LA-UR 91-3188

LA-UR--91-3188

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TITLE: FUTURE ISSUES IN INTERNATIONAL SAFEGUARDS

AUTHOR(S): E. A. Hakkila, J. T. Markin, and M. F. Mullen

SUBMITTED TO: Fourth International Conference on Facility Operations/Safeguards Interface (ANS/INMM)
Albuquerque, New Mexico
September 29-October 4, 1991

Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FUTURE ISSUES IN INTERNATIONAL SAFEGUARDS

E. A. Hakkila, J. T. Markin, and M. F. Mullen
Los Alamos National Laboratory
Los Alamos, New Mexico

ABSTRACT

The introduction of large bulk-handling facilities into the internationally safeguarded, commercial nuclear fuel cycle, increased concerns for radiation exposure, and the constant level of resources available to the International Atomic Energy Agency (IAEA) are driving new and innovative approaches to international safeguards. Inspector resources have traditionally been allocated on a facility-type basis. Approaches such as randomization of inspections either within a facility or across facilities in a State or the application of a fuel-cycle approach within a State are being considered as means of conserving resources. Large bulk-handling facilities require frequent material balance closures to meet IAEA timeliness goals. Approaches such as near-real-time accounting, running book inventories, and adjusted running book inventories are considered as means to meet these goals. The automated facilities require that safeguards measures also be automated, leading to more reliance on operator-supplied equipment that must be authenticated by the inspectorate. New Non-Proliferation Treaty signatory States with advanced nuclear programs will further drain IAEA resources. Finally, the role of special inspections in IAEA safeguards may be expanded. This paper discusses these issues in terms of increasing safeguards effectiveness and the possible impact on operators.

I. FUEL CYCLE APPROACHES

A fuel-cycle approach to safeguarding a State's nuclear facilities differs from the conventional facility-oriented approach because the size and complexity of the fuel cycle determines the inspection effort assigned to individual facilities in the former case, whereas the conventional approach assigns the same effort to similar facilities independently of the fuel cycle context. Among the fuel cycle approaches are the following: diversion assumption changes, such as assuming less risk of diversion of low-enriched uranium (LEU) and spent fuel if there are no enrichment or reprocessing facilities within a State; inspection goal relaxation, such as allowing a longer time between inspections of spent fuel in States without a reprocessing facility; a zone approach incorporating an extended materials balance area (MBA) encompassing multiple facilities; and random selection of inspection opportunities across a

State's fuel cycle. Among these, the zone approach and randomization of inspections are the most promising in terms of saving inspection resources and being practical to implement.

II. ZONE APPROACH

The zone approach[1,2] is based on an extended MBA that can encompass multiple facilities within a State's fuel cycle. Under this inspection regime, facility MBAs containing materials of similar safeguards significance (e.g., LEU, spent fuel, or direct-use material) are combined into a single zone for purposes of closing a materials balance on this larger accounting area. Resources are conserved under this approach because the zone balance eliminates the need to verify intra-zone flows of material. Instead, only flows crossing the zone boundary and simultaneous inventories of material within the zone are verified. Although the State's system of accounting would continue to report safeguards-related information on a facility MBA basis, the Agency would verify only the zone balance. A satisfactory safeguards conclusion for the zone would imply a similar conclusion for the facility MBAs contained in the zone.

Among the zones that could bc defined according to material category are the following:

(1) an LEU zone with input transfer at the receipts area of an enrichment plant, an output transfer where fresh fuel enters the reactor core, and material inventories in enrichment facilities, fuel fabrication facilities, and fresh fuel stores at reactors;

(2) a spent fuel zone with input transfer from the reactor core to the reactor spent fuel pond, output transfer from the spent fuel pond at a reprocessing plant to the dissolution tank in the separations area, and inventories of spent fuel in the reactor core, the spent fuel ponds at the reactor, and the reprocessing plant or at interim storage facilities; and

(3) a plutonium zone with input transfer at the dissolution tank of a reprocessing plant, output transfer where fresh fuel is moved into a reactor core, and inventories in chemical separation and storage areas of reprocessing plants, conversion plants, fuel fabrication plants, and fresh fuel storage areas at reactors.

Among the operational considerations for implementing a zone approach are the following: the periodic need to assemble extra inspection resources to conduct the required simultaneous inventory within a zone; the development of anomaly resolution procedures for resolving a discrepancy in zone accounting information when intra-zone flows have not been verified; the localization of a zone anomaly to specific facility MBAs; and the question of the acceptability of eliminating the verification of intra-zone flows when these include inputs and outputs to such sensitive facilities as enrichment and reprocessing plants.

The Agency has successfully applied the zone approach to the natural uranium fuel cycle used by the CANDU reactors in Canada, including nearly simultaneous physical inventory verifications (PIVs), and has limited experience with the LEU fuel cycle in the Republic of Korea.

III. RANDOMIZATION OF INSPECTIONS

Although the International Atomic Energy Agency (IAEA), in most instances, has adequate resources to verify safeguarded materials, future increases in the size, complexity, and number of nuclear facilities combined with limitations on the growth of inspection resources could degrade safeguards effectiveness. Among the factors that could increase resource requirements are additional States signing the Nuclear Non-Proliferation Treaty (NPT) and a decision to increase the resources applied to the commercial fuel cycles in weapons States. Anticipating a future shortfall in inspection effort, recent studies have suggested randomly selecting facilities for inspection.[3-5] Although this innovation in IAEA inspection procedures, in general, is not now needed to attain safeguards goals, it is a potential means for addressing future shortages in inspection effort.

Randomization of inspections is applicable when there are insufficient resources to perform a comprehensive verification at all inspection opportunities. Indeed, this principle is currently applied to a material stratum where random samples of items are selected for verification because the cost of verifying the entire stratum is prohibitive. Absence of an anomaly in the sample results in acceptance of the entire population of items as being verified. Similarly, absence of an anomaly in a randomly selected sample of inspection opportunities among a group of facilities would result in the extension of a satisfactory safeguards conclusion to all facilities in the group. The function of randomization is to maintain the possibility of anomaly detection at all inspection opportunities while conserving inspection resources.

Randomization could, in principle, be applied to any collection of inspection opportunities including PIVs, interim inspections for timeliness, and flow verifications at a single facility or at any combination of facilities in a State's fuel cycle. Example populations include all PIVs at a State's bulk facilities, all interim inspections at a State's light-water reactors (LWRs), and all flow verifications at a single facility.

A random sample of inspections to be carried out can be drawn from an announced schedule of inspection opportunities that is known to the operator or done on an unannounced basis at times that are a priori unknown to the operator. In either case, the operator would receive short notice of the inspection. The announced schedule of possible inspection opportunities has the advantage of allowing the operator adequate time to prepare records, materials, and facility areas for access by an inspector. Thus, randomized inspections for PIVs at bulk facilities based on an unannounced schedule would not be practical, whereas interim inspections at power reactors where operators would have less to prepare could be feasible.

A. Conditions for the Validity of Conclusions Based on Random Inspections

Conditions for validity of safeguards conclusions based on the random selection of inspection opportunities can be derived from similar conditions for the random selection of items for verification. The Safeguards Criteria specify conditions that should be satisfied to assure the validity of conclusions based on measurements of randomly selected items from a material stratum. These conditions are

(a) that the operator's measurement results for all items in the population are available to the IAEA before the selection of items for measurement is known to the operator,

(b) that any item in a population is equally likely to be selected for IAEA measurement (where items are not identical, a probability of selection proportional to material amount may be appropriate), and

(c) that the IAEA can assure itself that the operator did not modify any selected item during the interval between its selection and measurement by the IAEA.

These conditions can be generalized to assure the validity of conclusions based on the random selection of facilities for inspection.

1. Operator Declaration. Because disclosure of the Agency's random inspection plan could invalidate the safeguards conclusions based on randomization, it is essential that the operator commit to a physical inventory listing describing the status of materials in a facility before the inspectorate's intent to carry out an inspection is known. A mechanism for assuring the integrity and time of the declaration could be an operator telex of the list to the Agency or a "mailbox" at the facility that would automatically time stamp the declaration and prevent subsequent alteration. The declaration should be made before the earliest possible indication to the operator of the inspector's intent.

2. Equal Likelihood of Selection When Randomly Selecting Inspections. When randomly selecting inspections from a group of inspection opportunities, we can consider the collection of items from the same material stratum at each inspection opportunity as an extended material stratum. The condition of equal likelihood of selection then applies to all items in this extended stratum and the probability P_I that an item is selected during one of the random inspections is given by $P_I = P_F \times P_S$ where P_F is the probability that the item is in a facility selected for an inspection and P_S is the probability that the item is selected in a random sample of the stratum. Where all inspection opportunities are at facilities of the same type, this condition is most easily satisfied by keeping P_F and P_S constant for all inspections, i.e., by maintaining an equal probability of choosing each inspection opportunity and by sampling the same fraction of the material stratum at each opportunity.

Under this regime, an equal likelihood of selecting each item is realized if each item has the same residence time within the material stratum. Where item residence times are not equal, some items may remain longer in the stratum and therefore have a higher probability of being selected for verification than items with shorter residence times. One proposed method for restoring equal likelihood of selection would be to, in effect, allow each item only one chance to be verified, i.e., any item either previously verified or available for verification at some earlier inspection opportunity would not be considered in sampling for verification at subsequent inspections.

A further practical difficulty with maintaining an equal selection probability is the difference in effort that may be required to access each item. Depending on the items chosen in the random sample and the verification method, the time allocated for verification could be exceeded. This circumstance could make it difficult to maintain a constant P_S for all facilities.

3. Integrity of Randomly Selected Items. Modification of an item between the time that an operator knows an inspection will be carried out and the time when an inspector verifies the item would, of course, invalidate conclusions based on random inspections. If this time interval is sufficiently long, the operator could attempt to restore a previously modified item to its declared condition. Thus, item integrity can only be assured if the time between the earliest indication of an inspection to be implemented and inspector arrival is less than the time for an operator to restore a falsely declared item to its original state.

B. Operational Considerations

1. Clustering of Facilities. For facilities such as LWRs, inspections are typically carried out on tours wherein facilities that are geographically clustered are inspected on the same trip. The benefit of this procedure is to reduce the amount of travel time relative to the number of inspected facilities. This procedure is clearly more efficient than individual trips for each inspected facility. Depending on the strategy chosen, randomization of these inspections may reduce the benefits of inspecting on tours by introducing inefficiencies in the travel schedule.

General strategies for randomizing inspections when facilities are clustered are to (1) randomize over clusters, i.e., randomly select clusters to be visited and inspect all facilities in the selected clusters, or (2) to randomize with clusters, i.e., to visit all clusters but randomly select facilities within each cluster for inspection. Each strategy has disadvantages. The first strategy would give some operators advance notice that an inspection would not be carried out through observation that other facilities in the cluster were not being inspected. The second strategy would create inefficiencies in the use of inspection resources when inspectors travel to a cluster but only inspect a few facilities or when the random selection of facilities creates additional travel days because there are longer distances between inspected sites as compared to the optimized travel route of current practice.

2. Surveillance. Under a randomized inspection regime, failure to carry out an inspection at a facility such as a power reactor where surveillance is applied would result in nonattainment of the timeliness goal and loss of surveillance until the next inspection. Current Agency implementation of surveillance could accommodate randomized inspections without reductions in safeguards effectiveness through technological advances that would extend the current three-month maximum period for unattended operation of the surveillance device. Methods for achieving a longer surveillance period are to use multiple closed-circuit television (CCTV) units and automatically sequence the initiation of recording by each unit, to increase the storage capacity of the CCTV device by using optical disk storage, and to introduce front-end processing of surveillance data to selectively record only those scenes in which motion has occurred.

IV. TIMELINESS

In the early years of international safeguards, accounting was performed using conventional accounting. In item facilities, items were tracked with the goal of detecting one missing item. For bulk-handling facilities, all transfers through the facilities were measured, but the timeliness of detection was governed by the frequency of performing a physical cleanout inventory. For reprocessing plants, this was on an annual basis; therefore, the timeliness of detection was on the order of 1 year.

In the mid-seventies, it became clear that for future large bulk-handling facilities (reprocessing, mixed oxide, enrichment) using conventional accounting, it would be impossible to detect the loss of significant quantities of nuclear material in a timely manner. Researchers began investigating more frequent means of closing a material balance that would not require shutting down the facility.

A. Near-Real-Time Accounting (NRTA)

In the mid seventies, the US DOE began funding a series of studies at Los Alamos to apply NRTA to mixed oxide (MOX) and reprocessing facilities for domestic safeguards.[6,7] These studies were extended in the late seventies to international safeguards applications.[8]

> In 1978 the IAEA convened an advisory group meeting on safeguards for large reprocessing plants.[9] This led to the formation of the International Working Group on Reprocessing Plant Safeguards (IWG RPS), which met for three years to discuss various approaches to safeguarding the large plants planned for the eighties and nineties. Among its recommendations, the group included,[10] "Work needs to be continued on assessing the impact of NRTA on plant design and operating procedures," and "New procedures and techniques for physical inventory determination should be investigated. Specifically procedures which permit the accurate measurement of inventory quantities with minimum process shutdown and cleanout activities should be investigated."

In the late seventies the Japanese began R&D activities on applying NRTA at the Tokai reprocessing plant. A series of reports was published demonstrating the feasibility of NRTA, with the later studies performed in conjunction with the IAEA.[11]

The UK also initiated experiments in NRTA for a small fast breeder fuel reprocessing plant and demonstrated that timeliness and sensitivity goals could be met.[12] As a result of these experiments and work performed by British Nuclear Fuels Limited, the Thorp reprocessing plant will use NRTA as a fundamental safeguards measure.

Theoretical studies on NRTA were performed by the Federal Republic of Germany for the Wackersdorf facility, but studies were concluded when the plant was cancelled.

B. Adjusted Running Book Inventory (ARBI)

Studies on ARBI were initiated by the US Nuclear Regulatory Commission in 1988. ARBI can be considered as a form of NRTA, differing in the way in-process inventory is determined. When similar statistical tests are applied to NRTA and ARBI data, comparable detection sensitivities should be achieved.

C. Cumulative Flux[13]

The cumulative flux technique was developed by France and extensive studies have been performed at the reprocessing plant at La Hague. The technique differs from NRTA and ARBI in that all of the in-process inventory and its uncertainty is estimated from process operating data. The method will be used at the UP-3 plant at La Hague.

D. Batch Follow Up[14]

Batch follow up or F BOMB was applied as a primary safeguards measure at the ALKEM MOX facility at Hanau. Input batches for the process are planned so a measurable difference exists in the plutonium isotopic composition of successive batches. Thus from input and output measurements, the inspector can determine when a new batch is introduced, when the previous batch is completed, and thus the inventory associated with each batch.

A major issue in applying these techniques will revolve around the willingness of the inspectorate to accept values for in-process inventory, and the uncertainties in these values, based upon operator-declared values.

Large bulk-processing facilities that have high throughput will require integrated measurement systems installed in-line to provide continuous quantitative information for process control and for NRTA of nuclear materials. In particular, automated facilities that limit access to the process area during operations will require nondestructive assay (NDA) instrumentation to be installed at the appropriate locations to provide unattended, continuous measurements at critical processing areas in the facility. For NRTA to be effective, the in-line NDA systems installed throughout the facility, coupled with video surveillance, will need to be linked by secure local area networks through which they can continuously transmit their status and information to the central NRTA system computer. In these systems, authentication and reliability will take on increasing importance.

NRTA systems connected to continuous measurement instrumentation will produce vast quantities of data and require large storage systems to reliably hold the information. The difficulty in storing and sorting this data will require that sophisticated data compression algorithms be developed to reduce the collection of unneeded data. The development and application of pattern recognition, artificial intelligence, and neural net software will be needed to help inspectors review the data. In addition, the ability to combine data from a variety of measurement stations, to search for patterns in nuclear material movement, and to check the consistency of nuclear material flows through various points in a process will increase the effectiveness of safeguards. This information will complement safeguards inspection data obtained from the advanced nuclear material accountability systems.

Continuing improvements in NDA systems, instrumentation, and physics analysis techniques coupled to an integrated NRTA safeguards system with sophisticated artificial intelligence software will be required to meet the challenges facing Agency inspections of large, automated bulk-processing facilities.

An example of an automated facility under IAEA safeguards is the plutonium fuel production facility (PFPF) at Tokai. Automated NDA equipment used jointly by the operator and the IAEA has reduced inspector time by an estimated 90%.

VI. AUTHENTICATION

As noted above, where equipment used for safeguards is supplied by, or shared with, the inspectorate, authentication is a requisite. Several definitions of authentication have been proposed. In the Agency's Working Paper for the 1981 Advisory Group Meeting on Instrument Authentication Techniques for In-Plant Measurement Equipment Applied to IAEA Safeguards, the definition provided is "the word 'authentication' is defined here to mean the process by which the inspector determines that the instrument (the in-plant equipment which may be owned by the facility, a State inspection organization or by the Agency itself) is giving valid measurement results." Kuroi, in a 1989 discussion paper for LASCAR defines authentication as "the technique needed to assure that valid results have been obtained for safeguards purposes using operator provided equipment." The 1991 IAEA Consultants Meeting on Authentication of Operators' Systems for Safeguards Purposes provided the following definition: "Authentication is the process to assure that genuine information is obtained for safeguards purposes using equipment (including systems and methods) for which the IAEA lacks sufficient control or knowledge."

A key element in all of these definitions centers around the concept that the IAEA does not have complete control or knowledge of the equipment fabrication, installation, or operation.

Because authentication is applied to operator-owned or operator-provided equipment or procedures, it must address three basic methods for subverting the equipment.

- Materials tampering. Is the instrument measuring the material as claimed by the operator?
- Instrument tampering. Has the instrument been miscalibrated or degraded?
- Data tampering. Has the operator falsified data output from the instrument?

Technology that can be used to authenticate safeguards information could include the following:

- seals,
- visible cable runs between the detector and the inspector's electronics,
- modular components that can be replaced by standard IAEA equipment,
- software replaceable by inspectors,
- software diagnostics to detect interruption of or tampering with the signal,
- inspector-owned check sources or calibration sources to verify the total system's performance,
- containment and surveillance techniques, and
- data encryption from detector to data processing.

VII. INITIAL INVENTORY

Several IAEA member States recently either have signed or have indicated their willingness to sign the NPT. These States have had significant unsafeguarded nuclear activities for a number of years, and the IAEA must be able to verify the States' declared initial inventory of nuclear material. In the case of enrichment facilities, this may require measurement and mass balancing of product and tails with declared feed, which in itself will be difficult to verify. Reprocessing will require mass balancing product uranium and plutonium with declared burnup and input of spent fuel to the plant. Possible isotopic correlations of uranium and plutonium may be helpful in verifying an operator's declared statements.

VIII. SPECIAL INSPECTIONS

For many years, the IAEA has had the authority to conduct special inspections to clarify situations in which the information available to the Agency by other means (such as routine inspections or reports from the State) is inadequate. This authority is, in effect, a "safety net" that can be used when other verification measures need reinforcement. For a variety of reasons, the right to perform special inspections has not been fully exercised in the past. More recently, however, partly as a result of events in Iraq, there has been considerable discussion of the possibility of using the IAEA's special inspection authority more extensively. Proposals to expand the role of special inspections will raise a number of challenging technical and policy questions that will need to be examined carefully by the technical safeguards community and by the IAEA member States.

One issue with important technical and policy ramifications is the question of how to focus special inspections. What should be inspected and how often? What mechanisms might be used to trigger a special inspection? Many observers, including the Director General, have noted that information from national intelligence programs is one possible trigger mechanism.

Similar issues have been discussed in other arms control arenas, and examination of these precedents could provide some insights into the range of options potentially available to the IAEA. One possible approach for using "non-safeguards information" is suggested by the "challenge inspection" concept, which has been discussed in the context of the proposed Chemical Weapons Convention (CWC). This concept would provide for individual states to issue a challenge, i.e., to call upon the Board of Governors to initiate the special inspection process. In the CWC formulation, the challenging State is expected to provide some information on the "nature and circumstances of the suspected noncompliance" but is not required to provide detailed justifications or divulge sensitive intelligence sources or methods.

Alternatively, the IAEA might be endowed with its own independent information collection and analysis capability and could have the sole responsibility for determining when to initiate a special inspection. Many other possible arrangements can be envisioned, each with its own set of advantages and disadvantages. Again, the concepts discussed in other arms control regimes like the CWC, the Convention Forces in Europe Treaty, and other bilateral and multilateral arrangements may be of interest in defining the options.

Special inspections could also be used with various kinds of randomization and could be coordinated with randomization of routine inspections. One possibility that has been suggested is to use special inspections in lieu of some routine inspections in such a way that overall safeguards effectiveness might be enhanced while conserving resources at the same time. Expanding the scope of inspections to include access to additional locations and information creates new possibilities for randomization and for fuel cycle approaches to safeguards that have not yet been thoroughly investigated.

Finally, the inspection activities to be carried out during special inspections will require additional study and analysis, and there may be a need to develop additional technologies and procedures to support special inspections. At first glance, the problem may appear intractable, given the inherent open-endedness of special inspections. However, the possible routes to proliferation are limited, the indicators of proliferation that might be uncovered can be bounded, and the inspector's job in carrying out special inspections, although potentially more complex and technically challenging than traditional routine inspections, is amenable to the kind of disciplined analysis that has been used to help guide safeguards and identify technology needs for many years. Indeed, the credibility of special inspections may require that such analyses be done and that the associated technologies be made available to the IAEA.

IX. SUMMARY AND CONCLUSIONS

The IAEA is faced with safeguarding an increasing number of large bulk-handling facilities in States with advanced nuclear programs. Many of these facilities will be automated permitting minimal access to nuclear material for measurements. New member States will additionally tax IAEA resources. The IAEA will have to use innovative safeguards approaches to meet its requirements to member States.

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12/26/91