EFFICIENT IMPLEMENTATION OF SAFEGUARDS BY DESIGN FOR DISPOSED SPENT NUCLEAR FUEL

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Abstract

Challenges for safeguarding a geological repository of spent nuclear fuel pose many high-level opportunities. First, being a relative late-comer among the various types of nuclear facilities subject to safeguards, the geological repository is an ideal candidate for applying "safeguards by design" (SBD).

Second, a repository is unlike all other nuclear facilities such that containment and surveillance (C/S) arguably should constitute the primary safeguards approach, rather than material accountancy.

Several states have already invested many years and resources toward implementing final disposal of spent nuclear fuel in a geological repository. We consider the unfolding safeguards consideration of geological repositories from the perspectives of SBD, safety, security and safeguards (3S), and C/S.

In this paper, a proposed approach for efficient implementation of Safeguards-by-Design (SBD) early into the design process of repository of spent nuclear fuel is proposed. The proposed approach describes the involved parties, their roles and responsibilities, ways of coordination and collaboration as well as main areas to be considered. International best practices in this regards are also presented and discussed.

1. INTRODUCTION

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 revivification 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);
— Unattended environmental sampling and radiation detection;
— Plans to update or replace the containment and surveillance (C/S) system periodically.

There is no internationally or nationally 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 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 revivification 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 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".

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. 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. 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.

2. VERY LONG-TERM STORAGE OF SPENT FUEL

2.1 Methods of Spent Fuel Storage [1]

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.

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.

3. CURRENT IAEA APPROACHES POTENTIALLY APPLICABLE TO VLTS SAFEGUARDS

3.1. Frequency of Inspections [2]

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.” 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”.

The conversion times estimated by SAGSI for different material categories are given in Table 1.

TABLE 1. ESTIMATED MATERIAL CONVERSION TIMES [2]

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 233U 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

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 fulfil 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:

— 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);
— 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 Emblaze 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. 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 an 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.

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.

3.4 Safeguards Technology Research and Development [3]

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 system that can provide more efficient safeguards with real-time 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.

3.4.1 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 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).

3.4.2 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 (CANE1499) 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.

4. CHALLENGES TO A VERY LONG-TERM STORAGE SAFEGUARDS APPROACH [4]

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.

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.

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 revivification. 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, revivification 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 revivification, 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 revivification. 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 revivification 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.

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.

5. SAFEGUARDS BY DESIGN [5]

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.

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 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 [5].

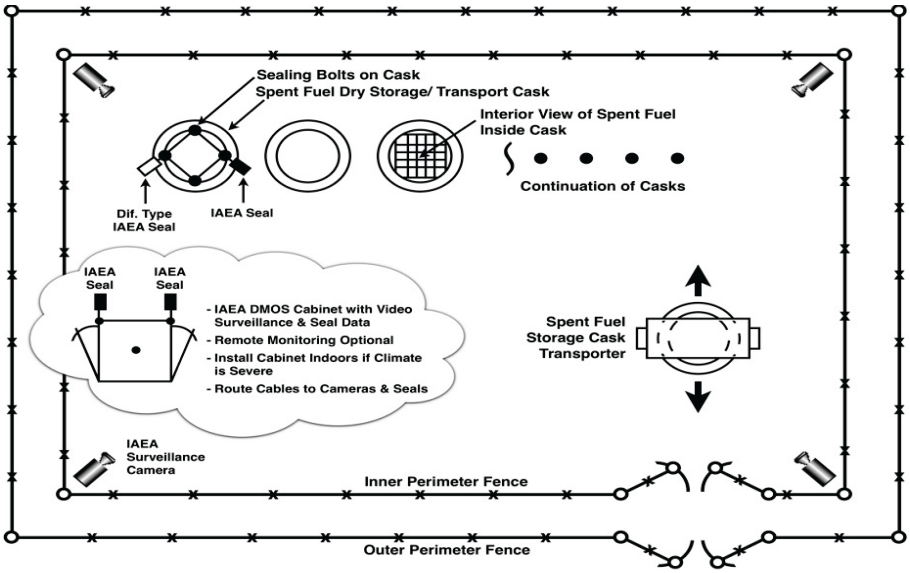

FIG. 1. Typical layout of IAEA safeguards equipment for ISFSI

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 revivification 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 revivification 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 revivification. 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.

5.1 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 UF6 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 revivification;
— Explore how C/S and NDA can be employed in a combined system to obtain CoK;
— Design casks and canisters that allow for revivification 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 safeguard 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 [5]

Safeguards Measures	Current IAEA Approach	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 Revivification of spent fuel in casks per formed in case of	Requires inspector presence Revivification 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

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 revivification 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;
— 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.

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