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Long-Term Information Management (LTIM) of Safeguards Data at Repositories: Phase II

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Long-Term Information Management (LTIM) of Safeguards Data at Repositories: Phase II

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Executive Summary

One of the challenges of implementing safeguards for geological repositories will be the long-term preservation of safeguards-related data for 100 years or more. While most countries considering the construction and operation of such facilities agree that safeguards information should be preserved, there are gaps with respect to standardized requirements, guidelines, timescales, and approaches. This study analyzes those gaps and explores research to clarify stakeholder needs, identify current policies, approaches, best practices and international standards, and explores existing safeguards information management infrastructure. The study also attempts to clarify what a safeguards data classification system might look like, how long data should be retained, and how information should be exchanged between stakeholders at different phases of a repository's lifecycle. The analysis produced a variety of recommendations on what information to preserve, how to preserve it, where to store it, retention options and how to exchange information in the long term.

Key findings include the use of the globally recognized international records management standard, ISO15489, for guidance on the development of information management systems, and the development of a Key Information File (KIF). The KIF could be used to identify only the most relevant, high-level safeguards information and the history of decision making about the repository. The study also suggests implementing on-site and off-site records storage in digital and physical form; developing a safeguards data classification system; long-term records retention with periodic reviews every 5 to 10 years during each phase of the repository lifecycle; and establishing transition procedures well in advance so that data shepherds and records officers can transfer information with incoming facility managers effectively and efficiently. These and other recommendations are further analyzed in thise study.

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NOMENCLATURE

DOE	Department of Energy
SNL	Sandia National Laboratories
LTIM	Long-Term Information Management
C/S	Containment and Surveillance
MC&A	Material Control and Accountancy
IAEA	International Atomic Energy Agency
CoK	Continuity of knowledge
DIQ	Design Information Questionnaire
DIV	Design Information Verification
SNF	Spent Nuclear Fuel
SSM	Swedish Radiation Safety Authority
NAA	National Archives of Australia
OECD	Organization for Economic Cooperation and Development
VLLW	Very low-level waste
LILW-SL	Low- and intermediate-level short-lived waste
ILW-LL	Intermediate-level long-lived wate
HLW	High-level waste
KCT	Knowledge Consolidation and Transfer
RK&M	Records, Knowledge and Memory
KIF	Key Information File
IGM	International Governmental Mechanisms
INGM	International Non-Governmental Mechanisms
INIS	International Nuclear Information System
NEWMDB	Net Enabled Waste Management Database
MoSaIc	Modernization of Safeguards Information Technology
NCL	Non-Conventional Literature
IG	Information Governance

1 INTRODUCTION

The long-term management of safeguards information at geological repositories will be an important aspect of the safeguards approach at these facilities. In a recent study by Sandia National Laboratories (SNL), [1] it was found that specific criteria or requirements on the *types* of safeguards data to preserve, *how* to preserve it, *how long* records should be retained, and *who* should retain the information have not yet been established. The management or governance of safeguards-related data in the long term (100 years or more after closure) will need to take into account a number of factors, including:

- IAEA requirements on safeguards for spent fuel at repositories, which call for maintaining safeguards after the repository has been back-filled and sealed, *for as long as the safeguards agreement remains in force*. [2]
- Domestic records management regulations; and
- Absence of an exisiting, operational repository for high-level waste as a use case.

Analysis of stakeholder needs, best practices, international standards, and existing information management systems could clarify possible requirements for a long-term information management system (LTIM).

1.1 Objective

The purpose of this project is to review findings of the FY15 study, 'Long-Term Information Management (LTIM) of Safeguards Data at Geological Repositories' [1], clarify stakeholder needs, identify gaps in current policies and approaches, identify best practices, and and explore existing safeguards information management infrastructures. The study also attempts to clarify what a safeguards data classification system might look like, how long data should be retained, and how information should be exchanged between stakeholders at different phases of a repository's lifecycle. Finally, the study offers recommendations and options for possible approaches.

1.2 Context

Geological repositories pose a unique challenge to the international nuclear safeguards community in that these facilities lie outside of the normal fuel cycle process. Once encapsulated materials are transported to a repository for permanent disposal, the safeguards approach will focus almost exclusively on containment and surveillance (C/S) as opposed to material control and accountancy (MC&A) due to the inaccessibility of the materials and the long, extended lifecycle of these facilities. Given the unusually long, extended lifecycle of a repository from design through operation and post-closure, both the safeguards approach and the management of safeguards information will require special consideration. Not only will the *type* of safeguards-related information need to be clearly defined, but *how* to retain it (e.g., physical, digital, etc.) and for *how long* will be important questions to clarify for relevant stakeholders.

A geological repository is a zone located several hundred meters below ground that is constructed to ensure the long-term isolation of radionuclides from the biosphere. The facility consists of shafts and ramps, underground tunnels and excavations, emplacement areas (also known as vaults, drifts or caverns), and a container-receiving facility. Like all nuclear facilities, geological repositories must be safeguarded by the International Atomic Energy Agency (IAEA). Moreover, spent fuel disposed in geological repositories is subject to safeguards *indefinitely*, or for as long as the safeguards agreement remains in force. [2] A critical aspect of implementing safeguards for repositories will be keeping track of relevant information related to the entire lifecycle of the facility during pre-operational, operational and post-closure phases. This information will be used to help maintain continuity of knowledge (CoK) of the nuclear material emplaced underground and will inform future generations of the measures taken to assure the absence of undeclared nuclear materials and activities. It could also be used to inform future re-verification in the event material is retrieved prior to back-filling.

1.3 Scope of Study

The scope of this study explores certain gaps in the area of LTIM of safeguards information at geological repositories and possible options for addressing them. Gaps identified in the FY15 study [1] include:

- A lack of clearly defined requirements for maintaining safeguards data at repositories;
- An absence of guidelines on specific safeguards data to be preserved in the long term;
- No defined timescales during which safeguards-related information should be preserved or disposed; and
- No widely accepted plan for maintaining a records- or information-management system for hundreds or thousands of years.

In order to address some of these gaps, this study explores stakeholder needs and best practices, which could be used to inform requirements. It also reviews international standards on records management (e.g., data classification, records-retention schedules), which could address the issue of timescales, and existing safeguards information-management infrastructure and information-sharing options that could inform future LTIM plans. Based on the research and analysis, recommendations are made about options for an LTIM system.

2 STAKEHOLDER NEEDS

2.1 Inspectorate, Regulator and Operator Needs

Stakeholders with relevant equities in the long-term management of safeguards data include the IAEA, European Atomic Energy Community (Euratom), regulators, and operators. They will be responsible for oversight, safeguards inspections, management, and operations of these facilities in the short, medium, and long terms. Their needs with respect to data management will undoubtedly inform future requirements for an LTIM system of safeguards-related data. Requirements generally reflect a documented need about how a particular process or product must perform. They describe how the stakeholder wants to interact with the intended solution, the LTIM system, and what they need that system to do. Better understanding the needs of the IAEA, Euratom, regulators and operators for the long-term management of safeguards data will inform requirements for an LTIM system.

2.1.1 IAEA

The IAEA has identified certain types of safeguards-related data that should be preserved about geological repositories, including:

(a) Design Information:

- Draft plans for a repository;
- Description of intended exploratory underground workings for a repository;
- Information on local buildings which could be used to hide covert activities;
- Information on old local mines
- Detailed 'as built' drawings and technical descriptions of the areas;
- Facilities and equipment in the repository that are of relevance to safeguards;
- Reports from Design Information Verification (DIV) inspections; and
- The State's response to the Design Information Questionnaire (DIQ). [3] [4]

(b) Material Control and Accountancy (MC&A) data:

- Accounting records of nuclear material locations and quantities; [5]
- Verification of facility operating records (Requires inspector presence); and
- Complete records of all activities involving nuclear material (including receipts, relocations within the facility, inventory quantity and location, shipment, etc.)

(c) Containment and Surveillance (C/S) data:

- Record of where cameras, radiation monitors, and tamper-indicating seals are located;
- Schematic diagrams of ultrasonic sealing bolts being used on some spent fuel containers;

– Record of gamma ray and neutron fingerprinting methods utilized to verify dry casks by radiation signatures; and

– Documentation required for visual inspection, unique cask identification, and portal monitoring for the operating repository. [4]

While high-level requirements for records retention of safeguards data at repositories have been considered by the IAEA, they are nearly twenty years old (1997). [3] The additional information needs identified more recently by the IAEA (2003) [4] will help inform detailed, precise requirements. Nonetheless, needs often evolve, so it will be important to maintain a clear understanding of what the Agency wants in terms of an information management system, the types of information to preserve, where the information will be saved, and how it will be maintained for the long term.

2.1.2 Euratom

As an inspectorate and key stakeholder in the geological repository safeguards process, Euratom has needs similar to those identified by the IAEA. Moreover, Euratom has specifically stated that retention of data and knowledge of all nuclear material deposited underground must be preserved throughout "the entire timescale" of geological repository disposal projects. [6] Presumably, this means preserving data about the nuclear materials from encapsulation through emplacement and closure, or indefinitely given that, according to IAEA policy [2], as the post-closure phase never ends. [2] In addition, Euratom has expressed a need for both preliminary data on the basic design and operation of the repository [7], as well as detailed information about the spent nuclear fuel (SNF) to be disposed. In some cases, Euratom may request more than what is legally required, depending on the facility, the type of material to be disposed, and provisions of applicable safeguards obligations of the State. [6] Euratom has also expressed a need to know where the material is placed within the repository. For this, Euratom suggests 3D scanning the entire underground facility and preserving the data in an LTIM system. [6] This data will need to be accessible over the short, medium and long term, and will also need to be compressed. [8]

To summarize, Euratom has expressed a number of needs regarding the management and preservation of safeguards-related data at geological repositories, including:

- Preservation of data about the material to be disposed throughout the entire timescale of the repository;
- Preservation of preliminary data on the basic design and operation of the repository;
- Preservation of detailed information about the SNF to be disposed; and
- Preservation of information on where material is placed within the repository.

All stakeholders will need this information to be accessible over a long period of time, a non-trivial challenge given rapid changes in information technology. This challenge, particularly with respect to the long-term preservation of digital records, has been repeatedly identified by archivist and information-governance professions as a significant risk to organizations across a large swath of industries. For example, according to the Information Governance Initiative (IGI) [32], overreliance on shared network drives for the long-term preservation of digital information creates serious threats to information access because storage solutions like network drives are at risk of hardware and software obsolescence. This could mean that the long-term digital records and information may not be readable or useable in the future, especially given the pervasive lack of strategic planning on how to diversify digital-storage solutions. In addition to accessibility, sustainability will also need to be taken into consideration when developing requirements for an LTIM system. Who is responsible for maintaining and sustaining the information in the long term and whether or not the organizations tasked with preserving the information will dedicate the time, resources and planning necessary are of equal importance.

2.1.3 Regulators

While each State's regulatory system will be unique, some regulators have indicated that certain types of information must be preserved over the long term. In addition to safeguards data, this information will likely be diverse, covering topics such as design information about the repository and canisters, the amounts of material deposited, and the properties of the radioactive contents. [9] In a 2011 study conducted by the Swedish Radiation Safety Authority (SSM) [9], a minimum set of information categories in a national, regulatory record were estimated. It includes:

- Design information about the repository and the canisters. This information should include coordinates, dimensions, tunnels, drifts, shafts, canister positions, the method for sealing and backfilling the repository, etc. This information explains the limitations of use of the repository site. It is also needed if a retrieval of the deposited material becomes necessary.
- The amounts of material deposited in the repository. This includes both bulk material such as copper, iron and uranium, and the smaller amounts of material in the fuel and the fuel cladding. Since it is unclear what types of material will be valuable in the future, even small amounts may be important to declare. The amounts of material should be declared at least on the canister level, together with associated uncertainties.
- Properties of the radioactive contents. This includes the residual heat and levels of radiation as a function of time. [9]

The SSM study also identified fuel data that need to be preserved for state regulatory and national archiving purposes. This would include:

- Isotopic composition: concentrations or masses within a specified uncertainty (could be recorded as "miscellaneous"); concentrations or masses of isotopes accompanied by the maximum uncertainty of each value with relative uncertainty within 5%, with a 99% confidence interval.
- Power reactor operating data for each assembly.

This information could be beneficial for both regulators and inspectorates. For example, the isotopic composition could help inspectorates better understand the types of safeguards that were applied to the material prior to encapsulation. Operating data could be used for future regulators needing to conduct core simulations.

2.1.4 Operators

Operators will have their own criteria for information management and preservation. In most cases, these stakeholders will be concerned primarily with the safety of the facility. However, given their involvement in the safeguards inspection process, operators may also need to preserve safeguards data in the long term. Nonetheless, their primary concern is ensuring that the facility operates as safely and predictably as possible throughout all phases of the facility's lifecycle in order to avoid any disruption to repository activities.

3 BEST PRACTICES

In this section, we explore examples of best practices in information management and how, in addition to those discussed in our FY15 study [1], they could inform a possible future LTIM system. We also analyze the new 2016 International Standard on records management, ISO15489-1-2016.

3.1 National Archives of Australia

Lauded as one of the most ambitious and successful efforts to digitally transform analogue records, the National Archives of Australia (NAA) released its 'Digital Continuity 2020' policy in 2015. [10] It calls for all 'agencies' (e.g., non-corporate and corporate Commonwealth entities, and wholly owned companies including government business enterprises) to transition to entirely digital work processes. That is, business processes including authorizations and approvals are to be completed digitally, and that information is to be created and managed in digital format. This policy promotes a consistent approach to information governance across the Australian Government and within individual agencies. It applies to government information, data and records, as well as systems, services and processes. The new policy operates on three main principles:

1. Information is valued;
2. Information is managed digitally; and
3. Information, systems and processes are interoperable.

The Australian Government recognizes that information is as important as finances, property and equipment. It informs public policy and debate, ensures accountability and underpins how the government conducts business. Thus, digital information managed as a strategic asset makes the Australian Government's digital transformation initiative possible. When information is accountably created, managed, described, and stored, the potential future value of information increases. Future value of information depends on its ability to be used, re-used and shared. In contrast, information that is not appropriately managed is more likely to become unreadable, unusable, and have limited potential future use and value. [10] The lesson for the long-term management of safeguards-related data at repositories is that *the information must be valued and carefully and systematically managed*, whether in paper or digital form. For a geological repository, it could be argued that if the information is of no value—e.g. it will not be used or reviewed by relevant stakeholders—it is not worth expending the resources required to save, organize, archive and maintain for centuries to come. Thus, determining the value of information will be an important part of the requirements-development process.

The Australian 'Digital Continuity 2020' initiative also subscribes to the principle that developing end-to-end digital work processes provides opportunities for agencies to establish more mature and efficient procedures and services that engage the public directly and effectively, while providing opportunities for process improvements and innovation. [10] Their reasoning is that information kept in digital form is more usable and can be shared more easily and at less cost compared to physical hardcopy format.

As previously discussed, for the long-term management of nuclear safeguards-related data, the constant, rapid change in information technology will need to be carefully analyzed before taking a certain approach, including going strictly digital. While it is likely that the majority of safeguards-related data at repositories will be generated and stored digitally, it is impossible to know what will and will not be accessible in the next one hundred years and beyond. Moreover, should a strictly digital approach be adopted, the appropriate resources will need to be allocated to maintaining, upgrading, and consistently transferring information to readable systems. For example, information stored on floppy discs in the 1980s and 1990s eventually had to be transferred to compact discs (CDs). When CDs became less desirable, information was migrated to the 'cloud.' We do not yet know if this form of digital information storage will be sustainable in the very long term. And while it is presumably cheaper than physical, hard copy data storage, it will still require the time and effort of dedicated records management individuals and organizations to maintain it. Moreover, other challenges such as cybersecurity of digital data will require dedicated resources to ensure the integrity, authenticity and security of the information. These are important considerations that will need to be taken into account when considering an LTIM system and do not necessarily guarantee that digital data storage will be more efficient and less costly over the long term. Should digital be the preferred medium, repository stakeholders will need to carefully select what type of digital system will be used (cloud vs. network drive vs. standards-based digital preservation system).

3.2 OECD/NEA Records, Knowledge and Memory (RK&M) Project – Phase II (2014-2017)

As noted previously and in the FY15 study [1], one gap in LTIM of safeguards data at repositories includes a lack of a *widely accepted plan* for an LTIM system. One option for addressing this gap is to examine current research and analysis being done by the Organization for Economic Cooperation and Development (OECD) on knowledge consolidation and transfer (KCT) with respect to radioactive waste and geological repositories. Initiated in 2009, the proposed initiative recognized the importance of preserving information and marking a waste repository site such that future generations have the ability to make informed decisions about how to manage these facilities and their content. In conjunction with a 1999 IAEA technical report on requirements for preserving information on radioactive waste [11], the 2009 OECD proposal evolved into the Records, Knowledge and Memory (RK&M) project. This international effort, which focuses on developing an approach to long-term knowledge and information management at repositories, is now in Phase II (2014-2017), which will continue to explore options and best practices for records retention at geological repositories [12]. This phase will examine certain priorities, such as archives, development of a key information file (KIF) with critical repository information, international mechanisms, and the transfer of responsibilities.

3.2.1 RK&M Archives

In phase II of the RK&M initiative, participating organizations' experiences with and expectations in relation to archives in their countries, especially national archives, will be examined. RK&M members will provide an overview of current relations with archives. These overviews will be used to develop an understanding of how national archives can contribute to

RK&M preservation. As archives traditionally work in a historical perspective, there is a possible need for dedicated nuclear archives that take safety aspects into account. In addition, the RK&M initiative is building up a working relationship with representatives of national archives in order to examine preservation and accessibility issues with these specialists. [13] If the international nuclear-safeguards community decides to develop an LTIM system for safeguards data, it would be beneficial to include such data in the RK&M 'nuclear archives' initiative. At a minimum, those leading the RK&M effort should be consulted.

3.2.2 RK&M Key Information File

The KIF corresponds to the top level of a three-tiered information system, consisting of the following levels:

- A *basic level* consisting of documents sent to the archives as a result of legal and regulatory requirements. Typically, public bodies have to send all the documentation in their internal archives to the national archive. This documentation goes beyond safety-case documents.
- A *second level* at which a selection would take place that aims at extracting the documents that are related to the post-closure safety. These documents would be identified as such and also kept in the national archives and elsewhere.
- A *top, third level* which would consist of a summary of the previous documentation in a format and language accessible to a public of non-specialists. The summary (KIF) would contain information not necessarily limited to safety, but referring also to the history of decisions about the repository. [13]

The RK&M initiative will develop a table of contents for the KIF. Existing national examples of similar documents, such as the French radiation safety authority's synthesis document based on documents related to its *Centre de la Manche* disposal facility, will serve as useful references. In a following step, the table of contents will be tested among participating organizations. [13] If the international nuclear safeguards community decides that a widely accepted, systematized plan for an LTIM system is a worthwhile investment, the KIF and its table of contents will be an important reference point. Its benefit will be twofold: 1) provide a template of a possible LTIM system, and 2) help prioritize the types of information to be preserved, i.e., the key, essential safeguards-related information that will be important for future decision making.

3.2.3 International Mechanisms

The RK&M initiative reviewed international mechanisms that could be used to collaborate on and/or adapt to specifics in the field of radioactive waste management to help preserve information about repositories. [13] These mechanisms were divided into two categories: international governmental mechanisms (IGMs) and international non-governmental mechanisms (INGMs). The former consists of entities and activities that are based on mutual agreements between a number of national governments. The latter consists of entities and activities that bring together non-governmental, private or commercial organizations. For a safeguards LTIM system, the IAEA and/or Euratom could be the IGM that adapts or hosts the information preservation system. This would help establish a central mechanism whereby all

States with plans to develop geological repositories would send their relevant safeguards-related data to a central database, archive, or cloud-based system.

3.2.4 Transfer of Responsibilities

The question of transferring responsibilities during a repository's three major lifecycle phases has been significant for the RK&M initiative. This is typically the period of time in which organizations demonstrate a willingness to continue maintaining oversight of the facility. It is also when responsibilities are handed over to another institutional body that much information is lost. [13] Similarly, for an LTIM system that will exist over an extended period of time, the transfer of responsibilities throughout the repository lifecycle phases will be critical to the management of safeguards information. For example, when the repository lifecycle moves from the operational phase to the post-closure phase, and oversight responsibility at the site shifts from the operator to the regulator or a contractor, procedures will be needed for the change in information management responsibility. It might also be useful to outline how resources will be allocated to support this activity. Such procedures and thoughtful, advanced budgeting and strategic planning by the appropriate international mechanism could support a more widely accepted LTIM plan.

3.3 France

France has specific regulations governing information management of radioactive waste data. The French National Radioactive Waste Management Agency (Andra) maintains specific guidelines and rules on information preservation at various facilities containing radioactive waste. For "very low-level" facilities, a standard archiving system that preserves information for a 30-year monitoring period is sufficient. For a "low- and intermediate-level" facility, information is to be preserved for *three centuries* after the beginning of the monitoring phase. And for "high-level" waste repositories, the regulatory guideline is *five centuries* after the closure of the facility. [14]

Andra is also planning a phased approach to long-term memory preservation. In the initial phases of the repository lifecycle, a short book (less than 200 pages) will be drafted for an international audience, including the public and decision-makers. This short reference book will contain general information about the site and will be updated every ten years. In a second phase, Andra plans to develop detailed documentation to answer questions about future scenarios in order to help operators and managers understand various physical, environmental, social, historical, and safety data related to the site. This document will likely contain around 500,000 pages of information, with new data added every five years. In the short term, i.e., within the next few decades, Andra plans to manage information about various repository facilities through a digital database. For LTIM, however, Andra does not plan to digitize *all* of its data and will instead select certain information to preserve for future generations on "permanent paper" to be printed every five years. One copy will be stored at the French National Archives, and one will be kept at the disposal facility. Owing to challenges with technology obsolescence, Andra does not consider digital technologies and databases to be an exclusive solution for long-term data preservation.

Andra has also developed a so-called 'synthesis report' [15] that offers a detailed description of all current and future radioactive materials and waste found in France. This report outlines radioactive materials and waste management efforts, legacy situations, and special reports on topics such as existing or planned solutions in France for long-term management of radioactive waste. The report is one of five volumes of the French national inventory of radioactive materials and waste. The inventory itself provides a snapshot of the nature, quantity and location of radioactive materials nationwide that is as complete and exhaustive as possible. Updated every three years, the national inventory constitutes a valuable tool for guiding radioactive materials and waste management policy in France. It also fulfills the European Union directive to establish a national program for the management of spent fuel and waste in each Member State. Assuming most States with repository plans have similar inventory requirements, it would not be difficult to add safeguards-related data to the system for LTIM or archiving purposes.

France has also pursued other thought-provoking concepts regarding long-term data management. In 2012, Andra worked on the development of a sapphire disk onto which information is engraved using platinum [16]. Made from two thin disks of industrial sapphire, the team of scientists who developed the technology claimed it will last 1 million years or more. Data is etched in platinum onto one side of one of the disks, before the other is placed on top to form an information sandwich. Then, the disks are molecularly fused together and a single disk can store 40,000 miniaturized pages. Future archaeologists would only need to rely on a microscope, rather than digital technology or a computer device, to read the material. Based on acid tests for durability and to simulate aging, the scientists believe the disk can survive at least 1 million years. Should the sapphire disk successfully complete testing and go to commercialization, it could provide a unique solution for long-term information management of safeguards data at repositories.

3.4 International Standard on Records and Data Management: ISO15489

The internationally recognized standard on information, documentation, and records management, ISO15489, will be an important reference for a safeguards LTIM system as it establishes certain broad guidelines and criteria for managing information. It consists of two parts: ISO15489-1:2016, the document establishing the core concepts and principles for the creation, capture and management of records, and ISO15489-2:2001, the implementation guide. While it is still likely that specific requirements for the safeguards-related data will be needed, ISO15489 could inform the LTIM framework.

ISO15489-1:2016 was developed in response to consensus among participating ISO member countries to standardize international best practices in records management. It provides guidance on managing records of originating organizations, public or private, for internal and external clients. ISO15489-1:2016 covers topics such as records management requirements; design and implementation of a records system; records management processes and controls; and monitoring and auditing. The records management guidelines, ISO15489-2:2001 provide an actual methodology to facilitate the implementation of the concepts and principles outlined in ISO15489-1:2016. It provides an overview of the processes and factors to consider in organizations wishing to comply with ISO15489-1. Specifically, ISO15489-2 examines a step-by-step process to design and implement a records management system. Steps include:

A. Preliminary investigation (provides an organization with understanding of administrative, legal, business and social contexts in which it operates in order to create and maintain records);
B. Analysis of business activity (develops a conceptual model of what an organization does and how it does it);
C. Identification of requirements for records (identify an organization's requirements to create, receive and keep records of its business activities, and to document requirements);
D. Assessment of existing systems (survey an organization's existing systems for records and any other information systems to measure the extent to which they capture and maintain records of business activity);
E. Identification of strategies for satisfying records requirements (determine the most appropriate policies, procedures, standards, tools and other tactics that an organization should adopt to ensure that it makes and keeps the necessary records of its business activity);
F. Design of a records system (convert strategies and tactics selected in the 'identification of strategies' process step into a plan for a records system that fulfills requirements);
G. Implementation of a records system (systematically identify and put in place an appropriate mix of strategies to implement the records system), and
H. Post-implementation review (measure the effectiveness, evaluate, and monitor the records system).

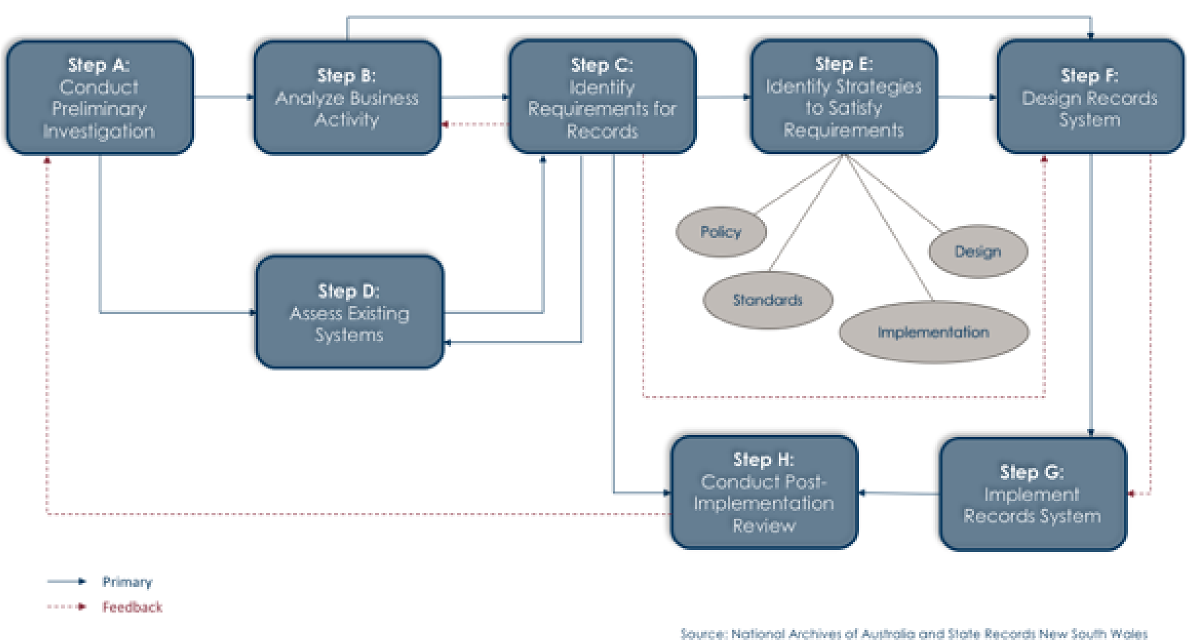

Figure 1. ISO15489-2 records management process

Repository stakeholders tasked with information governance or management could use this process to establish their own LTIM system.

4 EXISTING SAFEGUARDS INFORMATION MANAGEMENT INFRASTRUCTURE

Already established information management infrastructure may be an option for the storage, maintenance and archiving of safeguards-related data from geological repositories. Rather than starting from scratch to develop and implement a new LTIM system, it may be advantageous, efficient, and less time consuming to leverage existing systems. Two options are the IAEA's International Nuclear Information System (INIS) and its Net Enabled Waste Management Database (NEWMDB), and the Modernization of Safeguards Information Technology (MoSaIc) project.

4.1 IAEA International Nuclear Information System (INIS) and the Net Enabled Waste Management Database (NEWMD)

The IAEA's INIS hosts one of the world's largest collections of published information on the peaceful uses of nuclear science and technology. With over 3.8 million bibliographic records, it offers online access to a unique repository of non-conventional literature (NCL) of over 350,000 full-text documents such as scientific and technical reports, conference proceedings, patents and theses dating back to the 1970s that are not available through commercial channels. [17] While INIS provides a plethora of information on various aspects of the nuclear fuel cycle, including research and publications on geological repository safeguards, membership is required to gain access to full text NCL documents. In order to become a member, a formal request must be made by the appropriate national/institutional authority to the Director General of the IAEA, expressing an interest to participate in INIS and undertaking to supply literature input regularly to the System. [17]

With respect to the use of INIS as a possible long-term storage option for repository safeguards information, a few factors should be considered. First, access to the information will be critical. While safeguards information should be easily accessible, it should also be limited to those with a need-to-know in order to protect any sensitivities such as safeguards confidential information identified by facility operators or regulators. The INIS membership would allow IAEA Member States with repository programs the ability to maintain some form of access control, but they would also need to decide if the level of access provided through INIS is appropriate. Second, the question of technology obsolescence, as discussed in the FY15 study [1], should be taken into account. Ensuring that INIS is still accessible through the internet or a cloud-based system in 10 to 20 years and longer will require regular maintenance, updates, and committed resources, which are most likely planned. However, maintaining this kind of access for hundreds or thousands of years will take significant thought and strategic planning on behalf of the IAEA. In fact, in the Information Governance (IG) profession, there is significant concern that technology (hardware) and software obsolescence could mean that long-term digital records and information are at risk of not being readable or usable in the future. [18] Strategic planning will be needed to determine how best to host the information in a sustainable, accessible and protected manner. Third, hosting a database of geological repository safeguards-related information on INIS may not be enough. Including the context for the various types of information will also be important. That is, how documents are related to one another, which are the most important, why they have been saved, and how long they should be preserved will be useful information for future generations.

Given the above mentioned factors, one option could be to host an LTIM system for repository safeguards data using the IAEA's NEWMDB. This system provides a platform for Member States to store information on national radioactive waste management programs, radioactive waste inventories, radioactive waste disposal, relevant laws and regulations, waste management policies, and plans and activities. [19] While much of the information on NEWMDB is open source, some of it, such as waste management infrastructure, strategies, and future plans, are kept private to protect facilities for either proprietary or security reasons. Given that the system is digitized, similar technology obsolescence challenges will need to be addressed through long-term strategic planning and consistent maintenance. However, the infrastructure is already in place to store safeguards-related data if necessary.

4.2 IAEA MoSaIc System

A possible third option for hosting an LTIM system using existing infrastructure is the IAEA's MoSaIc project. The MoSaIC project is an effort by the IAEA to build a collaborative, secure, and efficient IT system that strategically enables the implementation of safeguards. With the first phase of the project completed in May 2015, MoSaIc seeks to enhance existing IT tools and applications, introduce new IT tools and applications, and strengthen information security at the IAEA. [20] Over 60 million records have been migrated from an old to a new system called the 'Integrated Safeguards Environment' (ISE). This migration effort included replacing computer hardware and software, modernizing some of the processes, and training the users about the new system. [21] Assuming the ISE platform is regularly maintained to avoid the technology obsolescence issue, it could be a logical place to host an LTIM system for repository safeguards information.

5 SAFEGUARDS DATA CLASSIFICATION SYSTEM

This section explores the concept of a safeguards data classification system for geological repositories. It examines the following topics:

1. Definition of a safeguards data classification system;
2. Existing data classification systems employed by IAEA Member States planning to develop geological disposal systems; and
3. Information classification approaches based on material type and lifespan.

For the purposes of this discussion, we will define classification as the systematic identification and/or arrangement of business activities and/or records into categories according to logically structured conventions, methods, and procedural rules. A safeguards data classification structure within the LTIM system would likely include records on the types of nuclear waste encapsulated and emplaced in the repository, the characteristics of the waste, and the safeguards approaches applied. It might also include information identified by the IAEA as being important to the repository safeguards approach, such as DIV, PIV C/S and MC&A data as well as where nuclear material is emplaced in the repository itself.

Existing data classification systems in areas such as spent fuel management are useful benchmarks for a possible safeguards classification system at repositories. For example, per the requirements outlined in the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [22], IAEA Member States who have joined the convention are obligated to submit annual reports with an inventory of spent fuel that is being held in storage, including a description of the material and other appropriate information available, such as volume or mass, activity and specific radionuclides. These inventories typically classify data on waste into five categories:

1. Very low-level waste (VLLW)
2. Low- and intermediate-level short-lived waste (LILW-SL)
3. Low-level long-lived waste (LLW-LL)
4. Intermediate-level long-lived waste (ILW-LL)
5. High-level waste (HLW)

At geological repositories, international nuclear safeguards are applied to power reactor and research reactor spent fuel for which no further use is foreseen, and to wastes containing unirradiated uranium, thorium, plutonium and other materials of safeguards concern. [23] In States with the full range of nuclear fuel cycle activities, wastes could include contaminated materials, manufacturing and processing waste, decommissioning waste, spent fuel reprocessing waste and unreprocessed spent fuel. The waste may be in either solid or liquid form prior to its disposal and are also likely to contain non-radioactive toxic substances. Some waste materials may be excluded, however, if they cannot be shown to be safe in the environment of the disposal facility. [23] A safeguards data classification system that takes into account the various types of waste material, characteristics, radiation levels, and safeguards applied to them will be an important component of an LTIM system at repositories. Table 1 illustrates an example of how such data might be organized and classified.

Table 1. Radioactive waste/spent fuel subject to geological disposal [23]

	Waste/spent fuel type	Characteristics	Radiation level	Safeguards Applicability	Comments
1.	Power reactor spent fuel (irradiated LEU and MOX)	Irradiated LEU fuel pellets contained in Zr cladding assembled into assemblies or consolidated into spent fuel packages	High gamma and neutron emissions.	Not subject to termination of safeguards after emplacement.	Safeguards measures defined by generic IAEA safeguards approaches.
2.	Research reactor spent fuel (irradiated HEU and LEU)	Cores from research reactors and critical assemblies in various forms and configurations	Low to high gamma emissions.	Not subject to termination of safeguards after emplacement.	Safeguards measures defined by generic IAEA safeguards approach.
3.	Unirradiated U, Th and Pu bearing waste	Various process wastes and scrap from nuclear fuel cycle manufacturing activities.	Low gamma and neutron emissions.	Subject to termination of safeguards only in very low concentrations and quantities.	Safeguards measures derived from generic IAEA safeguards approaches for spent fuel
4.	Vitrified high level waste.	Fission products and transuranic activation products resulting from reprocessing activities.	High gamma and neutron emissions.	Termination of safeguards expected at reprocessing facility before shipment to repository.	Radiation levels similar to those of power reactor spent fuel.
5.	Irradiated reactor and fuel components	Fuel assembly skeletons and end caps, control rods and guide tubes, leached hulls, internal reactor components.	Low to high gamma emissions.	Not subject to safeguards	Radiation levels may be similar to those of power and research reactor spent fuel.

	Waste/spent fuel type	Characteristics	Radiation level	Safeguards Applicability	Comments
6.	Other highly radioactive or long lived radioactive waste (non-U, Th or Pu bearing).	Various wastes from industrial and medical uses of radioactive materials.	Variable gamma and neutron emissions.	Not subject to safeguards.	Radiation levels may be similar to those of power and research reactor spent fuel.

For the purposes of LTIM, a classification system that categorizes information on waste and its corresponding applied safeguards could help establish both the types of information to be preserved and retention schedules. Depending on stakeholder needs and requirements, data classified in rows 1-4 of Table 1 could be considered relevant for an LTIM system.

6 RECORDS RETENTION SCHEDULES

In the context of a geological repository's lifecycle, which can span hundreds to thousands of years or more, the concept of records retention schedules is somewhat abstract. That is, requirements may be established for retaining records for tens of thousands of years, or permanently, but the actual process of determining the timespan during which records should be retained necessitates some review. Fortunately, there is guidance on determining what records should be retained and for how long. ISO15489-2, Section 4 (records processes and controls) provides specific guidance on records management operations, including how to determine which documents to be captured in a records system, and how long to retain them.

Determining what records should be captured and how long they should be kept is most effectively undertaken in a systematic way and according to laws and regulations (which may be country-specific, specific to different types of organizations or industries or related to certain products). According to ISO15489-2, instruments to standardize the decision-making may range from guidelines identifying what documents should be destroyed or captured into a records system to a formally approved schedule of classes of records, retention periods and appropriate disposition actions that is submitted for approval by an external authority. In some countries, the disposition authorities may prescribe permanent preservation, either within the organization or in a separate archives institution. In electronic records systems, the determinations about capture and retention should be considered in system design at the outset.

In order to determine what safeguards-related data at a repository should be preserved, stakeholders could, again, turn to ISO 15489-2 and analyze their organizational internal and external environments and identify the corresponding business functions and activities related to the safeguards records. For example, safeguards or repository records managers may consider doing the following:

a) Identify the broad level of records that need to be created to administer and manage each safeguards-related activity;
b) Identify the parts of the organization in which the safeguards records of the activity are captured;
c) Analyze the business activity to identify all constituent steps that make up the activity;
d) Identify all transactions that comprise each step in the business activity;
e) Identify the safeguards data required in the process of the transaction;
f) Determine the need to capture evidence of each transaction, and
g) Determine the appropriate point at which the record is to be captured. [30]

A key aspect of determining what safeguards-related data to keep and what to discard will be a *risk analysis*. For instance, should a repository organization decide not to require formal records capture of a specific type of safeguards-related data, it will need to assess the risk arising from having incomplete records. Risk management decisions should be a result of analysis of the regulatory and compliance environment, as well as perceived risk to the repository organization (operator and/or regulator). Ultimately, the records created or captured at the repository need to have a retention period assigned, so it is clear how long they should be maintained. [24]

ISO15489-2 also provides guidance on how to determine how long to retain records. The guidelines provide a five-stage analysis:

a) Determine the legal or administrative requirements for maintaining records within the system.
b) Determine the uses of the record within the system.
c) Determine the links to other systems.
d) Consider the broad range of uses of the record.
e) Allocate retention periods to the records on the basis of the total system evaluation. [24]

This analysis should be revisited on a regular basis (every 5 to 10 years) to determine if retention periods need to be revised. Moreover, the primary stakeholders (IAEA, operators and regulators) need to decide on retention records for safeguards information in the short, medium, and long terms.

6.1 Short Term

Short-term records retention would likely include a period of a few decades, or at least while the repository is in the pre-operational phase of planning (site selection, etc.), construction, and commissioning. This phase is expected to last appeoximately 10 to 20 years, although some early exporatory and research and development (R&D) efforts may effectively extend this to considerably longer. The retention of safeguards-related records during this period may not be as critical of an issue compared to later phases due to the fact that safeguarded nuclear materials will not yet be emplaced in the disposal facility.

6.2 Medium Term

Medium-term records retention would likely involve a longer period of time, up to 100 years or more, as it will involve excavation, as well as receipt, transfer and emplacement of disposal canisters in tunnels, backfilling, and closure. This operational phase might be one of the most crucial times for records preservation and retention schedules should be reviewed at least once every 10 years.

6.3 Long Term

Finally, the post-operational phase is when the long-term management of safeguards information should be considered for an LTIM system. This phase begins after final closure and permanent sealing of the geological repository facility. At this point, repository drifts, tunnels, shafts, and boreholes are backfilled and sealed, and surface installations are decommissioned. As noted in our previous study [1], this period broadly covers the timeframe after closure for at least 1,000 years. As it will be difficult to imagine what information management at this stage might entail, a starting point might be the records retention schedule established at the end of the operational phase, with periodic reviews every 5 to 10 years. Moreover, as discussed in our previous LTIM study, the “3-2-1” rule should also be considered. That is, at least three different copies of the most critical safeguards-related data in the KIF should be made in two different formats, with one of those copies stored off-site. While these are high-level suggested options, it is nearly impossible to predict how information will be managed or governed so far into the future, much less whether or not retention schedules will be established. In fact, the question may be mute given the IAEA's policy on the final disposal of spent nuclear fuel [2] which calls for the maintenance of safeguards "after the repository has been back-filled and sealed, and for as long as the safeguards agreement remains in force." In other words, if safeguards are applied in perpetuity, stakeholders will need to determine whether or not safeguards records are also retained forever, or if set retention schedules should be applied. It may be a question that can only be answered once facilities reach the end of the operational phase.

7 INFORMATION SHARING OPTIONS

The method and medium used to share safeguards-related information from a geological repository will depend on several factors. One of the most important factors with respect to the exchange of information will be the role of the data shepherds, or the records management officers assigned to the repository. Stakeholders will need to identify who the data shepherds will be as they will be responsible for the transfer of information between organizations at different phases of the repository lifecycle. Thus, data shepherds should be tasked with ensuring that vital information about a repository, including the safeguards data in the KIF, is protected, preserved, and made accessible to whoever will oversee the closed facility over the long term.

With respect to the information medium, stakeholders are likely to use both physical and digital mediums for information sharing and preservation. However, as the digital age continues to dominate and overtake the physical approach to records keeping, it will be important to have a palpable, realistic strategy for retaining critical information while also managing the challenge of rapid technology change over the long term.

For hard copy records, storage, handling and sharing processes should take into account their special physical and chemical properties of the records. Records of continuing value, irrespective of format, will require higher quality storage to preserve them for as long as that value exists. Storage conditions and handling processes should aim to protect records from unauthorized access, loss or destruction, and from theft and disaster. Each geological repository facility will need to have policies, procedures and guidelines for information storage and handling of physical, hard copy records, including guidance on converting and migrating records from one system or management organization to another.

For electronic or digital records, ISO defines similar standards, noting that systems that use electronic media should be designed so that records will remain accessible, authentic, reliable, and usable through any kind of system change, for the entire period of their retention. [31] This may involve migration to different digital systems as technology evolves. Thus, any LTIM system incorporating safeguards data will need to take such adaptability measures into consideration. As previously mentioned, one aspect of this process will involve data shepherds charged with identifying what safeguards-related information needs to be shared and by whom, how the information will be shared, and whether or not any data can be discarded.

Data shepherds responsible for records management during each phase of a repository's lifecycle will have an important, challenging mission to fulfill. In particular, once a repository enters the post-operational phase and management of the facility is transferred from one organization to another, a defined transition procedure will help the responsible data shepherds take the necessary steps to exchange safeguards information with the incoming facility manager. Given that it is difficult to predict how information will be managed and exchanged 100 or even 1,000 years from now, it may only be possible at this stage to consider some general approaches.

As a first step, repository operators and regulators should engage in information management or governance strategic planning long before a repository is closed. As part of this process, and in addition to the records management procedures defined in ISO15489, the team of data shepherds might consider a two-step approach:

1. Prioritize
    a. Identify records and information vital to a repository's history, such as the KIF (see section 3.2.2).
    b. Assign governance procedures and timescales to each category of information.
    c. Determine criteria for what information, if any, can be discarded.
2. Categorize and phase
    a. Categorize information based on content, anticipated use, and physical condition.
    b. Establish a phased procedure to share vital information with the incoming organization responsible for overseeing the repository site post-closure.

Precisely *how* information is exchanged between responsible parties is difficult to predict at this stage as we simply do not know what information management will look like 100 or more years from now. Thus, only general recommendations, such as those above, can be made.

8 CONCLUSION AND RECOMMENDATIONS

The application of safeguards at geological repositories will pose a variety of challenges for stakeholders involved in the construction, operation and closure of these facilities given their unique makeup and long lifespans. One of these challenges will be the long-term preservation of safeguards-related data for 100 years or more. While most countries considering geological repositories agree that information should be preserved, there are gaps with respect to standardized requirements, guidelines, timescales, and approaches. This study analyzed those gaps and explored research to clarify stakeholder needs, identify gaps in current policies and approaches, identify best practices and international standards, and explore existing safeguards information management infrastructure. The study also attempts to clarify what a safeguards data classification system might look like, how long data should be retained, and how information should be exchanged between stakeholders at different phases of a repository's lifecycle. The analysis produced a variety of recommendations on what information to preserve, how to preserve it, where to store it, retention options and how to exchange information over the long term.

8.1 *What* to Preserve

The primary stakeholders who will be involved in the preservation of safeguards-related information will be the IAEA, Euratom, facility operators and regulators. Our analysis found that better understanding the needs of these stakeholders with respect to safeguards information will inform requirements for an LTIM system. At a high-level, those needs include the preservation of:

- Design Information Verification (DIV) data
- Material Control and Accountancy (MC&A) data
    - Accounting records of nuclear material locations, quantities, isotopic composition
- Containment and Surveillance (C/S) data
    - Record of where cameras, radiation monitors, and tamper-indicating seals are located
- Information on location of buried spent nuclear fuel in the repository

In addition to the above types of information, our analysis found that, for any records management system, stakeholders need to consider the information's *value* in terms of *whether or not it will actually be used or reviewed by future stakeholders*. Thus, when a record is considered for long-term preservation, there should be careful consideration placed on how it might be used and whether or not it could be of value to the next generation.

Another approach to help clarify what information to preserve is to develop a safeguards data classification system. This system would take into account the various types of waste material, characteristics, radiation levels, and safeguards applied to them. A classification system that categorizes information on waste and its corresponding applied safeguards could help establish both the types of information to be preserved and retention schedules.

8.2 *How* to Preserve Information

When exploring how to preserve safeguards-related information, we turned to both international standards and examples of best practices. ISO15489-2, the step-by-step guide to designing and implementing a records management system, provides useful insight into how a safeguards information management system could be developed. The process would involve an investigation of exisiting information management systems at the repository organization, an analysis of the organization's activities, identification of records requirements, an assessment of existing systems and, ultimately, the design and implementation of a records system (see Figure 1.)

Based on current best practices, our analysis found that Phase II of the OECD's Records, Knowledge and Memory (RK&M) project provides useful insight into long term knowledge and information management at repositories. Specifically, the RK&M project has identified what is known as a Key Information File (KIF), which is the top level within a three-tiered information system, that summarizes archived and post-closure safety documentation. The KIF is formatted and written in a language accessible to the public and includes both relevant safety information and the history of decision making concerning the repository. We posit that the the KIF could be used as possible template for an LTIM system for safeguards data. It could also help prioritize the types of information to be preserved, i.e., the key, essential safeguards-related information that will be important for future decision making.

8.3 *Where* to Preserve Information

Identifying where information should be stored in the long term will also likely be an important challenge. While in the short- and medium-term, most records will be stored on site by the facility operator and/or regulator, over the long term, we suggest that the IAEA and/or Euratom host the information preservation system. This would establish a central mechanism whereby all States with plans to develop geological repositories would send their relevant safeguards-related data to a central database, archive, or cloud-based system.

At the IAEA, there are two options: the NEWMDB and MoSaIC's Integrated Safeguards Environment (ISE). Assuming the ISE platform is regularly maintained to avoid the technology obsolescence issue, it could be a logical place to host an LTIM system for repository safeguards information.

8.4 *How Long* to Preserve Information (Retention Schedules)

Retention schedules are another important aspect of records management, particularly for geological repositories given their long lifespans. We propose the following recommendations:

1. Follow ISO15489-2 guidelines on retention based on legal requirements, use of records in the system, and links to other systems. Review analysis every 5-10 years.
2. Retain safeguards-relevant data throughout the operational phase. Review records and retention schedules at least once every 10 years.
3. Initiate long-term records retention schedule based on that which was established at the end of the operational phase with periodic reviews every 5 to 10 years. Implement 3-2-1

rule (three copies, two formats, one copy stored off-site) to avoid challenges with exclusively digital information.

8.5 How to *Exchange* Information Over the Long Term

The exchange of information between lifecycle phases of a repository will also be an important consideration, especially given that information is often lost when responsibility shifts from one oversight organization to another. Based on international standards and best practices, we found that procedures will be needed for the change in information management responsibility. It might also be useful to outline how resources will be allocated to support this transition. Such procedures and thoughtful, advanced budgeting and strategic planning by the appropriate mechanism could support a more widely accepted LTIM plan. Specifically, we recommend that repository organizations establish transition procedures well in advance so that data shepherds and records officers can exchange information with incoming facility managers effectively and efficiently. We also recommend that repository organizations follow ISO15489-1 guidelines, which note that systems that use electronic media should be designed so that records will remain accessible, authentic, reliable, and usable through any kind of system change, for the entire period of their retention. This may involve migration to different digital systems as technology evolves. Thus, any LTIM system incorporating safeguards data will need to take such adaptability measures with respect to electronic records management into account. Finally, should physical records still be used at the end of the operational phase, it is recommended that the management organization establish policies, procedures and guidelines for information storage and handling of physical, hard copy records, including guidance on converting and migrating records from one system to another.

Each repository facility will be unique and have its own approach to information management. The above recommendations are easily adaptable options for the preservation of safeguards-related information in the long term.

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