Further Readings


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**Introduction**

The International Atomic Energy Agency (IAEA) defines in the model comprehensive safeguards agreement (CSA), INFCIRC/153,1 the technical aim of safeguards as "the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection." The whole philosophy underpinning the IAEA safeguards inspection system stems from that statement.

The reader will see in this chapter that the IAEA has built its safeguards system to fulfill this technical aim of safeguards by defining the concepts of significant quantities of nuclear material and timeliness of detection. Hence, the principles behind the IAEA Safeguards Criteria are based on defining a set of guidelines using the concepts of significant quantities and timeliness to allow inspectors to fulfill the technical aims of safeguards for the suite of facilities that the IAEA must inspect. Safeguards inspectors and their management use these criteria and established Agency practices for a facility to lay out an inspection schedule for a material balance period (MBP), which is approximately one calendar year and no more than 14 months long and is the period between two IAEA Physical Inventory Verification (PIV) inspections.3 The types of and amounts of nuclear materials and their physical forms determine the quantity goals and timeliness goals for a facility, as shown in Table 5.1.

**Table 5.1** Definition of significant quantities for IAEA nuclear material types.

<table>
<thead>
<tr>
<th>Nuclear Material Type</th>
<th>SQ Amount (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pu (&lt;80% 239Pu)</td>
<td>8kg Pu</td>
</tr>
<tr>
<td>U-233</td>
<td>8kg 233U</td>
</tr>
<tr>
<td>HEU (=&gt;20% 235U)</td>
<td>25kg 235U</td>
</tr>
<tr>
<td>LEU (&lt;20% 235U including natural U and depleted U)</td>
<td>75kg 235U (or 10t nat. U or 20t depleted U)</td>
</tr>
<tr>
<td>Thorium</td>
<td>20t thorium</td>
</tr>
</tbody>
</table>


3IAEA, Safeguards Criteria.
This chapter presents a basic example of an IAEA inspection regime under the traditional CSA at a facility, the activities planned, and the driving philosophies behind it. The reader will be exposed to the concepts of IAEA safeguards in much the same fashion as a novice IAEA inspector would in the three-month Introductory Course on Agency Safeguards (ICAS), albeit in a much condensed and simplified version. The reader should realize that verification of material accountancy in the traditional safeguards is a keystone of the IAEA safeguards, and even with the implementation of INFCIRC/340 Additional Protocols and the move to more investigative safeguards as part of the Strengthened Safeguards System, material accountancy will remain the keystone of the safeguards system. Hence, the reader needs to be able to understand traditional comprehensive safeguards as a first step in comprehending the challenges the IAEA safeguards system faces.

The Concept of Significant Quantities of Nuclear Material and Timeliness of Detection

Over the years the IAEA has developed a means of defining the proliferation risk involved in various types, amounts, and forms of nuclear material. The term significant quantity (SQ) refers to any nuclear material that can create one nuclear weapon. There are some controversies regarding the definition of the SQ. Part of the assumption in determining the SQ includes process losses associated with the fabrication of a weapon and that the state does not possess a sophisticated nuclear weapons expertise. These amounts stem from the content of throughputs does not exceed 5 effective kilograms of nuclear material or less where the content of throughputs does not exceed 5 effective kilograms of nuclear material shall not have more than one inspection per year. Table 5.2 contains the definitions for an effective kilogram of nuclear material for all the forms of nuclear material. For other facilities with more nuclear material, the number, intensity, duration, timing, and mode of inspections shall be determined by the nominal declared amount of nuclear material in the facility and shall not be no more intensive than is necessary and sufficient to maintain continuity of knowledge of the flow and inventory of nuclear material. Hence, the CSA states that the inspection intervals and activities will be of a nature that will not be intrusive and excessive and are based on a grading safeguards concept, as touched upon earlier in this chapter. The Safeguards Criteria give a more detailed description of the allowable activities and categorize facilities as shown in Table 5.4.

A constant estimate of the number of each type of facility that is under IAEA safeguards is given in Table 5.4. The Agency classifies the facilities as item or bulk handling facilities. The item facilities have nuclear material that is contained in an "item" form, such as fuel rods and fuel pins; bulk handling facilities have nuclear material that is contained in a "bulk" form, such as UF₆, in cylinders, U₂O₅ powder, and reprocessed plutonium stored in containers. Item facilities have the advantage to the inspector of having the nuclear material in an integral physical form that will not change. Bulk handling facilities have the disadvantage of having nuclear material in gas, liquid, or powder forms that will be manipulated.

<table>
<thead>
<tr>
<th>Nuclear Material</th>
<th>Material Form</th>
<th>Conversion Time</th>
<th>IAEA Timeliness Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pu, HEU or U-233</td>
<td>Metal</td>
<td>Few days (7-10)</td>
<td>1 month</td>
</tr>
<tr>
<td>Pure Pu components</td>
<td>Oxide (Pu₂O₅)</td>
<td>Few weeks (3-8)</td>
<td>1 month</td>
</tr>
<tr>
<td>Pure HEU or U-233 compounds</td>
<td>Oxide (U₂O₅)</td>
<td>Few weeks (1-3)</td>
<td>1 month</td>
</tr>
<tr>
<td>MOX</td>
<td>Nonirradiated fresh fuel</td>
<td>Few weeks (1-3)</td>
<td>1 month</td>
</tr>
<tr>
<td>Pu, HEU or U-233</td>
<td>In scrap</td>
<td>Few weeks (1-3)</td>
<td>1 month</td>
</tr>
<tr>
<td>Pu, HEU or U-233</td>
<td>In irradiated fuel</td>
<td>Few months (1-3)</td>
<td>3 months</td>
</tr>
<tr>
<td>LEU, Nat U, Dep U, and Th</td>
<td>Unirradiated fresh fuel</td>
<td>Order of 1 year</td>
<td>1 year</td>
</tr>
</tbody>
</table>

5 International Safeguards Inspection: An Inside Look at the Process
Table 5.3 IAEA effective kilogram (ekg) definition.

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Definition of Effective Kilogram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plutonium</td>
<td>Weight in kilograms</td>
</tr>
<tr>
<td>Uranium with an enrichment of 0.01 (1%) and above</td>
<td>Weight in kilograms multiplied by the square of the enrichment of the material</td>
</tr>
<tr>
<td>Uranium with an enrichment below 0.01 (1%) and above 0.005 (0.5%)</td>
<td>Weight in kilograms multiplied by 0.0001</td>
</tr>
<tr>
<td>Depleted uranium with an enrichment of 0.005 (0.5%) or below</td>
<td>Weight in kilograms multiplied by 0.00005</td>
</tr>
<tr>
<td>Thorium</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.4 Nuclear facilities under IAEA safeguards.

<table>
<thead>
<tr>
<th>Facility Type (Defined by IAEA Safeguards Criteria)</th>
<th>Approximate Number of Facilities Under IAEA Safeguards Worldwide</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Light water reactors (LWRs)</td>
<td>180</td>
</tr>
<tr>
<td>2. On-load reactors (OLRs)</td>
<td>20</td>
</tr>
<tr>
<td>3. Other types of reactors</td>
<td>10</td>
</tr>
<tr>
<td>4. Research reactors and critical assemblies (RRCA)</td>
<td>170</td>
</tr>
<tr>
<td>5. Natural and low enriched uranium conversion</td>
<td>50</td>
</tr>
<tr>
<td>and fabrication plants</td>
<td></td>
</tr>
<tr>
<td>6. Fabrication plants handling direct-use material</td>
<td>5</td>
</tr>
<tr>
<td>(MOX or HEU)</td>
<td></td>
</tr>
<tr>
<td>7. Reprocessing plants</td>
<td>10</td>
</tr>
<tr>
<td>8. Enrichment plants</td>
<td>20</td>
</tr>
<tr>
<td>9. Storage facilities</td>
<td>80</td>
</tr>
<tr>
<td>10. Other facilities (~60 other facilities under SGs)</td>
<td>60-70</td>
</tr>
<tr>
<td>11. Locations outside facilities (LOFs)</td>
<td></td>
</tr>
</tbody>
</table>

Chemically or isotopically altered. The inspector will encounter material stored in containers where both the operator and the inspector will always be uncertain of just how much material is present. The operator, whether he is an honest conscientious individual or a devious proliferator, will always have over the course of a material balance period, as stated above, one year, some material unaccounted for (MUF). MUF is calculated for a material balance area (MBA) over a material balance period (MBP) using the material balance equation, commonly written as:

\[ \text{MUF} = (PB + X - Y) - PE \]

where:

- \(PB\) = Beginning physical inventory
- \(X\) = Sum of increases to inventory
- \(Y\) = Sum of decreases from inventory
- \(PE\) = Ending physical inventory

Because book inventory is the algebraic sum of \(PB, PE, X,\) and \(Y,\) MUF can be described as the difference between the book inventory and the physical inventory. (The equivalent term in U.S. domestic safeguards, for both the Nuclear Regulatory Commission and the Department of Energy, is inventory difference, or ID, as described in 10CFR 74.4 and DOE Manual 470.4-6.) For item MBAs, MUF should be zero, and a nonzero MUF is an indication of a problem (for example, accounting mistakes) which should be investigated. For bulk handling MBAs, a nonzero MUF is expected because of measurement uncertainty and the nature of processing bulk materials. The operator’s measurement uncertainties associated with each of the four material balance components are combined with the material quantities to determine the uncertainty of the material balance.\(^{11}\)

Hence, the large enrichment plants and large reprocessing plants with their large throughputs of material in a year will find it statistically difficult using the best measurement techniques to obtain a MUF that is smaller than a significant quantity of nuclear material. This is a major challenge for the IAEA and its inspectors to verify nuclear material in such facilities. Hence, because of the need for experience and more in-depth training for bulk handling facilities, training new inspectors touches generally on bulk handling facilities but focuses on item facilities. An inspector without experience in bulk handling will usually find that it takes almost two to three years to grasp the rudiments of planning and executing a large PIV at an enrichment plant or reprocessing plant. This chapter focuses on the ubiquitous LWR, which is the focus of ICAS. At the end of the ICAS, the class will perform a mock inspection at an LWR.

Basic Goals of IAEA Safeguards at LWRs

An LWR contains two types of nuclear material: LEU and plutonium. As noted previously, it is an item facility so that all nuclear material is an item form. The fresh fuel rods contain the unirradiated LEU, and the core fuel and spent fuel rods contain the irradiated LEU burned by and Pu produced by the fission process. Although a fuel rod will change material composition during the fission process, the uranium and Pu stay contained in the fuel rod. The LWR in this example is a pressurized water reactor (PWR) with LEU fuel and no MOX with a yearly refueling cycle.

The inspector must understand the type of nuclear material and the operations at the facility. The state is obligated to provide to the Agency a Design Information Questionnaire (DIQ) prior to the operation of the plant.\(^{12}\) The Agency then will do Design Information Verification (DIV).\(^{13}\) The state has a continuing obligation to provide the Agency with updates to the DIQ. For example, an operator may upgrade the thermal power of an LWR during its operational life by replacing steam generators. The Agency, by doing a DIV, will verify that the operator has done this activity.

An inspector should understand the types and uses for the nuclear material located in the facility, the operations associated with the nuclear material, and the material quantity and timeliness goals. Starting with a new LWR, the first material to be introduced will be the fresh LEU fuel. This material will have a goal quantity of a significant quantity that is 75 kg of \(235\text{U}\) in the LEU fuel and timeliness of one year (Table 5.1). Hence, until the reactor begins to operate, the LWR will need to be inspected yearly.

When the reactor begins to operate with the uranium fissioning, the fresh fuel now becomes core fuel. This material is now seen as irradiated direct-use material since the fission process will convert \(238\text{U}\) into Pu. A significant quantity of Pu equals 8 kg elemental Pu. Irradiated Pu has a timeliness of three months. Hence, the inspector needs to inspect the LWR on a quarterly basis, with a yearly PIV at the refueling. When the core is refueled for the first time, there will then be irradiated direct-use material in the form of spent fuel removed to cool in the spent fuel pond. The operator inserts new fresh fuel into approximately one third of the core. The inspector will be responsible for verifying the new fresh fuel, the remaining core fuel, and the spent fuel. The next section describes how the state and

\(^{13}\text{IAEA, IAEA Safeguards Glossary, 2001 Edition, p. 27.}\)
the operator designate the material balance areas (MBAs) and the key measurement points (KMPs) of the reactor for the Agency and the Agency's safeguards approach to LWRs.

The MBA and KMP Safeguards Concepts Applied to LWRs

INFCIRC/153 states that the aforementioned design information shall not only identify the features and nuclear material relevant to safeguards, as discussed previously, but shall "determine material balance areas to be used for Agency accounting purposes and to select those strategic points which are key measurement points and which will be used to determine the nuclear material flows and inventories." INFCIRC/153 states that the MBA size should be "related to the accuracy with which the material balance can be established." The use of "containment and surveillance to help ensure the completeness of flow measurements and thereby simplify the application of safeguards and concentrate measurement efforts at key measurement points" should be pursued. Furthermore, to respect the sensitivity of a proprietary process, "a special material balance area around a process step involving commercially sensitive information may be established." INFCIRC/153, para. 46, states how the Agency intends to implement safeguards using the design information from an operator to negotiate specific MBAs and KMPs in a facility to enable the IAEA to get the information needed to verify the facility's declarations and protect the operator's sensitive information.

This balancing of access and protecting sensitive technologies and industrial processes is one of the challenges of safeguards, especially where an operator may have a technical process that he does not want to reveal to a rival and lose his crucial competitive edge. This process is a serious consideration with respect to enrichment, reprocessing, and fuel fabrication processes and industrial operations where market shares could be won or lost if the IAEA inspectors performed industrial espionage. Hence, the IAEA has the concept of "Safeguards Confidential" information. The IAEA will honor the confidentiality of the information from the state and the operator provide to the Agency. Inspectors are made aware of this obligation not to divulge this information during their Agency careers and beyond.

The IAEA and the state must negotiate subsidiary arrangements that include a general part and a facility attachment for each facility under safeguards in the state. Paras. 39 and 40 of INFCIRC/153 describe the subsidiary arrangements. The Agency and the state shall make subsidiary arrangements that specify the necessary details to permit the Agency to fulfill its procedural responsibilities under the CSA both effectively and efficiently. The general part applies to all common nuclear activities of the state concerned. A facility attachment contains specific provisions necessary for safeguards implementation at a facility. The subsidiary arrangements include the results of the examination of INFCIRC/153, para. 46, shows how the Agency will use the MBA to determine how the IAEA draws its safeguards conclusions, an effective SSAC smooths the implementation of IAEA safeguards.

The IAEA considers LWRs to be Type I or Type II for safeguards purposes, shown in Figures 5.2 and 5.3, respectively. PWRs, such as this chapter's example generic PWR, are usually

FIGURE 5.1 Legal structure of safeguards.

FIGURE 5.2 LWR of the Type I Configuration: Spent fuel pond inside of containment.

Type II with the spent fuel pond outside the containment. These features, which are a basic part of the design information, will determine how the IAEA will create a safeguards approach.

The IAEA, in setting up the MBA and KMP structures in a facility, attempts to take into account the safeguards concerns and possible diversion scenarios in the facility. In an LWR without MOX (Mixed Oxide) fuel, nuclear fuel containing uranium and plutonium such as this chapter's example PWR, the diversion scenarios exist as listed in Table 5.5. It should be noted that the use of MOX fuel complicates safeguards at a reactor since the MOX will have a timeliness of one month (Table 5.1), forcing the IAEA to inspect the reactor on a
Table 5.5 LWR diversion scenarios: PWR without MOX.

<table>
<thead>
<tr>
<th>Diversion</th>
<th>Method</th>
<th>Timing/Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEU fresh fuel diversion</td>
<td>Substitution of dummy element for actual element</td>
<td>After fresh fuel verification, prior to core loading From reactor pool, SF pool, or SF transfer cask From SF pool or SF transfer cask</td>
</tr>
<tr>
<td>Spent fuel assembly diversion</td>
<td>Substitution of dummy element for actual element</td>
<td>From reactor pool, SF pool, or SF transfer cask</td>
</tr>
<tr>
<td>Spent fuel pin diversion</td>
<td>Substitution of dummy element for actual element</td>
<td>From SF pool or SF transfer cask</td>
</tr>
<tr>
<td>Unreported Pu production</td>
<td>Insertion of fertile targets for irradiation in core fuel — PWR guide tubes or burnable poison rod</td>
<td>From reactor pool, SF pool, or SF transfer cask</td>
</tr>
</tbody>
</table>

monthly basis and to worry about nuclear material with a high strategic value to a potential proliferator.

A PWR as an item facility, unlike more complicated reprocessing and enrichment plants, has only one MBA, which simplifies accountancy. The PWR’s KMPs aim at giving the IAEA the appropriate access to make the measurements needed to verify that the diversions in Table 5-3 can be detected. The example PWR will have the following KMP structure. It should be noted that a flow KMP is a KMP in which material passes into and out of the facility, and an inventory KMP is a KMP in which material is stored or used in the facility:

Flow KMPs
KMP 1. Receipts of nuclear material (nominally fresh LEU fuel)
KMP 2. Nuclear loss and nuclear production for core fuel discharged

where:
Nuclear loss = The reduction in uranium occurring from burnup of fuel
Nuclear production = The production of plutonium from neutron capture in 235U
KMP 3. Shipments of nuclear material (nominally spent LEU fuel to dry storage or reprocessing)
KMP 4. Exemption/exemptions of nuclear material, accidental gain/loss, etc.
Inventory KMPs
KMP A. Fresh fuel storage (LEU fuel)
KMP B. Reactor core (LEU fuel and plutonium)
KMP C. Spent fuel pond (spent LEU fuel containing uranium and plutonium)
KMP D. Any other locations of nuclear material

The concept of flow KMPs focuses on shipments (spent fuel) and receipts (fresh fuel) of nuclear material at the plant and the nuclear loss of uranium created by fission and the nuclear gain of plutonium formed by neutron capture to 239Pu and decay to 239Pu. The inventory KMPs keep track of the location of the nuclear material in the facility so as to delineate fresh fuel, core fuel being burned, and spent fuel from each other. The inspector’s main job in CSA safeguards is to be the material accountant who must verify that the material is where the operator declares it exists and that all items maintain their integrity.

Inspection Frequency at LWRs

For the IAEA to be able to verify the operator's declaration of the nuclear material locations and shipments from and to the facility, the state, the operator and the Agency must agree to facility access. As described previously, the negotiations that created the facility attachment provide the legal framework for Agency access to the facility.

In an LWR under traditional INFCIRC/153 safeguards, the Agency completes a yearly PIV and three interim inspections for timeliness and inspections of shipments of spent fuel in casks to dry storage. The number of inspections is determined by the type of material and movements of material at the facility. As described earlier, this chapter’s example PWR has LEU fuel, which has a timeliness goal of one year. Hence, the yearly PIV suffices to verify the LEU fresh fuel on a timely basis. Once the reactor begins operation, the LEU fuel begins to fission and creates plutonium. The reactor now has irradiated direct-use material, plutonium, which has a timeliness goal of three months. Hence, the IAEA must inspect the reactor every three months to verify the correctness of the declaration with respect to the plutonium at the reactor. When the reactor is refueled, the old core fuel now migrates to the spent fuel pool. The spent fuel must also be verified on a quarterly basis exactly as the core fuel.

The Agency performs three basic activities to verify the completeness and correctness of the operator’s declaration. The inspector checks the reactor’s nuclear material accountancy (accounting and operating records), verifies the material itself and the items’ identity by visual and nondestructive assay (NDA) techniques, and uses containment and surveillance to check that the nuclear material and the reactor are not being diverted and misused, respectively. Material accountancy is basically examining the books that contain the ledger describing the nuclear material at the facility. In an LWR, the operator also provides the Agency with maps of the core and the spent fuel pool. These maps delineate the location of every fuel assembly in these areas. The inspector will then attempt to verify the accountancy by visually counting and identifying the fuel elements and applying various NDA techniques using a random sampling plan designed to give the appropriate confidence level for the desired probability of detection. The confidence level is a limit set around a measured value or estimate that expresses a degree of confidence with regard to the “true” value of the measured or estimated amount. NDA techniques take advantage of the radiation emitted by nuclear

\[ J. \text{ L. Jaeck, Statistical Methods in Nuclear Material Control, TID-26298, Technical Information Center, Oak Ridge, Tennessee (1973).} \]
The facility's physical inventory is determined by the operator as a result of a physical inventory taking (PIT) and is reported to the IAEA in the physical inventory listing (PIL). The physical inventory is verified by the IAEA during the physical inventory verification (PIV) inspection. The Agency and the operator center the yearly PIV around the refueling, which in most plants has been a yearly occurrence. The IAEA will be present during the core opening to verify the new core and the spent fuel pool configuration. In facilities on a stretched-out refueling schedule, a closed core PIV is done as best as possible for timeliness sake, and the core is verified during the refueling period. A PIV at a PWR, used as an example in this chapter, has three distinct phases, denoted as the pre-PIV, the PIV activities, and the post-PIV.

During the pre-PIV the inspector must go to the reactor and prepare the facility for the PIV following the Safeguards Criteria for LWR inspections as the ruling guide. The inspector must verify the fresh fuel that the plant received since the last PIV. The inspector will visually inspect, count, and check the serial numbers stamped on the fuel and perform NDA.

\[ n = N \left(1 - \beta^d\right) \]

where:
- \( n \) = The number of items in the stratum
- \( N \) = The number of items in the stratum
- \( \beta \) = The nondetection probability
- \( d = \lceil M \rceil \) = The number of defects in the stratum rounded up to the next integer
- \( M \) = The goal amount
- \( x \) = The average nuclear material weight of an item in the stratum

Since the IAEA must consider all states potential adversaries, it is critically important that the facility operator have some level of uncertainty as to which items the Agency will select for verification. By using this random approach, even the IAEA inspector does not know for certain which items will be selected. There will be no human-based pattern that an adversary could use to their advantage. Therefore, this places the operator or adversary at great risk for detection should they choose to tamper with or substitute an item. At the same time, by using a scientific-based approach to sampling, which includes random selection, the number of SQs present, and an acceptable risk factor, the IAEA can draw defensible safeguards conclusions.

**LWR PIV Inspection**

The facility's physical inventory is determined by the operator as a result of a physical inventory taking (PIT) and is reported to the IAEA in the physical inventory listing (PIL). The physical inventory is verified by the IAEA during the physical inventory verification (PIV) inspection. The Agency and the operator center the yearly PIV around the refueling, which in most plants has been a yearly occurrence. The IAEA will be present during the core opening to verify the new core and the spent fuel pool configuration. In facilities on a stretched-out refueling schedule, a closed core PIV is done as best as possible for timeliness sake, and the core is verified during the refueling period. A PIV at a PWR, used as an example in this chapter, has three distinct phases, denoted as the pre-PIV, the PIV activities, and the post-PIV. During the pre-PIV the inspector must go to the reactor and prepare the facility for the PIV following the Safeguards Criteria for LWR inspections as the ruling guide. The inspector must verify the fresh fuel that the plant received since the last PIV. The inspector will visually inspect, count, and check the serial numbers stamped on the fuel and perform NDA.

20Jeanch, Statistical Methods in Nuclear Material Control.

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**For fresh fuel, the Agency does a “gross defects” test, which entails testing to see if the fuel assembly does contain uranium.**

The concept behind these Agency tests is based on the approaches an adversary might take to divert nuclear materials. Such approaches include abrupt diversion of an SQ within the timeliness goal period versus protracted diversion of a SQ within a MBP and complete versus partial removal of nuclear material from an item under any of these scenarios. (Note: A partial defects test would test to see whether 50% of the assembly's nuclear material as declared is present, and a bias defect tests to see whether, within a small range of uncertainty, all the assembly's nuclear material as declared is present.) For fresh fuel, the Agency can use a CdZnTe detector to search for the characteristic 185 KeV 235U gamma spectrum peak. As shown in Figure 5.4, the inspector in the left-hand photograph, squatting among fresh LWR fuel (VVER 440 fuel in this case), is holding the mini multichannel analyzer (MMCA) connected to the CdZnTe detector, which is inserted carefully in a space between the fuel pins in a manner shown in the right-hand photograph of Figure 5.4. The inspectors observe the 185KeV 235U gamma peak and can attest that the declared LEU fresh fuel really contains uranium.

A reactor, such as the example PWR in this chapter, has containment and surveillance measures to maintain what the IAEA calls continuity of knowledge (CoK). Once the Agency has verified nuclear material, it must either maintain a constant vigil over that material to assure that it can detect any tampering with the material or reverify the nuclear material on a required frequency. Reverification can be both costly and time consuming for both the IAEA and the operator.

Since human surveillance would be rather intrusive to the operator and expensive for the Agency to maintain a constant vigil over all the material in the world, safeguards have developed a portfolio of containment and surveillance measures. For the example PWR, both containment and surveillance measures would be in place.

Referring to Figure 5.3 for locations, IAEA tamper-indicating devices (TID), metal access hatch on the containment dome where, during refueling, equipment is moved in and out of the reactor hall and the gate that separates the spent fuel pool from the reactor core's pool. These measures provide tamper indication if the operator has opened the reactor hatch of the canal gate to access the core fuel to divert the nuclear material. The design information
provided by the operator enables the IAEA to create this safeguards approach by allowing the Agency to understand where the diversion pathways exist in the plant.

Of course, if the operator removes core or spent fuel from the spent fuel pond out the containment hatch, he has a clear path to misuse the material as he pleases. If he removes the containment hatch, he has a clear path to misuse the material as he pleases. If he removes the containment hatch, he has a clear path to misuse the material as he pleases.

Agency, the inspectors will see the fresh fuel again in the reactor core during the refueling and to still keep the CofK. In a PWR, the inspector will then depart to return for the

Once the inspection team will arrive at the facility and be on call to perform the

The inspection team will arrive at the facility and receive the accounting documents from the operator. The PWR accounting records include the General Ledger (with material accountancy summaries), fuel history cards and fuel assembly certificates for being able to track and identify fuel items, and an itemized list of the fuel assemblies located at the reactor. The operating records can include the power histogram and estimates of burnup, the all-important core and spent fuel pond maps with assembly locations, and cask shipment and crane movement information (important in drawing safeguards observations from images from the surveillance cameras).

The inspector will then proceed to verify the core fuel, as shown in Figure 5.6, by item counting of the core fuel from the core barrel edge and using the operator’s underwater TV (UWTV) camera system to check off that the serial numbers of the fuel assemblies match the declared locations on the core map. Since the canal gate seal is not in place, the operator can shuffle items between the core and spent fuel pools without the Agency’s knowledge. Hence, the Agency must verify the spent fuel pool or pools immediately or they cannot assure that the absence of substitution of items in the spent fuel pool for items in the core has occurred between the time of the core verification and the spent fuel verification. For example, if the inspector finishes the core verification late in the day and the inspector and operator agree to continue with the spent fuel pool verification in the morning, the operator has time to shuffle the core and possibly bring in uranium targets for irradiation and for unreported plutonium production or substituting spent fuel items in the spent fuel pond with spent fuel from the core and removing spent fuel from the facility without the inspector being able to see the state of the spent fuel pool and whether there are suspicious items in the pool.

The inspectors now reconcile their observations of the spent fuel pond with the SF core map and the assembly burnup data. The standard technique is to use the Improved Cerenkov Viewing Device (ICVD) to observe the blue Cerenkov glow emitting from the spent fuel assemblies (Figure 5.7, left-hand graphic). The Cerenkov glow appears in water originating from radiation products in the spent LWR fuel. Cerenkov light is seen mainly in the ultraviolet region with peak intensity in the 300 nm region. The light can be seen as a faint blue glow passing through the water, with hotter assemblies being brighter than longer-cooled assemblies.

The ICVD is simply a more sensitive or improved device based on the concept of a sighted vision device focused on detecting the visible band of Cerenkov radiation by amplifying the Cerenkov light intensity and discriminating the Cerenkov light from other light sources in
Once the inspectors have verified the core fuel and spent fuel ponds, they can attend to servicing the surveillance systems in the facility by checking that they have not been tampered with (seal replacement) and accessing and retrieving image data from the system. At this time the inspectors may be able to service and remove the temporary cameras in the reactor hall (and outside the containment) and replace the seals on the containment hatch after the PIV. Hence, the inspectors may have to schedule a separate post-PIV inspection to complete the post-PIV activities, a separate inspection may be avoided.

Generally, the facility at the PIV, especially a PWR, will not have any nuclear material outside of the core fuel and spent fuel to verify. However, there may be extra fuel stored at the facility. With a multiple unit power plant, especially in Russia, PWRs (VVER is the Soviet countries, PWR is used as the acronym), there may be fuel for another unit with a different designation for light water pressurized reactor; in Western 

\[ \text{The inspectors may have to schedule a separate post-PIV inspection to complete the post-PIV activities, a separate inspection may be avoided.} \]

When the inspectors return to Vienna, they must perform some very important tasks with the operators. The inspectors confirm that the core fuel and spent fuel ponds have been inspected and that the seals match the Agency records and the seals were not tampered with. The inspectors must also complete the inspection report. It is far better to reconcile any problems before they become anomalies. The IAEA checks that the seals match the Agency records and reconcile it. For example PWR, the SF is not shipped off-site. In many facilities the operator ships SF to Away Dry Storage (AFS) or puts the SF in dry storage casks and sends these casks to a and in many cases must verify the seals and status with IAEA seals prior to shipment. seals that they removed from the facility for verification. The IAEA seals verification group checks that the seals match the Agency records and that the seals were not tampered with or inadvertently damaged by the inspector. As the inspectors turn into the seal verification group in Vienna, the IAEA checks that the seals match the Agency records and that the seals were not tampered with. The inspectors gather up the verification team, and their working papers from the inspection.

The inspectors’ tasks prior to obtaining the PIV include: the inspectors complete surveillance reviews and get the report done prior to obtaining the PIV, including post-PIV activities, the IAEA can close the material balance for the

\[ \text{Interim Inspections for Timely Detection in LWRs} \]

As described earlier, the IAEA does timeliness inspections at facilities due to the fact that some materials have shorter timeliness periods than the material balance period or that shipments and receipts occur at the facility and need a timely verification. For the example PWR, the IAEA seals can replace IAEA seals on the containment hatch door and the canal gate. The removed seals are sent to the IAEA Vienna office for verification. If the seals have not been tampered with, the inspectors have successfully verified the core fuel.
The inspectors must also verify the spent fuel pond. Knowing that the canal gate seal was intact allows the inspectors to verify that no items passed from the SF pond to and from the core. If the surveillance also shows no items removed from the spent fuel pond, it is declared. However, if the surveillance images cannot conclusively show that there could not have been a movement from the core.

The inspectors can verify that the spent fuel pond is as declared. However, if the surveillance images cannot conclusively show that there could not have been a movement from the core, the inspectors must verify the seal by reviewing the surveillance images. Again, they must get these activities and the report done in a timely fashion to obtain the safeguards timeliness goal.

Review of Safeguards at an LWR: Generic PWR

This chapter has given the reader a glimpse into the process of the IAEA inspection regime for a sample generic PWR without MOX, which falls in the agency LWR facility category. As for a sample generic PWR, without MOX, which falls in the agency LWR facility category. As for a sample generic PWR without MOX, which falls in the agency LWR facility category.

The reader should also realize that at other facilities, especially bulk handling facilities such as enrichment and reprocessing plants, the complexity of the verification work increases with the number of participants involved. Furthermore, with states implementing the Strengthened Safeguards System dramatically. The International Atomic Energy Agency (IAEA) relies heavily on the use of unattended monitoring systems (UMS) to provide continuous monitoring of nuclear facilities around the world. The states possessing these nuclear facilities permit such monitoring to allow the IAEA to confirm that nuclear material in these facilities is not being diverted from peaceful to military uses. This monitoring is an important tool of international safeguards and helps states meet their obligations under the Nuclear Nonproliferation Treaty (NPT). Several states also use UMS to meet domestic legal and regulatory requirements for accounting for nuclear materials and operating nuclear facilities safely and securely.

There are currently over 100 UMS worldwide, with an average of 10 new systems installed per year. The primary overall goal for these systems is to never lose safeguards-significant data under even the most challenging infrastructure and operational environments.

The growing reliance on UMS and the stringent data-gathering goals demand that these systems have high reliability. Other issues for monitoring systems include the integrity of hardware and software, the interplay among worldwide vendors, the flexibility for systems upgrades, the ease of implementation and configuration, and operator training.

Introduction

The International Atomic Energy Agency (IAEA) relies heavily on the use of unattended monitoring systems (UMS) to provide continuous monitoring of nuclear facilities around the world. The states possessing these nuclear facilities permit such monitoring to allow the IAEA to confirm that nuclear material in these facilities is not being diverted from peaceful to military uses. This monitoring is an important tool of international safeguards and helps states meet their obligations under the Nuclear Nonproliferation Treaty (NPT). Several states also use UMS to meet domestic legal and regulatory requirements for accounting for nuclear materials and operating nuclear facilities safely and securely.

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The growing reliance on UMS and the stringent data-gathering goals demand that these systems have high reliability. Other issues for monitoring systems include the integrity of hardware and software, the interplay among worldwide vendors, the flexibility for systems upgrades, the ease of implementation and configuration, and operator training.

This chapter introduces current UMS as deployed by the IAEA as well as the goals, benefits, challenges, and financial issues for such systems. The UMS technologies the IAEA uses for international safeguards are always in flux as the next generation is designed, tested, and implemented. Nevertheless, the basic principles do not change.

Background

The concept of unattended monitoring systems is not new, neither in concept nor in implementation. The first example is the use of film cameras to monitor spent fuel ponds in reactors. In the 1970s, the IAEA relied on twin Minolta film cameras for this monitoring effort. The cameras had a fixed interval of 20 minutes based on the operational time for moving a spent fuel cask, and they required regular film changes. The effort to review these images was quite problematic. Black-and-white images of a spent fuel pond with very little activity and no way to advance to images of interest challenged the most astute viewer to maintain attention through the entire review of the images.

With the advent of integrated circuitry and computers, this field has seen a revolution in capability. One of the first implementations of a modern distributed UMS took place at the Darlington Candu reactor in Canada in the late 1980s. A Los Alamos National Laboratory...