physical inventory listings need to be generated only at the time of the physical inventory takings which is normally once a year.

3. Pattern recognition methods

The more I think about fuel cycle safeguards, the more I get convinced about the possibility of using the methods of pattern recognition for this type of safeguards. The safeguards activities in individual facilities provide titbits of safeguards relevant information which may once in a while permit safeguards relevant statements for such facilities. Only the integrated information from individual facilities with the different cross-linkages and correlations among the flows and inventories permits one to extract the relevant data base for the fuel cycle as a whole.

Recently I found a picture which depicts an arrangement of a number of black, grey and white rectangles which I have included with this letter. A close observation and analysis of the individual rectangles does not reveal the fact that they depict the picture of a human head. Nevertheless this relatively small number of rectangles is sufficient to allow us to recognize the features of President Lincoln as soon as we step back a few paces away from the picture or blur the outlines of each of the rectangles by half closing our eyes.

This particular example tells us a number of interesting things about the possibilities of recognizing the features of a whole system from its components. It shows that our brain compares the blurred contours of the individual rectangles and the interlinkages among these rectangles with the archetype of a face stored and identified in our memory. After this comparison we recognize the face of Lincoln in this combination of rectangles inspite of the missing parts. It also indicates that even the most painstaking analysis of the individual rectangles or evaluation of the exact shades and dimensions of the rectangles cannot reveal the underlying fact that combined and linked together they form the picture of the head of Abraham Lincoln. And finally, the example shows in a forceful manner that eventhough individual details of these squares are useful in selecting parameters for a particular strategy, they are not useful when trying to recognize the underlying system or the behaviour of that particular system. It shows also that up to a certain point - the more blurred the focus is for the individual rectangles - the easier it is to see what the whole system is.

In a certain sense, for the system approach one has to proceed in two distinctly different steps: The individual rectangles have to be analyzed and investigated to a certain degree of detail. After that it will be more important to arrange these rectangles into their proper context by recognizing the interlinkages and correlations than to examine them in even greater detail. If the second step is forgotten, then one learns a lot about the details of the individual rectangles, but very little about the system as a whole and its behaviour. This is mainly because of the fact that the characteristics and behaviour of the system depends less on the characteristics of the individual rectangles themselves than on the linkages between them.

I feel that similar is the case with the fuel cycle safeguards. The flow and inventory patterns in individual facilities correspond to the characteristics of the individual rectangles in the example cited above. One has to know to a certain extent, the detailed characteristics of these elements. However, to arrive at a safeguards relevant statement for the fuel cycle as a whole, one has to work out and establish the linkages and the cross correlations of the flow and inventory dynamics amongst the individual facilities. The recognition of such linkages is more important than knowing all the details of the flow and inventory characteristics of these facilities. A number of useful methods in connection with pattern recognition has been discussed in the book by K.S. Fu titled "Sequential methods in pattern recognition and machine learning", Mathematics in Science and Engineering, Vol. 52, published by Academic Press Incorp., 1968. Unfortunately, I do not have anybody at the EKS at present who could go through the methods in some detail and find out the possibility of using them for safeguards in fuel cycles as a whole. Maybe you or somebody from Brookhaven National Laboratory might have the possibility to investigate this matter.

4. Timeliness of Agency actions in connection with safeguards

The question of timeliness has apparently become a bone of contention particularly in the United States. Some in the United States have contended, as was pointed out by a recent publication of the INMM (safeguarding nuclear materials, January 1985), that IAEA safeguards must provide 'timely warning', that is, detection of diversion in time for diplomatic action to prevent the fabrication of the first weapon, which is claimed to be only a few days. Fortunately, it was very correctly pointed out in this publication that to provide this type of timely warning is not an objective of the Agency safeguards. Such timely warnings, if at all relevant, have to be provided by totally different types of international or national measures.

Any action which the Agency can take in case a diversion has been definitely established, can only be through its Board of Governors. The Agency requires, as many other international organizations, probably a few months, immediately after a diversion has been established, before it can report this matter officially to the Board. This time delay is inherent in the decision making system of the Agency and has been considered by many as sensible and useful. It permits the Agency to avoid any misinterpretations of its results and allows the state time to resolve any anomalies which may be caused by false alarms.

With reference to the reference fuel cycle, the activities and their time scales of the Agency inspections in zones 1 and 2 of the fuel cycle are such that the time required to report to the Board of Governors is expected to be of the same order of magnitude as the time considered to be necessary for making an explosive device from nuclear materials out of these zones after their diversion from the safeguarded sector. Therefore, the problem of timeliness is not that relevant for these two zones. For zone 3 materials, the safeguards system has been designed in such a manner that the continuity of knowledge for the Agency is ensured. If a diversion were to take place from this zone, the detection time for this diversion would correspond approximately to the time required for the manufacture of nuclear explosives after the material has been diverted from the safeguarded sector. The Agency interprets the timeliness for this type of materials in a different way. It considers its safeguards activities to be timely if a detection of a diversion can be made within this timescale. This is inspite of the fact that even in these cases, the Board can be officially informed only a few months after such a detection has taken place. The main difference between the idea of the timeliness by the Agency and that by some in the United States lies in the fact that the Agency considers the objective of timeliness to be met when a detection of a diversion of a given category of material has been made within the range of time which is considered to be relevant for that category of material. Some in the United States on the other hand, interpret the timeliness as the point from which time onwards sufficient time would still be available to prevent the manufacturing of the first bomb by the diverting state.

Prevention of the fabrication of a nuclear explosive is, however, not an objective of Agency safeguards. This is like condemning a cow because it cannot fly. As I had said earlier, totally different types of measures are required to ensure a timely prevention of the fabrication of nuclear explosive devices.

The type of safeguards approach which we have been considering for the fuel cycle safeguards, enables the Agency to maintain its continuity of knowledge with regard to the amount and location of a given category of nuclear materials which is in conformity with the corresponding detection times. Some improvement in timeliness against the facility based safeguards approach can be expected because of the fact that the information system is generated on a semi-real-time basis and the flow of the safeguards relevant information can become a little more faster between the states and the Agency. However, the time required by the Agency to report to its Board of Governors will not be altered much by the fuel cycle safeguards.

5. <u>Different types of fuel cycles</u>

Willy had in one of his recent letters raised the interesting question of how the safeguards approach which we are considering could be used for other types of fuel cycles, for example, cycles having only reactors and fabrication facilities or only a few facilities of the same type with some research activities. I don't think that a fuel cycle safeguards approach for this type of incomplete fuel cycles would be much different to the facility based safeguards approach which the Agency practices at present. Some correlations between the interface of the two consequent stages of a fuel cycle might simplify some of the present activities. The actual safeguards effort may not be very much influenced by utilizing fuel cycle approach for such partial systems. I would think that the inspection activities would range between 2-5 IMD/WSQ.yr for bulk handling facilities and around 0.4-0.5 IMD/WSQ.yr for reactors. However, the timeliness and transparency of the information system for such fuel cycles may be expected to improve if the basic ideas in our approach are incorporated there. The maximum advantage from a fuel cycle approach can be obtained when different categories of materials are simultaneously used in a fuel cycle and cross-linkages or correlations between external and internal flows and inventories can be established.

Table 9: Items Follow-up in the Reference Fuel Cycle

Category of Materials	Per Facility (Item)	Per Zone (Item)	Per Zone (Amount)
Zone 1			
Input: UF_6-Cylinders	216	648	819 tU
Output: Fresh Fuel Assemblies	720	2160	810 tU
Inventory			
Input: UF_6-Cylinders	26	78	99 tU
Process: UO_2-Bulk	240	720	14.4 tU
UO_2-Pellets	943	2829	14.1 tU
Fuel rods	9300	27900	147 tU
FFA	75	225	84 tU
Zone 2			
Input: FFA	72	1440	540 tU
Output: Spent Fuel (SFA)	72	1440	540 tU + 5400 kg Pu
Inventory: FFA	72	1440	540 tU
SFA (Core)	216	4320	1620 tU + 12500 kg Pu
SFA (Wet Storage)	360	7200	2700 tU + 27000 kg Pu
Zone 3A Reprocessing			
Input: SFA	576	576	216 tU + 2160 kg Pu
Act.Tank Batches	288	288	216 tU + 2160 kg Pu
Output: UN	535	535	214 tU
PuO_2	1070	1070	2140 kg Pu
Inventory: SFA	576	576	216 tU + 2160 kg Pu
Process: PuN	~ 25	25	65 kg Pu
PuO_2	~ 1200	1200	2400 kg Pu

Table 9 ctd.

Category of Materials	Per Facility (Item)	Per Zone (Item)	Per Zone (Amount)
Zone 3B MOX Fab.			
Input: UO_2	40	40	16 tU
PuO_2	220	220	440
Output: MOX FA	78	78	16 tU + 440 kg Pu
Inventory: UO_2	20	20	8 tU
PuO_2 in BC	110	110	220 kg Pu
Process: PuO_2-Bulk	220	220	74 kg Pu
MOX-FA	40	40	8 tU + 220 kg Pu

Note to Table 9:

1. The waste batches have not been considered.

2. The U-Inventories in the process areas of Reprocessing and MOX Fabrication Facilities have been ignored.

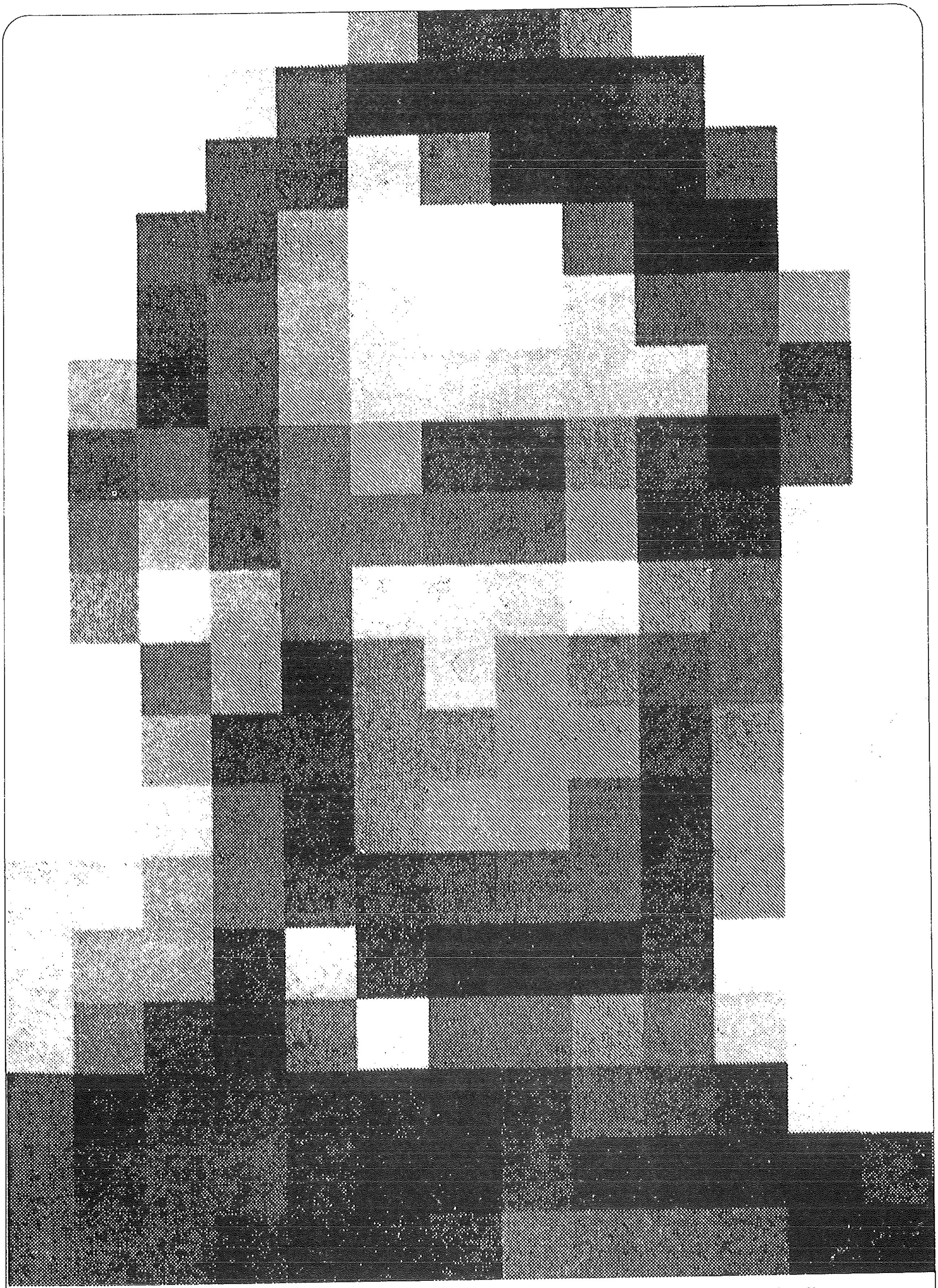

Abb. 1 Das Ganze und die Details

Um die Aussage des Gesamtmusters dieser Quadrate zu erfahren, müssen die Quadrate selbst zurücktreten, indem das Bild aus größerer Entfernung oder unscharf (z. B. ohne Brille) betrachtet wird. Dadurch treten die Beziehungen zwischen den Quadraten stärker hervor und enthüllen ein Porträt von Abraham Lincoln.

Fig. 1 The complex unity and the details

To experience the statement of the overall pattern of these squares, they must be put in the background by looking from a larger distance or blurry (e. g. without glasses) at the picture. Therewith the relations between the squares stand out in relief and uncover a portrait of Abraham Lincoln.

Taken from: F. Vester; A. von Hesler;Umweltforschungsplan des Bundesministers des Innern; Ökologie und Planung in Verdichtungsgebieten. Forschungsbericht 80-101 040 34 (1980)

4. Contributions by William A. Higinbotham,
Brookhaven National Laboratory, LI, NY, USA.

4. Contributions by William A. Higinbotham, Brookhaven National Laboratory, LI, NY, USA

4. 1 Excerpt of a Letter to James de Montmollin with Comment on Extended MBA Approach — Dec. 19, 1984

4. 2 Comments on Alternative Safeguards Approach to Zone 3 — Dec. 19, 1984

4. 3 Letter to J. de Montmollin and D. Gupta on Distribution of Inspection Efforts in Different Zones — Feb. 25, 1985

4.1 Excerpt of a Letter of W. A. Higinbotham to J. de Montmollin on Extended MBA Approach. Dez. 19, 1984

Although it is very useful to look at zones rather than just to the facilities within the zones, I am not convinced that one can omit verification of inter MBA flows, as now intended, without reducing the assurance that safeguards is intended to provide. There are other ways to assign inspection effort more efficiently. If the Agency can't accomplish what it considers it should due to resource or other constraints, it can't design itself out of this but report its findings to the Board.

I have some problems with your zone-2 approach and with the present approach of the Agency. I have become convinced that there is usually no need to verify a shipment before and after it takes place. Verification at one end should be enough. To justify this requires discussing each type of transfer, the possible diversion-concealment schemes, the verification activities, and which end might require the least effort by Agency and facility personnel.

Obviously transfer of fresh fuel into reactors and removal of spent fuel should be observed. In order to meet the timeliness requirement, the contents of the reactor pools should be verified directly or indirectly every three months. The Agency employs camera surveillance in order to avoid reinventorying every three months. If the cameras show unexplained activity or confirm that a shipment has occurred, the Agency should reinvertory that pool. In the first case fuel may have been removed and it may have been substituted for.

The second case is more complicated. It does not seem very important to me to have inspectors observe and seal partially loaded casks. An operator could overload casks. In any case, inspectors should observe the unloading of casks at a reprocessing or AFR pool or the loading before shipment at a reactor. Since assemblies could be replaced by substitutes or rods could be removed during shipment, verification of the number and some NDA after receipt would be more convincing as to what was received and to be accounted for at the receiving facility.

It does not guarantee that more assemblies were not removed. In this case the assemblies in the pool would need checking. Substitutes could have been brought in in the shipping cask. I don't consider radioactive substitutes very credible, unless that adversary should decide to replace higher by lower burnup assemblies. Cheap NDA should provide reasonable assurance that technically simple assembly substitution is not taking place.

The point is not that cameras can be designed to record for a year. The films should be reviewed every three months to see if a reinventory is needed.

There are technical possibilities which might significantly reduce the need for interim visits, which you and your associates have proposed. Cameras could be designed so that the operators could change the cassettes and mail them to the Agency every 2 or 3 months for review. Also, cameras could be designed to record how many assemblies were loaded into a cask; or VACOSS seals designed for plant personnel to attach to the spent fuel casks. A combination of the two might save effort and be at least as convicting as the present approach.

Another problem is how much effort might really be saved. Reviewing films is tedious and not 100 % effective in detecting real anomalies. It is also likely to observe ambiguous situations which should be investigated.

Perhaps a way out of this confusion would be for the Agency to identify and state its limitations. In such a case, a State which might be concerned about another State could understand to what extent the IAEA provides assurance and what it would have to determine by national means, should this be important. It would also suggest to a State which expects the Agency to provide assurance on its behalf, that it might assist the Agency in doing a better job.

4.2 Comments on Alternative Safeguards Approach to Zone 3 (Dez. 19, 1984)

The reference fuel cycle chosen for study has nuclear materials of different safeguards significance in each of three zones, which are described elsewhere. Since the material which would require the least amount of processing and effort to make it useful for a nuclear explosive is plutonium, it seems reasonable to consider what alternative safeguards approach might be employed in Zone-3 first.

At present the important MBAs are essentially the following:

Table 1

1. The chemical separations process area of the reprocessing plant.
2. The uranium and plutonium product storage areas.
3. The $Pu(NO_3)_4$ to PuO_2 conversion area.
4. The PuO_2 product storage vault at No. 3
5. The PuO_2 receiving/storage vaults at the MOX fabrication facilities.
6. The MOX fuel fabrication areas.
7. The MOX fuel product storages areas.
8. MOX fuel utilization facilities, not analyzed here.

The following are the key measurement points:

Table 2

A. Input accountability tank at the reprocessing facility.
B. U and Pu product accountability systems at the reprocessing plant.
C. $Pu(NO_3)_4$ accountability tank between 2 and 3, above.
D. The accountability system for the PuO_2 product of 3, above.
E. UO_2 and PuO_2 feed measuring systems at the MOX facilities.
F. MOX fuel assembly NDA stations.

In addition there are KMPs for all of the waste discard streams from the several processes, and KMP's to measure intermediate products for near-real-time-accountancy (NRTA) and after a clean out for a physical inventory at MBAs 1, 3, and 6.

Present plans envisage the following inspection activities:
Essentially contiuous inspector presence at the reprocessing plant to:

(1) verify identity of assemblies chopped and dissolved,
(2) verify measurements of U and Pu at the input accountability tank,
(3) verify measurements of U product batches (sometimes) and of Pu-nitrate batches transferred to storage tanks,
(4) verify NRTA in-process measurements,
(5) verify measurements of Pu-nitrate batches transferred from the storage tanks to the conversion process,
(6) audit books and records and cooperate with other Agency sections in analyzing data,
(7) investigate anomalies, and
(8) observe and verify PIT measurements, when these occur.

It is assumed that inspectors will visit the conversion and MOX fuel fabrication plants frequently (at last once a month). Inspection activities at the conversion plant would supplement the reprocessing plant/conversion plant transfer verifications listed above, observe operation of the process, verify PuO_2 product containers in the vault and possibly attach seals to them, and verify physical inventories when they are performed.
At a MOX fuel fabrication facility, inspectors should verify the UO_2 containers on hand in the receiving area or check the seals, verify the in-process materials available for NRTA verification, verify the MOX fuel assemblies on hand, audit books and records, observe and verify physical inventories when they occur, and investigate anomalies.

On the basis of these activities, the inspectors and the Agency should be able to: maintain current books on the amounts, isotopic compositions and locations of the plutonium in all of the process and storage MBAs; form NRTA and 6 or 12 month material balances for each MBA; have some reasonable possibility to detect postulated attempts to conceal the fact that plutonium is missing; observe anomalies so that investigation can be initiated promptly.

This approach obviously calls for a large amount of intelligent effort. The question is, could some of these activities be reduced or omitted without significantly affecting the degree of assurance provided, as measured by technical effectiveness criteria, for example. Just how effective the base case, by-MBA, approach may be is not at issue. The question is would an alternative approach leave uncovered some diversion/concealment schemes which now are covered, or might it significantly lower the probability that the present activities might detect anomalies which should be investigated. It is conceivable, but doubtful, that an alternative approach might be more effective.

Before discussing alternatives it may be useful to discuss inspector effort, in general, for these facilities. Everyone agrees that it is essential to verify the plutonium into the zone at the reprocessing plant, the MOX or other products which would be removed from the zone, and physical inventories when these are performed. It is generally agreed that inspectors should have access to a reprocessing plant at any time in order to verify flows and inventories. In order to meet the timeliness goals, inspectors should visit the conversion and MOX fabrication plants at least once a month. At least for the reprocessing plant, it will be impractical to send inspectors from Vienna for visits. Several inspectors should be permanently stationed near the reprocessing plant. Someone must be available to witness the measurement of each input dissolver batch, which operation probably will occur twice a day or more often, seven days a week while the equipment is operating.

Probably, the conversion process will be located in or next to the reprocessing plant. Often the MOX fabarication plant or other safeguards sensitive facilities will be located nearby. It is possible, even probable, that the same inspectors which would be required under the present facility-oriented approach to inspect the reprocessing plant could also perform the presently proposed inspection activities at the conversion and MOX fabrication plants.

It does not make sense in this case to simply add up the hours which inspectors are estimated to use on inspections. At a reprocessing plant these may be 1 or 2 hour stints, several hours in a 24 hour day and 7 days a week. The inspectors probably would have the time to perform the inspections at the other facilities, without being overworked.

It would be very inefficient to send two inspectors from Vienna every month to perform these operations. Before considering alternative inspection activities seriously, the inspector effort, including resident housing and travel time for the base should be understood.

Zone 3 as an Extended MBA

This is one extreme case. The flow of plutonium into the zone is verified at the reprocessing plant input accountability vessel and the flow of plutonium out of the zone is verified for the MOX fuel assemblies transferred to some facility which is artificially defined as another zone not involved in this analysis. Presumably all intra-zone transfers would be recorded and some (between facilities) reported to the Agency; but none of these would be verified, as such.

In order to meet the timeliness goals, the entire inventory should be verified frequently (e.g., once each month). At the bulk processing facilities, not all materials will be accessible for verification. For near-real-time accounting, as much of the material as possible would be directly verified and the remainder estimated on the basis of experience or modelling. It is assumed that the bulk processes would be shut down at least once a year and cleaned out for physical inventories, which would be observed and verified by the inspectors. It will be assumed that the plutonium in storage areas could be verified frequently and accurately, although this may not always be the case especially for the plutonium nitrate storage tanks.
Waste products, which are to be disposed of, should be verified in this and in all other alternatives.
It will be useful to postulate some data on flows, inventories, and measurement accuracies, in order to estimate what impact this alternative might have on the technical effectiveness of safeguards. These data are for the purpose of comparing the alternatives. They are arbitrary, but hopefully, realistic enough for the comparison. Only actual data should be used to estimate the actual sensitivity of material balance accounting, as practised by the Agency for MBAs, however defined.

Diversion Assumptions

The divertor, if any, might attempt to introduce undeclared feed (assemblies) to the dissolvers at the reprocessing plant or to alter volume data or samples to persuade the Agency that less plutonium entered the zone than actually did. This diversion/concealment scheme would affect the base case and any alternative approach equally. Likewise, any scheme to convince the Agency that more plutonium is shipped out of the zone in waste discards or in MOX assemblies does not affect a comparison of alternative approaches. Both these schemes deserve attention, but not here.
It is assumed that plutonium compounds could be removed from any of the process or storage areas without being observed. Accountancy is the primary safeguards measure, although C/S may be used to provide continuity of knowledge:
seals on PuO_2 containers, for example, or surveillance devices at the Pu nitrate storage tanks.
In the base case, an adversary might attempt to mislead Agency inspectors as to the volume, weight, or plutonium concentration in items at any of the verified KMPs within or between the several processes. When these would not be verified, in the extended MBA case, the operator would only have to falsify records and reports, if that should serve any purpose.
In both cases, some or a lot of emphasis is placed on verifying in-process and storage area inventories every month for NRTA. It may be possible for the hypothetical adversary to bias weight or volume or samples to conceal missing material for some time. Once material has been diverted it remains missing. It may be detected in subsequent NRTA periods and should be detected when all of the processes are cleaned out and the physical inventories are verified, assuming that all are inventoried at the same time or in a sequence which should detect paper transfer.

Borrowing or shuffling only appears to be a practical concealment scheme for a few of the materials in this zone because the forms of the material change as operations are performed. One material that exists at three plants is the PuO_2 powder (2.5 kg Pu per can). Another is the MOX assemblies which would be at the two fabrication plants. Either or both of these might be sealed so as to avoid the need for reverifications. In either alternative, these would probably be verified once a month.

Table 3: Flows (plutonium only)[1]

KMP	Tank or Container Transfer Rate	kgPu per Day	Month	Year	Measurement[2] Accuracy		Method[3]
Reprocessing Input	2/day	5	150	1500	5%	1%	A
Reprocessing Product	1/day	5	150	1500	1	0.5	A(B)
Reprocessing Waste	1/week			7.5 to 15	50	20	A
Conversion Input	irregular		150	1500	1	0.5	A
Conversion Product	2/day	5	150	1500	0.5	0.25	A(C)
Conversion Wastes	1/week		0.75	7.5	50	20	A
MOX Fabrication[4] PuO_2	1/day	2.5	75	750	0.5	0.25	A(C)
MOX Fabrication[4], assemblies	1/6 days		75	750	2.0	1.0	C
MOX Fabrication[4], recycle[5]	1/month		7.5	75	2.0	1.0	C
MOX Fabrication[4], wastes	1/month		0.375	3.75	20	10	C

Notes:

1. Waste discharges and recycle excluded from totals.
2. First number is random, second is systematic.
3. A is volume or weight and sample analysis, B is K-edge absorption and gamma-ray spectrometry, and C is weight, passive gamma and neutron NDA.
4. For each of two MOX fabrication plants.
5. Scrap returned to reprocessing plant.

Table 4: In-process and S/R Storage Inventories (plutonium only)

Location	Operating Inventory	NRTA Uncertainty
Reprocessing MBA	15 - 30 kg Pu	2.5 - 5.0 kg
Pu nitrate tanks	5 - 1000 kg Pu	0.5 to 2.5 % (systematic)
Conversion process	5 - 15 kg Pu	not estimated
Conversion PuO_2 stor	5 - 500 kg Pu	0.25 % (systematic)
MOX Fabrication, PuO_2 store	5 - 250 kg Pu	0.25 % (systematic)
MOX Fabrication, process	50 - 100 kg Pu	2.5 - 5.0 kg
MOX Fabrication, recycle	0 - 15 kg Pu	1.0 % (systematic)
MOX Fabrication, assemblies	0 - 300 kg Pu	1.0 % (systematic)

Notes:

MOX data are for each of two plants' in-process inventories. In-process inventory accuracies vary from plant to plant. Capacity of Pu nitrate storage tanks and verification accuracies vary from plant to plant.

It does not appear that the choice of approaches should be influenced by this possibility.
The zone approach does not appear to leave any of the postulated diversion/ concealment schemes uncovered. It may not provide as timely detection and it may not be as sensitive for some diversion scenarios as the present, by-MBA, approach. Also to be examined is the saving of inspection effort, if any.

Annual Material Balances

Using the numbers in Tables 3 and 4, and making some assumptions as to possible correlations, the sensitivity of an annual material balance is not much different whether the balances are performed by MBA and combined or simply based on the uncertainties of the zone inputs and outputs and total inventory. See Appendix A for further discussion of this.
In most cases, the systematic errors are controlling. It is not likely that the systematic errors will be correlated for measurements made on different forms of the material and by different techniques. It is probable that the materials transferred from one facility to another will be measured only once, or at least by the same methods. In such cases, the systematic errors will tend to cancel each other. The result is that the limit of error, determined either way, is about 25 kg Pu. No conclusions should be drawn from this as to the LEMUF that the Agency might attain in any case. What this indicates is that the sensitivity for annual material balances is probably not much different for the two alternatives, regarding the zone as a whole. There is the difference that in the base case, material balances can be calculated for each of the MBAs. For some of these, the measurement accuracies achievable are significantly better than for some others.

Looking at the zone as a whole, the attractiveness for diversion of the material does not appear to be much different,whether it is as a nitrate solution, an oxide powder or a MOX pellet. It would, however, be somewhat more difficult to divert material proportionately and over a considerable time from each of the process MBAs. The base case approach has the advertage that a loss is identified with an MBA, which might simplify its investigation. On other hand, an honest facility operator's records should locate a loss.

That some of the important measurements are more accurate than some others, suggests that it might be possible to save some effort in the base case by designing inspection activities to match the zone rather than what may be achievable at each MBA. A few examples are suggested, using measurements data from Table 3. These are only illustrative examples. If the overall sensitivity of a material balance for the plutonium in the zone is 25 kg, sampling plans might be based on 95 % detection for a loss of 15 kg plutonium, rather than 8 kg. It might be acceptable to use the K-edge densitometer/gamma ray spectrometry method to assay Pu nitrate samples and thus to avoid sending such samples to Vienna for chemical analysis. Only a minimal effort might be assigned to verification of waste discards or of physical inventories which contain less than say 5 kg Pu.

Timeliness

The timeliness goal for plutonium is based on one philosophical and one practical consideration. The philosophical reason for timeliness goals for recovered plutonium, plutonium in spent fuel, and for uranium containing less than 20 % U-235 are explained by the Agency as being related to the different times that it might take for a State to convert each material to a form useable in a nuclear explosive. Another philosophical reason, suggested by others than the Agency, is that a reprocessing plant would be needed to extract plutonium from spent fuel and this plus a reactor or an enrichment plant to produce plutonium or HEU from natural or low enriched uranium. Any such plant would take time and money to build and such facilities might be detacted by national means, whereas relatively simply equipment would be needed to make plutonium metal from plutonium nitrate or oxide. The practical reason why prompt detection of an anomaly is important is that anomalies will be observed, perhaps frequently, by Agency inspectors at facilities in States which have no intention to divert nuclear materials. Prompt detection and localization should greatly facilitate resolution of such anomalies.

Before comparing the MBA to the zone approach for timeliness and other features, a few words are in order regarding the way that flows between the MBAs in Zone 3 might be verified (see Table 3 for the flow KMPs):

The plutonium content of the input dissolver batches to the reprocessing separations MBA are to be verified as they are measured in either alternative. Pu nitrate batches transferred from the separation process to the nitrate storage tanks and from the nitrate storage tanks to the conversion process are to be verified when measured in the MBA alternative.

PuO_2 containers should be measured by the conversion plant operators as they are produced there, and by the MOX fabrication plant operators before or when being fed into the process for blending with UO_2. In both cases it is probable that these measurements would not be verified directly but that sampling plans would be designed for verification of items produced at the conversion plant and after receipt at the fabrication plants, at the time of monthly inspector visits. Seals might be attached to verify containers to keep track of those which traveled between the facilities between visits and to avoid reverifications.

MOX fuel assemblies would be verified after being fabricated and before shipment, during monthly visits.

Waste batches should be verified before being written off as having no further safeguards significance. Since these streams contain relatively small amounts of plutonium, the State and Agency might agree on some schedule to minimize efforts, possibly involving randomized verifications. These have to be verified for either alternative.

It would appear that the flow verifications are significantly different for the nitrate solutions in the two alternatives, but that the flow verifications for the PuO_2 containers and assemblies are not distinguishable from the monthly inventory verifications anticipated for the conversion and fabrication plants in both alternatives.

Both alternatives assume direct verification of clean-out physical inventories at the bulk processing areas.

The major difference, then, relates to verification of the flows from reprocessing to the nitrate storage tanks to the conversion operation, as these may affect the technical effectiveness and timeliness of the approaches for the zone.

The isotopic composition of the plutonium, including Am-241, is of commercial and safeguards significance. Commercially the fissile/fertile ratio is important, and the Am-241 gamma rays are important for safety in handling. Safeguards NDA techniques require knowing the isotopic ratios.

Tracking different isotopic ratios through the processes may be useful for verification purposes. Since the isotopic ratios for plutonium in spent fuel are functions of the original enrichment, exposure in a reactor, and other factors, the isotopic ratios of the plutonium entering the separations process at a reprocessing plant will vary somewhat from batch to batch and significantly when fuels with different histories are reprocessed. Pu-241 decays to Am-241 with a half-life of about 14.5 years. The Am-241 is extracted with the fission products during reprocessing. The ratio of Pu-241 to Am-241 is a function of the time since the Am-241 was removed.

From Table 4, some estimates can be made of the time a particular batch of plutonium spends in each process and storage area and of the possible changes in isotopic ratios which may occur:

Table 5

Location	Residence Time	Am-241/Pu-241
Separations	3 - 5 days	0
Nitrate Tanks	7 - 150 days	.0001 to .020
Conversions	1 -2 days	.0001 to .020
PuO_2 Stores	30 - 300 days	.0050 to .060
MOX Fabrication	30 - 60 days	.0090 to .068
Assemblies	Indefinite	.009 plus

As noted above, the plutonium isotopic ratios may be expected to change significantly every few days, from the input to reprocessing. During the separations operations some mixing of batches will occur. Most reprocessing plants will have plutonium nitrate storage tanks to serve as a buffer between the reprocessing and conversion operations and in order to blend batches with uniform isotopic composition to facilitate fabrication of MOX with uniform fissile content. The capacity of the storage tanks chosen for this illustration are large enough to blend the plutonium solutions produced during half a year's operation. At actual facilities the blends might be this large or considerably smaller. Large blends would have the advantage that the plutonium ratios would not often need to be verified for interpreting NDA data.

It would appear to be technically complex to perform abrupt diversions simultaneously from the several MBAs. If the zone approach is used, and the Pu nitrate batch measurements are not verified, the operator could divert from anywhere in the separation, nitrate storage, and conversion MBAs, and falsify the records to make it appear that proportionate amounts of material were missing from all three. Assuming that the flows into the PuO_2 storage areas and through the fabrication plant would be verified at the monthly visits for both alternatives, there should be no difference between the two cases as regards these MBAs.

Near-real-time accounting (NRTA) has been studied for application to the chemical reprocessing area as a sensitive means to detect abrupt diversions, and as a means to increase the sensitivity to detect more protracted diversions by sequential analysis of the NRTA balances. In order to perform NRTA balances for this process area, it is necessary to verify the plutonium in the input dissolver batches, in the plutonium nitrate batches, in the waste discards, and to verify the in-process inventory periodically (once a week to once a month) in so far as is possible at a specific facility. The facility operators may attempt to falsify the flow and inventory records and to alter the volume and/or concentration indicators which the inspectors verify.

Application of NRTA has also been proposed for the conversion process, based on verification of the plutonium fed to the process as nitrate solution, the PuO_2 product, the waste streams, and possibly simulation of the process. If the plutonium nitrate transfers are not to be verified, the separation, tank storage, and conversion processes would have to be treated as one big MBA (the PuO_2 product would be verified each month as was explained above). This would have been necessary at the Mol, Belgium reprocessing plant which had no nitrate storage and no nitrate solution accountability station, but converted the nitrate solution to an oxide powder directly. At a plant such as the one described here, there would be a large and varying in-process inventory in the extended MBA which includes the nitrate storage tanks.

Inspection Effort

A substantial inspection effort would be required for the facilities in Zone 3, in a State with such facilities, for either of the alternatives considered. The flows into and out of the zone should be verified in either case; inventories are to be verified, as well as possible, every month, and physical inventories at least once a year. What might be omitted, with the zone approach, are verification of the many batches of plutonium nitrate solution transferred from reprocessing to the nitrate storage tanks and from the tanks to the conversion process. What, if any, effort might be assigned to verification of the reprocessing and conversion in-process inventories is discussed in the following section. It would not be a large fraction of the total effort in any case.

Inspection effort estimates for the activities which might be performed at these facilities have been presented in several papers. The estimates have a range of about 2 to 1, due to different assumptions as to the design and capacities of the facilities and as to how long it might take to perform the postulated inspection activities. It may be pure chance that they are this close. The inspection activity which is assumed to call for the greatest effort is verification of the plutonium in the dissolver solution batches, which activity is required in all alternatives. This activity involves verifying which assemblies are fed to the dissolvers, verifying the volume measurements and observing preparation of samples to be shipped to the Agency from each accountability batch, and other activities. The main time consuming acitvities which would not be performed in the zonal approach are verification of the plutonium nitrate batches transferred from reprocessing to the storage tanks and from the tanks to the conversion process. These involve verification of volumes and observation of sample preparation or of sample assay using densitometry and gamma-ray spectrometry.

The following inspection effort estimates are only intended to indicate in a very qualitative way what might be the difference for the two alternatives in this hypothetical case. It is not considered likely that the difference in percent would be larger in any actual case.

Table 6

MBA	MBA Approach	Zone Approach
Reprocessing	900	700 man days
Storage Tanks	260	60
Conversion	150	150
MOX Fabrication	250	250
MOX Fabrication	250	250
	1810	1410 man days

The requirement that inspectors should verify every input batch to the reprocessing plant's chemical extraction MBA implies that inspectors should be available to verify such measurements whenever they occur, day or night while the process is operating. In consideration of the other inspection activities assumed for either alternative and inspections to be performed at the receiving spent fuel storage MBA that is in Zone 2, it would appear to be necessary to assign 5 inspectors, who reside nearby, to the reprocessing plant, the nitrate solution storage tanks and the conversion plant, or at least 1,000 inspector working day.

In any given case there should be other ways to make more efficient use of inspectors at these facilities, procedures to provide assurance of the integrity of samples, local sample analysis using Agency equipment, more effective use of isotopic correlations, etc.

Tentative Conclusions

In the MBA approach, the flows into and out of each MBA are to be verified, the in-process inventories are to be verified to the extent possible every month, and physical inventories are to be verified when they are performed. In the zone approach, flows into and out of the zone are to be verified, and the in-process and clean-out physical inventories are to be verified as before, except that all physical inventories should be performed and verified at about the same time.

The effort-intensive verification of plutonium in dissolver batches entering the zone must be performed when the input batches are measured in either alternative.

The flows of PuO_2 in containers produced by the conversion process, transferred to the MOX fabrication plants and used there, are verified during the interim visits to these facilities, along with the interim inventory verifications. For this reason, interim and annual material balances can be verified for the MOX fabrication plants and the storage areas located there, in either alternative.

Some inspector effort might be saved by omitting verification of the plutonium nitrate batches transferred to and from the plutonium nitrate storage tanks, in the zone approach. This would, in effect, create an extended MBA for verification of interim (monthly) and annual (or semi-annual) inventories consisting of the chemical processing area, the nitrate storage tanks, and the conversion process.

It was assumed that the storage tanks would have a large capacity, that the amount of plutonium in the tanks would vary in response to operating decisions, not influenced by the Agency, and that the tanks may be designed for comparatively accurate verification of the contents, or they may not be well designed for this purpose. At other facilities the tanks may have considerably smaller capacities, or none.

If the facility should be designed to produce PuO_2 directly as the product, as was the reprocessing plant at Mol, the whole system would be treated as a single MBA, the input and outputs would be verified for both of the alternative approaches, and there would be no difference. NRTA could be performed on such a restricted and continuous process.

Only if the chemical separation and conversing processes are separate, and especially if there are large plutonium nitrate storage tanks, would there be a significant difference as to inspection activities and inspection effort for the two alternative approaches.

For the case described, performing the in-process inventory verifications for the separate and extended MBAs would probably be similar, but the amounts on inventory would be large and variable and NRTA for the extended MBA would certainly be less sensitive to abrupt and more protracted diversions. The very rough estimates given here suggest that perhaps as much as 22 % of the inspection effort assigned to this zone might be saved if the zonal approach were to be adopted. Analysis of a hypothetical fuel cycle, such as this, can only suggest roughly how much effort might be saved this way and

to identify the more obvious impacts of such a choice on the technical effectiveness. There are only a few States, and for some time will only be a few States, which have Zone 3 facilities of substantial size.
The tentative conclusion in this case is that the reduced technical effectiveness of the zone approach probably would not justify the relatively small saving of inspection effort. It would appear to be necessary to analyze each individual case to see if this conclusion is valid for it.

Appendix: LMUF in the zonal and MBA-Approach

Material balances are derived from the flow data in Table 3 and the inventory data in Table 4, except that the inventories for the three process areas after a cleanout for a physical inventory should be quite small and accurately measureable. There are three PuO_2 storage areas, at the conversion and the two MOX fabrication plants. Since the UO_2 measurements are included in the flow data, it is assumed that the UO_2 containers would be treated as items for annual inventories.

The following measurements are considered to be uncorrelated, because the measuring procedures are different in each case: reprocessing input, Pu product and liquid wastes; PuO_2 powders (see below), MOX fuel assemblies; conversion and MOX fabrication wasters.

The following inter-MBA measurements are correlated because the same procedures are used for measurement and S/R differences should be resolved: Pu nitrate from reprocessing to storage tanks, to conversion; PuO_2 from conversion to the MOX fabrication facilities. Any bias in these measurements should cause a loss at one of the MBAs and gain in the other.

The same measurement procedures will probably be employed at both of the two MOX fabrication facilities. In this case the systematic flow errors for the two plants are additive.

It is assumed that inventory measurements will have both random and systematic errors. The only inventory material which is likely to have a significant impact on a material balance is the plutonium stored in the storage tanks at that time. At sometime during the year, the amount of plutonium in these tanks should be small and the measurement error correspondingly small. At an inventory the amount may be estimated on the basis of one or more direct measurements and from the difference between additions and removal since the tanks were nearly empty.

An LE of 5 kg at an inventory is arbitrarily used below to emphasize that this may be significant.

For the zone as a whole, the flow variances are the reprocessing plant input, the MOX assembly output, the several waste streams, and scrap recycle from fabrication to reprocessing. The last item will be ignored. Only systematic errors are considered:

$$15^2+(2x7.5)^2+2^2+1.5^2+(2x.375)^2=457 \text{ kg}^2$$

It is assumed that the LEs for the processing areas are each 1 kg, for the Pu nitrate storage tanks, 5 kg, and no others. The total variance for beginning and ending inventories is: 40 kg^2.

The LE for the zone is, then, 22 kg Pu.

Next, the material balances for the following MBAs are calculated: reprocessing separation, Pu nitrate storage tanks, conversion including the PuO_2 store, one MOX fabrication plant including PuO_2 and MOX assembly stores.

Annual material balance for the reprocessing plant separations MBA variances (input, Pu product, wastes, beginning end ending inventories):

$$15^2+7.5^2+2^2+1^2=286, \text{ LE}=17 \text{ kg Pu}$$

As noted above, the nitrate storage tank MBA is a special case, taken here to have an LE of 7 kg Pu $(50)^{0.5}$.

The conversion plant flow plus inventory variance is:

$$7.5^2+3.75^2+1.5^2+1^2=73.5, \text{ LE}=8.6 \text{ kg Pu}$$

For one MOX fuel fabrication plant the numbers are:

$$1.875^2+7.5^2+.375^2+1^2=61, \text{ LE}=7.8 \text{ kg Pu}$$

Except for the nitrate storage tanks, most of the uncertainty comes from the flow measurements. In this example, the major measurement errors are taken to be for the input to the reprocessing plant, and for the MOX assembly products of the zone.

If one simply combines the four variances above, the resulting LE is 23 kg Pu, which is not significantly different from the zone LE. However, if the LEs for the two MOX fabrication plants are taken as additive, the result is 25.5 kg Pu.

If material balances are drawn around each of the MBAs, as illustrated above, the Agency can draw conclusions regarding each MBA, and for the zone as a whole, assuming that physical inventories are performed simultaneously, or nearly so, for all of the MBAs in the zone. Balances by MBA are more sensitive to diversion or loss from one MBA than would a zone balance be. Perhaps more important is the fact that anomalies, Agency - facility differences which will occur, would probably be more promptly observed with the MBA approach, and easier to resolve when located by MBA. However, since the facility operators should have records by MBA, locating what might need investigation may be possible with the zone approach.

4.3 Distribution of Inspection Efforts in Different Zones (Letter of W. A. Higinbotham to J. de Montmollin and D. Gupta, Feb. 25, 1985)

Recently, Dipak said that the assignment of effort in zone 1 is very high compared to that assigned in zone 3 per SQ. What numbers one assigns for inspection effort depends on a number of assumptions. On the basis of my assumptions, there is not a great imbalance. For discussion I assume:

A. 2 LEU fuel fabrication plants producing 300 MT/year each
B. 20 LWRs with 30 MT reloads per year each
C. 1 200 MT/ year reprocessing plant and colocated conversion facility
D. 1 MOX fabrication plant producing Pu-recycle fuel with the Pu from C
E. Recycle of MOX fuel in 3 of the LWRs. Fresh MOX fuel will be there half of the time.

Inspectors visit each A plant once a year for a PIV and 11 times to verify LEU fuel assemblies before shipment.

Inspectors visit each LWR 4 times/year, once for a PIV and 3 times to check fresh LEU fuel and C/S equipment. A PIV takes 6 and an interim 2 man days.

At C inspectors should be available any time, day and night. Several should reside nearby in order to do this. I arbitrarily guess that 5 or 6 could do this with sick-leave and vacations.

The Agency now plans to have monthly visits to a MOX fuel plant. I assume two PIVs and 10 interim visits per year. A PIV takes 2 inspectors 5 days and an interim visit 2 inspectors for 3 days.

The three reactors that use MOX fuel are assumed to have this on-hand half a year or less. Verifying the fresh MOX fuel calls for 4 extra visits/year to each of these and extra time during the 2 other visits/6 months. For these (E) I add 2 inspectors X2 days X6 visits per reactor.

I assume the LEU is 3 % and that spent fuel contains 1.0 % Pu. I add 1 day/inspector for travel per visit except for the resident inspectors at C.

This gives the following table:

Item		Inspections	Travel		Total
A.	2 facilities X (15+44) =	118	+ 25	=	143
B.	20 x 12 =	240	+ 160	=	400
C.	60 x 150 = 900	900	-	=	900
D.	20 (PIV) + 60 (interim)	80	+ 24		104
E.	3 x 24 = 72	72	+ 8	=	80

On these assumptions, the man days/SQ are: A = 0.6, B = 0.53, C = 3.6, D = 0.42, E = 0.64. The reprocessing/conversion facility is the one which is out of line.

One could significantly increase the effort in zone 1 by adding inspector days for more NDA of the LWR fresh fuel assemblies at facilites A or B or both. My thought is that the active collar should be used but that a sampling formula at much less than 90 % probability for detection of one SQ should be acceptable for this material of less safeguards significance.

I toss this in to stimulate discussion.

I think that we should consider what we might conclude from our study. It seems to me that we and others may conclude that less effort should be devoted to zone 1 and more to zone 3, at least in advanced nuclear countries. What do we say then about countries with a couple of power reactors, or six of them and fuel fabrication?

I have given a lot of thought to the zone approach and the possibility of treating a zone as an extended MBA. I don't think that this would be acceptable for zone 3. Since little effort is now assigned to verifying flows in zone 2, it doesn't make much difference here. In zone 1, I feel that verification of UF_6 receipts is not important if the shipments from enrichment plants are adequately verified. The real problem in zone 1 is how and where to verify, the fresh LWR fuel assemblies. Unlike Jim I feel that the use of seals may be very usefuel on these, in order to dispose of the shuffling and borrowing scenarios that the Agency is so worried about.

Obviously, attempting to detect diversion of one SQ at every nuclear facility doesn't make sense, much less if the goal is for a whole, advanced country. What makes sense to me is the percentage or fraction of a State's fuel that could reasonable be detected by agency verification, perhaps by zone. I know that this is too simplistic an approach; but it is reasonable to study variations of it. At present the Agency designs sampling plans to have a 90 % probability to detect a loss of one SQ per facility, if possible. The result is that a lot of effort is assigned to some facilities although the conceivable detection probability for the whole country may be many times larger.

I would suggest that we not attempt to analyze safeguards as a deterrent because most of the countries under safeguards have no intention to divert and the objective of safeguards is to provide assurance, as I understand this subject.

3.2 Points to be Considered for the Joint Paper on Fuel Cycle Safeguards

1. Possibilities for readjusting the relative importance of the different categories of nuclear materials after taking into consideration the characteristics of the fuel cycle as a whole and subsequent possibilities of improving allocation of safeguards resources.

2. Timeliness of inspector validated safeguards information and the reporting system of the State.

3. Possibilities of improving the verification capability of inspectors at the facilities.

4. Alternative concept for inspection goals, and safeguards relevant statements.