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Title: **LAYERED AND SEGMENTED SYSTEM ORGANIZATION (LASSO) FOR HIGHLY RELIABLE INVENTORY MONITORING SYSTEMS (IMS)**

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Layered and Segmented System Organization (LASSO) for Highly Reliable Inventory Monitoring Systems (IMS)

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Abstract
The Trilateral Initiative is preparing for International Atomic Energy Agency (IAEA) verification of excess fissile material released from the defense programs of the United States and the Russian Federation. Following acceptance of the material using an Attribute Verification System, the IAEA will depend on an Inventory Monitoring System to maintain Continuity of Knowledge of the large inventory of thousands of items. Recovery from a total loss of Continuity of Knowledge in such a large storage facility would involve an extremely costly inventory re-verification This paper presents the framework for a Layered and Segmented System Organization that is the basis for a highly reliable IMS with protection-in-depth.

Introduction
Pursuant to Article VI of The Treaty on the Non-Proliferation of Nuclear Weapons (NPT), nuclear weapon state signatories are committed to eventual total nuclear weapon disarmament [1]. Following the NPT Review Conference of 1995, the United States (US), the Russian Federation (RF), and the International Atomic Energy Agency (IAEA) announced a Trilateral Initiative in 1996 to consider the legal, technical, and financial issues associated with irreversibly removing weapon materials from defense programs and placing them under IAEA verification [2]. The progress of this Trilateral Initiative has been reported at each of the IAEA General Conferences in Vienna since September 1997 and at the NPT Review Conference at the United Nations in April 2000.

Verification is recognized by the *three* parties as being a fundamentally different monitoring regime than IAEA safeguards in non-weapon states. In particular, the safeguards timeliness criterion for detection of proliferation does not have the same meaning in non-weapon and weapon states. In addition, the safeguards significant quantity criterion for manufacture of weapons does not have the same impact in non-weapon and weapon states.

The Trilateral Initiative has been organized into three parallel efforts to consider technical, legal, and financial issues related to IAEA verification of excess weapon materials. In the technical arena, the IAEA verification discussions have focused on two areas: initial measurements of the materials for acceptance, and continuing monitoring of the materials after acceptance. In general, traditional IAEA non-destructive assay (NDA) safeguards measurements are not acceptable for weapon materials because some properties such as mass and isotopics are classified by the weapon states. Under Article I of the NPT the weapon states are obligated not to release this classified information to the IAEA because this act could contribute to proliferation. Thus, there has been a Trilateral Initiative effort in attribute measurements to define an acceptable set of material parameters for IAEA verification and a complementary activity to develop an information barrier for the measurement instruments that precludes the release of classified data. For the intended application, the IAEA would be presented with a closed storage container and verify that (1) the container holds plutonium, (2) the total plutonium mass exceeds an agreed threshold appropriate to each facility, and (3) the ratio of Pu240/Pu239 in the plutonium is less than a specified threshold [3].

The second area for technical consideration in the Trilateral Initiative is Inventory Monitoring Systems (IMS). An IMS is necessary to maintain Continuity of Knowledge (CoK) of the weapons material after its acceptance by the IAEA and between the periods of subsequent inspections. A tripartite working group of technical experts has been meeting to address IMS topics. At its first meeting in January 2000 the technical experts working group reached agreement on the IMS items, functions, goals, and operational requirements [4]. The inventory item is a container, or group of containers, of weapon material. The IMS functions are to (1) establish unique item identification, (2) confirm item integrity, and (3) monitor item location during storage or movement within the storage facility. The IMS goals are to minimize (1) the need to re-inventory a substantial portion of the inventory, (2) the total costs of maintaining CoK, (3) the effort required by the IAEA to draw independent conclusions, (4) the radiation dose to the IAEA inspectors, and (5) the intrusiveness of verification on facility operations. The operational requirements are to (1) prevent the dissemination of classified nuclear weapons information, (2) prevent access of IAEA inspectors to unauthorized information, (3) keep facility sensitive information at the facility, (4) ensure the authenticity of data used by the IAEA to reach independent conclusions, and (5) use only equipment approved by the Host State and the IAEA.

The IMS experts have reached provisional agreement on the IMS Provisional General Technical Requirements (GTR) document [5]. The GTR includes general requirements for IMS hardware, software, data generation and collection, verification information authentication, classified information protection, system effectiveness and reliability, and documentation, and presents some block diagrams. Other discussion topics included a system concept, function diagram, and model facility.

A significant development during the IMS experts meetings was the concept of a Layered and Segmented System Organization (LASSO) for the IMS. This conceptual system architecture will maintain CoK without the need for a substantial re-inventory in the case of component failures. The remainder of this white paper describes in detail the LASSO and presents some examples of the application of this concept to IMS.

Definition of IMS and Assured CoK

For the Trilateral Initiative, the expected **inventory** at the **US** and RF facilities is thousands of containers of nuclear materials from weapons and defense programs. The required **monitoring** for IAEA verification is maintaining continuity of knowledge of these containers after initial IAEA measurement and acceptance of the material and between the subsequent periodic inspections. The **system will** consist of numerous authenticated sensors and a secure data acquisition system for unattended and possibly remote monitoring.

The IMS must collect the sensor data necessary to provide the IAEA with the **knowledge** to make independent conclusions. The IMS must monitor the items with the necessary **continuity** to ensure detection of credible diversion scenarios. The IMS must be highly reliable so that the IAEA is **assured** of maintaining CoK and the need to re-inventory a substantial portion of the inventory is ***minimized.***

LASSO Concept

Taking into account the five complementary goals of the IMS and its intended application to thousands of containers in each facility leads to a realization that a very effective approach is a layered and segmented system organization Such a system has subsequent layers that identify a smaller and smaller set of items where CoK can be maintained if it is lost in preceding layer(s). The LASSO concept adheres to the following guidelines:

(1) To the extent possible no failure shall cause loss of CoK that requires re-verification of a substantial portion of the inventory. This implies that any failure must be localized to a small portion of the inventory and hence a small portion of the IMS.

(2) The system shall consist of multiple independent layered monitoring subsystems. Thus if one layer fails another independent layer is unlikely to have a common mode failure.

(3) The highest level subsystem or outer layer must provide continuous information to the IAEA such that segments of the inventory can be identified for which this outer layer has lost CoK. This is accomplished by a layer of active sensors with each individual sensor monitoring a specific portion of the inventory. Hence if a given sensor fails, the IAEA will know which subset of containers may have lost CoK.

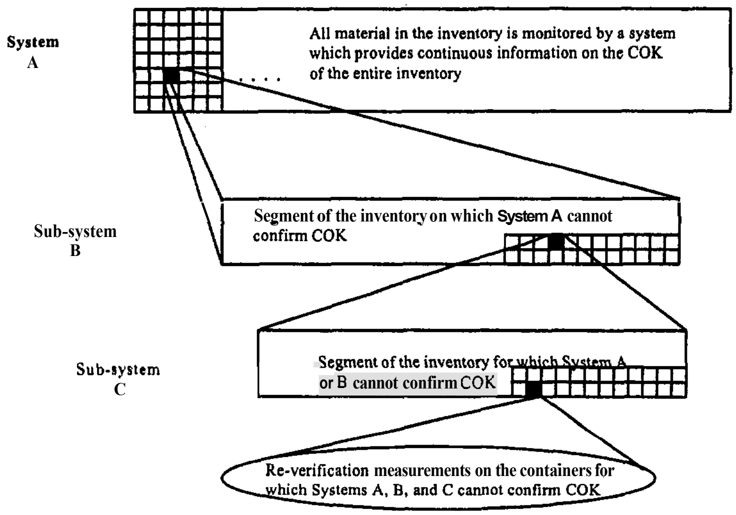
(4) Each subsequent inner layer(s) of the system shall identify smaller segments of the inventory for which CoK may have been lost. This means that each segment in an outer layer **is** divided into more segments in the next inner layer. The sensors in this inner layer each monitor a smaller segment of the inventory than the outer layer. This provides further localization of the possible loss of CoK to a smaller subset of the inventory with each subsequent layer of sensors that monitors a successively smaller segment. The innermost layer will consist of sensors that monitor individual containers. Only if this innermost layer and the corresponding elements of all preceding outer layers have failed will CoK be lost.

(5) The layered system shall be designed such that the number of inventory items that need to be re-verified at each inspection due to failures is not more than the IAEA random sample size for re-verification. In other words, the number of layers, the segmenting of each layer, and the specific types of sensors should be chosen such that the number of containers for which CoK is lost due to the expected failure rates

is less than the number of containers randomly chosen by the IAEA for re-verification during a normal inspection.

The **LASSO** concept is illustrated in Figure 1.

Figure 1. Multi-layered System Concept

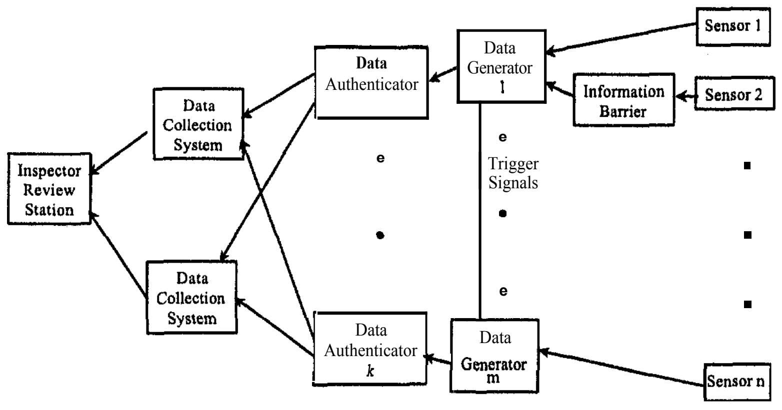


In this schematic the IMS consists of three layers. Note that each layer monitors the entire inventory but each inner layer has segments that monitor a smaller portion of the total inventory. In order to lose CoK on a given container there must be a failed segment in each layer and at least one segment in the corresponding subset of segments in the next inner layer must also have a failure. In a well-designed IMS this is expected to be an unlikely set of events. Preferably the monitoring components in the outer layers are active sensors integrated into an unattended monitoring system. This allows the IAEA working from their office to quickly localize the failure to a small portion of the total inventory and minimize the need for an intrusive inspection.

Details of one of the outer layers are shown in Figure 2.

Each segment in this layer of the IMS consists of several sensors. If this sensor were monitoring a classified parameter, then an information barrier would be required between the sensor output and the remainder of the data acquisition system. Each sensor interfaces with a data generator that typically translates the sensor output to a digital data message. A data authenticator that uses an encryption key to calculate a unique digital

Figure 2. System A Conceptual Diagram



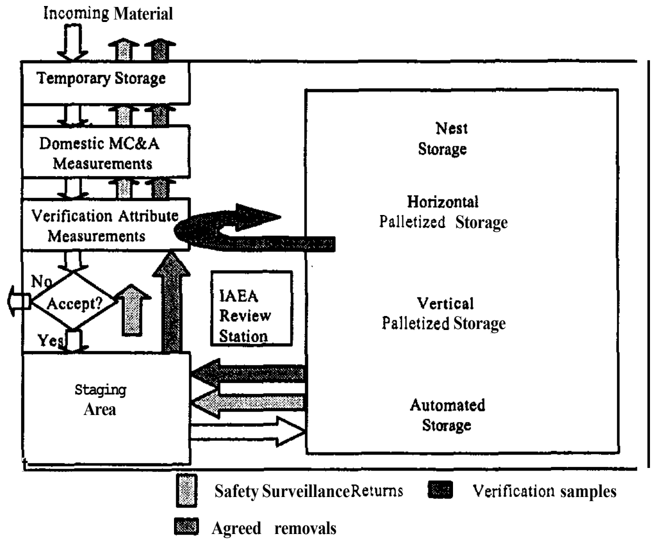
signature that is attached to each message follows the data generator. Another function of the data generator is to provide temporary storage of sensor messages to prevent loss of CoK due to system power or communications failures. The sensor, information barrier (if it exists), data generator, and data authenticator are all co-located in a secure tamper-indicating enclosure to provide data surety for the IAEA. The sensor sub-system is connected to the data collection computer(s) by a communications network. The data collection computer contains the permanent IMS database. Dual data collection computers provide additional protection against loss of CoK due to computer failure. The IAEA inspector review station provides the user interface to the IMS database.

Thus the LASSO concept of a segmented, layered sensor sub-system combined with back-up capability and redundant components in the data acquisition sub-system provides very effective protection-in-depth for the IMS.

To further explore the LASSO concept, consider the model facility diagram shown in Figure 3. The model facility floor plan is divided into several functional areas.

(1) Temporary Storage. The incoming material is received and temporarily stored while awaiting material measurements. Receipt checks are likely performed here and a Host State facility seal may be applied.
(2) Host State MC&A Measurements. Various Host State material measurements are performed in this area, one container at a time. Measurement instruments in this area are probably a subset of weight scale, gamma-ray spectrometer, neutron multiplicity counter, and calorimeter.

Figure 3. Model Facility Diagram



(3) Verification Attribute Measurements. The IAEA material attribute verification measurements are conducted here. For classified materials this includes neutron multiplicity counting and high-resolution gamma-ray spectrometry. These instruments will have an integral information barrier to prevent the release of classified information. For unclassified materials or measurements the measurement equipment is possibly shared for joint use by the Host State and the IAEA.

(4) Staging Area. This area is used for any re-packaging of individual containers into the facility-specific group storage configuration and temporary storage while awaiting availability of the item handling equipment for movement into long-term storage.

(5) Long Term Storage. A variety of facility-specific long-term storage configurations have been envisioned. These include (a) nest storage in vertical sub-floor tubes, (b) floor-stackable pallets of horizontal containers, (c) floor-stackable pallets of vertical containers, and (d) automated storage of individual containers on wall hooks.

(6) IAEA Office. The IAEA office contains the data review station and is also used for secure storage of portable measurement equipment, reference material standards, and spare parts.

Now consider the expected material flows through this model facility. During a lengthy period of facility loading, the normal incoming material flow is through temporary storage, the measurement areas, and into long term storage via the staging area. After the material measurements are performed there is a decision point for the Host State and the IAEA to accept this material for verification based on a prior agreed range of material parameters. Some facilities may have a material safety surveillance program that allows temporary removal of inventory items for a set of safety readings in one of the measurement areas. This material would normally be returned to long term storage. All facilities will require procedures for emergency removal of material to address safety problems without delays for measurements. This material may not be returned to the storage facility or may be returned in another container after stabilization and re-packaging. In either case the returning material would be treated as new incoming material. In addition, a relatively small sample of randomly selected inventory items may be retrieved from the long-term storage area for the purposes of re-measurement for Host State or IAEA inventory verification Ideally this sampling would simultaneously satisfy both Host State and IAEA needs. Finally, there may be some agreed permanent removal from the facility such as for the next step in material disposition.

The **LASSO** concept fits well with these facility operations. During the facility loading phase, the IMS would be built up starting with the innermost layer of individual item segments and continuing through each layer filling each segment at a time and successively each layer to the outermost layer. Not until the facility is fully loaded would all segments and layers be fully implemented, yet the IMS would be effective for monitoring CoK of all parts of the inventory as it grows. While lengthy, the loading period is still expected to be relatively short compared to the fully loaded long-term storage period when the IMS layers and segments are fully populated except for a *small* fraction of temporary removals. **During** these temporary removals, whether for scheduled or emergency activities, the minimum necessary IMS segments in the innermost layer would be accessed while the other segments in that and the other layer would continue to monitor CoK for all other partitions of the full inventory. In the eventual case of material disposition and the associated unloading of long-term storage, the items would be removed in a succession that essentially reverses the loading sequence, Individual items are removed in the innermost layer in a series that completely vacates a segment in that layer and then progressively vacates segments in successively outer layers until the facility is completely unloaded.

Conclusion

An Inventory Monitoring System with Layered and Segmented System Organization is expected to maintain Continuity of Knowledge with high reliability due to its protection-in-depth. In this scheme the IMS consists of multiple independent segmented layers of sensors. Each segment in an outer layer is divided into several segments in the next inner layer. The multiple independent layers significantly reduce the likelihood of losing Continuity of Knowledge for any inventory item. The increasingly segmented layers direct the inspectors to a decreasing number of items for which Continuity of Knowledge must be verified. Features of the data acquisition system such as temporary data storage at the sensor and redundant data collection computers provide additional assurance that Continuity of Knowledge will be maintained with high probability. This monitoring system architecture is well suited to a large fissile material storage facility and its operations **during** loading, long-term storage, safety surveillance, and emergency removal. The conceptual design of an IMS for the first expected Trilateral facility in the **US** illustrates the application of this Layered and Segmented System Organization.

References

1. *Treaty on the Non-Proliferation of Nuclear Weapons (NPT),* Adopted June 12, 1968; Entered into Force March 5, 1970 (IAEA INFCIRC/140)
2. Thomas Shea, et al, *The trilateral Initiative: IAEA Verification of Weapon-Origin and Other Fissile Material Released from Defense Programs,* 42 Annual Meeting of the Institute of Nuclear Materials Management, July 15-19, 2001
3. John Puckett et al, *General Technical Requirements and Funntional Specifications for an Attribute Measurement System for the Trilateral Initiative, 42* Annual Meeting of the Institute of Nuclear Materials Management, July 15-19, 2001
4. Igor Kuleshov et al, *General Technical Requirements for an Inventory Monitoring System for the Trilateral Initiative,* 42 Annual Meeting of the Institute of Nuclear Materials Management, July 15-19, 2001
5. ibid

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