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Safeguards Approaches for Very Long-Term Storage of Spent Nuclear Fuel

Nuclear Engineering Division

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by
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CONTENTS

FIGURE

TABLES

ACRONYMS AND DEFINITIONS

AFR	away from reactor
AR	at-reactor
BRC	Blue Ribbon Commission on America's Nuclear Future
BWR	boiling water reactor
CANDU	CANada Deuterium Uranium reactor
CLAB	Swedish central interim storage facility
CoK	continuity of knowledge
C/S	containment and surveillance
DCSS	dry cask storage system
DOE	United States Department of Energy
EURATOM	The European Atomic Energy Community
GCR	gas-cooled reactor
HEU	high-enriched uranium
HWR	heavy water reactor
IAEA	International Atomic Energy Agency
ISFSI	independent spent fuel storage installation
KMP	key measurement point
LWR	light water reactor
MBA	material balance area
MC&A	material control and accountancy
MPC	multi-purpose canister
MRS	monitored retrievable storage
MUF	material unaccounted for
MUND	mobile unit neutron detector
NDA	non-destructive assay
NRC	U.S. Nuclear Regulatory Commission
PDI	person-days of inspection
PHWR	pressurized heavy water reactor
PIV	physical inventory verification
PWR	pressurized water reactor

RBMK	Reaktor Bolshoy Moshchnosti Kanalniy
RM	remote monitoring
SAGSI	Standing Advisory Group on Safeguards Implementation
SBD	safeguards by design
SQ	significant quantity
UMS	unattended monitoring system
VIFB	VXI integrated fuel bundle
VIFC	VXI integrated fuel core
VLTS	very long-term storage

SAFEGUARDS APPROACHES FOR VERY LONG-TERM STORAGE OF SPENT NUCLEAR FUEL

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EXECUTIVE SUMMARY

Many States are considering interim very long-term storage (VLTS) strategies for spent fuel storage while final disposition options are developed. Under the VLTS approach, spent fuel will be stored for periods that could exceed 50 to 100 years. The long-term storage of spent fuel — and the increasing stockpile of plutonium contained in this spent fuel — exacerbate the international safeguards and verification needs for spent fuel. In particular, significant delays in any verification of the contents of spent fuel assemblies prior to disposition may cause even further delays in the final disposition (or reprocessing) of spent fuel. As a result, the resources required by the International Atomic Energy Agency (IAEA) to safeguard the increasing stockpile of spent fuel will increase. Safeguarding these interim storage facilities and subsequently, the transportation of long-term stored fuel, will place additional demands on IAEA resources if the current approach, which relies heavily upon inspectors being present at the facility, is to be continued.

Current IAEA approaches to safeguarding above ground dry storage sites do not take into account the challenges associated with longer-term storage and are also very dependent on inspector presence. The IAEA is moving toward remote and unattended monitoring systems for safeguards and these systems should be utilized at VLTS facilities as much as possible. The research and development of various monitoring systems should be continued.

The main safeguards challenges at VLTS facilities in the future include varying spent fuel types and storage canister designs, difficult verification and reverification of spent fuel assemblies, difficult detection of gross and partial defects, and constraints of safeguards resources in the future. It is therefore recommended that safeguards approaches for VLTS facilities include the following:

- Robust accounting records
- Radiation portal monitoring systems
- Robust cask fingerprinting that is valid and usable over a long period of time
- Ultrasonic seals with real-time tampering indication
- Storage casks designed with verification in mind
- Integrated remote monitoring systems with non-destructive assay (NDA) capabilities that can collect and transmit real time data to IAEA headquarters
- Unattended environmental sampling and radiation detection
- Plans to update or replace the containment and surveillance (C/S) system periodically

1. Introduction

Following the cancellation of the Yucca Mountain geological repository project, the Secretary of Energy of the United States commissioned the Blue Ribbon Commission (BRC) on America's Nuclear Future study. The final BRC report in 2012 recommended a new strategy for management and disposition of commercial spent fuel. This strategy includes: a new, consent-based approach to siting future nuclear waste management facilities; prompt efforts to develop one or more geological repositories; and active U.S. leadership in international efforts to address safety, waste management, non-proliferation, and security concerns. As recommended by the BRC study, long-term dry cask storage of spent fuel should be implemented at a centralized facility until geological disposition is available.[1] The U.S. Department of Energy (DOE) has taken the BRC recommendations into account and devised a strategy for the management and disposal of spent fuel.[2] DOE plans to implement a program in which a pilot interim storage facility will be operational by 2021, a larger interim storage facility will be available by 2025, and a full-scale geological repository will be available by 2048.

Other countries are also considering and planning interim very long-term storage (VLTS) strategies for spent fuel while final disposition options are developed. It will be several decades before geological repositories are available in all of the major nuclear countries. Therefore, spent fuel will have to be stored in interim storage longer than initially intended and storage times may have to be extended up to 100 years and beyond. As in the United States, the majority of spent fuel in the world is currently being stored at the plant where it was generated. However, many national plans often involve the establishment of centralized interim storage facilities until geological repositories become available. In contrast, Russia, Japan, India, France, and more recently, South Korea, are the only countries that plan to reprocess spent fuel and recycle the products in reactors; thus, drastically reducing the amount of waste for permanent disposal.[3] The European Atomic Energy Community (EURATOM) has also stated that "surface and sub-surface storage" could be considered as a complementary solution to disposal provided that a permanent solution is defined, but the storage is not considered sustainable in the long-term.[4]

There is no internationally or nationally[5] agreed upon definition for "very long-term storage (VLTS)," so it is defined, for the purpose of this paper, as an approach in which spent

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[1] Blue Ribbon Commission on America's Nuclear Future, "Report to the Secretary of Energy." January 2012.

[2] U.S. Department of Energy, "Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste." January 2013.

[3] Summary reports for the "International Conference on Management of Spent Fuel from Nuclear Power Reactors," May-June 2011. Available at: http://www-ns.iaea.org/meetings/rw-summaries/vienna-2010-mngement-spent-fuel.asp. Accessed May 2013.

[4] EURATOM Report "On the implementation of the obligations under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management," Fourth Review Meeting of the Contracting Parties, Vienna, May 2012.

[5] The U.S. DOE uses the term "very long-term storage" (but not the abbreviation VLTS) as "storage approaching 100 years or more." See "Used Fuel Disposition Campaign International Activities Implementation Plan" report prepared for the U.S. DOE in Nov. 2010: http://energy.gov/ne/downloads/used-fuel-disposition-campaign-international-activities. Accessed May 2013.

fuel is stored in an above-ground dry facility for periods that exceed 50 years and could even exceed 100 years. In many cases, the end point (i.e., geological repository or reprocessing) of the spent fuel has not yet been identified. VLTS facilities include multipurpose casks, silos, and other similar structures utilized for the dry storage of spent fuel. Interim dry storage facilities that were originally meant to store spent fuel for less than 50 years could inadvertently become VLTS facilities if there are delays in spent fuel disposal policies.

The long-term storage of spent fuel and the increasing stock pile of plutonium contained in this spent fuel exacerbate the international safeguards and verification needs for spent fuel. The resources required by the International Atomic Energy Agency (IAEA) to safeguard the increasing stockpile of spent fuel will inevitably increase. Safeguarding these interim storage facilities and subsequently the possible reverification and transportation of long-term stored fuel would place additional demands on IAEA resources if the current approach, which relies heavily upon inspectors being present at the facility, is to be continued.

The goal of IAEA safeguards is to "independently verify the correctness and the completeness[6] of the declarations made by States about their nuclear material and activities" and to "allow the IAEA to draw safeguards conclusions both about the non-diversion of declared nuclear material and the absence of undeclared nuclear material and activities in a State".[7]

To provide credible assurance to the international community of the non-diversion of nuclear materials and deterrence of such by the risk of early detection, the IAEA has defined a significant quantity (SQ) of nuclear material, or a "quantity of safeguards significance" as the approximate quantity of nuclear material with respect to which — taking into account any conversion process involved — the possibility of manufacturing a nuclear explosive device cannot be excluded. [8] The IAEA specifies the following detection goals for nuclear material in the form of spent fuel: 8 kg of plutonium within three months of possible diversion, 8 kg of U-233 within three months, 75 kg of U-235 (in low-enriched fuel) within one year, and 20 tonnes of thorium within one year. Therefore, primarily due to the plutonium content, the IAEA must verify that diversion of spent fuel has not occurred at a minimum timeline of every three months. As of the latest IAEA Annual Report (2011), there are 136,744 SQs of plutonium (1 SQ = 8 kg Pu) contained in safeguarded reactor core fuel and irradiated spent fuel worldwide.[9] This plutonium accounts for over 75% of the total safeguarded material, in terms of SQs, in the world.

The increasing amount of spent fuel that will sit in VLTS without a near-term permanent disposition path combined with current detection goals will place a serious burden on

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[6] *Correctness* of a State declaration is the assurance of non-diversion of nuclear material as declared by the State. *Completeness* of a State declaration is the verification and assurance of the absence of undeclared materials and activities not declared by the State.

[7] International Atomic Energy Agency, http://www.iaea.org/OurWork/SV/Safeguards/what.html. Accessed February 2013.

[8] International Atomic Energy Agency, *The structure and Content of Agreements between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons,* INFCIRC/153 June 1972.

[9] International Atomic Energy Agency, "IAEA Annual Report 2011." GC(56)/2.

international safeguards. The goals of this project are to describe the current IAEA approach to safeguarding long-term above-ground storage sites, to discuss potential safeguards approaches that depend less upon inspector presence and more upon containment/surveillance (C/S) and remote monitoring, and to identify any gaps in the IAEA's current safeguards toolkit for VLTS. The following sections include a description of VLTS, current safeguards approaches, challenges to those approaches, recommendations and potential new safeguards approaches, and conclusions.

2. Very Long-Term Storage of Spent Fuel

2.1 Methods of Spent Fuel Storage

Countries around the world have adopted different methods for the interim storage and disposition of spent fuel. These methods mainly include on-site spent fuel pools, on-site dry cask storage, national centralized interim storage, and geological repository. International centralized storage facilities have also been proposed.

A typical light water reactor (LWR) in the United States discharges and refuels about one-fourth to one-third of the fuel in the core every 12 to 18 months. The spent fuel is then transferred to a temporary wet storage pond. Spent fuel pools vary greatly in size both in the United States and around the world. Pool size is the dominant factor in determining spent fuel pool capacity. However, spent fuel pool size is dependent on the overall spent fuel management policy at the time that a plant is built. For example, in the United States, DOE is required by law to dispose of commercial spent fuel. Many on-site spent fuel pools were sized with the expectation that, after sufficient cooling time, spent fuel would be removed and become the responsibility of DOE, making room in the pool for newly discharged spent fuel. However, numerous political issues have delayed DOE from taking possession of the spent fuel, and this has resulted in numerous spent fuel pools in the United States reaching their physical capacities. This is also the case in some nuclear power plants in South Korea, Argentina, Pakistan, and Canada. Spent fuel pools are often re-racked to increase capacity, but eventually, additional interim spent fuel storage is needed until a permanent storage solution is available.

Dry cask spent fuel storage is a form of interim dry storage in which the spent fuel is placed in a sealed metal canister that is placed within a metal or concrete outer shell. In some designs, casks are placed horizontally. In others, they are set vertically on a concrete pad in either an at-reactor (AR) or away-from-reactor (AFR) facility. In a dry cask storage system (DCSS), several spent fuel assemblies are placed in a sealed metal container with a metal or concrete outer casing to shield the radiation. In the case of DCSS in the United States, the Nuclear Regulatory Commission (NRC) requires that the fuel assemblies must have been cooled for at least 5 years in the spent fuel pool before they can be transferred to a dry storage system. In the United States, spent fuel is currently in dry storage at 53 general-licensed independent spent fuel storage installations (ISFSIs) and 15 specific-licensed ISFSIs with site-specific licenses. [10]

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[10] Nuclear Regulatory Commission NRC, Fact sheet on Dry Cask Storage of Spent Nuclear Fuel, 2012.

Many countries, including the United States, have adopted DCSS as a part of their strategy for the interim storage of nuclear fuel. Even though the various DCSSs are designed under similar mechanical, thermal, and safety related parameters, there are over 10 different types of dry cask storage available; all of them with certain proprietary designs and configurations. For example, older designs hold as few as four pressurized water reactor (PWR) assemblies while newer designs may hold as many as 33 PWR assemblies or 61 boiling water reactor (BWR) assemblies. The newer multi-purpose canister (MPC) type of cask can be used for both interim storage and as a transportation cask.

Regional or centralized interim storage can be used in combination with AR dry storage, as is the case in Germany and Sweden. The BRC report also recommends utilizing both AR and centralized storage facilities in the United States. Centralized or regional storage is usually in the form of a monitored retrievable storage (MRS) facility. An MRS facility is meant to be used for the interim storage of spent fuel. The facility could also prepare the spent fuel for final disposal or it could serve as a central receiving station for nuclear waste. A single site allows for better surveillance and security, but it could also be more attractive for diversion because of the increased inventory. Overall, centralized VLTS storage in a State or region would decrease the IAEA resources needed to safeguard spent fuel in that area because the material would be consolidated instead of being spread across different dry storage facilities; thus, reducing the surveillance of and travel to multiple sites.

For countries that do not plan to reprocess their spent fuel, a deep geological repository remains the preferred option for the final disposal of most high level waste forms. A geological repository is sited on a stable landform, preferably in an unpopulated area. A receiving and handling facility is usually located outside of the entrance tunnels. Spent fuel, and other waste forms, are packaged into metal containers and sent down the tunnels to their final locations. There can be several engineered barriers to keep the radioactive waste from entering the accessible environment, including the waste form itself, waste package, tunnel, and surrounding rock. While some countries around the world are in the process of siting or licensing a deep geological repository, none has been officially opened.

The concept of a multi-national fuel cycle has been proposed to promote nuclear energy expansion while reducing proliferation risk. This model utilizes reliable fuel-cycle service arrangements to ensure that States get fuel without the need to develop enrichment, fabrication, and reprocessing technologies. This may also involve creating international fuel cycle facilities with multinational investment and operation, while being safeguarded by the IAEA. An international fuel cycle facility would most likely require countries who borrow nuclear fuel to return it when it is used. Whether the State of origin decides to reprocess the returned spent fuel or not, some variation of an international spent fuel storage facility may arise. This facility may be for interim storage before reprocessing or before final disposal in a geological repository. An international or a multi-national storage facility would likely be much larger in size than a storage facility that is on-site at a reactor and; therefore, it may require a different or an altered approach to safeguards.

2.2 Time Frame of VLTS

The exact time frame for VLTS cannot be defined because interim dry storage facilities may inadvertently become VLTS facilities as there are delays in spent fuel disposal policies. For example, a storage site that is meant to store fuel for 20 years before final disposal could end up storing the fuel for 50 years due to delays in opening a geological repository, as is the case in the United States. As mentioned previously, VLTS in this paper is defined as above-ground interim storage for a period of more than 50 years.

The IAEA monitors and inspects the transportation of spent fuel differently from stationary spent fuel storage. In this paper, only the stationary storage, and not the transportation phase, will be evaluated. The transfer of spent fuel from the spent fuel pool to dry storage, transportation between storage sites, and transportation to final disposal or reprocessing are not included in the safeguards of VLTS, but are important to consider in the State-level safeguards approach.

The safeguards approach for VLTS includes non-destructive assay (NDA) verification upon spent fuel receipt, material control and accountancy (MC&A), continuity of knowledge (CoK), key measurement points (KMPs), and material balance areas (MBAs). Safeguards begins when the spent fuel (nuclear material) arrives on-site of the VLTS facility and ends when it is transferred to another location, presumably a final disposal facility. This is the case for any facility with nuclear material and it is not unique to a VLTS facility.

2.3 Challenges of VLTS

The long-term interim storage of spent fuel presents many safeguards challenges. Original nuclear energy policies did not necessarily consider the challenges of siting, constructing, and operating geological repositories to dispose of high-level nuclear waste. The United States is a prime example of having a nuclear waste management policy that did not work out in the way it was originally envisioned and that evolved incrementally over time due to political factors. While VLTS may be a temporary solution to the lack of a geological repository for final disposal, it comes with its own challenges. VLTS combines the already existing challenges of interim dry storage with the added factors of longer time periods and increased accumulation of nuclear material.

The quantitative and qualitative verification of spent fuel in dry storage areas is a demanding task for the IAEA. For example, the number of spent fuel assemblies in interim dry storage is rapidly increasing. The IAEA spends significant inspector resources to maintain CoK while the spent fuel is placed in interim long term storage. Some of the challenges of VLTS are inherent to the diversity of reactor designs employed around the world. For example, heavy water reactors (HWRs), such as the CANDU (CANada Deuterium Uranium) reactor, utilize smaller fuel assemblies than typical LWRs. Smaller assemblies are used because CANDU's are typically refueled online. The IAEA employs more stringent safeguards on CANDU spent fuel assemblies because they are easier to divert due to their smaller size. Therefore, different safeguards approaches are applied to CANDU spent fuel assemblies and the storage of them. Even among LWR spent fuel storage facilities, safeguards measures are typically unique to each facility because there are many different dry storage canister designs utilized around the world to accommodate different fuel types. The equipment that is used by the IAEA to verify spent fuel in casks is dependent on the design of the cask and also on the type of fuel. Radiation signatures vary depending on the type of fuel and reactor design.

Different safeguards approaches may also be taken at different sites, depending on whether the storage facility is on-site at the power plant, off-site from the power plant, centralized in a State, or in an international storage facility. Facilities with much higher capacities may be more difficult and also more important to safeguard, since a larger amount of nuclear material is present in a single MBA. In addition, the IAEA may take a different approach to safeguarding facilities in different countries based on the State-level safeguards approach as determined by the State-Level Concept and Additional Protocol agreement status of each State.

Safeguarding a VLTS facility with nuclear material for 50, 100, or 200 years will present many challenges. First of all, the integrity of the fuel or cask may deteriorate. The radioactive signature of the fuel will also change. As the fuel cools, it may become more attractive for diversion. Even though the State has the means to handle very radioactive spent fuel, cooler spent fuel will still be more attractive to divert because it is easier to handle and reprocess. Keeping data on the facility for that long may also be a challenge. If the past 50 years are any indication of the future, it is difficult to predict what the safeguards challenges and needs will be in just the next 50 years.

3. Current IAEA Approaches Potentially Applicable To VLTS Safeguards

3.1 Frequency of Inspections

The frequency of inspections is driven by the objective of safeguards, which is the "timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection."[11] The IAEA safeguards system assumes that diversion of an SQ of nuclear material must be detected on a timely basis. The IAEA establishes in each particular situation the frequency and timing (of the inspections) with which it must draw a conclusion as to whether there has been no diversion, as well as the quantity of material to which the conclusion refers, the probability of detection, and the probability of a false alarm. The Standing Advisory Group on Safeguards Implementation (SAGSI) made the provisional recommendation that "detection time" be used as a parameter for timeliness and that it should correspond in order of magnitude to the "conversion time".[12] The conversion times estimated by SAGSI for different material categories are given in Table 1.

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[11] "The Structure and Content of Agreements between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons," International Atomic Energy Agency, INFCIRC/153.

[12] Generally, "conversion time" is defined as the minimum time required to convert different forms of nuclear material to the metallic components of a nuclear explosive device and "detection time" is defined as the maximum time which may elapse between a diversion and its detection by Agency safeguards.

Pending the acquisition of additional practical experience and further discussions within SAGSI and other advisory groups, the IAEA is continuing to use the values in question as guidelines. In addition to these general guidelines for timeliness and significant quantities, the IAEA must strive for a safeguards system which has a certain probability of meeting these inspection goals. The degree of probability within which these goals are to be met must be defined. Neither INFCIRC/66/Rev.2 nor INFCIRC/153 specifically mentions the concept of degree of certitude of detection, but the IAEA has interpreted these documents as implicitly embodying this concept. The a priori probability of detection which is sought is usually 90% or higher and is most often 95%.

Table 1: Estimated Material Conversion Times[13]

Material Classification	Beginning Material Form	Estimated Conversion Time
1	Pu, HEU, or ^{233}U metal	Order of days (7-10)
2	PuO_2, $Pu(NO_3)_4$ or other pure compounds; HEU or ^{233}U oxide or other pure U compounds; MOX or other non-irradiated pure mixtures containing Pu, U ($^{233}U + ^{235}U \geq 20\%$); Pu, HEU and/or ^{233}U in scrap or other miscellaneous impure compounds	Order of weeks (1-3)[a]
3	Pu, HEU or ^{233}U in irradiated fuel	Order of months (1-3)
4	U containing < 20% ^{235}U and ^{233}U; Th	Order of one year
[a] This range is not determined by any single factor but the pure Pu and U compounds will tend to be at the lower end of the range and the mixtures and scrap at the higher end.		

The purpose of routine inspections is to verify that the information contained in the reports submitted by the State is consistent with its accounting and operating records; to verify the location, identity, quantity and composition of safeguarded materials; and to verify information about the cause of shipper/receiver differences; book inventory uncertainties; and material unaccounted for (MUF). Ad hoc inspections are made to verify design information, initial reports and changes since initial reports, and to verify the material involved in international transfers. Special inspections are made to verify information in special reports or to collect additional information when the IAEA considers information provided by the State or obtained through routine inspections to be inadequate for the IAEA to fulfill its responsibilities.

3.2 Technologies Used for Safeguards

Under the current safeguards approach, some of the equipment used to maintain CoK by C/S and NDA measurements of the nuclear material at spent fuel storage facilities includes:[14]

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[13] "IAEA Safeguards Glossary," International Atomic Energy Agency; 2001 Edition.

- **Mini MCA with a NaI detector probe (MMCN) or the Inspector 2000 MCA with a NaI detector probe (IMCN)** — used to perform attribute tests of spent fuel in the silo once the silo is full and sealed (verification of Cs-137 peak from the silo),
- **Hand-Held Monitor Version 5 (HM-5)** — detector used to scan the shielded flask before and after the spent fuel basket has been loaded inside the storage silo,
- **IAEA seals (e.g. ARC, Vacoss, Cobra and type –E)** — used to seal the plug on top of the silos (as a containment measure of the nuclear material in full silos), and
- **Surveillance cameras (e.g. ALIS, ALIP)** — overseeing spent fuel storage area, the spent fuel pond, and welding station.

3.3 Remote and Unattended Monitoring

A typical unattended monitoring system (UMS) for interim spent fuel storage, such as the one put in place at the Embalse CANDU-type nuclear power plant in Argentina, consists of several components that work together as a whole system. At Embalse, there are safeguards measures and equipment employed to remotely monitor the transfer of spent fuel from the spent fuel pool to the interim storage silo, without the need for the constant presence of an inspector. Some of the safeguards measures used for the silo can be potentially applicable to safeguarding long-term above-ground spent fuel storage sites. The entire Embalse UMS is described in Appendix A, but the elements of the safeguards approach that could be used for a VLTS safeguards approach are described below:

- A set of mobile unit neutron detectors (MUND) are installed on top of the transport flask to confirm the presence of nuclear material in the welded basket and to monitor the flask during the time period between the welding station and the dry storage area. An ALIP camera is installed on top of the transport truck for surveillance.
- A set of four directional silo entry gamma monitoring systems (SEGM) are set on top of four silos (one system per silo) to perform a NDA measurement and confirm that the basket has been lowered into the silo and to prevent removal of these baskets before the final welding and sealing of the silo has been performed. A set of ALIP cameras is installed on top of an already sealed full silo, adjacent to the one being filled, for surveillance.
- All of this data is being stored at the surveillance stations located in the designated safeguards office. These surveillance station cabinets are under IAEA seals.
- The operator fills out a declaration form, with the daily activities, and sends it to the IAEA every week.
- There are announced inspections once every 45 days for a one-week period to review the data at the designated safeguards office to confirm the information provided by the operator in the declarations.
- There are also unannounced inspections within the 45-day period.

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[14] "Safeguards Techniques and Equipment: 2011 Edition," International Atomic Energy Agency, International Nuclear Verification Series No. 1 (Rev.2); Vienna, 2011.

A typical remote monitoring system would include the aforementioned UMS system, but the data would be remotely transmitted to IAEA headquarters in Vienna. The remote monitoring (RM)-based safeguards approaches include inspections for physical inventory verification (PIV) and other routine or ad hoc inspections or design information verification visits for the following purposes:

- Confirming that the RM equipment has not been tampered with.
- Performing activities required by the Agency's safeguards criteria which cannot be covered by the transmission of data from RM devices, e.g., verification of transfers, examination of facility accounting and operating records and supporting documents, and design information verification.

The inspection effort is dependent on the complexity of the facility and of the remote monitoring system; and on the quantities, types and categories of nuclear material involved; but is less than the presently applied effort. The reduction is based on the achieved performance of the facility safeguards system, on the accumulated implementation experience, and whether inspections at the facility are performed with or without advance notification (announced or unannounced inspections). The required inspection effort is reviewed annually by the IAEA in light of the accumulated experience with the RM system at the facility, with a goal to reduce the inspection effort.

The future of UMS is moving toward fully integrated systems which incorporate the direct integration of surveillance systems with local area networks to provide a server-type central collection computer. Such a system would use UMS-type sensors to trigger cameras. One of these systems is already in operation at the BN-350 complex in Kazakhstan. A newer integrated version is currently being tested at the Safeguards Equipment Support Facility and scheduled for installation in the Chernobyl Spent Fuel Conditioning Facility. Another similar remote system with a direct integration of the surveillance system is being used in the United States for bilateral arms control.

As of March 2011, the IAEA had a total of 258 systems with RM capabilities in 20 countries. They include 150 surveillance systems (with 569 cameras) and 108 radiation detection systems.[15] In addition to the deployed systems, further work is currently under way to provide additional monitoring features so that RM can be extended to other equipment types.

3.4 Safeguards Technology Research and Development

To reduce inspector presence and to use resources more effectively, the IAEA and Member States are developing and improving technologies that will move more facility safeguards from traditional safeguards to unattended monitoring and optimally to complete remote monitoring. Remote monitoring systems need to contain robust components that work together to create a robust system that can provide more efficient safeguards with real-time

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[15] Presentation to the ESA (European Space Agency) by J. Regula, IAEA Unit Head – Remote Monitoring Safeguards Division of Technical Services, 2011-04-06, http://iap.esa.int/sites/default/files/1.6.3%20-%20Regula%20-%20IAEA.pdf.

monitoring. Because VLTS is a relatively static facility, with minimal movement of fuel (especially once the facility is full), remote monitoring would be the ideal safeguards method to utilize, freeing up limited IAEA inspection resources for more active facilities with frequent or constant nuclear material movement.

The following research and development (R&D) activities include those funded by the regular IAEA budget and those expected to be funded by Member State Support Programmes.[16]

1. **Develop new systems, using approved components to the maximum extent, according to operations divisions' needs**
   The IAEA is currently standardizing its instrumentation for NDA hardware through the development of the Universal NDA Data Acquisition Platform (UNAP). The UNAP will be the central data acquisition system for almost all applications. The Next Generation ADAM[17] Module (NGAM) is being completed under this project and it will be for spent fuel applications at CANDUs only. Finally, the Agency requires an extremely low power, fully battery-operated, limited-capability data acquisition system. This will be the follow-up to the MUND system, which is based on a collection of low-quality commercial components. MUND needs to be reengineered with a single, coherent design. It will provide the low-power, battery-operated system that is used mostly for portable and mobile applications (e.g., transport trucks and railcars).

2. **Maintain and extend lifetime of currently installed unattended monitoring system**
   Preventive maintenance and regular system upgrades are the key factors to ensure the seamless operation of the unattended systems and extend their lifetimes, realizing immediate savings in cost and manpower since much of the cost is up-front investment. This effort is supported by the MSSPs through different industry support tasks like VIFM Implementation Support (CAN E 1530) and URM Systems Standardization and Support (USA E 1274). These tasks are ongoing and they assure that adequate resources are devoted to adopting those improvements that are made possible by the use of new technologies.

   Under this objective, another important activity is the development of the NGAM (CANE 1499) aimed at providing a replacement for the aging VXI based ADAM unit used by the VIFM systems. The new unit will provide better performance and enhanced functionality, including Ethernet connectivity for easy integration with other data generators.

3. **Develop a standardized data review platform**
   The possibility of using a standardized software platform for data collection from different data generators offers various advantages, like better usability and serviceability, and reduced training requirements, both for end users and technicians. The IAEA started the redesign and integration into a single software suite of the different tools for data collection and data review in 2004, through the assistance of the U.S. Support Program. The main developer

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[16] "Research and Development Programme for Nuclear Verification 2010-2011," International Atomic Energy Agency Department of Safeguards, Vienna.

[17] Autonomous Data Acquisition Module (ADAM).

responsible for the complete suite is Los Alamos National Laboratory. The two main products of this suite are the Multi-Instrument Collect (MIC) software and the Integrated Review Software (IRS). Development has reached the final stage. The IAEA expects to receive the Baseline 3 release, considered to be the final one incorporating the complete set of functionalities it requested. The software tool will then allow the users to import the operator's declarations and compare them directly with the events identified, for instance, by analyzing the radiation data, flagging any mismatch and/or anomalies. The MIC software will also extend its support to new data generators, like the new family of electronic seals.

The development of the Digital Unattended Multichannel Analyzer (DIUM) falls under the same objective. The DIUM is expected to address the lack of a multichannel analyzer (MCA) fulfilling the requirements for unattended operation, like local storage capability, automatic restart, Ethernet connectivity, and data authentication. Following the German Support Program's agreement to support the upgrade of the portable Miniature Multichannel Analyzer (MMCA) with digital technology, there was a proposal to wait for this effort to be completed before considering its potential integration as an UNAP/MCA. Consequently, task GER A 1269 was put on standby until complete specifications of the UNAP/MCA interface are defined, at which time the integration of the upgraded Digital MMCA board could be considered under this task.

4. **Improve the capability of UMS to interface with the Remote Monitoring infrastructure. Test and implement new systems with RM capabilities.**
   The purpose of this activity is to facilitate the connection between UMS and RM so that UMS data can be easily sent back to the IAEA headquarters for review. Both the UMS hardware and the remote monitoring network infrastructure exist. An important aspect is facilitating the interface between the two systems. Software will continue to be enhanced to improve the interface to the remote monitoring infrastructure. The activities will be focused on checking the data integrity and integration of all data carriers, including data pre-review. An important element will be dedicated to preparing the integration of the Next Generation Surveillance Systems (NGSS) and the Universal NDA Data Acquisition Platform (UNAP) in the SG-RM concept. Data security will be evaluated and enhanced. The Sign and Forward (SNFS) method for authenticating data will be improved and its use will be extended.

4. Challenges to a Very Long-Term Storage Safeguards Approach

One of the main goals of the IAEA in the near future is to further develop the State-level concept of information-driven safeguards. The State-level safeguards approach is a "customized approach to implementing safeguards for a State, consisting of a set of safeguards objectives and applicable safeguards measures, implemented in the field or at headquarters, to address those objectives." This allows for a holistic approach to safeguards that considers the State and its nuclear activities as a whole.[18] In this section, the constraints of the traditional safeguards approach will be discussed as a whole, as well as how they apply to VLTS.

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[18] "IAEA Department of Safeguards Long-Term Strategic Plan (2012-2013)" Available at http://www.iaea.org/OurWork/SV/Safeguards/documents/LongTerm_Strategic_Plan_(20122023)-Summary.pdf.

4.1 Current IAEA Safeguards Approaches

Traditional safeguards basically use optical surveillance as well as sealing systems which are primarily applied in power reactor and storage facilities. Providing that the inspection results are conclusive and do not indicate anomalies, these C/S measures help to reduce time-consuming and labor-intensive on-site verification activities such as non-destructive assay measurements. On the other hand, C/S measures require some effort for installation, maintenance, repair, replacement, integrity check, data retrieval and review; and therefore, their cost-effectiveness should always be assessed to avoid wasting resources.

Integrated Safeguards is expected to effectively and efficiently find a balance between inspector activities and use of unattended monitoring that will result in a decrease of inspector presence and resources utilized by the IAEA. In practical terms, the resources required for the implementation of the Additional Protocol (information treatment and evaluation, complementary access, reporting, and drawing conclusions) should come from the savings in person-days of inspection (PDI) and from the equipment the IAEA makes in safeguarding nuclear facilities.

Integrated Safeguards supports the tendency to make extended use of unattended C/S measures to increase the efficiency, in particular, by reducing the on-site inspection effort. The major features of adequate C/S measures are sufficient system reliability, data security, and remote monitoring capability. While these systems ensure CoK, there is still the possibility of a failure in CoK, emphasizing the need to reverify the spent fuel assemblies.

4.2 Factors Affecting the Safeguards Approaches for VLTS

The VLTS of spent fuel presents safeguards challenges and no single safeguards approach will work for every VLTS site. There are many reactor types and fuel types around the world that have different storage cask designs. In addition, cask designs differ based on the manufacturer; and thus, different safeguards equipment may be needed. VLTS facilities could be on-site at a nuclear power plant or off-site in a much larger centralized storage facility. The safeguards criteria for each storage facility will be different. The key technical parameters to be considered in safeguarding spent fuel at a VLTS facility are listed below. These parameters are used to verify the facility declaration by determining the plutonium content of the nuclear material through modeling and NDA.

- Thermal load of spent fuel
- Burnup of the stored spent fuel
- Radionuclide inventory
- Physical integrity
- Fuel/reactor type
- Irradiation and handling records (e.g., cooling time from discharge)

The application of safeguards approaches in spent fuel storage facilities will depend primarily on the type and design of spent fuel being stored. Although the predominant commercial nuclear fuel type today is LWR, there are several other fuel types such as pressurized heavy water reactor (PHWR), gas-cooled reactor (GCR), and Reaktor Bolshoy Moshchnosti Kanalniy (RBMK) that still exist and will have spent fuel that needs to be stored now and in the future. Emerging fuel cycles (e.g., Thorium-based fuel cycle) and reactor types (e.g., small, medium, and pebble-bed reactors) may also need consideration when developing a safeguards approach for the interim storage of spent fuel. Fuel cycle and irradiation history during reactor operation will dictate the post-irradiation characteristics of spent fuel and its safeguards relevant fissile material content.

Besides the safeguards challenges of the material to be stored, there are also challenges with VLTS from a more holistic point of view. Once spent fuel is placed into silos, canisters, or casks for storage, item counting of assemblies and the continuity of knowledge becomes much more difficult because the spent fuel is in a more difficult-to-access form. Verification of the assemblies presents major difficulties based on the currently deployed LWR canister designs. Although some HWR silos have verification tubes for detector insertion, it is still very difficult to detect the partial diversion of fuel assemblies. The traditional split of safeguards techniques into the two major areas of C/S and NDA may not be sufficient to maintain CoK for VLTS due to the difficulty of accessing the material. Therefore, systems which more effectively maintain CoK by combining material measurement and C/S should be explored further for safeguards in VLTS facilities.[19]

The CoK will also be more difficult to maintain over a long period of time. The IAEA requires methods to demonstrate that the cask content has not changed in the event of loss of CoK or as part of periodic routine requirements for reverification. The limited penetration of radiation from the inner assemblies and the interference of neighboring casks when measuring neutrons represent significant challenges when seeking to quantify directly the content of a dry storage by NDA. Therefore, maintenance of safeguards equipment, such as seals and cameras, will have to be consistent to ensure CoK. Concerns of equipment being able to last the entire period of the VLTS facility (50 to 100 years or more) will have to be addressed. Because of the long time period, it is more likely that CoK could fail; and thus, reverification of spent fuel assemblies or casks will be needed.

At present, the IAEA takes a gamma fingerprint at the time of positioning a cask into the dry silo. In the case of reverification, another gamma fingerprint is measured and compared to the original to verify that no nuclear material has been altered or diverted. As the spent fuel is stored for longer periods of time, the gamma fingerprint changes significantly due to radioactive decay and is more difficult to compare to the original fingerprint. The integrity of fuel assemblies or even casks may be compromised over time, presenting challenges to safeguards with regard to reverification. If spent fuel assemblies need to be transferred to new storage containers due to cask degradation over a long period of time, then a strategy for maintaining CoK and performing reverification needs to be considered. The U.S. NRC actually assumes that dry casks will need to be replaced after 100 years of interim storage due to degradation.[20]

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[19] Anita Nilsson, “Safeguards of Spent Fuel in Long Term Storage - A Brief Overview-” Swedish Nuclear Power Inspectorate. http://esarda2.jrc.it/db_proceeding/mfile/P_1992_salamanca_007.pdf.

[20] “Waste Confidence Generic Environmental Impact Statement,” U.S. Nuclear Regulatory Commission, NUREG-2157, August 2013. http://pbadupws.nrc.gov/docs/ML1315/ML13150A347.pdf.

It is likely that the IAEA will face significant resource constraints in the future if the budget remains stagnant and the number of facilities and the amount of nuclear material continues to grow. As discussed previously, VLTS facilities have little movement of nuclear material compared to other facilities in the fuel cycle, especially if the VLTS facility is at capacity. Therefore, the IAEA will likely prefer to allocate resources to more active facilities; and thus, remote monitoring would become the ideal safeguards approach for VLTS facilities. As an example, an IAEA inspection at the Swedish central interim storage facility (CLAB) takes at least two full days when verification of inventory is included.[19] At the traditional safeguards inspection frequency of once every three months (to meet timeliness goals described in Table **1**), this level of effort will not be acceptable in the future as IAEA resources are constrained.

In summary, the main aspects of VLTS facilities that could present safeguards challenges are as follows:

- Varying spent fuel types and storage canister designs
- Difficulty of maintaining continuity of knowledge over a long period of time
- Difficult verification and reverification of spent fuel assemblies due to changing gamma fingerprint
- Difficult detection of gross and partial defects
- Constraints of safeguards resources in the future

5. Potential New Safeguards Approaches for VLTS

With the safeguards challenges outlined in the previous section, it is evident that some new or developing safeguards approaches will need to be utilized for the very long-term storage of spent fuel. An effective safeguards system will involve the State-level safeguards approach. While there will be safeguards specific to the VLTS facility, the facility safeguards will need to be able to contribute to the broader safeguards conclusions. While some of the recommended approaches to safeguarding VLTS are not necessarily novel, they may deviate from current safeguards approaches to interim spent fuel storage. The general goal of the following recommendations for a potential new safeguards approach is to utilize safeguards methods that depend less on inspector presence and more on C/S and remote monitoring.

5.1 Technology Requirements for Safeguards Approach

The utilization of safeguards approaches that rely less on inspector presence and more on containment and surveillance and remote monitoring will require more robust technology than is currently used in traditional interim spent fuel storage safeguards. The following requirements for safeguards technologies need to be addressed before they are employed in the field:

- Resilience and robustness of technology
- Equipment risk analysis
- Transfer of technical knowledge from IAEA inspector to facility operator

- Advantages and disadvantages of technology (i.e., inspector presence/time, maintenance)
- Cost/resource analysis of remote technology versus inspections
- Remote diagnostic and communication ability of technology
- Data management of system
- Maintenance of CoK if the technology fails

Unattended remote monitoring safeguards technology that is currently in R&D is detailed more in the *3.4 Safeguards Technology Research and Development* section on page 9. Maintaining CoK is the most important aspect of safeguards in VLTS once the nuclear material is received and verified. Any UMS technology needs to have a backup plan to maintain CoK if it fails. This can be accomplished by utilizing traditional seals described in previous sections.

5.2 Safeguards Approach Similar to Geological Repository

VLTS has many safeguards challenges similar to those of final disposal of spent fuel in a geological repository. It is recommended that approaches that are planned to be utilized in geological repository safeguards are also evaluated for use in VLTS safeguards. As an example, Sweden and Finland have both adopted the policy of a once-through fuel cycle and they plan to dispose of spent fuel in a geological repository after interim wet and/or dry storage. The two countries are working together and have the same strategy for the final disposal of spent fuel and have also designed a general safeguards approach.

The general safeguards approach to the Swedish and Finnish geological repositories will be to verify the spent fuel placed in waste canisters by NDA and then maintain CoK throughout the final disposal process. NDA verification would likely be done by a portal at the entrance of the facility or disposal tunnels. If the C/S measures for CoK fail after NDA, reverification must be reestablished by NDA. Also, the safeguards system must not interfere with the operator's regular activities. Therefore, NDA measurements after the loss of CoK need to be done without the need for a backflow of material out of the tunnels to the surface of the facility. Dual C/S in the tunnels and during the encapsulation process is instituted to minimize the risk of complete loss of C/S. In addition, fingerprinting casks would enhance the C/S system by making it more robust. Finally satellite imagery is to be used after the geological repository has been closed. Satellite imagery can show if the site is being opened again as an undeclared activity to retrieve spent fuel.[21]

This general safeguards approach for the geological repository can also be used for VLTS. The concepts of a portal monitor with canister fingerprinting, maintaining CoK, and dual C/S all work toward long-term above-ground storage and the safeguards goals. However, there are many challenges still facing this proposed system. Some of the technology to be used is still in R&D. Specifically, an NDA verification system to detect partial diversion from casks or assemblies has yet to be fully developed. The performance of portal monitors at the facility also

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[21] Fritzell, A., T. Honkamaa, P. Karhu, O. Okko, A. Håkansson, and G. Dahlin. 2008. C/S in Final Disposal Processes – Swedish and Finnish Perspectives. *ESARDA Bulletin* 38:10-16.

needs to be investigated further. In addition, detecting diversion with satellite imagery will not work for VLTS as it would for a geological repository. Retrieving spent fuel from deep ground disposal requires a large construction project that could be detected by periodic satellite imagery. However, diverting spent fuel from above-ground storage takes much less time and would require constant satellite imagery that is not publicly available; and thus, would incur a much greater safeguards cost. Other types of remote monitoring should be considered for VLTS.

5.3 Safeguards By Design

Safeguards by design (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. Utilizing SBD for VLTS could allow for more effective and efficient safeguards of the facilities over a longer period of time and with minimal inspector presence. The safeguards approach described in the previous section will require safeguards to be considered in the design phase of the facility. This is especially true for C/S and portal monitoring systems.

Implementation of SBD to interim storage will benefit from consideration of extrinsic and intrinsic factors of the spent fuel and the spent fuel storage facilities. Intrinsic factors, such as fuel and reactor type, and extrinsic factors, such as the State's approach to the nuclear fuel cycle, will need to be considered. The VLTS facility designers and operators will need to engage with the State Regulatory Authority and IAEA. The dialog between the parties involved with the design and implementation process and the IAEA should be interactive throughout all the phases (conceptual design to start-up). Communication between all parties will help to more effectively and efficiently incorporate IAEA safeguards into the design of the VLTS facility.

SBD at independent spent fuel dry storage installations (ISFSIs) has already been outlined in a guidance document written by the National Nuclear Security Administration.[22] Since VLTS facilities are very similar (or the same) as ISFSIs, this guidance document can also be applied for an SBD approach for VLTS. However, the main aspect to keep in mind is that the safeguards approaches for VLTS will be for a longer time period. The key elements of a safeguards approach outlined in the guidance document include:

- Nuclear material accountancy
- Verification of spent fuel receipts
- Verification of spent fuel inventory
- Verification of spent fuel shipments
- Detection of potential facility misuse (including undeclared activities)
- Detection of nuclear material borrowing
- Verification of facility design information

All of these safeguards activities are also required in the safeguards approach for VLTS. Therefore, the SBD approach for ISFSIs may also be applied to VLTS facilities. The first step of

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[22] "Guidance for Independent Spent Fuel Dry Storage Installations," from the Next Generation Safeguards Initiative Safeguards-By-Design Facility Guidance Series; National Nuclear Security Administration. May 2012.

an SBD approach is to design the facility in a manner that will accommodate international safeguards while minimizing interference with the operation of the facility. Figure 1 shows the ideal layout of safeguards equipment for a typical outdoor, above ground dry storage facility. It is important for the facility designer to take into account the safeguards systems while also designing the layout of the security and physical protection systems.

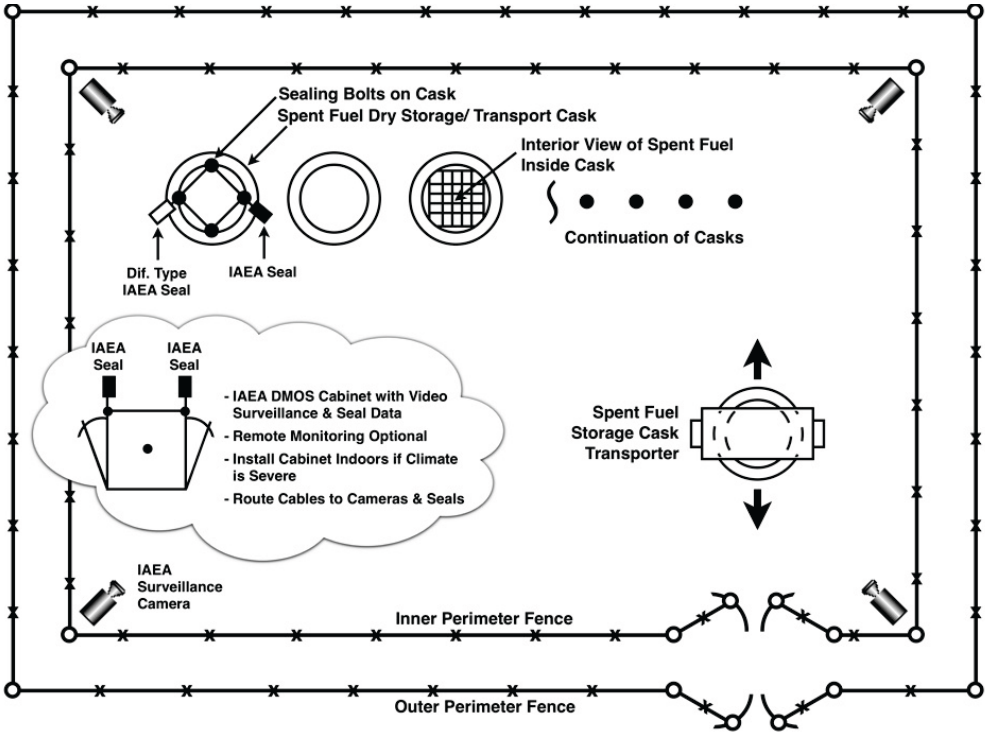

Figure 1: Typical layout of IAEA safeguards equipment for ISFSI[23]

The safeguards systems shown in Figure 1 include two types of IAEA seals per canister and a surveillance system with a clear view of all canisters. In addition, remote monitoring may include radiation detection systems to verify receipt of spent fuel. Since equipment for the reverification of spent fuel once it is in dry storage is currently being developed, it is likely that it will be used for safeguards in the future. Designing dry storage canisters to allow for the insertion of a detector system will make reverification much easier. For example, some storage canisters for CANDU fuel assemblies have a hollow tube inside of the concrete cask to allow for insertion of a detector that can take readings with minimal shielding, which makes the readings far more accurate for reverification. Keeping international safeguards systems in mind during the design phase of both the canisters and VLTS facility will help alleviate the need for retrofitting the safeguards systems into the facility after construction. This would save time and resources for both the operator and IAEA.

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[23] "Guidance for Independent Spent Fuel Dry Storage Installations," from the Next Generation Safeguards Initiative Safeguards-By-Design Facility Guidance Series; National Nuclear Security Administration. May 2012.

5.4 Safeguards Recommendations for VLTS

To effectively safeguard VLTS facilities and the growing amount of spent fuel, the IAEA will need to use limited resources efficiently by reducing inspector presence in the field and by increasing the use of remote and unattended monitoring systems. Since VLTS facilities are relatively stagnant with little nuclear material movement, an opportunity exists for the IAEA to use fewer resources for VLTS safeguards and to focus on other nuclear fuel cycle facilities that have more nuclear material movement. While the move to remote and unattended monitoring is currently underway at safeguards facilities, some technology gaps still exist. In addition, unique safeguards challenges are presented when spent fuel is stored for a period that is much longer than originally expected. Table 2 outlines the current safeguards measures and IAEA approaches for ISFSIs and presents the challenges with VLTS and recommendations. These recommendations are based on some of the safeguards approaches discussed in the previous section, mainly pertaining to safeguards by design and geological repository safeguards. The main recommendations include designing storage casks to make verification less difficult, having robust C/S to maintain CoK with real-time remote monitoring, and utilizing a portal system to verify incoming and outgoing canisters.

5.5 Next Steps for Developing the VLTS Safeguards Approach

The following steps can be taken to accomplish the recommendations outlined in Table 2. These recommendations are based on some of the safeguards approaches discussed in the previous section, mainly pertaining to safeguards by design and geological repository safeguards.

- Develop a comprehensive spent fuel database that contains unique identifiers and tracking of spent fuel. A similar approach has been proposed for the tracking of UF_6 cylinders.

- Study methods and technologies that allow for a robust fingerprinting scheme that is valid and usable over a long period of time to be used for reverification.

- Explore how C/S and NDA can be employed in a combined system to obtain CoK.

- Design casks and canisters that allow for reverification of nuclear material in a way that the removal of whole assemblies or parts of assemblies can be identified.

- Utilize robust integrated surveillance systems with capabilities to collect and transmit real-time data to IAEA headquarters.

- Develop a safeguards by design report for designers of VLTS facilities that may expand on the current ISFSI safeguards by design report.

- Evaluate how the VLTS safeguards will fit into the State-Level Concept Safeguards approach, taking into account transportation between sites.

Table 2: Challenges to the Current Safeguards Approach and Recommendations for VLTS

Safeguards Measures[24]	**Current IAEA Approach**[24]	**Challenges to VLTS**	**Recommendations**
Nuclear material accountancy	Verification of facility operating and accounting records Requires inspector presence	Accounting records contain a large quantity of information over VLTS lifetime	Maintain robust accounting records
Verification of spent fuel receipts	Verification in spent fuel pool before cask loading and then cask is sealed before transfer/shipment to storage facility	Could be long time between spent fuel verification and cask receipt so verification is necessary Requires inspector presence or surveillance	Utilize radiation portal monitor system and remote monitoring
Verification of spent fuel inventory	Random replacement of seals by inspector to detect potential tampering Reverification of spent fuel in casks performed in case of dual C/S failure	Requires inspector presence Reverification of very large amount of casks in case of dual C/S failure	Use ultrasonic seals with real-time tampering indication Design casks verification tube
Verification of spent fuel shipments	Cask is sealed Shipment is verified at receiving facility	Requires inspector presence or surveillance at receiving facility	Utilize radiation portal monitor system and remote monitoring
Detection of potential facility misuse	Dual C/S systems Random verification of declared empty casks by inspector Environmental samples collected by inspector	Dual C/S system could fail if facility is very old Inspector presence required for verification of empty casks and environmental sampling	Have plan to update or replace C/S system periodically Utilize unattended environmental sampling and radiation detection
Detection of nuclear material borrowing	Dual C/S systems	Dual C/S system could fail if facility is very old	Have plan to update or replace C/S system periodically
Verification of facility design information	Physical inspection of facility by inspector	Requires inspector presence	None

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[24] "Guidance for Independent Spent Fuel Dry Storage Installations," from the Next Generation Safeguards Initiative Safeguards-By-Design Facility Guidance Series; National Nuclear Security Administration. May 2012.

6. Conclusion

The expansion of nuclear energy and the growth of nuclear material stockpiles will place a strain on IAEA safeguards in the future. The IAEA will need to use limited resources effectively and efficiently by reducing inspector presence in the field and by increasing the use of remote and unattended monitoring systems. Since VLTS facilities are relatively stagnant with little nuclear material movement, an opportunity exists for the IAEA to use fewer resources for VLTS safeguards and focus on other nuclear fuel cycle facilities with more nuclear material movement. However, unique safeguards challenges are presented when spent fuel is stored for a period much longer than originally expected.

The main aspects of VLTS facilities that could present safeguards challenges include varying spent fuel types and storage canister designs, difficult verification and reverification of spent fuel, difficult detection of gross and partial defects, and constraints of safeguards resources in the future. Therefore, it is recommended that safeguards approaches for VLTS facilities include the following:

- Robust accounting records
- Radiation portal monitoring systems
- Robust cask fingerprinting that is valid and usable over a long period of time
- Ultrasonic seals with real-time tampering indication
- Storage casks designed with verification in mind
- Integrated remote monitoring systems with non-destructive assay (NDA) capabilities that can collect and transmit real time data to IAEA headquarters
- Unattended environmental sampling and radiation detection
- Plans to update or replace the containment and surveillance (C/S) system periodically

The most effective safeguards approach for VLTS facilities will be one that is self-sustaining and that requires little inspector presence. The goal should be to invest most of the cost of safeguards in the beginning of the facility's lifetime and utilize fewer resources for retrofitting and upkeep. A very robust integrated remote monitoring system could reduce or eliminate the need for routine inspections by the IAEA.

If the construction and opening of permanent disposal sites for spent fuel continues to be delayed, it will be important for the IAEA to utilize the recommended safeguards approaches, as interim spent fuel storage facilities inevitably become VLTS facilities. The worldwide plans to expand nuclear energy, constant introduction of new nuclear material to the fuel cycle, and buildup of spent fuel in storage will place immense constraints on IAEA resources in the future.

Appendix A: Embalse Nuclear Power Plant Safeguards Approach for Interim Spent Fuel Storage

The unattended monitoring system (UMS) for interim spent fuel storage at the Embalse Nuclear Power Plant in Argentina (CANDU-type reactor) is described below. Details about the components, data, and inspections are listed.

Components:

- A VIFB detector system (VXI Integrated Fuel Bundle counter for CANDU) — an unattended system that monitors a strategic location in the spent fuel bundle pathway of an on-load refueled power reactor. Collimated gamma-ray detectors detect the fuel bundle as it passes. The proper placement of detectors and the use of the appropriate algorithm for the facility enable the device to count the bundles as they pass — even when two bundles are moving together — and record the direction in which they are moving. This provides high operational reliability and great dynamic detection sensitivity.

- A VIFC detector system (VXI Integrated Fuel Core discharge monitor for CANDU) — a typical unattended monitoring system operating in an inaccessible area. The VIFC detects irradiated fuel upon discharge from the core face of a CANDU reactor. Both neutron and γ-ray intensities are continuously monitored. The inspector, upon reviewing the data, is able to identify in a straightforward, unambiguous manner the abrupt, but characteristic, change in count rate associated with fuel bundle discharge. The review technique is valid for irradiated fuel discharge both when the reactor is powered on and when it is shut down. Because of the linear increase in background signal, the system can also track the operating power level of the reactor.

- A set of NaI directional detector systems inside the spent fuel pond to perform NDA measurements on each fuel bundle being loaded into the basket to confirm that it contains nuclear material as declared by the operator.

- Two underwater cameras that are installed inside the spent fuel pond to confirm that the basket has been filled to full capacity and to make sure that the fuel is following the correct path from the tray to the basket.

- A set of gamma/neutron detectors that are installed inside the welding cell to confirm the presence of nuclear material inside the basket.

    - A set of Mobile Unit Neutron Detectors (MUND) is installed on top of the transport flask to confirm the presence of nuclear material in the welded basket and to account for the time period between the welding station and the dry storage area. An ALIP camera is installed on top of the transport truck for surveillance.

    - A set of four directional Silo Entry Gamma Monitoring systems (SEGM) is set on top of four silos (one system per silo) to perform a NDA measurement and confirm that the basket has been lowered into the silo. They also prevent removal of these baskets before the final welding and sealing of the silo has been performed. A set of ALIP cameras is installed on top of an already sealed full silo, adjacent to the one being filled, for surveillance.

Data:

- All of this data is being stored at the surveillance stations located in the designated safeguards office. These surveillance station cabinets are under IAEA seals.

- The operator fills out a declaration form, with the daily activities, and sends it to the IAEA every week.

Inspections:

- There are announced inspections once every 45 days for a one-week period to review the data at the designated safeguards office, to confirm the information provided by the operator in the declarations.

- There are also unannounced inspections once every 45 days.

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