ELECTRIC POWER RESEARCH INSTITUTE

Impacts Associated with Transfer of Spent Nuclear Fuel from Spent Fuel Storage Pools to Dry Storage After Five Years of Cooling, Revision 1

2012 TECHNICAL REPORT

Impacts Associated with Transfer of Spent Nuclear Fuel from Spent Fuel Storage Pools to Dry Storage After Five Years of Cooling, Revision 1

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1025206

Final Report, August 2012

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Energy Resources International, Inc.

NOTE

Acknowledgments

The following organization, under contract to the Electric Power Research Institute (EPRI), prepared this report:

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This report describes research sponsored by EPRI.

This publication is a corporate document that should be cited in the literature in the following manner:

Impacts Associated with Transfer of Spent Nuclear Fuel from Spent Fuel Storage Pools to Dry Storage After Five Years of Cooling, Revision 1. EPRI, Palo Alto, CA: 2012. 1025206.

Product Description

In 2010, EPRI performed a study of the accelerated transfer of spent fuel from pools to dry storage in response to the threat of terrorist activities at nuclear power plants (report 1021049). Following the March 2011 Great East Japan Earthquake and the subsequent accident at the Fukushima Daiichi nuclear power plant, some organizations issued a renewed call for accelerated transfer of used fuel from spent fuel pools (SFP) to dry storage. Their reasoning was that this would lessen the potential consequences from a loss-of-spent-fuel cooling accident by decreasing the heat load and source term available for release. This report revises the 2010 study to evaluate the dose and cost impacts of accelerating transfer of used fuel from SFPs to dry storage for two scenarios—one taking 10 years to transition the removal of all fuel cooled for at least five years, and the other taking 15 years to complete the transition.

Background

EPRI report 1021049 did not assess the amount of decay heat and radionuclide source term reduction in SFPs due to lower numbers of used fuel assemblies in the pools. As cesium-137 (Cs-137) is one of the dominant radionuclides contributing to land contamination in some areas around the Fukushima Daiichi plant, EPRI has now included assessments of the potential reduction in decay heat and source term from Cs-137 and Cs-134 inventory resulting from accelerated off-loading of used fuel out of SFPs.

Objectives

The 2010 report assumed the transition of five-year cooled fuel could be accomplished in five years. Industry feedback indicated a more realistic time frame is 10 to 15 years. Key objectives were to revise the report using the more realistic transition time and taking into account new assessments of decay heat and source term.

Approach

Cost and dose estimates are determined for a representative PWR, BWR, new plant, and the industry as a whole. The report includes a detailed review of assumptions impacting evaluations for areas ranging from fuel inventory, decay heat, and source term to impacts on cask capacity, design, and fabrication. Operational limitations such as the availability of SFPs and cask handling equipment have been taken into account in the two scenarios.

Results

The accelerated transfer of used fuel to dry storage would have significant radiological impacts due to loading fuel with higher decay heat and higher dose rates and to loading more packages. The increase in worker dose for the U.S. nuclear industry as a whole is estimated at 1650 and 2090 person rem for the 10-year and 15-year transition for five-year cooled fuel, respectively. The estimated increase in worker dose is 6 to 21 person-rem for a representative PWR plant, 11 to 12 person-rem for a BWR plant, and 65 person-rem for a new plant.

The economic impact for the U.S. nuclear industry of accelerating dry storage is estimated to be $3.5 to $3.9 billion. Costs included are associated with procurement of dry storage cask systems (DSCs), cask loading operations, dry storage facility construction and/or expansion, and annual operation and maintenance. The cost estimations use more realistic assumptions associated with increased DSC costs to account for 1) high burnup, short-cooled spent nuclear fuel, 2) impacts of increased annual demand for DSC manufacturing, and 3) licensing changes.

Accelerating the transfer of fuel to dry storage for all fuel cooled more than five years would reduce pool inventories by an estimated 67% to 78% for a PWR plant and 73% to 78% for a BWR plant. This transfer would decrease the decay heat remaining in the pool by an estimated 23% to 32% for a PWR plant and 32% for a BWR plant. The corresponding reduction in potential source term from cesium is estimated to be 43% to 53% for a PWR and 47% to 48% for a BWR.

Applications, Value, and Use

It is unclear whether the *potential* risk reduction due to lower amounts of decay heat and cesium in the SFPs would offset the *real* increase in risks, occupational safety hazards, operational impacts, and costs associated with a policy decision to transfer SNF from SFPs at an accelerated rate. This report will prove useful as decision makers in the nuclear industry examine the impacts and benefits of transferring spent nuclear fuel from SFPs to dry storage.

Keywords

Nuclear Power Plants
Spent Fuel Pools
Spent Fuel Pool Fires
Fukushima Daiichi Nuclear Power Plant
Spent Fuel
Spent Fuel Storage
Dry Storage

Table of Contents

List of Figures

List of Tables

Section 1: Introduction

1.1 Background

In November 2010, the Electric Power Research Institute (EPRI) published a technical report that examined the impacts associated with the accelerated transfer of spent nuclear fuel (SNF)[1] from spent fuel storage pools (SFP) to dry storage. At that time, the threat of terrorist activities at nuclear power plants led some to recommend that used nuclear fuel be moved to dry storage on an "accelerated" basis, after five years cooling in SFPs. In EPRI Report 1021049, *Impacts Associated with Transfer of Spent Nuclear Fuel from Spent Fuel Storage Pools to Dry Storage After Five Years of Cooling*, EPRI evaluated the radiological, operational, economic, and other impacts of such a change in SNF handling practices [EPRI 2010b]. In that report, EPRI found that there would be consequences in three areas – radiological, operational, and cost resulting in an increase in the net present value costs associated with early transfer of used fuel into dry storage of an estimated $3.6 billion for the U.S. nuclear industry.[2] The increase was primarily related to loading dry storage cask systems (DSC) [3] much earlier than would be done under existing industry practices and to the additional capital costs for new DSCs and construction costs for the dry storage facilities. In addition to economic impacts, the early movement of used fuel into dry storage would also have significant radiological impacts. Worker radiation exposure in the U.S. would increase by an estimated 507 person-rem over 60 years because of the additional handling of used fuel. Moreover, an additional 711 dry storage packages would have to be handled compared to the base case, increasing the risks associated with cask handling and with the construction of additional DSCs.

Following the March 2011 accident at the Fukushima Daiichi nuclear power plant in Japan that resulted after the Great East Japan Earthquake and subsequent tsunami, there were renewed calls from policy makers, individuals, and organizations for the accelerated transfer of SNF from pool storage to dry storage [CRS 2012]. The rationale was that transferring SNF to dry storage

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[1] While the term "spent nuclear fuel (SNF)" is used throughout this document, the report applies as well to "used" fuel (i.e., with potential reuse either directly or via a recycling method)

[2] While this assessment was done just for the U.S. nuclear industry, a similar approach could be taken to assess the impacts in other countries.

[3] The term "dry storage cask system" or "DSC" is used throughout this report. This term includes dual-purpose canister based systems, dual-purpose casks, and storage-only dry storage casks and canister systems. For a description of the various types of DSC refer to EPRI 2010a.

would lessen the potential consequences associated with a loss of SFP cooling capability by decreasing the heat load and radionuclide source term associated with SNF stored in SFPs as a result of decreasing the amount of SNF stored in those pools.

EPRI 2010b did not include an assessment of the amount of decay heat and radionuclide source term reduction in the SFPs due to lower numbers of used fuel assemblies in the pools. As cesium (Cs), particularly Cs-137, is one of the dominant radionuclides contributing to land contamination in some areas around the Fukushima Daiichi plants, an assessment has been included in this report regarding the reduction of decay heat and Cs-134 and Cs-137 inventory (source term) in SFPs that would result from accelerated off-loading of used fuel out of SFPs. [4]

EPRI 2010b utilized conservative assumptions in its analysis of impacts associated with the early transfer of SNF. Following feedback from EPRI member companies, this report updates the analysis contained in EPRI 2010b in order to provide more realistic assumptions under scenarios that would require an accelerated transfer of SNF from pool storage to dry storage, such as assumptions associated with worker dose, increased DSC costs, DSC manufacturing impacts, time periods available to transfer SNF to dry storage, etc.

Based on feedback from nuclear operating companies following publication of EPRI 2010b, EPRI determined that transferring the entire U.S. inventory of SNF that has been cooled for at least five years could not be accomplished over the five year time frame that was assumed in EPRI 2010b. This is due to the fact that the SFPs and equipment used to load DSCs, such as the cask handling crane, are only available for the purpose of loading DSCs for a limited time in each reactor operating cycle. Nuclear power plants that have multiple units that share a SFP and/or cask handling crane have even more constraints. In this report, EPRI has taken into account the availability of SFPs and cask handling equipment to load DSCs.

Nuclear operating company experience has also shown that loading DSCs with high burnup, shorter-cooled SNF that has higher decay heat and radiation dose can result in increased worker dose during loading operations, as well as increased site dose. In order to reduce the impacts of increased worker dose, companies may need to utilize additional personnel during cask loading operations, employ additional shielding during certain loading operations, or implement changes in equipment to reduce worker dose. In order to reduce the impacts of the increased site dose, companies may employ additional shielding in DSCs or put in place earthen berms around an ISFSI site. All of these changes can result in increasing the cost of dry storage as a result of the need to load shorter-cooled, hotter fuel with the early transfer of SNF from SFPs to dry storage. In this report, EPRI quantifies potential dose, operational, and cost impacts associated with the

[4] Cs-134 has a half-life of 2.062 years and Cs-137 has a half life of 30 years. Thus, for a PWR SNF assembly with a burnup of 55 GWd/MTU, Cs-134 represents 60% of the Cs source term after one year of cooling, but only 8% after 10 years of cooling.

transfer of high burnup, short-cooled SNF. EPRI 2010b also did not attempt to quantify the cost impact associated with the need to design, certify and deploy new DSC designs that are capable of storing only five-year cooled SNF, nor the cost impact of a short-term increase in dry storage fabrication requirements during the time period that existing SNF inventories are being off-loaded to dry storage. This report includes an assessment of possible increased costs associated with a short-term increase in DSC fabrication capacity and it examines the schedules necessary to increase DSC fabrication capacity and to amend existing DSC designs or certify new designs.

1.1.1 Dry Storage of SNF in the U.S.

When commercial nuclear power plants were built in the United States (U.S.), the plants' SFPs were not designed to store the entire inventory of SNF expected to be generated over the licensed life of the nuclear reactors. The SFPs for many nuclear power plants that were built in the late 1960s and 1970s were designed to store SNF in the SFPs for several years following discharge from the reactor core, and then it was expected that the SNF would be sent to a reprocessing facility for recycle. Due to policy considerations and nuclear non-proliferation concerns, reprocessing was halted in the mid 1970s. This resulted in the need for nuclear operating companies to find alternative means for storing their SNF. Companies began to expand the storage capacity of their SNF pools using high-density storage racks through a process referred to as reracking. While SNF storage capacity expansion through the use of high-density storage racks was the technology most widely used by utilities to increase in-pool storage capacity over the past 40 years, this option has generally been exhausted in the U.S. The majority of nuclear operating companies have reracked their SFPs at least once. Some companies have reracked SFPs multiple times as storage rack technologies advanced. Since the capacity of SFPs is limited by the physical size of the pool structure, the nuclear industry needed to develop additional storage alternatives to provide storage capacity outside of that provided by the SFPs.

With the passage of the Nuclear Waste Policy Act (NWPA) in 1982, nuclear operating companies had a new SNF storage alternative available – dry storage of SNF in at-reactor Independent Spent Fuel Storage Installations (ISFSIs). Section 218 of the NWPA required the Secretary of Energy to establish a demonstration program, in cooperation with the private sector, for dry storage of SNF at civilian nuclear power reactor sites.

The U.S. Nuclear Regulatory Commission (NRC) first developed a separate regulatory framework for storage of SNF outside of the reactor SFPs in November 1980 with the issuance of U.S. Code of Federal Regulations, Title 10, Part 72, "*Licensing Requirements for the Independent Storage of Spent Fuel and High-Level Radioactive Waste*" (10CFR72). This new regulation was supported by NRC's "*Final Generic Environmental Impact Statement on Handling and Storage of Spent Light Water Power Reactor Fuel*," in which NRC determined that additional SNF storage capacity would be needed outside of reactor SFPs [NRC 1979]. The regulation is applicable to both wet and dry storage facilities at reactor sites or away from reactors. In 1990, the NRC revised 10CFR72 to include new regulations that govern the general license procedures for dry storage, as directed by the NWPA. The NRC regulations for storing SNF are discussed in more detail in EPRI's Industry Spent Fuel Storage Handbook [EPRI 2010a].

The first dry storage facility was licensed by the NRC in 1986 at Virginia Electric Power Company's (Virginia Power) two-unit Surry Station under NRC's site-specific ISFSI licensing procedures. By 1998, the year that the U.S. Department of Energy (DOE) was to begin acceptance of spent fuel under the Federal waste management system, there were eleven operating ISFSIs at commercial nuclear power plant sites in the U.S. Since that time, there has been an increase in the number of at-reactor dry storage facilities in the U.S., as shown in Figure 1-1. With the near-term prospects for an operational repository fading, it is expected that every nuclear power plant site will need to implement dry storage of SNF by approximately 2025 in order to support continued operation of their power reactors. In addition, SNF is expected to remain in dry storage at reactor sites for decades.

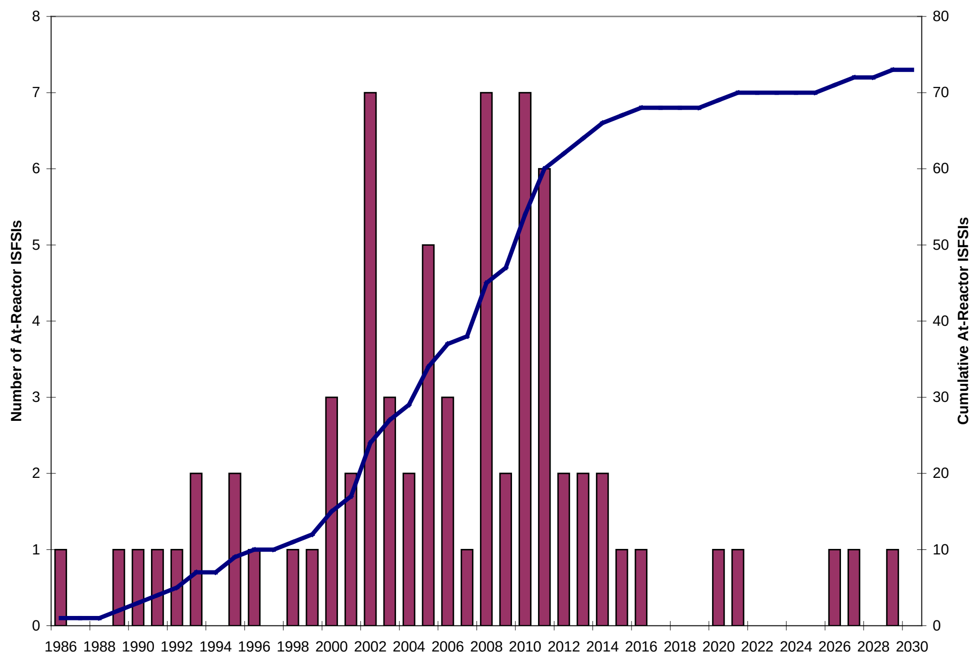

Figure 1-1
At-Reactor SNF Dry Storage Facilities, 1986 to 2030

As of August 2012, there were 57 operational ISFSIs at nuclear power plant sites storing SNF from 95 nuclear power plants, with several more ISFSIs expected to become operational during 2012. There are also two ISFSIs that are not located at nuclear power plant sites – a wet storage facility operated by General Electric in Morris, Illinois, and a dry storage facility operated by DOE at the Idaho National Laboratory. At year-end 2011, approximately 67,300 MTU of permanently discharged SNF was in storage (both wet and dry) with more than 17,300 MTU of SNF loaded into more than 1,500 DSCs. As shown in Figure 1-2, EPRI projects that there will be 32,000 MTU of SNF in dry storage by 2020 stored in approximately 2,900 DSCs. Total SNF discharges by 2020 are projected to be approximately 86,000 MTU. By 2060, by which time all of the currently operating nuclear power plants will reach the end of their renewed operating licenses, there will be approximately 136,600 MTU of SNF in storage at reactor sites.[5] The current practice is for SNF to be moved from SFPs to at-reactor dry storage facilities as additional space is needed in the SFPs to support staging of new fuel and the permanent discharge of SNF at the end of an operating cycle.

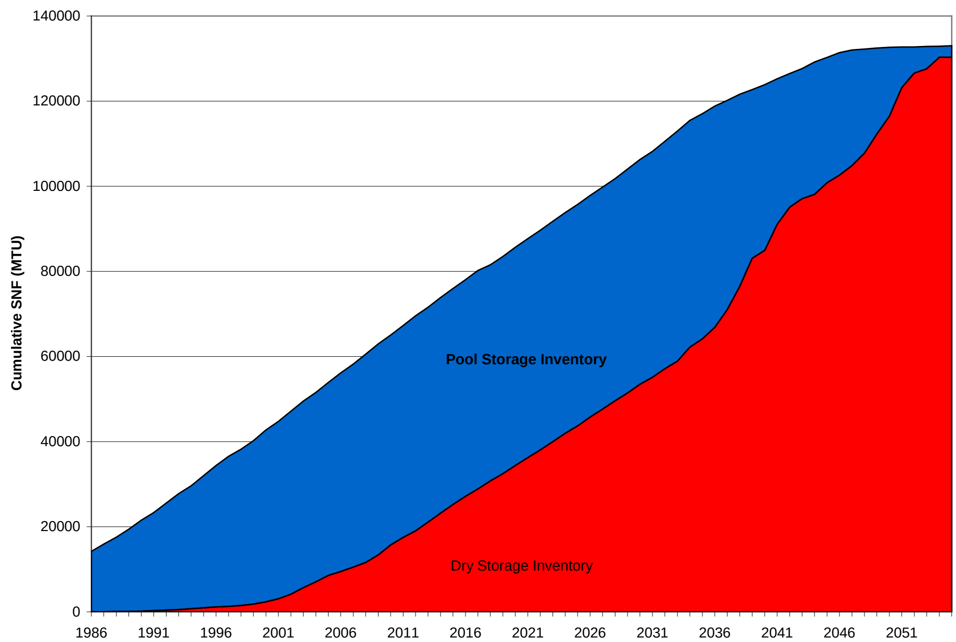

Figure 1-2
Historical and Projected SNF Discharges, 1986-2020

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[5] These projections do not include SNF discharges from new nuclear power plants that are currently planned or under construction in the U.S. A new nuclear power plant would be expected to discharge between 1,500 and 2,000 MTU of SNF over an assumed 60-years of commercial operation.

1.1.2 Proposals to Accelerate the Removal of SNF to Dry Storage

In 2003, Robert Alvarez, et al, published a paper in the spring 2003 issue of Science and Global Security, "*Reducing the Hazards from Stored Spent Power-Reactor Fuel in the United States*" [Alvarez 2003]. In that paper, the authors opined that the risks of a postulated terrorist attack targeting SFPs would justify their costly recommendation to remove all SNF cooled more than five years from the storage pools into DSCs. Following publication of Alvarez 2003, several interest groups published similar reports and called for SNF to be moved from storage pools to dry storage once it was cooled for five years [MPIRG 2004]. As discussed in Section 1.2, since 2003, NRC has taken action to implement additional security measures at nuclear power plant sites, which protect SNF in SFPs from beyond design basis events. During testimony before the Blue Ribbon Commission on America's Nuclear Future (BRC), interest groups urged the BRC to recommend that nuclear power plants accelerate transfer of SNF from SFPs and implement "hardened onsite storage," that is, dry storage casks stored within buildings rather than on a concrete storage pad as is current practice in the U.S. today [BRC 2012].[6]

1.2 NRC Actions Regarding SNF Pool Safety – Post September 11, 2001

In response to the events of September 11, 2001, the NRC performed a review of its safeguards and security programs and requirements. On February 24, 2002, NRC issued orders to 10CFR50[7] licensees that required licensees to implement interim compensatory measures (ICMs), some of which were related to storage of SNF in storage pools [Reyes 2004].

In August 2003, the NRC staff issued a white paper rebutting Alvarez' assessment of SNF pool risks and stating that NRC did not believe that the recommendation to move all SNF more than five years old into dry storage was justified. NRC concluded that SNF stored in both wet and dry storage configurations is safe and that the public was adequately protected [NRC 2003].

On October 26, 2006, the NRC published a proposed rule in the Federal Register (71 FR 62664) that included requirements regarding licensee procedures for responding to notifications of potential aircraft threats and for the mitigation of the loss of large areas of their facilities due to large fires or explosions. The proposed rule noted that the proposed requirements were similar to those previously imposed under section B.5 of the February 24, 2002, ICMs.

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[6] In Recommendation 5, Prompt Efforts to Develop One or More Consolidated Storage Facilities, of the BRC's January 2012 Report to the Secretary of Energy, the BRC recommended that as part of NRC's regulatory oversight efforts associated with SNF dry storage, that NRC examine "the advantages and disadvantages of options such as "hardened" onsite storage that have been proposed to enhance security at storage sites." [BRC 2012]

[7] 10CFR50: Title 10, U.S. Code of Federal Regulations, Part 50, Domestic Licensing of Production and Utilization Facilities

On March 27, 2009, NRC published a final rule, *Power Reactor Security Requirements* (FR 74 13925-13993). In that rule, NRC codified in its regulations the ICMs that the agency previously issued through orders to its licensees. In this rulemaking, 10CFR50.54(hh)(2) requires licensees to develop guidance and strategies for addressing the loss of large areas of the plant due to explosions or fires from a beyond-design basis event. The regulation states that "[e]ach licensee shall develop and implement guidance and strategies intended to maintain or restore core cooling, containment, and SFP cooling capabilities under the circumstances associated with loss of large areas of the plant due to explosions or fire." Thus, through rulemaking NRC imposed measures that licensees must take to safeguard SNF in at-reactor SFPs from a beyond design basis event.

1.3 NRC Actions Regarding SFP Safety Issues – Post Fukushima

During the emergency at the Fukushima Daiichi nuclear power plant in Japan following the Great East Japan Earthquake and subsequent tsunami, there were concerns regarding the safety of SNF stored in SFPs at the Fukushima Daiichi site and the potential consequences of a release of radioactive material from one or more spent fuel pools. While it was ultimately determined that the SNF that was stored in the SFPs at Fukushima Daiichi was safe, and that the Unit 4 hydrogen explosion was not caused by the SFP [EPRI 2012], the uncertainty surrounding the SNF condition diverted the attention of the nuclear power plant operators. In response to the emergency at the Fukushima Daiichi site, the NRC Commissioners directed NRC staff to establish a Near-Term Task Force (NTTF) that was charged with conducting a review of NRC processes and regulations to determine whether the agency should make additional improvements to its regulatory system and to make recommendations to the Commission for its policy direction [NRC 2011a].

In its recommendations to the Commission, the NTTF noted that the "lack of information on the conditions of the fuel in the Fukushima spent fuel pools was a significant problem in monitoring the course of the accident and contributed to a poor understanding of possible radiation releases and to confusion about the need and priorities for support equipment. The Task Force therefore concludes that reliable information on the conditions in the spent fuel pool is essential to any effective response to a prolonged SBO or other similarly challenging accident." "The Task Force concludes that clear and coherent requirements to ensure that the plant staff can understand the condition of the spent fuel pool and its water inventory and coolability and to provide reliable, diverse, and simple means to cool the spent fuel pool under various circumstances are essential to maintaining defense-in-depth." As a result, the NTTF recommended "enhancing spent fuel pool makeup capability and instrumentation for the spent fuel pool", with a discussion of specific actions that licensees would be expected to implement [NRC 2011a].

In an October 2011 report to the Commission regarding prioritization of recommended actions to be taken in response to Fukushima lessons learned, NRC staff recommended additional issues that may warrant regulatory action but which were not included with the NTTF recommendations. One of the issues identified for additional consideration was the transfer of SNF from SFPs to dry storage [NRC 2011c].

NRC is currently considering whether there are "potential benefits of removing spent fuel from pools earlier than planned and achieving lower density storage in the spent fuel pools" [NRC 2011b]. NRC recognizes that although "removal of the spent fuel would decrease the inventory of radionuclides in the pools, it also raises risks of cask drops and increases worker doses. Consequently, we [NRC] are currently conducting a Spent Fuel Pool Scoping Study for an initial quantitative assessment of the impacts on risk associated with offloading the fuel" [NRC 2011b]. NRC's Spent Fuel Pool Scoping Study will estimate the change in accident consequences associated with the early transfer of SNF from SFPs to dry storage.

1.4 Objectives of this Study

Both pool storage and dry storage provide for the safety and security of SNF. SNF has been stored safely in wet storage pools for more than 40 years and in dry storage for more than 25 years. Any analysis associated with a policy decision to accelerate transfer of SNF from SFPs to dry storage should include a balanced assessment of the benefits and risks of such a decision, including the reduction in SFP source term, lower density of SNF and lower heat load in the SFP, as well as the impacts on nuclear power plant operation associated with such a policy decision. Impacts on nuclear power plant operation include increased worker dose, an increase in cask handling operations and a subsequent increase in the risks associated with cask handling, potential impacts of larger cask loading campaigns on nuclear power plant operations, and increased costs associated with the storage of SNF due to the need to load additional DSCs, increased costs associated with new DSC designs, short-term need for increased fabrication capacity, and increased dry storage loading costs.

This study updates the analyses contained in EPRI 2010b in order to provide more realistic assumptions associated with worker dose; increased DSC costs associated with the need to handle high burnup, short-cooled SNF; impacts of increased annual demand for DSC manufacturing and schedules to increase fabrication capability; schedules associated with amending existing DSC designs or for certification of new designs; and SFP and cask loading equipment and personnel availability for transfer of SNF to dry storage. In this report, EPRI also modifies the maximum discharge burnup for pressurized water reactors (PWR), decreasing the assumed burnup from 58 gigawatt days per metric ton of uranium (GWd/MTU) to 55 GWd/MTU and updates maximum heat loads that have been approved for NRC certified DSCs.

EPRI calculates the costs associated with procurement of DSCs, cask loading operations, dry storage facility construction and/or expansion, and annual operating and maintenance. The costs associated with moving existing five-year cooled SNF inventories from SFPs to dry storage are evaluated for the industry as a whole as well as for a "representative" PWR, boiling water reactor (BWR) and a representative new plant. In determining the time period over which the five-year cooled SNF inventory could be transferred from pool storage to dry storage, EPRI has taken into account the availability of SFPs, cask handling equipment and personnel that are needed to load DSCs by examining other activities necessary for the operation of nuclear power plants that utilize these same resources. EPRI examines two scenarios associated with transferring the five-year cooled SNF inventories to dry storage and compares these results to a scenario in which the industry, and the "representative" plants, would load SNF into dry storage in order to maintain the capability to discharge the full reactor core into the SFP. The costs are examined in both constant and net-present-value dollars.

In addition to examining the costs associated with an accelerated transfer of SNF from pool storage to dry storage, the study also examines the potential increase in worker dose associated with loading SNF with higher decay heat and higher dose rates into dry storage, as well as that associated with loading more packages.

This report also examines the impact of accelerated transfer of five-year cooled SNF inventories on SFP decay heat and the related radiological source term.

EPRI also identifies the other potential impacts including costs (such as an increase in ISFSI decommissioning costs) that may result from a policy decision to accelerate transfer of SNF to dry storage.

Section 2: Overview of Assumptions

This section provides an overview of the assumptions made by EPRI in order to estimate the impacts associated with the accelerated transfer of five-year cooled SNF inventories from SFPs to dry storage. This section describes:

- Assumptions associated with the projection of future SNF discharges from nuclear power plants and requirements for dry storage. This includes assumptions regarding fuel burnup, decay heat, and Cs source term, as well as dry storage technology capacity and heat load capability;
- Assumptions associated with the time periods available to load DSC at nuclear power plant sites; and assumptions regarding worker doses associated with cask loading operations.
- Assumptions regarding the costs associated with construction and operation of an at-reactor ISFSI; and possible cost increases associated with accelerated transfer of SNF to dry storage including costs associated with the need for a short-term increase in DSC fabrication capacity, costs to load additional SNF casks, and the need to increase shielding capability of DSCs in order to store SNF with shorter cooling times.

The scenarios evaluated in Section 3 and 4 of this report for the industry Base Case, in which SNF is transferred from SPFs to dry storage as needed to maintain capacity in the SFP and two accelerated transfer cases, in which SNF is transferred from SPFs to dry storage on an accelerated schedule. The two accelerated transfer cases assume (1) a ten-year transfer of SNF from SFPs to dry storage during the period 2015 to 2024 (Case 2) and (2) a 15-year transfer of SNF from SFPs to dry storage during the period 2015 to 2029 (Case 3). All costs provided are in constant 2012 dollars (Constant $2012), and are also discounted to 2012 net present value (NPV) dollars in order to show the impact of the time value of money associated with moving SNF to dry storage on an accelerated schedule. The unit costs presented in this study are based on estimates by the author or from cited references. It should be noted that this is a generic cost estimate and should be used accordingly. Individual nuclear power plants may have costs that are higher or lower than those presented in this report due to conditions that are specific and/or unique to the site, storage technology, fuel characteristics and existing inventories, and company practices and procedures.

SNF decay heat and Cs source terms are also considered to be generic estimates and should be used accordingly. Actual decay heat and Cs source terms for SNF will be dependent upon the specific fuel design, initial enrichment, burnup, and operating history of the fuel. Individual SNF assemblies may have decay heat and Cs source terms that are higher or lower than those used in this report due to the specific characteristics of the SNF assemblies.

2.1 Projected SNF Discharges

The first step in determining the additional on-site storage requirements for U.S. nuclear power plants is the projection of permanently discharged SNF. EPRI's projection of SNF storage requirements assumes:

- All U.S. licensed nuclear power plants continue to operate for a period of 60 years through the end of their extended licenses;
- Plant capacity factors average approximately 90%;
- Average SNF discharge burnups gradually increase to approximately 55 GWd/MTU for PWRs and 48 GWd/MTU for BWRs;[8] and
- Average initial enrichments for 55 GWd/MTU PWR fuel are approximately 4.5 to 5.0 weight percent (w/o) uranium-235 (U-235) and for 48 GWd/MTU BWR fuel are approximately 3.7 to 4.2 w/o U-235 respectively.

These assumptions result in a total lifetime generation of spent fuel of approximately 136,600 MTU. Total SNF discharges are 2% higher than the projected discharges in EPRI 2010b due to a reduction in the assumed maximum discharge burnup for PWR SNF from 58 GWd/MTU to 55 GWd/MTU.

While EPRI has not included new nuclear power plants in its projection of SNF discharges, a typical 1,100 MWe to 1,600 MWe plant would be expected to produce between 1,500 and 2,000 MTU of SNF over a 60-year operating period. New plants are expected to have at least ten years of spent fuel storage capacity in storage pools. EPRI does include Watts Bar Unit 2 in its industry-wide analysis since the Tennessee Valley Authority expects the plant to begin commercial operation in late 2015.

In calculating additional SNF storage requirements, EPRI assumes used fuel capacities for SFPs include those for those companies that have submitted license amendments to the NRC to increase pool storage capacity. In addition, EPRI assumes that plants with SFPs that are shared by multiple units reserve space for only one full core in the SFP. SNF discharges are based on historical and

[8] EPRI 2010b assumed maximum PWR burnups of 58 GWd/MTU. Based on feedback from nuclear operating companies, the maximum PWR burnup used in this study is 55 GWd/MTU. Some companies may not reach this lower maximum discharge burnup due to fuel management decisions taken by those companies. Lower discharge burnups would result in the discharge of more SNF and subsequently, more SNF to transfer to dry storage.

projected discharge data reported by nuclear operating companies to the U.S. Department of Energy's Energy Information Agency (as of December 31, 2002) and on projected discharges calculated using Energy Resources International, Inc.'s SPNTFUEL model.

In order to project SNF discharge data (number of assemblies, discharge burnups, etc.) at the end of each cycle, the amount of SNF discharged in MTU is based on a plant's licensed thermal rating (megawatts-thermal, MWT), discharge burnup (BUP in MWd/MTU), capacity factor (CF in %), cycle length (CYL in years) as shown below:

MTU = (MWT) x (CYL) x (CF/100) x (365 days/year) / (BUP)

For example, for a 3000 MWT plant with an 18-month operating cycle operating at a 90% capacity factor and an average used fuel assembly burnup of 45,000 MWd/MTU, the amount of used fuel discharged at the end of the cycle would be:

3000 MWT x 1.5 years x 90/100 x 365 / 45,000 MWd/MTU = 32.85 MTU

The projected number of discharged assemblies (ASSY) is calculated by dividing the MTU discharge size by the assembly unit weight. The assembly unit weight is calculated by dividing an individual plant's core weight by the number of assemblies in the core. Since fuel assembly discharges are in whole assembly increments, the adjusted assembly discharge (ASSY*) is calculated by rounding ASSY and the adjusted discharge weight (MTU*) recalculated based on the assembly unit weight. The adjusted discharge burnup (BUP*) is then recalculated based on the adjusted discharge size MTU* as shown below:

BUP* = (MWT) x (CYL) x (CF/100) x (365 days/year) / (MTU*)

Projected discharge burnups for Cycle X+1 for each nuclear power plant are calculated using the discharge burnup from Cycle X as the starting point in the calculation. Future maximum burnups for PWR and BWR fuel are specified as well as an annual rate of increase in burnup for PWR and BWR fuel (approximately 1.3% annually). For example, if the discharge burnup for a PWR in Year N is 45,000 MWd/MTU and the PWR burnup rate of increase is 1.3% per year, a discharge in the Year N+1 is projected at 45,585 MWd/MTU (45,000 x 1.013), 46,118 MWd/MTU two years out, etc. The projected burnup is increased in whole year increments with the appropriate burnup applied based on a plant's assumed cycle length. The projected burnup will increase each year until the maximum projected for that reactor type is reached (e.g., PWR maximum burnup is 55 GWd/MTU).

The SNF inventory at a nuclear power plant is specific to that plant based on actual SNF discharged through December 2002 (as noted above), and projected SNF discharge data thereafter. The projected SNF discharges at each nuclear power plant are calculated based on each plant's rated thermal capacity, core size and fuel load per fuel assembly, capacity factor and cycle length. For each discharge batch after the 2002 historical data, the following data are projected: discharge date, number of assemblies discharged, corresponding MTU discharged, batch average SNF burnup. As described above, SNF burnup values are based on actual prior discharge burnups which are then incremented upward to the maximum PWR burnup of 55 GWd/MTU and the maximum BWR burnup of 48 GWd/MTU. Each plant will reach these maximum burnup values at different times based on the plant's operating history. Thus, utilizing these actual and projected SNF burnup values and discharge dates, SNF cooling time, decay heat, and Cs source terms are able to be calculated.

Additional SNF storage requirements are calculated using the assumed pool capacity for each plant or SFP (some storage pools are shared by more than one plant), and the cumulative SNF discharges. The cumulative number of fuel assemblies discharged is subtracted from the SFP capacity, on an annual basis, assuming that each SFP retains space in the SNF pool to discharge one full core of fuel (referred to as "Full Core Reserve" or "FCR"). During years in which no SNF is discharged at plants operating on 18-month or 24-month cycles, there would be no change in the SFP inventory. If there are more assemblies requiring SNF storage than there is space in the SFP (minus one FCR), these additional storage needs are the SNF storage requirements for that plant. In this analysis, EPRI assumes that future SNF storage requirements will be met using at-reactor dry storage of SNF rather than expansion of SNF pool capacity.

2.2 SNF Burnup, Heat Load, and Cesium Inventory Assumptions

2.2.1 SNF Burnup Assumptions

As noted in Section 2.1, EPRI assumes that average discharge fuel burnups gradually increase to approximately 55 GWd/MTU for PWRs and 48 GWd/MTU for BWRs. These average discharge burnups assume the current maximum peak rod burnup limit of 62 GWd/MTU [EPRI 2001]. As shown in Figure 2-1, SNF burnups have continued to gradually increase since the 1990s. Current PWR average discharge burnups are approximately 48 GWd/MTU and current BWR average discharge burnups are approximately 43 GWd/MTU. As shown in Figure 2-1, both PWRs and BWRs will reach the assumed maximum discharge burnups of 55 GWd/MTU and 48 GWd/MTU, respectively, by approximately 2020. Fluctuation in discharge burnup seen in Figure 2-1 after 2030 are due primarily to the discharge of final reactor cores, in which some SNF will have discharge burnups that are lower than the assumed industry average discharge burnup.

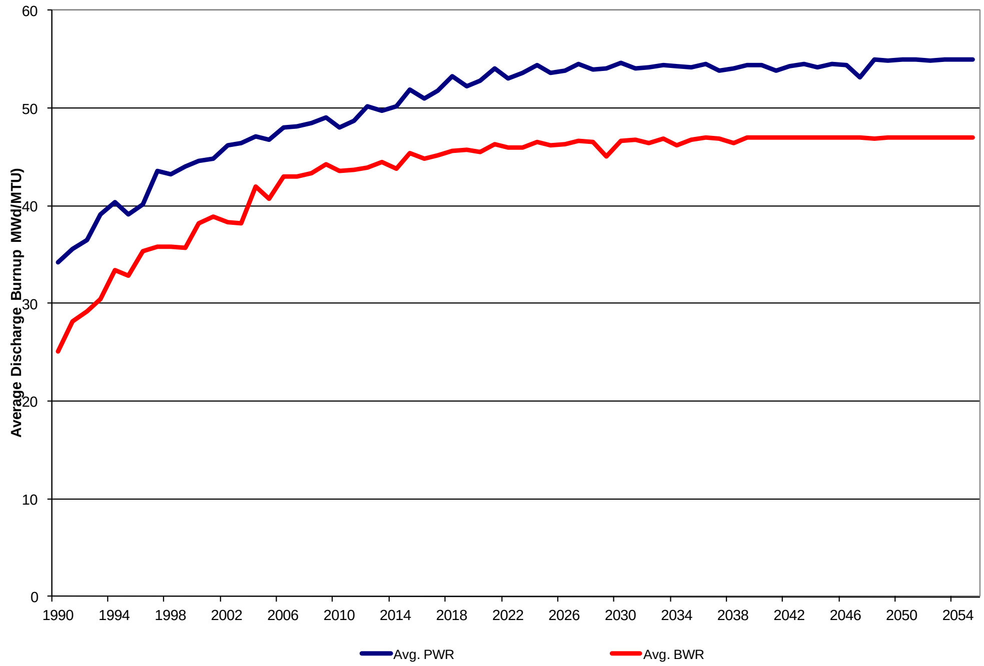

Figure 2-1
Historical and Projected Average PWR and BWR Discharge Burnups

2.2.2 Fuel Assembly Decay Heat and Cesium Inventory as a Function of Burnup and Cooling Time

As fuel assembly burnups increase, the decay heat of the fuel assembly (watts per metric ton heavy metal (MTHM) or MTU) and the Cs inventory (TeraBequerel [TBq] per MTHM) in the fuel increase. Following final discharge, the decay heat and Cs inventory of the used fuel assembly both decrease with time. Figure 2-2 shows representative fuel assembly decay heat and Cs inventory (1000s TBq) versus decay time for PWR fuel assemblies with discharge burnups of 40 GWd/MTU and 55 GWd/MTU.

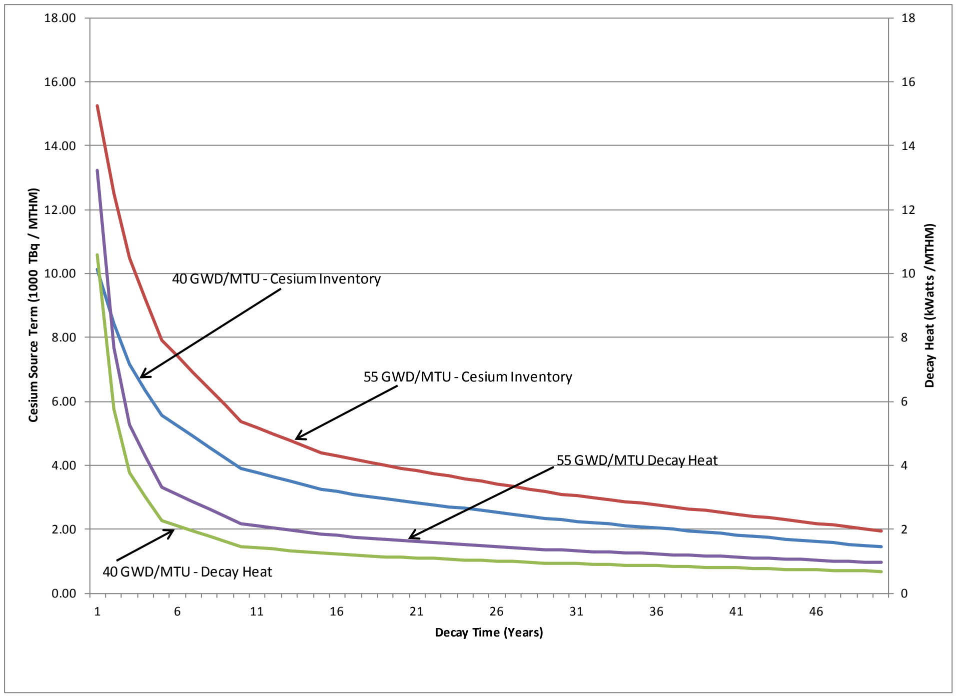

Figure 2-2
PWR SNF Assembly Decay Heat (right axis) and Cesium Inventory (left axis) as a Function of Burnup and Cooling Time ***[BSC 2001, DOE 1992]***

SNF assembly decay heat for a 40 GWd/MTU assembly that has cooled for five years is approximately 1,100 watts (from Figure 2-2, ~2.3 kW/MTHM * 0.45 MTHM/assembly), while the decay heat for a 55 GWd/MTU assembly that has cooled for five years is approximately 1,500 watts (from Figure 2-2, ~3.3 kW/MTHM * 0.45 MTHM/assembly). Similarly, the combined Cs-134 and Cs-137 inventory for five-year decayed 40 GWd/MTU assembly is 2.5 x 10^3 TBq/assembly (from Figure 2-2, 5.6 x 10^3 TBq/MTHM * 0.45 MTHM/assembly) or 6.8 x 10^4 Ci/assembly. For a 55 GWd/MTU, five-year cooled assembly the combined Cs inventory is 3.6 x 10^3 TBq (7.9 x 10^3 TBq/MTHM * 0.45 MTHM/assembly) or 9.6 x 10^4 Ci/assembly [BSC 2001, DOE 1992].

Thus, if a 24-PWR assembly dry storage package has a maximum heat load of 24 kilowatts (kW) per package[9], approximately 21 assemblies with a decay heat of 1,100 watts/assembly could be stored assuming uniform fuel assembly burnup of 40 GWd/MTU and a 5 year decay time. In contrast, assuming uniform fuel assembly burnups of 55 GWd/MTU with decay heat of 1,500 watts per assembly and a decay time of 5 years, only 16 assemblies could be stored in a package with a maximum decay heat of 24 kW. In comparison, loading 10-year cooled 40

[9] This example of a 24-PWR assembly package with a maximum heat load of 24 kilowatts is used for illustrative purposes only, in order to demonstrate the potential impact of higher burnup, shorter cooled SNF on package capacity. 24-PWR assembly packages have been certified with heat loads that are higher than this example as shown in Table 2-1.

GWd/MTU SNF, with a decay heat of approximately 700 watts/assembly would allow storage of 24 PWR assemblies in a 24-PWR assembly package with a maximum package heat load of 24 kW. Loading 10-year cooled 55 GWd/MTU SNF, with decay heat of approximately 1,000 kW/assembly would allow a total of 24 assemblies to be stored in a 24 PWR assembly package with a maximum package heat load of 24 kW. The above discussion is for the illustrative purpose of demonstrating the impact of assembly heat load on total package capacity. Existing cask designs cannot simply be short-loaded (e.g., load fewer assemblies than the maximum assembly capacity) in order to stay within the maximum package heat load. In existing cask designs, both the maximum cask heat load and the peak assembly heat load allowed by the cask CoC must be met. The peak assembly heat load may be the limiting factor. In order to short-load a dry storage system, the number of assemblies, maximum heat load per assembly and specific SNF characteristics of the SNF to be loaded would have to be addressed specifically in a cask CoC.[10]

It should be noted that most of the current dry storage technologies allow both uniform loading of SNF and regional loading. Under uniform loading, the peak assembly heat load which can be loaded in each location is determined by the total cask heat load divided by number of locations. Uniform loading is defined by peak assembly decay heat. Regional loading of SNF allows higher decay heat SNF assemblies to be loaded in certain regions of the dry storage canister basket, and requires lower decay heat SNF assemblies in other regions such that the total package heat load is not exceeded.

If SNF is required to be transferred to dry storage after it has cooled for five years, by approximately 2020, EPRI assumes that PWRs will be discharging SNF at the maximum PWR burnup level of 55 GWd/MTU, as discussed in Section 2.2.1 and shown in Figure 2-1. If all five-year cooled SNF is transferred to dry storage under an accelerated schedule, by 2025 the only SNF available to be transferred to dry storage from SFPs will be five-year cooled SNF with burnups at this maximum burnup of 55 GWd/MTU (since the inventory of SNF with lower burnups and longer cooling times will have already been offloaded to dry storage). Thus, under an accelerated transfer of SNF to dry storage, once the existing SFP inventories, which contain SNF with a range of burnups and cooling times, have been completely offloaded to dry storage, there would be no opportunity to utilize regional loading since most of the SNF remaining in the SFP would have higher decay heat associated with five-year cooled SNF.[11]

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[10] Dry storage designs must ensure that the peak assembly temperature can be maintained below the limits provided in NRC Interim Staff Guidance, ISG-11, during all facets of operation (with the highest temperatures occurring during the drying phase). The ISG-11 temperature limit is even more restrictive for high burnup fuel (> 45 GWd/MTU). Short loading a canister (that is, loading fewer assemblies than the maximum canister capacity allows) may not achieve the proper temperatures for higher peak assemblies.

[11] For the purpose of this study, it is assumed that the discharge burnups for all PWR SNF eventually reach the assumed maximum burnup of 55 GWd/MTU. Some companies may not reach this maximum discharge burnup due to fuel management decisions taken by those companies. Lower discharge burnups would result in the discharge of more SNF and subsequently, more SNF to transfer to dry storage.

Figure 2-3 shows representative fuel assembly decay heat and Cs inventory versus decay time for BWR fuel assemblies with discharge burnups of 40 GWd/MTU and 50 GWd/MTU. SNF assembly decay heat for a 40 GWd/MTU BWR assembly that has cooled for five years is approximately 360 watts/assembly (from Figure 2-3, ~ 2.0 kW/MTHM * 0.18 MTHM/ assembly), while the decay heat for a 50 GWd/MTU assembly that has cooled for five years is approximately 520 watts per assembly (from Figure 2-3, ~2.9 kW/MTHM * 0.18 MTHM/assembly). The combined Cs-134 and Cs-137 inventory for five-year cooled 40 GWd/MTU SNF is 1.1 x 10^3 TBq/assembly (from Figure 2-3, 6.3 x 10^3 TBq/MTHM *0.18 MTHM/assembly) or 3.0 x 10^4 Ci/assembly. For a 50 GWd/MTU, five-year cooled assembly, the combined Cs inventory is 1.3 x 10^3 TBq (from Figure 2-3, 7.0 x 10^3 TBq/MTHM * 0.18 MTHM/assembly) or 3.4 x 10^4 Ci/assembly [NRC 1999, DOE 1992].

Thus, if a hypothetical 60-BWR assembly dry storage package has a maximum heat load of 20 kW per package[12], approximately 55 assemblies with uniform decay heat of 360 watts/assembly could be stored assuming uniform fuel assembly burnup of 40 GWd/MTU and a five-year decay time. Assuming uniform fuel assembly burnups of five-year cooled 50 GWd/MTU SNF with decay heat of 520 watts per assembly, only 38 assemblies could be stored in a 60-assembly-capacity package with a maximum decay heat of 20 kW. In comparison, loading 10-year cooled 40 GWd/MTU SNF, with a decay heat of approximately 250 watts/assembly would allow storage of 60 BWR assemblies in a 60-BWR assembly package with a maximum heat load of 20 kW. In comparison, loading 10-year cooled 50 GWd/MTU SNF, with decay heat of approximately 350 kW/assembly, would allow a total of 57 assemblies to be stored in a 60 BWR assembly package with a maximum heat load of 20 kW. The above discussion is for the illustrative purpose of demonstrating the impact of assembly heat load on total package capacity. Existing cask designs cannot simply be short-loaded (e.g., load fewer assemblies than the maximum assembly capacity) in order to stay within the maximum package heat load. In existing cask designs, both the maximum cask heat load and the peak assembly heat load allowed by the cask CoC must be met. The peak assembly heat load may be the limiting factor. In order to short-load a dry storage system, the number of assemblies, maximum heat load per assembly and specific SNF characteristics of the SNF to be loaded would have to be addressed specifically in the CoC.[13]

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[12] This example of a 60-BWR assembly package with a maximum heat load of 20 kilowatts is used for illustrative purposes only, in order to demonstrate the potential impact of higher burnup, shorter cooled SNF on package capacity. BWR DSCs with capacities in excess of 60 BWR assemblies have been certified with heat loads that are higher than this example as shown in Table 2-1.

[13] Dry storage designs must ensure that the peak assembly temperature can be maintained below the limits provided in NRC Interim Staff Guidance, ISG-11, during all facets of operation (with the highest temperatures occurring during the drying phase). The ISG-11 temperature limit is even more restrictive for high burnup fuel (> 45 GWd/MTU). Short loading a canister (that is, loading fewer assemblies than the maximum canister capacity allows) may not achieve the proper temperatures for higher peak assemblies.

BWR dry storage technologies also allow for both uniform and regional loading of SNF. If SNF is required to be transferred to dry storage after it has cooled for five years, by approximately 2020, EPRI assumes that BWRs will be discharging SNF at the maximum BWR burnup level of 48 GWd/MTU, as discussed in Section 2.2.1 and shown in Figure 2-1. If all five-year cooled SNF is transferred to dry storage under an accelerated schedule, by 2025 the only SNF available to be transferred to dry storage will be five-year cooled SNF with burnups at this maximum burnup of 48 GWd/MTU. Thus, under an accelerated transfer of SNF to dry storage, once the existing SFP inventories, which contain SNF with a range of burnups and cooling times, have been completely offloaded to dry storage, there would be no opportunity to utilize regional loading since most of the SNF remaining in the SFP will have higher decay heat.[14]

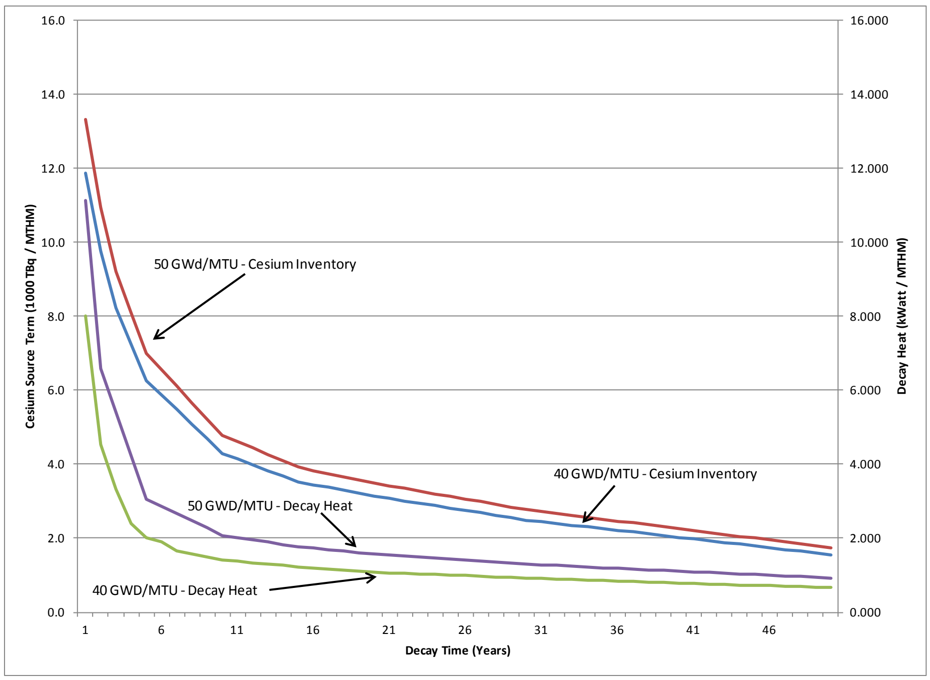

Figure 2-3
BWR SNF Assembly Decay Heat (right axis) and Cesium Inventory (left axis) as a Function of Burnup and Cooling Time ***[NRC 1999, DOE 1992]***

[14] For the purpose of this study, it is assumed that the discharge burnups for all BWR SNF eventually reach the assumed maximum burnup of 48 GWd/MTU. Some companies may not reach this maximum discharge burnup due to fuel management decisions taken by those companies. Lower discharge burnups would result in the discharge of more SNF and subsequently, more SNF to transfer to dry storage.

2.3 Dry Storage Technology Capacity and Decay Heat Assumptions

There are currently three companies that are supplying dry storage technologies to commercial nuclear power plants in the U.S.: Holtec International, Inc. (Holtec), NAC International, Inc. (NAC), and Transnuclear, Inc. (Transnuclear). All three companies have DSCs that have been certified by the NRC for storage of high burnup SNF (that is, burnups > 45 GWd/MTU), using both regional and uniform loading of SNF in the packages. EPRI reviewed the Final Safety Analysis Reports (FSAR) and Certificates of Compliance (CoC) from each of the three dry storage vendors in order to determine the package decay heat limits for existing dry storage technologies. It should be noted that there are two nuclear power plant sites that are currently loading SNF into bolted, metal dual-purpose casks. The analysis in Section 4 assumes that these two sites continue to load these casks, but no other sites are assumed to utilize metal casks.

As shown in Table 2-1, the decay heat load per dry storage package varies depending upon the design and capacity of the DSC. PWR capacities and package heat loads include:

- 24 PWR assembly dry storage package capacity decay heat loads:
  - Holtec HI-STORM 100 MPC-24: 34 kW,
  - NAC UMS: 23 kW, and
  - NUHOMS-24PTH: 40.8 kW;
- 32 PWR assembly dry storage package capacity decay heat loads:
  - HI-STORM 100 MPC-32: 34 kW;
  - NUHOMS-32PTH1: 40.8 kW;
- 37 PWR assembly dry storage package capacity decay heat loads:
  - Holtec HI-STORM FW MPC-37: 47 kW; and
  - NAC MAGNASTOR: 35.5 kW; and
- 40 PWR assembly dry storage package capacity heat loads:
  - TN-40HT: 32 kW.

BWR capacities and package heat loads include:

- 61 assembly dry storage package capacity decay heat load:
  - NUHOMS-61BT: 31.2 kW;
- 68 assembly dry storage package capacity decay heat load:
  - HI-STORM 100 MPC-68: 34 kW; and
  - TN-68: 30 kW.
- 87 assembly dry storage package capacity decay heat load:
  - NAC MAGNASTOR: 33 kW; and
- 89 assembly dry storage package capacity decay heat load:
  - Holtec HI-STORM FW MPC-89: 46.36 kW.

The CoCs for all of these package designs allow both uniform and regional loading. Package CoCs and FSARs should be consulted for the specific requirements associated with fuel assembly burnup, cooling time, and decay heat for fuel that can be stored in these DSCs.

Table 2-1
SNF Dry Storage Technology – Package Decay Heat Limits

Dry Storage Vendor and Package Design	Fuel Type	Canister Type	Capacity (Assemblies)	Maximum Decay Heat Per Package (1) (kW)
Holtec HI-STORM 100 [Holtec 2008, Holtec 2012]]	PWR	MPC-24	24	34
	PWR	MPC-32	32	34
Holtec HI-STORM FW [Holtec 2011]	PWR	MPC-37	37	47
NAC UMS [NAC 2009a]	PWR	24P	24	23
NAC MAGNASTOR [NAC 2012]	PWR	37P	37	35.5
Transnuclear NUHOMS [Transnuclear 2003, Transnuclear 2006]	PWR	24PTH	24	40.8
	PWR	32PTH1	32	40.8
Transnuclear TN-40HT	PWR	Bolted	40	32.0
Holtec HI-STORM [Holtec 2011]	BWR	MPC-68	68	34
Holtec HI-STORM FW [Holtec 2011]	BWR	MPC-89	89	46.36
NAC MAGNASTOR [NAC 2012]	BWR	87B	87	33
Transnuclear NUHOMS [Transnuclear 2006]	BWR	61BTH	61	31.2
Transnuclear TN-68	BWR	Bolted	68	30.0

(1) The maximum decay heat per assembly for uniform loading can be calculated by dividing the package decay heat by the number of assemblies. Maximum decay heat per assembly under regional loading schemes will generally be higher than the maximum decay heat per assembly assuming uniform loading. Cask CoCs should be consulted to determine the specific maximum assembly decay heat limits for each storage location in the basket.

As discussed in Section 2.2.1 and 2.2.2, EPRI assumes that the industry will reach the maximum assumed burnups of 55 GWd/MTU for PWRs and 48 GWd/MTU for BWRs by 2020. If all SNF is transferred to dry storage once it has cooled for five years, this means that all SNF being loaded into dry storage by approximately 2025 will be at the EPRI-assumed maximum discharge burnups.

As discussed in Section 2.2.2, in order to load shorter-cooled, high heat load SNF, lower capacity DSCs that are capable of storing this higher heat load SNF may need to be developed and certified, or existing DSC designs could be amended to allow the packages to be short-loaded in order to accommodate higher heat load SNF. In order to determine the impact of loading five-year cooled SNF into dry storage, EPRI utilizes the maximum decay heat per package for PWR and BWR dry storage technologies, shown in Table 2.1, in order to determine the approximate capacity of a dry storage package needed to store five year cooled PWR SNF with burnups of 55 GWd/MTU and five-year cooled BWR SNF with burnups of 48 GWd/MTU (discussed in more detail in Section 3).

It should be noted that DSCs that allow regional loading of SNF may have limits not only on maximum SNF burnup and associated heat load, but also on the burnup and heat load associated with certain storage locations in a regional loading scheme. Prior to 2025, EPRI assumes that nuclear power plant sites will continue to load DSCs with the capacities currently being utilized at individual sites (for example, most PWRs are loading or planning to load 32 to 37 assembly systems, and most BWRs are loading 61 to 68 assembly systems). PWR sites that are loading 24-assembly systems currently are assumed to continue to do so. The two sites that are loading bolted, metal dual-purpose casks are assumed to continue to load these casks. It should be noted that all three dry storage vendors have NRC approval for higher capacity storage systems or are in the process of NRC review of higher capacity storage systems. Thus, while EPRI's analysis in this report evaluates the dry storage impacts based on the systems being loaded at most nuclear power plant sites today, it is likely that many nuclear operating companies will transition to higher capacity systems in the future in order to reduce the number of DSCs that need to be loaded. However, if a policy decision is made to accelerate the transfer of SNF from SPFs to dry storage, these higher capacity systems may not be able to be utilized to load inventories that consist of only high burnup, five-year cooled SNF after 2025. Thus, the evaluation of DSC costs in Section 3 and Section 4 of this report underestimate the cost of accelerated transfer of SNF to dry storage since EPRI's analysis assumes that the DSCs that are currently being loaded or are planned to be loaded at a specific site, are utilized in the future at those sites, and that no sites transition to the higher capacity DSC systems that are available or will be available in the future.

2.4 Availability of Spent Fuel Pool and Cask Handling Equipment

As noted in Section 1.1, based on discussions with nuclear operating companies regarding the time periods over which the existing five-year-cooled SNF inventories could be transferred from pool storage to dry storage, EPRI determined that transferring the entire U.S. inventory of SNF that has been cooled for at least five years could not be accomplished over the five year time frame that was assumed in EPRI 2010b. This is due to the fact that the SFPs and equipment used to load DSCs, such as the cask handling crane, are only available for the purpose of loading DSCs for a limited time in each reactor operating cycle, as discussed in more detail below. Nuclear power plants that have multiple units that share a spent fuel storage pool and/or cask handling crane have even more constraints.

2.4.1 Spent Fuel Pool Activities

There are 65 nuclear power plant sites with operating reactors in the U.S. Of these, 43% of the sites have a single operating reactor and generally one SFP and cask handling crane. Only 26% of nuclear power plant sites have multiple units that have separate SFP and separate cask handling cranes. The remaining 31% of reactor sites either share a single SFP and cask handling crane or have two connected SFPs with one cask handling crane. As an example, at one reactor site, two units share a SFP and a third unit has a separate SFP. However, the three units share a single cask handling crane making coordination of outage and maintenance activities with SNF dry cask loading operations challenging.

Activities that support operation of the nuclear power plants that take place in the SFP or require the cask handling crane, or that prohibit the movement of SNF during certain times include, but are not limited to:

- SFP cleanup activities post outage
- Restrictions on pre-outage loading
- Repositioning of SNF in SFP in advance of refueling outage
- Refueling outage
- Restrictions on movement of heavy loads after an outage
- Healthy fuel inspections, special nuclear material (SNM) physical inventory
- Fuel sipping campaigns (periodic)
- Top nozzle repairs (PWR, may be done once or in stages)
- SFP neutron absorber inspections (SFP rack dependent)
- Maintenance, surveillance, and inspection of cask handling crane, ventilation systems, and other equipment
- Weather or seasonal restrictions (may prohibit dry storage loading in some locations)
- Debris and non-fuel related material cleanup and removal
- Control rod movement in SFP
- New fuel receipt and positioning of new fuel in pool
- Scheduled training, vacations and holidays

The actual SFP or cask handling crane related activities and activity durations that take place at each site will be reactor specific, as discussed in more detail in the discussion that follows.

Figure 2-4 presents an illustrative 2-unit nuclear power plant site with a shared SFP and cask handling crane. This illustrative nuclear power plant operates on

18-month refueling cycles. Outages at most U.S. plants typically last between four and six weeks (EPRI assumes a five week refueling outage in Figure 2-4), with four week pre-outage and post-outage restrictions (pre- and post-outage restrictions will be site specific). Repositioning of SNF prior to an outage is assumed to take two weeks, new fuel receipt and inspection - three weeks, preventative maintenance for cask handling cranes and other equipment - two weeks, healthy fuel inspections - two weeks, and scheduled training, vacations and holidays approximately four weeks. Other activities that are described above (listed on the bottom of Figure 2-4), may take place for a few days or periodically, but would also have to be accommodated in the schedule. In addition, there may be unplanned activities that require the use of the SFP or cask handling crane that have not been identified above such as unplanned outages, foreign material (FM) identification and retrieval, equipment failures and repairs, etc. Scheduled activities may also take longer due to unforeseen problems such as equipment problems.

EPRI assumes that this illustrative 2-unit site loads twelve DSCs every three years, as outage schedules permit, as shown in Figure 2-4. EPRI assumes that it takes 10 weeks to load six casks (1.6 weeks per cask). Industry loading times range from one to two weeks per cask. In Year 1, in which only Unit 1 has a refueling outage, six DSCs are loaded with SNF and there are approximately 11 weeks available to perform other SFP activities or activities that require the cask handling crane. During Year 2, both Unit 1 and Unit 2 have refueling outages, based on the activities that are required to be performed, there are only 5 weeks available to perform other SFP activities or to load SNF to dry storage. In Year 3, Unit 2 has a refueling outage, six DSCs are loaded with SNF and there are approximately 11 weeks available to perform other SFP activities or activities that require the cask handling crane. Thus, over a three-year period, this illustrative 2-unit site loads an average of four casks per year and there are an average of 9 weeks available for SFP activity cleanup, SNM physical inventory, fuel sipping campaigns, top nozzle repairs, SFP neutron absorber inspections, weather restrictions, debris and non-fuel related material cleanup and removal, control rod movement in SFP, etc. In addition, this does not account for the time needed to implement near-term modifications and inspections in response to NRC actions associated with post-Fukushima Daiichi lessons learned.

The time periods discussed above are illustrative. Some companies may have different outage lengths, different requirements for pre- and post-outage restrictions, different maintenance requirements due to differences in facilities and equipment, different requirements for pre-outage fuel positioning, etc. Based on information from nuclear operating companies, the overall time periods for SFP activities assumed by EPRI in this report are representative of the timing of activities at different sites.

While it may be possible to load additional DSCs during years in which there is only one outage, the schedule for doing so must compete with the other activities identified above. Over a three year period there are 27 weeks available to accomplish the additional activities discussed above or to load additional DSCs. Assuming that the additional SFP related activities comprise approximately 12 of the 27 weeks, this would allow an additional 15 weeks for loading DSCs. Assuming 1.6 weeks per system, it is possible that an additional 9 DSCs could be loaded over that three-year period – increasing the number of systems loaded from 12 DSCs to 21 DSCs, or an average of 7 DSCs per year. If one assumes that this is a 2-unit PWR site, with an inventory of 2,400 SNF assemblies in its SFP that had been cooled for at least five years, under the current practice of loading an average of 4 32-PWR assembly DSCs per year, the company would load 75 32-PWR DSCs over a 19 year period. If an average of 7 DSCs per year are loaded, it would take approximately 11 years to load 75 32-PWR DSCs. If DSC capacity must be reduced to accommodate storage of only high burnup, short-cooled SNF, this time period would increase to approximately 12 years to load 80 30-PWR DSCs.

Two-unit sites that operate on 24-month refueling cycles would have some additional flexibility to perform SFP related activities as well as load casks to dry storage since there would only be one refueling outage per year. The most limited sites would be those with three units and shared SFPs and/or cask cranes. During years in which there are two refueling outages, there would be limited time available to load additional casks to dry storage.

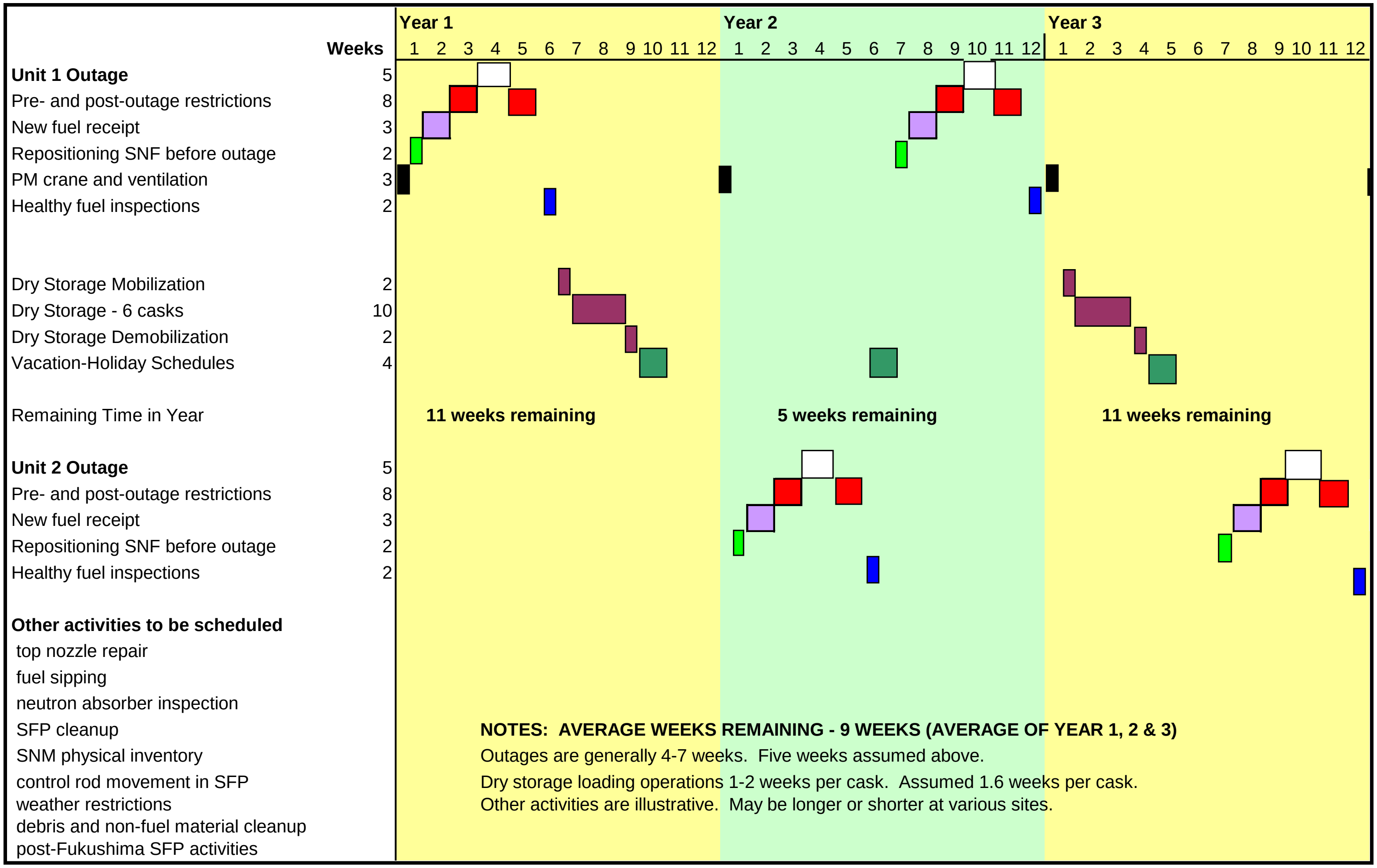

Figure 2-4
SFP Activities and Scheduling for an Illustrative 2-Unit Site with Shared Cask Handling Crane, 18-Month Refueling Cycle

Based on feedback from nuclear operating companies and taking into account the limited time periods that are available to load DSCs at nuclear power plant sites, it appears that a realistic estimate of the time period needed for the transfer of existing inventories of five-year cooled SNF from SFPs to dry storage is between eight and fifteen years. However, the time available to load DSCs is very site specific. Thus, there is not one time period over which all sites could accomplish the transfer of existing inventories to dry storage. In this report, EPRI assumes that existing five-year cooled inventories of SNF are transferred to dry storage over a ten-year period. Some sites with multiple units and shared SFPs and/or cask cranes may require a longer period of time to transfer the five-year cooled inventory to dry storage if a policy decision is made that requires this action. Thus, EPRI also evaluates the impacts associated with transfer over a 15-year period.

2.4.2 Possible Industry Actions to Accelerate Transfer of SNF

As noted in Section 2.4.1, almost 31% of nuclear power plant sites are multi-unit sites that share cask handling cranes and/or SFP resources, thereby limiting the time periods available to transfer SNF from pool storage to dry storage. In addition, based on current practice at nuclear operating companies, multiple-unit sites (57% of sites) share equipment (such as transfer cask) and/or loading crews between units at one site, and some companies share equipment (such as transfer casks) and loading crews with other sites at which they have operating ISFSIs. Thus, under current practice, this would further limit the time periods during which dry storage loading operations can take place at multi-unit sites that share equipment or crews or for companies that share equipment or crews among multiple sites. Some companies lease transfer casks and associated loading equipment from their dry storage vendor. Since that equipment is shared among multiple customers of the dry storage vendor, the time periods during which dry storage loading operations can take place are limited by the loading schedules at the other sites that are leasing the same equipment. If a policy decision is made that requires the accelerated transfer of SNF from pool storage to dry storage, in order to provide additional flexibility for cask loading operations, sites that currently share or lease equipment could acquire additional cask loading equipment (such as transfer casks) in order to increase the flexibility to transfer SNF at these sites. Sites that share loading crews could either train additional crews or utilize contractor loading crews to provide additional flexibility. It should be noted that in order to increase the number of trained crews to support cask loading, whether utility staff or contractor crews, two years of training is generally required. Utility feedback indicates that finding qualified personnel to support cask loading operations can also be challenging. However, shared spent fuel storage pools and shared cask handling cranes would continue to be the limiting factor at most sites.

Based on current industry practice, nuclear operating companies generally carry out one cask loading campaign at any one time at any one site. In addition, dry storage loading campaigns are not carried out when there is a refueling outage for any unit at that site. During a refueling outage, there is a site-wide focus on that outage and activities that would divert attention away from the outage (such as a dry storage loading campaign at another unit at the site) are avoided. For example, at a two-unit site that has separate SFPs and separate cask cranes, when Unit 1 is in a refueling outage, there would generally not be a cask loading campaign at Unit 2 even if Unit 2 had available time to load casks. Most nuclear operating companies focus all of their site resources on safely completing refueling outages on very precise schedules and there would not be sufficient skilled and trained personnel available to support a cask loading campaign at Unit 2 when Unit 1 is in a refueling outage. While it is possible that contractor resources could be used to support a cask loading campaign at the second unit if it were necessary, site maintenance crews would still be needed to support a dry storage loading campaign and these resources may be a limiting factor at many sites during a refueling outage.

In addition, sites that do not share SFPs and cask handling equipment, may have more flexibility to load SNF to dry storage than sites that share cask handling equipment. Under current industry practice, most sites only have one set of cask loading equipment (transfer cask, cask lift yoke and related auxiliary equipment, welding equipment, cask transporter, etc.). A 2-unit site with two SFPs that do not share cask handling equipment could purchase an additional transfer cask, auxiliary equipment and other equipment needed for loading such that during certain time periods when both units do not have other SFP-related activities scheduled, SNF could be loaded into DSCs at the same time at both units. As noted in Section 2.4.1, only 26% of nuclear power plant sites have multiple units that have separate SFP and separated cask handling cranes. Sites that currently share cask loading equipment could also purchase their own transfer casks and auxiliary equipment to provide some additional flexibility to conduct cask loading campaigns.

2.4.3 Realistic Time Periods for Accelerated Transfer of 5-Year Cooled SNF Inventories

Following discussions with nuclear operating companies and review of the time constraints associated with transfer of SNF to dry storage discussed above, it appears that a time period of between 8 and 15 years would be needed at most sites to safely transfer existing inventories of SNF that have been cooled for five years from pool storage to dry storage. In Section 3 and Section 4 of this study, EPRI analyzes a Base Case, in which SNF is transferred to dry storage as it is necessary in order to maintain full core discharge capability and two scenarios (Case 2 and Case 3), in which there is an accelerated transfer of five-year cooled SNF to dry storage. The accelerated transfer cases are:

1. Case 2: Accelerated transfer over a ten-year period (2015 to 2024) and
2. Case 3: Accelerated transfer over a 15-year period (2015 to 2029).

The 10-year scenario results in an average of 3 times the number of casks being loaded annually during 2015 to 2024, compared to the Base Case in which SNF is transferred to dry storage as needed to maintain the ability to offload the reactor core into the SFP.

The 15-year scenario results in an average of 2.5 times the number of DSCs being loaded annually during the period 2015 to 2029 compared to the Base Case in which SNF is transferred to maintain full core discharge capability. Table 2-2 describes the parameters for the three Cases evaluated in Section 3 and Section 4 including the number of years over which accelerated transfer of SNF to dry storage takes place, the time period for accelerated transfer, and the DSC system capacities assumed in the three cases. As shown in Table 2-2 and discussed in more detail in Section 3.3.1, the PWR DSC system capacities are assumed to be lower beginning in 2025 in order to load only five-year cooled, high heat load SNF to dry storage.

Table 2-2
Assumptions in Base Case and Accelerated Transfer Cases

Assumptions	Base Case	Accelerated Transfer Cases	
		Case 2	Case 3
SNF Transferred to Dry Storage	As needed for FCR	Accelerated	Accelerated
Number of Years for Accelerated Transfer	Not applicable	10 Years	15 Years
Time Period for Accelerated Transfer	Not applicable	2015 to 2024	2015 to 2029
PWR DSC System Capacities	Existing capacities 24 PWR 32 PWR 40 PWR 37 PWR	See Section 3.3.1 24 PWR 30 PWR (from 2025) 30 PWR (from 2025) 30 PWR (from 2025)	See Section 3.3.1 24 PWR 30 PWR (from 2025) 30 PWR (from 2025) 30 PWR (From 2025)
BWR DSC System Capacities	Existing capacities 61 BWR 68 BWR	Existing capacities 61 BWR 68 BWR	Existing capacities 61 BWR 68 BWR

As noted above, the time frame over which existing SNF inventories can be transferred to dry storage will be site specific. From a logistical basis, a site with multiple units and only one cask handling crane can simply not load as many DSCs as a site with multiple units and separate cask handling cranes. Thus, if there is a policy decision that requires existing SNF inventories that have been cooled for five years or longer be transferred to dry storage, it will not be possible for all nuclear power plant sites to accomplish this in the same time period.

2.5 Development, Certification and Deployment of New DSC Designs

As noted in Section 5.2 of EPRI 2010b, if a policy decision is made to accelerate the transfer of SNF from pool storage to dry storage after SNF has cooled for five years, it is likely that existing dry storage designs may need to be amended or new designs may need to be certified by the NRC. This may require advances in the heat transfer capabilities of DSCs either through improved materials or improved methodology; lower DSC capacities, changes in shielding, etc. The lead times needed to obtain either amendments to existing CoCs or to certify new designs ranges from one year to approximately five years.

EPRI reviewed the NRC licensing dockets for existing DSC CoCs in order to quantify the time periods that have been required to amend an existing 10CFR72 CoC or to gain NRC certification for a new design. In order to amend an existing CoC, NRC review time can take from six months to more than 3 years, depending upon the complexity of the CoC amendment, NRC staff workload, and the completeness of the supporting information submitted by the dry storage vendor as part of the license application to amend the CoC. In addition, dry storage vendors would spend between six and 18 months to prepare the license amendment request for the CoC amendment, depending upon the complexity of the amendment. Thus, the total lead time to amend a CoC ranges from approximately one to five years.

For a new DSC design, NRC review time for recent applications for new CoCs ranges from two to three years on average. If new materials or new methodologies, which have not previously been reviewed by NRC, are used by the dry storage vendor in a new design, longer review time may ensue. Dry storage vendors would spend between 12 and 18 months to prepare a new DSC design. Thus, the total lead time to receive a CoC for a new DSC design would range from three years to more than five years.

In order for nuclear operating companies to deploy new DSC designs at their ISFSIs, companies must begin the planning process three to five years in advance of loading SNF into these new designs. Activities that must take place include:

- Identification and implementation of any site modifications needed to deploy a new dry storage design.
- Development of site specific procedures associated with loading SNF, handling, and transfer of the new DSC design to the ISFSI.
- Receipt of new equipment associated with the new design (transfer cask and ancillary equipment, storage overpacks or components, DSCs, etc.)
- Training of personnel in procedures associated with the new system; performance of internal and external dry runs; and readiness review for loading.
- NRC inspections to support deployment of the new dry storage design.

In addition, in order to support the accelerated transfer of five-year cooled SNF from SFPs to dry storage, nuclear operating companies may need to expand their ISFSIs. This might include clearing and preparing additional land on which to expand the ISFSI, design and construction of additional concrete storage pads, expansion of fencing and security systems consistent with the size of the expanded ISFSI, etc. Lead times associated with expanding ISFSIs are expected to range from two to three years, depending upon the complexity of the ISFSI expansion and other competing projects at a site.

The cost to develop and certify a new DSC design are estimated to range from $5 to $10 million, assuming that the design is a new DSC design and not an amendment to an existing system design. License amendments to existing DSC designs would cost up to several million dollars to perform the necessary design, analysis, NRC review and certification of the amendment, depending upon the complexity of the amendment, and the degree of changes to the existing design, materials or analytical methods utilized. New designs and amendments to existing CoCs that utilize new methodologies or new materials may require additional analysis and result in longer NRC review times and higher overall development and certification costs.

2.6 DSC Fabrication

As discussed in Section 2.4.3, if there is a policy decision to accelerate the transfer of five-year cooled SNF from pool storage to dry storage, there would be a subsequent increase in the number of DSCs loaded during the time period over which the five-year cooled SNF inventories are transferred to dry storage. In this report, EPRI evaluates 10-year and a 15-year transfer period. If SNF inventories are transferred from pool storage to dry storage over a 10-year period (e.g., 2015 to 2024), there would be almost a three-fold increase in DSCs loaded. If the SNF inventories are transferred over a 15-year period, this would result in an approximate 2.5 fold increase in DSCs loaded during 2015 to 2029, compared to the base case in which SNF is transferred to dry storage in order to support staging of new fuel and the permanent discharge of SNF at the end of an operating cycle.

This would require a 2.5 to 3-fold increase in DSC fabrication capability with potential impacts that include increased NRC inspection and oversight for DSC vendors, fabricators and dry storage loading operations. This increase in fabrication requirements could result in the need to expand fabrication capacity at existing fabricators or to bring new fabricators on line. Discussions with DSC vendors and fabricators indicated that it would take two to three years to bring a new fabrication shop on line and up to production capacity. This includes approximately 12 to 18 months to set up the fabrication shop for production of DSCs including installation of the needed stations, equipment, and fixtures for fabrication of DSC components. Once the equipment is installed and initial production begins, an additional 12 months would be required to ensure that the new fabrication facility procedures and processes are integrated and to bring the dry storage fabrication up to full production capacity.

The actions and capital needed to expand fabrication capacity at existing fabricators will vary depending upon the individual situations of the fabrication facilities. Some fabricators that do not currently operate multiple shifts could simply increase the number of shifts in order to double their production capacity of DSCs. Fabricators can also utilize subcontractor support for production of dry storage components. However, DSC vendors expressed concern regarding possible impact to quality as subcontractors are utilized. The use of subcontractors requires additional resources from the DSC vendor and the primary fabricator for oversight and quality control of the subcontractor. This oversight could result in increased fabrication cost. Other fabricators may need to invest in additional equipment, manufacturing stations and fixtures in order to increase their DSC production capacity. Manufacturing facilities that require the addition of manufacturing floor space in order to increase production would have higher capital costs than a facility that only needed to invest in additional equipment. One dry storage vendor has its own manufacturing capability, while the other two vendors utilize both domestic and international fabrication facilities. A concern of both DSC vendors and nuclear operating companies is the assurance of a steady supply of fabrication capacity at the high quality levels required for DSCs. Thus the impact of accelerated transfer of five-year cooled SNF to dry storage on the demand for quality fabrication services is a key concern to the industry.

If a policy decision is made to require the accelerated transfer of five-year cooled SNF inventories from SFPs to dry storage, the cost associated with a temporary (10 to 15 year) increase in fabrication production capacity is a concern. Since the offload of five-year cooled SNF inventories would be undertaken over a limited time period (e.g., 10 to 15 years), fabrication facilities that require capital investments in order to meet the 2.5 to 3-fold increase production capacity would have to recover their investments over these time periods. The capital investments required at fabrication facilities would likely be amortized over the 10 to 15 year time period by the fabricators, which could result in an increase in DSC fabrication costs. Once the existing SNF pool inventories have been transferred to dry storage, there would be a sudden drop in fabrication demand and a subsequent ramp-down in cask fabrication requirements.

The increased supply of materials for the 2.5 to 3-fold increase in storage system requirements could also result in an increase in DSC costs depending upon the demand for materials (e.g., stainless steel, carbon steel, neutron absorbers, forgings, etc.). During 2008 through 2011, there were +/- 20% changes in the Producer Price Index for Iron and Steel (WPU101), indicating recent volatility in the prices for these materials which are primary materials used in DSCs. Labor cost have not increased as dramatically over the same time period; however, during periods of manufacturing growth, the cost of skilled labor will increase due to demands for this skilled labor in other industries. Labor costs typically comprise 40% to 50% of the cost of DSC manufacturing, with the remaining 50% to 60% of costs attributed to materials or fixed costs.

A large increase in DSC requirements would require an increase in DSC vendor and nuclear operating company oversight of DSC component manufacturing.

Most DSC vendors have a strong presence at the fabrication facilities that are used to manufacture their DSC components. Many nuclear operating companies also have dedicated staff responsible for manufacturing oversight of DSCs. There would also be a subsequent increase in NRC oversight of fabrication facilities resulting in higher NRC fees associated with DSC oversight.

Since the DSC vendors utilize a range of fabrication facilities – from vendor-owned manufacturing to the use of multiple domestic and international facilities –the cost impact on DSC fabrication cost associated with a temporary increase in DSC manufacturing will vary depending upon the degree of expansion of existing facilities or the necessity to qualify new fabricators. In order to assess possible cost increases associated with the need to increase fabrication capacity, EPRI considers the impact of a 20% increase in the labor portion of fabrication costs in Section 2.7.2, during the time periods over which there is an accelerated transfer of five-year cooled SNF from pool storage to dry storage. EPRI would not expect that the increase in demand for metals needed to fabricate the additional casks to have a material impact the broader markets for these materials and the associated PPI for these materials. Thus, EPRI does not consider increases in the material portion of fabrication costs, since cost increases for materials such as stainless steel would be expected to be driven by broader demand.

2.7 Dry Storage Cost Assumptions

At-reactor dry storage costs are generally classified as upfront costs, incremental costs, decommissioning costs, annual operating costs during reactor operation and annual operating costs following shutdown for decommissioning. As discussed in more detail below, there may be higher dry storage costs associated with accelerated transfer of SNF from SFPs to dry storage under Case 2 and Case 3 compared to the industry Base Case. Assumptions regarding the transfer of SNF to dry storage under the Base Case, and the two accelerated transfer cases, Case 2 (10-year transfer of existing inventories) and Case 3 (15-year transfer of existing inventories) are summarized in Table 2-2.

2.7.1 Upfront Costs

Upfront costs include engineering, design, and licensing costs; equipment costs; construction costs; and start up and testing costs. More specific details regarding the types of cost elements that go into each of these cost categories are discussed in the *Industry Spent Fuel Storage Handbook* published by EPRI in 2010 [EPRI 2010a].

It should be noted that upfront costs for ISFSI construction and site infrastructure improvements will be dependent upon site specific and plant specific conditions and can vary widely from ISFSI to ISFSI. Upfront costs for ISFSIs that are in operation range from several million dollars to tens of millions of dollars.

2.7.1.1 Upfront Costs for the Base Case

In its assessment of the costs associated with dry storage of SNF, EPRI amortizes the upfront costs for an ISFSI over each DSC loaded. For example, if the upfront cost of a dry storage facility for storage of 40 DSCs is $24 million, the amortized upfront cost for one DSC would be $600,000. In this analysis, EPRI assumes that the amortized upfront cost for one DSC is $650,000. In calculating this estimated cost, EPRI relied on two publicly available cost estimates associated with two separate dry storage facilities because both cost estimates provided the upfront ISFSI costs associated with storing a fixed number of DSCs. In its application to the Minnesota Public Utilities Commission for a certificate of need for the ISFSI at the Monticello Generating Station, Xcel Energy estimated that the upfront costs for the Monticello ISFSI would be $21.5 million to store 30 DSCs – approximately $720,000 per storage system ($2005) [Xcel 2005]. In a spent fuel management plan submitted to the NRC in accordance with 10CFR 50.54(bb), Entergy estimated that the upfront costs to build an ISFSI at the Pilgrim Nuclear Power Station would be $22 million to store 53 DSCs – approximately $415,000 per storage system ($2006) [Entergy 2007]. EPRI inflated these two cost estimates to 2012 dollars and averaged the two estimates to calculate an estimated amortized upfront cost of approximately $650,000 per storage system (Constant $2012).

2.7.1.2 Upfront Costs Assuming Early Transfer of 5-Year Cooled SNF

If there is a policy decision that requires the accelerated transfer of SNF from pool storage to dry storage, there may be additional costs that nuclear power plant sites will incur in order to facilitate this accelerated transfer. As discussed in Section 2.4.1, 31% of nuclear power plant sites are multi-unit sites that share cask handling cranes and/or SFP resources, thereby limiting the time periods available to transfer SNF from pool storage to dry storage. In addition, based on current practice at nuclear operating companies, multiple-unit sites share equipment (such as transfer cask), which limits the time periods during which dry storage loading operations can take place at both sites. Some companies lease transfer casks and associated loading equipment from their dry storage vendors. To provide additional flexibility for cask loading operations if a policy decision is made to require the early transfer of SNF from pool storage to dry storage, sites that currently share or lease equipment could acquire additional cask loading equipment in order to increase the flexibility to transfer SNF at these sites. In its analysis associated with the early transfer of five-year cooled SNF inventories to dry storage, EPRI assumes that multi-unit sites that have more than one cask handling crane purchase an additional transfer cask and ancillary equipment to facilitate the transfer of SNF to dry storage. Costs associated with purchase of a transfer casks and transfer equipment range from about $2 million to $4 million. For the purpose of this analysis, EPRI assumes $3 million for additional cask transfer equipment at those sites with multiple cask handling cranes. EPRI is aware of several sites that share transfer casks, and assumes that three sites that share a transfer cask with other sites purchase a separate transfer cask. Thus, a total of 19 sites are assumed to have a one-time purchase for additional transfer casks to support increased transfer of SNF beginning in 2015.

As discussed in Section 2.2.1 and 2.2.2, EPRI assumes that the industry will reach the maximum assumed burnups of 55 GWd/MTU for PWRs and 48 GWd/MTU for BWRs by 2020. If all SNF is transferred to dry storage once it has cooled for five years, this means that all SNF being loaded into dry storage by approximately 2025 will be five-year cooled SNF with discharge burnups at the EPRI-assumed maximum discharge burnups. Nuclear operating company experience has also shown that loading DSCs with shorter-cooled, high burnup SNF that has higher heat loads and radiation dose can result in increased site dose to workers as well as increased off-site dose. In order to reduce the impacts of increased worker dose and off-site dose, companies may need to employ additional shielding in DSCs or put in place earthen berms around an ISFSI site. In this analysis, EPRI has not estimated the cost of constructing earthen berms around ISFSIs since such cost estimates would be site specific and difficult to estimate in a generic analysis. In addition, additional shielding can be added to DSC concrete overpacks, as discussed further in Section 2.7.2.1.

2.7.2 Incremental Costs

Incremental costs are the costs associated with the purchase and loading of DSCs on a periodic basis. These costs include the capital costs for the DSC including the dual-purpose canister and concrete overpack as well as loading costs for the storage systems. In this analysis, EPRI assumes that all future SNF will be placed in dual purpose canister technologies. However, it should be noted that several ISFSIs are loading metal storage casks or dual-purpose metal casks, and plan to continue loading these systems in the future.

2.7.2.1 Incremental Costs for the Base Case

In this analysis, EPRI assumes that the cost for canisters and concrete overpacks is $988,000 (Constant $2012) for DSCs loaded under the Base Case, which assumes that SNF is transferred to dry storage as needed in order to maintain the capability to discharge the full reactor core into the SFP. This includes approximately $208,000 per concrete overpack and $780,000 per canister. This is consistent with the unit costs for DSCs that EPRI utilized in an estimate of costs for a Generic Interim Storage Facility [EPRI 2009]. EPRI assumes that the cost to load a canister-based storage technology is $312,000 per system loaded (Constant $2012). These unit cost estimates fall within the range of costs that nuclear operating companies have experienced to purchase and load canister-based systems, with some companies having higher or lower costs than assumed by EPRI in this report.

2.7.2.2 Incremental Costs Assuming Early Transfer of 5-Year SNF

As discussed in Section 2.2.2, based on EPRI's projection of SNF discharge burnups both PWR and BWR burnups will reach the average discharge burnup of 55 GWd/MTU for PWRs and 48 GWd/MTU for BWRs by approximately

2020. Under a scenario in which the existing inventories of SNF with at least 5 years of cooling are offloaded from SFPs to dry storage, all of the SNF loaded into dry storage by 2025 will be at these maximum discharge burnups. New DSC designs that are capable of storing only five-year cooled, high burnup PWR SNF would need to be designed, certified and fabricated. New designs with additional shielding capability or new features may also be necessary to store five-year cooled, high burnup BWR SNF in order to reduce worker dose and site dose.

At the present time, some of the dry storage vendors offer concrete overpack designs that provide additional shielding in order to decrease the worker dose, site dose, and offsite dose associated with operation of an ISFSI. While feedback from some vendors indicated that existing DSC designs could continue to be used for storing only five-year cooled SNF without a reduction in system capacity, the DSC CoCs would still have to be amended to reflect the change in the DSC contents or to provide additional shielding in the concrete overpacks.

EPRI has assumed that beginning in 2025, when only five-year cooled, high burnup SNF is available for loading into dry storage, there will be several potential cost adders to address increased fabrication costs, additional shielding capability in concrete storage overpacks; and higher loading costs due to increased worker dose and implementation of the fatigue rule that result in longer cask loading durations or the need to utilize additional crews. Cask loading operations at some sites are already impacted by the fatigue rule.

<u>Fabrication Cost Adder</u>: As discussed in Section 2.6, labor costs are approximately 40% to 50% of the cost of DSCs. Assuming that the labor portion of canister and concrete overpack cost (40% of $988,000) increase by 20%, this results in a fabrication cost adder of $79,040 per DSC as shown in Table 2-3. EPRI assumes that this fabrication adder is applied to dry storage incremental costs beginning in 2015 through the time period over which the existing five-year cooled inventories are transferred to dry storage (e.g., 2015 to 2024 in Case 2, and 2029 in Case 3).

<u>Shielding Cost Adder</u>: Assuming that 30% of the concrete overpack cost is associated with concrete shielding and that shielding is increased by 40%, this results in a concrete overpack shielding cost increase of $24,960 per overpack ($208,000 * 30% * 40%). EPRI assumes that the shielding adder applies beginning in 2025 when only high burnup, 5 year cooled SNF will be available for transfer to dry storage.

There may also be some additional cost associated with amending existing CoCs or certifying new designs. These costs may be passed on to nuclear operating companies through the price of the DSC systems or may be directly billed to nuclear operating companies by cask vendors if the amended or new designs are specific only to that utility. However, given the uncertainty regarding whether this would be done through amendments to existing CoCs or through new DSC designs and the wide range of costs for implementing such changes, EPRI has not attempted to quantify this cost impact, which results in the cost estimates in Section 3 and 4 for the accelerated transfer Case 2 and Case 3 being conservative.

Loading Cost Adder: In Section 2.7.2.1, EPRI assumes that the cost to load a canister-based storage technology is $312,000 per system loaded (Constant $2012). Due to the increased costs associated with increased worker dose, longer loading times, the need to load more DSCs, and the application of fatigue rules during cask loading operations, EPRI assumes that loading costs per system will increase by 20% as shown in Table 2-3, or total loading costs of $374,400 per system loaded. This loading cost adder is applied beginning in 2015 to address the additional DSCs associated with increased worker dose, the need to load additional DSCs, and implementation of the fatigue rule due to longer cask loading times.

Table 2-3
Cost Increases Associated With Fabrication Supply and Increased Shielding (Constant $2012)

Cost Component	**Base Case Unit Cost**	**% of Unit Cost Impacts**		
		Fabrication	**Shielding**	**Loading**
Canister	$780,000	40%	–	–
Concrete Overpack	$208,000	40%	30%	–
Loading	$312,000	–	–	100%
Cost Component	Base Case Unit Cost	Adder to Unit Costs		
		20%	40%	20%
Canister	$780,000	$62,400	–	–
Concrete Overpack	$208,000	$16,640	$24,960	–
Loading	$312,000	–	–	$62,400

In its analysis of dry storage costs associated with the accelerated transfer of SNF to dry storage, EPRI did consider and evaluate sensitivity analysis using somewhat higher and lower cost adders for the three cost components discussed above. However, the results were not materially different from the results for the cost adders summarized in Table 2-3. In addition, as was shown in EPRI 2010b and summarized in Section 4 of this report, the main reason for the large cost increase associated with the accelerated transfer of SNF to dry storage is the time value of money, not the unit costs of DSCs. Thus, the analysis in this report includes only the cost adders shown in Table 2-3, since the inclusion of a broader range of cost adders would not have significantly different results than those presented in Section 3 and 4.

2.7.3 Annual Operating Costs

Annual operating costs for an ISFSI during reactor operation include the costs associated with NRC inspections; security; radiation monitoring; ISFSI operational monitoring; technical specification and regulatory compliance, including implementation of new CoC amendments; personnel cost and code maintenance associated with fuel selection for dry storage; personnel costs for SNF management and fabrication surveillance activities; electric power usage for lighting and security systems; road maintenance to the ISFSI site; and miscellaneous expenses associated with ISFSI maintenance. NRC license fees for dry storage are included as part of the 10CFR50 operating license fee. EPRI 2010b assumed that annual operating costs were $600,000 per year. Based on feedback from nuclear operating companies and published costs for this component, EPRI assumes that annual operating costs for an ISFSI at an operating nuclear power plant site are $1.1 million per year.[15] Operating nuclear power plant sites may experience annual ISFSI operating costs that are higher or lower than the amount assumed by EPRI in this report. Nuclear operating companies will also incur costs to implement new DSC designs at their ISFSIs as well as costs to implement amendments to existing DSC CoCs. Since the costs to implement amendments and new DSC designs will be periodic and company specific, EPRI has not attempted to quantify such costs on a system wide basis. It should be noted that since the majority of nuclear power plant sites have already implemented dry storage, only a few sites would be expected to implement dry storage at an earlier date if a policy decision is made to accelerate the transfer of SNF to dry storage. Annual operating costs are a function of when a company begins dry storage. Thus changes to this unit cost will not affect the results presented in Section 3 and Section 4.

Annual operating costs for an ISFSI at a shutdown nuclear power plant include security, license fees (either 10CFR50 license fees, or 10CFR72 site specific license fees if facility has not retained its 10CFR50 license), taxes, insurance, personnel costs, monitoring costs, electric power usage, and miscellaneous expenses associated with ISFSI maintenance. EPRI assumes that annual operating costs for an ISFSI at a shutdown nuclear power plant site are $6.24 million (Constant 2012$) per year [SMUD 2010, MYAPC 2010], which are largely attributed to ISFSI security costs (at operating nuclear power plants, the ISFSI security costs are generally a fraction of the security costs associated with the operating plant). Shutdown plant sites may experience actual operating costs that are higher or lower than the amount assumed by EPRI in this report.

2.7.4 Other Costs

In addition to the upfront costs, incremental costs and annual operating costs, nuclear operating companies must estimate the total costs to decommission the ISFSI once all SNF has been transferred offsite. In EPRI's cost analyses that are summarized in Section 3 and Section 4 of this report, EPRI estimates the costs for at-reactor dry storage of SNF from 2012 to 2099. In its analysis, EPRI assumes that SNF remains in dry storage at reactor sites indefinitely since there is

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[15] There is wide variability in published estimates of annual operating costs for an ISFSI at an operating nuclear power plant site. EPRI is aware of estimates as low as $212,000 per year and as high as $2 million per year [2012 $]. EPRI assumes $1.1 million per year in this analysis [GAO 2009, APS 2007, VEPCO 2002].

currently no basis for assuming that SNF will be shipped off site at some specific date in the future. Therefore, the cost to decommission at-reactor ISFSIs is not included in EPRI's analysis since it is not possible to determine when ISFSIs may be decommissioned. The costs associated with decommissioning an ISFSI will be proportional to the size of the ISFSI. The more packages loaded and stored at an ISFSI, the higher the costs will be to decommission the facility.

EPRI's analysis also does not include the cost to transfer SNF from at-reactor ISFSIs to transportation casks for shipment off site. Due to the uncertainties in the Federal waste management system, it is not possible to determine when SNF will be shipped off site in the future. The costs associated with transfer of SNF from dry storage to transport casks for shipment off site would be proportional to the number of DSCs that must be transferred. The more packages loaded and stored at an ISFSI, the higher the costs will be to transfer this fuel from dry storage to be readied for transport.

2.8 Worker Radiation Exposure Assumptions

Radiological impacts associated with dry storage of SNF at reactor sites include: worker dose during DSC loading, unloading and handling activities; worker dose associated with ISFSI operations, maintenance, and surveillance activities; and worker dose associated with additional ISFSI construction as discussed in more detail below.

Worker dose associated with DSC loading operations vary depending upon the technology being loaded, the characteristics of the fuel being loaded (fuel age and burnup), and fuel loading patterns in the DSC (e.g., the location of short-cooled, high burnup SNF or colder SNF within DSC baskets using regional loading). For the Base Case, EPRI utilizes an assumed worker dose of 400 person-mrem per DSC loaded. This dose is consistent with that used by EPRI in EPRI 2010b and in an analysis of worker impacts associated with loading SNF for transport to the proposed Yucca Mountain repository [EPRI 2008, DOE 2008]. However, it should be noted that some sites achieve per package dose ranges in the range of 200 to 300 person-mrem per package, while other sites experience much higher per package dose rates.

As noted previously, if there is a policy decision to offload the existing five-year cooled inventories of SNF, by 2025 all SNF loaded into DSCs is expected to be high burnup, five-year cooled SNF. Accelerated transfer of SNF to dry storage results in casks being loaded at an earlier date than in the Base Case and possibly the need to load more DSCs if DSC capacity must be reduced in order to store five-year cooled, high heat load SNF. Under an accelerated transfer case, once the existing SFP inventories have been offloaded to dry storage and only five-year cooled, high heat load SNF remains, the ability to place low heat load SNF in the peripheral storage locations of the DSC basket is lost, which increases the cask dose rate during loading and storage. Thus, one of the impacts associated with loading only high burnup, five-year cooled SNF into dry storage, will be an increase in the per-package worker dose above the assumed Base Case worker dose of 400 person-mrem per package. Some nuclear operating companies have indicated that loading high burnup SNF into dry storage can increase DSC loading dose to as high as 1,000 mrem per package loaded. In this analysis, EPRI assumes that the dose to load high burnup, five-year cooled SNF into dry storage beginning in 2025 will be approximately 750 mrem per DSC.

There is worker dose associated with annual operation and maintenance of the ISFSI, including inspection, surveillance and security operations. In the Base Case, EPRI assumes an annual dose of 120 person-mrem per site per year for inspection and security surveillance activities and 1,500 person-mrem per year per site for ISFSI operations and maintenance. This is also consistent with the assumptions used in EPRI 2010b and by the U.S. Department of Energy (DOE) in its Environmental Impact Statement for the proposed Yucca Mountain repository [EPRI 2008, DOE 2008]. In Section 2.7.2.2, EPRI assumes that companies would increase the shielding provided by concrete overpacks so that worker dose associated with ISFSI operations and maintenance would not increase. This increased shielding was reflected in a shielding cost adder that was applied to the incremental costs as discussed in Section 2.7.2.2. Therefore, EPRI has not assumed an increase in the worker dose associated with operations and maintenance.

There will also be radiological impacts associated with construction of additional storage capacity and expansion of an operational ISFSI. EPRI assumes that there would be a worker dose of 170 person-mrem per additional DSC loaded per site. This is consistent with assumptions made in EPRI 2010b and by DOE in its assessment of a No Action Alternative in the Yucca Mountain EIS [EPRI 2008, Jason 1999, Rollins 1998]. EPRI assumed that companies would increase the shielding provided by concrete overpacks so that worker dose would not increase. Therefore, EPRI has not assumed an increase in the worker dose associated with construction of additional storage capacity and expansion of operational ISFSIs.

There will also be a dose to workers associated with the transfer of loaded DSCs from an ISFSI to a transportation cask for transport off site at some time in the future. As noted in Section 2.7.4, EPRI's analysis also does not include the cost to transfer SNF from at-reactor ISFSIs to transportation casks for shipment off site. Due to the uncertainties in the Federal waste management system, it is not possible to determine when SNF will be shipped off site in the future. While the BRC recommended that the U.S. develop one or more facilities for consolidated interim storage and disposal of SNF, there are not yet any sites identified or a schedule for development of such facilities. However, it should be recognized that there will be a radiological impact to workers associated with this activity and the radiological impacts will increase if workers must transfer more DSCs and DSCs with higher dose rates associated with high burnup SNF.

Section 3: Impact on Representative PWR, BWR, and New Plant

Using the assumptions discussed in Section 2 associated with projecting SNF discharges, SNF burnup and heat load, Cs inventories, dry storage technology capacity and decay heat, ISFSI costs, and radiological impacts of dry storage, this section summarizes the impacts on a "representative" PWR and BWR associated with transferring SNF to dry storage at nuclear power plant sites after the SNF has cooled for five years. The representative PWR and BWR are based on actual nuclear power plants that have not yet implemented dry storage at their plant sites. In addition, while EPRI's industry-wide analysis in Section 4 does not include the impacts associated with a new nuclear power plant, this section addresses the impacts of transferring five-year cooled SNF to dry storage at a new nuclear power plant.

3.1 Description of Representative PWR, BWR and New Plant

3.1.1 Representative PWR

EPRI assumes that the representative PWR has not yet implemented dry storage but will do so in the near future. The representative PWR is a one-unit station with a rated capacity of approximately 1,000 megawatts-electric (MWe). It began operating in the 1970s and will reach the end of its extended operating license by approximately 2037. EPRI assumes that the reactor core contains 193 assemblies and the SFP has a capacity of approximately 1,800 assemblies. EPRI assumes a FCR margin of 193 assemblies will be maintained in the SFP. By the end of 2012, a total of 1,520 assemblies will have been discharged and stored in the storage pool with SNF burnup and cooling time ranging from 12 GWd/MTU with more than 25 years of cooling to more than 50 GWd/MTU with less than one year of cooling. The unit operates on an 18-month cycle, discharging 78 to 84 assemblies per cycle. The representative PWR is expected to implement dry storage of SNF beginning in 2013 and will load approximately three DSCs every 18 months in order to maintain FCR in the SFP. By the time the unit permanently ceases operation in 2037, approximately 3,060 assemblies will have been discharged at this representative PWR.

3.1.2 Representative BWR

EPRI assumes that the representative BWR has not yet implemented dry storage but will do so in the near future. The representative BWR is a single unit with a rated capacity of approximately 850 MWe. The representative BWR began operating in the 1970s and will reach the end of its extended operating license by approximately 2034. EPRI assumes that the reactor core contains 560 assemblies and the SFP has a capacity of approximately 2,800 assemblies. By the end of 2012, a total of 2,380 assemblies will have been discharged and stored in the storage pool with SNF burnup and cooling time ranging from 20 GWd/MTU with more than 25 years of cooling to approximately 46 GWd/MTU with less than one year of cooling. The unit operates on 24 month cycles, discharging approximately 200 to 224 assemblies per cycle. The representative BWR is expected to implement dry storage in 2012 and after loading an initial eight DSCs, will load approximately four DSCs biennially in order to maintain FCR in the SFP. When the unit shuts down in 2034, approximately 5,300 assemblies will have been discharged at this representative BWR.

3.1.3 Representative New Nuclear Power Plant

EPRI assumes that the representative new plant is a 1,100 MWe PWR that begins operating in 2017 and reaches the end of an extended operating license in approximately 2077. EPRI assumes that the reactor core contains 157 assemblies and the SFP has a capacity of approximately 1,000 assemblies, with a FCR margin of 157 assemblies in the SFP. The unit operates on 18-month cycles, discharging approximately 52 assemblies per cycle. The new plant is expected to begin dry storage in 2045 and will load approximately two DSCs every 18 months in order to maintain FCR in the SFP. When the unit shuts down in 2077, approximately 2,295 assemblies will have been discharged from the new plant with burnups ranging from 45 GWd/MTU to 55 GWd/MTU (note that some SNF discharged from the initial reactor core for a new plant may have lower burnups, depending upon the fuel management plans utilized).

3.1.4 Decay Heat and Cesium Source Term for the Representative PWR, BWR and New Plant

As fuel assembly burnups increase, the decay heat of the fuel assembly (watts per MTU) and the Cs inventory in the fuel increase. Following discharge of SNF from the reactor core, the decay heat and Cs inventory of the SNF assembly both decrease with time. Under the assumptions discussed in Section 2.2.2 associated with SNF decay heat and Cs source term for PWR and BWR SNF, EPRI has calculated the decay heat and cesium inventory for the estimated inventories of SNF in the Reference PWR and BWR SFPs as of June 2013, as summarized in Table 3-1. Since the representative new plant has not yet started operation, there is no fuel for which to estimate decay heat and cesium source term.

In order to show the possible impact on decay heat and cesium source term associated with removing all SNF with five years of cooling from the representative PWR and BWR SFPs, EPRI has performed a similar calculation but assumes that only the SNF assemblies that have less than five years of cooling remain in the SFPs for the representative PWR and BWR. The remaining five-year cooled SNF inventory, associated decay heat and Cs source term for these SFPs are summarized in Table 3-1.

Table 3-1
Base Case Dry Storage Costs for Representative PWR and BWR, 2012 to 2099

Parameter	Representative PWR	Representative BWR
SFP Inventory: Pre-Transfer of 5-Year Cooled SNF		
Assemblies	1,520	2,380
– Decay Heat (kW)	2,170	1,076
Cs Source Term (Million TBq)	3.0	2.1
(Million Ci)	81	56
SFP Inventory: Post-Transfer of 5-Year Cooled SNF		
Assemblies	340	540
– Decay Heat (kW)	1,480	727
Cs Source Term (Million TBq)	1.4	1.1
(Million Ci)	38	29
Post Transfer Inventory Remaining	22%	22%
Post Transfer SNF Decay Heat Remaining	68%	68%
Post Transfer Cs Source Term Remaining	47%	52%

For the representative PWR, an estimated 1,520 fuel SNF assemblies are in the SFP as of August 2012, with SNF burnup and cooling time ranging from 12 GWd/MTU with more than 25 years of cooling to more than 50 GWd/MTU with less than one year of cooling. The representative PWR SPF inventory has an estimated decay heat of 2,170 kW and a Cs source term of 3.0 million TBq (or 81 million Ci). If only the assemblies that have less than five years of cooling remain in the SFPs for the representative PWR, a total of 340 assemblies would remain in the SFP, and that reduced inventory would have an estimated decay heat of 1,480 kW and an estimated Cs source term of 1.4 million TBq (38 million Ci). The number of assemblies with less than five years of cooling that remain in the SFP would be just 22% of the pre-transfer inventory. However, the decay heat of the post-transfer inventory would be 68% of the pre-transfer decay heat, as shown in Figure 3-1, and the Cs source term would be 47% of the pre-transfer source term, as shown in Figure 3-2.

For the representative BWR, an estimated 2,380 SFN assemblies are in the SFP as of August 2012, with SNF burnup and cooling times ranging from 20 GWd/MTU with more than 25 years of cooling to approximately 46

GWd/MTU with less than one year of cooling. The representative BWR SFP inventory has an estimated decay heat of 1,076 kW and a Cs source term of 2.1 million TBq (56 million Ci). If only the assemblies that have less than five years of cooling remain in the SFPs for the representative BWR, a total of 540 assemblies would remain the SFP, and that reduced inventory would have an estimated decay heat of 727 kW and an estimated Cs source term of 1.1 million TBq (29 million Ci). The number of assemblies with less than five years of cooling that remain in the SFP would be just 22% of the pre-transfer inventory. However, the decay heat of the post-transfer inventory would be 68% of the pre-transfer decay heat, as shown in Figure 3-1, and the Cs source term would be 52% of the pre-transfer source term, as shown in Figure 3-2.

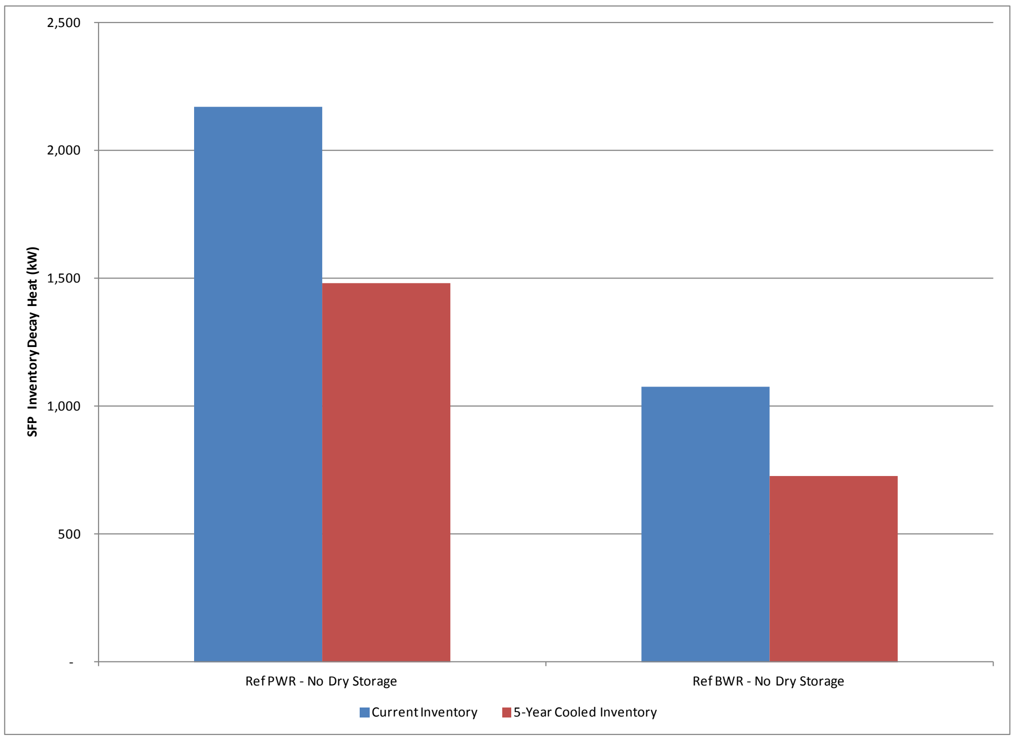

Figure 3-1
SFP Inventory Decay Heat for Reference PWR and BWR

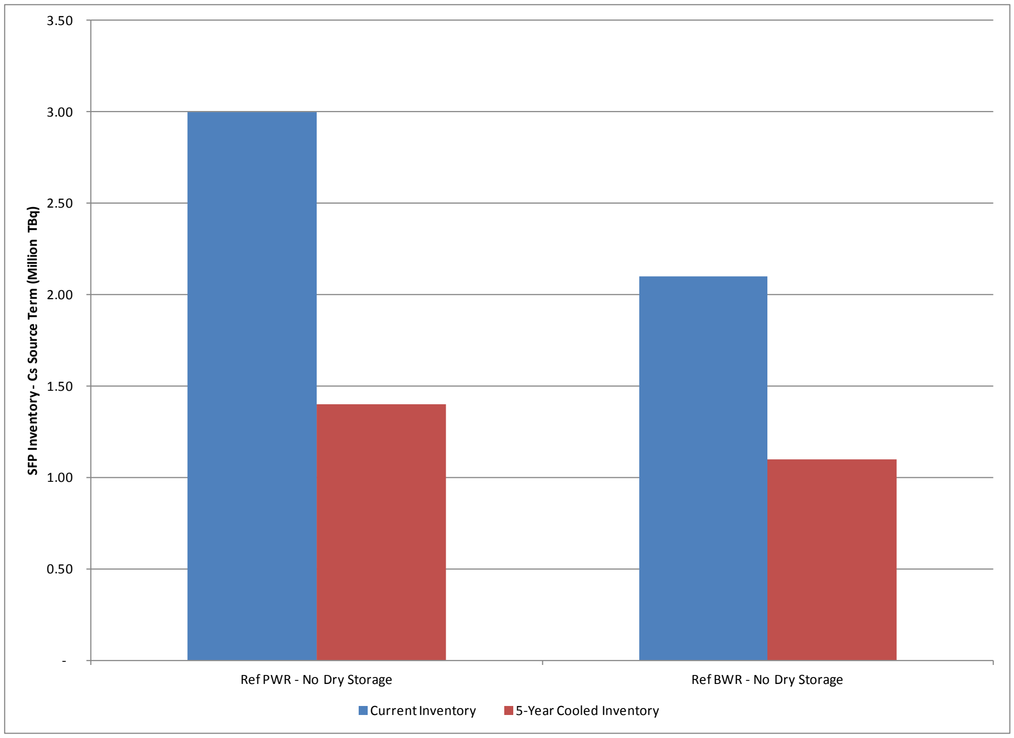

Figure 3-2
SFP Inventory Cesium Source Term for Reference PWR and PWR

Note that these values should be considered to be generic estimates as noted in the introduction to Section 2. Actual decay heat and Cs source terms for SNF will be dependent upon the specific fuel design, initial enrichment, burnup, and operating history. Individual SNF assemblies may have decay heat and Cs source terms that are higher or lower than those used in this report due to the specific characteristics of the SNF assemblies. Other nuclear power plants would have results that are specific to an individual plant's SFP inventory, including the specific fuel designs associated with the SNF, and the specific burnups, operating histories, and cooling times for the SNF assemblies in a plant's SFP.

3.2 Base Case - Dry Storage Requirements and Costs For Representative PWR, BWR and New Plant

3.2.1 Dry Storage Requirements for Representative PWR, BWR and New Plant

In the Base Case analysis of dry storage requirements and costs for representative PWR, BWR and new plant, EPRI assumes that SNF is loaded into dry storage as needed to maintain FCR capacity in the SFP. Table 3-2 summarizes the dry storage requirements for the representative PWR, BWR and new plant. These dry storage requirements were calculated using the assumptions discussed in Section 3.1.

Table 3-2
Base Case Dry Storage Requirements for Representative PWR, BWR and New Plant

Representative Plant	Year Dry Storage Begins	Total Number of Assemblies Discharged	Assumed DSC Capacity (Assemblies)	DSCs Loaded
PWR	2013	3,060	32	96
BWR	2012	5,300	68	78
New Plant	2045	2,295	32	72

For the representative PWR, dry storage begins in 2013, using a 32-assembly capacity DSC. Assuming that a total of 3,060 assemblies are loaded during 60 years of operation, a total of approximately 96 DSCs are required. For the representative BWR, dry storage begins in 2012, using a 68-assembly capacity DSC. Assuming that a total of 5,300 assemblies are loaded during 60 years of operation, approximately 78 DSCs are required. For the representative new plant, dry storage begins in 2045, using a 32-assembly capacity DSC. Assuming that a total of 2,295 assemblies are loaded during 60 years of operation, a total of approximately 72 DSCs are required.

3.2.2 Base Case: Dry Storage Costs for the Representative PWR, BWR and New Plant

Using the dry storage cost assumptions discussed in Section 2.7, EPRI calculates dry storage costs associated with upfront and incremental DSC capital and loading costs (this includes the amortized upfront capital costs discussed in Section 2.7.1), and annual operating costs during reactor operation and following shutdown for decommissioning. Annual operating costs were calculated through 2099 as discussed in Section 2.7.4. EPRI's analysis does not include the costs to transfer SNF from dry storage to transportation casks for transport offsite and the subsequent ISFSI decommissioning costs since it is not possible to estimate when this may occur.

Table 3-3 summarizes the Base Case costs associated with dry storage for the representative PWR, BWR, and new plant. Costs are calculated in Constant $2012 as well as in NPV $2012. EPRI utilizes two separate real discount rates to show the impact of discounting on the overall costs. For the NPV1 discount rate, EPRI assumes a 9% cost of money and a 3% rate of inflation. This yields a real discount rate of 5.8% for NPV1 scenario. For the NPV2 discount rate, EPRI assumes a 6% cost of money and a 2.5% discount rate. This yields a real discount rate of 3.4% for the NPV2 scenario [OMB 2012].

Table 3-3
Base Case Dry Storage Costs for Representative PWR, BWR and New Plant, 2012 to 2099

Representative Plant	Dry Storage Costs (Millions $)		
	Dry Storage Costs (Constant $2012)	**NPV1 Scenario Real Discount Rate: 5.8%**	**NPV2 Scenario Real Discount Rate: 3.4%**
PWR			
Upfront and Incremental Costs	$187	$ 64	$ 95
Operating Costs	$420	$ 41	$ 90
Total Costs	**$607**	**$105**	**$185**
BWR			
Upfront and Incremental Costs	$152	$ 66	$ 88
Operating Costs	$436	$ 46	$ 98
Total Costs	**$588**	**$112**	**$186**
New Plant			
Upfront and Incremental Costs	$140	$ 6	$20
Operating Costs	$179	$ 5	$19
Total Costs	**$319**	**$11**	**$39**

For the representative PWR, dry storage upfront and incremental costs are $187 million, operating costs are $420 million, and total costs are $607 million (Constant $2012). Under the NPV1 scenario, total costs are $105 million (NPV1 $2012), assuming a real discount rate of 5.8%. Under the NPV2 scenario, total costs are $185 million (NPV2 $2012) for the representative PWR, assuming a real discount rate of 3.4%. Higher real discount rates results in lower NPV costs, as shown in Table 3-3. These costs are lower than calculated in EPRI 2010b due to the fact that the representative PWR in that report was a two-unit PWR. EPRI assumes a single PWR in this report in order to make a more direct comparison of total costs between the three representative nuclear power plants.

For the representative BWR, dry storage upfront and incremental costs are $152 million, operating costs are $436 million, and total costs are $588 million (Constant $2012). Operating costs are higher than those for the representative PWR due to the fact that the representative BWR reaches the end of its operating license at an earlier date (and therefore has more years of post-shutdown operating costs). These costs are higher than calculated in EPRI 2010b due to this report using 2012$ instead of 2010$ as well as the use of higher dry storage operating costs in this report. Under the NPV1 scenario, total costs are $112 million (NPV1 $2012). Under the NPV2 scenario, total costs are $186 million (NPV2 $2012) for the representative BWR.

For the representative new plant, dry storage upfront and incremental costs are $140 million, operating costs are $179 million, and total costs are $319 million (Constant $2012). Operating costs are lower than both the representative PWR and BWR due to the fact that the representative new plant reaches the end of its operating license in 2077 and has fewer years of post-shutdown operating costs. Under the NPV1 scenario, total costs are $11 million (NPV1 $2012). Under the NPV2 scenario, total costs are $39 million (NPV2 $2012) for the representative PWR. The costs associated with NPV1 and NPV2 scenarios are much lower than the Constant $2012 costs because the representative new plant does not begin dry storage until 2045 and all of the costs associated with dry storage are discounted significantly.

3.3 Case 2 - 10-Year Accelerated Transfer of SNF Case – Dry Storage Requirements and Costs for Representative PWR, BWR and New Plant

3.3.1 Case 2 - Dry Storage Requirements for Representative PWR, BWR, and New Plant

In Case 2, EPRI assumes that existing five-year cooled SNF inventories are transferred to dry storage over a ten-year period, 2015 to 2024. In the analysis of dry storage requirements and costs for a representative PWR, BWR and new plant, EPRI assumes that during the period 2012 to 2014, SNF is transferred to dry storage as required to maintain FCR using the same unit costs assumed in the Base Case. During the period 2015 to 2024, all SNF that has been cooled for five years is also transferred to dry storage. Most SFPs will have several hundred to several thousand assemblies that have been cooled for at least five-years by 2015. EPRI assumes that the SNF inventory as of 2010 (this includes the entire pool inventory of SNF that will have been cooled for at least five years by 2015) will be transferred to dry storage over a ten-year period (2015 to 2024). In addition, beginning in 2016, all SNF that has been cooled for five-years is transferred to dry storage (for example, SNF discharged in 2011 would be transferred to dry storage in 2016, etc.).

EPRI's analysis assumes that during the period 2012 to 2024, the representative PWR and BWR load DSCs that have the same capacities assumed in the Base Case. That is, the representative PWR loads SNF into DSCs with a capacity of 32 PWR assemblies and the representative BWR loads SNF into DSCs with capacities of 68 BWR assemblies. As discussed in Section 2.2.1, by approximately 2020, the industry average discharge burnups will reach 55 GWd/MTU and 48 GWd/MTU for PWR SNF for BWR SNF, respectively. Assuming that all SNF discharged in 2020 and later have achieved these discharge burnups, transferring only five-year cooled SNF into dry storage may require the use of lower-capacity DSCs in order to load a full cask with all high decay heat assemblies, as discussed in Section 2.2.2. The impact of the increased cost for the reduced capacity DSCs is accounted for through the cost of additional systems rather than increasing the cost per system.

3.3.1.1 PWR DSC Capacity

The decay heat for a five-year cooled PWR assembly with a discharge exposure of 55 GWd/MTU is approximately 1,500 watts [BSC 2001, DOE 1992]. As shown in Table 2-1, the highest DSC decay heat that has been approved for storage of PWR SNF by the NRC is 47.0 kW for the HI-STORM MPC-37. If a DSC has an approved decay heat limit of 47.0 kW and all of the PWR SNF assemblies to be stored in the system have a decay heat of 1,500 watts (discharge burnup of 55 GWd/MTU and five years of cooling), then only 31 PWR assemblies can be stored in that 37-PWR package (47 kW/1,500 watts). It should be noted that the 47 kW heat load is approved specifically for the HI-STORM MPC-37 package. However, if one 37-PWR capacity design can achieve heat loads of 47 kW, it is possible that other designs could also increase total package heat load with future amendments to DSC CoCs.

In its analysis of the accelerated transfer of five-year cooled SNF in this report, EPRI assumes that all PWR SNF transferred to dry storage beginning in 2025 will be loaded into DSCs with a capacity of 30 PWR assemblies. At the time that EPRI performed the analysis contained in EPRI 2010b, the highest PWR package heat load was 40.8 kW for a NUHOMS 32-PWR system. If this total package heat load were used to load SNF assemblies with decay heat of 1,500 watts per assembly, the package capacity would need to be reduced to 27 assemblies. Since several of the other certified dry storage packages have package decay heat limits that are lower than 47 kW (which would result in PWR DSC capacities that are lower than 30 assemblies), EPRI considers the assumption of using a 30-PWR assembly package to be conservative as it does not overestimate the number of additional dry storage packages that would have to be loaded under Case 2.

It should also be noted that the dry storage vendors are continuing to increase DSC capacity. If nuclear operating companies, that currently utilizing 32-PWR assembly systems, were to move to higher capacity PWR assembly systems in the Base Case, which is a possibility, there would be a larger impact associated with a policy decision to offload SNF inventories that have been cooled for at least five years.

3.3.1.2 BWR DSC Capacity

The decay heat for a five-year cooled BWR assembly with a discharge exposure of 48 GWd/MTU is approximately 480 watts [NRC 1999, DOE 1992]. As shown in Table 2-1, the highest DSC decay heat that has been approved for storage of BWR SNF by the NRC is 46 kW for the HI-STORM FW system. Assuming that a DSC has an approved decay heat limit of 46 kW and all of the BWR SNF assemblies to be stored in the package have a decay heat of 480 watts (discharge burnup of 48 GWd/MTU and five years of cooling), there is no need to reduce the package capacity since a total of 89 five-year cooled assemblies can be loaded into this package. In its analysis of Case 2, EPRI assumes that it is not necessary to reduce the capacity of BWR DSCs in order to store five-year cooled SNF. For the representative BWR, EPRI assumed DSCs with capacities ranging from 61 to 68 BWR assemblies – the same assumption that EPRI makes in its Base Case analysis.

3.3.1.3 Dry Storage Requirements

Table 3-4 summarizes the dry storage requirements for the representative PWR, BWR and new plant in Case 2. These dry storage requirements were calculated using the assumptions discussed above.

Table 3-4
Case 2 - 10-Year Accelerated Transfer of SNF Case, Dry Storage Requirements for Representative PWR, BWR and New Plant

Representative Plant	Year Dry Storage Begins	# Assemblies Discharged	Assumed DSC Capacity (Assemblies)		DSCs Loaded
			2012-2024	2025 +	
PWR	2013	3,060	32	30	99
BWR	2012	5,300	68	68	78
New Plant	2023	2,295	32	30	77

For the representative PWR, dry storage begins in 2013, using a 32-assembly capacity DSC – the same assumption made in the Base Case. Beginning in 2015, the SNF pool inventory that has been cooled for five years is transferred to dry storage as discussed above. By 2020, EPRI assumes that all of the SNF discharged from the representative PWR will have burnups of 55 GWd/MTU. This will result in the need to load 30-PWR assembly DSCs beginning in 2025, as shown in Table 3-4. Due to the reduced DSC capacity, the total number of DSCs that must be loaded increases to 99 DSCs, compared to 96 in the Base Case.

As shown in Table 3-4, for the representative BWR, dry storage begins in 2012, using a 68-assembly capacity DSC – the same assumption made in the Base Case. Beginning in 2015, the SNF pool inventory that has been cooled for five years is transferred to dry storage as discussed above. By 2020, EPRI assumes that all of the SNF discharged from the representative BWR will have burnups of 48 GWd/MTU; however, there is no need to reduce the BWR DSC capacity as discussed above. This results in the representative BWR loading a total of 78 DSCs, the same result as in the Base Case.

For the representative new plant, dry storage begins in 2023, twenty-two years earlier than dry storage begins in the Base Case for the new plant. In 2023 and 2024, EPRI assumes that the representative PWR loads SNF into a 32-PWR assembly DSC. By 2020, EPRI assumes that all of the SNF discharged from the representative new Plant will have burnups of 55 GWd/MTU. This will result in the need to load 30-assembly PWR DSCs beginning in 2025. This results in an increase in the total number of DSCs loaded to 77, compared to 72 in the Base Case for the representative new plant.

3.3.2 Case 2 - Dry Storage Costs for the Representative PWR, BWR, and New Plant

Using the dry storage cost assumptions discussed in Section 2.7, EPRI calculates dry storage costs associated with upfront and incremental cask capital and loading costs, and annual operating costs during reactor operation and following shutdown for decommissioning for Case 2. Annual operating costs were calculated through 2099 as discussed in Section 2.7.4. This analysis does not include the cost associated with transfer of SNF from dry storage to transportation casks for transport offsite or ISFSI decommissioning costs, since it is not possible to estimate when this may occur. As discussed in Section 2.7.2, incremental costs (the costs associated with canisters and concrete overpacks and cask loading) have been adjusted to include fabrication, shielding and loading cost adders to address the expected additional costs associated with the need for increased fabrication capacity, the need for additional shielding in concrete storage overpacks to reduce worker dose, and higher loading costs associated with larger SNF loading campaigns and longer loading campaigns to load high burnup, five-year cooled SNF in ISFSIs.

Table 3-5 summarizes the dry storage costs associated with Case 2, 10-Year Accelerated Transfer of SNF Case for the representative PWR, BWR, and new plant. Costs are calculated in Constant $2012 as well as in NPV $2012. EPRI utilizes two separate real discount rates to show the impact of discounting on the overall costs, as discussed in Section 3.2. Also shown for comparison purposes in Table 3-5 are the results from Table 3-3, the Base Case dry storage costs and for Case 3.

For the Case 2 representative PWR, dry storage upfront and incremental costs are $204 million, operating costs are $420 million, and total costs are $624 million (Constant $2012). The operating costs for the representative PWR are the same as those for the Base Case, since dry storage begins in the same year in both cases. Under the NPV1 scenario, total costs are $145 million (NPV1 $2012), $40 million more than the Base Case. Under the NPV2 scenario, total costs are $224 million (NPV2 $2012) for the representative PWR, $39 million more than the Base Case. The increase in costs for the two NPV scenarios is a result of DSCs being loaded earlier than in the Base Case, the need to load additional DSCs in Case 2, and the application of cost adders discussed above.

For the representative BWR, dry storage upfront and incremental costs are $160 million, operating costs are $436 million, and total costs are $596 million (Constant $2012). Although the same number of DSCs are loaded in the Base Case and Case 2, the incremental costs are higher due to the application of cost adders for shielding, fabrication and loading costs as discussed in Section 2.7.2.2. Under the NPV1 scenario, total costs are $137 million (NPV1 $2012), $25 million more than the costs for the Base Case. Under the NPV2 scenario, total costs are $210 million (NPV2 $2012), $24 million more than the Base Case. The cost increases in the two NPV cases for the representative BWR are due to DSCs being loaded at earlier dates than in the Base Case (increasing the NPV cost) as well as the application of cost adders discussed above.

For the Case 2 representative new plant, dry storage upfront and incremental costs are $157 million, operating costs are $203 million, and total costs are $360 million (Constant $2012). The incremental costs and the operating costs are $41 million higher than the Base Case costs for the representative new plant due to the need to load additional DSCs, the application of cost adders, and because dry storage begins 22 years earlier that in the Base Case. Under the NPV1 scenario, total costs are $38 million (NPV1 $2012), $27 million more than in the Base Case for the representative new plant. Under the NPV2 scenario, total costs are $80 million (NPV2 $2012), $41 million more than in the Base Case for the representative new plant.

3.4 Case 3 - 15-Year Accelerated Transfer of SNF Case – Dry Storage Requirements and Costs for Representative PWR, BWR and New Plant

3.4.1 Case 3 - Dry Storage Requirements for Representative PWR, BWR, and New Plant

In Case 3, EPRI assumes that existing five-year cooled SNF inventories are transferred to dry storage over a 15-year period, 2015 to 2029. In the analysis of dry storage requirements and costs for representative PWR, BWR and new plant, EPRI assumes that during the period 2012 to 2014, SNF is transferred to dry storage as required to maintain FCR, assuming the same unit costs assumed in the Base Case. During the period 2015 to 2029, all SNF that has been cooled for five years is also transferred to dry storage. Most SFPs will have several hundred to several thousand assemblies that have been cooled for at least five-years by 2015. EPRI assumes that the SNF inventory as of 2010 (this includes the entire pool inventory of SNF that will have been cooled for at least five years by 2015) will be transferred to dry storage over a ten-year period (2015 to 2029). In addition, beginning in 2016, all SNF that has been cooled for five-years is transferred to dry storage (for example, SNF discharged in 2011 would be transferred to dry storage in 2016, etc.).

EPRI's analysis assumes that during the period 2012 to 2024, the representative PWR and BWR load DSCs that have the same capacities assumed in the Base Case. That is, the representative PWR loads SNF into 32-assembly PWR DSCs and the representative BWR loads SNF into 68-assembly BWR DSCs. Beginning in 2025, the representative PWR and representative New Plant load 30-assembly PWR systems as discussed in Section 3.3.1. The representative BWR continues to load 68-assembly BWR systems in 2025. The dry storage requirements for the representative PWR, BWR and new plant are the same in Case 2 and Case 3, presented in Table 3-4. The representative PWR must load 99 DSCs; the representative BWR loads 78 DSCs; and the representative new plant loads 77 DSCs.

3.4.2 Case 3 - Dry Storage Costs for the Representative PWR, BWR, and New Plant

Using the dry storage cost assumptions discussed in Section 2.7, EPRI calculates dry storage costs associated with upfront and incremental DSC capital and loading costs, and annual operating costs during reactor operation and following shutdown for decommissioning for Case 3, 15-Year Accelerated Transfer of SNF Case. Annual operating costs were calculated through 2099 as discussed in Section 2.7.4. This analysis does not include the cost associated with transfer of SNF from dry storage to transportation casks for transport offsite or ISFSI decommissioning costs, since it is not possible to estimate when this may occur.

Table 3-5 summarizes the dry storage costs associated with Case 3 for the representative PWR, BWR, and new plant. Costs are calculated in Constant $2012 as well as in NPV $2012. EPRI utilizes two separate real discount rates to show the impact of discounting on the overall costs, as discussed in Section 3.2. Also shown for comparison purposes in Table 3-5 are the results from the Base Case and Case 2 cost analysis discussed in the prior sections.

For the Case 3 representative PWR, dry storage upfront and incremental costs are $204 million, operating costs are $420 million, and total costs are $624 million (Constant $2012). These are the same costs as Case 2 since the same number of casks are being loaded – they are just loaded over a different time period. The operating costs for the representative PWR are the same as those for the Base Case, since dry storage begins in the same year in both cases. Under the NPV1 scenario, total costs are $139 million (NPV1 $2012), $34 million more than the Base Case. Under the NPV2 scenario, total costs are $220 million (NPV2 $2012) for the representative PWR, $35 million more than the Base Case. The increase in costs for the two NPV scenarios is a result of additional DSCs being loaded earlier than in the Base Case, the need to load additional DSCs in Case 3, and the application of cost adders discussed above.

For the Case 3 representative BWR, dry storage upfront and incremental costs are $160 million, operating costs are $436 million, and total costs are $596 million (Constant $2012). Although the same number of DSCs are loaded in the Base Case and Case 3, the incremental costs are higher due to the application of cost adders for shielding, fabrication and loading costs as discussed in Section 2.7.2.2. Under the NPV1 scenario, total costs are $137 million (NPV1 $2012), $25 million more than the costs for the Base Case. Under the NPV2 scenario, total costs are $210 million (NPV2 $2012), $24 million more than the Base Case. The cost increases in the two NPV cases for the representative BWR are due to DSCs being loaded at earlier dates than in the Base Case (increasing the NPV cost) as well as the application of cost adders discussed above. There were minor differences between the overall costs in Case 2 and Case 3 for the Representative BWR due to the timing of when DSCs are loaded in each case. However the differences in the NPV costs were minor and cannot be identified when rounding to the nearest million dollars.

For the Case 3 representative new plant, dry storage upfront and incremental costs are $157 million, operating costs are $203 million, and total costs are $360 million (Constant $2012). The incremental costs and the operating costs are $41 million higher than the Base Case costs for the representative new plant due to the need to load additional DSCs, the application of cost adders, and because dry storage begins 22 years earlier that in the Base Case. Under the NPV1 scenario, total costs are $38 million (NPV1 $2012), $27 million more than in the Base Case for the representative new plant. Under the NPV2 scenario, total costs are $80 million (NPV2 $2012), $41 million more than in the Base Case for the representative new plant. There were minor differences between the overall costs in Case 2 and Case 3 for the representative new plant due to the timing of when DSCs are loaded in each case. However the differences in the NPV costs were minor and cannot be identified when rounding to the nearest million dollars.

Table 3-5
Base Case, Case 2, and Case 3 - Dry Storage Costs for Representative PWR, BWR and New Plant

	Dry Storage Costs (Constant $2012)	NPV1 Scenario Real Discount Rate: 5.8%	NPV2 Scenario Real Discount Rate: 3.4%
Base Case Dry Storage Costs (Section 3.2.2)			
PWR **Upfront and Incremental Costs** **Operating Costs** **Total Costs**	$187 $420 **$607**	$ 64 $ 41 **$105**	$ 95 $ 90 **$185**
BWR **Upfront and Incremental Costs** **Operating Costs** **Total Costs**	$152 $436 **$588**	$ 66 $ 46 **$112**	$ 88 $ 98 **$186**
New Plant **Upfront and Incremental Costs** **Operating Costs** **Total Costs**	$140 $179 **$319**	$ 6 $ 5 **$11**	$20 $19 **$39**

Table 3-5 (continued)
Base Case, Case 2, and Case 3 - Dry Storage Costs for Representative PWR, BWR and New Plant

	Dry Storage Costs (Constant $2012)	NPV1 Scenario Real Discount Rate: 5.8%	NPV2 Scenario Real Discount Rate: 3.4%
Case 2 Dry Storage Costs (Section 3.3.2)			
PWR			
Upfront and Incremental Costs	$204	$104	$134
Operating Costs	$420	$ 41	$ 90
Total Costs	**$624**	**$145**	**$224**
BWR			
Upfront and Incremental Costs	$160	$ 91	$112
Operating Costs	$436	$ 46	$ 98
Total Costs	**$596**	**$137**	**$210**
New Plant			
Upfront and Incremental Costs	$157	$26	$49
Operating Costs	$203	$12	$31
Total Costs	**$360**	**$38**	**$80**
Case 3 Dry Storage Costs (Section 3.4.2)			
PWR			
Upfront and Incremental Costs	$204	$98	$130
Operating Costs	$420	$ 41	$ 90
Total Costs	**$624**	**$139**	**$220**
BWR			
Upfront and Incremental Costs	$160	$ 91	$ 112
Operating Costs	$436	$ 46	$ 98
Total Costs	**$596**	**$137**	**$210**
New Plant			
Upfront and Incremental Costs	$157	$26	$49
Operating Costs	$203	$12	$31
Total Costs	**$360**	**$38**	**$80**

3.5 Estimate of Radiological Impacts to Workers for the Representative PWR, BWR and New Plant

As discussed in Section 2.8, there are radiological impacts associated with dry storage of SNF at reactor sites including worker doses during DSC loading and handling activities; worker dose associated with ISFSI operations, maintenance, and surveillance activities; and additional ISFSI construction after SNF has already been loaded at the ISFSI. EPRI has estimated the radiological impacts to workers associated with dry storage at the representative PWR, BWR and new plant using the dry storage requirements presented in Section 3.2 for the Base Case, Section 3.3 for Case 2, 10-Year Accelerated Transfer of SNF from pool storage to dry storage, and Section 3.4 for Case 3, 15-Year Accelerated Transfer of SNF.

Table 3-6 summarizes the radiological impacts to workers for the representative PWR, BWR and new plant under the Base Case, Case 2 and Case 3 over the period 2011 to 2099. Using the assumptions discussed in Section 2.8, EPRI assumes that the worker dose associated with loading operations for a DSC is 400 person-mrem per DSC loaded in the Base Case. This dose rate is also utilized in Case 2 and Case 3 from 2011 to 2024. After 2025, EPRI assumes that the only SNF available for transfer to dry storage will be high burnup, 5 year cooled SNF, which will result in higher loading doses from 2025 forward in Case 2 and Case 3. In Case 2 and Case 3, EPRI assumes that the cask loading dose rate will increase to 750 mrem per DSC beginning in 2025 when only high burnup, five-year cooled SNF is loaded into dry storage.

EPRI assumes an annual dose of 1,500 person-mrem per year per site for ISFSI operations and maintenance and an additional 120 person-mrem per year per site for ISFSI inspection and security surveillance activities. EPRI assumes that the worker dose associated with construction of additional storage capacity and expansion of an operational ISFSI will incur an additional 170 person-mrem for each additional DSC loaded at an ISFSI site [EPRI 2008]. As discussed in Section 2.8, EPRI did not assume increases in these ISFSI operations and maintenance dose rates since EPRI's analysis assumes that additional shielding will be provided by the concrete storage casks in order to offset the increased dose rates.

Under these assumptions for the Base Case, the estimated worker dose for the representative PWR over the period 2011 to 2099 includes 38 person-rem for DSC loading operations, 141 person-rem for annual maintenance and inspection activities, and 16 person-rem for construction of additional dry storage capacity during ISFSI operations for a total worker radiation dose of 195 person-rem. Under Case 2 in which five-year cooled SNF inventories are transferred to dry storage over the period 2015 to 2024, the estimated worker dose of the representative PWR includes an estimated 54 person rem for DSC loading operations, 141 person-rem for annual maintenance and inspection activities, and 16 person-rem for construction of additional dry storage capacity during ISFSI operations. Total worker radiation dose for this case is 211 person-rem. The worker radiation dose associated with DSC loading for Case 2 are higher than the Base Case due to the need to load additional DSCs and the increased DSC loading dose rates beginning in 2025. Under Case 3 in which five-year cooled SNF inventories are transferred to dry storage over the period 2015 to 2029, the estimated worker dose of the representative PWR includes an estimated 59 person rem for DSC loading operations, 141 person-rem for annual maintenance and inspection activities, and 16 person-rem for construction of additional dry storage capacity during ISFSI operations. Total work radiation dose for this case is 216 person-rem. The worker radiation doses for Case 3 are higher than those for Case 2 due to more systems being loaded after 2025 when the dose rate is assumed to increase to 750 mrem per package loaded.

The estimated worker dose for the representative BWR Base Case over the period 2011 to 2099 includes 31 person-rem for DSC loading operations, 143 person-rem for annual maintenance and inspection activities, and 13 person-rem for construction of additional dry storage capacity during ISFSI operations for a total worker radiation dose of 187 person-rem. Under Case 2 in which five-year cooled SNF inventories are transferred to dry storage over the period 2015 to 2024, the estimated worker dose of the representative BWR includes an estimated 42 person rem for DSC loading operations, 143 person-rem for annual maintenance and inspection activities, and 13 person-rem for construction of additional dry storage capacity during ISFSI operations. Total work radiation dose for this case is 198 person-rem. The worker radiation dose associated with DSC loading for Case 2 are higher than the Base Case due to the increased DSC loading dose rates beginning in 2025. Under Case 3 in which five-year cooled SNF inventories are transferred to dry storage over the period 2015 to 2029, the estimated worker dose of the representative BWR includes an estimated 43 person rem for DSC loading operations, 143 person-rem for annual maintenance and inspection activities, and 13 person-rem for construction of additional dry storage capacity during ISFSI operations. Total worker radiation dose for this case is 199 person-rem, slightly higher than that for Case 2. This is due to more systems being loaded after 2025 when the dose rate is assumed to increase to 750 mrem per package loaded.

The estimated worker dose for the representative new plant Base Case over the period 2011 to 2099 includes 29 person-rem for DSC loading operations, 89 person-rem for annual maintenance and inspection activities, and 12 person-rem for construction of additional dry storage capacity during ISFSI operations for a total worker radiation dose of 130 person-rem. Under Case 2 and Case 3, the estimated worker dose of the representative new plant includes 57 person rem for DSC loading operations, 125 person-rem for annual maintenance and inspection activities, and 13 person-rem for construction of additional dry storage capacity during ISFSI operations. Total work radiation dose for this case is 195 person-rem. Since there are no existing inventories of SNF at the representative new plant in 2015, the timing associated with loading DSCs does not differ between Case 2 and Case 3. The worker radiation dose associated with DSC loading and construction of additional storage capacity for Cases 2 and 3 are higher than the Base Case due to the need to load additional DSCs and the increased DSC loading dose rates beginning in 2025.

Table 3-6
Estimated Radiological Impacts to Workers for the Representative PWR, BWR and New Plant Under the Base Case and the 5-Year Cooled SNF Case, 2011 to 2099 (Person-Rem)

Representative Plant		Base Case	Case 2 10-Year Transfer	Case 3 15-Year Transfer
PWR	DSC Loading	38	54	59
	Annual Maintenance and Inspection	141	141	141
	Construction During ISFSI Operation	16	16	16
	TOTAL	**195**	**211**	**216**
BWR	DSC Loading	31	42	43
	Annual Maintenance and Inspection	143	143	143
	Construction During ISFSI Operation	13	13	13
	TOTAL	**187**	**198**	**199**
New Plant	DSC Loading	29	57	57
	Annual Maintenance and Inspection	89	125	125
	Construction During ISFSI Operation	12	13	13
	TOTAL	**130**	**195**	**195**

Section 4: Industry-Wide Impacts

Using the assumptions described in Section 2, this section summarizes the industry-wide impacts associated with the industry Base Case; Case 2, 10-Year Accelerated Transfer of SNF Case; and Case 3, 15-Year Accelerated Transfer of SNF Case. The underlying assumptions for these cases are the same as those discussed in Section 3 for the representative PWR, BWR and new plant. The industry-wide impacts discussed in this section are based on a plant-by-plant analysis of dry storage requirements, the costs associated with these dry storage requirements, and the radiological impacts to workers associated with dry storage facility activities. The industry-wide impacts are assessed for all currently operating nuclear power plants (including Watts Bar Unit 2 which is expected to begin operation in 2015) and existing shutdown plants. This section also describes other potential impacts associated with a policy decision to transfer all SNF to dry storage once it has cooled for five years.

EPRI did not include new nuclear power plants in this analysis since the number of new plants and operating dates for these new plants is not certain at this time. Instead, EPRI included an assessment of the impacts on a representative new plant in Section 3.

4.1 Dry Storage Requirements

The industry Base Case, assumes that SNF is loaded into DSCs as needed in order to maintain FCR capacity in the SFP. This is the same assumption used to assess the impacts for the representative PWR, BWR and new plant in Section 3.

Case 2, EPRI's 10-Year Accelerated Transfer of SNF Case, assumes that, during the period 2012 to 2014, SNF is transferred to dry storage as required to maintain FCR. Beginning in 2015, all SNF that has been cooled for five years is transferred to dry storage (that is, the SNF pool inventory in 2010). Since the majority of SFPs will have several hundred to several thousand assemblies that are five-year cooled in 2015, EPRI assumes that the SNF inventory as of 2010 (this includes the entire pool inventory of SNF that will be cooled for at least five years by 2015) will be transferred to dry storage over a ten year period (2015 to 2024). Beginning in 2016, all SNF that has been cooled for five years is also transferred to dry storage (for example, SNF discharged in 2011 would be transferred to dry storage in 2016, etc.). These same assumptions were utilized to assess the impacts for the representative PWR, BWR and new plant in Section 3.

Case 3, EPRI's 15-Year Accelerated Transfer of SNF Case, assumes that, during the period 2012 to 2014, SNF is transferred to dry storage as required to maintain FCR. Beginning in 2015, all SNF that has been cooled for five years is transferred to dry storage (that is, the SNF pool inventory in 2010). EPRI assumes that the SNF inventory as of 2010 (this includes the entire pool inventory of SNF that will be cooled for at least five years by 2015) will be transferred to dry storage over a fifteen year period (2015 to 2029). Beginning in 2016, all SNF that has been cooled for five years is also transferred to dry storage (for example, SNF discharged in 2011 would be transferred to dry storage in 2016, etc.).

Table 4-1 summarizes the dry storage requirements calculated by EPRI for the industry Base Case and Cases 2 and 3. A total of 475,600 assemblies are projected to be discharged over sixty years of operation of existing nuclear power plants (including plants that have already shutdown for decommissioning).[16] By the end of 2012, EPRI projects that approximately 1,700 DSCs will have been loaded at nuclear power plants sites. Under the industry Base Case, a total of 10,827 DSCs will be needed to store the entire inventory of SNF for existing nuclear power plants. After 2012 while plants continue to operate, a total of 4,636 DSCs would be loaded at reactor sites in order for the plants to maintain FCR capability and to support continued operation of the plants. EPRI assumes that all SNF will be offloaded from SFPs to dry storage within five years of the existing plants reaching the end of their extended operating licenses. An additional 4,491 DSCs would be needed to offload SNF pool inventories to support plant decommissioning.

Table 4-1
Comparison of SNF Storage Requirements for the Industry Base Case and the Industry 5-Year Cooled SNF Case

Description	Assemblies Discharged	# DSCs Loaded			
		Year-End 2012	During Operation	Post Shutdown	Total
Industry Base Case	475,600	1,700	4,636	4,491	10,827
Case 2: 10-Year Accelerated Transfer of SNF Case		1,700	7,934	1,321	10,955
Case 3: 15-Year Accelerated Transfer of SNF Case		1,700	7,983	1,337	11,020

[16] Projected SNF discharges are calculated using Energy Resources International, Inc.'s SPNTFUEL model.

Under Case 2, a total of 10,955 DSCs will be needed to store the entire inventory of SNF for existing nuclear power plants. This is 128 more DSCs than needed in the industry Base Case. After 2012 while plants continue to operate, a total of 7,934 DSCs would be loaded at reactor sites in order to transfer all SNF to dry storage once it has cooled for five years. A total of 3,298 more DSCs are loaded while plants are operating than needed in the industry Base Case. EPRI assumes that all SNF will be offloaded from SFPs to dry storage within five years of the existing plants reaching the end of their extended operating licenses. A total of 1,321 DSCs would be needed to offload the remaining SNF pool inventories to support plant decommissioning. This is 3,170 fewer DSCs than are loaded after plants shutdown in the industry Base Case due to the reduced SFP inventories that result after offloading the five-year cooled inventories during 2015 to 2014 under Case 2.

Under Case 3, a total of 11,020 DSCs will be needed to store the entire inventory of SNF for existing nuclear power plants. This is 193 more DSCs than needed in the industry Base Case. After 2012 while plants continue to operate, a total of 7,983 DSCs would be loaded at reactor sites in order to transfer all SNF to dry storage once it has cooled for five years. A total of 3,347 more DSCs are loaded while plants are operating than needed in the industry Base Case. EPRI assumes that all SNF will be offloaded from SFPs to dry storage within five years of the existing plants reaching the end of their extended operating licenses. A total of 1,337 DSCs would be needed to offload the remaining SNF pool inventories to support plant decommissioning. This is 3,154 fewer DSCs than are loaded in the industry Base Case after plants shutdown due to the reduced SFP inventories that result after offloading the five-year cooled inventories during 2015 to 2029. A total of 65 additional DSC systems are assumed to be loaded under Case 2 than in Case 3. This is due to EPRI's assumption that PWR DSC capacities will be decreased beginning in 2025. Since there would still be some of the existing SNF inventory being offloaded through 2029, this results in a somewhat higher estimate of the number of DSC systems being loaded in Case 3.

Figure 4-1 shows a comparison of the number of DSCs loaded industry-wide on an annual basis between the industry Base Case and Cases 2 and 3. The cost impact of a large number of DSCs being loaded earlier will be evident in the NPV cost estimates presented in Section 4.2. Under Case 2 and 3, Figure 4-1 clearly shows that more DSCs are loaded through approximately 2025 than in the industry Base Case – this is the result of loading the existing SNF inventories into dry storage during the period 2015 to 2024 in Case 2 and 2015 to 2029 in Case 3.

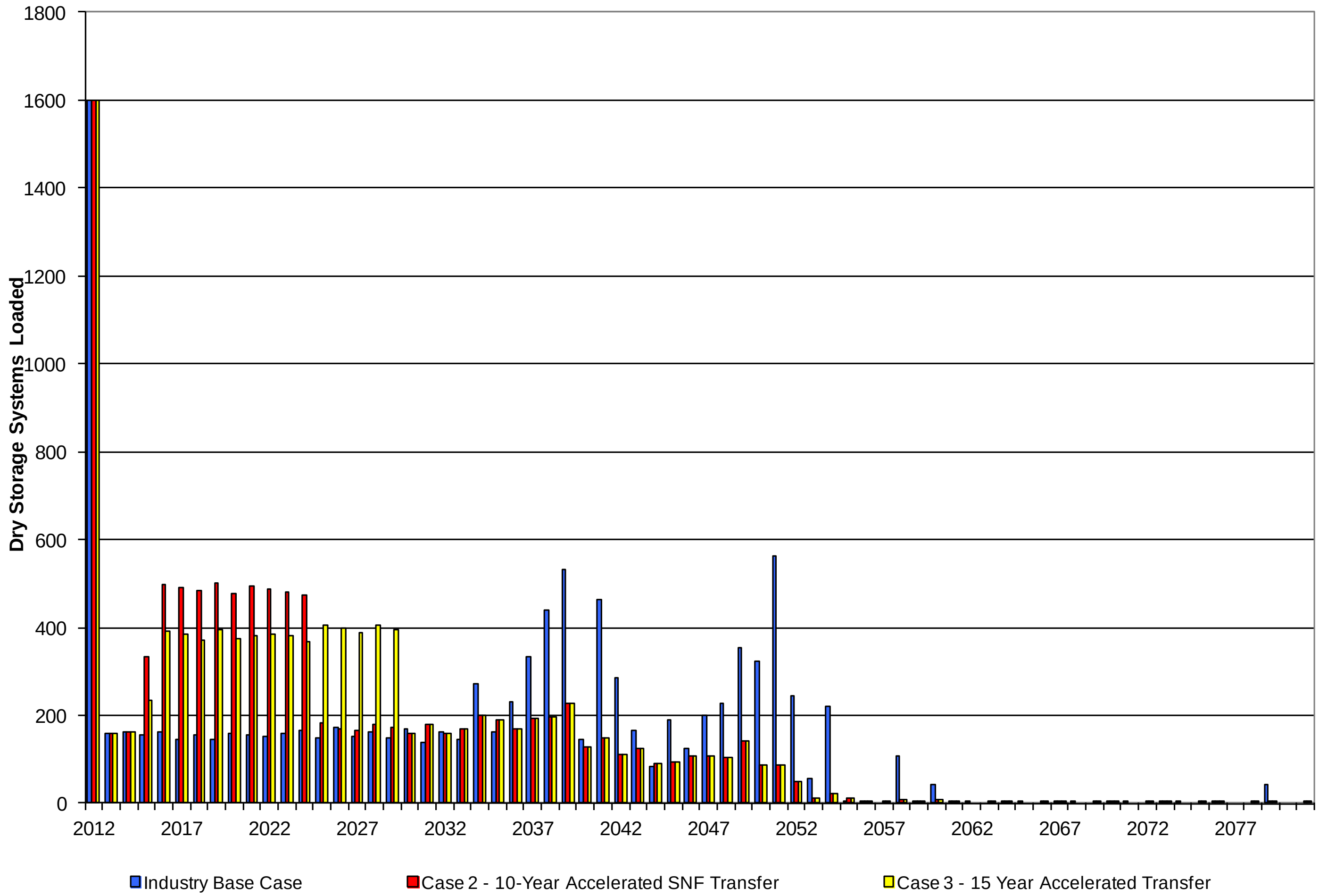

Figure 4-1
Comparison of Annual DSCs Loaded Industry-Wide

Under Case 2, during the period 2015 to 2024, an average of 8 DSCs per year are loaded at reactor sites – with as many as 15-19 per year being loaded at a number of sites annually. Potential impacts associated with these large DSC loading campaigns are discussed in Section 4.5. Under Case 3, during the period 2015 to 2029, an average of 6 DSCs are loaded annually at reactor sites – with some sites loading an annual maximum of 12-16 per year. In comparison, under the industry Base Case, on average nuclear power plant sites load 3-4 DSCs annually – with some sites loading an annual maximum of 7-10 DSCs. These estimates in the industry Base Case assume that nuclear power plants load SNF to dry storage as needed to maintain FCR, and may not reflect companies that choose to conduct large loading campaigns of 8-12 DSCs on a periodic basis.

Figure 4-2 presents the cumulative number of DSCs loaded industry-wide by year under the three cases. This figure shows that not only are DSCs loaded earlier in Case 2 and Case 3, but due to the reduced capacity of DSCs needed to load five-year cooled, high heat load SNF beginning in 2025, a greater number of DSCs are loaded compared to the industry Base Case.

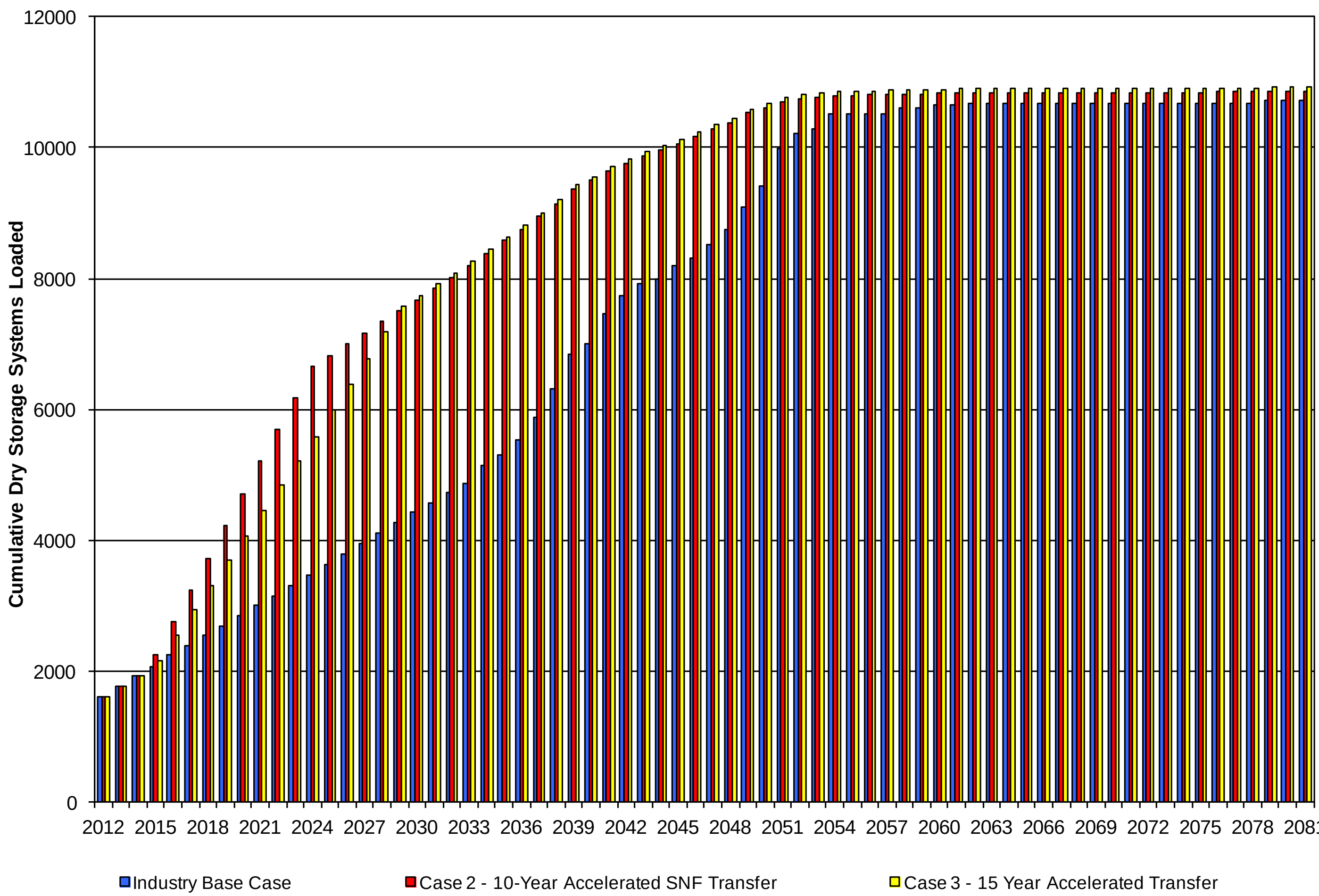

Figure 4-2
Cumulative DSCs Loaded Industry-Wide

4.2 Dry Storage Costs

Using the dry storage cost assumptions discussed in Section 2.7, EPRI calculates dry storage costs associated with upfront and incremental DSC capital and loading costs and annual operating costs during reactor operation and following shutdown for decommissioning. Note that in Case 2 and Case 3, a total of 19 sites are assumed to purchase additional transfer casks to support increased transfer of SNF beginning in 2015 as discussed in Section 2.7.1.2. Annual operating costs were calculated through 2099 as discussed in Section 2.7.4. EPRI does not calculate costs to transfer SNF from dry storage to transportation casks for transport offsite or the costs for ISFSI decommissioning since there is no way to estimate when this may occur.

By approximately 2020, the industry average discharge burnups for PWR SNF will reach approximately 55 GWd/MTU and 48 GWd/MTU for PWR SNF and BWR SNF, respectively. Assuming that all SNF discharged in 2020 and later will achieve these discharge burnups, EPRI assumes that lower capacity DSCs will be needed in order to load five-year cooled high heat load PWR SNF into dry storage beginning in 2025, but there is no capacity reduction for five-year cooled high heat load BWR SNF.

Under Case 2, in which SNF inventories are transferred from pool storage to dry storage over a ten year period (2015 to 2024), EPRI's analysis assumes that during the period 2012 to 2024, all plants load dry storage packages that have the same capacities that EPRI assumes in the industry Base Case. That is, PWRs that are currently loading 24-assembly, 32-assembly, 37-assembly or 40-assembly DSCs will continue to load these systems through 2024 (note that the majority of PWRs are loading 32-assembly DSCs). As discussed in Section 3.3.1, EPRI assumes beginning in 2025, PWR DSC capacity is reduced from 32-PWR assemblies to 30-PWR assemblies in order to load only high-burnup, short cooled SNF. Note this is higher than assumed in EPRI 2010b due to the fact that a higher PWR package heat load has been assumed 47 kW per package, compared to 40.8 kW per package assumed in EPRI 2010b. PWRs that are currently loading 24-PWR DSCs continue to load these systems throughout the Case 2 and Case 3 analysis. BWRs that are currently loading 61-assembly or 68-assembly DSCs continue to load these DSCs without a need to reduce capacity to accommodate five-year cooled SNF with higher heat loads, as discussed in more detail in Section 3.3.1.

Under Case 3, in which SNF inventories are transferred from pool storage to dry storage over a 15-year period (2015 to 2029), EPRI's analysis assumes that during the period 2012 to 2024, all plants load dry storage packages that have the same capacities that EPRI assumes in the industry Base Case. That is, PWRs that are currently loading 24-assembly, 32-assembly, 37-assembly or 40-assembly DSCs will continue to load these systems through 2024 (note that the majority of PWRs are loading 32-assembly DSCs. Beginning in 2025, EPRI assumes that PWRs that were loading 32 to 37-PWR DSCs, begin to load DSCs with a capacity of 30 PWR assemblies. PWRs that are currently loading 24-PWR DSCs continue to do so after 2024. BWRs that are currently loading 61-

assembly or 68-assembly DSCs continue to load these DSCs without a need to reduce capacity to accommodate five-year cooled SNF with higher heat loads, as discussed in more detail in Section 3.3.1.

Table 4-2 summarizes the dry storage costs associated with the industry Base Case, Case 2 and Case 3. Costs are calculated in Constant $2012 as well as in NPV $2012. As done in Section 3, EPRI utilizes two separate real discount rates to show the impact of discounting on the overall costs. For the NPV1 discount rate, EPRI assumes a 9% cost of money and a 3% rate of inflation. This yields a real discount rate of 5.8% for NPV1 scenario. For the NPV2 discount rate, EPRI assumes a 6% cost of money and a 2.5% discount rate. This yields a real discount rate of 3.4% for the NPV2 scenario [OMB 2012]. It should be noted that the costs identified in Table 4-2 are those associated with dry storage upfront and incremental costs and operating costs. This analysis has not monetized the increase in worker dose that would occur under the accelerated transfer cases, Case 2 and Case 3, but simply accounts for the increased dose associated with loading higher heat load SNF into dry storage in Cases 2 and 3.

Table 4-2
Comparison of Industry-Wide Dry Storage Costs

Description	Dry Storage Costs (Billions $)		
	Dry Storage Costs (Constant $2012)	NPV1 Scenario (Real Discount Rate: 5.8%	NPV2 Scenario Real Discount Rate: 3.4%
Industry Base Case			
Upfront and Incremental Costs	18.0	5.8	8.7
Operating Costs	31.5	3.5	7.1
Total Costs	**$49.5**	**$9.3**	$**15.8**
Case 2: 10-Year Transfer Case			
Upfront and Incremental Costs	19.4	9.6	12.4
Operating Costs	31.5	3.6	7.2
Total Costs	**$50.9**	**$13.2**	**$19.6**
Case 3: 15-Year Transfer Case			
Upfront and Incremental Costs	19.6	9.2	12.1
Operating Costs	31.5	3.6	7.2
Total Costs	**$51.1**	**$12.8**	**$19.3**
Increased Costs Associated with Case 2: 10 Year Transfer	**$1.4**	**$3.9**	**$3.8**
Increased Costs Associated with Case 3: 15 Year Transfer	**$1.6**	**$3.5**	**$3.5**

Total costs for the industry Base Case, are $49.5 billion (Constant $2012). This includes upfront and incremental costs of $18 billion and operating cost of $31.5 billion. Under the NPV1 scenario, total costs are $9.3 billion, with upfront and incremental costs of $5.8 billion and operating costs of $3.5 billion. Under NPV2 scenario, total costs for the industry Base Case are $15.8 billion with upfront and incremental costs of $8.7 billion and operating costs of $7.1 billion.

Total costs for Case 2, which assumes that existing SNF inventories will be transferred to dry storage over a 10-year period, are $50.9 billion (Constant $2012), an increase of $1.4 billion above the costs for the industry Base Case. This includes incremental cost of $19.4 billion and operating costs of $31.5 billion. The increase in costs are due to a somewhat larger number of dry storage systems being loaded, cost adders for fabrication, shielding and loading associated with the accelerated transfer of SNF to dry storage, and the purchase of additional transfer casks at 19 sites. Under the NPV1 scenario, total costs are $13.2 billion (NPV1 $2012), approximately $3.9 billion higher than the industry Base Case using NPV1 assumptions. NPV1 includes incremental costs of $9.6 billion and operating costs of $3.6 billion. Under the NPV2 scenario, total costs are $19.6 billion (NPV2 $2012), approximately $3.8 billion higher than the cost of the industry Base Case using NPV2 assumptions. NPV2 includes incremental costs of $12.4 billion and operating costs of $7.2 billion.

Total costs for Case 3, which assumes that existing SNF inventories will be transferred to dry storage over a 15-year period, are $51.1 billion (Constant $2012), an increase of $1.6 billion above the costs for the industry Base Case. This includes incremental cost of $19.6 billion and operating costs of $31.5 billion. The increase in costs are due to a somewhat larger number of dry storage systems being loaded, cost adders for fabrication, shielding and loading associated with the accelerated transfer of SNF to dry storage, and the purchase of additional transfer casks at 19 sites. Under the NPV1 scenario, total costs are $12.8 billion (NPV1 $2012), approximately $3.5 billion higher than the industry Base Case using NPV1 assumptions. NPV1 includes incremental costs of $9.2 billion and operating costs of $3.6 billion. Under the NPV2 scenario, total costs are $19.3 billion (NPV2 $2012), approximately $3.5 billion higher than the cost of the industry Base Case using NPV2 assumptions. NPV2 includes incremental costs of $12.1 billion and operating costs of $7.2 billion.

Figure 4-3 compares the annual costs for the industry Base Case , Case 2 and Case 3 (Constant 2012$). As shown, Case 2 has higher costs during the period 2015 to 2019 and Case 3 during the period 2014 to 2029, the time periods over which existing SNF inventories are assumed to be transferred to dry storage. These higher costs are associated with off-loading all five-year cooled SNF pool inventories to dry storage during these time periods. The higher costs shown for the industry Base Case after 2035 are costs associated with transferring SNF to dry storage after plants reach the end of their extended operating licenses. After approximately 2060, all three scenarios have similar costs, mainly those associated with operations and maintenance at shutdown plant sites.

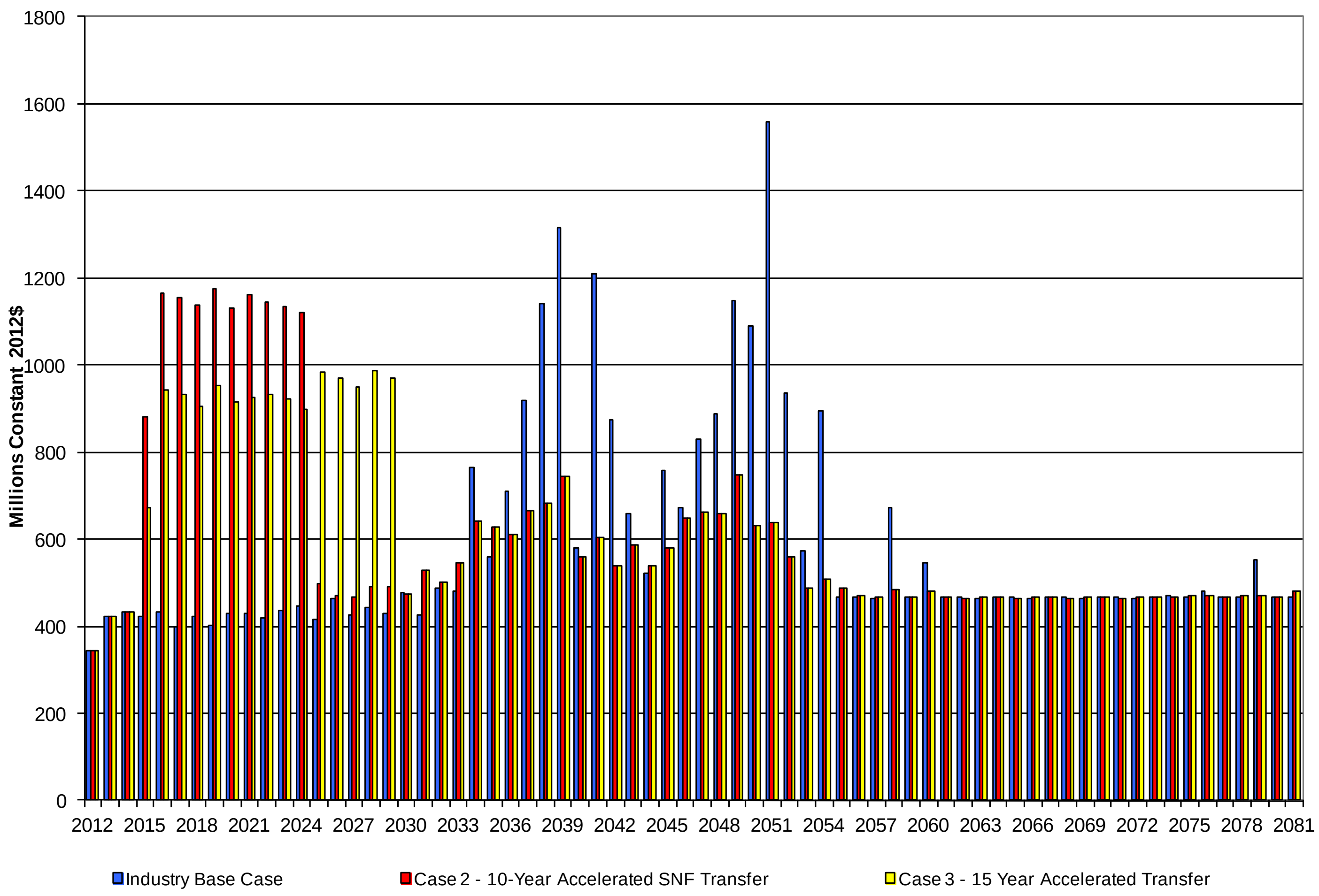

Figure 4-3
Comparison of Industry-Wide Annual Costs (Constant 2012$)

The upfront and incremental costs for Case 2 ($19.4 billion, Constant $2012) are higher than those for industry Base Case ($18.0 billion, Constant $2012) because in Case 2, an additional 128 DSCs are needed; increased costs associated with fabrication of DSCs during the period 2015 to 2024; increased loading costs associated with loading a larger number of DSCs annually and with loading hotter SNF into dry storage; increased shielding provided to concrete storage overpacks beginning in 2025; and the purchase of additional transfer casks at 19 sites in Case 2. Operating costs between the two cases are the same between the industry Base Case and Case 2 since there are only minor differences associated with a limited number of plants having to implement dry storage earlier than needed under the industry Base Case, but these differences do not impact the Constant 2012$ calculation.

The upfront and incremental costs for Case 3 ($19.6 billion, Constant $2012) are higher than those for the industry Base Case ($18.0 billion, Constant $2012) because in Case 3, an additional 193 DSCs are needed; increased costs associated with fabrication of DSCs during the period 2015 to 2029; increased loading costs associated with loading a larger number of DSCs annually and with loading hotter SNF into dry storage; increased shielding provided to concrete storage overpacks beginning in 2025; and the purchase of additional transfer casks at 19 sites in Case 3. Operating costs between the two cases are the same between the industry Base Case and Case 3 since there are only minor differences associated with a limited number of plants having to implement dry storage earlier than needed under the industry Base Case, but these differences do not impact the Constant 2012$ calculation.

As a result of the calculated reduction in PWR DSC capacity only being reduced from a 32-PWR DSC to a 30-PWR DSC, fewer than 200 additional DSCs are needed in Case 2 and Case 3, compared to the requirements in the industry Base Case. Even though there is only a small increase in the number of DSCs loaded in Case 2 and Case 3, there is still a significant cost to the nuclear industry, as a whole, due to the time value of money associated with the accelerated transfer of SNF to dry storage. The results of the two NPV scenarios show that the cost impact associated with transferring a significant quantity of SNF to dry storage on an accelerated schedule compared to the industry Base Case, results in a significant increase in NPV costs. The incremental costs for the industry Base Case for NPV1 are $5.8 billion compared to incremental costs of $9.6 billion for Case 2 and $9.2 billion for Case 3. The NPV difference in incremental costs is $3.9 billion for Case 2 and $3.5 billion for Case 3 compared to the industry Base Case (NPV1 $2012). The annual operating costs between the three cases are similar since the majority of nuclear power plants will have to implement dry storage by 2025, resulting in a relatively small number of plant sites building dry storage earlier in Case 2 and Case 3 than in the industry Base Case. The difference in the upfront and incremental costs for NPV2 is $3.8 billion for Case 2 and $3.5 billion for Case 3, compared to the industry Base Case.

Figure 4-4 presents a comparison of the annual costs for the industry Base Case and Cases 2 and 3 using the discounted costs associated with the NPV2 scenario. Comparing Figure 4-4 to Figure 4-3, it is evident that the Constant $2012 costs that occur in Cases 2 and 3 in Figure 4-3 have a much higher NPV cost than the annual costs for the industry Base Case due to the time value of money. Hence, while the difference in Constant $2012 between the two cases is $1.4 billion (Table 4-3), the NPV cost difference is $3.9 billion for the NPV1 and $3.8 billion for the NPV2 discounted cash flow scenarios.

As discussed in Section 3.3.1, in EPRI's assessment of DSC capacity for Case 2 and Case 3 in which only high burnup, five-year cooled SNF is loaded into DSCs, EPRI determined that the capacity of a 37-PWR DSC with a 47 kW package heat load would have to be reduced to approximately 30-PWR assemblies in order to store only five-year cooled SNF. In the analysis in EPRI 2010b, the PWR system that had the highest heat load at that time was a 32-PWR system with a package heat load of 40.8 kW, showing that DSC capabilities continue to advance. All three dry storage vendors have NRC approval for higher capacity storage systems or are in the process of NRC review of higher capacity storage systems. Thus, while this analysis evaluated the dry storage impacts based on the systems being loaded at most nuclear power plant sites today (e.g., 32-PWR assembly and 61 to 68-BWR assembly systems), it is likely that nuclear operating companies will transition to these higher capacity systems in the future in order to reduce the number of DSCs that need to be loaded. Thus, the evaluation of DSC costs under the industry Base Case are conservative since EPRI's analysis assumes that the DSCs that are currently being loaded or are planned to be loaded at a specific site, are utilized in the future at those sites. Thus, the costs associated with accelerated transfer of SNF in Case 2 and Case 3 are lower than if EPRI had assumed, in the industry Base Case, that some sites will transition to higher capacity DSC systems that are now available or will be available in the future.

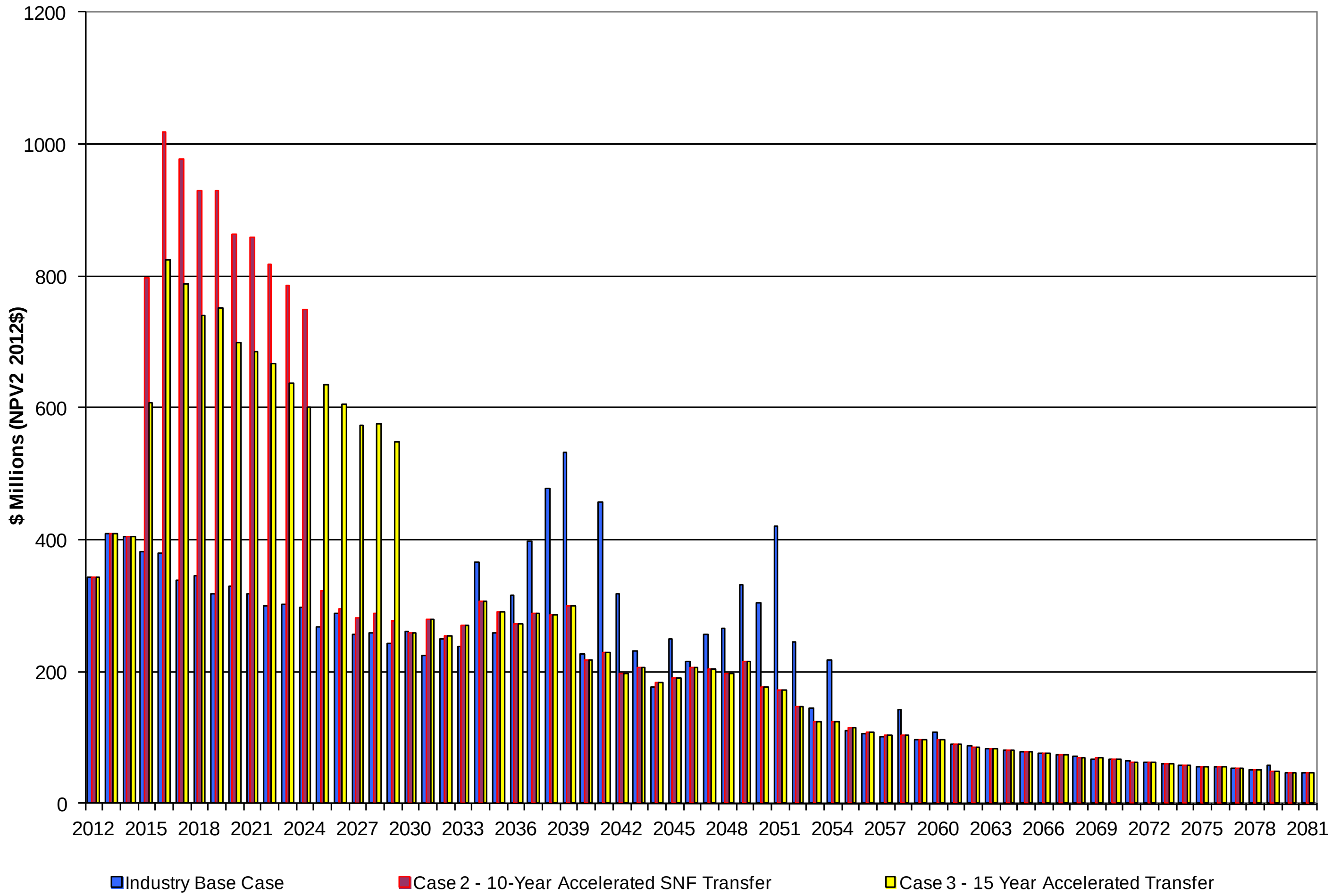

Figure 4-4
Comparison of Industry-Wide Net Present Value Annual Costs (NPV2 2012$)

4.3 Estimated Radiological Impacts to Workers for the Industry Base Case, Case 2, and Case 3

As discussed in Section 2.8, there are radiological impacts associated with dry storage of SNF at reactor sites including worker doses during DSC loading and handling activities; worker dose associated with ISFSI operations, maintenance, and surveillance activities; and additional ISFSI construction after SNF has already been loaded at the ISFSI.

Table 4-3 summarizes the estimated radiological impacts to workers associated with dry storage of SNF under the industry Base Case, Case 2 (10-Year Transfer of SNF Case), and Case 3 (15-Year Transfer of SNF Case). Using the assumptions discussed in Section 2.8, under the industry Base Case, there is an estimated worker dose of 3,750 person-rem associated with DSC loading operations, 10,460 person-rem for annual maintenance and inspection activities, and 1,590 person-rem for construction of additional dry storage capacity during ISFSI operations for a total worker radiation dose of 15,800 person-rem over the period 2012 to 2099. The estimated annual worker dose is several hundred person-rem per year for the industry Base Case, as shown in Figure 4-5.

Table 4-3
Comparison of Industry-Wide Estimated Radiological Impacts, 2011-2099 (Person-Rem)

Description	Industry Base Case	Case 2 10-Year Transfer of SNF	Case 3 15-Year Transfer of SNF
DSC Loading	3,750	5,270	5,690
Annual Maintenance and Inspection	10,460	10,570	10,570
Construction During ISFSI Operation	1,590	1,610	1,630
TOTAL	15,800	17,450	17,890

Under Case 2, there is an estimated worker dose of 5,270 person rem associated with DSC loading operations, 10,570 person-rem for annual maintenance and inspection activities, and 1,610 person-rem for construction of additional dry storage capacity during ISFSI operations. Total worker radiation dose for this case is 17,450 person-rem over the period 2012 to 2099, an increase of 1,650 person-rem compared to the industry Base Case. This is due to more DSCs being loaded in Case 2 compared to the industry Base Case and also due to the assumed increase in the DSC loading dose from 400 mrem per system loaded to 750 mrem per system loaded beginning in 2025 associated with loading only five-year cooled, high heat load SNF into DSC systems. As discussed in Section 2.8, some nuclear operating companies have indicated that loading high burnup SNF into dry storage can increase DSC loading dose as high as 1,000 mrem per package loaded. In this analysis, EPRI assumes that dose to load high burnup, five-year cooled SNF into dry storage beginning in 2025 will be approximately 750 mrem.

Under Case 3, there is an estimated worker dose of 5,690 person rem associated with DSC loading operations, 10,570 person-rem for annual maintenance and inspection activities, and 1,630 person-rem for construction of additional dry storage capacity during ISFSI operations. Total work radiation dose for this case is 17,890 person-rem over the period 2012 to 2099, an increase of 2,090 person-rem compared to the industry Base Case. This is due to more DSCs being loaded in Case 3 compared to the industry Base Case and also due to the assumed increase in the DSC loading dose from 400 mrem per system loaded to 750 mrem per system loaded beginning in 2025. Case 3 doses associated with DSC loading and construction during ISFSI operations are higher than in Case 2 since more DSCs are loaded in Case 3 than in Case 2.

As shown in Figure 4-5, the annual worker radiation doses during the time periods over which the five-year cooled SNF inventories are transferred to dry storage in Case 2 and Case 3 (2015 to 2024 under Case 2 and 2015 to 2029 for Case 3) are significantly higher than those in the industry Base Case. The higher annual worker radiation exposure after 2035 under the industry Base Case is associated with offloading SNF from storage pools to dry storage once plants reach the end of their extended operating licenses. As shown in Table 4-1, fewer DSCs are loaded during the post-shutdown period in Case 2 and Case 3 than in the industry Base Case.

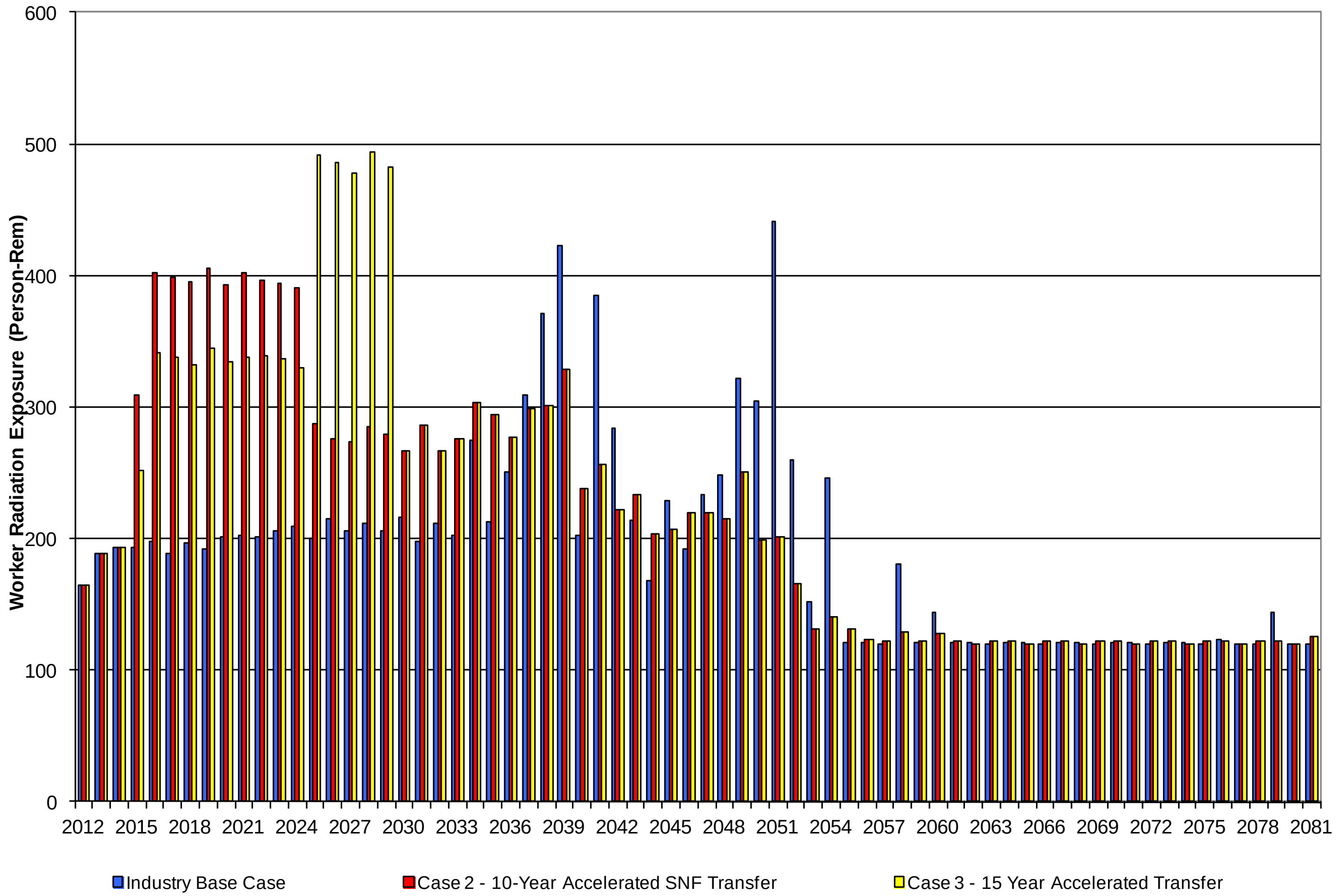

Figure 4-5
Comparison of Industry-Wide Worker Radiation Exposure

4.4 Impact of Accelerated SNF Transfer on SFP Decay Heat and Cesium Inventory

As discussed in Section 1.3, during the emergency at the Fukushima Daiichi nuclear power plant in Japan in March 2011, there were concerns regarding the safety of SNF stored in SFPs at the Fukushima Daiichi site and the potential consequences of a release of radioactive material from one or more spent fuel pools. While it was ultimately determined that the SNF that was stored in the SFPs was safe and did not contribute to the Unit 4 hydrogen explosion [EPRI, 2012], the uncertainty surrounding the SNF condition caused considerable anxiety at that time [NRC 2011a].

In an October 2011 report to the NRC Commissioners regarding prioritization of recommended actions to be taken in response to Fukushima lessons learned, NRC staff recommended additional issues that may warrant regulatory action but which were not included with the NTTF recommendations. One of the issues identified for additional consideration was the transfer of SNF from SFPs to dry storage [NRC 2011c]. NRC is currently considering whether there are "potential benefits of removing spent fuel from pools earlier than planned and achieving lower density storage in the spent fuel pools" [NRC 2011b].

Many nuclear power plants that began loading SNF prior to the mid-2000s, transferred low burnup SNF (e.g., burnup < 45 GWd/MTU), since NRC had not broadly approved DSC CoCs for storage of high burnup SNF (e.g., burnup > 45 GWd/MTU). NRC first approved a dry storage CoC for storage of high burnup SNF in 2002 for HI-STORM 100, Amendment 1. [17] Subsequently, other dry storage vendors also received amendments to CoCs to enable nuclear power plants to load high burnup SNF in other DSC designs. Thus, SNF inventories in SFPs at nuclear power plant sites that implemented dry storage prior to the mid-2000s were only able to transfer low burnup SNF to dry storage. As a result, today many of the sites that implemented dry storage prior to the mid-2000s have SFP inventories with predominantly high burnup SNF.

As fuel assembly burnups increase, the decay heat of the fuel assembly and the Cs inventory in the fuel increase. Following discharge of SNF from the reactor core, the decay heat and Cs inventory of the SNF assembly both decrease with time. As shown in Figure 2-2 and Figure 2-3, SNF assembly decay heat and Cs source term change at different rates as a function of cooling time following discharge of the SNF from the reactor core. EPRI examines the decay heat and Cs source term associated with the SNF inventory from a PWR and a BWR SFP that have been offloading SNF to dry storage for more than ten years. (Note that these are not the same nuclear power plants that serve as the reference PWR and BWR in Section 3, since those units were assumed to have not yet transferred SNF to dry storage). Table 4-4 provides a summary of the results of EPRI's analysis. EPRI estimates the decay heat (watts per assembly) and Cs-134 and Cs-137 source

[17] The NAC UMS was certified in 2000 and specifically addressed high burnup SNF assemblies from Maine Yankee. However, at that time, it was not generic approval to store high burnup SNF from other nuclear power plants that utilized at system.

term (TBq per assembly) for individual fuel assemblies in the SNF inventories associated with the PWR SFP and the BWR SFP, based on the date of discharge of the fuel assembly, SNF assembly discharge burnup, and estimated years of cooling time (to 2012). In calculating the estimated decay heat and Cs source term of SNF inventories, EPRI utilized the same assumptions to estimate SNF decay heat and Cs source term data for PWR and BWR SNF that were utilized in Section 2 to produce the PWR and BWR burnup and Cs inventory versus cooling time curves shown in Figures 2-2 and 2-3 [NRC 1999, DOE 1992, BSC 2001]. Actual SNF assembly discharge dates and discharge burnups are used for SNF discharged through December 2002. For estimated discharges from January 2003 through August 2012, EPRI utilized projected SNF discharges and burnups based on nuclear operating company estimates provided as part of the RW-859 database or based on the methodology described in Section 2.1 if those utility estimates did not extend to August 2012.

As shown in Table 4-4, EPRI examines the SFP decay heat and Cs inventory for a PWR, which began operating in the mid-1970s and began transfer of SNF to dry storage in the mid-1990s. A total of 1,695 PWR assemblies are projected to be discharged from the PWR through August 2012, with 860 assemblies in dry storage and a remaining SFP inventory of 835 assemblies. EPRI estimates a decay heat of 2,010 kW and a Cs inventory of 2.2 million TBq, associated with the 835 assemblies stored in the SFP as of August 2012. If all SNF assemblies that have cooled for five years or greater are transferred to dry storage, a total of 279 SNF assemblies would remain in the SFP, and these assemblies would have a decay heat of 1,540 kW and a Cs inventory of 1.26 million TBq. The SFP inventory, post transfer of five-year cooled SNF, would store only 33% of its original 2012 inventory, but those 279 SNF assemblies would have a decay heat that is 77% of the original 2012 inventory's decay heat, as shown in Figure 4-6, and 57% of the original 2012 inventory's Cs source term, as shown in Figure 4-7. Since SNF assembly decay heat and Cs source term change at different rates as a function of cooling time following discharge of the SNF from the reactor core as shown in Figure 2-2, this results in different percentages of the decay heat and Cs source term for the SNF inventory that remains in the SFP.

EPRI also examines the SFP decay heat and Cs inventory for a BWR that began operating in the mid-1970s and began transfer of SNF to dry storage in the late-1990s. A total of 5,040 BWR assemblies are projected to be discharged from the BWR through 2012, with 1,840 assemblies in dry storage and a remaining SFP inventory of 3,200 assemblies. EPRI estimates a decay heat of 1,900 kW and a Cs source term of 3.5 million TBq, associated with the 3,200 assemblies stored in the SFP as of 2012. If all SNF assemblies that have cooled for five years or greater are transferred to dry storage, a total of 876 SNF assemblies would remain in the SFP, and these assemblies would have a decay heat of an estimated 1,300 kW and a Cs source term of 1.85 million TBq. The SFP inventory, post transfer of five-year cooled SNF, would store only 27% of its original 2012 inventory, but those 876 SNF assemblies would have a decay heat that is 68% of the original 2012 inventory's decay heat, as shown in Figure 4-6, and a Cs inventory that is 53% of the 2012 source term, as shown in Figure 4-7. Since SNF assembly decay heat and Cs source term change at different rates as a function of cooling time following discharge of the SNF from the reactor core as shown in Figure 2-3, this results in different percentages of the decay heat and Cs source term for the SNF inventory that remains in the SFP.

Table 4-4
Summary of SFP Decay Heat and Cesium Source Term – PWR and BWR SFPs, Before and After Accelerated Transfer of 5-Year Cooled SNF to Dry Storage

Parameters	PWR SFP and Inventory	BWR SPF and Inventory
Initial Plant Operation	Mid-1970s	Mid-1970s
Dry Storage Operation	Mid-1990s	Late 1990s
Dry Storage Inventory 2012 (assemblies)	860	1840
SFP Inventory 2012 (assemblies)	835	3200
SFP Inventory 2012 Decay Heat (kilowatts)	2,010	1,900
SFP Inventory 2012 Cs Source Term (Millions TBq)	2.2	3.5
SFP Inventory After 5-Year Cooled SNF Transferred to Dry Storage (assemblies)	279	876
SFP Inventory Decay Heat After 5-Year Cooled SNF Transferred to Dry Storage (kilowatts)	1,540	1,300
SFP Inventory 2012 Cs Source Term (Millions TBq)	1.26	1.85
Post Transfer SNF Inventory Remaining	33%	27%
Post Transfer SNF Decay Heat Remaining	77%	68%
Post Transfer SNF Cs Source Term Remaining	57%	53%

The decay heat of SNF remaining after the accelerated transfer of SNF from pool storage to dry storage will be dependent upon the characteristics of the SNF inventories at individual plants (burnup, discharge date, etc); characteristics of inventories that have been transferred to dry storage (e.g., cooling time and burnup of inventories already in dry storage); initial operation date for dry storage (e.g., before or after high burnup SNF was approved for transfer to dry storage); etc. Nuclear power plants that began operating in the late-1980s or later will tend to have SNF inventories with higher average burnups due to the evolution in fuel assembly design over the prior decade and an industry-wide trend for increasing discharge burnups. Older plants that have not yet transferred SNF to dry storage will have a broader mix of lower burnup, low decay heat SNF along with high burnup, high decay heat SNF. Thus, if there is a policy decision to accelerate the transfer of five-year cooled SNF to dry storage, the residual decay heat and related radioactive source term of SNF assemblies that remain in the SFP after existing inventories are transferred will be plant specific.

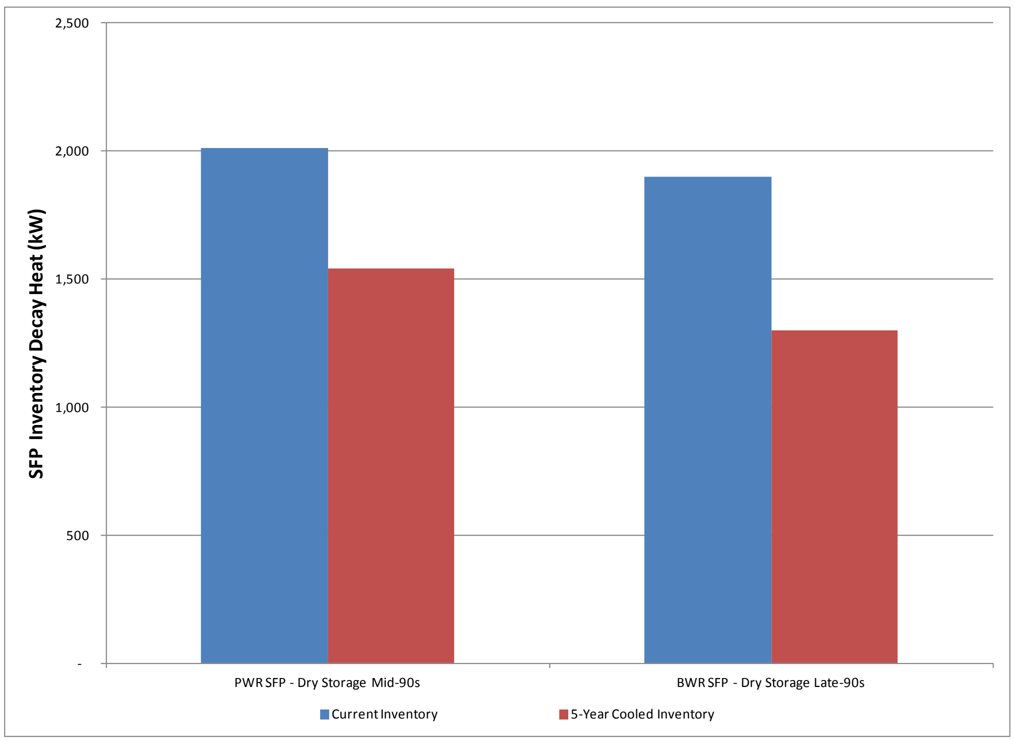

Figure 4-6
SFP Inventory Decay Heat, PWR and BWR SFPs

As shown in Table 4-4, the transfer of 67 - 73% of existing SFP inventories to dry storage, with significant worker dose implications and significant cost to the industry, will not result in a proportional reduction of the decay heat or Cs source term for the inventory remaining in the SFP since the highest burnup, shortest cooled SNF inventories will remain in the SFPs. As shown in Figures 2-2 and 2-3 for PWR and BWR SNF, respectively, the decay heat and Cs source term both decay with time with a faster rate of decay during the first ten years of cooling time after discharge from the reactor core compared to a slower rate of decay thereafter. The decay heat of an SNF assembly declines in accordance with the half-lives of the heat-producing radionuclides in the SNF (including Cs).

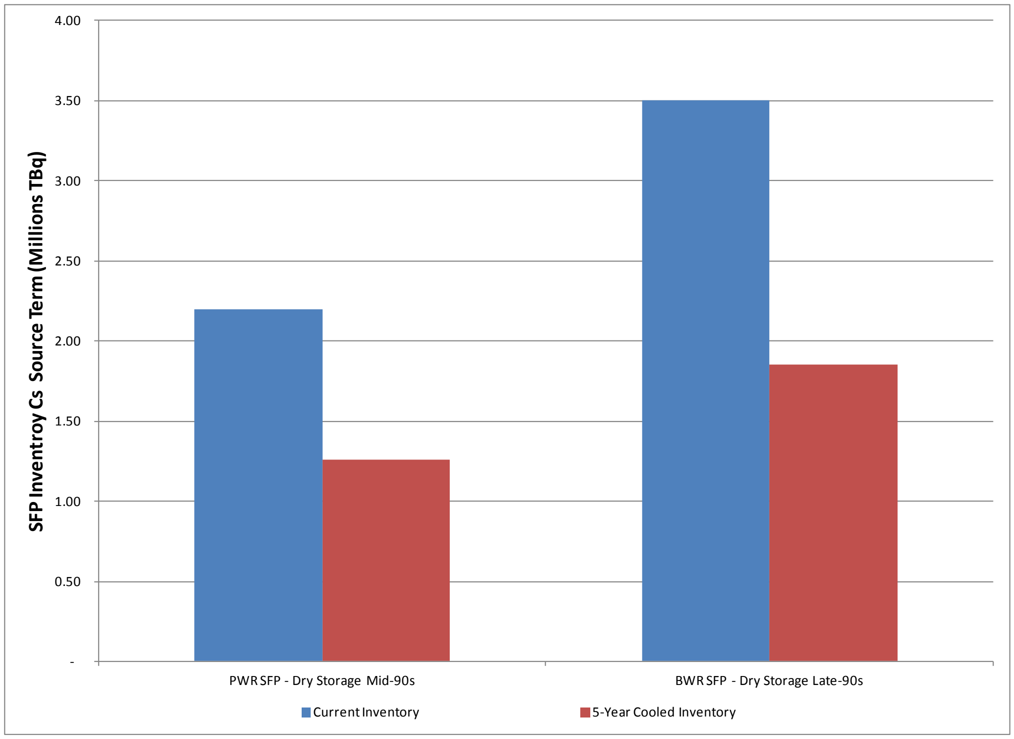

Figure 4-7
SFP Inventory Cesium Source Term, PWR and BWR SFP

Therefore, before a policy decision is made to require the accelerated transfer of existing five-year cooled SNF inventories from SFPs to dry storage, it will be necessary to comprehensively weigh the risks of hypothetical SFP accidents that would result in a release of radioactive material from SNF stored in SFPs against the increase in occupational safety hazards and the increased accident risk associated with accelerated transfer of SNF. Increased occupations safety hazards include: increased occupational radiological hazards such as the increase in worker dose associated with loading a more casks and higher heat load casks under the accelerated transfer case; increased occupational hazards associated with loading high decay heat SNF such as the need to handle thermally hot transfer casks, increase in maintenance staff associated with fatigue rule and subsequent increase in occupational hazards, etc. Increased accident risks associated with accelerated transfer of SNF include the increased accident risk associated with fuel drop or cask drop during cask loading operations. In addition to evaluating safety hazards and risks associated with SFP and dry storage accidents and occupational hazards, such a comprehensive evaluation would also include an evaluation of the costs and benefits associated with continued SFP storage using current industry practices compared to the cost and benefits associated with the accelerated transfer of SNF from pool storage to dry storage.

4.5 Other Impacts Associated with Transfer of 5-Year Cooled SNF

4.5.1 Increase in Annual DSCs Loaded

In Case 2, 10-Year Accelerated Transfer of SNF case, EPRI assumes that the existing SNF pool inventories will be transferred to dry storage over a ten year period from 2015 to 2024. As shown in Figure 4-1, this will result in an average of 440 DSCs being loaded per year from 2015 to 2024 in order to offload the existing SNF pool inventories and to offload additional SNF that reaches five-years of cooling during 2015 to 2024. In Case 3, 15-Year Accelerated Transfer of SNF case, SNF is offloaded to dry storage over a 15-year period from 2015 to 2029. During this time, an average of 380 DSCs are loaded annually. In comparison, under the industry Base Case, an average of 160 DSCs would be loaded per year during the 2015 to 2029 time period. Thus, under Case 2, the number of DSCs loaded annually is approximately 2.75 times higher than in the industry Base Case and under Case 3, the number of DSCs loaded annually is approximately 2.4 times higher than the industry Base Case.

As discussed in Section 2.6, the need to fabricate 400 to 450 more DSCs would require a 2.5- to 3-fold increase in DSC fabrication capability. While domestic and foreign fabricators could eventually ramp up to meet these needs, there will be impacts associated with doing so including increased NRC inspection and oversight requirements for DSC vendors, fabricators and dry storage loading operations. Since the DSC vendors utilize a range of fabrication facilities – from vendor-owned manufacturing to the use of multiple domestic and international facilities – it is difficult to estimate the cost impact on DSC fabrication cost associated with a temporary increase in DSC manufacturing. However, as discussed in Section 2.7.2.2, EPRI assumed that there would be a 20% increase in the labor costs associated with DSC fabrication during the time periods in which existing SNF inventories are being offloaded from SFPs to dry storage in Case 2 and Case 3. Actual cost impacts will be specific to individual fabricators and will depend upon the manufacturing demand for fabricated metal products across broad industries.

4.5.2 Increase in Logistical Complexity of Dry Storage Projects

As discussed in Section 2.4, the ability of nuclear power plant sites to transfer SNF to dry storage will be highly dependent upon: other activities that must take place in the SFP and that impact the use of the cask handling crane; whether multiple units share SFP and cask handling crane resources; outage length; and site specific restrictions on movements of heavy loads. Based on feedback from nuclear operating companies, it appears that a realistic estimate of the time period needed for the transfer of existing inventories of five-year cooled SNF from pool storage to dry storage is between eight and fifteen years. While some plants may be able to make changes to their existing practices associated with transferring SNF to dry storage as discussed in Section 2.4.2, it must be recognized that some sites are currently at their limit to transfer SNF to dry storage. The time frame over which existing SNF inventories can be transferred to dry storage will be site specific. From a logistical basis, a site with multiple units and only one cask handling crane can simply not load as many DSCs as a site with multiple units and separate cask handling cranes. Thus, if there is a policy decision that requires existing SNF inventories that have been cooled for five years or longer be transferred to dry storage, it will not be possible for all nuclear power plant sites to accomplish this in the same time period.

For example, under Case 2, during the period 2015 to 2024, an average of 8 DSCs per year need to be loaded at reactor sites. This is similar to the number of DSCs that some multi-unit sites load annually. However, between 15 to 20 nuclear power plant sites would need to load 15-19 DSCs annually during 2015 to 2024. Under Case 3, during the period 2015 to 2029, an average of 6 DSCs are loaded annually at reactor sites. Between 7 to 10 nuclear power plant sites must load 12-16 DSCs annually during 2015 to 2029. Under the industry Base Case, on average nuclear power plant sites load 3-4 DSCs annually – with some sites loading an annual maximum of 7-10 DSCs. As discussed in more detail in Section 2.4, sites that have shared SFPs and/or shared cask handling cranes may not have the capability to conduct large cask loading campaigns on an annual basis due to other activities or restrictions on using the SFP or cask handling resources.

There are likely to be impacts associated with such large DSC loading campaigns including the need for more management attention to dry storage for longer periods; potential impacts on plant outage schedules or maintenance schedules due to the increased need for maintenance staff to support dry storage operations; availability of equipment to support cask loading operations, such as refuel floor cranes; increased risks associated with fuel handling and cask handling operations; and the need for increased ISFSI licensee oversight of ISFSI construction, DSC fabrication, and dry storage vendor oversight.

In addition to the increased radiological impacts to workers that were discussed previously, there may also be other occupational impacts associated with the accelerated transfer of SNF to dry storage. There may be additional impacts associated with increases in maintenance staff to support dry storage in order to address requirements for Managing Fatigue contained in Subpart I to 10CFR26, Fitness for Duty Programs. Some sites report that under their current dry storage loading campaigns it has been necessary to increase maintenance staff due to the need to comply with the fatigue rule. Thus, increasing the number of DSCs loaded would further increase these requirements.

4.5.3 Dry Storage Technology Advances

As noted in Section 2.3, dry storage vendors have continued to make advances in DSC designs in order to increase system capacities, increase allowable package heat load, broaden the range fuel types or fuel characteristics that can be stored, etc. All three dry storage vendors have NRC approval for higher capacity storage systems (37-PWR and 69- to 89-BWR assembly capacity) or are in the process of NRC review of higher capacity storage systems. If a decision is made to require existing SNF inventories to be offloaded to dry storage, this trend would likely change. As discussed in Section 2.5, DSC designs may need to be amended, or new designs may need to be certified, in order to load dry storage packages with five-year cooled, high burnup SNF on an ongoing basis. This may require advances in the heat transfer capabilities of DSCs either through improved materials or improved methodology; lower DSC capacities, etc.

As noted in Section 4.4, the existing inventories in SFPs will be dependent upon the characteristics of the SNF inventories at individual plants (burnup, discharge date, etc); characteristics of inventories that have been transferred to dry storage (e.g., cooling time and burnup of inventories already in dry storage); initial operation date for dry storage (e.g., before or after high burnup SNF was approved for transfer to dry storage); etc. Nuclear power plants that began operating in the late-1980s or later will tend to have SNF inventories with higher average burnups due to the evolution in fuel assembly design over the prior decade. Older plants that have not yet transferred SNF to dry storage will have a broader mix of lower burnup, low decay heat SNF along with high burnup, high decay heat SNF. As noted in Section 2.2.2, existing DSCs allow regional loading of SNF for both uniform loading of SNF, and regional loading of SNF. However, existing CoCs that allow regional loading of SNF generally have limits not only on maximum SNF burnup and associated heat load, but also on the burnup and heat load associated with certain storage locations in the DSC canister in a regional loading scheme. This broad range of SFP inventories at various nuclear power plant sites may result in the need to amend existing CoCs in order for companies to be able to efficiently offload SNF to dry storage since the approved contents under existing regional loading schemes may not provide sufficient flexibility for DSCs to be fully loaded using existing inventories.

4.5.4 Dry Storage Loading Issues Associated with High Decay Heat SNF

In addition to the possible need for amended or new DSC designs, the storage of high burnup, high decay heat SNF may result in DSC loading issues associated with higher thermal loads. Issues include: an increase in possible hydrogen generation during cask loading; the potential for water thermal expansion; higher package and canister lid temperatures; and increased worker dose rates during cask loading operations. There are also occupational safety issues associated with these higher heat loads and the high temperatures that transfer cask exteriors can reach.

Hydrogen gas generation can occur due to oxidation of aluminum in the canister basket while the canister is filled with water. Additionally, radiolysis of the water in the canister during loading operations can occur in high flux conditions creating additional combustible gases. DSC operating and monitoring procedures include procedures for monitoring for combustible gas concentrations prior to and during canister lid welding operations. One methodology that has been used is to purge the space below the canister lid with inert gas prior to and during lid welding operations to provide additional assurance that flammable gas concentrations will not develop in this space [EPRI 2010a].

There is also an increased potential for thermal expansion of water in the canister containing higher decay heat SNF during welding operations. While some amount of water is typically removed from a loaded canister to allow welding operations to proceed, the amount of water is minimized in order to provide shielding during welding operations. Higher heat loads will require more water to be initially drained to allow for more thermal expansion which may expose irradiated hardware at the top of assemblies, increasing the dose rate and worker dose received. Cask loading procedures have numerous steps and warnings to ensure that a sufficient amount of water is removed to allow room for thermal expansion of the water during welding operations. Several sites have experienced thermal expansion of water with sufficient force to cause thermally hot water to be expelled from the canister [EPRI 2010a].

Increasing the thermal load of a DSC can result in a rapid increase in the temperature of the storage canister lid after the canister has been backfilled with helium. Lid temperatures can be as high as 300°F, presenting personnel safety issues for staff involved in the cask loading operations. This phenomenon can be mitigated through the connection of a supplemental cooling system through the transfer cask annulus prior to helium backfill. In addition, high lid temperatures can also affect load handling equipment such as the slings used to lift the transfer cask. Some sites that are currently loading high heat load DSCs have had to change the type of clothing worn by workers during cask loading operations (for example, to prevent rubber booties or gloves from melting when in contact with the exterior of a hot transfer cask). Higher heat load canisters will also increase cask loading times due to worker comfort and installation of additional cooling equipment, which can result in the need for additional maintenance staff to support cask loading operations due to the implementation of NRC rules regarding worker fatigue.

4.6 DOE Standard Canister

In Fiscal Year (FY) 2012 appropriations, Congressional appropriators directed \$10 million to DOE's Office of Nuclear Energy (DOE-NE), Fuel Cycle Research and Development program, for "development and licensing of standardized transportation, aging, and disposal casks and/or canister." During FY 2012, DOE has started an evaluation of the use of existing dual purpose systems for eventual transportation of SNF from nuclear power plant sites and for possible disposal of SNF without the need for repackaging. However, based on the BRC recommendations that support the development of standardized canisters and a congressionally directed \$10 million in Fiscal Year 2012 to develop standardized canisters, DOE is also expanding its efforts regarding the possible development of standard canisters for transport, aging and eventual disposal. One concept that is under consideration is a "can-in-can" packaging concept that DOE claims would "allow flexibility in used fuel handling" [DOE 2012a] This "can-in-can" concept would entail small canisters with a capacity of 4 PWR to 9 BWR assemblies, or 1 PWR or BWR assembly, depending upon the geologic media used for disposal. For the purposes of storage and/or transportation, these small-capacity "cans" would be stored inside of larger canisters as shown in Figure 4-6.

According to a January 2012 DOE presentation, the disposal of SNF in salt, clay, and crystalline geologic media may require smaller waste package capacities (4 PWR or 9 BWR-assembly capacities) than currently loaded DSCs and deep borehole disposal concepts require substantially smaller packages (1 PWR or BWR assembly per canister [DOE 2012b]. According to DOE, repackaging SNF from existing DSCs (presumably at a DOE facility prior to disposal) would create financial, operational, radiological and regulatory "liabilities and uncertainties." Thus, DOE is investigating options to either modify disposal concepts that are under consideration or to develop "an integrated cask system that can address storage, transportation, and disposal issues."

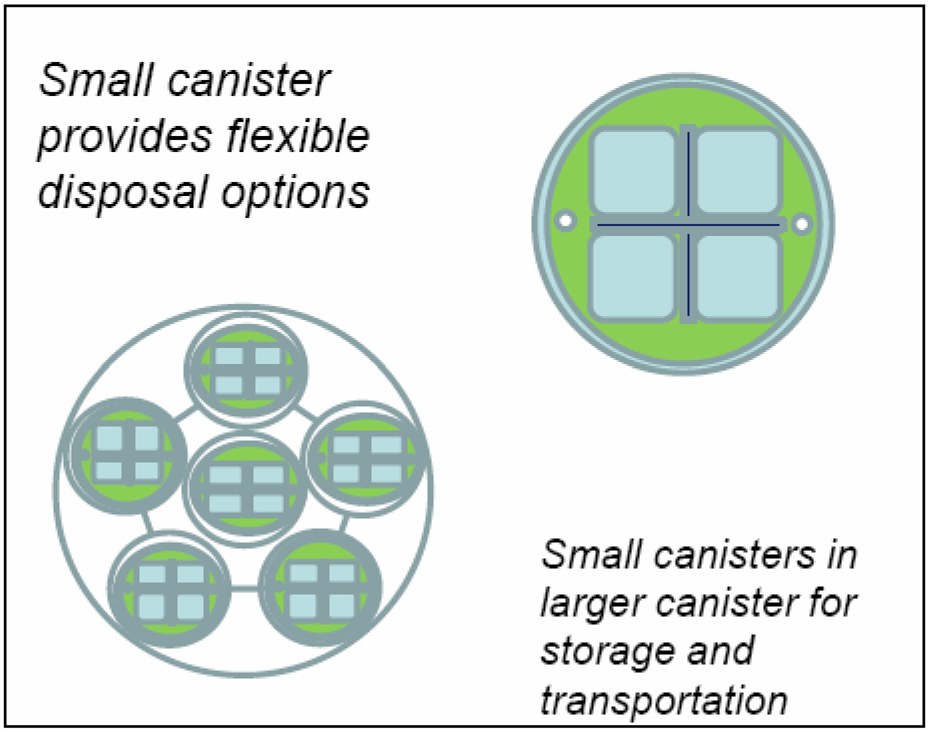

Figure 4-8
U.S. DOE, Can-In-Canister Concept [DOE 2012b]

At this time, it is not clear that a near-term move toward development of a standardized canister for storage, transport and disposal is warranted given that the U.S. does not have a geologic repository site selected, nor is the geologic media for a disposal facility known. As noted above, according to DOE, some geologic media may require smaller package capacities. However until there is path forward in the U.S. toward disposal, it would appear that any effort to develop "standardized" canisters for storage, transport and disposal is premature. The U.S. waste program has already seen several decades of changing plans for packages associated with interim storage, transport and disposal that have all, ultimately, been cancelled after millions of dollars expended – the 1980s DOE Cask System Development Program, the multi-purpose canister (MPC) program of the 1990s, the regional service providers of the early 2000s, and the transport, aging and disposal canister program of the late 2000s.

Aside from the concept of a standardized can-in-can concept being premature at this time, such a system would also create complexity for nuclear power plant operators if the expectation is for these small cans to be loaded with SNF at nuclear power plant sites rather than at a centrally located repackaging facility (that might be part of an interim storage facility or repository). By the end of 2012, approximately 69,500 MTU of SNF, roughly 241,000 assemblies, will be permanently discharged from U.S. nuclear power plants, and SNF will have been loaded into an estimated 1,700 dry storage canisters for onsite storage. An estimated 79% of the DSCs loaded by the end of 2012 will be dual-purpose systems – that is, these systems can be transported from nuclear power plant sites without the need to repackage the SNF. By 2025, an estimated 3,700 DSCs will be loaded and 91% of these systems will be dual-purpose systems. The number of DSCs loaded continues to increase annually thereafter as shown in Figure 4-2. If a move to standardized canister by DOE would result in nuclear operating companies having to repackage these already loaded DSCs, this would result in increased worker dose to open the DSCs, transfer SNF from the existing system into a new standardized can, perform closure operations on the standardized can (including vacuum drying, helium backfill, and welding operations), and then load multiple standardized cans into a larger can (including the possible need for additional vacuum drying, helium backfill, and welding operations) for transport offsite.

As shown in Table 4-5, the total number of fuel assemblies expected to be discharged from existing nuclear power plants is approximately 478,000 assemblies. Assuming an average standardized canister capacity of 6 assemblies (9 BWR or 4 PWR assembly capacity), approximately 79,700 standardized DOE cans would have to be loaded with SNF. As shown in Figure 4-6, one of the can-in-can packaging concepts would load six small cans into a larger can – with a total capacity of 24 PWR assemblies or 36 BWR assemblies. Thus, a further 13,283 larger capacity storage/transport canisters/casks would have to be loaded in order to store and transport the small capacity standard canister more efficiently. Assuming that this can-in-canister concept can be implemented by 2025, DSCs loaded by that date (an estimated 3,700 DSCs) would have to be opened, unloaded and the SNF repackaged in the DOE cans. This would result in an estimated 96,683 packages being handled under the DOE can-in-can concept compared to 10,827 DSCs being loaded under the industry Base Case.

Table 4-5
Comparison of DOE Can-In-Can Concept to Use of Existing DSCs for Dry Storage

	Current DSC for Storage/Transport	**DOE Can-in-Can for Storage/Transport**
Total Number of Fuel Assemblies Discharged	478,000	478,000
DSCs Loaded (Table 4-1, industry Base Case)	10,827	2012: 1,700 2025: 3,700 (Would be opened and unloaded)
DOE Small Cans Loaded	–	79,700
DOE Large Canisters (Storage/Transport)	–	13,283
Total Packages Handled (assuming DSCs only loaded until 2025)	10,827	96,683

While the exact loading sequence and requirements for packages closure associated with loading the small capacity DOE cans that would subsequently be loaded into larger canisters is not known, package loading operations would become increasingly complex and the radiological and non-radiological impacts associated with cask loading operations would increase significantly compared to current industry practice of loading large capacity DSCs.

Loading costs would be expected to increase even more due to the additional operations associated with vacuum drying, backfilling with helium, and welding closed multiple small packages instead of one large package.

There also would be unforeseen logistical issues. For example, at some nuclear power plants, the "real estate" in the cask loading area (floor space for equipment, cask set down areas in cask loading pools and cask decontamination pits, etc.) can be limited. If six small-capacity cans (which EPRI assumes are made of stainless steel and unshielded) are loaded sequentially prior to loading the six small cans into a larger canister for storage/transport, many if not all sites may not have space available in cask loading pools to store the loaded small cans prior to transferring them into the larger packages. Many cask handling cranes are prevented from travelling over the SFP in order to prevent potential accidents associated with the drop of a heavy load over irradiated SNF. Thus, these previously loaded small capacity cans cannot be stored in the spent fuel storage pool at many sites. Therefore, it is not clear that a can-in-canister scheme would be able to be executed at many nuclear power plant sites.

If DOE proceeds with this can-in-can concept and it happens to coincide with a policy decision to offload existing SFP inventories to dry storage, the development time needed for DOE's can-in-can concept would preclude the goal of accelerated offloading. Conversely, if a policy decision were made to require accelerated offloading of SNF to dry storage, this would result in a near term increase in the amount of SNF that would already be loaded into "non-standard" canisters – defeating the purpose of standardization. EPRI would expect that the impacts that it evaluates in this report would increase dramatically if a can-in-can concept were implemented along with a policy decision to offload existing SFP inventories. The time to transfer equivalent quantities of SNF to systems using this can-in-can process would increase dramatically, causing additional scheduling issues for SFP and cask handling crane availability. Worker dose would increase dramatically due to additional loading operations need to load small-capacity cans, and then load the small capacity cans into large cans since one of the highest dose activities during loading is from welding and the amount of welding would drastically increase.

Section 5: Conclusions

Both pool storage and dry storage provide for the safety and security of SNF. SNF has been stored safely in wet storage pools for more than 40 years and in dry storage for more than 25 years. Prior to any policy decisions being made to accelerate the transfer of SNF from pool storage to dry storage, policy makers should ensure that there is a comprehensive assessment of the potential benefits of doing so in comparison to the potential adverse impacts including increased worker radiation hazards, operational risk, impacts on operating plants, and cost associated with the accelerated transfer of SNF from pool storage to dry storage. Increased occupations safety hazards include: increased occupational radiological hazards such as the increase in worker dose associated with loading more casks and higher heat load casks under the accelerated transfer case; increased occupational hazards associated with loading high decay heat SNF such as the need to handle thermally hot transfer casks, increase in maintenance staff associated with fatigue rule and subsequent increase in occupational hazards, etc. Increased accident risks associated with accelerated transfer of SNF include increased accident risk associated with fuel drop or cask drop during cask loading operations. In addition to evaluating safety hazards and risks associated with SFP and dry storage accidents and occupational hazards, such a comprehensive evaluation would also include an evaluation of the costs and benefits associated with continued SFP storage using current industry practices compared to the cost and benefits associated with the accelerated transfer of SNF from pool storage to dry storage.

5.1 Summary of Economic and Radiological Impacts

This study examines the impacts associated with potential policy decisions that may result from the accelerated transfer of five-year cooled SNF from wet storage to dry storage. EPRI examines the cost impacts associated with procurement of DSCs, cask loading operations, dry storage facility construction and/or expansion, and annual operating and maintenance costs. EPRI calculates the impacts for the industry as a whole as well as for a representative PWR, BWR and new plant. The costs are presented in both constant and net-present-value dollars, in order to show the impact associated with the time period over which SNF is transferred into dry storage. EPRI also assesses the radiological impacts to workers associated with transferring SNF from pool storage to dry storage once the SNF has cooled for five years.

5.1.1 Radiological Impacts

As EPRI has shown in this analysis, there would be a significant increase in worker radiation exposure associated with an increase in cask loading operations. As shown in Table 4-3, the estimated radiological impacts to workers associated with Case 2 would increase by 1,650 person-rem, compared to the industry Base Case, if five-year cooled SNF inventories were transferred from SFPs to dry storage over a ten year period (2015 to 2024). Under Case 3, in which five-year cooled SNF would be transferred to dry storage over a 15-year period (2015 to 2029), estimated radiological impacts to workers would increase by 2,090 person-rem. In addition to the increase in radiological impacts, under Case 2, an additional 128 DSCs would be loaded and Under Case 3, an additional 193 DSCs would be loaded compared to the industry Base Case. The need to handle these additional DSCs increases the risks associated with cask handling and with the construction of additional DSCs.

As discussed in Section 2.8, nuclear operating company experience has also shown that loading DSCs with shorter-cooled, high burnup SNF that has higher heat loads and radiation dose can result in increased site dose to workers as well as increased off-site dose. In order to reduce the impacts of increased worker dose and off-site dose, companies may need to employ additional shielding in DSCs or put in place earthen berms around an ISFSI site. While EPRI did not estimate the cost of construction earthen berms or walls, since these types of costs would be highly site dependent, EPRI's cost analysis did assume that there would be additional cost associated with providing additional shielding in concrete storage overpacks.

There will also be a dose to workers associated with the transfer of loaded DSCs from an ISFSI to a transportation cask for transport off site at some time in the future. As noted in Section 2.7.4, EPRI's analysis also does not include the cost to transfer SNF from at-reactor ISFSIs to transportation casks for shipment off site. Due to the uncertainties in the Federal waste management system, it is not possible to determine when SNF will be shipped off site in the future. However, it should be recognized that there will be a radiological impact to workers associated with this activity and the radiological impacts are directly proportional to the number of DSCs loaded.

5.1.2 Economic Impacts

The cost of storing SNF at reactor sites would also increase significantly. As shown in Table 4-2, the NPV cost to transfer existing inventories of five-year cooled SNF from SFPs to dry storage is $3.8 to $3.9 billion for Case 2, in which SNF is transferred over a ten-year period and $3.5 billion under Case 3, in which SNF is transferred over a 15-year period (NPV $2012). EPRI's analysis of incremental costs (the costs associated with canisters and concrete overpacks and cask loading) under Case 2 and Case 3 included fabrication, shielding and loading cost adders to address the expected additional costs associated with the need for increased fabrication capacity, the need for additional shielding in concrete storage overpacks to reduce worker dose, and higher loading costs associated with larger SNF loading campaigns and longer loading campaigns to load high burnup, five-year cooled SNF in ISFSIs. However, as discussed in Section 3 and Section 4, the main factor in the significant economic impacts associated with the accelerated transfer of five-year cooled SNF inventories to dry storage is the time value of money. Accelerating the transfer of large quantities SNF to dry storage by decades, compared to when DSCs would be loaded in the base case, results in significantly higher NPV costs.

As presented in Section 3, the increased NPV cost for a representative PWR would be between $39 and $40 million (NPV2 and NPV1 $2012, respectively) under Case 2 and $34 to $35 million under Case 3 (NPV1 and NPV2 $2012, respectively). The increased NPV costs for a representative BWR would be $24 to $25 million (NPV2 $2012 and NPV1 $2012) under both Case 2 and Case 3, and for a representative new plant would be $27 to $41 million (NPV1 $2012 and NPV2 $2012, respectively) under both Case 2 and Case 3.

EPRI's analysis also does not include the cost to transfer SNF from at-reactor ISFSIs to transportation casks for shipment off site. Due to the uncertainties in the Federal waste management system, it is not possible to determine when SNF will be shipped off site in the future. The costs associated with transfer of SNF from dry storage to transport casks for shipment off site would be proportional to the number of DSCs that must be transferred. The more packages loaded and stored at an ISFSI, the higher the costs will be to transfer this fuel from dry storage to be readied for transport

5.2 Other Potential Impacts

5.2.1 Increase in Annual DSC Requirements

The accelerated transfer of five-year cooled SNF from SFPs to dry storage would result in an average of 380 DSCs (Case 3) to 440 DSCs (Case 2) being loaded annually, compared to the industry Base Case under which an average of 160 DSCs would be loaded annually. This would result in a 2.5 to 3-fold increase in DSC fabrication capability with potential impacts that include an increase NRC inspection and oversight requirements for DSC vendors, fabricators and dry storage loading operations. This increase in fabrication requirements could result in the need to expand fabrication capacity at existing fabricators or to bring new fabricators on line. Discussions with DSC vendors and fabricators indicated that it would take two to three years to bring a new fabrication shop on line and up to production capacity and to meet DSC vendors' quality assurance requirements in order to ensure that quality products will be produced. This includes approximately 12 to 18 months to set up the fabrication shop for production of DSCs including installation of the needed stations, equipment, and fixtures for fabrication of DSC components. Once the equipment is installed and initial production begins, an additional 12 months would be required to ensure that the new fabrication facility procedures and processes are integrated and to bring the dry storage fabrication up to full production capacity.

5.2.2 Increase in Dry Storage Logistical Complexity

As discussed in Section 2.4, the ability of nuclear power plant sites to transfer SNF to dry storage will be highly dependent upon other SFP related activities and activities that require use of the cask handling crane and site specific restrictions regarding movements of heavy loads before and after outages. The time frame over which existing SNF inventories can be transferred to dry storage will be highly site specific. From a logistical basis, a site with multiple units and only one cask handling crane can simply not load as many DSCs as a site with multiple units and separate cask handling cranes. Thus, if there is a policy decision that requires existing SNF inventories that have been cooled for five years or longer be transferred to dry storage, it will not be possible for all nuclear power plant sites to accomplish this in the same time period.

There are likely to be impacts associated with such large DSC loading campaigns including the need for more management attention to dry storage for longer periods; potential impacts on plant outage schedules or maintenance schedules due to the increased need for maintenance staff to support dry storage operations; availability of equipment to support cask loading operations, such as refuel floor cranes; increased risks associated with fuel handling and cask handling operations; and the need for increased ISFSI licensee oversight of ISFSI construction, DSC fabrication, and dry storage vendor oversight.

5.2.3 Dry Storage Loading Issues Associated with High Decay Heat SNF

The storage of high burnup, high decay heat SNF may result in DSC loading issues associated with higher thermal loads. Issues include: an increase in possible hydrogen generation during cask loading; the potential for water thermal expansion; higher package and canister lid temperatures; and increased worker dose rates during cask loading operations. There are also occupational safety issues associated with these higher heat loads and the high temperatures that transfer cask exteriors can reach. High lid temperatures can also affect load handling equipment such as the slings used to lift the transfer cask. Higher heat load canisters will also increase cask loading times due to worker comfort and installation of additional cooling equipment.

5.2.4 Implementation of New DSC Designs

DSC designs may need to be amended, or new designs may need to be certified, in order to load dry storage packages with five-year cooled, high burnup SNF on an ongoing basis. This may require advances in the heat transfer capabilities of DSCs either through improved materials or improved methodology; lower DSC capacities, etc. In addition to the possible need for amended or new DSC designs, the storage of high burnup, high heat-load SNF may result in cask loading issues associated with the higher thermal loads.

EPRI estimates that it would take between one and five years to amend an existing CoC or certify a new design, depending upon the complexity of the new design or CoC amendment, NRC staff workload, and the completeness of the supporting information submitted by the dry storage vendor as part of the license application to amend the CoC.

In addition, nuclear operating companies that are deploying new DSC designs at their ISFSIs, companies must begin the planning process three to five years in advance of loading SNF into these new designs. If ISFSIs must be expanded to support the accelerated transfer of five-year cooled SNF from SFPs to dry storage, a two to five year lead time would be necessary in order for companies to clear and prepare additional land on which to expand the ISFSI, design and construct additional concrete storage pads, expand fencing and security systems consistent with the size of the expanded ISFSI, etc.

5.3 Summary of Decay Heat and Cesium Inventory Reductions

As discussed in Section 3.1.4 for the reference PWR and BWR and in 4.4. for a PWR SFP and a BWR SFP, the transfer of 67 - 73% of existing SFP inventories to dry storage, with significant worker dose implications and significant cost to the industry, will not result in a proportional reduction of the decay heat or Cs source terms for the inventory remaining in the SFP since the highest burnup, shortest cooled SNF inventories will remain in the SFPs and Cs decays exponentially with time.

In Section 3.1.4 for the reference PWR, the percentage of SNF assemblies with less than five years of cooling that remain in the SFP would be just 22% of the pre-transfer inventory. However, the decay heat of the post-transfer inventory would be 68% of the pre-transfer decay heat and the Cs source term would be 47% of the pre-transfer source term. For the reference BWR, the results are similar. The percentage of SNF assemblies with less than five years of cooling that remain in the SFP would be just 22% of the pre-transfer inventory, and the post-transfer decay heat remaining would be 68% of the pre-transfer decay heat and the Cs source term would be 52% of the pre-transfer source term.

As summarized in Section 4.4., the percent of fuel assemblies remaining in the SFP for the PWR SFP and BWR SFP would be 33% and 27%, respectively. The percent of decay heat remaining for the SNF inventories remaining the in the PWR and BWR SFPs evaluated in Section 4.4 are 77% and 68%, respectively, and the percent of Cs inventory for the SNF inventories remaining are 57% and 53%, respectively.

Thus, neither the decay heat nor the combined Cs-134 and Cs-137 inventory are reduced as much as the SNF inventory is reduced. It is unclear whether the *potential* risk reduction due to lower amounts of decay heat and Cs in the SFPs would offset the *real* increased risks, increased occupational safety hazards, increased operational impacts and increased costs, associated with a policy decision to transfer SNF from SFPs at an accelerated rate.

5.4 Summary of EPRI's Analysis of the DOE-proposed Can-in-Can Approach

If DOE proceeds with this can-in-can concept and it happens to coincide with a policy decision to offload existing SFP inventories to dry storage, the development time needed for DOE's can-in-can concept would preclude the goal of accelerated offloading. Conversely, if a policy decision were made to require accelerated offloading of SNF to dry storage, this would result in a near term increase in the amount of SNF that would already be loaded into "non-standard" canisters – defeating the purpose of standardization. EPRI would expect that the impacts that it evaluates in this report would increase dramatically if a can-in-can concept were implemented along with a policy decision to offload existing SNF inventories. The time to transfer equivalent quantities of SNF to systems using this can-in-can process would increase dramatically, causing additional scheduling issues for SFP and cask handling crane availability. Worker dose would increase dramatically due to additional loading operations need to load small-capacity cans, and then load the small capacity cans into large cans since one of the highest dose activities during loading is from welding and the amount of welding would drastically increase.

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