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Used Fuel Storage Security[1]

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ABSTRACT

With the policy decision not to pursue the Yucca Mountain Repository for final disposal of used light water reactor fuel, the tactical strategy is to store used fuel at the utility sites in either pool or dry cask storage systems. This strategy has been affirmed by the National Academies of Sciences as a safe and secure management option for used fuel. Current storage system operations are proven, and the regulatory framework is stable. In addition, this storage provides flexibility to readily adapt to decisions regarding reprocessing or direct disposal. This strategy also implies that the used fuel will be stored for a very long and indeterminate time. Although no time threshold has been defined, current guidance suggests that planning for long term storage needs to be considered for up to 300 years. This presents possible regulatory and technical issues with regard to both storage safety and security. This paper discusses work in progress to address security for very long term storage (VLTS) of used fuel. Security requirements from the U.S. Nuclear Regulatory Commission and the U.S. Department of Energy are reviewed and will be evaluated for impacts over the longer timeframe. Two of the issues associated with maintaining security for VLTS are discussed. Specifically, the applicability of self-protection is addressed and differences between NRC and DOE requirements are summarized. This work is part of a larger effort to provide options to address research and development needs, security issues, and concepts for investigating the technical and regulatory aspects of VLTS of used fuel and the used fuel storage system.

INTRODUCTION

The Used Fuel Disposition (UFD) Campaign in the U.S. Department of Energy Office of Nuclear Energy (DOE/NE) Fuel Cycle Research and Development (FCRD) Program is responsible for evaluating packaging and storage options for radioactive material produced from existing and alternative future nuclear fuel cycles. To address these options, the UFD Campaign has initiated efforts to address a broad spectrum of technical, regulatory, institutional, and operational issues for storage of fuel cycle wastes. The three key areas include (1) Research and Development (R&D) Opportunities; (2) Security; and (3) Concept Evaluation. The overall objectives of the work are to provide options to address R&D needs, security issues, and concepts for investigating the long-term storage of nuclear fuel cycle wastes, including legacy used nuclear fuel (UNF), used fuel being discharged from the current fleet of U.S. power reactors, as well as potential used fuel and process wastes from alternative future nuclear fuel cycles.

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This paper discusses work in progress to identify and evaluate security issues for very long term storage (VLTS) of used fuel. Security requirements are reviewed for UNF storage, including those in the U.S. Nuclear Regulatory Commission (NRC) regulations and in the DOE directives, for possible impacts over the longer timeframe. A discussion of two issues associated with maintaining security for VLTS of used fuel is presented. Specifically, the applicability of self-protection is discussed and differences in NRC and DOE requirements are summarized.

Background

The policy decision not to pursue the Yucca Mountain Repository for final disposal of light water reactor (LWR) used fuel has created a lack of an identified disposal path for UNF. The "store-in-place" tactical strategy will require VLTS of legacy fuel, used fuel being discharged from the current fleet of commercial reactors, as well as the potential of used fuel and process wastes discharged from alternative future nuclear fuel cycles.

Currently, three fuel cycles approaches are being considered by DOE/NE under the FCRD Program: an optimized once-through open cycle, a modified open cycle, and a full recycle (closed cycle). Figure 1 illustrates these three approaches.[3] The production of used fuel is common to all three cycles, and its safe and secure storage is an integral part of each fuel cycle. Storage of HLW and LLW produced in the modified open cycle and full recycle will also be required.

The policy change regarding Yucca Mountain has a significant impact on the current once-through fuel cycle as well as on the other fuel cycles being considered by DOE/NE in the FCRD Program. One of the most immediate concerns is the need to resolve issues associated with VLTS of LWR uranium oxide (UOX) used fuel; thus, the focus of the effort this year is on VLTS of LWR UOX used fuel.

Current practices for storage of UNF include pool storage or dry storage on concrete pads at most operating commercial reactors. In addition, General Electric operates a storage pool at the Morris, IL, site that contains used fuel from several reactors [1]. The NRC regulates both pool storage and dry surface storage of used fuel under Title 10 of the Code of Federal Regulations (CFR), Part 72 [2]. Part 72 discusses licensing of both Independent Spent Fuel Storage Installations (ISFSIs) and Monitored Retrievable Storage (MRS) facilities. The term "ISFSI" refers to both wet (pool) and dry surface storage facilities. An MRS is a used (spent) fuel storage facility operated by the DOE pending shipment of the material to a HLW repository. ISFSIs are currently licensed for 20 years, and some licenses have been extended to a total of 60 years. HLW and Greater-than-Class-C (GTCC) LLW, as well as used fuel can be stored at ISFSIs.

The time period for storage depends on the eventual availability of a disposition path or a geologic disposal option. The time period associated with VLTS is generally accepted to be well past the current 60-year licensing period. Although no time threshold has been defined, NRC guidance suggests that planning for long term storage needs to be considered for up to 300 years [3]. This presents regulatory and technical issues with regard to both storage safety and security.

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[3] DOE/NE, 2010. *Draft Implementation Plan – Developing Sustainable Fuel Cycle Options*, U.S. Department of Energy Office of Nuclear Energy, Washington DC (draft).

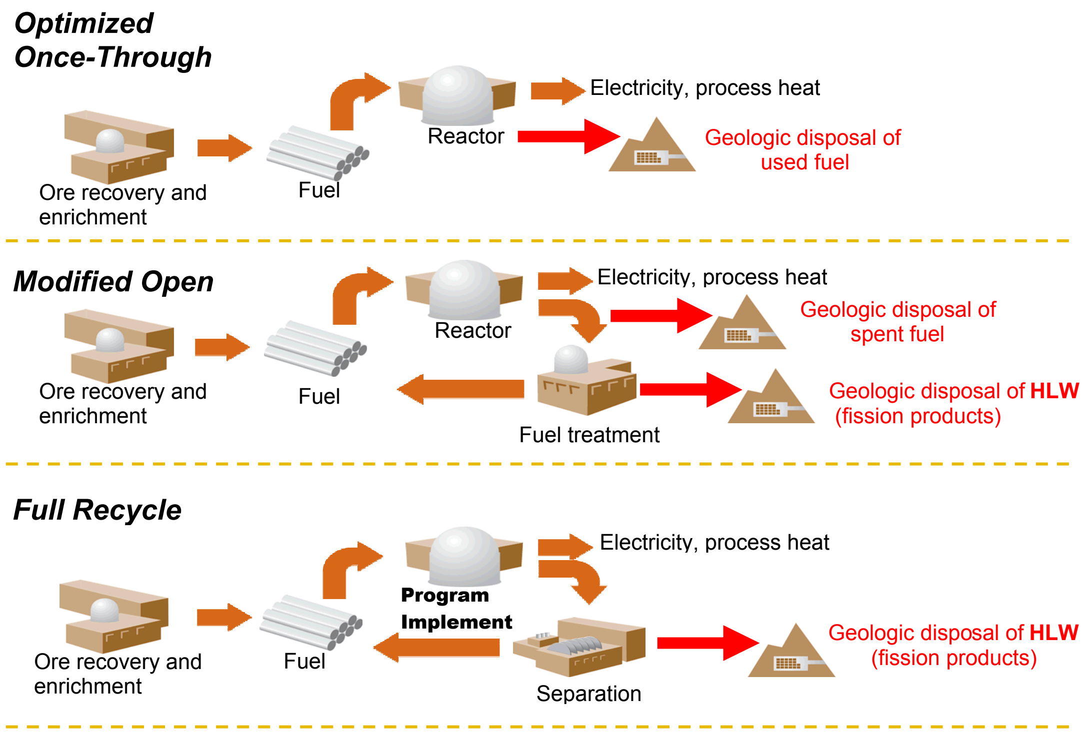

Figure 1. Fuel cycle approaches.[4]

The Concept Evaluation Interim Report [4] discusses the safety and licensing regulations and current practices for storage of UNF in more detail. In addition, the report provides a preliminary description of a process to evaluate options for investigating relevant technical aspects of VLTS of used fuel. Four options are proposed, including the following:

- Monitor storage operations at existing ISFSIs, relying on the fuel examinations that the managing utility performs for data collection.
- Implement a UNF storage system project at an existing ISFSI, expanding operations to include introduction of high burn-up UNF and periodic examination of the stored UNF at an off-site facility.
- Implement a UNF storage system project at an existing government surface storage facility, expanding operations to include introduction of high burn-up UNF and potentially several types of HLW, coupled with examination of the stored UNF and HLW at an on- or off-site facility.
- Construct and operate a UNF storage system project at a new site with operations to include introduction of high burn-up UNF and several types of HLW, and the examination of the stored UNF and HLW either at a facility constructed along with the UNF storage system project or at an on- or off-site facility.

Security for VLTS of used fuel is being addressed within the context of these four options, as well for future commercial storage sites, and requires consideration of both NRC and DOE requirements.

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[4] DOE/NE, 2010. *Draft Implementation Plan – Developing Sustainable Fuel Cycle Options*, U.S. Department of Energy Office of Nuclear Energy, Washington DC (draft).

REGULATORY REQUIREMENTS

Current regulatory requirements pertinent to security for used fuel storage are provided in NRC regulations and guidance and DOE Directives. These are summarized as follows.

Overview and Applicability of NRC Regulations

The CFR, Title 10, Energy [2], provides the regulations for NRC licensing of commercial nuclear facilities. Within Title 10, requirements are provided for licensing independent storage of spent nuclear fuel (SNF), HLW, and reactor-related GTCC LLW. The NRC a licensee to establish a physical protection system (PPS) for these storage sites with the objective of providing high assurance that activities involving SNF and HLW do not constitute an unreasonable risk to public health and safety. The NRC achieves this strategic goal by requiring ISFSI licensees to comply with the security requirements specified in 10 CFR Part 73. Following the terrorist attacks of September 11, 2001 (9/11), the NRC has continued to implement this requisite high assurance for all facilities licensed to store SNF through a combination of these security regulations and the issuance of security orders. These orders ensured that a consistent overall protective strategy is in place for all types of ISFSIs, given the current threat environment.

The current ISFSI security regulatory structure is complex and the specific requirements vary depending on the type of license (general or specific under Part 72) and the location of the ISFSI. The ISFSI may be collocated at an operating power reactor, a possession-only reactor or independent of a reactor. The NRC has begun the rulemaking process to propose a set of security requirements that will achieve consistent outcomes across the wide range of SNF and HLW storage facilities that either exist today, or could be licensed by the NRC under Part 72 in the future [5].

NRC Regulations for Used Fuel Storage

The principal parts of 10 CFR regulating the licensing and operation of commercial used fuel storage facilities and their applicability are summarized below. Although the current focus for this work in on used fuel storage security, the requirements summarized here include those for facility safety and licensing, physical protection of special nuclear material (SNM) at fixed sites and in transit, and material control and accountability (MC&A).

- <u>10 CFR 72 – Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste</u>

  This part establishes the requirements, procedures, and criteria for issuing licenses to receive, transfer, and possess power reactor SNF, power reactor-related GTCC waste, HLW, and other radioactive materials associated with spent fuel storage in an ISFSI and the terms and conditions under which the NRC will issue a license.

  This part also establishes requirements, procedures, and criteria for the issuance of a license to the DOE to receive, transfer, package, and possess power reactor SNF, HLW, and other radioactive materials associated with the storage of these materials in an MRS.

  Under the requirements of 10 CFR 72, license applications for ISFSIs must include a physical security plan that describes how the requirements of 10 CFR 73 will be met. Additionally, Sections 72.72, 72.76, 72.76 and 72.78 contain specific requirements for MC&A.

- <u>10 CFR 73 – Physical Protection of Plants and Materials</u>
  This part regulates the physical protection of SNM at fixed sites and in transit. The regulation defines categories of material to reflect the quantity of SNM present. Category I (Cat I) materials involve a formula quantity of SNM.[5] Category II (Cat II) and Category III (Cat III) have successively smaller quantities of SNM. Protection requirements are most stringent for Cat I materials and successively less stringent for Cat II and Cat III. 10 CFR 73 also places requirements on irradiated reactor fuel as a sabotage concern.

  The requirements of 10 CFR 73.51 state that each licensee must establish and maintain a physical protection system (PPS) with the objective of providing high assurance that activities involving SNM do not constitute an unreasonable risk to public health and safety. Currently, 10 CFR 73.51 specifies physical protection requirements for storage of SNF and HLW. The requirements of 10 CFR 73.51 apply to each licensee that stores SNF or HLW under a specific license at an ISFSI, MRS, or geologic repository operations area. In addition, ISFSIs collocated at operating power reactors may be subject to stricter requirements contained in 10 CFR 73.55.

  For SNF storage facilities, the design basis threat (DBT) for radiological sabotage of power reactors under 10 CFR 73.1 is not applicable because of the exemptions provided in 73.6. A separate protection goal defined for these facilities requires that the PPS must be designed to protect against loss of control of the facility that could be sufficient to cause radiation exposure exceeding the dose described in 10 CFR 72.106. Access to UNF or HLW stored within the protected area requires passage or penetration through two physical barriers – one barrier at the perimeter of the protected area with isolation zones on each side and one barrier offering substantial penetration resistance, which may be provided by an approved storage cask or building walls, such as those of a reactor or fuel storage building.

- <u>10 CFR 74 – Material Control and Accounting of Special Nuclear Material</u>
  This part establishes the requirements for the control and accounting of SNM at fixes sites and for documenting the transfer of SNM. The general reporting and recordkeeping requirements of 10 CFR 74, Subpart B do not apply to licensees whose MC&A reporting and recordkeeping requirements are covered by Sections 72.72, 72.76, 72.76 and 72.78.

The current NRC regulatory framework for SNF storage security is undergoing a rulemaking process. The NRC initiated rulemaking to revise the existing security requirements in 10 CFR 73 that apply during the storage of SNF at an ISFSI and during the storage of SNF and/or HLW at an MRS facility. This rulemaking will also make conforming changes to the ISFSI and MRS licensing requirements in 10 CFR 72. The NRC's specific objectives for this rulemaking are to: (1) update the ISFSI security regulations to improve the consistency and clarity of Part 73 regulations for both types of ISFSI licensees (i.e., general and specific), to reflect current Commission thinking on security requirements, and to incorporate lessons learned from security inspections and Force-on-Force evaluations conducted since these regulations were last updated; (2) to make generically applicable requirements similar to those imposed on ISFSI licensees by the post-9/11 security

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[5] Formula quantity means strategic SNM in any combination in a quantity of 5000 grams or more computed by the formula: grams = (grams contained U-235) + 2.5 (grams U-233 + grams plutonium). Strategic SNM means U-235 in uranium in a concentration of at least 20%, U-233, and plutonium.

orders; and (3) to use a risk-informed and performance based structure in updating the ISFSI and MRS security regulations [5].

Overview and Applicability of DOE Directives

The 470 series of DOE directives (policies, orders, manuals, guides, and notices) provides the requirements for DOE safeguards and security (S&S). The DOE directives applicable to security of used fuel storage facilities and their applicability are summarized below.

- DOE M 470.4-1A – Safeguards and Security Program Planning and Management [6]
  This manual establishes the overall requirements for the DOE Safeguards and Security Program. It addresses program planning and management, the DOE tactical doctrine, security conditions, site S&S plans, and vulnerability assessment (VA) program. The DOE S&S philosophy is that interests and activities must be protected from theft, diversion, terrorist attack, industrial sabotage, radiological sabotage, chemical sabotage, biological sabotage, espionage, unauthorized access, compromise, and other acts that may have an adverse impact on national security; the environment; or pose significant danger to the health and safety of DOE Federal and contractor employees or the public. The requirements for site security plans address the overall process for describing a site's protection plan.

- DOE M 470.4-2A – Physical Protection [7]
  This manual establishes the requirements for the physical protection of interests under DOE purview ranging from facilities, building, government property, and employees to national security interests such as classified information, SNM, and nuclear weapons. The manual provides direction for planning, implementing, and monitoring the application of physical protection measures, and describes the procedures and management process applicable to DOE operating environments. With regard to material categorization, physical protection of SNM must consider the following factors: quantities, chemical forms, isotopic composition purities, ease of separation, accessibility, concealment, portability, radioactivity and self-protecting features. This manual specifies general requirements for physical protection as well as specific requirements for different categories of SNM, including the type of security area, access controls, personnel and vehicle access, barriers, intrusion detection and assessment, alarms, and protection for storage and transportation.

- DOE M 470.4-6 Chg 1 – Material Control and Accountability [8]
  This manual provides the requirements to establish a program for MC&A of nuclear material within DOE. MC&A requirements are applied under the graded safeguards approach to provide the greatest relative amount of control and accountability for the type and quantities of SNM that can be most effectively used in a nuclear explosive device. Under DOE graded safeguards, commercial used fuel would be categorized as "all other materials" (highly irradiated forms),[6] which is Attractiveness Level E, and reportable quantities of DOE Cat IV.

- DOE O 470.3B – Graded Security Protection Policy (Official Use Only (OUO)) [9]
  This order provides OUO graded threat guidance strategies to allow for the development and evaluation of appropriate safeguards and security measures. These requirements address asset categorization, the graded security protection levels, graded protection strategies, adversary

[6] DOE further defines "highly irradiated material" as material having a radiation level of at least 100 rem/hour at 1 meter [10].

types and considerations, and determination of system effectiveness. Depending on material categorization, this order may not be applicable to UNF storage security.

USED FUEL STORAGE SECURITY

NRC and DOE requirements are discussed and considered here in light of the options for a UNF storage system project, which may be located at a commercial site and/or a government site. Within the NRC regulations in 10 CFR 73, self-protection is attributed to SNM "which is not readily separable from other radioactive material and which has a total external radiation dose rate in excess of 100 rems per hour[7] at a distance of 3 feet from any accessible surface without intervening shielding." LWR UNF is considered self-protecting because its large size, high thermal heat and radioactivity make it extremely dangerous to handle. Because of self-protection, commercial used fuel is not considered an attractive theft or diversion target in the NRC design basis threat [11].

The DOE material types have a similar attribute for irradiated fuel found in the Guide for Implementation of DOE 5633.3B [12]. This guide states that "highly radioactive special nuclear materials" (highly radioactive SNM) are those materials that "unshielded, emit a radiation dose [rate] measured at 1 meter that exceeds 100 rem/hour." The basis for this threshold is a 350-rem absorbed dose, the midpoint of the 250- to 450-rem range, which was generally accepted at the time the DOE Graded Safeguards Table [8] was generated, as the dose at which 50% of exposed people are expected to die and was considered the "50% lethal dose." Based on this guidance, highly radioactive SNM are considered to be those materials that will deliver a 350-rem dose within 3 hours, which was rounded to a dose rate of 100 rem/hour.

Used Fuel Self-Protection

It is important to revisit the validity of self-protection of used fuel against today's threats, especially within the context of VLTS of used fuel. The current regulations were established before the terrorist events of 9/11. In addition, the self-protection afforded by high dose rates will diminish over the timeframe for VLTS of used fuel. Lloyd et al. [13] previously calculated dose rate curves for fission product decay of spent fuel out to 50 years. As part of investigating the issue of self-protection for VLTS of used fuel, these dose rate calculations were extended to 200 years for several pressurized water reactor (PWR) and boiling water reactor (BWR) fuels with different burn-up rates. The preliminary results indicate that the dose rate falls below the current threshold in about 100 years for BWR fuel and between 120 to 150 years for PWR fuel. The time to reach this threshold increases with increasing burn up.

Additional dose rate estimates were calculated with MCNPX (version 2.6.0) for a ring detector at 1 meter from the assembly using updated fluence-to-dose conversions. An 18-group photon source calculated with Scale6 was assumed to be uniform over the "active region" of the assembly. Self-shielding was assumed for the average density of the uranium, Zircaloy, and hardware (as iron) mass distributed homogeneously through the overall assembly – 3.418 g/cc and 3.21 g/cc for BWR and PWR, respectively. Preliminary results in Figure 2 show a comparison of the current work and the results from Lloyd et al. [13] and indicated that the dose rate at 1 meter may be significantly lower than previously reported. The extended lines are effectively an extrapolation of this previous work assuming a simple analytical model with the top 10 photon emitters – all are consistent with a ^{137}Cs decay slope for longer cooling times. Work is in progress to better understand why the

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[7] This dose rate is equivalent to 100 rad/hr or 1 Gray/hr (Gy/hr) absorbed dose of gamma radiation.

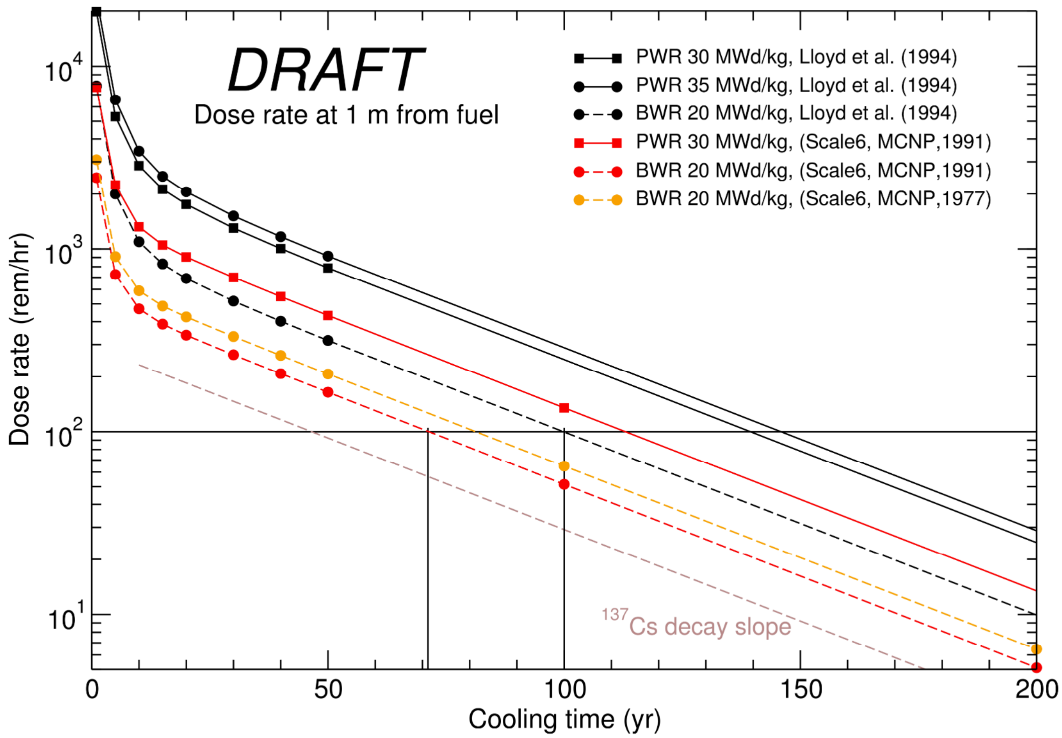

Figure 2. Comparison of dose rate of low burn-up fuel assemblies over time (current work using Scale6 and MCNPX (red) and Lloyd et al. [1994] (black).

current dose calculations are lower by about a factor of two. A factor of about 1.5 can be accounted for by the use of updated fluence-to-dose factors. However, the additional difference has not yet been accounted for – the self-shielding approach seems equivalent and the primary gamma source after about 50 years results from well understood fission products of ^{137}Cs and ^{90}Sr. In any case, the results seem to provide an indication that BWR and PWR used fuel in the current inventory fall below the current threshold for self-protection after a shorter period of time.

In terms of effects on potential adversaries, for fuel that has cooled for 15 years, a lethal dose of 450 rem (LD50 – exposure is fatal for 50% of the exposed population) would be received at 3 feet after about several minutes [13]. This exposure, however, may not be immediately incapacitating. More recent work by Coates et al. [14] for research and test reactor spent fuel looks at radiation effects on personnel performance capability in terms of incapacitation that prevents an exposed individual from completing an intended task. These authors indicate that a dose rate of 10,000 rad/hour (100 Gy/hour) at 1 meter "was determined to be the level that significantly affected performance of the perpetrator and offered limited self-protection (in the range of minutes)." Considering the higher level of self-protection that would result in actual incapacitation of an adversary, the dose calculations in Figure 2 indicate that commercial used fuel falls below this threshold within the first decade of cooling. This 10-year timeframe is generally consistent with the results of a follow-on study of self-protection of commercial reactor fuels by Coates and Broadhead [15].

The analyses of self-protection for used fuel indicate that much of the inventory will fall below the current threshold over the timeframe of VLTS. The current level of 100 rem/hour at 1 meter may also be too low to provide adequate self protection for more than the first few decades of storage.

The consequences of these considerations will require further evaluation as part of the development of security strategies for VLTS of used fuel.

Differences between NRC and DOE Requirements

One major difference in the physical protection requirements of NRC versus DOE is the safeguards and security categorization of the material. The DOE uses a graded safeguards concept that takes into account the form of the material in determining the attractiveness. The NRC categorization is based totally on the quantity, and for uranium, the enrichment level; no consideration is given to the form of the material. This results in the NRC having three categories (levels) of nuclear material protection, whereas DOE has four levels, which may not be directly comparable for similar categories. An example is fresh mixed oxide (MOX) fuel. The DOE regulations consider a fresh MOX fuel assembly consisting of 4.5% plutonium as Attractiveness Level D to be protected at the DOE Cat II level. NRC regulations consider the same MOX fresh fuel assembly as NRC Cat I material requiring a higher level of protection. For UNF, this may not be an issue, since in the past both NRC and DOE regulations have taken into account the "self-protection" afforded to SNF due to the extremely high dose rates. As discussed above, for VLTS of used fuel, this self-protecting feature will diminish and the approach for material categorization then focuses on quantity of SNM in the fuel, which could result in the stored fuel becoming a Cat I quantity of material with very strict protection requirements. In addition, the material may become more attractive to an adversary wishing to obtain nuclear material. Over time, the threat of theft may need to be addressed in addition to the threat of radiological sabotage. The DOE and NRC physical protection requirements for theft differ in some instances, including storage and transportation. These differences need to be evaluated when determining the security requirements for the options for investigating VLTS of used fuel and the used fuel storage system.

Another major difference is that NRC requires SNF to be stored within a protected area, while DOE requires storage only in a locked area within a property protection area. Requirements for a DOE property protection area are similar to those for an NRC owner-controlled area, while DOE and NRC requirements for protected areas are similar.

SUMMARY

Current NRC and DOE security requirements are different when applied to commercial used fuel storage. DOE uses a graded safeguards approach to determine material attractiveness and category, while NRC does not apply attractiveness levels. Over the timeframe for VLTS of used fuel, credit for self-protection does not apply. Specific physical protection measures differ as well.

Given the results of the dose rate calculations over time, credit for self-protection should not be used for determining physical protection requirements for VTLS of used fuel. Without consideration of self-protection, it is expected that under the current NRC and DOE requirements additional physical protection measures may be needed. Based on the form and composition of this material, security assessments should be performed to determine the appropriate protection measures. The outcome of performing the security assessments is to develop a recommended set of physical protection requirements for VLTS of used fuel. Integrated aspects of security (for example, facility security, fuel characteristics, and cask design), operational activities for long-term monitoring and institutional control, and identification of "intrinsically secure" system features will also be considered for opportunities to address any gaps and to improve security performance over the long-term.

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