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USED FUEL SECURITY – PRIORITIZED ISSUES, R&D NEEDS, BEST PRACTICES, AND SECURITY RISK ANALYSIS FOR EXTENDED STORAGE*

Felicia A. Durán
Sandia National Laboratories

Gregory D. Wyss
Sandia National Laboratories

Scott DeMuth
Los Alamos National Laboratory

James A. Blink
Lawrence Livermore National Laboratory

ABSTRACT

In light of the report, *The Blue Ribbon Commission on America's Nuclear Future*, lessons learned from the accident at Fukushima, and a variety of other factors, increased emphasis is being placed on extended storage of used nuclear fuel (UNF), especially dry storage, potentially for many decades. In addition to domestic security needs, the Blue Ribbon Commission (BRC) stressed the importance of "active U.S. leadership in international efforts to address safety, non-proliferation and security concerns." In FY2012, the Material Protection Accounting and Control Technologies (MPACT) Campaign in the U.S. Department of Energy Office of Nuclear Energy (DOE/NE) Fuel Cycle Technologies (FCT) Program initiated activities related to safeguards and security (S&S) for extended storage of UNF. These efforts focus on technical analyses and guidance documents needed to assure that the security risks associated with extended storage are understood and minimized, and that reliable and technically sound information is available to address stakeholder concerns. A prioritized issues list has been developed, and current efforts focus on research and development (R&D) needs and activities. The MPACT prioritized issues extended work performed in the Used Fuel Disposition Campaign on security issues relevant to extended storage. In addition, issues from the BRC report specific to S&S of UNF as well as input from other technical experts were considered. The prioritized issues list has provided the basis for R&D needs for S&S for extended storage of used fuel in the MPACT campaign. This paper will discuss the latest efforts on security for extended storage of UNF, focusing on the prioritized issues and R&D needs.

INTRODUCTION

In light of the report, *The Blue Ribbon Commission (BRC) on America's Nuclear Future* [1], lessons learned from the accident at Fukushima, and a variety of other factors, increased emphasis is being placed on extended storage of used fuel, especially dry storage, potentially for many decades. As part of this emphasis, technical analyses and guidance documents are needed to assure that the security risks associated with extended storage are understood and minimized, and that reliable and technically sound information is available to address any stakeholder concerns that may arise. In FY2012, the Material

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Protection Accounting and Control Technologies (MPACT) Campaign in the U.S. Department of Energy Office of Nuclear Energy (DOE/NE) Fuel Cycle Technologies (FCT) Program initiated activities to provide such technical analyses and guidance documents for safeguards and security of extended storage of used fuel. These efforts focus on technical analyses and guidance documents needed to assure that the security risks associated with extended storage are understood and minimized, and that reliable and technically sound information is available to address stakeholder concerns. Sandia National Laboratories (SNL), Los Alamos National Laboratory (LANL), and Lawrence Livermore National Laboratory have developed a prioritized issues list [2], and current efforts focus on research and development (R&D) needs [3], and best-practice guidance related to security measures for extended storage of UNF. In addition, security risk assessment work is continuing. The MPACT prioritized issues complements and extends work performed in the Used Fuel Disposition Campaign [4] on security issues relevant to extended storage and includes review of previous National Academy of Sciences and U.S. Government Accountability Office studies to address issues for the back end of the fuel cycle, including safety and security of UNF storage. In addition, issues from the BRC report specific to S&S of UNF as well as input from other technical experts were considered. The prioritized issues list has provided the basis for R&D needs for S&S for extended storage of used fuel in the MPACT campaign. This paper discusses the latest efforts on security for extended storage of UNF. The focus will be on the identified prioritizes issues and R&D needs.

PRIORITIZED SAFEGUARDS AND SECURITY ISSUES FOR EXTENDED STORAGE OF USED FUEL

Over the years, several studies have addressed the back end of the fuel cycle, including disposition of used (spent) fuel. One of the most recent is the study by the BRC to conduct a comprehensive review of policies for managing the back end of the nuclear fuel cycle and recommend a new strategy [1]. To develop prioritized issues for safeguards and security of extended storage of used fuel, Durán et al., [2] revisited several past studies that have addressed the back end of the fuel cycle, including disposition of used (spent) fuel [8-20].

Review of Key Recommendations from Previous Studies

Generally, all of the previous studies to review used (spent) fuel storage agree that the current methods for dry cask storage at current operating and shut down reactor sites are safe and secure and likely to remain so for up to about 100 years. However, in a related study on spent nuclear fuel safety [16], the NAS noted and the BRC reiterated in Chapter 9 of its report [1] that "malevolent acts against spent fuel and high level waste are major technical and societal concern." Many of the previous studies advocate a move from pool storage to dry cask storage. The more recent studies call for consolidated storage with a priority of moving stranded fuel from decommissioned reactors sites. Safe and secure storage is required for many decades before a geologic repository would be operational, and then for many more decades after that for the long-term campaign to move used fuel from storage to disposal.

The BRC recommendations for a new strategy [1] include four elements relevant to spent fuel storage and transportation:

- Prompt efforts to develop one or more consolidated storage facilities as part of an integrated plan for managing the back end of the fuel cycle.
- Prompt efforts to prepare for the eventual large-scale transport of spent nuclear fuel and high-level waste to consolidated storage.

- Support for continued U.S. innovation in nuclear energy technology and for workforce development.
- Active U.S. leadership in international efforts to address safety, waste management, non-proliferation, and security concerns.

Specifically related to used fuel storage and transportation security, the BRC has recommended an assessment of lessons learned from the Fukushima accident and revisiting previous spent fuel storage security studies, continued R&D on vulnerability and terrorism, and an examination of the advantages and disadvantages of "hardened" storage options. In addition the BRC calls for the U.S. to work with others in the international community "to ensure that all spent fuel remains under effective and transparent control and does not become 'orphaned' anywhere in the world with inadequate safeguards and security" [1, p. xiv].

The MIT studies [10, 13] recommend consolidated storage for stranded fuel only, as an option to consolidate and reduce the operational costs, including significant security costs, from distributed shutdown sites and to avoid additional risks of transporting fuel from operating reactors where current storage remains safe and secure.

One NAS study [15] focused on potential safety and security risks of spent fuel presently stored in cooling pools at commercial reactor sites. Their recommendations include additional analysis to more fully understand the threats, vulnerabilities, and consequences for attacks on spent fuel pools and dry cask storage. In addition, appropriate actions were recommended to address significant vulnerabilities, reduce potential consequences by moving used fuel from pools to dry storage, and to identify possible upgrades to dry casks to improve their resistance to terrorist attacks. Finally, the NAS recommended review and upgrades of security requirements for protecting individual spent fuel rods and portions of rods being stored in pools as well as an assessment of the effectiveness and adequacy of surveillance and security measures by an independent organization.

Prioritized Issues for MPACT Storage Safeguards and Security

The DOE/NE FCT Program has been conducting R&D for alternative nuclear fuel cycles, including nuclear fuel recycling and waste management. All of the fuel cycle alternatives include production of used fuel and the need for its safe and secure storage. More specifically, the FCR&D Program is working to develop options to current practices to enable the safe, secure, economic, and sustainable expansion of nuclear energy while reducing proliferation risks. The focus of the FCRD Program is on long term, science-based research and development of technologies with the potential to produce transformational changes to the way in which the nuclear fuel cycle, and particularly nuclear waste, is managed. The MPACT campaign is charged with R&D associated with nuclear materials protection, including safeguards and security.

In addition, the FCT program has been conducting R&D for storage, transportation and disposal of used fuel in the UFD Campaign. This work has included R&D to address used fuel security for storage and transportation. In FY2012, the used fuel safeguards and security efforts for extended storage have transitioned to the MPACT Campaign in the FCRD Program. Efforts will continued in the UFD Campaign focused on security issues for more near-term efforts on consolidated storage and transportation. The prioritized issues in the MPACT Campaign will focus on safeguards and security for extended storage and will be coordinated to complement work in the UFD Campaign and other FCT efforts to address the BRC report recommendations.

Based on key recommendations from previous studies, as well as previous work that was done in the UFD Campaign and ongoing work in the MPACT Campaign, a set of prioritized issues were identified [2]. Each priority level includes important significant work; the prioritization has been done on a relative basis. The prioritized issues and associated recommendations are summarized below:

Highest Priority Issues

- **Vulnerabilities and Risks of Sabotage and Terrorist Attacks on Used Fuel Storage Sites**
  Specific Efforts and Related Activities:
  - Review of previous studies, including classified reports
  - Additional R&D to identify, characterize and assess the vulnerabilities, risks, and consequences of used fuel storage, including consideration of larger system characteristics
  - Risk assessment methods to evaluate security risk over the timeframe of extended used fuel storage, including approaches to evaluate factors that change over time
  - Review of ongoing NRC regulatory activities, including classified ISFSI rulemaking, DBT, and material categorization
  - Cask sabotage experiments to develop data on spent fuel dispersal
  - Security evaluations of different storage concepts, including hardened storage

- **Best Practices for Consolidated Storage**
  Additional Efforts and Related Activities:
  - Early identification of best practices for security design and operation of new storage facilities

- **Surveillance and Security Measures for Individual Fuel Rods and Portion of Rods**
  Specific Efforts and Related Activities:
  - Review of the effectiveness and adequacy, and upgrades for surveillance and security measures for protecting fuel rods not contained in fuel assemblies
  - Investigate the need and technologies to improve protection of these used fuel materials

Moderate Priority Issue

- **Improved Safeguards for Monitoring, Accounting and Control of Used Fuel**
  Specific Efforts and Related Activities:
  - Review of the effectiveness and adequacy, and upgrades for surveillance and security measures for protecting used fuel, including independent assessment
  - Investigate current approaches and the need for improved used fuel monitoring, accounting and control technologies that could be deployed for the timeframe of extended storage

Lower Priority Issue

- **Pool Storage of Used Fuel**
  Specific Efforts and Related Activities:
  - Keep apprised of ongoing NRC initiatives
  - Evaluate prioritization of this issue based on extent the pool storage is used in future storage concepts

R&D NEEDS – SAFEGUARDS AND SECURITY FOR EXTENDED USED FUEL STORAGE

Based on the identified prioritized issues, R&D needs [3] have been developed to address safeguards and security for extended storage of used fuel. The status of commercial used fuel storage, the regulatory framework, FCT programmatic context, and previous recommendations from previous studies have provided the basis for a set of prioritized issues for safeguards and security for extended storage of used fuel. In addition, the DOE has issued the Administration's response to the BRC final report and recommendations [21, 22]. The DOE strategy for used fuel storage includes a pilot-scale interim storage facility focused on servicing shutdown reactors with planned operation in 2021 and a larger capacity consolidated interim storage facility for planned operation in 2025. The strategy also includes a geologic repository with planned operation in 2048. These facilities will be NRC-licensed and must address security risks and safeguards requirements and implement protection measures commensurate with those risks and requirements.

As part of the DOE strategy, the FCT Program has initiated the Nuclear Fuel Storage and Transportation Program to address the shorter timelines to the pilot and consolidated interim storage facilities. Also, within the FCT Program, a system architecture study [23] is working to identify alternatives for used fuel management. These alternatives consider the different pathways used fuel may take to get to consolidated storage and subsequently to a geologic repository. With the expected increase, and possibly difference, in activities associated with used fuel storage, the need remains to assure that the security risks and safeguards requirements associated with extended storage are understood and minimized, and that reliable and technically sound information is available to address any stakeholder concerns that may arise.

R&D Needs to Address Highest Priority Issues

The three highest priority issues that have been identified include the following:

- Vulnerabilities to and Risks of Sabotage and Terrorists Attacks
- Best Practices for Consolidated Storage
- Surveillance and Security Measures for Individual Fuel Rods and Portions of Rods

The R&D needs to address these highest priority issues are discussed the following sections.

R&D Needs to Address Vulnerabilities to and Risks of Sabotage and Terrorist Attacks

The BRC, NAS, and GAO studies all recommend additional R&D efforts to address the vulnerabilities to and risks of sabotage and terrorist attacks on used fuel storage sites. Extended storage at reactor sites will most likely be dry cask storage; therefore MPACT efforts in this area should focus on security risk assessment for dry cask storage facilities as a first step for the technical basis of recommendations for protection measures commensurate with the security risk.

Security Risk Assessment for Extended Storage of Used Fuel

A key issue here is the need for an appropriate approach to evaluate the security risk of used fuel storage for the timeframe of extended storage ranging from several decades to a few centuries. Efforts to address this issue were initiated in the UFD Campaign [4] and continue in the MPACT Campaign. A framework has been established to characterize adversary attack scenarios and evaluate the difficulty of those attacks. In addition, self-protection analyses have been performed to characterize this used fuel characteristic over the timeframe of extended storage, methods have been developed to evaluate

attractiveness of the used fuel materials and integrated with the security risk assessment, and a preliminary set of future adversary capabilities has been developed. Further development of approaches to evaluate factors that change over the timeframe of extended storage, including self-protection, material attractiveness, adversary technologies (e.g., improved breaching tools, robotics), and aging containers and fuel. Developing and implementing security risk assessment methods provide the basis for determining protection measures that are commensurate with the security risk.

Consequence Analyses for Used Fuel Storage

The risk assessment methodology that is being applied for used fuel storage security risk also requires evaluation of the consequences associated with the associated adversary attack scenarios. The types of consequences of concern for used fuel storage are the releases of radioactive material and subsequent doses to members of the public. Previous DOE and NRC studies, including classified studies, have focused on addressing the need for data on consequences of sabotage and terrorist attacks on spent fuel casks. This work has focused on understanding how spent fuel performs when subjected to attack using high energy density devices. The most recent efforts include the multinational test program that focused on characterization of aerosol dispersal as a result of sabotage attacks on spent fuel casks [24, 25] and an NRC-sponsored parametric study to analyze dose consequences from the release of spent nuclear fuel from dry storage casks [26]. The goal of both these efforts is to provide consequence data that are relevant to sabotage attacks on used fuel casks and to associated risk assessments.

In terms of determining dose consequences for potential releases from used fuel storage casks, it is important to characterize the aerosol dispersal of used fuel particles that would result from a sabotage attack on a storage cask. The previous work from the cask sabotage test program has tested several surrogate materials to measure aerosol characteristics, including respirable fractions produced; amounts, nuclide content, and produced particle size distributions and morphology; measurements of volatile fission product species enhanced sorption – enrichment factors onto respirable particles. In addition the test program used the collected data as the basis to develop the spent fuel ratio (SFR) that is needed for scaling studies and analyses of other attacks using other types of high energy density devices.

The MPACT Used Fuel Storage Security Team will used the data from these previous efforts to estimate the consequences of the adversary attack scenarios that are being evaluated in current used fuel storage security risk assessment effort. However, a continuation of the work to characterize used fuel performance when subjected to sabotage attacks is still needed. The DOE/NE MPACT Team has initiated technical exchange activities with the NRC Nuclear Security and Incident Response (NSIR) organization. These exchange activities would serve well for planning a restart of the interagency and international collaborative efforts for the Phase 4 testing of actual spent fuel rodlets.

Zirconium Fires in a Used Fuel Storage Cask

Another key issue that has been identified through related cask sabotage work is the risk of a zirconium fire in fuel that has been damage in a cask sabotage attack. An extension of the security risk assessment effort would include an evaluation of adversary attack scenarios that could result in a zirconium fire in a breached cask. To support evaluation of the possible consequences for this attack scenario, an additional effort would include the development of a computational model of heat transfer and fluid flow in and through a breached cask. This effort would also involve a review of the consequence modeling efforts to look at this issue.

Security Assessments for Different Used Fuel Storage Concepts

As previously mentioned, the systems architecture study is evaluating alternatives for used fuel management. Alternative cask and canister concepts, as well as different operational concepts, might change key characteristics of the target material for safeguards and security considerations. The MPACT Used Fuel Security Team has initiated baseline security assessments for current storage configurations and plans to proceed to performing assessments for the alternative storage concepts and operations from the systems architecture study. These assessments will include an evaluation of the hardened storage concept and consideration of larger system characteristics that have impacts on vulnerabilities and security risks of extended storage.

Related Activities

A key recommendation from NAS and GAO has been review of previous classified vulnerability and other security studies associated with used fuel storage. The MPACT Used Fuel Security Team has initiated Technical Exchange meetings with the NRC and has had two to date (August 2012 and March 2013) with another planned for April 2013. The purpose of these meetings has been to share information on the research (DOE Official Use Only and NRC Classified) both parties are doing and to identify possible areas of collaboration. These activities are continuing and through these interactions, the following activities will be pursued:

- Review of classified Design basis Threat (DBT) related to IFSIs. Implementation of this DBT would impact the security requirements at storage sites.
- Evaluation of potential NRC changes to the categorization of nuclear material (i.e., graded safeguards concept presently used by DOE). Changes to how the NRC categorizes material, specifically related to radiation levels, could impact the security requirements at ISFSI sites.
- Continued review of NRC rulemaking for ISFSI security requirements. In 2009, NRC published for public comment a technical basis evaluation for a propose rule to revise security requirements for storing fuel away from a reactor. This evaluation included a proposal to establish a security-based dose limit that would require ISFSIs to develop site security strategies to protect against a potential radiological release that exceeds NRC's acceptable dose limits at a site boundary. NRC received public comments showing a preference for guarding against a specific threat rather than the dose-based approach. As a result, the NRC has delayed the proposed rule in order to gather more information regarding the public comments and plans additional studies to assess the situation and determine the appropriate security strategy [8].

Best Practices for Consolidated Storage

The BRC, NAS, and GAO all recommend the development of one or more consolidated storage facilities. Early identification of best practices for the security design and secure operation of new facilities is critical. In addition, the BRC recommends active U.S. leadership in international efforts to address safety, waste management, non-proliferation, and security concerns. Part of the MPACT Campaign's FY2012 efforts included planning for the development of Best Practices for Used Fuel Storage Security that would address both these recommendations. This effort could proceed with a Safeguards and Security By Design approach that identify design features and safeguards concepts, especially innovative approaches and new technologies that would support operational efficiencies over the period of extended storage.

Surveillance and Security Measures for Individual Fuel Rods and Portions of Rods

The BRC and NAS have recommended a review of the effectiveness and adequacy, and upgrades for surveillance and security measures for protecting fuel rods not contained in fuel assemblies. The MPACT Campaign R&D should investigate the need for and technologies to improve protection of these used fuel materials.

R&D Needs to Address Moderate Priority Issue

The one moderate priority issue that was identified includes the following:

- Improved Safeguards for Monitoring, Accounting, and Control of Used Fuel

The R&D needs to address this moderate priority issue is discussed the following sections.

Improved Safeguards for Monitoring, Accounting and Control of Used Fuel

The BRC and NAS have recommended a review of the effectiveness and adequacy, and upgrades for surveillance and security measures for protecting used fuel, including an assessment by an independent organization. In addition to a review of surveillance and security measures, the MPACT Campaign R&D should investigate current requirements, approaches and the need for improved used fuel monitoring, accounting and control technologies that could be deployed for the timeframe of extended storage.

R&D Needs to Address Lower Priority Issue

The one moderate priority issue that was identified includes the following:

- Issues for Pool Storage of Used Fuel

The R&D needs to address this lower priority issue is discussed the following sections.

Issues for Pool Storage of Used Fuel

Previous studies have discussed the issue of a zirconium cladding fire in a used fuel pool. This was a primary focus of the NAS study in 2006 [15]. Significant efforts have been taken to address and mitigate the possibility of a used fuel pool fire in response to this NAS study as well as to the Fukushima accident. Since Fukushima Daiichi, NRC has been engaged in ongoing initiatives related to items such as addressing a loss of off-site electricity and seismic hazard reevaluation. It has been conducting a study on the consequences of accident scenarios affecting spent fuel pools, is undertaking a probabilistic risk assessment to quantify spent fuel risk for a selected reactor site of interest, has had plants install monitoring equipment to remotely measure a wider range of water levels in spent fuel pools, and has required plants to ensure the effectiveness of water mitigation measures [8]. In addition, as a response to Fukushima, spent fuel management alternatives for the U.S. nuclear fleet have been developed in the UFD Campaign to address additional fuel pool vulnerabilities.

Related Activities

Related activities to address issues for pool storage include the following:

- Security risk assessment of options to accelerate the transfer of fuel out of spent fuel pools

- Options for additional protection measures or consequence mitigation to address security risks for transfer operations
- Review of previous spent fuel vulnerabilities to determine if additional vulnerabilities should be considered

Extended storage is expected to emphasize dry storage. As a result, R&D efforts to address issues associated with pool storage are a lower priority for the MPACT Campaign. If consolidated storage includes pool storage, this prioritization may need to be revised.

CONCLUSIONS

The DOE/NE FCT Program has been conducting R&D for alternative nuclear fuel cycles, including nuclear fuel recycling and waste management. All of the fuel cycle alternatives include production of used fuel and the need for its safe and secure storage. More specifically the FCR&D Program is working to develop options to current practices to enable the safe, secure, economic, and sustainable expansion of nuclear energy while reducing proliferation risks. The focus of the FCRD Program is on long term, science-based research and development of technologies with the potential to produce transformational changes to the way in which the nuclear fuel cycle, and particularly nuclear waste, is managed. The MPACT campaign is charged with R&D associated with nuclear materials protection, including safeguards and security.

Previous efforts identified a set of prioritize issues for safeguards and security for extended storage of used fuel. These issues have been revisited to provide the basis for the MPACT used fuel safeguards and security R&D needs. In addition, the status of commercial used fuel storage, the regulatory framework, the FCT programmatic context, the DOE strategy for used fuel storage, and FCT systems architecture efforts have been addressed to provide a basis for developing R&D needs for safeguards and security in this report.

A number of key efforts and activities have been outlined to address the prioritized issues and key recommendations from previous studies, including the following:

- Continued security risk assessment activities, including development of methods and approaches and assessment of dry storage and pool storage
- Consequence analysis activities, including review of past studies to incorporate consequence data to support ongoing security risk assessment efforts and a proposed restart of the cask sabotage test program
- Review of previous R&D for zirconium fires in a breached cask, and proposed modeling of the heat transfer and fluid flow for this type of cask breach
- Security assessments for various storage and operational concepts, including baseline assessment for current storage configurations, hardened concepts, and those proposed in the systems architecture study.
- Best practices guidance, including safeguards and security by design approaches to identify design features and safeguards concepts, especially innovative approaches and new technologies that would support operational efficiencies over the period of extended storage.
- Investigation of the need and technologies for protecting individual fuel rods and portions of rods
- Investigation of current requirements, approaches and the need for improved used fuel monitoring, accounting and control technologies that could be deployed for the timeframe of extended storage

- Activities to address issues for pool storage, including security risk assessment of options to accelerate the transfer of fuel out of used fuel pools, additional protection measures or consequence mitigation to address security risks for transfer operations, and review of previous spent fuel vulnerabilities to determine if additional vulnerabilities should be considered.

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