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Extending Spent Fuel Storage until Transport for Reprocessing or Disposal

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Abstract

Spent fuel (SF) must be stored until an end point such as reprocessing or deep geological disposal is implemented. Selection and implementation of an end point for SF depends upon legislation, future funding, licensing and other factors that cannot be predicted with certainty. Past presumptions related to the availability of an end point have often been wrong and resulted in missed opportunities for properly informing SF management policies and strategies. For example, dry cask storage systems were originally conceived to free up needed space in reactor SF pools and also to provide SF storage for up to 40 years until reprocessing and/or deep geological disposal became available. Hundreds of dry cask storage systems are now employed throughout the world and will be relied upon well beyond the originally envisioned design life.

Given present and projected rates for the use of nuclear power coupled with projections for SF reprocessing and deep geological disposal capacities, one concludes that SF storage will be prolonged, potentially for several decades. The US Nuclear Regulatory Commission has recently considered 300 years of storage to be appropriate for the characterization and prediction of ageing effects and ageing management issues associated with extending SF storage and subsequent transport.

This paper, a summary of a forthcoming IAEA Technical Report (see reference), encourages addressing the uncertainty associated with the duration of SF storage by design – rather than by default. It suggests ways that this uncertainty may be considered in design, licensing, policy, and strategy decisions, and proposes a framework for safely, securely, effectively, and sustainably storing and maintaining transportability of SF until it can be transported for reprocessing or deep geological disposal – regardless of how long that may be. The paper however is not intended to either encourage or facilitate needlessly prolonging SF storage durations.

1. Introduction

Insufficient political will and public acceptance present significant challenges to implementation of disposal and reprocessing for spent nuclear fuel – resulting in the need for extending storage periods. Given present and projected rates for the generation of nuclear electricity coupled with the fact that sufficient worldwide reprocessing and disposal capacity to reduce spent fuel (SF) inventories is decades away, it is clear that SF and associated high-level radioactive wastes (HLW) will continue to accumulate and license periods for SF storage facilities will need to be extended – perhaps multiple times in most Member States.

National policy must be decided and implemented before SF (and HLW) in storage can begin moving to reprocessing or disposal. Given the political challenges that have been experienced in siting a repository coupled with the relatively low near-term costs and risks associated with continued storage, it is likely that SF will remain in storage much longer than originally envisioned, perhaps many decades or longer. Openly discussing this reality has proven controversial largely because it is not consistent with existing public and political expectations. Although indefinite storage is not considered acceptable, the fact is that due to the dependency on unpredictable future events, storage durations cannot be predicted with certainty. Acknowledging this fact suggests a very different framework for planning, design, operation, and regulation of SF storage (SFS) and associated systems. Specifically, it enables us to address by design rather than by default the reality of uncertain storage durations.

Increased SF inventories and storage times increase the technical challenges for ensuring safety during storage as well as post-storage transport. Managing these technical challenges will affect packaging and storage facility decisions, designs, and strategies. Packaging requirements will also be driven by the technologies and requirements applied at the time of post-storage transport.

2. Design of Future SF Storage Systems

Much of the past and current effort related to extending SF storage has focused on developing the technical basis for ensuring that existing SF, packaging components, and related safety-significant structures, systems, and components (SSCs) will continue to perform their credited safety functions during extended storage. Although this is a necessary activity for extending the storage periods of existing facilities, recognition and acceptance of the fact that SF will be stored for multiple licensing periods provides opportunities to include up-front design and functional requirements that will improve the effectiveness of future SFS facilities.

Future SFS facilities and packages should consider designs that facilitate extending storage and that could adapt to different safety strategies that may be necessary as a result of changing conditions, regulations, and societal values that may occur over extended storage periods. Although these design considerations may result in increased up-front investment, the life cycle costs may be lower than more traditional approaches that presume static conditions over the SFS facility lifetime.

SFS systems designed to accommodate extended storage must contemplate a broader range of scenarios that could occur over the longer time period. These include the potential for increased magnitude and likelihood of challenges due to natural phenomena, the accrued effects of aging; and the impacts of changing societal values and policies. Designs for extended SFS should consider increased safety margins to accommodate the potentially broader range of conditions that may be encountered during extended storage.

Designs for extended SFS must include provisions to mitigate age-related stressors such as mechanical, thermal, chemical, radiation, and other stresses that can accumulate or change over time. Packaging and/or drying technologies should be selected to reduce the likelihood of future cladding failures. And fuel storage and package configurations should facilitate inspection and monitoring systems. Designs for extended SFS should also consider the challenges associated with maintaining quality controls and records needed for extending storage periods.

Designs for SFS facility, equipment, and packaging should consider the possibility that SF in storage may require remediation to ensure safe transportability and/or to ensure compatibility with future SF management steps. Hence, SFS facilities should be able to maintain, confirm, and, if needed, restore transportability.

To ensure that safety is maintained as storage periods are extended, evaluation of the cumulative effects of both physical ageing and equipment obsolescence must be an ongoing activity. This can be achieved by an adaptation of the well-known "Plan-Do-Check-Act" cycle, a widely accepted practice for continuous process improvement, to the ageing management of SFS facilities as shown in Figure 1.

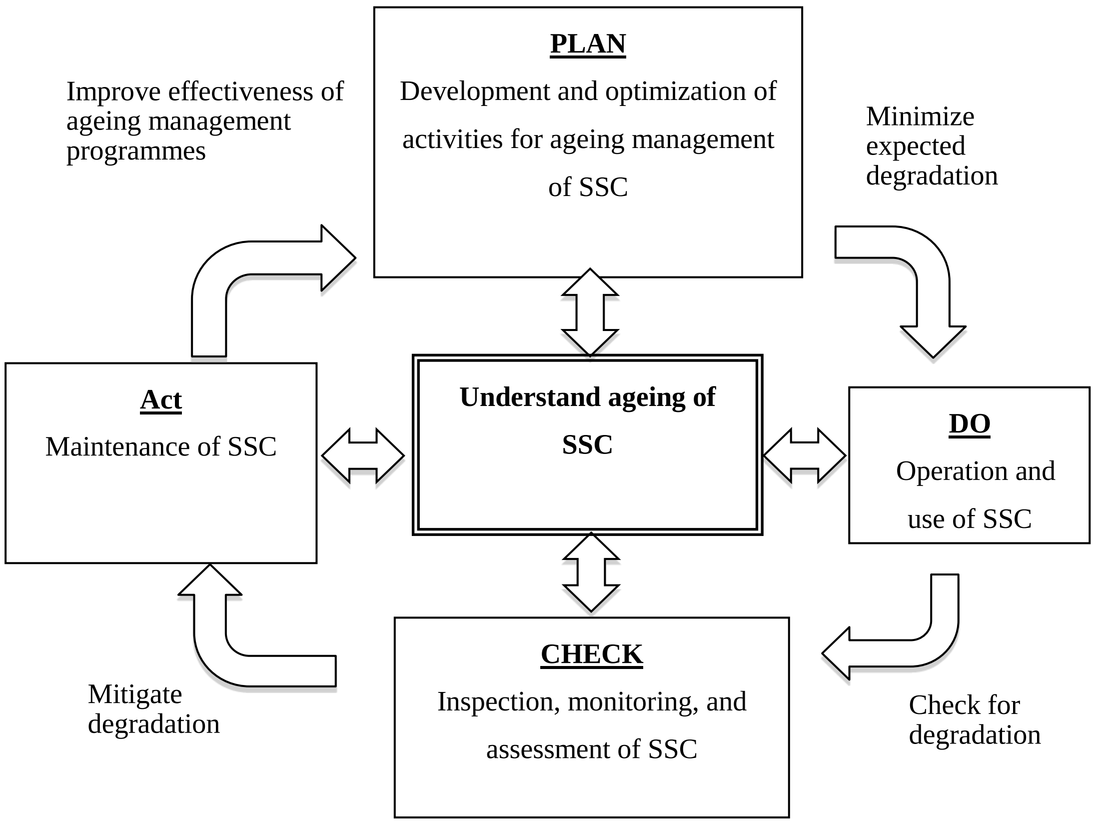

Figure 1. Systematic approach to managing ageing of a structure or component

Monitoring and inspection systems should consider advanced surveillance and non-destructive examination (NDE) techniques to monitor storage conditions and support ageing management through both preventive and predictive maintenance.

3. SFS Packaging Considerations

Until an end state is identified and implemented, uncertainty will remain with respect to the optimum design for the packaging and disposal container as well as the acceptance criteria for the contained waste form. This has significant implications for SFS relative to how and when SF is placed into containers. Key decisions in selecting an SFS configuration to meet present and future needs are related to whether SF will be packaged for transport and/or disposal prior to or after storage, as shown in Figure 2. Each of these decisions affects the availability of future options. Available alternatives should be evaluated to select a storage strategy that can be sustained over extended storage periods while maintaining flexibility and adaptability to accommodate a broad range of plausible future scenarios.

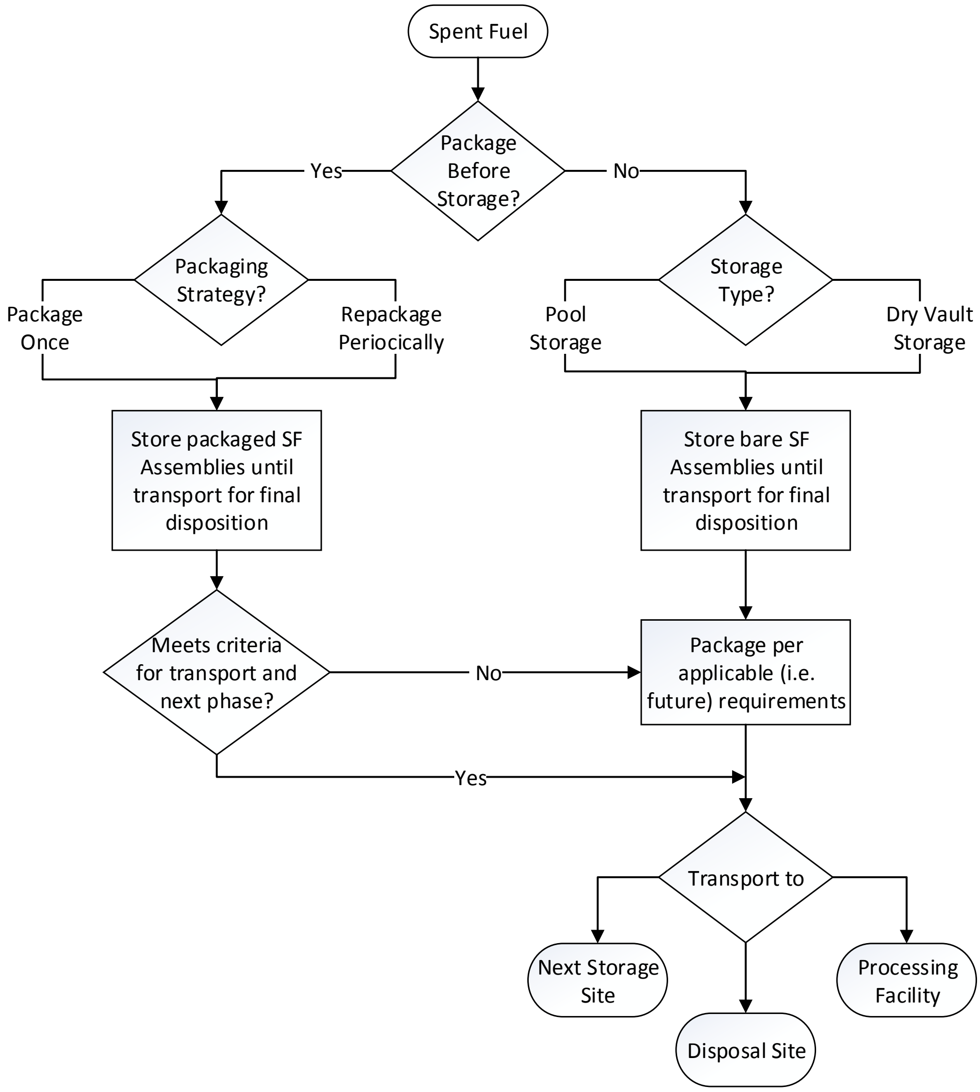

Figure 2. Decision path for selecting SFS configuration

A successful packaging strategy that avoids the need for future repackaging would require choosing a canister or cask that will be suitable for the full duration of storage, subsequent transport, and eventual disposal. As such, if fuel is packaged prior to storage, a more robust strategy may be to assume that repackaging will eventually be necessary and to design packaging and operational strategies to facilitate it. An approach that plans for periodic repackaging can (1) provide a basis for cost planning; (2) enable periodic inspection to confirm compliance with performance requirements and to obtain data to support R&D needs; and (3) allow for renewal and updating of SF, of SF packaging components, and of monitoring equipment. This allows one to not only monitor and address any unacceptable degradation but also to capitalize on new technologies and to address new or changed requirements. However, repackaging adds risk, cost, and personnel exposure and also generates additional radiological waste. Cost estimates for future repackaging are highly dependent upon discount rates and other assumptions used in the economic analysis. Some estimates have shown that periodic repackaging could increase costs by nearly an order of magnitude.

The alternative to packaging SF prior to storage is to store SF as bare assemblies. Bare SF can be stored in pools or in dry vaults that provide shielding and other necessary safety features. Although pool or vault storage systems will require a larger initial investment and increased reliance on active systems for safety and security, there are several advantages worth consideration. A key advantage of storing bare, unpackaged SF assemblies is the relative ease of access for monitoring and inspection throughout the storage period. Thus, any degradation that may occur over extended storage is more readily detected.

Postponing packaging reduces the technical gaps and associated research and development needed to predict the condition of SF stored in sealed containers, allows packaging designs to capitalize on future technologies and materials, and provides a 'fresh' package for post-storage transport and handling. Storing bare SF that can be packaged for transport and disposal after storage also allows repository design and selection to proceed without being constrained or influenced by decisions related to SF packaging.

4. Regulatory Considerations

To ensure regulations, guidance, equipment designs, and inspection programs will be adequate to ensure safety and maintain transportability for as long as may be needed; ageing management and storage systems should be considered holistically by regulators, industry, and research institutions.

The length of licensing periods has normally been determined by regulatory or policy considerations and typically represents an interval that was considered sufficiently long to meet the anticipated SFS storage period. Alternatively, Figure 3 illustrates a regulatory framework designed to address the present situation (i.e. unknown storage periods) while ensuring safe storage until a national policy for an SF end-state is decided and implemented. The lower portion of the figure illustrates SF accumulating in storage until it can be transported to either reprocessing or disposal. The primary focus of the license renewal process, or periodic reassessment, shown in the upper loops is the validity of the time-limited ageing analyses and adequacy of the ageing management programme. This license renewal process continues for as long as the SFS facility is needed.

If the approach illustrated in Figure 3 is effectively implemented, the number of license renewals need not be limited. Compliance with requirements is assessed and confirmed one finite step (i.e. licensing period) at a time and thus ensures safety for as long as necessary.

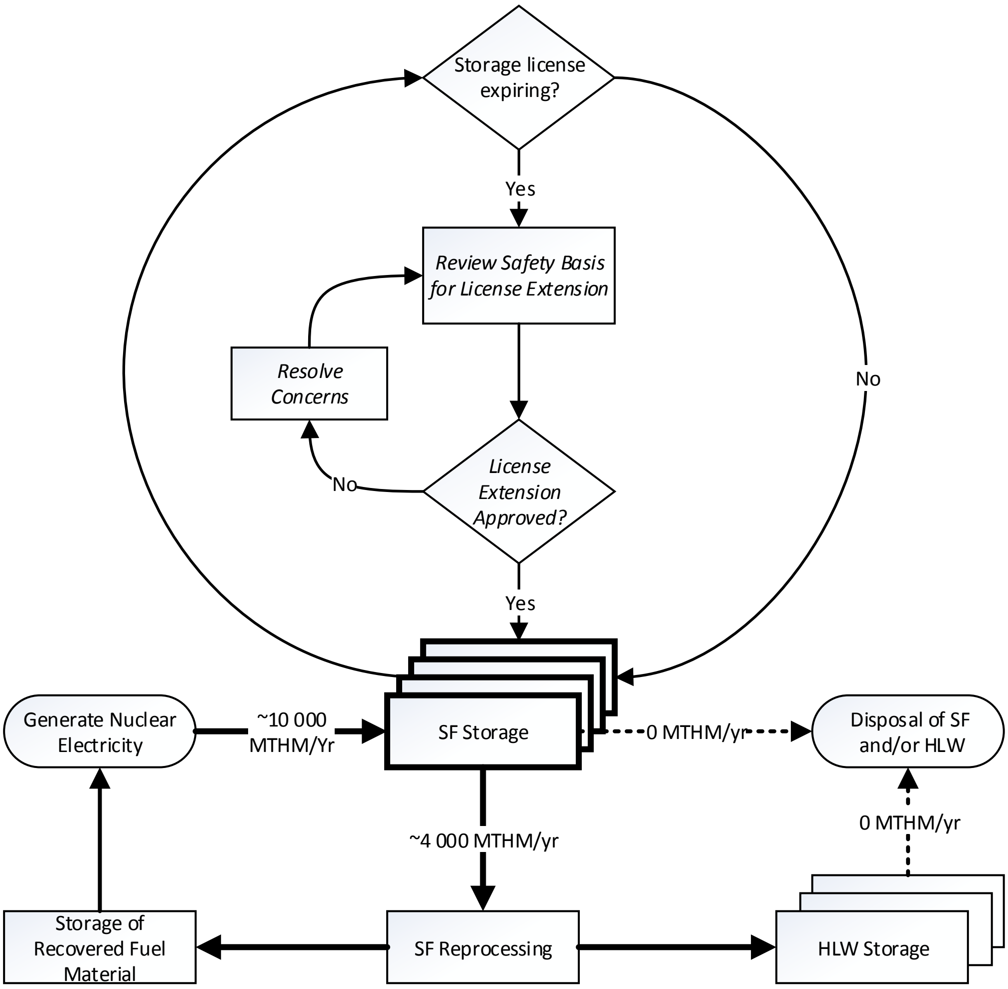

Figure 3 Licence renewal until reprocessing or disposal

Risk analyses provide a better understanding of the probability and consequence of specific age-related failures, which may offer insights and alternative approaches for ensuring safety. For example, some SFS safety functions are often allocated to SF cladding, which helps to confine radiological materials and maintain the geometry of the SF. Cladding integrity is difficult to inspect and not feasible to repair or replace. For extended storage periods, it may be prudent to consider safety strategies that shift safety functions to SF packaging components or SF facility features that can be more readily monitored and inspected and, if needed, repaired or replaced. This is similar to the current practice of "canning" to provide an additional barrier and means of handling for suspect SF assemblies. A regulatory approach that credits the package for performing safety functions typically allocated to cladding integrity may, without compromising safety, lessen the burden on designers and regulators to do extensive research on how ageing affects fuel cladding properties.

A performance-based regulatory approach is independent of assumptions about the storage duration, the storage and packaging technologies to be employed, and the final disposition path. Performance-based approaches establish requirements based on satisfying specified performance criteria without explicitly prescribing the methods for meeting the criteria. By focusing on assuring safe conditions while leaving flexibility to the licensee as to the means of meeting established safety criteria, performance-based regulation can provide the flexibility to accommodate evolving technologies and policies. However, when providing this flexibility, the regulator must also consider the licensee's need for clearly defined and objective requirements.

Effective use of risk-informed and performance-based approaches will encourage development of new technologies and/or more effective approaches for addressing uncertainties associated with the need for SFS license extensions and for ensuring long-term SFS safety.

5. Policy and Public Confidence

Some have expressed concern that developing a framework for safely extending storage could have the unintended consequence of reducing political pressure for a final solution, thereby enabling further postponement of essential policy decisions and commitments. Nonetheless, in the case of SF management, there is a professional and ethical obligation to ensure safe and effective SFS for as long as may be needed. This is achieved by providing a safety basis with sufficient margin to accommodate the full range of potential future scenarios that may be encountered in the time until reprocessing or disposal becomes available. However, development of the capabilities needed to safely extend storage periods is not intended to either facilitate or encourage needlessly extending SFS durations and should not be used as an excuse to delay establishing the necessary disposal facilities.

It must be recognized that delaying a final solution will result in escalating inventories and SF management costs – making it progressively more difficult to achieve the fundamental solution. Delays in reaching an end state, and growing SF inventories, will also negatively impact the public confidence needed to move forward with any lasting solutions. Therefore, a strong caution is given that policies relying on extending SF storage, though presently necessary, be managed to ensure that commitment to achieving a sustainable solution is maintained.

Failure to achieve sufficient public acceptance has been a persistent source of difficulties, delays, and challenges to maintaining the political will needed for successful siting and licensing of a repository for final disposal of SF and HLW. Missed commitments and continued difficulty making substantive progress re-enforce risk perceptions and further erode public confidence that the nuclear waste problem can be solved – which increases both the quantity of SF and the duration of SFS while further increasing the challenges associated with siting and licensing SFS facilities.

This circular effect is illustrated in Figure 4. Ironically, a lack of public confidence and political will to address the problem can go full circle and ultimately aggravate the problem – further impeding a lasting solution. However, it should be noted that public confidence is influenced not only by perceived risk but also by perceived benefits – suggesting that both areas present opportunities for bolstering public confidence.

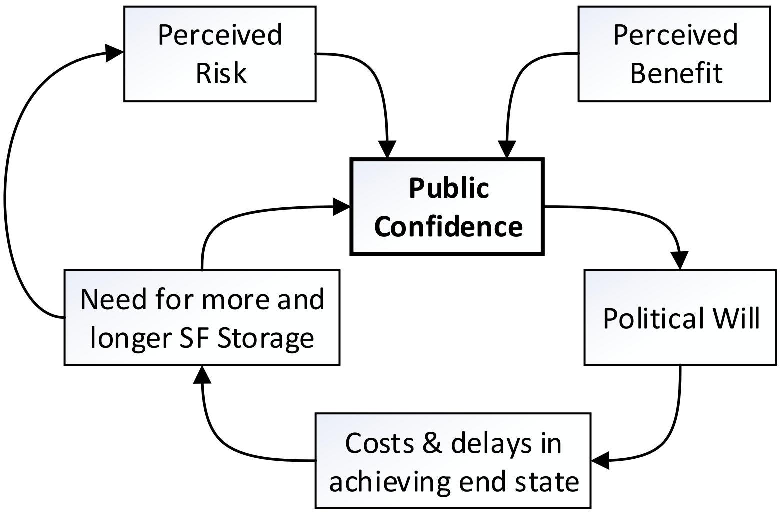

Figure 4. The public confidence dilemma – or opportunity

A key observation from the above figure is that public confidence is actually part of a balance that considers both risks and rewards. Hence, although adequate safety performance is necessary, reducing risks and risk perceptions alone is unlikely to be sufficient to reverse the cycle. There must also be recognized and valued benefits. Building the public confidence requires that the public recognize the opportunity for real benefit, and/or to avoid real cost, relative to their values. Absent this incentive, there is no motive for constituents to reconsider their risk perceptions.

6. Managing Interfaces throughout the Fuel Cycle

A holistic approach to management of the entire fuel cycle becomes increasingly important as SF storage periods are extended. It enables decisions that consider the entire life cycle and discourages local optimization achieved at the expense of overall system performance.

Some regulatory frameworks or different safety approaches and/or practices in the storage, transportation, and disposal or reprocessing of SF may result in compatibility issues that could increase costs and/or risks as SF storage periods are extended. For example; design, operational, and regulatory decisions may not necessarily consider scenarios in which SF is stored for extended periods in sealed canisters. This may result in the need to inspect packaging and/or SF, and possibly the need for repackaging in order to meet transport or disposal requirements.

Integration across design, operational, regulatory, and policy aspects of fuel cycle management enables decisions that ensure compatibility of materials, operations, equipment, packaging, and waste forms with future SF management steps, thus reducing risks and life-cycle costs. For example, storage and transport requirements may not be fully compatible. Further, requirements may change and/or transport licenses may expire while SF is in storage. Hence, it is recommended that storage and transport licenses be maintained to ensure consistency during SF storage.

7. Conclusions

Selection and implementation of any defined end state depends upon future funding, legislation, licensing, and other conditions that cannot be predicted with certainty. Specifically, any planned end state is not certain until achieved. Due to ongoing public and political debate associated with use of nuclear energy and with siting and licensing a deep geological repository, storage periods and projected SF inventories cannot be known with certainty. Accepting this uncertainty requires planning to store SF until sufficient SF reprocessing or disposal becomes available, regardless of how long that may be.

Although potential hazards, available technologies, and applicable requirements may change over time, storage periods can safely be extended for as long as necessary. By developing technical and regulatory processes that assure unacceptable degradation of safety-related SSCs will be detected and corrected prior to failure, it is not necessary to limit SFS durations. Rather, uncertain storage periods can be addressed by extending SFS, one careful step at a time, until a disposition path becomes available. That said, this paper is not intended to either encourage or facilitate needlessly prolonging SF storage durations. Rather, it encourages addressing the uncertainty associated with the duration of SF storage by design – rather than by default.

8. References

Daft Technical Report “Storing Spent Fuel until Transport to Reprocessing or Disposal” to be published, IAEA (NES).