DEFINING SPENT FUEL PERFORMANCE MARGINS

by NEI Spent Fuel Margins White Paper Development Task Force

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Abstract

This paper examines the nuclear industry's 30 years of experience with the loading and maintenance of dry cask spent nuclear fuel (SNF) storage and transportation systems in an effort to identify improvements to the regulatory framework for licensing these systems. Over this time, the dry storage of SNF has become a proven and well-established operation at over 70 US nuclear sites. To date, over 3,000 dry storage systems have been safely loaded and placed into storage. Some have been in service for over 30 years, and licenses for many systems have been extended from the original 20-year storage period to as much as 60 years. However, the dry storage licensing process does not reflect what has been learned about the high level of safety of these activities and has, as a result, become highly inefficient. An inordinate level of detail in licensing documents drives licensees and cask vendors to submit an excessive number of license amendment requests for changes to design features. As a result, industry and the U.S. Nuclear Regulatory Commission (NRC) resources are diverted from more safety significant activities.

In an effort to address this problem, the paper builds on NRC's principles of good regulation, recent efforts by NRC management to improve efficiency, and risk insights to explore opportunities to apply a more thorough understanding of dry storage performance margin to improve the licensing framework. Performance margin is specifically addressed in the following 5 areas; Source Terms, Thermal Parameters, Radiological Parameters, Fuel Qualification, and Criticality.

Based on what is now understood about performance margin in each of these areas, the paper develops 16 specific recommendations. These recommendations fall into the following three categories:

1. Actions that industry can take within the confines of existing regulations and guidance,
2. Actions that NRC can take by tailoring their regulatory guidance and their review and inspection practices to recognize the existence of performance margin, and
3. Actions that will need industry and NRC to engage in a dialogue to develop improved regulatory tools and guidance

Because none of these recommendations will require rulemaking and many of them can be implemented without the development of additional formal guidance, the paper concludes that meaningful improvements in regulatory efficiency should be achieved in a relatively short period of time and with minimal resources (with respect to the Category 1 and 2 recommendations). These improvements can be further extended through dialogue proposed in the Category 3 Recommendations. Some of the recommendations will translate into Certificate of Compliance Amendments or Topical Reports that industry would submit to NRC for review and approval. These improvements will be vital to assuring the continued long-term success of dry spent fuel storage and transportation.

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I. Introduction

A. Background

The dry storage and transportation of Spent Nuclear Fuel (SNF) (also commonly referred to as Used Nuclear Fuel (UNF)) is governed by 10 CFR Part 71, 10 CFR Part 72, and related NRC guidance. These documents constitute the regulatory framework for dry storage and provide analysis guidance and technical limits which define the development of dry storage systems and processes for the industry. This regulatory framework was developed from the information and data available at a time when dry storage technology was relatively new and there was limited information from real loading and storage experience to inform it. Where a knowledge gap existed, known conservative values and/or conservative approaches were selected to ensure public health and safety. For the most part, this guidance and recommended approaches have not been substantially updated since their inception.

Over the last 30 years, the dry storage of SNF has become a proven and well-established operation at over 70 US nuclear sites. To date, over 3,000 dry storage systems have been safely loaded and placed into storage[1]. Most of these are dual purpose systems which are also designed and licensed for transportation. Some have been in service for over 30 years, and licenses for many systems have been extended from the original 20 year storage period to as much as 60 years.[2] In 2014, NRC completed its continued storage Environmental Impact Statement which concluded that these systems could remain in place, continuing to protect public health and safety for at least 100 years with no need to repackage the fuel.[3] During this time, the knowledge base on dry storage has expanded and deepened significantly, yet the conservative regulatory framework initially built to accommodate uncertainties associated with the lack of operating experience remains in place.

Additionally, the industry, EPRI, NRC, DOE, national laboratories, universities, and international organizations have performed numerous studies, tests, and analyses to improve the designs and loading processes and expand the amount and type of fuel being placed in storage and – in the case of dual purpose systems – also configured for transportation. The results of these efforts continue to confirm that the risks associated with dry storage and transportation are extremely low – well below what was conservatively assumed in the development of the existing regulatory framework. With the volume of new technical information and experience available, it is prudent to revisit this framework and develop appropriately risk-informed safety limits and guidance.

B. Problem Statement

Conducting business under the existing SNF regulatory framework has proven to be highly inefficient and burdensome for both industry and NRC, and should be viewed as contrary to the principles of good regulation. The dry storage and transportation cask licensing process is unnecessarily resource intensive and time consuming given what is now known about the high level of safety and low risk significance of

[1] UxC, LLC, StoreFuel, Vol. 21, No. 254, dated October 8, 2019
[2] 10 CFR 72.214 "List of approved spent fuel storage casks" 84 Federal Register 52751
[3] 10 CFR Part 51 "Continued Storage of Spent Nuclear Fuel" 79 Federal Register 56238, September 19, 2014

these activities. An inordinate level of detail in licensing documents drives licensees and cask vendors to submit an excessive number of license amendment requests for changes to design features. In most cases these changes have a negligible impact on safety. As a result, industry and NRC resources are diverted from more safety significant activities.

The extent of this problem for Certificate of Compliance (CoC) holders and NRC reviewers is significant. Over the last 25 years the 15 NRC approved dry storage CoCs have been amended 74 times.[4] Preparation of amendments requires between two and nine months of effort on the CoC holder's part and one to three years of review at NRC – although in a few cases it has taken considerably longer. The process typically involves two rounds of Requests for Additional Information (RAIs) from NRC. Staff can also issue Requests for Supplemental Information and Requests for Clarification. Normally NRC asks between one and two dozen RAIs with many RAIs having multiple subparts. The nature of the RAIs reveal that the NRC staff is too often performing what amounts to a redundant third-party validation of the details of the underlying calculations, rather than a licensing review of the application, keeping in mind that the calculations have already received an independent review in accordance with an NRC approved QA program. The result is unnecessary delay, while staff and the applicant/CoC holder spend inordinate amounts of time exchanging highly detailed information on the calculations and how these details might be affected by uncertainties, when the amount of uncertainty is often significantly less than the existing margin of safety. In other words, the fine tuning of the details being discussed in this resource-intensive conversation is not effectively contributing to reasonable assurance of adequate public health and safety.

Similarly, operating plant sites are impacted by this. Since the amendment process is required for changes to items in the Approved Contents section of CoCs such as fuel types and heat load requirements as well as some processing changes, this leads to a situation where identical casks at the same storage facility are loaded under different amendments. It is not unusual for a single dry storage facility to have between 2 and 7 distinct and different sets of licensing documentation, including site-specific calculations, for casks that are essentially identical in physical design. Transitioning to a new amendment takes approximately 6 months to one year of utility and vendor effort, since calculations and procedures have to be revisited. Managing this documentation becomes an unnecessarily complex challenge for industry licensing and engineering professionals and makes it more difficult for NRC inspectors to assess compliance with no commensurate increase in safety. All of this effort diverts resources away from activities which are more important to safety.

Much of this effort could be eliminated if the licensing process was guided by a more risk-informed framework.

C. Current Situation

NRC is aware of these circumstances. On May 23, 2018, the Executive Director for Operations submitted a paper to the Commissioners calling for transformative changes that would expand the use of risk and

[4] Gutherman Technical Services, e-mail correspondence to Rod McCullum NEI, August 26, 2019

safety insights in decision-making at the NRC.[5] Prior to his retirement, former Nuclear Material Safety and Safeguards (NMSS) Office Director Marc Dapas offered his perspective on how this objective might be met with respect to dry spent fuel storage, highlighting in a January 15, 2019 Memorandum to staff "the need for systematic and expanded use of risk and safety insights in decision making, including the need to appropriately scale the scope of staff review and the level of detail needed from an applicant for licensing decisions."[6]

NRC and industry have held multiple discussions, most recently during a public meeting on April 23, 2019, on how to achieve the vision that NRC senior management has put forth for SNF. As a result of this discussion it has become apparent that the key to a more risk informed process will be an improved understanding of the high level of performance margin that exists in dry storage – as demonstrated by experience and scientific research. This paper will outline an effort to apply existing margin as a foundation for improved design standards and limits, more efficient licensing processes and dry storage operations, and more effective regulatory oversight of these operations. This will improve overall regulatory efficiency while continuing to enable industry and NRC to provide reasonable assurance of adequate protection of public health and safety.

D. Objectives

The objective of the effort identified in this report is to use the contemporary body of knowledge to understand and identify the existing margin between actual conditions and existing regulatory safety limits and criteria, and then applying that knowledge in a risk informed manner. In some cases, this may take the form of straightforward actions that can be implemented by industry or NRC. In other cases, this may require more interaction between industry and NRC, and may result in development of more accurate analytical models (not necessarily more complex) and analysis approaches, as well as more realistic, scientifically based limits for thermal, radiological, criticality, and confinement safety analyses and design. Effectively achieving this objective will permit resources to focus attention on the most safety significant parameters and phenomenon.

To accomplish this objective, it will be necessary to confirm a precise definition of what is necessary to reasonably assure safety. For example, the current definition of safety is equated with no cladding gross rupture and/or no canister breach. This definition may be more restrictive than is necessary to fulfill the mission of providing "reasonable assurance of adequate protection of the public health and safety." In fact, NRC recently approved the renewed license to the U.S. Department of Energy Idaho Operations Office for Special Nuclear Materials (SNM) License No. SNM-2508 for the receipt, possession, transfer, and storage of radioactive material from the Three Mile Island Unit 2 (TMI-2) reactor core in the TMI-2 independent spent fuel storage installation (ISFSI) on September 16, 2019. This NRC-approved dry storage system contains grossly ruptured fuel with a tortuous release pathway through the inlet/outlet port nozzles and a HEPA filter as the confinement boundary. NRC made the safety determination that

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[5] NRC SECY-18-0060, "Achieving Modern Risk-Informed Regulation," dated May 23, 2018 (ADAMS Accession No. ML 1811OA187)

[6] Marc L Dapas "Memorandum to Office of Nuclear Material Safety and Safeguards Staff" January 15, 2019 ML18110A186

the public health and safety is maintained with this system. This raises the question of what is truly meant by the term "cladding gross rupture" as defined in ISG-1 and confinement in terms of reasonable assurance of adequate protection of the public health and safety?[7]

Structure

This document is organized into technical sections that cover the applicability of risk insights to support the objective, and then by specific technical topics that relate to dry SNF storage safety. Specifically, this report addresses performance margin of SNF in the following areas:

- Source terms
- Thermal parameters
- Radiological Parameters
- Fuel Qualification
- Criticality

The report then discusses the applicability of the margins in the practical development and implementation of dry storage, to demonstrate the benefits of recognizing and using the performance margin to enhance overall safety while optimizing resources for utilities, vendors and the NRC.

E. Recommendations

This report makes 16 specific recommendations. These recommendations fall into three categories:

1. Actions that industry can take within the confines of existing regulations and guidance,
2. Actions that NRC can take by tailoring their regulatory guidance and their review and inspection practices to recognize the existence of performance margin, and
3. Actions that will need industry and NRC to engage in a dialogue to develop improved regulatory tools and guidance

This report is not recommending any changes to NRC's regulations. It is believed that 10 CFR Part 72 in its current form is adequate to provide a reasonable assurance of adequate protection of public health and safety in a risk informed manner if it is applied with a recognition of known safety margin in mind. While the regulation could be improved to more explicitly recognize what has been learned through industry's considerable experience with dry cask storage, any rulemaking would be time consuming and resource intensive and would not provide substantially greater benefit over simply applying the current regulation in a more risk informed manner.

In October 2012 industry submitted a Petition for Rulemaking (PRM 72-7). NRC accepted PRM 72-7 for review in July 2014. The recommendations of this paper reflect what has been learned about the safety margins inherent in the use of dry storage technology since 2012. It is now believed that most of the

[7] Federal Register Notice https://www.federalregister.gov/documents/2019/09/25/2019-20853/us-department-of-energy-idaho-operations-office-three-mile-island-unit-2-independent-spent-fuel

efficiencies sought in PRM 72-7 can be achieved within the framework of existing regulations if the understanding of safety margin that we now have is effectively considered in the application of these regulations. Implementation of these recommendations would supplant the need for most of the changes called for in PRM 72-7.

The specific recommendations of this report are highlighted as they occur in the discussion of each area of margin (Sections III through VII). They are also listed organized by the above categories in Section X of this report.

II. Risk Insights

SNF performance margin can be divided into two categories:

- Performance margin in the SNF itself, i.e. the SNF has more capacity than we assign it in our evaluations; and
- Margin that exists in the methods used to evaluate SNF storage safety – Instances where we use approaches in our analyses that include conservatisms to account for a number of uncertainties or unknowns, or to provide a bounding evaluation to simplify the analyses.

In the areas discussed in this paper, one or both of these types of performance margins exist. The objective is to identify and characterize these margins so that we can develop approaches to optimize designs, analyses, operations and regulatory reviews.

Risk insights can serve as a valuable tool during the design, analysis and regulatory review process to provide focus on those technical areas that have the most significant impact on the calculated results. Using a graded approach, less significant aspects can then be considered on a best-estimate or realistic basis, as the difference between realistic and bounding assumptions will have little to no impact on the safety performance of the storage system.

More realistic thermal, dose, and criticality modeling with realistic as-loaded assumptions versus conservative design basis assumptions provides management tools for making better decisions during design and execution of short-term operations, dry storage, and transportation which will result in several benefits. Examples of such benefits from thermal modeling include:

- Substantially less concern with the potential embrittling effects of hydride reorientation:
  - Realistic thermal models indicate that fuel loaded in the U.S. have not experienced temperatures that could enable hydride reorientation
  - Recent research findings and NRC NUREG-2224 conclude that hydride reorientation is not a concern and that utilities and vendors can use cladding-only properties as a result
  - A risk-informed approach could eliminate the biasing of thermal models to avoid high temperatures that could initiate hydride reorientation
- Loading hotter fuel sooner with greater operational flexibilities:
  - More efficient loadings allowing more optimized canister designs with higher heat rejection capabilities could translate into fewer canisters loaded, which could reduce the number of canisters, thus reducing the overall radiation exposure to workers
  - Improved operational flexibilities that could reduce worker doses, e.g. allow additional shielding measures to be employed during loadings
  - Allowing fuel assemblies with shorter minimum required cooling times to be loaded into canisters, thus enabling reduced heat loads in spent fuel pools, and more timely decommissioning

After multiple decades of operational experience with spent fuel storage and transportation, the question remains: How do we create the best overall approach to safely store and transport spent fuel to ensure public and worker health and safety while using resources in the most effective manner possible and maintaining reasonable costs? The approach to use conservative licensing basis assumptions for thermal, radiological, and criticality modeling may have been useful in the past, however, using this approach is contrary to a fully optimized strategy for reducing risks during the entire long-term back-end operation. Modernizing the approach to use best-estimate models with appropriate uncertainties could be mutually beneficial to the public, workers, utilities, and government institutions.

A significant part of the answer to the question posed above can be found in two sources; the aforementioned January 15, 2019 Marc Dapas Memorandum to NRC staff and a recently launched initiative in NRC's Office of Nuclear Reactor Regulation (NRR) entitled "Low Safety Significance Issue Resolution" or LSSIR.[8] In this regard, the following commentary from Mr. Dapas is particularly instructive:

> *"Reviewers should consider the relative margin to any applicable regulatory limits pertaining to the item under review. If the licensee or applicant has reasonably demonstrated that there is significant margin from the regulatory limits, then a detailed review of the item may not be warranted beyond confirming the adequacy of the licensee's or applicant's models, codes, and/or approach, including any key parameters and assumptions, used to demonstrate that significant margin exists. If there is little margin, a more detailed review may be justified to carefully consider the key parameters and assumptions, and independent confirmatory analyses will likely be appropriate. In each case, the reviewer's focus should be on the applicant's demonstration of meeting (or not meeting) the applicable requirements."*[9]

This paper advances 16 recommendations to implement this advice that are consistent with process improvements already underway at NRC. As outlined in an August 7 NRC Public Meeting Presentation, NRR, through the ongoing LSSIR process is seeking to develop a structured approach "to disposition issues of very low safety significance early on in the inspection process using a practical approach".[10] While the LSSIR initiative focuses on NRC's inspection processes, it is more appropriate that the focus here be on licensing reviews because, unlike reactor licensing, in the current dry storage regulatory approach many items of low safety significance that could be adequately verified through inspection currently require prior NRC approval in the licensing process. For example, fuel types and thermal patterns currently reside in the Approved Contents portion of the CoC. Addition of new fuel types or thermal patterns thus require a license amendment. However, if these items resided in the final safety analysis report (FSAR), they could be added by the vendors via the 72.48 process. The NRC periodically inspects these 72.48s at which time their adequacy could be verified. The recommendations of this

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[8] "Current Status of Low Safety Significant Issue Resoultion (LSSIR), NRC Presentation at Office of NRR Public Meeting August 7, 2019

[9] Marc L Dapas "Memorandum to Office of Nuclear Material Safety and Safeguards Staff" January 15, 2019 ML18110A186

[10] "Current Status of Low Safety Significant Issue Resoultion (LSSIR), NRC Presentation at Office of NRR Public Meeting August 7, 2019

paper therefore seek to provide a "practical approach" for determining which items are, and are not, of sufficient safety significance to warrant the application of licensing resources.

The first of these recommendations links directly to the remarks of Mr. Dapas above. In a presentation at NRC's 2019 Division of Spent Fuel Management Regulatory Conference (REG CON) on September 18, 2019, NRC staff suggested that "Acceptance Review Grading" could be applied, "giving a relative ranking on what the level of review needs to be from the very outset of the review."[11] In this approach, NRC staff would apply a ranking system informed by risk insights upon receiving an application, for example, on a scale of 1 to 5 with each level calling for a well-defined gradation in the level of review. This concept is reflected in the following recommendation:

<u>Recommendation II-1:</u> NRC should develop an Acceptance Review Grading process that would assign varying levels of review to an application, from the time it is initially received, based on risk insights. This is a Category 2 recommendation which would require NRC to revise its internal review guidance and practices.

Separately, it is important to note that the problem we are seeking to solve here is not entirely a function of NRC's dry storage licensing review processes. Mr. Dapas also had advice for licensees/applicants with respect to actions they could take on their own to address the use of margin to inform risk insights

> *Regulatory standards should already include the appropriate margin the Commission previously deemed necessary to provide for adequate protection. There is no requirement or expectation for additional margin beyond these regulatory standards, even if additional margin is reflected in any "acceptance criteria" contained within guidance documents.*[12]

The Category 1 recommendations appearing in the subsequent sections of this report will be largely founded on this advice.

[11] USNRC "Transcript of Proceedings" DSFM Regulatory Conference 2019, Conference 2 pp. 23-37
[12] Marc L Dapas "Memorandum to Office of Nuclear Material Safety and Safeguards Staff" January 15, 2019 ML18110A186

III. Guidance for Further Advancing the Definition of Performance Margin for Source Terms

A. Introduction

The degree of conservatism in source term calculations is related to how source terms are generated. The source term codes in use today are considered to be robust, and in fact with very precise information on the fuel assembly (rod-by-rod or even pin-by-pin enrichments) and irradiation history (specific power history, burnup etc.) these codes produce very accurate source terms. Unfortunately, it is not feasible to model each fuel assembly within a multiple assembly cask, or for multiple casks, within the license or application. As a result, bounding assumptions are made so as to qualify and accommodate a wide range of fuel assembly specific values in a generic fashion. This in turn leads to thermal and radiological source terms that are overpredicted, sometimes dramatically so. This results in additional burden on the end users, who need to make provisions to address the hypothetical consequences of these over-predictions in terms of heat loads and dose rates that do not exist in actuality.

Therefore, recommendations in this section are focused on approaches to improve the inputs to those codes, while not becoming overly burdensome. The question is how much accuracy in the fuel data (burnup, enrichment, irradiation history) is needed to reduce these over conservatisms.

B. Analysis

The source term is generally regarded as the amount, location and form of the radiological material contained in the storage container. The term “source term” is used generically to refer to either the radiological content or the decay heat used in many of the safety analyses performed (thermal, shielding, and confinement) to ensure the cask design meets the regulatory requirements of 10 CFR Part 72.[13] While many of these disciplines introduce conservatisms through the discipline methodology itself (i.e., minimum shielding thicknesses in dose analysis, conservative gaps between materials in thermal, conservative meteorology assumptions in confinement), this section focuses on the specific conservatisms introduced in the development of source terms for use in safety analyses.

1. Regulatory Requirements and Corresponding Guidance for Source Terms

There are no specific regulatory requirements on the determination of source terms. However, the typical approach is to generate conservative source terms using bounding input assumptions to allow for the storage of a wide variety of radioactive materials (fuel assemblies, non-fuel hardware, or Greater than Class C waste) inside the system. This straight-forward approach introduces significant conservatisms in the calculation of the downstream safety analysis parameters such as dose, material temperatures, etc. that are used to show compliance with regulatory requirements. This produces

[13] U.S. Code of Federal Regulations, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-level Radioactive Waste," Part 72, Title 10, "Energy."

results presented in the Safety Analysis Report that are not representative of the observed values seen during actual loading operations.

2. Generation of the Source Term

There are four main aspects that are considered in the specification of the source term in the safety analysis:

- The amount and intensity of the radiological material within the cask (influenced principally by the parameters of burnup and cooling time)
- The physical and geometric form of the radiological material
- The operating conditions under which the nuclear fuel and other material were irradiated and became radioactive, and
- The location and/or distribution of the source term within the cask, especially under accident conditions where relocation is assumed to occur

In each of these aspects conservatism is introduced to assure that the downstream safety analyses will produce conservative results for comparison to either regulatory limits or limits established in NRC guidance documents.

The generation of the source term is performed by 1) the cask vendor/CoC holder to support the analysis described in the FSAR to garner regulatory approval of the cask system and 2) the cask user (i.e., utility licensee) in the site-specific analysis for the generation of decay heat values (both per cell and per canister) and calculation of the dose at the site boundary to confirm compliance with the requirements specified in the CoC or Code of Federal Regulations (CFR).

The available methods to generate the radiological/decay heat source for use in safety analysis are:

- Use of Regulatory Guide 3.54 for determination of decay heat[14], or
- Use of depletion computer codes to develop bounding source terms for use in decay heat calculations and radiological analysis

Additionally, cask users may apply an additional source term penalty associated with the specified burnup of individual fuel assemblies from the reactor records. This may be applied as a reduction in the allowable burnup (for the given cooling time) established in the CoC, or an increase in the fuel burnup of record. A value of 5% is often used.[15]

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[14] Reg Guide 3.54: Regulatory Guide 3.54, Revision 2, "Spent Fuel Heat Generation in an Independent Spent Fuel Storage Installation," December 2018.

[15] EPRI Report TR-112054 "Determination of the Accuracy of Utility Spent Fuel Burnup Records" – July 1999.

3. Conclusion

Source terms are used in dry cask storage as an input into many of the safety analyses, and therefore using a bounding source term approach has impacts in many different disciplines, including dose in radiological analyses and peak cladding temperature in thermal analyses. As an indication of this, comparison of calculated dose with measured dose values from loaded casks and best-estimate calculated temperatures with measured temperatures from the High Burnup Demo has demonstrated large discrepancies. Recent studies have shown that the assumptions on source term tend to be significant contributors to these discrepancies.

Consequently, to ensure that the maximum benefit is achieved in defining and characterizing the regulatory margin, it is recommended that the CoC holder use more realistic source terms to demonstrate the adequacy of the cask design. Bounding results are still assured by the use of conservative modeling assumptions in the downstream calculations (i.e., minimum shielding thicknesses, appropriately conservative gaps between conductive materials in thermal analysis).

For source terms generated by the cask user, current guidance allows for the use of source term calculations based on the individual site characteristics and fuel/hardware inventory for the determination of decay heat values and calculation of the site-specific shielding calculations to demonstrate compliance with 72.104 and 72.106. The additional application of a source term uncertainty (i.e., burnup uncertainty) on top of the conservative site-specific source term specification is not needed.

In summary, the use of bounding source terms results in an overestimation of safety analysis parameters that are important to characterizing the behavior of the cask system.

C. Recommendations

Recommendation III-1: Licensees/CoC holders define and utilize more realistic source terms, supported by conservative modeling in the downstream calculations, in their applications to demonstrate the adequacy of dry storage system design. This is a Category 1 recommendation which requires no specific action by NRC, unless staff finds it necessary to update its internal review guidance.

Recommendation III-2: In cases where conservative source term calculations demonstrate compliance with 72.104 and 72.106, licensees/CoC holders should not also apply a source term uncertainty (i.e. burnup uncertainty) in their applications. This is a Category 1 recommendation which requires no specific action by NRC, unless staff finds it necessary to update its internal review guidance.

Recommendation III-3: In cases where applicants have applied conservative source terms, conservative modeling, and source term uncertainty (i.e. burnup uncertainty) in their applications, NRC should conduct a much less detailed review (i.e. simply check that sound methodologies have been applied instead of trying to independently repeat results). This is a Category 2 recommendation which would require NRC to revise its internal review guidance and practices.

IV. Guidance for Further Advancing the Definition of Performance Margin for Thermal Parameters

A. Introduction

Thermal limits have historically focused predominantly on ensuring that the peak cladding temperature (PCT) limits of spent nuclear fuel were not exceeded during short term operations and dry storage. These limits were designed to ensure fuel cladding integrity is maintained throughout the cask loading and storage process. NRC ISG-11 Revision 2 sets the limit to 400°C.[16] Revision 3 provides the option to allow a higher short-term temperature limit if the applicant can show, by calculation, that the best estimate hoop stress on the fuel cladding is ≤ 90 MPa for low burnup fuel.[17] Furthermore, recent work by DOE, EPRI and NRC (NUREG-2224) is supporting the re-evaluation of the performance restrictions on high burn-up fuel. Over the past decade, additional considerations for thermal limits have focused on issues related to aging management of the dry storage canisters for extended storage renewal periods due to concerns over localized corrosion and chloride stress corrosion cracking (NRC Managing Aging Processes for Storage NUREG-2214).[18]

B. Analysis

Thermal models used in current submittals are focused on meeting the PCT limits for spent fuel integrity in ISG-11 Revision 3 to meet 10 CFR Part 72.122h:

> *Confinement barriers and systems. (1) The spent fuel cladding must be protected during storage against degradation that leads to gross ruptures or the fuel must be otherwise confined such that degradation of the fuel during storage will not pose operational safety problems with respect to its removal from storage. This may be accomplished by canning of consolidated fuel rods or unconsolidated assemblies or other means as appropriate.*

These models contain multiple overlapping conservatisms while still demonstrating the fuel is always below the 400°C regulatory limit with margin.[19] There are two areas for consideration which contribute to conservatisms in thermal analyses: modeling conservatisms and limit conservatisms.

In thermal modeling, multiple overlapping conservatisms exist in the licensing basis assumptions that fundamentally bias the thermal predictions to higher temperatures compared to more realistic temperatures. For example, the ambient temperature assumptions are conservative to the highest expected temperatures that could potentially be experienced for the Independent Spent Fuel Storage Installation (ISFSI) location and not the actual temperatures during canister loading, drying, and

[16] Division of Spent Fuel Storage and Transportation Interim Staff Guidance-11 NRC Spent Fuel Project Office https://www.nrc.gov/docs/ML0221/ML022110372.pdf July 30, 2002.
[17] Division of Spent Fuel Storage and Transportation Interim Staff Guidance-11 NRC Spent Fuel Project Office https://www.nrc.gov/docs/ML0221/ML022110372.pdf July 30, 2002.
[18] US NRC, NUREG-2214 Managing Aging Processes for Storage July 2019
[19] Division of Spent Fuel Storage and Transportation Interim Staff Guidance-11 NRC Spent Fuel Project Office https://www.nrc.gov/docs/ML0221/ML022110372.pdf July 30, 2002.

emplacement. Additional assumptions are also focused on obtaining conservative upper bound temperatures to meet the PCT limits.

Conservatism in thermal limits apply specifically to the PCT limit , which is currently defined in the existing regulatory guidance as 400°C. For example, the ISG-11 Revision 3 PCT limits on cladding hoop stress were derived from creep data and analysis. This is different than the potential degradation mechanism of concern driving the PCT limit which was the embrittling effects of hydride reorientation. This potential degradation mechanism is impacted by elevated temperatures at and above 400°C, which drives hydrogen into the cladding and precipitates out as hydrides during cooling. NRC, EPRI, and DOE have conducted substantial research activities that show that hydride reorientation does not impact the mechanical performance of the fuel during storage and transportation (NRC NUREG-2224). However, the 400°C value was selected as a limit mostly on the basis of knowingly being a conservatively low value at the time.[20] Additionally, this limit is treated as a cliff edge effect where at 401°C the fuel cladding is assumed to have entirely failed. Also, of note is the fact that the PCT only occurs in a very small, localized volume of the hottest fuel assembly, so most of the fuel cladding is well below this peak value.

These multiple overlapping conservatisms, for both the thermal modeling and PCT limits, significantly impact dry storage canister designs, loading efficiencies, needed cooling times in spent fuel pools, decommissioning activities, etc. Furthermore, the thermal models used in current submittals are non-conservative for modeling actual canister temperatures.

For example, design basis thermal models could over-predict the external canister temperatures, which under-predict the timing of potential canister degradation mechanisms such as localized corrosion and chloride induced stress corrosion cracking for aging management. These over-predicted PCT limits can also severely limit the flexibility of the cask design to accommodate the distribution of the fuel assembly heat loads present in the spent fuel pool. Therefore, the goal with this performance margin item is to (1) determine if PCT is the appropriate measure of safety, and if not, then identify a better parameter and implement it, or (2) if PCT limit is the correct parameter, then identify a more realistic value of a cladding temperature limit or alternate approach which incorporates some acknowledgement of the localized nature of PCT, and (3) determine if modeling conservatisms can be minimized through an overall graded approach related to safety and possibly combined with other spent fuel integrity metrics, measurement, and/or models.

C. Recommendations

<u>Recommendation IV-1:</u> As a first step to defining the parameters on which thermal modeling should be focused, develop a Phenomena Identification and Ranking Table – PIRT – and use it to identify (a) the inputs, modeling approaches/techniques that have large impact on the results, and (b) those that don't and hence don't require scrutiny (i.e. a reasonable value can be assumed and not questioned). This is a

[20] Electric Power Research Institute, "Technical Basis for Extended Storage of Spent Fuel," Product # 1003416 Dec 29, 2002

Category 3 recommendation as both industry and NRC, along with the scientific community, would have to engage in the PIRT process.

Recommendation IV-2: In cases where applicants have applied the results of the PIRT described in Recommendation IV-1, NRC should revise its internal review guidance to limit the review to verification that the results of the PIRT have been appropriately applied instead of trying to independently repeat results. This is a Category 2 recommendation which would require NRC to revise its internal review guidance.

Recommendation IV-3: Assess how thermal modeling is done and what can be simplified. Develop an industry consensus based thermal modeling methodology and document this as a best practices guide. This is a Category 1 recommendation which requires no specific action by NRC, unless staff finds it necessary to update its internal review guidance.

Recommendation IV-4: Develop a thermal modeling metric such as a peak cladding temperature limit (PCT) that is based on more scientific information. Currently in the US we are using 400°C as a “cliff edge” limit. Consider a higher ultimate limit structured with stepped lower limits (e.g., under 380°C, not a concern at all; 381°C-425°C, provide some additional rigor in PCT calculations and assumptions review; over425°C up to 450°C, high level of rigor in PCT calculations and assumptions review [or other values as may be agreed]). This is a Category 3 recommendation that will require significant engagement between industry and NRC and will likely result in the development of regulatory guidance.

Recommendation IV-5: Develop a graded approach for thermal modeling analyses considering the effects of multiple overlapping conservativisms to prevent gross ruptures and its relationship to providing reasonable assurance of adequate protection of public health and safety of spent fuel integrity during short term operations and/or storage. This is a Category 3 recommendation that will require significant engagement between industry and NRC and will likely result in the development of regulatory guidance.

V. Guidance for Further Advancing the Definition of Performance Margin for Radiological Parameters

A. Introduction

Unlike other disciplines, the radiological safety analyses documented in the cask Final Safety Analysis Report (FSAR) do not and cannot demonstrate ultimate compliance with the most relevant regulatory dose requirements, since these demonstrations are site-specific. Hence there is no direct regulatory requirement to be fulfilled by the analyses and their results as documented in the FSAR. The safety analysis is instead conducted with the goal of conforming to the guidance documents (currently NUREG-1536 Revision 1, expected to be superseded by NUREG-2215). However, this guidance is no longer in line with the established practices in the industry, and do not account for the successful experience in loading casks over the last 20 years. It is proposed that this guidance be revised accordingly.

Additionally, there are performance margins in radiological evaluations including modeling conservatisms and methodology conservatisms. As low as reasonably achievable (ALARA) principles are used in the development of the designs but multiple conservatisms in the design and design basis may lead to overconservative designs and operational burden, as indicated by the often-times stark differences between calculated and measured dose rates around storage systems. Therefore, based on the vast amount of measured and calculated dose values, modeling guidance for dose analyses should be developed, or existing guidance revised accordingly. This would serve to reduce overpredictions of dose rates and therefore improve operational efficiencies for cask loading campaigns.

Finally, dose rates are influenced by the selection of fuel and calculations of source terms. These are discussed in other Section of this paper, namely III (source terms) and VI (fuel qualification).

Analysis

1. Main Regulatory Dose Requirements and Corresponding Guidance

The most important regulatory dose requirement is from 10CFR72.104, which sets an annual dose limit of 25 mrem at the owner-controlled area boundary. This is typically the site boundary, so in the following discussions the term site boundary is used. This dose limit is cumulative and compliance assessments must include the dose from the entire ISFSI and any reactors at the site. Since every ISFSI implementation is different, compliance with this limit requires a site-specific safety analysis. As a result of this, there is no clear target for the safety analyses in the FSAR, either with respect to the scenario analyzed, or the numerical limit that is to be used. The corresponding regulatory guidance document, NUREG-1536 Revision 1, states in Section 6.1 that the design should be “sufficient and reasonably capable of meeting the operational dose requirements…” (similar text is in the proposed NUREG-2215)[21]. NUREG-1536 Section 6.4 then outlines the analyses expected in the FSAR, including the

[21] US NRC, NUREG-2215 “Standard Review Plan for Spent Fuel Dry Storage Systems and Facilities”, Draft Report for Comment, January 2018

requirement that analyses are performed with bounding source terms.[22] However, these expectations are somewhat arbitrary, since there is no direct link to the regulatory requirements, in that meeting the expectation does not necessarily support the conclusion that the regulation is or can be met, and conversely, not meeting the expectation does not necessarily support the conclusion that the regulation is not met. These expectations were useful and necessary in the early stages of development of dry storage systems based on 10CFR Part 72 and NUREG-1536, where no relevant precedence existed. However, given the many ISFSIs successfully implemented and casks successfully loaded, it has been demonstrated that the current designs are more than capable of meeting the regulatory requirements, so this should no longer be a subject of extensive review. Additionally, with the accumulated industry experience, the current practices for ISFSIs designs are predominantly based on actual radiological data, not information in the FSAR. When this is considered, the expectations in NUREG-1536 Section 6.4.1 appear unnecessarily prescriptive, particularly the expectation to use bounding source terms.[23]

2. Shielding Analysis

In view of the site specific CoC dose measurement requirements that have been in place, there is a vast amount of measured and corresponding calculated dose rates information available for the many systems that have been loaded to date. In many cases, these show significant differences between measured and calculated values, with the calculated values higher. These result from the conservatisms in the numerous inputs to the analyses, and/or from deliberate conservative simplifications in the analytical approaches. Even if calculations are performed specifically for a loaded system, differences of a factor of two are not unusual. If significant conservatisms are used in the analyses, differences can easily reach an order of magnitude. Note that computer codes and related cross section libraries are considered to have a negligible effect here, they are well understood and known to be robust and sufficiently accurate for these analyses.

The additional margin identified through measurement would be above the margin that is kept between the calculated values and the regulatory limits. The overall margins should be considered when establishing the level of detail in the analyses. For example, using nominal or best estimate inputs rather than bounding values or additional uncertainty considerations may be all that is needed, and would reduce the effort and free up resources. However, this would require some principal agreement on the approach being taken, and hence some dialogue between industry and NRC.

3. Conclusion

Compliance with main regulatory dose requirements are site specific and shown in site specific analyses, not in the FSAR of the storage system. Dose information in the FSAR is provided based on expectations in the regulatory guidance documents, analyzing certain standard situations, even though compliance with the regulatory requirements cannot be derived from those situations. This was a valuable approach

[22] . US NRC, NUREG-1536 "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility" July 2010

[23] . US NRC, NUREG-1536 "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility" July 2010

in the early days of dry storage, where little if any practical dose experience existed to assist in the design and layout of an ISFSI. However, with the large number of ISFSIs established and casks loaded, the approach to the design and layout of ISFSIs, and demonstrating compliance, is mainly based on or derived from operational experience, with little if any reference to the doses reported in the FSAR. The industry experience also consists of a large body of dose comparison data between calculated and measured values, showing generally lower measured dose rates, which should be considered to inform the level details needed in the analyses. Consequently, the guidance should be amended to bring it in alignment with current practice. Specifically:

- The expectations in Section 6.4 should be revised to request typical/realistic/representative instead of bounding dose rates, consistent with the reduced safety significance of the presented results;
- In Section 6.4, the discussion that implies that the dose and dose rates provided in the FSAR demonstrate that the design is sufficient to meet the regulatory dose requirements should be removed or appropriately modified, since this is no longer correct, and
- Guidance should be provided on the level of detail accounting for the actual dose margins that are experienced.

Maintaining the FSAR dose evaluations in their current form is very resource intensive, given the changes in designs and loading parameters needed to meet the industry's needs, while the safety relevance of the evaluation results has diminished significantly over time. The changes proposed above would make resources available that could be applied to areas with greater safety significance, and hence improve efficiency.

B. Recommendation

Recommendation V-1: Revise the guidance in Section 6.4 of the proposed NUREG-2215 to 1) request typical/realistic/representative instead of bounding dose rates, consistent with the reduced safety significance of the presented results and to 2) remove or appropriately modify the discussion that implies that the dose and dose rates provided in the FSAR demonstrate that the design is sufficient to meet the regulatory dose requirements at the site boundary. This is a Category 3 recommendation which would require NRC to revise its regulatory guidance.

Recommendation V-2: Revise the guidance in Chapter 6 of the proposed NUREG-2215 with respect to details of modeling of the dose rate evaluations to consider experience from the many loaded dry storage systems. This is a Category 3 recommendation which would require some dialogue between industry and NRC, and would require NRC to revise its regulatory guidance.

VI. Guidance for Further Advancing the Definition of Performance Margin for Fuel Qualification

A. Introduction

Application of a risk-informed approach to fuel qualification would be beneficial in reducing the regulatory efforts to add and change fuel types to be included in a spent fuel cask design. Currently all fuel qualification requirements reside in the CoCs. Application of a risk-informed approach would ideally keep only those parameters in the CoC that are required to assure that the spent fuel cask system meets its operating requirements (shielding, thermal, criticality control) and relocate the very specific details of the fuel assemblies and designs from the Technical Specifications into the FSAR. This would enable some fuel changes to be made by the CoC holder or licensee without having to submit an amendment request to NRC every time a new fuel sub-type is added.

B. Analysis

Risk insights can be used to inform the process, and thus improve safety. Such risk insights would inform a graded approach which would identify those areas that are more significant vs. those that are less significant to safety, and truly focus licensing efforts and resources on the more significant issues, and less on those that have little safety significance.

This approach is currently being piloted as described in NEI's Regulatory Issue Resolution Protocol RIRP-I-16-1 via TN America's submittal and NRC's review of Amendment 16 to Standardized NUHOMS® Certificate of Compliance No. 1004 for Spent Fuel Storage Casks (Docket 72-1004). In Revision 6 of the pilot application (Submitted to NRC on September 3, 2019), risk insights have been applied to define an approach where only the Fuel Qualification Tables (FQTs) representing the highest overall heat loads in a canister, and the highest heat loads in the periphery fuel locations (if they are not the same), would need to remain in the CoC. This means at least one, and sometimes two FQTs for each of the DSC designs would remain, but all others would move to the FSAR. This will result in an approximate 90% reduction in the amount of information requiring NRC review before the CoC can be approved.[24] Since changes to the FQTs are one of the primary reasons that CoC's require amendment, this reduction in detailed information will result in substantially fewer amendments being needed in the future and hence, a commensurate reduction in the amount of licensing resources needed to assure safety with respect to fuel qualification.

It is also worth noting that the implementation of a graded approach also resulted in about 1/3 of the information in the CoC not related to fuel qualification being removed and transferred to the FSAR

[24] Amendment 16 to Standardized NUHOMS® Certificate of Compliance No. 1004 for Spent Fuel Storage Casks (Docket 72-1004), Revision 6, September 3, 2019

which further improves the efficiency and hence allows the CoC holder and NRC to focus on those items most significant to safety.[25]

While the pilot application submitted by TN America appears to be on a path to succeed in moving some information from the CoC into the FSAR, there is still more that can be done. As noted above, the changes have resulted in a 90% reduction of the amount of information requiring NRC review for the Standardized NUHOMS® system, other CoCs may not see as much benefit due to differences in fuel qualification approaches. Further, it should be possible to remove all FQT information from the CoC, similar to the approach applied at operating plants (where fuel qualification is not a part of the technical specifications but rather covered in other programs. For fuel in the core, the Core Operating Limits Report (CLOR) evaluates the fuel for use in the core, which enables fuels to vary from core to core without having to obtain prior NRC approval for every core load of fuel. Similarly, there are not FQTs for spent fuel storage in the plant spent fuel pools, rather fuel is qualified for insertion into the racks under an administrative program).

C. Recommendations

<u>Recommendation VI-1:</u> CoC holders should amend their CoCs to follow the precedent established through Regulatory Issue Resolution Protocol I-16-01 wherein a graded approach was developed to apply risk insights which resulted in a pilot amendment (#16) to Standardized NUHOMS® Certificate of Compliance No. 1004 for Spent Fuel Storage Casks (Docket 72-1004) that achieved a 90% reduction in the amount of information requiring NRC approval in the Fuel Qualification Table and reduced the overall size of the CoC by 33%. This is a Category 1 recommendation which requires no action by the NRC (other than to review graded approach amendments as they are submitted).

<u>Recommendation VI-2:</u> Align approaches in fuel qualification information for dry cask storage systems CoC (Technical Specifications) with current practices in operating reactors. This is a Category 3 recommendation as Industry and NRC will need to engage in a dialogue to determine the best way to accomplish this.

[25] Amendment 16 to Standardized NUHOMS® Certificate of Compliance No. 1004 for Spent Fuel Storage Casks (Docket 72-1004), Revision 6, September 3, 2019

VII. Guidance for Further Advancing the Definition of Performance Margin for Criticality

A. Introduction

Criticality in a dry cask system can only occur when water is present in the canister, such as during loading and unloading of the fuel in the spent Fuel Pool (SFP), and during postulated transportation accidents. Performance margin for criticality control is identified in three specific areas: in the use of full burnup credit; full absorber credit, and an understanding of the role gross cladding rupture plays in fuel reconfiguration.

Burnup credit is extensively used in spent fuel pool rack design and analysis, and facilitates the loading of spent fuel for storage. Full burnup credit for UNF storage and transportation could enable the reduction of fixed neutron absorbers in the spent fuel basket, which is a significant cost item in the basket fabrication. Full burnup credit would also provide the ability of the cask user to select fuel assemblies to comply with both transportation and storage requirements at the time of loading. This would provide greater confidence to the industry, regulator and public that casks loaded for storage will also be transportable when a location becomes available.

B. Analysis

1. Methods

Currently, criticality analysis assumes worst case geometric locations of materials in conjunction with worst case tolerances on all components resulting in several sensitivity evaluations which have little effect on the criticality results (especially when considered against the margin). Structural and thermal analyses utilize nominal dimensions which provide direct results. Using nominal dimensions in the criticality models would greatly simplify the licensing submittal thereby reducing the NRC reviewer's level of effort and minimizing the need for Requests for Additional Information (RAI) associated with the methodologies used.

PWR burn-up credit methods have received significant scrutiny in the licensing of storage and transportation packages. For BWR casks, the fresh fuel assumption is still the primary method of evaluation. Several NUREGs have been issued, detailing burnup credit methods for BWR fuel, hence a more implementable approach for BWR burnup credit may be worthy of further consideration.

2. Safety/Administrative Margin

The required 5% margin on k_{eff} is excessive when all normal/off-normal/accident worst case conditions have already been considered, including code uncertainty and bias. The k_{eff} of 0.95 (with 95% probability and 95% confidence) is the pinnacle of criticality criteria.[26] As indicated in this section, with all the conservatisms applied and conditions evaluated, there's a reasonable basis to move this target a

[26] 10 CFR Part 50.68(b)(2), 63 FR 63130, Nov. 12, 1998, as amended at 71 FR 66652, Nov. 16, 2006

bit. However, if there are changes in other areas such as assumptions on input data, or more realistic calculational methodologies, perhaps this can be the surviving criteria.

3. Materials

Currently the NRC only allows a 75% or 90% credit on the minimum absorber content of the neutron absorber panels, thereby applying an unnecessary penalty given the current fabrication and manufacturing controls and combined with neutron attenuation testing methods.[27] This conservatism is not consistent with the approach applied for spent fuel pool criticality analyses, where full credit of the minimum areal density is allowed. Testing has determined that for the current neutron absorbers, such as the newer Metal Matrix Composite (MMC) materials crediting the effectiveness of the neutron absorbing material is warranted.

4. Damaged Fuel

Currently applied assumptions of "floating" fuel and optimum size/spacing introduces a significant conservatism. EPRI and NRC analyses have shown that a more "realistic" impact of fuel re-configuration scenarios as a result of damage is small.

Modeling a full fuel assembly of fuel pellets, suspended in optimal moderator to determine criticality compliance is significantly unrealistic. This same approach is also determinant in the thermal performance area. Recent post irradiation examination of fuel has found that there is a large degree of pellet to clad interference which would require the entire cladding to dissolve/disappear to release fuel pellets. Assuming there is any degree of cladding failure, breaching in terms of cross-section breaks or longitudinal splits, it is reasonable to assume some fraction of fuel is released as opposed to the complete pellet inventory of the fuel assembly(ies). This would enhance the thermal and criticality performance of the system.

The question remains on the definition of "gross rupture" in ISG-1 to comply with 10 CFR 72.122h. ISG-1 identifies gross rupture to mean a 1mm cladding failure size which is an unactionable metric that does not provide a direct rationale to reasonable assurance to adequate protection of the public health and safety. Furthermore, the definition of gross rupture has evolved over time as well as the requirements on how to meet 72.122h. Hence, it is recommended that a multidisciplinary team consider a graded or risk-informed approach to redefining "gross rupture" within the current context to reasonable assurance to adequate protection of the public health and safety.

C. Recommendations

<u>Recommendation VII-1</u>: Align approaches in criticality safety analyses for dry cask storage systems with current practices in spent fuel pools (full fission product burnup credit, 100% credit for neutron absorber capability). This is a Category 3 recommendation as Industry and NRC will need to engage in a dialogue to determine the best way to accomplish this.

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[27] Division of Spent Fuel Storage and Transportation, Interim Staff Guidance-23, January 18, 2011

Recommendation VII-2: Develop a more realistic approach to the modeling of fuel reconfiguration scenarios in criticality analysis. This is a Category 3 recommendation as industry and NRC will need to engage in a dialogue to determine the best way to accomplish this.

Recommendation VII-3: Develop a safety-focused definition of the term “gross rupture” through a graded or risk-informed approach that maintains reasonable assurance of adequate protection of the public health and safety as required by 10 CFR Part 72.122h. This definition should be clear and have a well-established basis so that it does not evolve over time. This is a Category 3 recommendation as Industry and NRC will need to engage in a dialogue to determine the best way to accomplish this.

VIII. Applications

A. Introduction

The previous sections of this document have discussed areas where there is significant margin between safety limits and actual conditions in the canisters. Licensing and operational parameters are selected as follows:

- Regulatory limits are developed to be below known / suspected / assumed values **(Margin 1)**
- Vendor performs calculations for Technical Specifications and FSAR values:
    - Technical Specification values are set below the regulatory limit **(Margin 2)**
    - NRC may require reduced values during licensing **(Margin 3)**
    - Values are treated as "cliff edge" **(Margin 4)**
- Utility applies administrative limit to ensure process limits are below Technical Specification values **(Margin 5)**
- Codes and methods used by utilities to calculate values, such as decay heat, are inherently conservative **(Margin 6)**
- Inputs to these codes and methods are conservative, such as adding 5% to burnup or a simplified operating history **(Margin 7)**

This process results in a "stacking" of conservatisms (margin) that compounds the effects. The 16 recommendations provided by this report constitute many, but not all of the various ways to apply this margin to improve the efficiency with which industry and NRC assure safety by saving dose, time, and resources. These savings will improve the ability of industry and NRC to maintain "reasonable assurance of adequate protection of the public health and safety" which is always the first priority, by allowing those resources to be focused on the most safety significant issues.

Benefits and Applications

Shared understanding of the existence, source, and relative magnitude of margins allows benefits to be realized in various ways. Some examples are described below:

1. Recognition that there is margin in the licensing safety analyses could allow for significant resource savings by the NRC. License amendment reviews could be performed by verifying reasonable inputs and methods as opposed to attempting to duplicate results. This principle is reflected in Recommendations III-3 and IV-2 and could be applied in other areas as well. In turn, this also results in significant resource savings for the applicant by reducing RAIs and re-analyses. This could be implemented by using a 'Best Practices Guide', as called for in Recommendation IV-3, or similar consensus document that would define/identify accepted conservatisms and methodologies.
2. Knowledge of margin can be used in a risk informed manner to allow for ranges of values as opposed to using a hard limit. The thermal parameter discussion in Section IV highlights a valuable opportunity to implement such an approach and Recommendations IV-1 through 54

outline specific efforts that could be undertaken toward this goal. Examples of the real-life impact of this approach in the area of thermal calculations are as follows:

a. Processing the loaded canisters requires the use of shielding packages. These shielding packages are placed on top of the canister lid and around approximately the top two feet of the transfer cask. This provides additional shielding to workers positioned in the vicinity during evolutions such as preparing the canister lid for welding, welding, NDE testing of the welds, etc. Since the transfer cask analyses credit the heat loss to the environment, which is now obstructed by the shielding, penalties are imposed that impact operations. Some analyses lower the individual fuel assembly heat load limit allowed in the canister. This restriction reduces the amount of heat that can be removed from the SFP, which in turn reduces the time-to-boil in the pool in the event of loss of active cooling. Other analyses reduce the environmental temperature allowed during the time the shielding is in place. This restriction could result in increased dose to the workers in the event the building temperature rises and the shielding has to be removed to remain in compliance with the analysis requirements. Either penalty imposes undue operational restrictions and misplaces the focus from the most safety significant parameters, such as SFP cooling and worker dose, to a conservative fuel cladding temperature.

b. The frequency of the overpack vent surveillance specified in the CoC Technical Specifications are also dictated by thermal calculations which analyze blocked vents. This surveillance is performed by visual inspections and is time consuming for a pad full of casks, especially for larger pads with many casks. Although small, dose is also accrued by the worker during this visual inspection. This also applies to accident conditions such as response times for flood, tornado, earthquake and snow, when personnel are dispatched to verify the condition of the vents. Following such events, plant personnel need to be focused on the most safety significant items. Conservative thermal analyses give the false impression that blocked vents are safety significant, when it is likely that other parts of the plant are more important to safe recovery. For example, in response to a snow storm, inlet vents need to be cleared to comply with existing Technical Specifications. In an actual event, workers responded during stormy conditions and slipped on ice, creating an undue hazard to the employee and an OSHA recordable event. Increasing the time between periodic surveillances would result in less dose to the workers. Increasing the response time following an event to address potentially blocked vents or a muddy canister would allow personnel to address more pressing safety significant issues using a truly risk-focused strategy.

c. The time allowed to complete the transfer operation is also set by thermal calculations. In this scenario, the time between blowdown of the canister and placing the canister into the overpack is prescribed. If the allotted time will be exceeded, additional cooling needs to be applied to the transfer cask. Connecting these cooling systems and waiting for the cooldown adds to the dose workers receive. Increasing this time would again result in decreased worker dose.

d. Similar issues exist for time-to-boil calculations, once the lid is placed on the canister in the SFP. In the event that the canister cannot be removed from the SFP within the appropriate amount of time, the lid would have to be removed so water circulation can occur and the water does not boil. This becomes troublesome if the reason for the delay is a crane malfunction. The crane would have to be manipulated by hand, delaying any repair efforts and again misplacing the focus of personnel from the most safety significant issue, such as ensuring a proper crane repair, to establishing an overly conservative time-to-boil.

e. The amount of time that the casks have to reside on a site's ISFSI pad is also dictated by the thermal calculations. Overly conservative thermal analyses will unnecessarily delay the transportation of canisters to a Consolidated Interim Storage (CIS) facility or even a permanent geologic repository. Thermal analyses are also instrumental in both selecting the geology required for the country's permanent repository and the type of canister used in this repository. These important decisions will be adversely impacted by overly conservative models and limits.

3. Credit for margin can also be provided by allowing more parameters to be within the control of the licensee (cask vendors or utilities). This is currently being demonstrated with respect to fuel qualification in a pilot application of a graded approach as discussed in Section VI. Parameters such as the individual fuel assembly heat loads could be removed from the CoC and placed in the FSAR. Here, the patterns and heat loads could be changed by the 10 CFR 72.48 process. This provides more flexibility to the user by accommodating the distribution of heat loads present at the site and would provide for better SFP and cask management. Not optimizing the fuel that can be removed from the SFP reduces the amount of heat that can be removed from the SFP, which as stated before, reduces the time-to-boil in the pool in the event of loss of active cooling. Not optimizing the fuel that can be loaded into canisters will result in higher dose canisters being loaded as time goes on. Overly conservative thermal parameters and patterns are forcing the loading of cooler fuel earlier, which could be used later in strategic locations to reduce the dose rates encountered during loading activities, impacting crew dose. In addition, although less significant, dose would be reduced during any storage activities on the pad. Widespread implementation of Recommendation VI-1 would facilitate realization of these benefits.

4. As discussed in Section V, it is evident that margins in dose calculations also exist. Readings of the overpacks and from the area surrounding the ISFSI show that the dose calculations are overly conservative. Examples of the real-life impact of improving dose modeling and calculations, such as would be the case if Recommendation V-1 were implemented, are as follows:

a. The extensive calculations performed for licensing purposes could be reduced. Each site performs site specific calculations to show the loaded cask systems on a full ISFSI pad will meet the requirements of 10 CFR 72.104. The compliance is then verified by dose measurements per the CoC, so compliance is assured independent from the analyses in the FSAR. In addition, more realistic dose estimates are performed for ALARA plans prior to each loading campaign. Reducing the amount and complexity of dose calculations will result in time and resource savings for both the NRC and licensees.

   b. Better dose calculations would also benefit all the mentioned applications. More accurate dose calculations would allow for fewer iterations of the utility off-site dose calculation to show compliance with the 10 CFR 72.104 requirements. In addition, a better off-site dose calculation would eliminate (or greatly reduce) administrative controls that may be imposed by having to take credit for 'as loaded' cask source terms. This would be a cost savings to the utility licensee, but more importantly, allow resources to be focused on issues with greater safety significance. In addition, overly conservative dose calculations lead to unnecessary efforts in ALARA planning. These resources could be better used in other areas of the plant.

5. As discussed in Section VII, in the area of criticality analyses, significant margin exists, in addition to the retained NRC margin. Most calculations do not take credit for burnup. In addition, when credit for burnup is taken, full burnup credit is not allowed. Examples of the real-life impact of full burnup credit in criticality calculations are as follows:
   a. Neutron absorbers are credited in the criticality analyses when the canister is flooded with water, either during loading and processing or during an accident scenario that assumes water intrusion. Full burnup credit would allow for less required neutron absorber credit, reducing the amount of absorber material required and thus the cost of the canisters.
   b. For some PWR canisters, the boron in the SFP water is credited in the criticality analysis. When loading higher enrichment fuel, the required boron concentration in the water is often above the site's normal operating value. Therefore, the SFP boron has to be increased before the canister can be loaded. Full burnup credit would allow for less (or potentially eliminate) boron credit, which results in less water processing for the utility. Water processing is an expensive and time-consuming operation and system alignments have to be planned way in advance to allow room in the processing tanks for the required volume of water. In addition, water processing produces radioactive waste that must be disposed of by the sites.
   c. Full burnup credit may also allow some relaxation in the control rod bank insertion time limits required by some transportation certificates. Some current Part 72 certificates for PWR fuel restrict insertion times for control rods during operation. This presents a resource challenge for utilities licensees to reconstruct the operational data for all fuel that operated under control rods. In addition, the review time for transportation certificates would be reduced, since full burnup credit would be a one-time review which could be referenced in new certificates. Now, each license amendment which credits control rod bank insertion time limits are complicated analyses that have to be reviewed on a case by case basis. This creates a resource drain on both the licensees and the NRC.

IX. Conclusion

Over the past 30 years, industry and NRC have learned a lot about how to most effectively assure the safety of spent fuel storage in dry storage systems. Over the past 10 years, as the use of dry cask storage has become more prevalent and the time periods over which it will be used have been extended, there has been a recognized need to improve the efficiency with which dry storage systems are licensed. This recognition is reflected in a Petition for Rulemaking (PRM 72-7) submitted by industry in 2012 and accepted for review by NRC in 2014. Since 2012 much has been learned about the safety margins inherent in the use of dry storage technology. It is now believed that most of the efficiencies sought in PRM 72-7 can be achieved within the framework of existing regulations if the understanding of safety margin that we now have is effectively considered in the application of these regulations. Significant margin exists with respect to dry storage source terms, thermal parameters, radiological parameters, fuel qualification, and criticality. Based on our current understanding of dry storage safety margin, a number of recommendations for near term efficiencies gains, and for dialogue to further extend these gains, can be made. Implementation of these recommendations will enable the risk-based application of NRC and industry resources while providing reasonable assurance of adequate protection of public health and safety.

X. Recommendations

The basis for each of the 16 specific recommendations contained in this report is contained in Sections II through VII. Section VIII provides additional information about the benefits that can be accrued from implementing these recommendations to improve the efficiency with which industry and NRC assure safety. All of the recommendations are summarized below, grouped by the extent to which they can be implemented by industry, NRC, or as a result of a dialogue between industry and NRC.

A. Category 1: Actions that industry can take within the confines of existing regulations and guidance

Recommendation III-1: Licensees/CoC holders define and utilize more realistic source terms, supported by conservative modeling in the downstream calculations, in their applications to demonstrate the adequacy of dry storage system design.

Recommendation III-2: In cases where conservative source term calculations demonstrate compliance with 72.104 and 72.106, licensees/CoC holders should not also apply a source term uncertainty (i.e. burnup uncertainty) in their applications.

Recommendation IV-3: Assess how thermal modeling is done and what can be simplified. Develop an industry consensus based thermal modeling methodology and document this as a best practices guide.

Recommendation VI-1: CoC holders should amend their CoCs to follow the precedent established through Regulatory Issue Resolution Protocol I-16-01 wherein a graded approach was developed to apply risk insights which resulted in a pilot amendment (#16) to Standardized NUHOMS® Certificate of Compliance No. 1004 for Spent Fuel Storage Casks (Docket 72-1004) that achieved a 90% reduction in the amount of information requiring NRC approval in the Fuel Qualification Table and reduced the overall size of the CoC by 33%. (Note: NRC would then have the action to review graded approach amendments as they are submitted.)

B. Category 2: Actions that NRC can take by tailoring their regulatory guidance as well as their review and inspection practices to recognize the existence of performance margin

Recommendation II-1 NRC should develop an Acceptance Review Grading process that would assign varying levels of review to an application, from the time it is initially received, based on risk insights.

Recommendation III-3: In cases where applicants have applied conservative source terms, conservative modeling, and source term uncertainty (i.e. burnup uncertainty) in their applications NRC should conduct a much less detailed review (i.e. simply check that sound methodologies have been applied instead of trying to independently repeat results).

Recommendation IV-2: In cases where applicants have applied the results of the PIRT described in Recommendation IV-1, NRC should revise its internal review guidance to limit the review to verification that the results of the PIRT have been appropriately applied instead of trying to independently repeat results.

C. Category 3: Actions that will need industry and NRC to engage in a dialogue to develop improved regulatory tools and guidance

Recommendation IV-1: As a first step to define the parameters on which thermal modeling should be focused, develop a Phenomena Identification and Ranking Table – PIRT – and use it to identify (a) the inputs, modeling approaches/techniques that have large impact on the results, and (b) those that don't and hence don't require scrutiny (i.e. a reasonable value can be assumed and not questioned). For this to be successful, industry and NRC, along with the scientific community, would have to engage in the PIRT process.

Recommendation IV-4: Work to provide a thermal modeling metric such as a peak cladding temperature limit (PCT) that is based on more scientific information. Currently in the US we are using 400°C as a "cliff edge" limit. Consider a higher ultimate limit structured with stepped lower limits (e.g., under 380°C, not a concern at all; 381°C-425°C, provide some additional rigor in PCT calculations and assumptions review; over425°C up to 450°C, high level of rigor in PCT calculations and assumptions review [or other values as may be agreed]). This is a Category 3 recommendation that will require significant engagement between industry and NRC and will likely result in the development of regulatory guidance.

Recommendation IV-5: Develop a graded approach for thermal modeling analyses considering the effects of multiple overlapping conservativisms to prevent gross ruptures and its relationship to providing reasonable assurance of adequate protection of public health and safety of spent fuel integrity during short term operations and/or storage. This a Category 3 recommendation that will require significant engagement between industry and NRC and will likely result in the development of regulatory guidance.

Recommendation V-1: Revise the guidance in Section 6.4 of NUREG-1536 to 1) request typical/realistic/representative instead of bounding dose rates, consistent with the reduced safety significance of the presented results and to 2) remove or appropriately modify the discussion that implies that the dose and dose rates provided in the FSAR demonstrate that the design is sufficient to meet the regulatory dose requirements

Recommendation V-2: Revise the guidance in Chapter 6 of the proposed NUREG-2215 with respect to details of modeling of the dose rate evaluations to consider the experiences from the many loaded dry storage systems.

Recommendation VI-2: Align approaches in fuel qualification information for dry cask storage systems CoC (Tech Specs) with current practices in operating reactors (fuel qualification is not in the TS). This is a Category 3 recommendation as Industry and NRC will need to engage in a dialogue to determine the best way to accomplish this.

<u>Recommendation VII-1:</u> Align approaches in criticality safety analyses for dry cask storage systems with current practices in spent fuel pools (full fission product burnup credit, 100% credit for neutron absorber capability). Industry and NRC will need to engage in a dialogue to determine the best way to accomplish this.

<u>Recommendation VII-2:</u> Develop a more realistic approach to the modeling of fuel reconfiguration scenarios in criticality analysis. Industry and NRC will need to engage in a dialogue to determine the best way to accomplish this.

<u>Recommendation VII-3:</u> Develop a safety-focused definition of the term "gross rupture" through a graded or risk-informed approach within the current context to reasonable assurance to adequate protection of the public health and safety as required by 10 CFR Part 72.122h. This definition should be clear and have a well-established basis so that it does not evolve over time. This is a Category 3 recommendation as Industry and NRC will need to engage in a dialogue to determine the best way to accomplish this.