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Redundant and Independent Containment and Surveillance Systems

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REDUNDANT AND INDEPENDENT CONTAINMENT AND SURVEILLANCE SYSTEMS

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ABSTRACT

Facilities are now coming under Agency safeguards which have large amounts of nuclear material and/or nuclear material which is very difficult to access for reverification. Containment and Surveillance (C/S) technologies may be used to assist in resolution of this problem. This study examines the concept of redundant and independent C/S Systems, and discusses how these systems could potentially be applied. The IAEA is investigating how redundant and independent C/S systems could be used to lower the need for remeasurement of materials which are difficult to access, or materials included in very large inventories. This paper does not address increasing levels of C/S measures to protect different types of materials. However, the paper does discuss how redundant and independent C/S Systems will improve the reliability of safeguards information. Equipment which may be used in such systems, and examples of potential systems, are presented. Decisions on how much C/S equipment is enough for a given facility, or type of material, must be made by the inspectorate.

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I. Introduction

Facilities containing large amounts of nuclear materials and/or materials which are very difficult to access are now coming under IAEA safeguards. Even more facilities are under construction, or are planned, which will be safeguarded in the not too distant future. As these facilities come into operation, the Agency task of providing adequate safeguards becomes more difficult.

The Agency is presently constrained to a near zero growth budget. This budget constraint makes it difficult to allocate the additional resources necessary to safeguard these facilities. Even if the Agency had unlimited resources, in some cases, it would still be difficult to provide traditional safeguards based on measurement of a random sampling of the inventory. In locations where there are large inventories consisting of literally tens of thousands of individual items, it is not reasonable to assume that inspectors could provide a meaningful sampling during each inspection. Even if the Agency could provide enough inspectors to support such routine large scale inspections, the facilities themselves may not have adequate resources to support these types of inspections. For example, the facility may not have enough cranes to move the amount of material necessary within the agreed upon inspection period, or enough facility personnel may not be always available. Even the number of people allowed in a facility or an area at a given time could constrain inspection activities. In the case of inventories which are very difficult to access, an inspector cannot use standard measurement techniques since it is not possible to physically access the material.

Since the Agency is constrained in budget, and is presented with these new and difficult safeguards tasks, new techniques are needed for providing continuity of verified information. These techniques must reduce, or even eliminate the need for material remeasurements and inspections. One technique of assuring the integrity of inventories, would be to rely on Containment and Surveillance (C/S) measures. This technique would be feasible since C/S measures would be relied upon to provide continuity of knowledge of the material, that is, C/S measures would be used to provide continuity of knowledge of materials which had been previously verified. In order to be assured that the initial declared composition of the material is accurate, a material measurement would be required before the C/S measures are applied. This is true in all cases, except for spent fuel. In the case of spent fuel, it is assumed that it is adequate to maintain C/S from the time the fuel is removed from the core, and thus no measurement of the plutonium content is required.

A question to many concerning the use of this technique is the reliability of the C/S equipment that would be required. If the reliability of a C/S System and the assurance it provides were high enough, and potential problems at the facility (such as loss of facility power or lighting) could be avoided, then a single C/S System could be used to provide continuity of knowledge. However, since C/S Systems do sometimes fail, and conditions at facilities may not always be optimal, multiple C/S systems may be required. These multiple systems should be redundant in that they provide the same type of safeguards information, and they should be independent (relying on different stimuli). Redundant and independent C/S Systems could be used to increase the reliability of safeguards information, thus lowering the frequency of C/S system failures and the resulting need for material remeasurement. Redundant and independent C/S Systems could also be used to improve the quality of safeguards information and/or improve the resistance of the safeguards system to defeat. Use of these systems need not be limited only to new types of facilities; they could also be used in many existing facilities.

The following sections will discuss the concept of redundant and independent C/S systems. Examples of equipment which could be used in such systems and examples of potential systems are presented. This study does not address the political acceptability of using C/S techniques as the sole means of providing assurance that material has not been removed from a facility, or that undeclared movements of material have been made. Decisions on how much C/S equipment is enough for a given facility, or type of material, must be made by the inspectorate.

II. Philosophy of Redundant Independent Containment and Surveillance Systems

Before any discussion of redundant and independent C/S Systems can begin, the terms must be defined and the differences between redundant and independent must be stated. It is important to note that the manner in which the terms redundant and independent are being used in this report may be different from the way they are used in other contexts.

The IAEA defines Containment and Surveillance in the following manner:[1]

"Containment - structural features of a nuclear facility or equipment which enable the IAEA to establish the physical integrity of an area or item by preventing undetected access to or movement of nuclear or other material, or interference with the item, IAEA safeguards equipment or data. Examples are the walls of a storage room or of a storage pool, transport flasks and storage containers. The continuing integrity of the containment itself is usually assured by seals or surveillance measures (especially for containment penetrations such as doors, vessel lids and water surfaces).

"Surveillance - the collection of information through inspector and/or instrumental observation aimed at the monitoring of the movement of nuclear material and the detection of interference with containment and tampering with IAEA safeguards devices, samples and data. The most important surveillance instruments are automatic optical devices (No. 257) and monitors (No. 258). Surveillance may also be used for observing various operations or obtaining relevant operational data. IAEA safeguards inspectors may carry out surveillance assignments continuously or periodically at strategic points.

"Containment/surveillance (C/S) measures - the application of containment and/or surveillance; an important safeguards measure complementing nuclear material accountancy. The application of C/S measures is aimed at verifying information on movement of nuclear or other material, devices and samples or preservation of the integrity of safeguards relevant data. In many instances C/S measures cover the periods when the inspector is absent and this contributes to cost effectiveness. C/S measures are applied, for instance,

- To ensure during flow and inventory verification that each item is inventoried without duplication and that the integrity of samples is preserved;
- To ensure that IAEA instruments, devices, working papers and supplies are not tampered with;
- To extend the validity of previous measurements and thereby reduce the need for remeasuring previously verified items.

"The indication of an anomaly by C/S measures does not necessarily by itself indicate that material has been removed. The ultimate resolution of C/S anomalies (e.g. broken seals) is provided by nuclear material accountancy.

"If any C/S measure has been, or may have to be, compromised, the IAEA shall, if not agreed otherwise, be notified by the fastest means available. Examples might be seals which have been broken inadvertently or in an

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1. IAEA Safeguards Glossary, 1987 Edition, Revision 1, International Atomic Energy Agency, Vienna, 1987.

emergency, or seals of which the possibility of removal after advance notification to the IAEA has been agreed between the IAEA and the operator."

Containment and Surveillance techniques are best applied in areas where there is little activity and a minimum of material movement. However, Containment and Surveillance techniques must be carefully designed and implemented to avoid imposing physical restriction on the movement of, or access to, material by the facility operator. This is the case since the Agency is required to avoid any undue interference in the operation of the facility. In general, containment and surveillance techniques must, in order to preserve the integrity of prior measurement of nuclear material, provide the Agency with information as to whether movements or access occurred while inspectors were not present.

Redundancy is a concept which is widely used in the nuclear industry. Many nuclear safety systems are built with individual components which are redundant. In some cases, entire systems are duplicated for redundancy. The purpose of these redundant components or systems is to increase reliability. If one component or system should fail, then the redundant component or system can take over and fulfill the necessary function. Whether or not redundant components are needed, is dependent upon the reliability of the system. If the reliability of the system is not adequate, then redundant components may be necessary to improve system reliability. The concept of redundant components may be illustrated with dual recorders used in some video systems.

An example of such a system is the Modular Integrated Video System (MIVS). The MIVS is a video surveillance system designed to record images of safeguards interest at specified intervals. Eight millimeter video tape recorders are used to store the surveillance images. It has been determined that the recorder is the principal component in the system, which affects its reliability. In order to increase the overall reliability of the system, two recorders are used instead of one. Thus, if one of the recorders should fail, there is no loss of surveillance since the images are recorded on the second recorder. By having redundant recorders, the main function of the system (recording video images) is fulfilled even if one of the recorders has failed. As with many other components within the MIVS, only one camera is used. Since the camera is a very reliable solid state device, providing a second redundant camera would not significantly improve the overall system reliability. The overall system reliability is determined by contributions from the redundant components, such as the recorders, and non-redundant components, such as the camera. When the failure rates for all of these components are properly combined, an overall system reliability may be found. For the MIVS, this reliability has been demonstrated to be 99.6%. If it is determined that in some situations even this high reliability is not adequate, then multiple systems could be utilized to further increase reliability. Even though these multiple systems would provide a very high reliability, they would still be susceptible to common mode failures, such as loss of lighting.

Systems which are independent are different from systems which are redundant. Redundant systems can be thought of as duplicate systems. They operate in the same manner and rely on the same stimulus. If that stimulus is removed, the primary system will not operate, and any redundant systems will also fail to operate. For example, optical surveillance systems rely on adequate light. If two duplicate, and therefore redundant, optical surveillance systems are used to monitor an area and the lighting fails, then no images will be recorded on either system. Even though the two systems are redundant, they are not independent. In the context of this study, independent systems are systems which do not rely on the same stimulus to obtain the relevant safeguards information. For two systems to be truly independent there must not be any single event which can cause a failure of both systems.

Safeguards systems can be designed which are both redundant and independent. The goal is for each of these systems to provide the same type and quality of safeguards information (i.e. redundant systems), but which obtain the safeguards information based on different stimuli (i.e. independent systems). In order to obtain the information independently the systems must not only rely on different stimuli, they must also not be affected by common failures, such as loss of facility power or lighting. Independent systems which are based on different physical principles (such as seals and cameras) avoid common mode failures. Redundant and independent C/S Systems consist of at least two systems. Each of the systems may include several devices. The devices within a given system may be subject to common mode failures. The two redundant and independent systems, however, are not subject to common mode failures.

In many cases it may be difficult to provide multiple systems with at least one which is independent of facility power. In order to eliminate this problem, systems with very large battery capacities can be utilized. Such systems must be able to survive long outages of facility power. Ideally, the battery capacity would be large enough to power the system for the entire period between inspections.

In the ideal redundant and independent C/S system, information from the multiple subsystems could be used interchangeably. That is, each of the redundant and independent subsystems provides the same quality of information. Thus, if one of the independent subsystems were to fail, it should still be possible to make definitive safeguards statements based on the results of only one of the independent subsystems. However, if instead of failing, one system provides information which is contradictory to the other, then further analysis would be required. Another feature of an ideal redundant and independent C/S system would be that it would be as easy to obtain and analyze the information from one subsystem as from any of the other subsystems. In the real world however, one system may provide higher quality information, or information which is easier to obtain.

Redundant and independent systems have several advantages over systems which are just redundant. The main advantage is that with two independent systems, the inspector has greater confidence than with one system that the information provided is correct and can be relied on. This is because it is more difficult to circumvent multiple independent systems than any one single system. This is the case since the systems are independent, and therefore different techniques will need to be developed to defeat each of the systems. Since more than one system must be defeated the probability of detection will also be increased. When independent systems are used the additional information provided by the multiple systems may be useful in resolving anomalies. If the information provided by one of the system is ambiguous, it may be possible to use information from another system to resolve the ambiguity.

Due to the relatively high cost of such systems, in the sense of providing some type of safeguards information, redundant and independent C/S Systems may only be used in special situations. These situations, as mentioned previously, include facilities where a very large amount of material is stored and facilities where material is very difficult to access. The consequence of C/S failure in these facilities could range from an extremely high cost of reverification, to a complete inability to provide assurances about the material which is contained within the facility. The cost of redundant and independent C/S Systems is justified by these extreme consequences and costs. Therefore, it may be expected that redundant and independent C/S Systems will only be used when the cost of reverification outweighs the cost of the system, or when the consequences of a loss of surveillance are severe. In these cases, C/S Systems are needed which will not fail.

Redundant and independent systems use information from the multiple subsystems in an independent, OR fashion. That is, information can be used interchangeably between the multiple subsystems. This ORing is desirable in the types of situations described above where extremely high reliability is required. When a redundant and independent system is used in this manner, a conclusive safeguards statement may be made even if one of the systems fails, but, the confidence the inspectorate would have in the result is obviously less than if <u>both</u> systems were operative.

For example, if systems A and B are redundant and independent C/S Systems, and system A fails, system B will still provide enough information to assure the continuity of knowledge of the material being safeguarded. This ability to make a conclusive safeguards statement, even though one of the systems has failed, illustrates how systems used in this manner increase the reliability of C/S.

Even though the goal of redundant and independent C/S Systems may be to improve the reliability of safeguards, the failure of one of the systems does not imply that the results of the other system may automatically be used. In the event that one of the systems does fail, the first step should be to look for the cause of the failure, specifically, to determine if tampering was involved. If tampering is suspected, the results provided by the other system are immediately called into question. Actions ranging from a thorough analysis of the other system, to a complete reverification of all the material being safeguarded may be required depending upon decisions made by the inspectorate. Only in cases where tampering is not detected or suspected as the cause of a system failure, may the results of the other C/S System be used without hesitation.

In certain situations, it may be desirable to use multiple C/S systems in a dependent, AND fashion. This might be necessary in cases where one subsystem cannot provide complete safeguards information, i.e., the subsystems are not completely redundant. In these situations, information from multiple subsystems may be required to make a positive statement. ANDing the output of the subsystems would mean that they are no longer being used independently, and that the loss of any one subsystem would constitute a loss of containment or surveillance. The VACOSS/MIVS interface[2] is an example of a multiple C/S System used in a dependent fashion. In this system, the MIVS is used to provide video coverage when a VACOSS seal is removed from a shipping cask. If either of these two systems fails, there is a loss of continuity of knowledge of the material contained within the casks.

An inspector may draw one of three conclusions from a C/S System: 1. No undeclared activity has occurred (termed positive); 2. Undeclared activity has occurred (termed negative); and 3. No conclusive safeguards statement can be made (termed inconclusive). Inconclusive results may be due to a variety of causes such as system failure, failure of facility power, loss of lighting, etc. If two C/S Systems are used, then a variety of different combinations of results may be obtained from the two systems. For example, both systems may provide a positive result, or both systems may provide a negative result, or one system may provide a positive result and one may provide a negative result. These various combinations are illustrated in Figure 1.

The figure shows the range of actions the inspectorate could take in each of the situations. As the figure shows, in the case where both C/S Systems provide a positive indication, continuity of knowledge is maintained, and no further action should be required. In any case where the system provides an inconclusive result, and tampering is suspected, then material remeasurement must be considered. Material remeasurement must also be considered in any situation where a negative result is provided by a system.

The real difference between C/S Systems which are used in a dependent and independent manner may be seen in the case where one system provides a positive result and the other provides an inconclusive result. The figure simply states that, in this situation, follow-up actions should be considered. If C/S Systems are being used in a dependent fashion this follow-up action would be a reverification of the material. This is the case since the loss of information from either system implies a loss of continuity of knowledge. If C/S Systems are being used in an independent fashion, then no material remeasurement should be necessary since continuity of knowledge has been maintained.

The use of independent systems which respond to different stimuli reduces the probability of a loss-of-continuity of safeguards knowledge. It can be argued that because different stimuli are being used, a potential diverter would have to devise a defeat technique which overcomes more than one stimulus. This could lead to the conclusion that independent systems provide greater assurance. For this conclusion to be acceptable, the assurance from the least-well-covered diversion paths would have to be enhanced by independent C/S so that the entire C/S system coverage is improved. Since, in some cases, the least-well-covered route is the containment, it may be necessary to enhance the C/S coverage of the containment in order to gain additional assurance.

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2. The VACOSS and MIVS are both described in Appendix I.

At a minimum, independent C/S functions as an alternative redundant system which reduces the probability of a loss of continuity of knowledge. If it can be shown to reduce the vulnerability of the least-well-covered diversion paths, an independent system can enhance the assurance of no diversion.

It has been suggested that different types of safeguards measures should be applied to different categories of material.[3] Reference 3, albeit in draft form, refers to conditions which, when C/S is relied upon, may result in the requirement to consider remeasurement. For example, more stringent safeguards may be needed for materials of high safeguards interest, than for materials of lower safeguards interest. C/S measures could be included as part of this hierarchy. Depending upon the type of material being protected, different levels of C/S measures could be applied. For example, redundant C/S systems, relying on different stimuli, could be used in an AND (dependent) mode for the protection of materials of high safeguards interest; while, only single systems with a certain reliability would be required for materials of lower safeguards interest. Decisions on whether single C/S systems, redundant and independent systems, or redundant and dependent systems, are necessary must be made by the Inspectorate. That is, the Inspectorate must decide how much C/S is adequate under different conditions.

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3. "Proposal for Performance Specifications for Containment and Surveillance Systems," Draft Discussion paper by IAEA Systems Studies Section.

FIGURE 1 – C/S SYSTEM CONCLUSIONS AND NEEDED ACTIONS

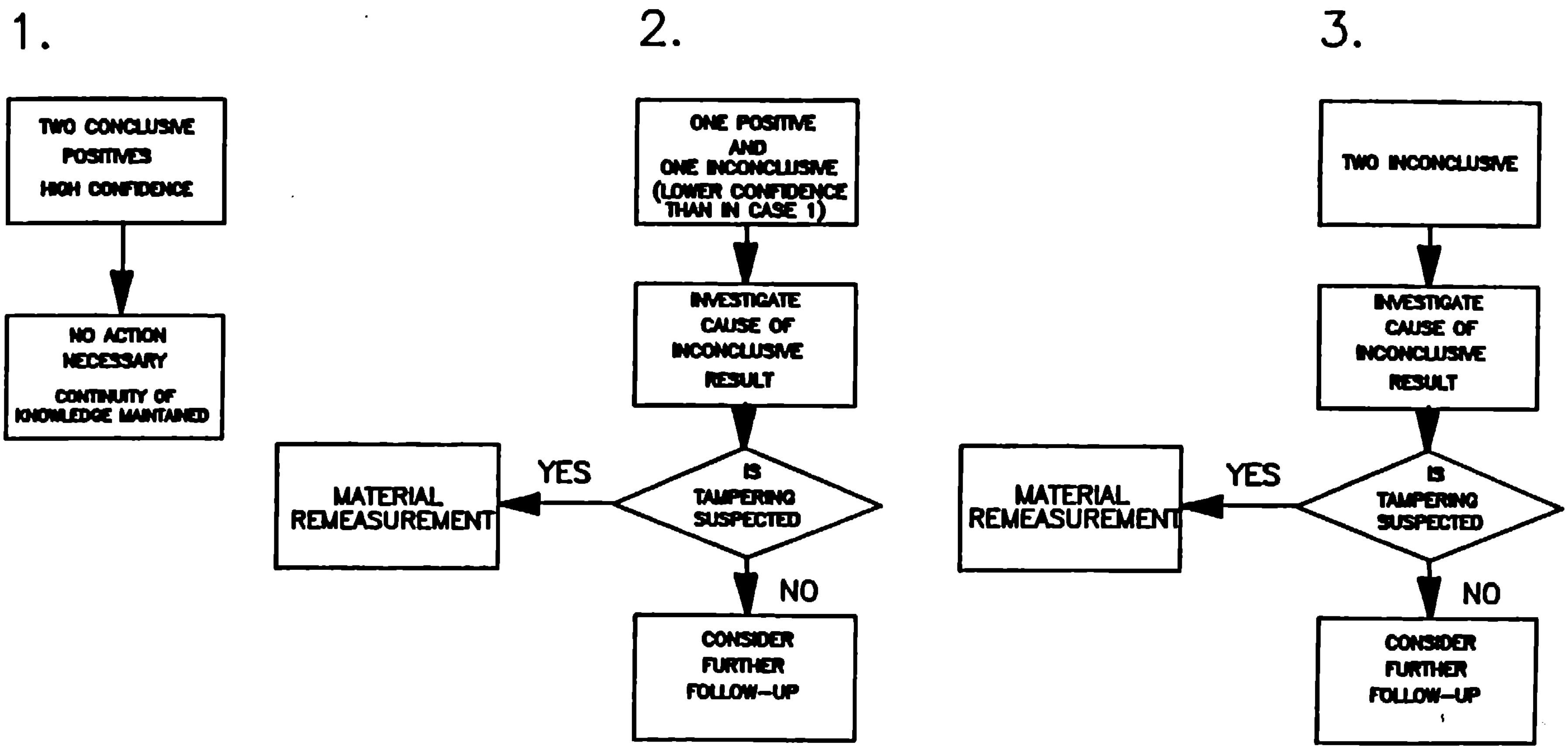
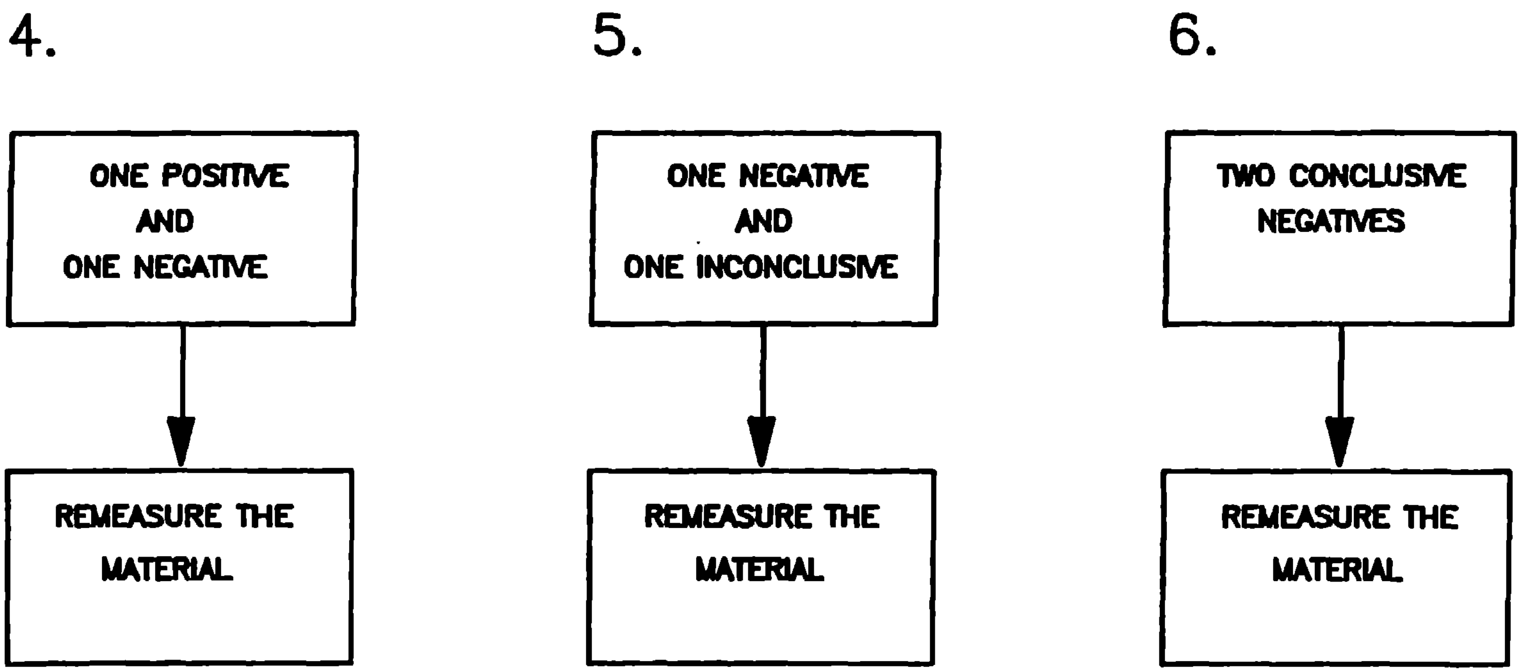


FIGURE 1 (CONTINUED) – C/S SYSTEM CONCLUSIONS AND NEEDED ACTIONS



III. Applicable Technologies

Containment and Surveillance development activities are performed by a number of laboratories in the IAEA Member States and to a limited extent by the IAEA at its Headquarters. Equipment is classified into one of four categories by the Agency. The categories are listed below.

Class I

Laboratory Device - The purpose of this equipment is to demonstrate the principle of operation, and the nature of the data produced, so the IAEA can comment on the approach and future design options. In most cases, such equipment will be operated by its designer.

Class II

Development Prototype - The purpose of this equipment is to allow joint IAEA/Development Laboratory evaluation, including laboratory and limited field testing. Technical experts at the IAEA will be trained to use the equipment. A preliminary equipment manual will be provided, and a preliminary safety analysis will be completed.

Class III

Field Evaluation Unit - This equipment has two purposes: (1) final evaluation of the device prior to production, and (2) limited use during IAEA inspections. The unit will have undergone a complete safety and reliability analysis. A complete equipment manual and development report will be provided. If limited quantities are required to meet IAEA needs, these units can be put into full operation by the IAEA after the field evaluation is complete.

Class IV

Production Model - Equipment developed to this point will have complete production drawings, production specifications, and test procedures, such that the IAEA can obtain commercial supplier quotes on fabrication, testing and delivery of multiples quantities.

A variety of containment and surveillance devices have been developed and are being developed by the IAEA and the various support programs. The equipment which is being used by the Agency at any given time is in a constant state of change as old systems are removed from use and new, and in most cases, more effective and reliable systems are brought into use. Appendix I provides information on equipment which is presently being used by the Agency, or is under development. This Appendix is included in order to illustrate the type of equipment which is available, or will become available, which could be used in the design of redundant and independent C/S Systems.

A careful review of Appendix I shows that some of the systems currently under development, such as the Variable Coding Seal System (VACOSS) Modular Integrated Video System (MIVS) interface, are actually based on combinations of C/S devices. These combinations yield systems which provide capabilities that could not be provided by the systems individually. In the case of the VACOSS/MIVS interface an operator is now provided with the capability of sealing casks (or unsealing depending upon how the overall system is used) without the need for inspector presence. This eases operational problems for the operator and reduces manpower requirements for the Agency. In these cases the combined C/S Systems are being used in a dependent manner. If either of the systems fails, remeasurement or reverification of the material will be needed.

Other systems described in Appendix I, such as the Portal/Penetration Monitor, combine a variety of specialized components to provide a C/S function. In general, these components are also used in a dependent fashion, however, individual components may by duplicated for redundancy.

While it may be necessary, in some cases, to develop specialized equipment for a particular part of a redundant and independent C/S System, it would be desirable to use as much existing equipment as possible. There are several advantages to using existing equipment. For example, the costs associated with development and testing can be significant as well as time consuming. The "in use" equipment described in Appendix 1 has already been developed and tested so these costs have already been expended. In addition, since this equipment has already gone through an acceptance procedure, the time required for this activity is eliminated. Facility operators may find some pieces of equipment too intrusive and thus do not wish to have them installed. With equipment previously developed, these issues have already been addressed so that there will be less concern about operator acceptability.

Even though designers may attempt to use as much existing C/S equipment as possible, there will always be cases where this will not be possible. In these cases, the possibility of using other equipment which may be adapted to C/S applications should be explored. For example, sensors and equipment which has been developed for domestic security applications may have direct use within redundant and independent C/S Systems. Appendix II presents a list of equipment which could potentially be used in redundant and independent C/S systems.

IV. System Examples

The main goal of any C/S System is to detect the undeclared removal of material of safeguards interest from a given area. Different C/S Systems are required, depending on the configuration of the facility and the form of the material to be safeguarded. Facilities with similar configurations may be grouped together as requiring similar C/S Systems. This grouping allows some generalizations to be made about the C/S Systems to be used. The following are some of the common configurations which must be addressed by C/S Systems.

- pools containing spent fuel or other materials
- dry fresh fuel storage areas
- fresh or spent fuel stored under sodium (such as at fast reactors)
- exterior and interior dry cask storage areas
- material vaults where material is stored as discrete items
- spent fuel repositories where the material is inaccessible
- process areas under remote or automatic control

Examples of redundant and independent C/S Systems for three of the above configurations are presented below. The purpose of these examples is not to provide specific system designs, but to illustrate the philosophy of redundant and independent C/S Systems. Estimates of hardware costs are included with each example. The hardware costs are included in order to provide some basis for comparison between the cost of a redundant and independent C/S System and the cost of reverification. These costs do not reflect any development, installation, or operational costs. Inspectors may require increased inspection time at facilities equipped with redundant and independent C/S in order to analyze the information from the multiple systems. This increased inspection time will also add to the actual cost of these systems. In many instances, these additional costs could be significant, surpassing the cost of equipment. Even though it is possible to classify general types of facilities where similar redundant and independent C/S Systems could be used, the final design of these systems may be somewhat facility specific.

Example 1: Plutonium Storage Vault

Facility Description:

In this example, Plutonium is being stored in birdcages within a vault. It is assumed that between 100 and 200 birdcages are stored in the vault and the vault has only one entrance where material may be brought in or out. It is also assumed that any penetrations of the vault will be readily apparent. The assumed configuration of the facility is illustrated in Figure 2.

Goal of C/S System:

To monitor whether there has been any undeclared removal of material from the vault.

Redundant Independent C/S System

The Plutonium storage vault has only one entrance through which material may enter and leave. By monitoring the flow of material through this entrance an Inspector may be assured that there are no undeclared movements of material.

Monitoring of the vault door can be provided with optical surveillance. Whenever the vault door is open surveillance images could be recorded. In order to trigger the camera, a door switch or motion sensor would be required on the vault door. When the vault door is opened, the door switch or motion sensor would send a trigger signal to the camera indicating that surveillance should begin. When the vault door is closed, a second signal would be sent indicating that surveillance should be terminated. This is an example of a C/S System utilizing subsystems which are used in a dependent fashion. If either the door monitoring system or the surveillance system fails, there is a loss of surveillance. The

MIVS (described in Appendix I), is designed to accept external triggers and could be easily used in this application.

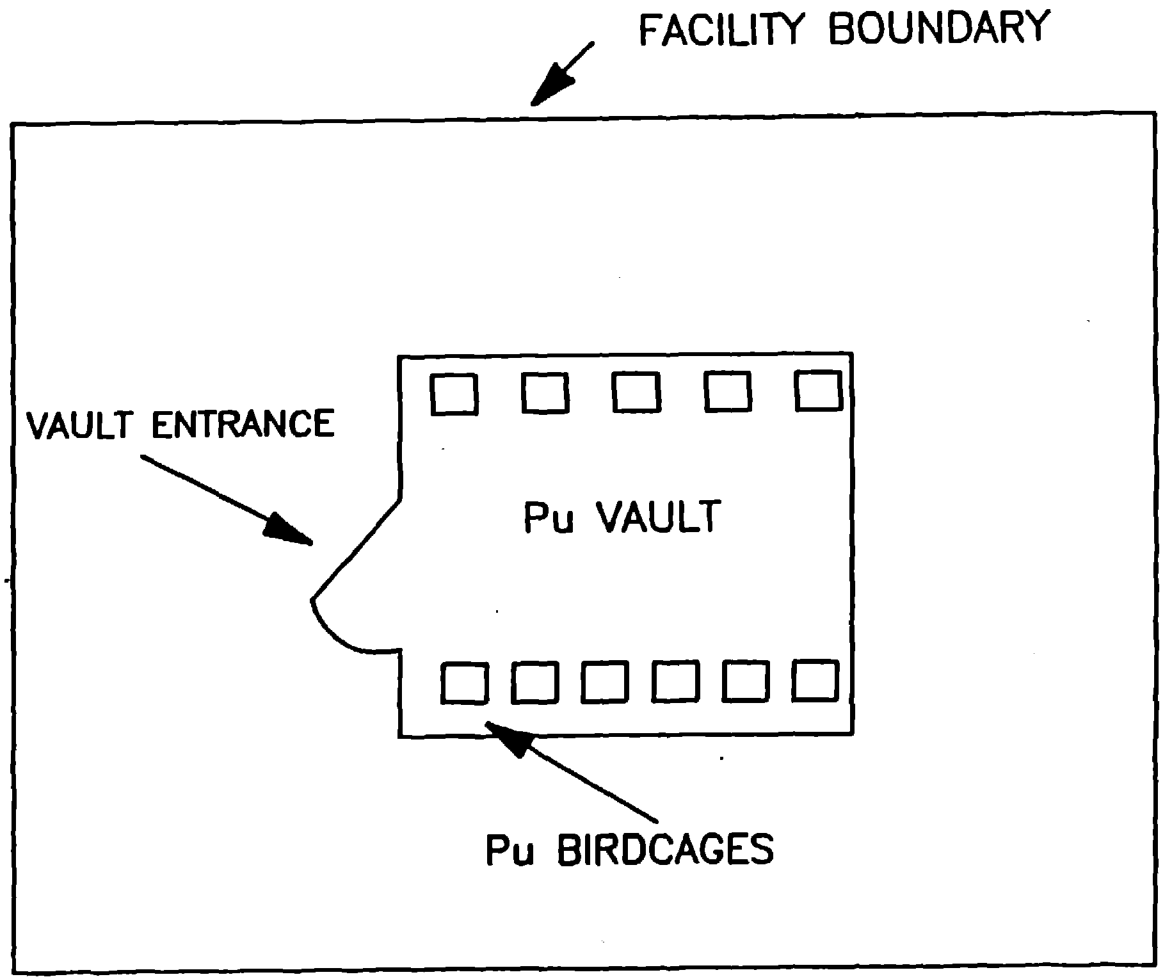


FIGURE 2 – PLUTONIUM STORAGE VAULT

The door switch could be hardwired to the optical surveillance device. In order to assure the integrity of the door switch, information transmitted on the data line between the switch and optical surveillance device would need to be authenticated. If it is difficult to run the necessary cables between the door switch and the optical surveillance device, then Authentication Item Monitoring System (AIMS - described in Appendix I), technology could be used. AIMS sensor transmitter packs could be used to transmit the door switch information over an authenticated RF link to the optical surveillance device.

During periods when the vault door is closed, surveillance images could be recorded at random intervals. This random recording would provide assurance that no actions were being taken which would bypass the door switch.

The optical surveillance based C/S System is dependent upon facility power and facility lighting. A second completely passive means of assuring that material has not been removed from the vault, would be to individually seal each of the birdcages. During inspections, the inspector must count the items to insure that all of the material is present. The inspector must also check the seals to insure that there has been no tampering with birdcages. In order to accomplish this, seals which provide both identity and integrity, such as the Cobra Seal, must be used. This type of seal is necessary to insure that there has been no complete substitution of birdcages.

Summary:

System 1:
- -optical surveillance of the door
- -door switch or motion detector on vault door

System 2:
- -seals on the birdcages

  OR
- -AIMS monitoring each birdcage or monitoring groups of connected birdcages.

Hardware Cost:
(Assume 100 birdcages)

System 1:

MIVS	$15,000
Door Switch or motion detector	$1,000
Data Line authentication	$5,000

System 2

Cobra Seal ($15/seal)	$1,500
Cobra Seal verification equipment	$8,000

Example 2: LWR Spent Fuel Pool

Facility Description:

This example addresses a generic LWR spent fuel pool area as shown in Figure 3. This pool area consists of a cask loading/unloading area, loading/unloading transfer channel, the spent fuel storage area, and a reactor transfer channel through which fuel is moved into and out of the reactor. Spent fuel assemblies are removed from the pool by placing them in a shipping cask and removing the cask from the pool. Due to the great size and weight of these casks there is usually only one portal through which the casks may enter and exit the pool area.

Goal of C/S System:

To detect the removal of spent fuel assemblies from the spent fuel pool area.

System Description:

Normally spent fuel pools are monitored using optical surveillance. This optical surveillance is used to monitor activities in the spent fuel pool, particularly the loading and unloading of shipping casks. Since spent fuel assemblies can only enter and exit the facility in shipping casks, it is assumed that the optical surveillance provides coverage of the areas where casks may enter and leave the pool.

Optical surveillance may also be used to monitor the reactor transfer channel. In order to do this a camera must be mounted directly adjacent to the channel so that activity within the channel can be monitored. An optical surveillance system covering the entire spent fuel pool area may not provide adequate detail of the activities within the channel.

The optical surveillance systems presently in use rely on facility power, although some battery backup is usually provided. All of these systems are, of course, dependent upon adequate lighting. Since optical surveillance systems already exist at many facilities, and provide the required detection of the removal of spent fuel assemblies, there is no need to completely replace them. These existing systems may be used as one of the elements in the redundant and independent C/S System. The other elements of an ideal redundant and independent C/S System would not rely on facility power, and would be independent of facility lighting.

Due to their high level of radiation, spent fuel assemblies may only be removed from the pool when contained within shipping casks. In most facilities, there is only one area within the spent fuel pool which is designed to support these casks. Thus, spent fuel assemblies may only be removed from the spent fuel pool area by moving them into the reactor area through the reactor transfer channel, or by loading them into shipping casks after transfer through the loading/unloading transfer channel. By monitoring these two transfer channels assurance could be provided that there had been no undeclared removal of fuel assemblies from the spent fuel pool.

A second C/S System could be designed and installed which would monitor these two channels. This system would need to detect fuel assemblies as they move through the channels. Radiation detectors could be used within the channels to provide this function. These detectors could be designed so that they would provide an indication of whether assemblies were entering or exiting the area.

This channel monitoring system would operate independently of facility lighting. However, the system would require facility power for operation. Since the system would not need to be portable, a very large battery backup capability could be provided.

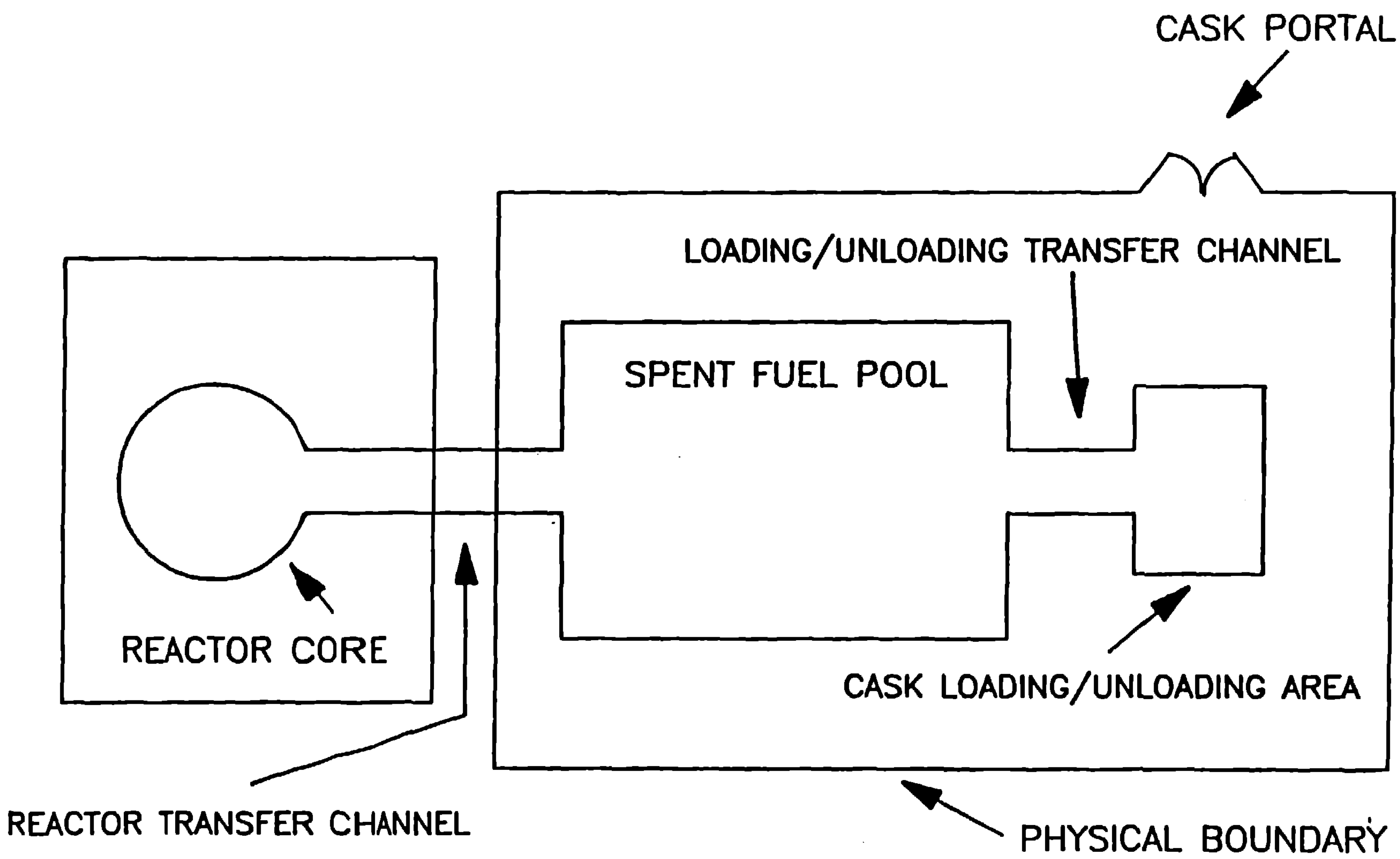


FIGURE 3 – LWR SPENT FUEL STORAGE AREA

Summary:

System 1:

-optical surveillance of the spent fuel pool
-optical surveillance of the reactor transfer channel

System 2:

-monitoring of the reactor transfer channel
-monitoring of the loading/unloading transfer channel

Hardware Costs:

System 1:

Optical surveillance for pool	$15,000
Optical surveillance for reactor transfer channel	$15,000

System 2:

Reactor channel monitor	$20,000
Loading/unloading channel monitor	$20,000

Example 3: Interior Dry Cask Storage Area

Facility Description:
This type of facility consists of a large building with a completely open interior where spent fuel storage casks are stored directly adjacent to one another. It is assumed that 100 or more casks are stored within the facility. There is only one entrance through which casks may enter or leave, as shown in Figure 4. It is assumed that sensors are sealed within the casks to monitor environmental conditions such as temperature, pressure, and radiation conditions. The operator monitors the output of these sensors, through a hardwire link to a control area, to insure that there are no problems within the casks. Once casks have been placed in this facility, they should remain static within the facility for long periods of time. There should not be any routine removal of casks from the facility.

Goal of C/S System:
The goal of a C/S System for this facility would be to detect when casks containing spent fuel enter or leave the area.

Redundant Independent C/S System:
The existing hardwire links between the casks and the control area can be utilized by the inspectorate to monitor that casks have not been removed. Since sensors are sealed within the casks, loss of signal from a sensor would indicate that a cask had been removed. In order to monitor that the signal is always present, and there has been no substitution of false sensor information, data authentication could be utilized between the casks and a data collection point within the control area.

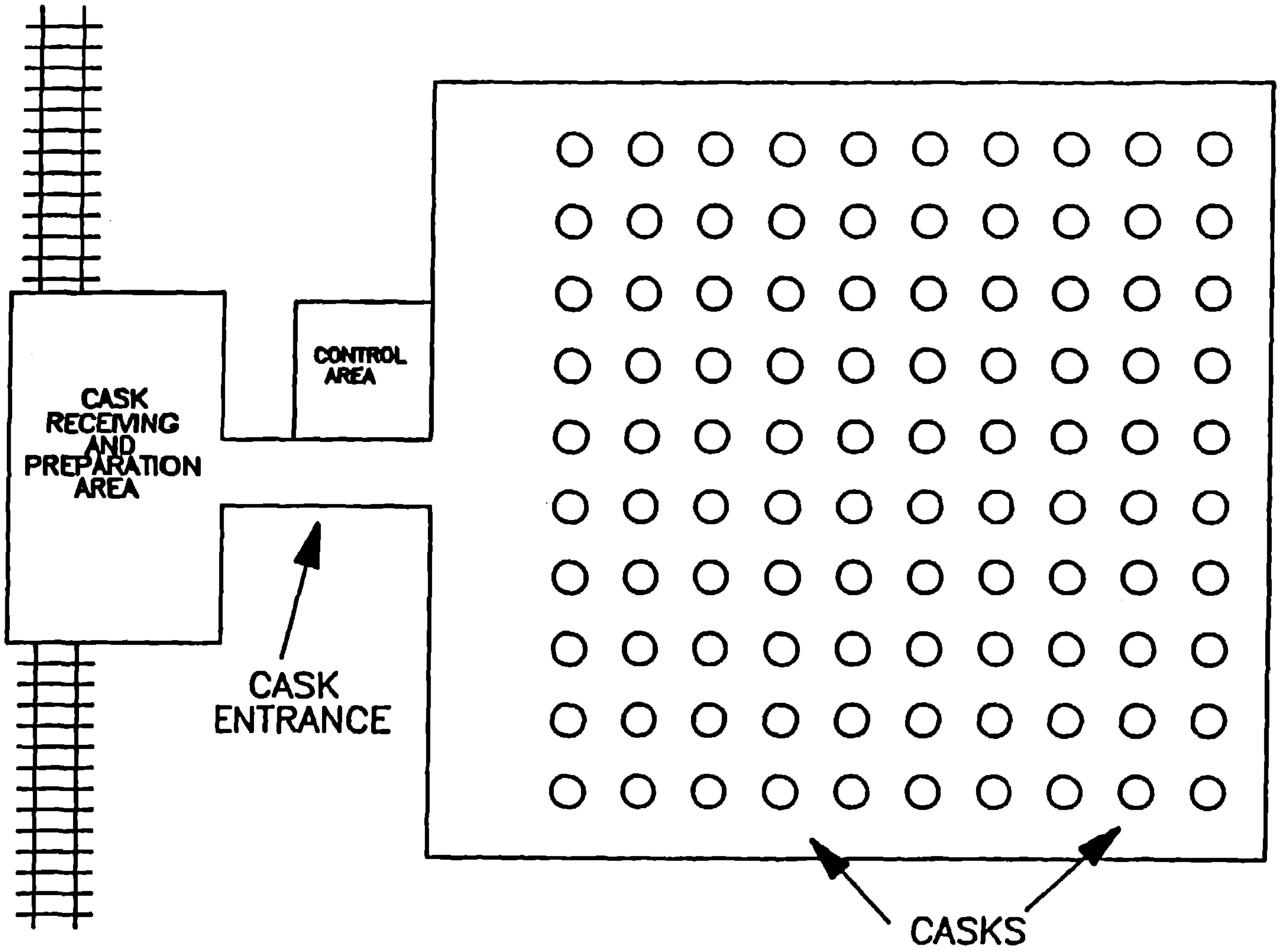


FIGURE 4 – INTERIOR DRY CASK STORAGE AREA

To Implement this scheme, a data authentication module would be added at each cask and information processing and data storage would occur at the control area. During Inspection, the inspector would access the stored data to determine whether there had been any failure of data authentication from any of the casks. A data authentication failure would Indicate that either the cask had been removed (signal was lost from the sensors), or that there had been an attempt to substitute false sensor data.

Since there Is only one entrance through which casks may enter and leave the building, monitoring this entrance will also provide an indication of whether casks have been removed. Optical surveillance could be used for this monitoring task. Radiation detectors located at the entrance could be used to trigger the optical surveillance. Whenever a cask moves through the entrance, the radiation detectors would detect its presence. Optical surveillance would then be Initiated to record the movement of the cask through the entrance.

If it is found that the radiation signal from the cask is too low to provide a camera trigger, then motion detectors at the entrance could be used instead. The motion detectors would detect the movement of the cask as it passes through the portal, and provide the camera trigger. A system utilizing motion detectors would be less selective than one utilizing radiation detectors. The motion detector based system would record the passage of anything through the portal, such as personnel, rather than just the passage of casks.

When the systems are operating normally, the inspector would only need to retrieve information from the data authentication system. If this system indicated that there was no movement of the casks, then the inspector would be assured that material had not been removed. During these normal inspections, the inspector would not need to review the surveillance tapes, other than to verify that the system is operational. However, if the data authentication system failed, then the inspector would need to review the optical surveillance to determine if any material was removed.

Summary:

System 1:
-Data authentication of the cask sensor signals

System 2:
- Optical surveillance of the storage area entrance triggered by radiation detectors or motion detectors

Hardware Cost:
(Assume 100 casks)

System 1:	
Data authentication	$20,000
System 2:	
Optical Surveillance	$15,000
Radiation detectors	$ 5,000

V. Summary

In locations where inventories are very difficult to access, it may not be possible to physically access and analyze the materials. Similarly, the individual items cannot be counted on a routine basis. Since the materials cannot be accessed, it is necessary in these situations to use C/S techniques to insure that the materials have not been removed. Of course, before the items are placed into these locations, measurements must be made to establish the composition of the inventory.

The C/S Systems used in facilities with inventories which are very difficult to access, must be extremely reliable, and there must be a very high confidence that the information provided is correct. Any failure of the C/S System in these facilities could cause a permanent inability to assure the integrity of the inventory, since it may not be possible to re-establish an inventory.

A similar situation exists in facilities with very large inventories. In these cases, it may be possible to access the materials but the cost of a complete reverification may be prohibitively expensive and time consuming. Redundant and independent C/S systems could be used within both of these types of facilities to assure high reliability, and thus provide continuity of knowledge.

In order to implement these systems, it is not necessary to discard already existing C/S Systems. In many cases, it should be possible to use part, if not all of the existing systems. Additional systems would simply be added to improve the reliability of the overall C/S System.

Ideally, redundant independent C/S Systems would be constructed using C/S equipment which has already been developed and tested. Using existing C/S equipment would lower the cost of the system, and ease operator and Agency acceptance. If this is not possible, then a variety of other commercially available equipment could be adapted for use within custom designed C/S Systems.

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APPENDIX I

C/S Equipment

Equipment In Use

The following list provides a brief description of C/S equipment which the Agency is presently using, is authorized to use, or is undergoing field commissioning. Even though film based optical surveillance systems will be phased out of use during the next several years, they are included in this list for completeness.

Seals

Metallic; Type-E

This is a seal which is widely used by the Agency. The seal consists of a wire, which is looped through the object to be sealed, and the seal body. The seal body is composed of two halves which interlock. To verify the integrity of the seal, an inspector removes the seal and returns it to Agency Headquarters for analysis. This seal may be used to seal doors, bird cages, casks, containers, etc.

Adhesive

This seal is also known as the paper seal. An adhesive backing on this seal allows it to be applied to a variety of surfaces. Doors and equipment lids can be sealed with this seal. Verification of this seal is performed on-site by visually examining the seal. If the seal is found to be torn, or the layers of the seal have become delaminated, this is an indication that tampering may have occurred.

Electronic Fiber Optic; VACOSS

A Fiber optic cable is used to provide locking and sealing functions in the Variable Coding Seal System (VACOSS). Opening and closing of the fiber optic cable are recorded with times and dates in a battery powered component which is housed in the seal. The information can be extracted from the seal using an adapter box. This interrogation can be carried out on site or remotely without removing the seal from the sealed item.

Shrink Tubing Seal

The shrink tubing seal was developed to seal container valves, such as valves on UF cylinders. The seal material is placed over the valve and then shrunk in place. The seal is verified on-site by visually examining the seal patterns.

Ultrasonic; ARC

The Atomic Energy of Canada Limited Random Coil (ARC) seal has been approved for sealing CANDU spent fuel storage racks. The seal is applied to bolts which secure the tops of the fuel storage racks. A Seal Pattern Reader (SPAR) is used to read the seal and determine whether any tampering has occurred.

Optical Surveillance Devices

Film Camera; Twin Minolta

The Twin Minolta camera system has been used for many years to provide images of items and activities of safeguards interest. Two film cameras are contained in a housing, which may be mounted overlooking a spent fuel pool, storage area, areas declared inactive, etc. This system has enough capacity to record one image every twenty minutes for a three month period. The film from these cameras must be developed and is normally reviewed off-site.

Film Camera; Advanced Photo Surveillance

This system is the same as the Twin Minolta system except that the film capacity is increased.

Video; Psychotronic

This is an optical surveillance system based on video technology. This system performs the same function as the film systems, that is, recording images of items and activities of safeguards interest. In this system, the camera may be separated from the recorder. Unlike the film systems, the tapes generated with this system may be reviewed on site.

Video; STAR

As with the Psychotronics CCTV system the Surveillance Television and Recording (STAR) system stores images on video tape. Images from two cameras may be recorded in a "split-screen" manner. Information on system status is presented to an inspector on a monitor. Prompting information is also presented on the monitor to ease the setup and operation of the system. The monitor may also be used to assure correct camera placement and to review tapes on-site.

Video; MIVS

The Modular Integrated Video System (MIVS) consists of a camera and a recording control unit (RCU). The camera may be located up to 100 feet from the RCU. Video authentication is applied to the line between the camera and the RCU to detect any tampering attempts. Two eight millimeter video tape recorders are used within the RCU to assure system reliability. Recording intervals from one to ninety nine minutes may be selected by an inspector.

Video; Ministar

The Ministar was designed to be used in applications which do not require the full capability of the Psychotronics or STAR System. The Ministar is a portable system which may be used to provide short term optical surveillance for applications such as reactor refueling. The Ministar uses one camera and one recorder.

Video; CANDU Multiplex

This system may be used to record video images from 10 or more cameras. The system may be used to monitor multiple spent fuel pools, enrichment facility cascade halls, or any other area where multiple cameras are required.

Video; Multiplex

This system performs the same function as the CANDU Multiplex. It will record video images from 10 or more cameras. The system may be used to monitor multiple spent fuel pools, enrichment facility cascade halls, or any other area where multiple cameras are required.

Video; Underwater

Several commercial underwater video systems from U.S., European and Japanese suppliers are in use. These systems allow a camera to be lowered into water and display the images in real time on a monitor at the surface. One of the uses of these systems is to view the identification numbers on fuel assemblies. These systems may be used in spent fuel pools and fresh fuel pools.

Monitors

Fuel Assembly Counter; CANDU Bundle Counter

This system utilizes a group of radiation detectors to register the passage of fuel bundles between a reactor discharge and the spent fuel storage pool. The system records information on the fuel movements for later retrieval by an inspector. This system was specifically designed for use at CANDU reactors.

Radiation Monitor; Film Badge

Film badges are used to detect undeclared movement of radioactive materials. These badges can be applied adjacent to doorways or in other passageways. The badges must be removed and sent to Agency Headquarters for reading.

Environmental Monitor; PASEM

The Passive Environment Monitor (PASEM) is a small passive package that can be placed in existing C/S equipment enclosures to obtain data on temperature, humidity, and radiation experienced by the equipment. The PASEM is used in defining C/S equipment operating environments. The PASEM can also be used in a stand-alone mode to determine basic facility environments.

Load and Position Monitors

Load and position monitors are used to provide a record of crane position and loads. This information may be used to determine at what times objects of safeguards interest were moved. These monitors may be used in a variety of facilities including power reactors and reprocessing plants.

Reactor Power Monitor

This type of monitor may be used to provide a record of reactor power output. This information can be used to determine when the reactor was operated, and to a limited degree, what the composition of the spent fuel should be.

Equipment Under Development

The C/S devices which are currently under development are listed below. The current Class of development is also listed.

<u>Seals</u>

Fiber Optic; CLTO (Class IV)

The CLTO optical seal consists of an optical guide connecting both ends of a fiber optic cable. Interference with the optical guide results in distortion of the received light. The ends of the cable are fitted into the guide in adjacent sides to prevent the loop from being opened by sawing the guide in a horizontal or vertical direction. One end of the seal is bonded into the optical guide at the factory. The other end is crimped into place in the field by an inspector. This seal can be verified in the field using special equipment.

Fiber Optic; Cobra (Class III)

The Cobra Seal is a fiber optic seal consisting of a loop of fiber optic cable secured with a seal assembly. A small blade is inserted into the seal body which cuts some of the fibers. When a light illuminates the face of the seal a characteristic pattern of light and dark spots formed by the cut and uncut fibers may be seen. This unique pattern is used to show the identity and integrity of the seal. The seal may be verified in the field by an inspector using special equipment.

Ultrasonic; VAK III (Class III)

This seal can be used on BWR fuel assemblies. The seal indicates whether the fuel assembly has been disassembled. The seal may be applied during fuel fabrication and can remain on the fuel assembly through the assemblies entire life, i.e. reprocessing or final storage. A special PC based reader may be used to verify the seal signature on site.

Ultrasonic; MEB (Class II)

This ultrasonic seal was designed specifically to seal multielement bottles containing reactor spent fuel. The seal may be verified by an inspector in the field using special equipment.

Ultrasonic; Other types (Class II and III)

Several other ultrasonic seals are in development. These seals will be used for a variety of specific applications. For example, the VAK III is being modified for sealing PWR fuel assemblies.

<u>Seal Pattern Readers</u>

Digitized Reader; CLTO (Class II)

A reader which provides an automatic comparison of seal signatures in the field for the CLTO seal is under development.

Digitized Reader; Cobra (Class II)

A reader which provides an automatic comparison of seal signatures in the field for the Cobra seal is under development.

<u>Optical Surveillance Devices</u>

Video; PSU (Class II)

The Portable Surveillance System (PSU) uses eight millimeter video recorder technology to provide a system for surveillance situations that require quick setups. The PSU has its own internal battery for short duration operations, and can be plugged into AC power mains for applications requiring longer surveillance periods. The PSU can record 26,000 scenes at time intervals of 1 to 99 minutes. The system uses several of the components from the MIVS.

Video; Review Station (Class III)

The MIVS records video information at specified time intervals, while also inserting consecutive scene numbers and tamper event information. The Review Station reads the inserted information and counts the number of missed scenes and/or tamper events encountered on the tape and reports this to the user. The Review Station will also check for any video loss on the tape.

Video; COSMOS (Class II)

The Compact Surveillance Monitoring System (COSMOS) is an eight millimeter video tape based surveillance system. The COSMOS utilizes a camera and recorder colocated in an enclosure which may be sealed. The COSMOS operates off of a battery for a three month period and has the capacity to record 30,000 scenes. A set-up unit is used to initialize the recording unit and a review unit is used for tape review.

Video - C/S Interfaces

VACOSS/Video Interface (Class II)

An interface has been developed between the VACOSS seal and the MIVS. This interface allows unattended operation of the VACOSS seal while making video recordings of the seal's installation or removal. The purpose of this system is to allow facility operators to apply or remove the VACOSS seal without the need for inspector presence. An inspector can review a MIVS video tape of the installation and make a determination that the seal was installed or removed correctly.

MIVS/Radiation Detector Interface (Class II)

An interface between the MIVS and a radiation detector is being developed for a specific application. The radiation detector will detect the passage of containers transporting spent fuel past a given point. The radiation detector will trigger the MIVS which will record the identification number of the container.

MIVS/Intrusion Detection Interface (Class II)

The MIVS is being interfaced to an intrusion detector. The combined system will detect motion within a specific area and record images of the cause of the motion.

Monitors

Laser Surveillance; LASSY (Class II)

The Laser Surveillance System (LASSY) utilizes two laser beams, scanning in common or parallel planes, to detect items penetrating that plane. Laser emitters are positioned in adjacent corners of a spent fuel pool. Each emitter transmits a laser beam into the pool. By processing the reflected signal from the lasers, the system can determine if an object is present. The approximate size and location of the object can also be defined. This system may be used to monitor spent fuel movements within a pool.

Portal/Penetration Monitor (Class III)

The Portal/Penetration Monitor is a system which monitors the passage of material and personnel in a facility. The system uses a variety of components including metal detectors, radiation detectors, motion sensors, and CCTV. The system was developed for a site specific application.

Remote Monitoring; RECOVER (Class III)

This system was developed to collect safeguards information at a site and transmit the information to a remote location.

Remote Monitoring; LOVER (Class III)

This system provides local verification of C/S data and equipment status. (No development activity is ongoing)

Integrated Monitoring System (Class III)

The Integrated Monitoring System utilizes a variety of equipment to provide information on when spent fuel has been shipped or received from a facility. Two of the main components are crane monitors and radiation detectors. This system has been superseded by the MIVS and its capability to accept external detector inputs.

Item Monitoring; AIMS (Class III)

The Authenticated Item Monitoring System (AIMS) provides a near real time indication of item movement. The main components of the system are sensor/transmitter packs, which are attached to the items to be monitored, and a receiver/processor unit which monitors the packs. The sensor/transmitter packs are firmly attached to the items to be monitored so that the pack moves whenever the item moves. Each pack contains a motion sensor. Whenever motion occurs, an authenticated data message is sent by short duration radio frequency signal to the receiver/processor unit. Other types of sensors which provide an on/off output may be substituted for the motion sensor in the sensor/transmitter packs.

Advanced Containment Surveillance System

In order to monitor the flow of material within a specific facility the Advanced Containment Surveillance (A C/S) System was developed. The A C/S System monitors when material enters the facility, where it is stored within the facility and when the material exits the facility. This information is stored for later retrieval by Agency Inspectors. Radiation detectors, crane monitors, door switches, cameras, recorders and computers are all elements of the system.

Thermal Flux Monitoring System

The Thermal Flux Monitoring System provides a quantitative measure of plutonium and tritium content by using a thermal fluxmeter.

APPENDIX II

Commercial Equipment with Potential C/S Applications

The following is a list of commercially available equipment which may be useful in redundant and independent C/S applications. The purpose of the list is to provide ideas about the kinds of equipment which may be useful and how it could be used. This list is only meant to provide examples of equipment and applications where the equipment could be used and is not meant to be exhaustive. When a system is actually being designed, any equipment which may be useful should be considered. The specific application will determine what equipment should be used.

Type of sensor:
Interior motion detection sensors

Description:
A wide variety of interior motion detection sensors exist. Motion detection sensors can rely on a variety of phenomena including ultrasonic, microwave, infrared, sonic, capacitance (proximity sensor), and vibration.

Potential Application:
Motion sensors could be used in material vaults or areas which have been declared inactive. The purpose of these sensors would be to detect undeclared material movements.

Comments:
Sensors detecting different phenomena can be combined in such a manner to yield a very low false alarm rate.

Type of sensor:
Low light level Cameras

Description:
Low light level cameras use a variety of techniques to intensify the image formed from available light.

Potential Application:
Cameras with image intensifiers could be used in areas with low light levels. Ideally, these cameras would be triggered for short term use by some other sensor. These cameras could also be used to backup normal surveillance cameras in areas where lighting is susceptible to failure.

Comments:
Image intensifying cameras have a relatively high cost. Life expectancy of these cameras is short which precludes their operation in applications which require continuous operation.

Type of Sensor:
Infrared cameras

Description:
These cameras are sensitive to the infrared portion of the spectrum and therefore do not rely on the visible light.

Potential Application:

This type of camera could be used in storage areas where there is no lighting and there is some thermal signature from the material stored. These cameras could also be used to backup normal surveillance cameras in areas where lighting is susceptible to failure

Comments:

The images formed by infrared cameras are typically blurred. Therefore, these cameras could not be used in applications requiring high resolution. As with Image Intensifiers, these cameras have a relatively high cost.

Type of Sensor:

Pressure sensors

Description:

Pressure sensors may be obtained in a variety of sizes and housings. The sensor chosen depends upon where and how the sensor will be used.

Potential Application:

Pressure sensors could be used on process lines within a reprocessing or enrichment facility. These sensors could be used to monitor whether the particular line operated during the period between inspections.

Comments:

Pressure sensors are routinely used in non-destructive assay systems to help determine the composition of materials. However, in this application the goal is to determine whether a system operated, not the composition of material being processed.

Type of Sensor:

Temperature sensors

Description:

Temperature sensors may be obtained in a variety of sizes and housings. The sensor chosen depends upon where and how the sensor will be used.

Application:

As with pressure sensors, temperature sensors can be used within facilities to determine whether a process line has been operated. Temperature sensors could also be used within inaccessible storage areas to monitor whether spent fuel (or some other heat generating material) remains in place.

Comments:

A system which utilizes temperature (or pressure) sensors must be carefully designed since it may be very easy to deceive these types of sensors.

Type of Sensor:

Fence Penetration Sensors (e.g. mechanical fence sensors, strain sensitive cables, taut-wire sensors.)

Description:

These sensors detect gross movements of a fence or penetrations through a fence.

Potential Application:

This class of sensors could be used to monitor the perimeter of a site where there is exterior storage of casks. The sensors would provide assurance that no casks had been removed from the site through a breach in the fence.

Comments:

These sensors could be added to existing, operator constructed, perimeter fences. These sensors would need to be used in combination with a portal monitor (such as an optical surveillance system which records traffic entering or leaving the facility).

Type of sensor:

Exterior point sensors (e.g. electromagnetic, geophone, seismic)

Description:

The purpose of point sensors is to detect movement within a given area. Detection ranges and sensitivities can be varied depending upon the sensor chosen.

Potential Application:

Sensors of this type could be used outside of facilities to monitor when very large vehicles carrying shipping casks enter or exit the facility.

Comments:

This type of sensor may be susceptible to false alarms and may not discriminate adequately between vehicles containing shipping casks and other types of large vehicles.

Type of sensor:

Vehicle scales

Description:

There are two types of vehicle scales, in-motion scales and static scales. In-motion scales are used to weigh vehicles while they are moving. Some scales are small and may be imbedded quickly into existing road surface.

Potential Application:

Scales could be used to monitor traffic entering and exiting a facility through a portal. Scales used in these locations could determine when vehicles heavy enough to be carrying shipping casks entered or exited the facility. Scales could also be used in a cask loading area to determine when vehicles are being loaded or unloaded.

Comments:

Unless scales are used in combination with other sensors they may be easily defeated by driving around the them or bridging over them.

Type of sensor:

Crane scales

Description:

Load cells are normally used within crane scales to determine the weight of an object being moved. Depending upon the type chosen, readout from crane scales may be located at the crane, transmitted through an RF link to a receiver, or transmitted over cable to a display.

Potential Application:

Scales may be used to monitor when objects of safeguards interest have been transported with a given crane.

Comments:

In order for crane scale to be effective there must be a method to discriminate between objects of safeguards interest and other objects which could be moved by the crane.

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