

Safeguards-by-Design: Guidance for Independent Spent Fuel Dry Storage Installations (ISFSI)

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May 2012



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Guidance for
Independent Spent Fuel Dry Storage Installations
(ISFSI)**

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**Prepared for the
National Nuclear Security Administration
Office of NA-24
and for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517**

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LIST OF ACRONYMS AND ABBREVIATIONS

3DLR	(IAEA) 3-Dimensional Laser Range Finder
AFR	(IAEA) Away-from-Reactor storage facility for spent fuel, also known as an ISFSI
Amp	Amperes (electrical current)
AP	(IAEA) Additional Protocol (see also INFCIRC/540)
CANDU	Canadian Deuterium Uranium Reactor
CAPS	(IAEA) Metal cap and wire seal
cm	Centimeters
DC	Direct Current
DI	(IAEA) Design Information
DIE	(IAEA) Design Information Examination
DIQ	(IAEA) Design Information Questionnaire
DIV	(IAEA) Design Information Verification
DOE	U. S. Department of Energy
EOSS	(IAEA) Next Generation Electro-Optical Sealing System
ES	(IAEA) Environmental (Swipe) Sampling
Hz	Hertz (cycles per second)
IAEA	International Atomic Energy Agency
ID	Identification
INFCIRC/66	(IAEA) Early Safeguards Agreement (now limited to India, Israel, and Pakistan)
INFCIRC/153	(IAEA) Model Comprehensive Safeguards Agreement
INFCIRC/540	(IAEA) Model Additional Protocol
ISFSI	(U.S. DOE/NRC) Independent Spent Fuel Storage Installation, also known as AFR Storage Facility
KMP	(Nuclear material flow or inventory) Key Measurement Point
LBIMS	Laser-Based Item Monitoring System
LWR	Light Water Reactor
m	Meter
MBA	Nuclear Material Balance Area
NDA	Non-Destructive Assay
NGSI	(U.S. DOE/NNSA) Next Generation Safeguards Initiative
NGSS	(IAEA) Next Generation Surveillance System
NNSA	(U. S. DOE) National Nuclear Security Administration
NPT	Treaty on the Non-Proliferation of Nuclear Weapons

NRC	United States Nuclear Regulatory Commission
RF	Radio Frequency
RM	(IAEA) Remote Monitoring
RMSA	(Canberra) Remotely Monitored Sealing Array
SBD	(NNSA) Safeguards-by-Design
SNRI	(IAEA) Short-Notice Random Inspection
SQ	(IAEA) Significant Quantity of Fissile Material
SSAC	State System of Accounting for and Control of Nuclear Material, (a function performed by the State Regulatory Authority)
UPS	Uninterruptible Power Supply
VAC	Volts, Alternating Current

Safeguards-by-Design: Guidance for Independent Spent Fuel Dry Storage Installations (ISFSIs)

1. INTRODUCTION

Introduction and Purpose

This document is part of a series of guidance documents developed by the National Nuclear Security Administration's Next Generation Safeguards Initiative to assist facility designers and operators in implementing international Safeguards-by-Design (SBD). SBD has two main objectives: (1) to avoid costly and time-consuming redesign work or retrofits of new nuclear fuel cycle facilities and (2) to make the implementation of international safeguards more effective and efficient at such facilities. In the long term, the attainment of these goals would save industry and the International Atomic Energy Agency (IAEA) time, money, and resources — i.e. a mutually beneficial endeavor.

The purpose of the IAEA safeguards system is to provide credible assurance to the international community that nuclear material and other specified items are not diverted from peaceful nuclear uses.¹ The safeguards system consists of the IAEA's statutory authority to establish safeguards, the safeguards rights and obligations in safeguards agreements and additional protocols, and technical measures implemented pursuant to those agreements. Of foremost importance as a basis for IAEA safeguards is the international safeguards agreement between a country and the IAEA, concluded pursuant to the *Treaty on the Non-Proliferation of Nuclear Weapons* (NPT).

According to a 1992 IAEA Board of Governors decision, countries must: notify the IAEA of a decision to construct a new nuclear facility as soon as such decision is taken; provide design information on such facilities as the designs develop; and provide detailed design information based on construction plans at least 180 days prior to the start of construction and on "as-built" designs at least 180 days before the first receipt of nuclear material.² Ultimately, the design information will be captured in an IAEA Design Information Questionnaire (DIQ), prepared by the facility operator typically with the support of the facility designer. The IAEA will verify design information over the life of the project. This design information is an important IAEA safeguards tool. Since the main interlocutor with the IAEA in each country is the State Regulatory Authority/SSAC or Regional Regulatory Authority (e.g. EURATOM), the responsibility for conveying this design information to the IAEA falls to the State Regulatory Authority/SSAC.^a

For the nuclear industry to reap the benefits of SBD (i.e., avoid cost overruns and avert schedule slippages), nuclear facility designers and operators should work closely with the State Regulatory Authority as soon as a decision is taken to build a new nuclear facility. Ideally, this interaction should

^a The SSAC is the State System of Accounting for and Control of Nuclear Material, and is the national system for the accounting and control of nuclear material subject to IAEA safeguards. The State Regulatory Authority is the governmental organization responsible for overseeing implementation of nuclear regulations in the country, including IAEA safeguards. The former refers to the system and controls, while the latter is the body that oversees implementation. Often these functions are performed by the same entity in the country, but not always. For the sake of implementing Safeguards-by-Design in this discussion, the national stakeholder is the State Regulatory Authority.

begin during the conceptual design phase and continue throughout construction and start-up of a nuclear facility. Such early coordination and planning could influence decisions on, for example, the chemical processing flow-sheet and design, the material storage and handling arrangements, and the facility layout. Communication among the designer, operator, SRA, and IAEA should be frequent and interactive throughout facility design, construction, and start-up. This dialog will help to more effectively and efficiently incorporate IAEA safeguards into the design of nuclear facilities and to minimize misunderstandings that could arise from misinterpretation of the safeguards input and guidance.

Background

In the absence of a national long-term spent fuel repository, spent nuclear fuel is being moved to ISFSIs and AFR storage for the interim. These are designed to provide safe storage for decades, until the fuel is either reprocessed or entombed in a long-term repository. Interim storage options include wet storage in pools, dry storage in designed casks and vaults, or storage in mines or tunnels. According to the NRC, the dry storage of spent fuel at reactor sites in specially designed casks and vaults is safe for at least 100 years, and is generally safer than pool storage.³ Deep mines and tunnels are generally being considered for long-term storage. Consequently, this document focuses on safeguards-by-design for ISFSIs using dry storage.

In the United States alone, there are 55 licensed ISFSIs using dry storage, with more planned for construction, making this the fastest growing type of nuclear facility in the country.⁴ Although the ISFSI may be collocated at the nuclear power plant site, it is typically outside of the reactor nuclear material balance area (MBA) and often considered by the IAEA and the State Regulatory Authority to be a separate facility. Regional or national ISFSIs are also being considered for interim storage in the absence of a national long-term spent fuel repository. Additional information regarding the design and selection of ISFSIs can be found in the IAEA technical document *Selection of Away-from-Reactor Facilities for the Storage of Spent Fuel Storage – A Guide Book*, IAEA-TECDOC-1558.⁵ Points in this regard have also been issued by the US NRC in 2011 in their *Fact Sheet on Dry Cask Storage of Spent Nuclear Fuel*.⁴ Examples of typical vertical and horizontal spent fuel dry storage casks or vaults used at ISFSIs are shown in Figures-1, 2, and 3, and a list of the major types of spent fuel storage casks and vaults is shown in Table-1.

The reader should be mindful that IAEA nuclear safeguards measures and equipment evolve over time. Best practices are also continuously being improved by the IAEA and facility operator to be more efficient and cost effective.

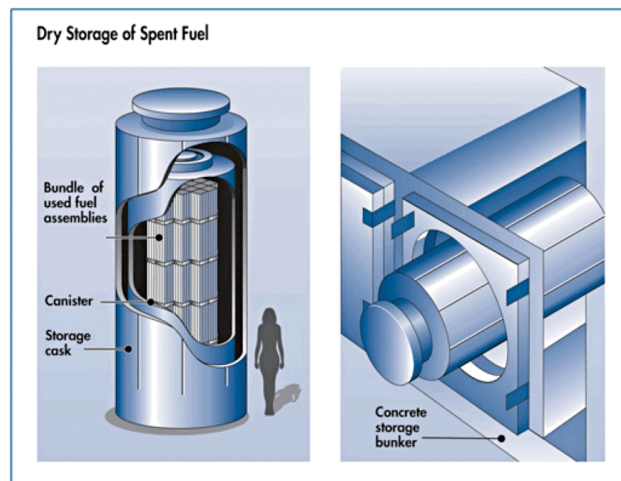


Figure-1: Vertical and Horizontal Dry Storage of Spent Fuel

(Source – U.S. Nuclear Regulatory Commission, 2011)



Figure-2: ISFSI with Vertical Spent Fuel Storage/Transfer Casks
(Source – U.S. Nuclear Regulatory Commission Library, 2011)



Figure-3: ISFSI with Horizontal Spent Fuel Storage Vault
(Source - SFEN Jeune Génération, 2009)

**Table-1: Types of
Independent Spent Fuel Storage Installations
(AFR Storage Facilities)**

(Source: IAEA-TECDOC-1558, *Selection of Away-from-Reactor Facilities for Spent Fuel Storage*, Table-2, 2007;
as modified by DNE, 2011)

Item	Type of Storage (ISFSI/AFR Facility)	Containment & Shielding	Features	Notes
1	Independent Spent Fuel Storage Pool (Wet Storage of Spent Fuel)	Water in a deep stainless steel lined concrete pool within an enclosed structure	Traditionally used for expanded storage of spent fuel	Many examples worldwide; Current trends are towards dry rather than wet storage, for reasons of reduced maintenance (water management) and improved safety and security.
2	Vertical Dual-Purpose Spent Fuel Dry Storage/Transfer Cask	Heavily shielded steel cask with spent fuel sealed in inner steel canister (i.e. double-lidded)	Vertical, dual purpose, dry spent fuel storage and transfer cask	Examples: CASTOR, TN NAC-ST/STC BGN Solutions
3	Vertical Concrete Dry Spent Fuel Storage Cask/Silo	Heavily shielded concrete cask/silo with spent fuel sealed in an inner steel canister	Vertical, dry spent fuel storage cask/silo	Examples: CONSTOR HI-STORM
4	Horizontal Modular Concrete Dry Spent Fuel Storage	Heavily shielded modular concrete storage with spent fuel sealed in an inner steel canister	Horizontal, modular dry spent fuel storage vault	Examples: NUHOHMS NAC-MPC/UMS MAGNASTOR
5	Concrete Dry Storage Vault with Thimble Tube Storage Wells	Heavily shielded concrete vault with thimble tube storage wells for spent fuel	Vertical, dry spent fuel or vitrified waste storage vault with thimble tube storage wells	Examples: MVDS MACSTOR
6	Dry Geologic Storage (Tunnel or Mine)	Dry gas-filled spent fuel canisters emplaced in an isolated deep tunnel or mine and backfilled with earth	Dry spent fuel storage in tunnel or mine; vertical or horizontal fuel orientation	Example: Olkiluoto NPP Spent Fuel Repository (Onkalo) ⁶

2. IAEA SAFEGUARDS

The basis for IAEA safeguards is the international safeguards agreement between the country and the International Atomic Energy Agency (IAEA), concluded pursuant to the *Treaty on the Non-Proliferation of Nuclear Weapons* (NPT). The NPT requires each Non-Nuclear-Weapon State, party to the NPT, to conclude a comprehensive safeguards agreement with the IAEA. IAEA document INFCIRC/153 (corrected), *The Structure and Content of Agreements between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons*, is the basis for comprehensive safeguards agreements (CSA) in connection with the NPT. A State may also conclude an additional protocol (AP) to its safeguards agreement, which requires the State to provide broader information and IAEA access to locations related to its nuclear fuel cycle beyond that provided by its CSA.

The objective of international nuclear safeguards is the timely detection of the diversion of significant quantities of nuclear material from peaceful to non-peaceful uses, and the deterrence of such by the risk of early detection.⁷ In addition, the IAEA must detect any potential misuse of the facility for undeclared purposes (i.e. undeclared receipt, transfer, shipment, or removal of spent nuclear fuel). To summarize, the IAEA safeguards objectives common to all states with a comprehensive safeguards agreement and AP are to detect:

- Diversion of declared nuclear material at facilities and locations outside facilities (LOFs)
- Undeclared production or processing of nuclear material at facilities and LOFs
- Undeclared nuclear material and activities anywhere in the State.

The IAEA is currently in transition, moving towards a state-level safeguards approach, and will rely less on facility-centric safeguards criteria in the future. In the interim, the safeguards goals summarized below will continue to define key elements of that approach and the safeguards tools and measures the IAEA may apply. Relevant safeguards goals are cited from the IAEA Safeguards Criteria for inspecting “Storage Facilities,” found in the IAEA *Safeguards Manual* and relevant annexes.^{8,9}

Safeguards Detection Goals

The specific IAEA safeguards detection goals, relevant to ISFSIs, are:

- Detect the diversion of 8 kg of plutonium in the form of spent fuel within three months of possible diversion.
- Detect the diversion of 8 kg of U-233 in the form of spent fuel within three months of possible diversion.
- Detect the diversion of 75 kg of U-235 in the form of spent low-enriched fuel within one year of possible diversion.
- Detect the diversion of 20 tonnes of thorium in the form of spent fuel within one year of possible diversion.
- Detect possible misuse of the facility for undeclared nuclear activities (e.g. use of an ISFSI as a temporary store for undeclared movements of nuclear fuel.)

Traditional vs. Integrated Safeguards

The over-arching goals of traditional (facility-level) nuclear safeguards and integrated safeguards are as noted above. In general, these same goals apply under integrated safeguards. The IAEA defines integrated safeguards as the “optimum combination of all safeguards measures available to the IAEA under comprehensive safeguards agreements and additional protocols to achieve maximum effectiveness

and efficiency in meeting the IAEA's safeguards obligations within available resources."¹⁰ More will be said about the typical safeguards strategy for ISFSIs in the following sections.

A key distinction regarding integrated safeguards is that it is applied to the country as a whole. Traditional IAEA safeguards were applied at the level of the facility. However, the goal of detecting the diversion of significant quantities of nuclear material or misuse of the facility remains relevant, as well as the material goal quantities. If an ISFSI were under integrated safeguards, additional measures such as the use of remotely monitored safeguards equipment, satellite imagery, and/or short-notice random inspections could enable a reduction in the frequency and number of on-site inspections. This is an example of achieving maximum effectiveness as well as efficiency.

In terms of design, the facility must accommodate IAEA safeguards equipment (e.g. seals, surveillance, and/or radiation detection systems), regardless of whether the ISFSI is under traditional (facility-level) or integrated safeguards. As the ISFSI is being designed and constructed, the facility operator, State Regulatory Authority, and IAEA should also discuss whether the ISFSI will need to accommodate other measures, such as the remote monitoring of safeguards equipment.

Safeguards Responsibilities

Engagement and dialog between the facility operator, the facility designer, the State Regulatory Authority, and the IAEA should begin early in the design process to ensure that IAEA safeguards goals can be efficiently and effectively met. The proposed timing for the engagement of the stakeholders in the case of a model design and construction project is described in more detail in the reference noted.¹¹

In the author's view, the responsibilities for implementing safeguards are:

- **Facility Designer:** Design the facility, per the requirements of the facility owner and operator (customer) to meet the specified operational objectives, and to be compliant with relevant national and international regulations, requirements, and guidelines. These include, but are not limited to nuclear safety, security, and safeguards regulations, requirements, and guidelines. The facility designer should design the facility in a manner that accommodates IAEA safeguards equipment and systems, facilitates design verification for safeguards purposes, and facilitates implementation of IAEA inspector activities during construction, operation, and decommissioning of the facility.
- **Facility Operator:** Operate the nuclear facility, for the purposes as declared to the State Regulatory Authority, in accordance with relevant national and international regulations, requirements, and guidelines. The facility operator prepares the construction specifications for the facility, which include specifications for implementing effective nuclear safeguards and providing space and utilities for nuclear safeguards equipment and measures. The facility operator hosts IAEA inspections and must operate the facility in the manner declared to the IAEA.
- **State Regulatory Authority:** Oversee the implementation of national (domestic) nuclear regulations within the country, particularly those pertaining to nuclear safety, security, and safeguards. Ensure effective accounting, control, and regulated use of nuclear material within the country and liaise with the IAEA to ensure the effective implementation of international nuclear safeguards, as per the safeguards agreement between the country and the IAEA. Dialog and engagement with the IAEA is coordinated through the State Regulatory Authority/SSAC.
- **IAEA:** Verify that the country is upholding its international safeguards agreement with the IAEA, concluded pursuant to the NPT. The IAEA Department of Safeguards uses the safeguards measures available to ensure that significant quantities of nuclear material have not been diverted from peaceful to non-peaceful uses within the defined timeliness goal for detection, and uses the risk of early detection to minimize the threat of diversion.

3. ELEMENTS OF DESIGN RELEVANT TO SAFEGUARDS

Spent Fuel Handling, Transfer, and Storage – An Overview

The spent fuel handling, transfer, and storage process is of fundamental importance to safeguarding the facility. The predominant and simplest case is the use of spent fuel transfer casks, which can also be used for storage, i.e. spent fuel transfer/storage casks. In this case, the ISFSI receives the spent fuel in the transfer/storage cask from the reactor, stores the fuel in the same cask for an interim period, and ships the spent fuel transfer/storage cask to a reprocessing plant or long-term storage repository at some point in the future.

A slightly more complicated case is the use of separate transfer and storage casks, in which transfer casks are received at the ISFSI, the canned spent fuel off-loaded to a separate storage cask or vault for interim storage, and the transfer cask reused. This is more complex than the first case, with canned spent fuel cask loading and unloading operations occurring upon receipt, and then again during shipping off-site.

A third case involves the use of a spent fuel conditioning hot cell or facility. In this case, the spent fuel would be reduced in volume by removing the spent fuel rods from the assembly or by cutting the fuel assembly. These processes have been used experimentally, but tend to be unattractive because of the potential release of gaseous and particulate fission products in the process of reducing the volume of the fuel. In this case, the spent fuel conditioning hot cell is typically collocated at the shipping reactor or is defined as a standalone hot-cell facility. As such, the relevant safeguards issues would be addressed under the associated facility type (i.e. Reactor or Hot-Cell Safeguards Guidance Document). Because the spent fuel is actually disassembled in this case, there would need to be more stringent safeguards measures and a more elaborate safeguards approach to verify that spent fuel has not been removed in portions or pieces. The point of the discussion is to make the facility designer aware that nuclear safeguards apply to the ISFSI (where the spent fuel is stored) as well as the facility involved in the spent fuel handling process (i.e. the spent fuel conditioning or packaging hot-cell).

Nuclear Material Balance Areas and Key Measurement Points

In the implementation of international safeguards, nuclear material accountancy is the safeguards measure of fundamental importance with containment and surveillance (seal, surveillance, and radiation detection systems) as important complementary measures. Simply stated, nuclear material accountancy is the accounting and control of the nuclear material inventory, and related inventory changes, with independent verification by the IAEA.

In order to account for the nuclear material inventory and associated changes, the facility operator defines a nuclear material balance area (MBA), in consultation with the IAEA. Typically each ISFSI would be defined as a separate and distinct MBA, although a very large regional ISFSI could be subdivided into multiple MBAs to facilitate accounting. The facility owner/operator and designer propose the MBA layout and structure to the State Regulatory Authority. In this regard, an MBA layout diagram should be prepared by the facility designer at the earliest design stage, because it allows them to visualize the over-arching issues regarding safeguarding of the nuclear material, i.e. where is the nuclear material stored, inventoried, and where could the transfers be verified. It is advisable to involve the IAEA in these discussions at an early stage, since the layout of the MBA and associated key measurement points (KMPs) impacts the implementation of nuclear safeguards.

The inventory KMP is where the nuclear material would be stored and made accessible for inventorying and verification by the facility operator, State Regulatory Authority (if required), and IAEA. The inventory flow KMPs, which are numbered and denoted by diamonds (in the following diagram), are positioned to verify the inventory changes or transfers.

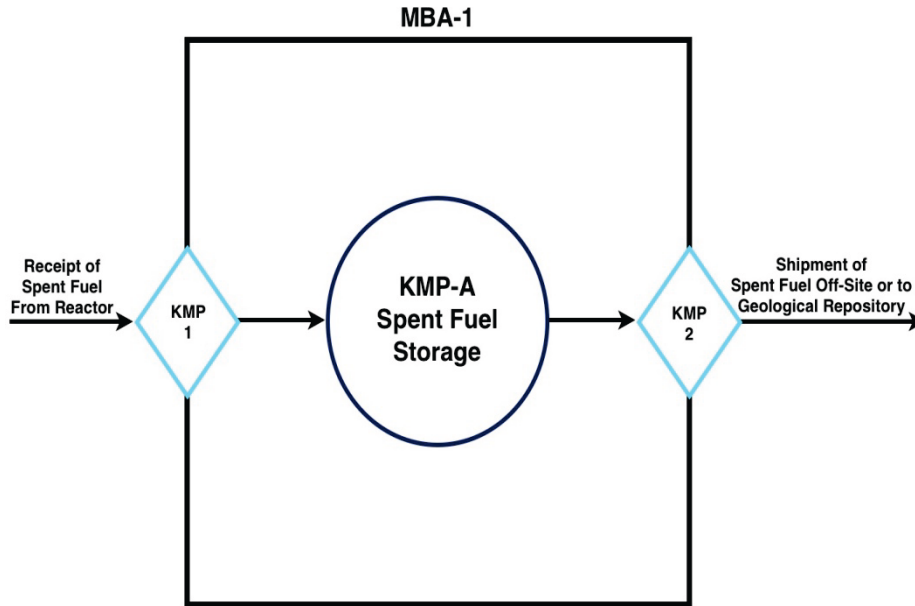


Figure-4: Typical Material Balance Area (MBA) Layout and Key Measurement Points (KMPs) for an ISFSI

(Source – DNE/INL, 2011)

The example above shows the most basic MBA layout diagram for a typical ISFSI. There is one inventory KMP, KMP-A, where the nuclear material would be stored. It does not matter if the spent fuel storage is in dry vertical casks, horizontal casks, or modular vaults. In the simplest case, there would be one nuclear material transfer path into the MBA, flow KMP-1, and one transfer path out, KMP-2. The MBA layout diagram indicates the spent fuel receipts would be verified, or checked at KMP-1, prior to storage. It also indicates that if the spent fuel were shipped from the ISFSI, such as to a long-term geologic repository, the spent fuel would be verified during shipment at KMP-2. The safeguards verification measures that the IAEA would typically use to verify the spent nuclear fuel inventory, receipts, and shipments will be discussed in more detail below.

Safeguards Strategy and Possible Diversion Scenarios

The development of the “Safeguards Approach” for the particular facility in the official sense is the strict purview of the IAEA. However, in order to implement safeguard-by-design, the facility designer must anticipate where the nuclear material could be removed and diverted from the facility being designed. This should not be viewed as doing the work of the IAEA. Merely, it helps prepare the facility designer for subsequent discussions with the IAEA on this subject.

In the simplest case noted above for an ISFSI, spent nuclear fuel comes into the facility in a transfer cask moved by a purpose built carrier and is placed in a designated location in the storage array, either in vertical or horizontal storage as shown in Fig. 1, 2, and 3. In this example, the most likely diversion scenarios are:

1. Diversion of spent fuel prior to transfer to the ISFSI
2. Diversion of spent fuel during transfer to the ISFSI
3. Diversion of spent fuel from storage at the ISFSI
4. Diversion of spent fuel during shipment from the ISFSI

A quick sketch of the typical safeguards strategy is presented to discuss the safeguards relevant design elements or features. The safeguards strategy and approach will be discussed in more detail in the next section. The following discussion is not meant to state exactly how the IAEA will safeguard the ISFSI. It is merely meant as an aid to the facility designer to help them understand the kind of safeguards measures and equipment that the facility design will need to accommodate.

To address Scenario-1, the IAEA would typically verify the spent nuclear fuel prior to, or during loading of the spent fuel, most likely at the nuclear reactor spent fuel pool where the fuel is being loaded. To address Scenario-2, the IAEA would typically observe the spent fuel as it is being moved from the shipping facility to the ISFSI. This may be by direct observation by a safeguards inspector. Alternatively, the shipping cask may be sealed by the IAEA prior to the transfer. In the latter case, the IAEA would verify that the seals had not been tampered with as the cask is being moved to the final storage location. To address Scenario-3, the IAEA would typically use containment and surveillance measures (seals and surveillance systems) to ensure that the spent fuel has not been removed from storage. To avoid the difficult re-verification of spent fuel in dry-storage, dual independent seal, surveillance and/or radiation detection systems (or a combination) would typically be utilized. If one system failed, the other should provide assurance that the spent nuclear fuel has not been accessed or removed without being detected. To address Scenario-4, the IAEA would typically verify the seal, surveillance, and radiation detection systems, covering the spent fuel being shipped, to ensure that it had not been removed. If the casks are sealed and shipped to the new location, the seal would be verified upon receipt at the new location. Similarly, the shipment to the new location may be directly observed by a safeguards inspector.

Regarding potential facility misuse, the primary misuse scenario is:

1. Use of the spent fuel storage casks to store spent fuel not previously declared by the facility operator.

To address this misuse scenario, the IAEA would verify that only the storage casks in the ISFSI declared to contain spent nuclear fuel actually have spent nuclear fuel. They would also verify that all movements of containers to and from the ISFSI are as per the facility operator's declaration and are consistent with the declared inventory of storage of spent fuel at the ISFSI. How the IAEA might verify spent fuel storage casks declared to be empty is still being discussed. The simplest case would be to remove the lid of randomly selected empty casks. Non-destructive assay (NDA) equipment is also being developed, which would allow the IAEA to verify that the cask is empty or not without lifting the lid. This will be discussed later in more detail.

Design Features Relevant to Safeguards

From the foregoing discussion, the ISFSI and associated spent fuel transfer and storage casks or vaults, should be designed to accommodate the following:

- Use of IAEA dual sealing systems
- Use of IAEA surveillance systems
- Use of IAEA radiation detectors (e.g. for spent fuel receipts from CANDU reactors)
- Possible remote monitoring and transmission of data from IAEA seal, surveillance, and radiation detection systems
- Safe engineered access to the spent fuel storage casks
- Use of emerging safeguards measures

If the IAEA plans to use sealing systems, then the spent fuel storage casks or vaults will need to be designed to accommodate IAEA seals. The requirements for the common IAEA sealing systems are noted in Section-5. Similarly, the space and utility requirements for the most common IAEA surveillance

systems and radiation detectors are also noted in Section-5. The arrangement and location of the IAEA surveillance systems (if used) would need to be discussed in advance between the facility operator, designer, State Regulatory Authority, and the IAEA. This would ensure that when the IAEA surveillance systems are installed, they will have the requisite space and utilities. In locating the surveillance cameras or radiation detectors, the IAEA will design the systems to have overlapping coverage. However, it is important that the design of the storage cask or vault array not be so dense as to preclude effective surveillance and monitoring. Similarly, surveillance and monitoring of the spent fuel transfer/storage cask entry and exit locations should not be blocked.

Whether the IAEA plans to remotely monitor the seal, surveillance, and/or radiation detection systems should be discussed. If this is the case, a connection should be provided to permit remote transmission of the data. However, the means of encrypted and secured data transmission is rapidly evolving. It is best to confirm these requirements directly with the IAEA at the time the ISFSI is being designed and constructed. Safe engineered access for inspectors is not a trivial requirement, since most ISFSI are designed to minimize storage area and maximize the density of spent fuel storage. In the simplest case, the IAEA would need engineered ladders and platforms to access the lid of the spent fuel storage casks or vaults to confirm the cask ID, service the seals, and re-verify the spent fuel in the casks. For this purpose it may be possible to use conventional rolling platforms and ladders, provided they can accommodate the personnel and equipment used in performing and observing the activity (i.e. typically an IAEA safeguards inspector, facility operator, facility health physicist, and representative from the State Regulatory Authority).

The use of emerging safeguards measures may not be required in the near term, i.e. the use of dual seal, surveillance, and/or radiation detection systems should suffice. However, as ISFSIs become very large, it may be desirable to use other safeguards measures to augment or replace existing safeguards systems. The following emerging measures may be considered in the future:

- Embedded electronic monitoring and tracking of spent fuel transfer and storage casks or vaults (i.e. “smart” casks).
- Enhanced remote monitoring of storage casks and status of the spent fuel in storage (i.e. radiation profile, lid opened/closed, cask movement, etc. (This data is additional to the seal and surveillance data that has been typically transmitted remotely and would provide more comprehensive knowledge regarding the status of the spent fuel in storage.)
- Over-head satellite imagery
- Localized seismic sensors, and possible remote transmission of this data
- NDA equipment for the re-verification of spent fuel in dry-storage casks

The point of this is not to concern the facility designer with safeguards equipment yet to be developed. It is just a note that as the storage facility grows in size, from dozens to hundreds of spent fuel storage casks, more efficient measures may be developed to ensure that the spent fuel is not being accessed or removed. It is in the interest of the facility designer to be aware of these trends. See the Appendix for more details regarding emerging technologies relevant to safeguarding an ISFSI.

4. KEY ELEMENTS OF SAFEGUARDS STRATEGY/APPROACH

The typical safeguards strategy implemented at an ISFSI has been outlined, but is described now in more detail below. The strategy focuses on accounting for the receipts, inventory, and shipments of spent nuclear fuel. Containment and surveillance measures (seals and video surveillance systems) are used to maintain the continuity of knowledge regarding the spent fuel transferred and held in storage. Because the re-verification of spent fuel in dry-storage is very challenging, the IAEA tends to use dual containment

and/or surveillance measures, i.e. two different types of seal or surveillance systems without a common mode of failure. To date, the IAEA has relied heavily on sealing systems, as these are generally easy to apply, easy to service, and easy to evaluate for tampering. However, as the number of spent fuel storage casks increases, the IAEA has the option to use video surveillance in addition to seals.

Nuclear Material Accountancy

The IAEA verifies the facility operating and accounting records, reports submitted by the State Regulatory Authority, and source documents at the facility, regarding the inventory of spent nuclear fuel stored at the ISFSI and associated inventory changes. The inspector verifies that the spent fuel receipts, inventory, and shipments are as declared by the facility operator. This activity typically takes place in an available office at or near the ISFSI. Associated field inspection activities are described below.

Verification of Spent Fuel Receipts

Spent nuclear fuel is typically verified at the nuclear reactor in the spent fuel pool, prior to being shipped to the ISFSI. If it is verified in this manner, the spent fuel transfer cask may be sealed. Consequently, the spent fuel transfer cask must accommodate the IAEA sealing system. The cask may also be left unsealed, if the safeguards inspector witnesses the transfer of the cask to the ISFSI. At the ISFSI, the spent fuel is stored in the final position in a combined spent fuel transfer/storage cask or is removed from the transfer cask to the final storage cask or vault position. This activity is observed directly by the IAEA inspector, or monitored by the IAEA surveillance and/or radiation detection system, to ensure that spent fuel is not removed from the facility. The number of casks, ID of the casks transferred, and final locations are confirmed by the inspector to be as declared by the facility operator.

Verification of Spent Fuel Inventory

Effective containment and surveillance measures (seals and/or video surveillance systems) are used to detect the undeclared removal or movement of stored spent nuclear fuel. Seals are randomly replaced by the inspector to detect potential tampering. If used, video surveillance systems are reviewed to verify that the receipts, shipments, and movements of spent fuel transfer/storage casks are as declared by the facility operator. Generally, the spent fuel in storage would be classified by the IAEA as “difficult to access,” because the fuel is typically stored inside a helium-filled inner container within the storage cask and welded shut. Consequently, opening and re-verification of the fuel is not normally permitted by the facility operator, for safety reasons. As long as the containment and surveillance systems do not both fail or indicate tampering, there would normally be no need to re-verify the spent fuel in storage. In the event the dual containment systems fail, the Compton Dry-Cask Imaging System may be used to re-verify the spent fuel in situ. This system is described in more detail in Section-5.

Verification of Spent Fuel Shipments

Seals and/or video surveillance systems are used to detect the undeclared removal or shipment of stored spent nuclear fuel. If a spent fuel shipment from the ISFSI occurs, the shipment would typically be verified at the receiving location. Seals are randomly inspected or replaced by the inspector to detect potential tampering of the stored fuel at the receiving location. If used, video surveillance systems are reviewed to verify that the receipts, shipments, and movements of spent fuel transfer/storage casks are as declared by the facility operator. If the seal and surveillance systems covering the spent fuel shipment fail or indicate potential tampering, the spent fuel would need to be re-verified as noted above. This could potentially be done with the aforementioned Compton Dry-Cask Imaging System.

Detection of Potential Facility Misuse (Including Undeclared Activities)

In addition to the use of seals and/or video surveillance just described, the inspector may also randomly inspect spent fuel transfer/storage casks declared to be empty to ensure that they are not being misused for the undeclared storage of spent nuclear fuel. How this is to be done is still an issue to be resolved by the IAEA. The simplest scheme would be to randomly open spent fuel transfer/storage casks

that are declared to be empty. However, it is recognized that the transfer/storage casks are designed to provide heavy shielding against highly radioactive spent fuel. Consequently, a safe process and procedure for verifying the empty status of spent fuel transfer/storage casks is being addressed by the IAEA. Alternatively, the IAEA may collect localized environmental samples. These samples could potentially detect the undeclared storage of spent fuel, if the spent fuel is irradiated short-term, i.e. has different isotopics from typical spent fuel.

Detection of Nuclear Material Borrowing

Nuclear material borrowing is the undeclared borrowing or exchange of similar nuclear material between facilities in the country in an effort to misrepresent the available nuclear material inventory, and consequently, deceive the IAEA. The IAEA would use the aforementioned seal and/or surveillance systems to detect the undeclared removal or “borrowing” of spent fuel. They could also conduct inspections at the ISFSI, simultaneously with other facilities in the country that could share or swap spent nuclear fuel.

Verification of Facility Design Information

Over the life of a nuclear facility, the IAEA examines and verifies the facility design information, relevant to nuclear safeguards. This activity is called design information examination and verification (DIE/DIV) by the IAEA. The inspector uses the information provided by the facility operator in the IAEA Design Information Questionnaire (DIQ), which would typically include the following drawings and design information:

- Facility MBA diagram, showing the nuclear material transfer paths and KMPs
- Process description, showing how the spent fuel is conditioned and packaged prior to being transferred and stored at the ISFSI
- Design of the spent fuel transfer cask and handling system, showing the spent fuel capacity per transfer cask
- Design of the spent fuel storage casks or vaults, showing the spent fuel storage capacity per storage cask or vault
- Equipment layout of the ISFSI, showing the dimensions and spacing of transfer/storage casks, vaults, and handling equipment
- Other drawings and information, deemed necessary by the IAEA for safeguarding the facility

The safeguards inspector would inspect the ISFSI to ensure that it has been designed and constructed as declared, i.e. that there are no concealed locations for the storage or transfer of spent nuclear fuel. To accomplish this, the inspector typically uses hand-tools and instruments. However, they may also use the IAEA 3D Laser Range Finder (3DLR). This is a modified laser-based survey instrument that allows the inspector to measure and confirm the construction and dimensions of large or complex facilities. More will be said about this instrument in Section-5. The safeguards inspector performs DIE/DIV at the facility, while it is being built, and periodically during operation, until it is officially shutdown and decommissioned (from the safeguards standpoint).

5. SAFEGUARDS BEST PRACTICES RELEVANT TO THE DESIGN

There are a number of safeguards related considerations that the designer of an ISFSI should take into account when designing the facility. The points below reflect this current state-of-the art, which is continuously evolving. The facility designer and operator should also raise these details with the State

Regulatory Authority and the IAEA during the design of an ISFSI to become aware of other relevant trends.

Layout Requirements

An idealized layout of the safeguards equipment for a typical ISFSI is shown in the figure below. This figure is intended merely as an example for illustration. The actual IAEA safeguards equipment and associated layout would be determined by the IAEA, in consultation with the facility operator and State Regulatory Authority. If a video surveillance or radiation detection system is used that requires a data collection cabinet, the cabinet should be installed in an enclosure near the ISFSI if the ISFSI is subject to extreme weather or dust conditions. The space and utilities required for each system are discussed further below. More detailed specifications regarding the safeguards equipment layout can be provided by the IAEA.

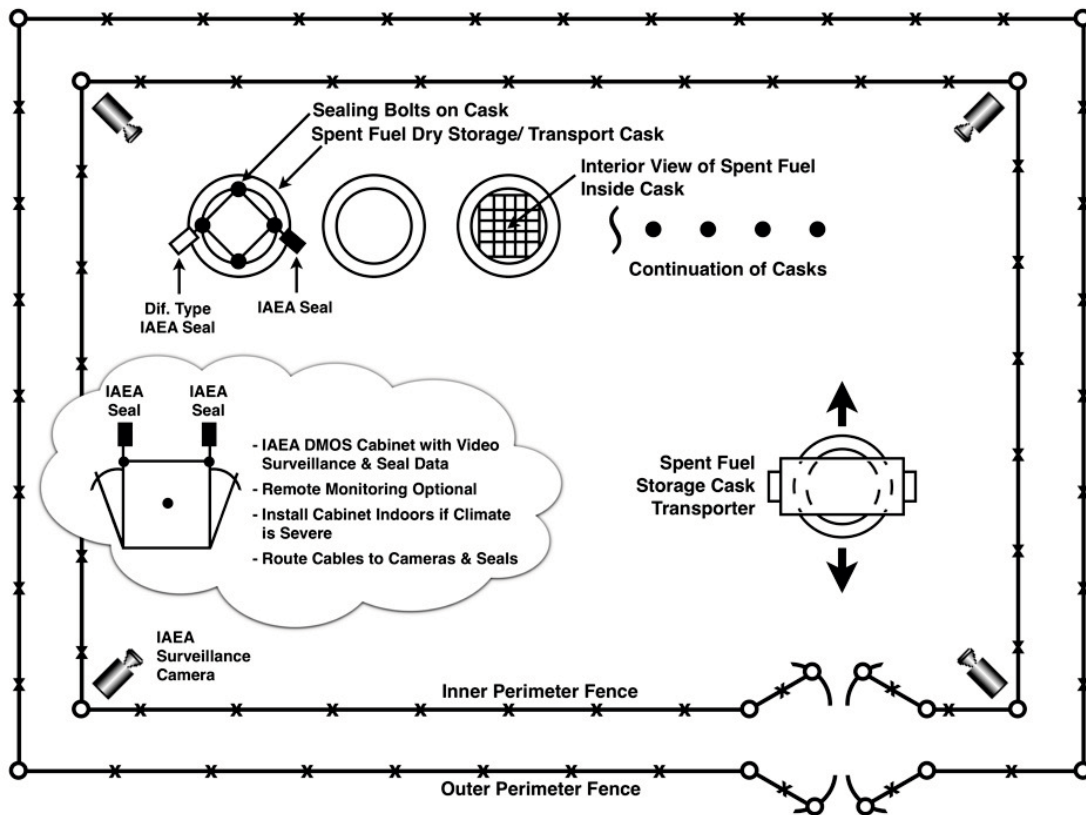


Figure-5: Typical Layout of IAEA Safeguards Equipment for an ISFSI
(Source – Durst Nuclear Engineering and Consulting Inc., 2011)

Regarding the equipment layout, it is important for the facility designer to recognize that the aforementioned equipment is for IAEA safeguards. The facility operator will require separate systems for security and physical protection, such as their own dedicated surveillance camera system, motion sensors, and double-perimeter fencing. The facility operator's systems are not addressed by this safeguards guidance document, although the final ISFSI layout design will need to accommodate both.

The space and layout requirements for typical IAEA safeguards equipment are as follows: IAEA seals are typically secured to the bolts at the lid of spent fuel transfer/storage casks and vaults and require 0.5 m² for servicing the seal. If surveillance systems are used, they require 1 m² per installed camera with a clear field of view of the safeguards area of interest. Safe engineered access must be provided to service

the seals on the spent fuel storage casks or vaults, and to service the surveillance cameras. If multiple cameras are utilized, a data collection cabinet may be used, requiring 3 m² per cabinet, with safe engineered access to the front and back doors of the cabinet. If radiation detectors are used, the space and layout requirements are comparable to the requirements stated for the surveillance cameras.

If the IAEA plans to use a spent fuel verification system, such as the Compton Dry-Cask Imaging System, additional space must be provided on top of the vertical spent fuel storage casks or vaults for using the system. If the IAEA plans to use the 3DLR for performing DIE/DIV, adequate space (4 m²) must be provided for using the 3DLR at the corners of the ISFSI. A 1-meter wide safe shielded path must be provided to move the 3DLR around the array of spent fuel storage casks.

Office Space

The IAEA needs to use an office near the ISFSI for performing a review of the operating and accounting records, source documents and state reports. The inspector could use a room temporarily made available by the facility operator. The review of these documents is infrequent and is performed at the time of field inspections by the IAEA inspector. The office should be protected from the elements and have convenient electrical power outlets for the inspector's laptop computer and peripheral equipment. The office space should be 16 m² or greater.

Sealing Systems

The IAEA uses sealing systems as tamper indicators on spent fuel transfer and storage casks and vaults at ISFSIs. Typically two different types of sealing systems are used in case one system fails. Ideally, the sealing systems should not have a common failure mode. The seals most commonly used currently are the metal cap seal and the variable-coded fiber optic seal (VACOS), which are shown in the figure below.¹² The next generation electro-optical sealing system (EOSS) is currently being field tested and is likely to become the IAEA's standard sealing system in the next 5 years.^{13, 14}

To use these seals, the spent fuel transfer and storage casks must be designed to accommodate the sealing system at the cask lid. More detailed size specifications for the particular sealing system can be provided by the IAEA. Verification that the cask lid and attaching bolts can accommodate IAEA seals should be specified as part of cask selection and procurement. In the past, facility operators have designed mechanical protection (e.g. metal covers and sleeves) to protect IAEA seals and cables, to minimize the risk of inadvertently damaging the seal during routine operation of the facility.

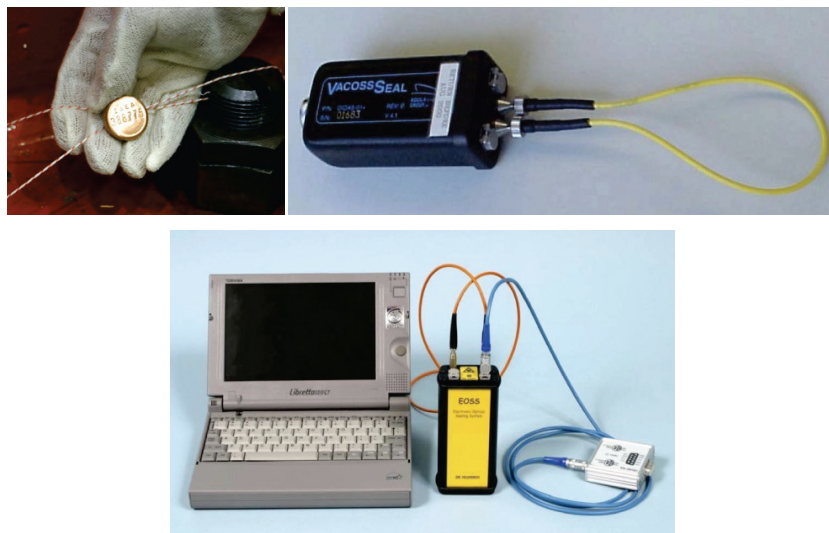


Figure-6: IAEA Sealing Systems – Cap Seal (left), VACOS (right), and EOSS (bottom center)
(Source – IAEA, 2007)

Surveillance Systems

The IAEA may use video surveillance systems in addition to seals, especially if the array of stored spent fuel transfer/storage casks or vaults is very large. In this regard, the cameras must have a clear field of view of all of the spent fuel storage casks and vaults, as well as the ISFSI entries and exits. Camera placement is determined by the IAEA, in consultation with the facility operator and the State Regulatory Authority.

The IAEA currently fields a variety of surveillance systems. However, in the near future the next generation surveillance system (NGSS) will become the IAEA standard.¹⁵ The NGSS and associated camera in a tamper proof enclosure are shown in the figure below. If a multiple camera system is used, then a data collection cabinet will likely be required as shown. This cabinet contains a computer server for storing the digital surveillance data and peripherals. Consequently, it should be located in an area that is not subject to extreme weather or dust conditions. In those cases, the cabinet should be located in a nearby structure or out-building. The designer should note that the facility operator's surveillance system for security and physical protection is separate and distinct from the IAEA safeguards surveillance system. Each camera unit requires approximately 1 m² of space with a clear field of view covering the safeguards area of interest. The data collection cabinet requires 3 m² per cabinet. More detailed specifications for the particular surveillance system can be provided by the IAEA.

If a surveillance system is required, it should be installed on a facility emergency power circuit and/or be powered by an IAEA un-interruptible power system (UPS). Cabling that is used for the IAEA seal and surveillance systems is tamper resistant and must be provided by the IAEA, especially the cabling that interconnects the cameras and seals to the data collection cabinet. The IAEA can provide more detailed specifications regarding these upon request.

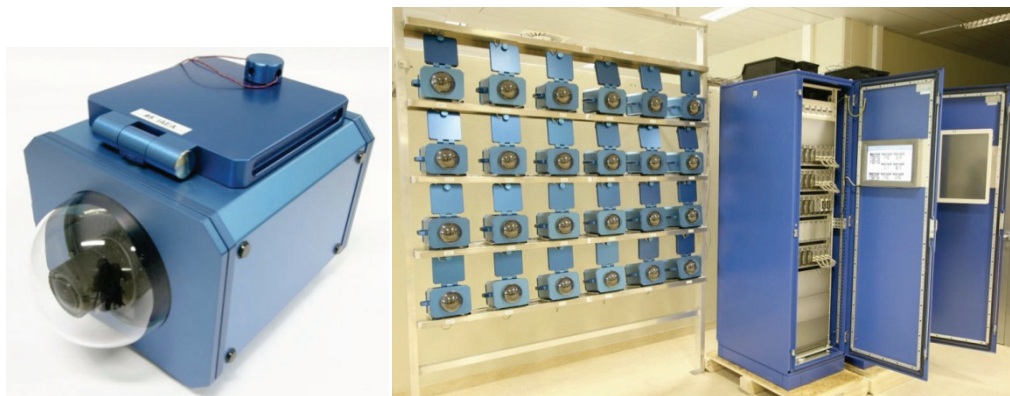


Figure-7: IAEA Next Generation Surveillance Camera and System

(Source – IAEA, 2010)

Radiation Detection Systems

In the case of CANDU and other on-load refueled reactors, the IAEA may use installed gamma radiation detectors, instead of direct inspector observation, to verify the receipts of spent fuel at the ISFSI over a period of several weeks. It is important that the vaults for storing spent CANDU fuel have channels to permit the installation and removal of the gamma detectors. In the past, the external free-convective cooling channels in spent CANDU fuel storage vaults accommodated the gamma detectors and probes. More detailed specifications regarding radiation detectors and associated equipment can be provided by the IAEA.

Remote Monitoring

To reduce the number of field inspections and for greater efficiency, the IAEA may propose to remotely transmit the safeguards seal, surveillance, and/or radiation detector information to a nearby IAEA regional office or to IAEA HQ in Vienna, Austria. The use of remote monitoring requires modification to the safeguards system, additional cabling, and a suitable connection for data transmission. The potential use of remote monitoring by the IAEA should be discussed between the facility operator, State Regulatory Authority, and IAEA early in the design of the ISFSI. The remote transmission of encrypted safeguards data is subject to the approval of the IAEA, facility operator, and State Regulatory Authority. The mode for the remote transmission of safeguards data is rapidly evolving and has varied greatly in just the last few years. More detailed specifications regarding the remote monitoring scheme and equipment can be provided by the IAEA.

Equipment for Re-verifying Spent Fuel in Storage

As previously noted, equipment for verifying spent fuel in dry-storage is being developed. One such system is the Compton Dry-Cask Imaging System, shown in the figure below, which has been developed for verifying spent LWR fuel in vertical dry storage casks. ¹⁶ The system requires the use of a universal mounting fixture, which the IAEA provides for the verification activity. A comparable system is being developed for verifying spent fuel in horizontal storage. More detailed specifications regarding the spent fuel verification system can be provided by the IAEA.

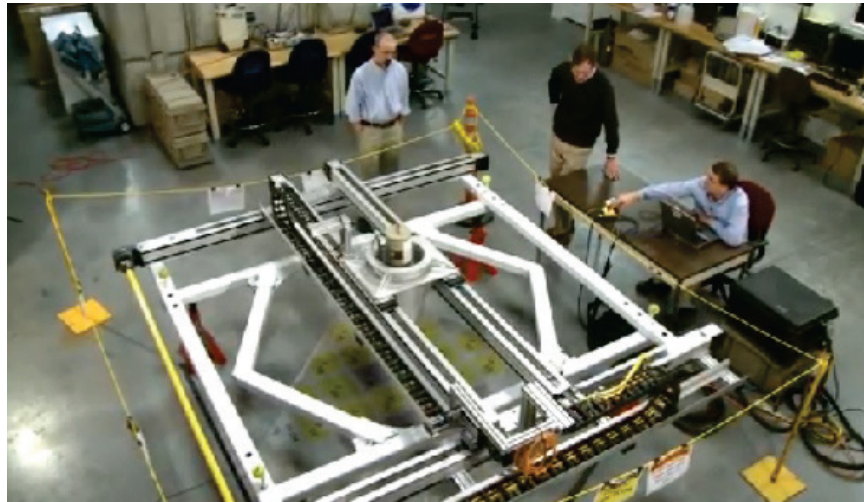


Figure-8: Compton Dry-Cask Imaging System
(Source – U.S. DOE Idaho National Laboratory, 2011)

Design Impacts of Facilitating Inspection

i. DIE/DIV Activities

IAEA safeguards inspectors perform DIE/DIV while the facility is under construction and after the facility begins operation, until the facility is decommissioned (from the standpoint of safeguards). The IAEA verifies that the facility has been designed and constructed as declared by the facility operator. They also verify that the ISFSI does not have concealed sub-basements, chambers, or undeclared spent fuel transfer or storage casks for the undeclared storage or handling of spent fuel. The space requirements for conducting the DIE/DIV are comparable to those required for performing the normal facility

operations or IAEA safeguards inspection activities, i.e. adequate space to walk around and inspect the spent fuel storage cask or vault array, service the seals and cameras, and check the field of view, etc.

The ISFSI designer should ask how IAEA inspectors intend to verify the design of the facility since the density of the spent fuel storage cask or vault array may preclude the use of certain equipment for verifying the facility design. IAEA inspectors typically use operator provided design information and drawings with portable tools and instruments to verify the safeguards relevant features of the design. The point of this activity is not to perform quality control of the facility construction, but to verify the safeguards-relevant design features. In larger and more complex ISFSIs, the IAEA may use the 3DLR, two versions of which are shown in the figure below. The 3DLR is a laser-based survey instrument that requires a free line-of-sight, i.e. if the array of spent fuel storage casks is too dense, it may not be possible to use the instrument.¹⁷ Typically the 3DLR would be positioned at the corners of the storage array to collect a suitable survey of the array and the spent fuel storage casks. The 3DLR requires 4 m² at each survey location, and a 1 meter-wide path for moving the instrument. Clear labeling or stenciling of the spent fuel storage casks or vaults also facilitates use of the 3DLR. More detailed specifications regarding the instrument that may be used for verifying facility design information can be provided by the IAEA.

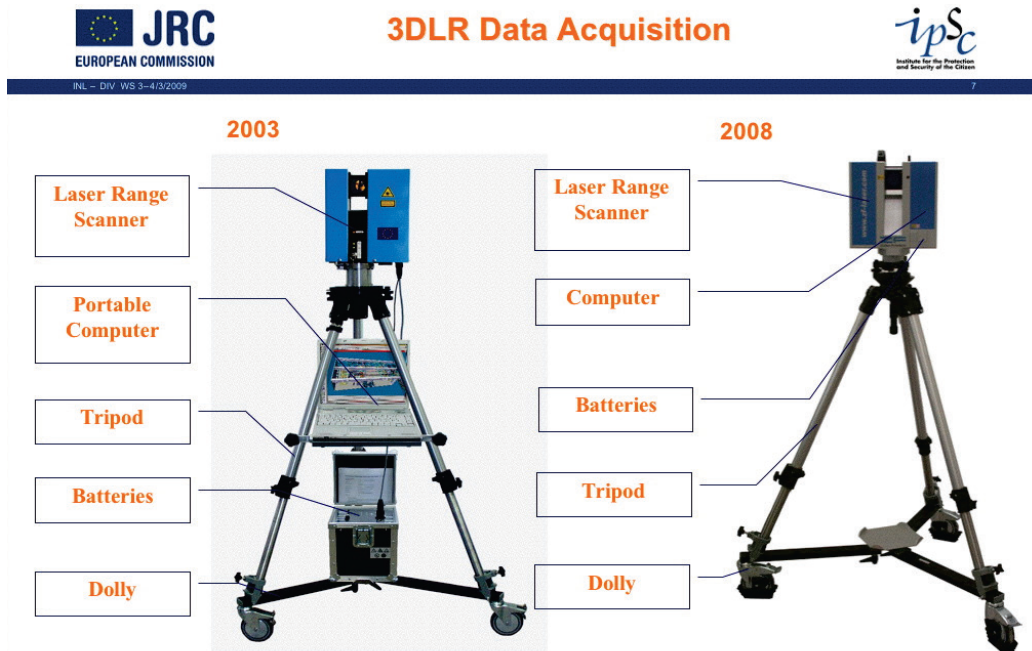


Figure-9: 3D Laser Range Finder (3DLR)
(Source – European Commission JRC/Ispra, ca. 2009)

ii. IAEA Inspections during Facility Operation

The IAEA inspector requires safe engineered access to walk around, inspect the array of spent fuel storage casks or vaults, service the seals and cameras, and check the field of view of the surveillance cameras and/or radiation detectors. They typically require platforms and ladders for accessing and servicing the surveillance cameras, since the cameras would usually be placed above the spent fuel transfer/storage casks or vaults looking downward. Similarly, they may require rolling platforms to reach the top of the vertical spent fuel storage casks or vaults to inspect the lids, verify the integrity of the seals, and to ensure that the spent fuel has not been accessed or moved. These platforms should be designed to accommodate up to three personnel (safeguards inspector, facility operator, and radiation monitor or

health physicist). The platforms should also be stable enough for the IAEA to lift and move the safeguards equipment for their verification activities.

Design Impacts (by Engineering Design Discipline)

i. Electrical/Instrumentation

The electrical and instrumentation design engineers should provide for the power and related cabling requirements of IAEA safeguards equipment, as specified by the IAEA. The following is based on standard practice to date, with consideration for the construction of very large ISFSIs anticipated in the near future. IAEA sealing systems are battery powered and do not require external power. IAEA surveillance systems may be battery powered or may require external power. Surveillance data collection cabinets typically require 30 amps per cabinet @ 90 – 265 VAC (50-60 Hz). The components within the IAEA data collection cabinet have internal circuit breakers. The data collection system is a computer server and requires a dedicated, isolated, and tested electrical earth ground suitable for sensitive computing equipment. The power for the IAEA surveillance data collection cabinets should be on a facility emergency power circuit, and/or have an IAEA-provided UPS within the cabinet. Cabling to and from the IAEA seal, surveillance, and/or radiation detection systems must be provided by the IAEA and meet IAEA tamper resistance specifications. If the seal, surveillance, or radiation detection systems are to be remotely monitored by the IAEA, they will specify other relevant requirements. The electrical power requirement for the Compton Dry-Cask Imaging System is 15 amps or less @ 100 - 230VAC (50 – 60 Hz). The electrical requirement for using the 3DLR is comparable to that as stated for the Compton Dry-Cask Imaging System. Both systems would utilize an electrical extension cord in the field routed from an all-weather convenience electrical power outlet provided by the facility.

ii. Mechanical

The mechanical design engineer should provide for safe engineered access so the IAEA inspector can service the seal, surveillance, and radiation detection systems, and access the lids of the spent fuel storage casks or vaults. Additional mechanical fixtures and modifications may be required to the facility equipment to permit use of the IAEA seal, surveillance, and radiation detection systems, and to provide IAEA inspector access to service these systems. These modifications will be as specified by the IAEA, and may include (but are not limited to) the following:

- Modifications to the spent fuel transfer/storage casks and vault lids for applying IAEA seals (e.g. seal and cable bolts, hasps, and covers)
- Modifications to the spent fuel vault external cooling channels to accommodate IAEA gamma radiation detectors and flow monitors (i.e. for spent CANDU fuel)
- Fixed stanchions for mounting surveillance cameras and additional perimeter lighting
- Fixed platforms and ladders for servicing surveillance cameras
- Rolling or fixed platforms and ladders to access the top of spent fuel transfer/storage casks and vaults for inspecting the lid and servicing IAEA sealing systems
- Movable mechanical fixture(s) for mating the Compton Dry-Cask Imaging System to the spent fuel storage cask or vault (typically provided by the IAEA)
- A condensate drain for the air conditioning system in the IAEA surveillance data collection cabinet

iii. Chemical/Analytical

Not relevant to this facility type.

iv. Industrial Safety

The industrial safety design engineer should provide for safe engineered access so the IAEA inspector can service the seal, surveillance, and radiation detection systems, and access the lids of the spent fuel storage casks or vaults. Design provisions for accommodating IAEA safeguards activities must not introduce other industrial hazards or risks.

v. Radiation Safety and Health Physics

The radiation safety design engineer or health physicist should provide for safe engineered and shielded access so the IAEA inspector can service the seal, surveillance, and radiation detection systems and access the lids of the spent fuel storage casks or vaults. Radiation dose to the inspector must comply with as-low-as-reasonably-achievable (ALARA) radiation guidelines and practices for comparable work as performed by the facility operator and their staff. The verification of spent fuel transfer/storage casks or vaults, declared to be empty, should be in accordance with the facility operator's procedures and practices. The verification of casks declared to be empty should be designed to be safely performed without excessive radiation exposure to the inspector or the facility operator and their staff. Moveable shielding and/or breathing respirators should be provided as necessary, to augment the designed radiation shielding and other safety features.

APPENDIX - EMERGING TECHNOLOGIES

Spent Fuel Containment and Surveillance

1. The foregoing guidance document presented the IAEA next generation Electro-Optical Sealing System (EOSS) and the Next Generation Surveillance System (NGSS). These systems are expected to become the primary IAEA seal and surveillance systems respectively, within the next 5 years.
2. Other systems are also being developed that could perform or enhance the nuclear material containment function that seals and surveillance systems currently perform for the IAEA. One of the challenges faced in using sealing systems is that they are difficult to apply to large numbers of spent fuel casks and vaults. This becomes problematic, as the number of spent fuel storage casks increases. To address this issue, a Remotely Monitored Sealing Array (RMSA) is being developed, which employs active electronic seals that use radio-frequency to communicate the seal status from multiple sealing points to a data collection system.¹⁸ In principle, this would eliminate the elaborate wire tying and daisy-chain cabling schemes that the IAEA has used in the past to cover multiple containers in large areas. The RMSA is currently being developed by Canberra/Areva USA and is undergoing testing and evaluation by the IAEA. The RMSA is designed to remotely transmit the seal status and disposition to IAEA headquarters in Vienna or the nearest IAEA regional office. The data would be fully encrypted and the remote transmission subject to the approval of the facility operator and State Regulatory Authority.
3. Another system that could be used for monitoring a large group of casks is a laser rastering system being developed at ORNL, the Laser-Based Item Monitoring System (LBIMS).¹⁹ Such a containment system would use fixed laser transmitter/receivers at the corners of the ISFSI and would rapidly raster and scan the spent fuel storage cask or vault area. The spent fuel casks/vaults and lids would have laser reflective tags for bouncing the rastered laser beams. If the spent fuel casks moved a small degree, such as during handling or opening the lid, the system would note the missing bounce and record the date and time of the event. Such a system, used in conjunction with surveillance, would be more efficient and easier to service than hundreds of seals applied to hundreds of spent fuel storage casks and vaults.

Spent Fuel Cask Monitoring and Tracking

4. The containment of spent fuel in storage casks and vaults at an ISFSI could be dramatically improved if so-called “smart” spent fuel storage and transfer casks were developed. Such casks would have tamper indicating and monitoring/tracking features integrated directly into the cask design. These features could be an add-on package or be integrated into the cask construction. The data monitored could include the: cask serial number and position, status of the cask lid (open or closed), radiation field near the cask lid, GPS coordinates, motion or speed of the cask (due to transfer), etc. The monitoring and tracking data could also potentially be remotely transmitted. If the data were transmitted to the State Regulatory Authority and/or IAEA, these organizations could know in real-time the status, disposition, and location of the spent fuel in storage. Radio-frequency monitoring and tracking systems have been developed for UF₆ cylinders, as sponsored by US DOE/NNSA.²⁰ The results from this research and development could also be adapted to the storage, tracking, and monitoring of spent fuel, especially at ISFSIs.
5. Overhead satellite imagery could be used to enhance the surveillance of sealed spent fuel storage and transfer casks and vaults. While the IAEA does not have access to real-time satellite imagery, it is still possible for the IAEA to use commercially available satellite imagery for enhanced surveillance, or as a back-up to the seals and surveillance cameras deployed on site. This would be especially useful if a localized seal and surveillance failure occurs. The availability of historic satellite imagery could provide enough assurance that the spent fuel was not removed, thereby precluding the need for the more arduous and intrusive on-site re-verification of spent fuel. To facilitate overhead surveillance, the spent fuel storage/transfer casks or vaults could be modified with individual lighting or over-sized identification numbers to improve overhead identification. However, it should be noted that some ISFSIs have structures and enclosures in which spent fuel transfer/storage casks are placed. In such cases, the use of over-head satellite imagery would be of limited value.
6. Another possibility is the use of geophysical sensors, such as seismic detectors. These could be used in tandem with motion sensors to detect whether heavy spent fuel transfer and storage casks or vaults are being moved or opened. For the sensors to be effective, they would need to be placed near the spent fuel storage casks or vaults being monitored. They could also be placed at the ISFSI entries and exits to detect spent fuel transfer cask receipts or shipments, and be placed near the lids of casks to detect the opening of casks with stored spent fuel. As noted above, the seismic data could be remotely monitored and uploaded to give the State Regulatory Authority and IAEA a real-time view of the status of the spent fuel storage casks and vaults at an ISFSI. This could also allow the State Regulatory Authority and IAEA the ability to monitor dozens or hundreds of ISFSI simultaneously, with a tremendous increase in efficiency. The use of seismic sensors could be especially useful in geological spent fuel storage installations (i.e. tunnels and mines), where the use of more traditional seal and surveillance measures may not be possible due to restricted personnel access.

Spent Fuel Cask Re-Verification

7. A Compton Dry-Cask Imaging System is being developed by INL to re-verify nuclear fuel in vertical spent fuel dry-storage/transfer casks.¹⁵ This system would detect and characterize the Compton-scattering produced by the fission products in the spent fuel in each dry storage cask, making a Compton “finger-print” of the cask. The resolution is such that the system can make a collective image showing the presence of each spent fuel assembly inside the cask. If the dual containment and surveillance devices covering the spent fuel casks at an ISFSI ever failed, the IAEA would have a means for re-verifying the contents of these casks to determine that spent fuel had not been removed. The primary benefit of this system is that it would be non-intrusive and would not require access to the spent fuel stored within the cask. Access to the spent fuel in the storage casks would not be possible under most circumstances, since the spent fuel is typically welded inside helium-filled inner containers and cannot be removed. The advantage of the Compton Dry-Cask Imaging System is that

it could interrogate the contents of the spent fuel storage cask from outside the cask to verify that the spent fuel has not been removed.

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