The Costs of Spent Nuclear Fuel Storage at the Diablo Canyon Power Plant

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Summary

This report addresses the management and operating (M&O) or predisposal costs of spent nuclear fuel at the Diablo Canyon Power Plant (DCCP). In doing so, it examines the estimate provided by the plant's operator, Pacific Gas and Electric (PG&E) as well as data from the U.S. Government Accountability Office (GAO), the Electric Power Research Institute (EPRI), the commercial nuclear industry, the U.S. Nuclear Regulatory Commission (NRC)and the U.S. Department of Energy.

Spent nuclear fuel M&O costs associated with the decontamination and decommissioning (D&D) of the DCPP are collected in an escrow fund borne by the consumer of electricity. Currently, PG&E estimates that the total D&D cost for both reactors is $2.5 billion, with $477.5 million (19%) going for the management of spent nuclear fuel (SNF). PG&E's estimate contains elements of speculation that exclude additional costs associated with waste repackaging, decay storage of high burnup spent nuclear fuel, and later official opening dates for a geological disposal repository.

When these are factored in, predisposal costs for spent nuclear fuel increase by $704 million to $1 billion. These costs exceed PG&E's total estimated spent fuel management expense by as much as 200 percent. Since the contract with the U.S. Energy Department for the disposal spent nuclear fuel from the Diablo Canyon Power Plant does not cover these added expenses, this would result in a significant shortfall in the D&D fund for the Diablo Canyon Power Plant, which creates a significant additional financial burden for PG&E's ratepayers.

Introduction

The announced closure of the Diablo Canyon Power plant's two reactors by 2025, is part of an accelerating trend of power reactor closures in the United States. Nuclear power reactors are no longer just about generating electricity. After several decades, these facilities are now major radioactive waste management operations holding what the U.S. Government Accountability Office describes as "one of the most hazardous substances on earth."

Yet after nearly 60 years, the quest for permanent nuclear waste disposal remains illusory. The U.S. government now estimates it could take several decades before a permanent disposal site might open. In recognition of major uncertainties, the U.S Department of Energy in 2011 reported that: "extended storage, for periods of up to 300 years, is being considered within the U.S."[1]

Over the past 29 years (1986-2015), the two pressurized water reactors at Diablo Canyon have generated about 1,314 metric tons of spent nuclear fuel contained in 2,932 assemblies holding[2] 774,048 rods. [3]The rods contain approximately 496 million curies (1.83 E+19 Bq) of intermediate and long-lived radioactive elements.[4] [5] The two reactor spent fuel pools contain about 5 times the amount of irradiated fuel than the reactor cores. Each reactor core contains about 83 metric tons, with about 863 metric tons stored in spent fuel pools. There are 34 dry casks at Diablo Canyon which currently hold about 47 percent (488 metric tons) of the sites' irradiated nuclear fuel.

As of 2013, approximately 63 percent of the spent nuclear fuel stored at DCCP (1,789 assemblies) was high burnup ranging from ~44,000 to 58, 000 MWd/ t. [6]Approximately 57% of its high burnup SNF was stored in the two reactor pools, while about 23% was in configured with lower burnup spent fuel in dry casks.

Repackaging

Under the Standard Contract for government acceptance of spent nuclear fuel (10 CFR Part 961), the U.S. Department of Energy (DOE) does not consider existing dry cask containers to be an acceptable waste form for geological disposal. Repository requirements will ultimately determine how spent nuclear fuel will have to be repacked. The current generation of dry casks was intended for short-term on-site storage, and not for direct disposal in a geological repository. NRC has licensed 51 different designs for dry cask storage, 13 which are for storage only. The Columbia Generating Station is listed by the Energy Department as having an unidentified number of "storage only" casks.[7] None of the dry casks storing spent nuclear fuel are licensed for disposal. Although the spent fuel dry casks at DCPP are described as being "multi-purpose," there are several hurdles to overcome.

Existing large canisters can place a major burden on a geological repository –such as: handling, emplacement and post closure of cumbersome packages with higher heat loads, radioactivity and fissile materials.

In 2012, Energy Department researchers concluded that "waste package sizes for the geologic media under consideration …are significantly smaller than the canisters being used for on-site dry storage by the nuclear utilities".[8] A nuclear industry study concluded in 2014 that " casks and canisters being used by the power utilities will be at least partially, and maybe largely, incompatible with future transport and repository requirements, meaning that some if not all, of the [used nuclear fuel] that is moved to dry storage by the utilities will ultimately need to be repackaged."

By the time DOE expects to open a repository in 2048, the number of large dry casks currently deployed is expected to increase from 1,900 to 12,000. Repackaging for disposal may require approximately 80,000" small" canisters. Currently, PG&E projects that it will load a total of 137 dry casks each containing 32 assemblies to accommodate spent fuel generated by the date of its license expiration in 2024. The small "Standardized Transportation, Aging and Disposal – (STAD)" canister currently envisioned by the DOE, would reduce the number of assemblies to four.

At DCPP, repackaging to small STADs could result in 1,095 canisters at an additional expense of approximately $380 million. This could nearly double the expense of spent fuel management after the DCPP is closed.

High Burnup

For some 16 years, U.S. reactor operators, including PG&E, have been permitted by the NRC to double the amount of time nuclear fuel can be irradiated in a reactor, by approving an increase in the percentage of uranium-235, the key fissionable material that generates energy. Known as increased "burnup" this practice is described in terms of the amount of electricity in megawatts (MW) produced per day with a ton of uranium.

There is growing evidence that as a result of higher burn-ups nuclear fuel cladding cannot be relied upon as a primary barrier to prevent the escape of radioactivity, especially during dry storage.

In 2012 the National Academy of Engineering of the National Academy of Sciences raised concern about the viability of high-burnup fuel by noting, "the technical basis for the spent fuel currently being discharged (high utilization, burnup fuels) is not well established… the NRC has not yet granted a license for the transport of the higher burnup fuels that are now commonly discharged from reactors. In addition, spent fuel that may have degraded after extended storage may present new obstacles to safe transport." http://www.nae.edu/File.aspx?id=60739

NRC's current staff guidance for the transport of high burnup SNF concludes: " *Data is not currently available* [emphasis added.).. High burnup fuel (i.e., fuel with burnups generally exceeding 45 GWd/MTU) may have cladding walls that have become relatively thin from in-reactor formation of oxides or zirconium hydride." http://www.nrc.gov/reading-rm/doc-collections/isg/isg-11R3.pdf.

At the Diablo Canyon Power Plant (DCPP) as of 2013 approximately15 percent its high burnup is in dry storage, while the remainder is in the reactor pools. SNF exceeding >46GWd/MTUto be regionally loaded in dry casks. According to PG&E a condition for DCPP's license amendment, would be that burnup's greater than 55GWd/MTU must remain in pool storage for 12 years prior to regional loading. Storage times significantly influence costs due to radioactive decay and heat and the availability of offsite storage and disposal.

DOE reports that the current level of allowable irradiation of uranium fuel at DCCP (burnup of 60,00MWd/t) is likely to require 100 years of surface storage to meet decay heat requirements for disposal.

Spent nuclear fuel M&O costs are subject to major uncertainties, particularly with respect to the availability of centralized interim storage, and ultimate disposal. To bound these uncertainties with a level of conservatism, this analysis assumes that onsite storage of spent nuclear fuel will continue until the opening of a repository. Such conservatism is justified given that, after more than half century, centralized interim storage of SNF and its geological disposal remain elusive.

Management and operation costs cover a range of activities ranging from its discharge from the reactor core to spent fuel pools, maintenance and operation of storage pools, construction of dry storage casks and SNF emplacement, onsite dry casks storage and repackaging for geologic disposal.

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Given these major uncertainties especially regarding a disposal site opening this analysis does not attempt to extrapolate beyond 60 years into the future. The elements of speculation are too significant to extrapolate out to a time that is several centuries longer than the formal existence of the United States.

Instead, three official scenarios are used to bound time in which management and operating costs are analysed.

- The 2013 PG&E D&D update which assumes a repository opening in the year 2024,
- the Department of Energy's (DOE) 2013 strategic plan, which has opening for a repository by the year 2048; and
- The U.S. Nuclear Regulatory Commission's (2014) "Waste Confidence" ruling with a repository opening in 2085 (60 years after the existing DCPP license expires in 2025).

The most significant impacts on M&O costs include: SNF repackaging requirements for disposal; decay time for high burnup spent fuel, and the opening date of a geologic repository. In this regard, costs estimates range from $447.5 million to $1.86 billion (Tables 1, 2&3).

While this study is focused on pre-disposal management, disposal costs are likely to be significant. However, uncertainties relative to disposal costs are greater. For instance, the current costs estimated by the DOE for disposal of spent nuclear fuel ranges from $24 billion to $81 billion depending on the geological medium selected. These costs are also borne by the ratepayer in the form of a user fee from consumers of nuclear-generated electricity as required by the Nuclear Waste Policy Act of 1982. If these estimates are applied to DCPP, the costs range from roughly from $323million $1.3 billion for spent fuel generated to the year 2025, when the current operating license expires. If PG&E is granted a 20-year license extension total costs would range from $485 million $1.7 billion.

Thus, a rough estimate for the management and disposal of spent fuel generated at the Diablo Canyon Power plant ranges from $933 million to $3.5 billion.

Table 1 DCPP Spent Nuclear Fuel M&O Costs
2024 Repository Opening (PG&E)

2025 reactor closure	
$447.5 million	

DCCP

2025 reactor closure with SNF repackaging	
$827.5 million	

Spent Nuclear Fuel M&O Costs
2048 Repository opening (DOE)

2025 reactor closure	
$703 million	

2025 reactor closure with SNF repackaging	
$1.1 Billion	

Table 3 DCCP Spent Nuclear Fuel M&O Costs
2084 Repository opening (NRC)

2025 reactor closure	
$876 million	

2025 reactor closure with SNF repackaging	
$1.33 Billion	

Introduction

By the year 2045, when the proposed operating license extension for Diablo Canon ends, the two power reactors are projected to generate 2,826 metric tons of spent nuclear fuel contained in 6,593 assemblies holding 1,740,552 rods.[9] If PG&E is permitted to increase the time of irradiation (burnup) to 72GWd/t, spent fuel generated between 2024 and 2045 would contain roughly 690 million curies of intermediate and long-lived radioactive elements (2.26E+19Bq). The total amount of intermediate and long-lived radioactivity from 1986 to 2045 thus would be approximately 1.9 billion curies (7.0E+19 Bq). This is more than 10 times the total radioactivity currently contained in military high-level radioactive waste tanks at the U.S. Department of Energy's Hanford site in Washington.[10]

In 2013 PG&E estimated that decontamination and decommissioning (D&D) expenses for the Diablo Canyon reactors totalled approximately $2.5 billion (2011 dollars).[11] PG&E's estimate assumed by 2025, the current operating license would expire, and the station would close. Of the total amount, $447.5 million is for the managing and operating (M&O) costs for spent nuclear fuel (SNF) generated to the year 2025. Starting in the year 2024, PG&E assumes that the U.S. Department of Energy (DOE) will begin to accept spent nuclear fuel for disposal and all will be removed between the years 2033 and 2055.

If granted a 20-year extension to the DCPP operating license, PG&E estimates that an additional 2,194 spent nuclear fuel assemblies will be generated by the year 2045. With an average rate of transfer of 6 canisters (192 spent fuel assemblies) per year,[12] this would require about 12 years to load an additional 69 dry casks. The additional capital and loading expense are approximately $173 million. Once loaded, the rate estimated by PG&E, indicates that the additional spent nuclear fuel would 11 more years for removal to a repository. The total cost for this additional amount of SNF is approximately $330 million above PG&E's estimate, based on reactor closure in 2025.

Spent fuel shipments would start nine years later with it all removed by the year 2079. A cash flow for an additional 31 years ($ 8.2 million/yr) would be required. This scenario adds $256 million to the total D&D cost and increases the M&O costs for onsite storage of spent nuclear fuel to $703.5 million. Spent fuel shipments would start nine years later with it all removed by the year 2079. A cash flow for an additional 31 years ($ 8.25 million/yr) would be required. This scenario adds $256 million to the total D&D cost and increases the M&O costs for onsite storage of spent nuclear fuel to $703.5 million.

WHO PAYS THE COSTS?

The rate payer and taxpayer are responsible for the costs of management and disposal of spent power reactor fuel. Under the Nuclear Waste Policy Act (42 U.S.C. 10101) fees are collected from ratepayers to finance the disposal of spent nuclear fuel in a geological repository. Because of the failure of the U.S. government to meet the deadline to open a disposal site under this law, nuclear power utilities are recovering funds from taxpayers as penalties associated with the added costs of at reactor storage and legal fees. In this regard, on September 5, 2012, Pacific Gas and Electric reached a settlement agreement with the U.S. Department of Justice for $266 (minus $16M in legal fees) to cover the costs for spent nuclear fuel management at Humbolt Bay and the

Diablo Canyon Power plant (DCPP). The agreement also allows PG&E to submit annual claims to recover costs from 2011 to 2013 (~$25M/yr). This money is to be refunded to rate payers. After 2013 PG&E must go back to court. PG&E concludes that: "Considerable uncertainties when and whether the DOE will meet its contractual obligation to the Utility and other nuclear plant owners to dispose of spent fuel." [13] While the PG&E ratepayer is reimbursed, the U.S. taxpayer bears the cost. Finally, funds for the management of spent nuclear fuel up to the point of disposal are collected from ratepayers to cover the costs of reactor decontamination and decommissioning.

Management and Operations Costs

Diablo Canyon Power Plant- 2025 license expiration: PG&E estimated in 2013 that decontamination and decommissioning (D&D) expenses for the Diablo Canyon reactors total approximately $2.5 billion (2011 dollars).[14] PG&E's estimate assumed by 2025, the current operating license would expire, and the station would close. Of the total amount, $477.5 million is for the managing and operating (M&O) costs for spent nuclear fuel (SNF) generated to the year 2025. This translates into a per SNF assembly cost of $102,000. Starting in the year 2024, PG&E assumes that the U.S. Department of Energy (DOE) will begin to accept spent nuclear fuel for disposal and all will be removed between the years 2033 and 2055. [15] Under current, law DOE cannot accept spent nuclear fuel until a disposal repository is opened.

However, in 2013 the DOE issued a new strategy document for the disposal of spent nuclear fuel that plans for the opening of a geologic repository by the year 2048.[16] Furthermore, the Nuclear Regulatory Commission officially contemplates a 60- year time-frame for a repository opening by year 2075.[17] In the absence of centralized, off-site interim storage, this effectively adds an additional 24-51 years of expenses for the management of SNF at the Diablo Canyon Power Plant.

Over the past 43 years, efforts to establish centralized interim storage sites for spent nuclear fuel have failed. Opposition by states remains high. Opening a centralized storage facility also requires a lengthy period beyond the authority of a given presidency or Congress. At this stage, the indefinite storage of spent nuclear fuel at reactor sites is a more likely possibility. Given these major uncertainties, cost estimates for the management of spent nuclear fuel should reflect the likelihood of indefinite on site storage.

- **DOE- Repository opening in the year 2048** -Spent fuel shipments would start nine years later with it all removed by the year 2079. A cash flow for an additional 31 years ($ 8.25 million/yr) would be required. This scenario adds $256 million to the total D&D cost and increases the M&O costs for onsite storage of spent nuclear fuel to $703.5 million.

- **NRC- Repository opening in the year 2084.** Complete removal of spent fuel would occur by the year 2107.A cash flow of an additional 52 years would be required. This scenario adds $586.5 million to the total D&D cost and increases the onsite M&O costs for spent nuclear fuel to $1033 million.

Diablo Canyon Power Plant 2045 license expiration (2024 repository opening)- If granted a 20-year extension to the DCPP operating license, PG&E estimates that an additional 2,194 spent nuclear fuel assemblies will be generated by the year 2045. With an average rate of transfer of 6 canisters (192 spent fuel assemblies) per year,[18] this would require about 12 years to load an additional 69 dry casks. The additional capital and loading expense are approximately $173 million. Once loaded, the rate estimated by PG&E, indicates that the additional spent nuclear fuel would 11 more years for removal to a repository. Total cost=$957 million.

- **DOE- Repository opening in the year 2048**: Spent fuel shipments for disposal would start nine years later and conclude by the year 2090. The total capital and M&O costs would be $445.3 million, approximately $190 million more than for (SNF) generated only to the year 2025.

- **NRC- Repository Opening in the Year 2084:** Complete removal of SNF would occur by the year 2117. A cash flow of an additional 62 years would be required for onsite storage. This scenario adds $512 million to the total D&D estimate. The increment of SNF generated by an extended 20-year license adds $354.5 million to the cost compared to a closure date of 2025.

High Burnup Spent Fuel

An important uncertainty impacting the expense of spent nuclear fuel storage is associated with high burnup spent nuclear fuel. Currently, DCPP is irradiating fuel at high burnup levels

For some 20 years, U.S. reactor operators have been permitted by the NRC to double the amount of time nuclear fuel can be irradiated in a reactor, by approving an increase in the percentage of uranium-235, the key fissionable material that generates energy. In doing so, NRC has bowed to the wishes of nuclear reactor operators, motivated more by economics than spent nuclear fuel storage and disposal.

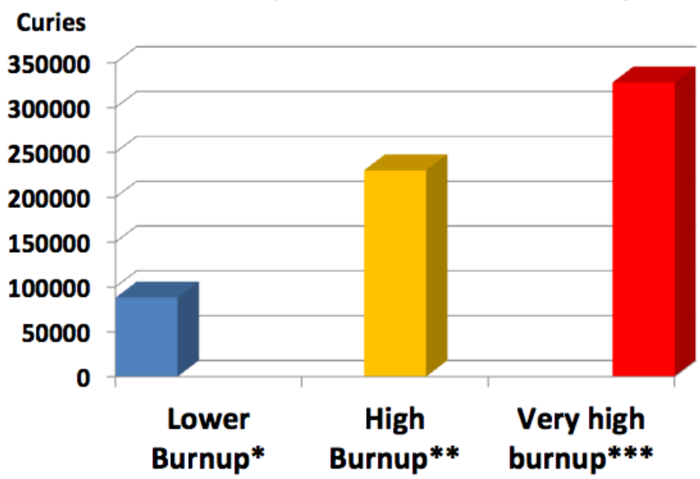
Known as increased "burnup" this practice is described in terms of the amount of electricity in megawatts (MW) produced per day with a ton of uranium. In 2012 the National Academy of Engineering of the National Academy of Sciences raised concern about the viability of high-burnup fuel by noting, "the technical basis for the spent fuel currently being discharged (high utilization, burnup fuels) is not well established… the NRC has not yet granted a license for the transport of the higher burnup fuels that are now commonly discharged from reactors. In addition, spent fuel that may have degraded after extended storage may present new obstacles to safe transport."[19] Even NRC admits, "there is limited data to show that the cladding of spent fuel with burnups greater than 45,000 MWd/MTU will remain undamaged during the licensing period." [20]

According to the 2011 report of the Diablo Canyon Independent Safety Committee, burnup at DCPP was approximately 60,000 MWd/t. PG& is considering increasing burnup to 72,00-MWd/t.[21]

The amounts of long-lived radioactive fission products in spent nuclear fuel increase significantly with high burnups (See Figure 1). If the current inventory in the spent fuel pool is high burnup (>45, 000 MWd/t) and subsequent discharges add more, this will significantly increase the concentration of radioactivity and decay heat, which put additional stress on the pool storage system as well as on the spent fuel itself creating potential degradation problems during dry cask storage.

Also, because higher burnups result in significant higher decay heat pool cooling systems will require upgrading as well as longer pool storage periods.[22] High burnup spent fuel with breeched cladding will result in an additional release of radioactive particulates to the water requiring enhanced water and air purification systems. Commensurate with these changes nuclear safety regulatory requirements would have to be revaluated. These changes will certainly drive up the M&O costs of spent fuel pool storage.

Figure 1 Estimated radioactivity in a PWR spent nuclear fuel assembly



* 41,200 MWd/MTHM
**50,000 MWd/MTHM
***72,000 MWd/MTHM

Sources DOE EIS-0250, Appendix A, http://energy.gov/sites/prod/files/EIS-0250-FEIS-01-2002_0.pdf
SAND2004-2757 (2004)

As of 2013, approximately 63 percent of the spent nuclear fuel stored at DCCP (1,789 assemblies) was high burnup ranging from ~44,000 to 58,000 MW/d/t. [23]Approximately 57% of its high burnup SNF was stored in the two reactor pools, while about 23% was in configured with lower burnup spent fuel in dry casks, The casks at DCPP have not exceeded an average loading above 45,000 MWd/t. However, in February 2014, the NRC approved a license amendment that deleted the 40,000 MWd/t limit and substituted it with "Alternative MPC-32 Fuel Selection Criteria."[24] This change would allow for "regionalized loading of high burn-up fuel (HBF) in dry casks.[25] However, high burnup must be stored in the pool for a minimum of 12 years before it can be regionally loaded.[26]

However, PG&E was found in 2013 by the NRC to have misloaded high burnup spent fuel assemblies into two casks, in violation of NRC's requirement. Also, the Holtec Corporation, which provides dry casks for the DCPP, has since adopted a technical standard that no longer allows for preferential loading.

Because of the lack of a technical basis for extended storage and transportation of high burnup spent nuclear fuel, the NRC has limited its storage in dry casks to 20 years and has yet to approve containers for its safe transport. Given these uncertainties, greater cooling in pools on the order of 29 years may be required. A minimum of 100 years of surface storage is estimated by the DOE for high burnup spent nuclear fuel before emplacement in a repository. [27]

Repackaging Expenses

Under the Nuclear Waste Policy Act, which sets forth the process for disposal of high-level radioactive wastes, the U.S. Government cannot accept title to spent nuclear fuel until it is received at an open repository site. The U.S. Government Accountability Office reported in 2014: "according to DOE, under provisions of the standard contract, *t*he agency does not consider spent nuclear fuel in canisters to be an acceptable form for waste it will receive. This may require utilities to remove the spent nuclear fuel already packaged in dry storage canisters".[28]

Repackaging expenses rely of the transportability of the canisters, but more importantly on the compatibility of the canister with heat loading requirement for disposal. In terms of geologic disposal, decay heat, over thousands of years, can cause waste containers to corrode, negatively impact the geological stability of the disposal site and enhance the migration of the wastes.[29] Peak temperatures in the repository of 100 degrees C (212F) can extend beyond 300 years after centuries of decay and active ventilation." [30]According to a 2012 DOE study:

> "Thermal analyses completed by the Used Fuel Disposition Campaign (UFDC) indicate that waste package sizes for the geologic media under consideration by the UFDC and comparable international repository concepts are significantly smaller than the canisters being used for on-site dry storage by the nuclear utilities.[31]

For instance:

- Crystalline and Clay Shale geologic media, SNF generated at DCPP with an average burnup of 40,000MWd/t would limit each disposal package to 4 assemblies, compared to the 32 assemblies, after 50 to 72 years of surface decay, in each dry cask now stored at the site.
- A maximum of 4 assemblies for high burnup of 60,000MWd/t would be permitted after 100 years of decay.
- For salt deposits, as many as 12 assemblies could be packaged after 50 years of decay.
- Larger packages containing no more than 21 assemblies could be disposed if there is forced ventilation for 50 to 250 years. This would significantly increase the cost of a repository.[32]

If spent fuel generated at DCPP until 2025 must be repackaged to fit into smaller containers holding no more than 4 assemblies for disposal, this could require as much as an additional $380 million to the D&D expense.[33] Potential repackaging costs of $190 million could be added for the increment of spent fuel generated between 2024 and 2045. Whether or not PG&E can recover this added expense from the taxpayer is an open question requiring federal legislation or litigation in federal court.

The Quest for Centralized Interim Storage

Over the next 10 years, DOE plans for a large interim storage facility that could accept spent nuclear fuel by 2025. Much of what must be accomplished to establish an interim storage site, is outside of the authority of the DOE.

Recent reactor closures, due to age and economics are generating a growing back-log of "orphan" wastes at decommissioned sites. One third of the U.S. reactor fleet is more than 40 years old. [34] With the continued operation of several more reactors in doubt, the backlog of "orphan wastes" could double over the next decade – comprising more than a third of all currently generated spent nuclear power spent fuel.

According to the Electric Power Research Institute a centralized interim storage facility capable of holding 40,000Mt of spent fuel would require approximately $590 million (2015 dollars) for design, licensing and construction. Annual operating costs are estimated at $321 million/yr during a 20-year loading period, with annual caretaking costs of $4.4 million/yr. [35]These costs come to a rough total of $7 billion. Notionally, when these estimates are applied to spent nuclear fuel at DCCP, the costs range from $353 million to $490 million. After more than four decades of failure in establishing a centralized storage facility, there are major uncertainties about the actual location, timing and, most important, political acceptance.

Disposal Costs

In 2013, the DOE estimated that the range of cost for the disposal of 140,000 MT of commercial power reactor spent fuel is between $24 billion to $81 billion (2012 dollars).[36] Table 2 below indicates the major time-line elements involved.

Table 2 Repository Time Elements (DOE 2013)

Element	Description
Waste Quantity	141,423 MTHM
Geologic Repository	One Repository
Transportation Mode	Mostly Rail
Storage	One Pilot Facility and One Consolidated Storage Facility
Authorizing Legislation Passed	2014
Pilot Storage Facility Opens	2021
Full-Scale Storage Facility Opens	2025
Repository Opens	2048
End of Emplacement	2099
End of Monitoring	2149
Closure	2157

The lowest costs are for disposal in a generic salt repository with Clay/Shale and Crystalline shale media at the highest cost. These costs assume that the repositories do not have a significant interim storage and repackaging infrastructures, and that the packages arriving are ready for disposal. Disposal costs would range from $171,428 MT to $600,000MT. If these estimates are applied to DCPP, the costs range from $323million $1.3 billion for spent fuel generated to the year 2025, when the current operating license expires. If PG&E is granted a 20-year license extension total costs would range from $485 million $1.7 billion.

Spent Nuclear Fuel Generation and Pool Storage

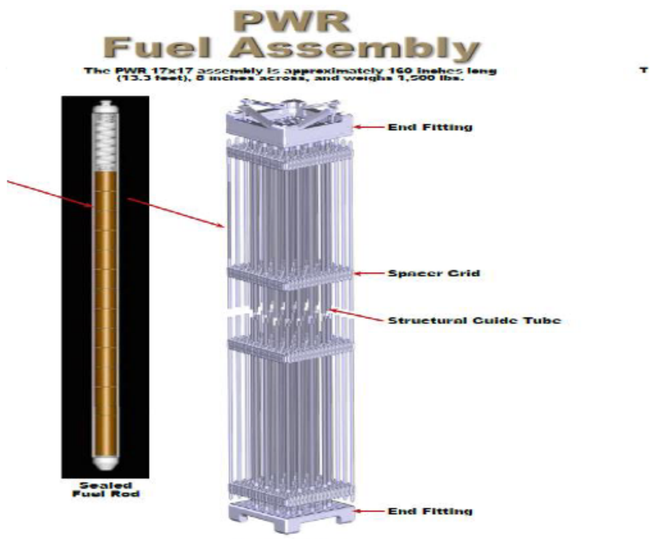
The two pressurized water reactors at Diablo Canyon were designed and sold by the Westinghouse corporation. Each reactor core contains 193 fuel assemblies. In the average of 20 months the reactors are shut down to discharge spent irradiated fuel and replace it with fresh fuel. About 88 assemblies (~ 45% of the core) are replaced, usually after six years of irradiation. Each reactor has a spent fuel pool with a capacity to hold 1312 and 1309 assemblies respectively.

The maintenance and operations costs for the handling and pool storage for spent nuclear fuel is estimated at $6 million/year for an operating reactor.[37] [38]This expense is born as part of the rate charged for electricity. During the DCPP license (1986-2024) the total operations and maintenance costs would be approximately $456 million (2015 dollars). If DCPP received a 20-year license extension (2024-2045) additional $240 million would be spent for pool storage.

As uranium fuel is irradiated in the two reactor cores at Diablo Canyon radioactive elements are created when the atoms of uranium-235 and other heavy isotopes are split (fission) as well as by absorption (activation) of neutrons in the atoms of many other isotopes. The fuel is enriched above its naturally occurring fraction of 0.7 percent of U-235 to as much as 4.9 percent at so it can serve as the primary isotope needed for fission and thus, the generation of energy.

The fuel used at Diablo Canyon has of two different configurations of WE 17x17 fuel: WE 17x17 Standard (STD) and WE 17x17 Vantage 5. These fuel designs have the same physical geometry but differ slightly in fuel rod diameter. Some 400 pellets made of slightly enriched ceramic uranium dioxide (U02) are stacked in zirconium metal alloy tubes and sealed at both ends. The gap between the rods and pellets of approximately 152 micrometres is filled with helium to a pressure of 10 bar or 145 pounds per square inch. Thickness of the rod cladding is between 3.18-5.56 mm (0.125 to 0.22 inches)[39] (See Figure1)

Figure 1



Source: U.S. Department of Energy, DOE/EIS-0283-S-2, July 2012.

The rods are held in the assembly by an end plate, a structural guide tube, as pacer grid and end fitting. All told there are some 20 million fuel pellets in a fuel core for each of the 2 reactors. The assemblies spend as long as 6 years undergoing irradiation and are replaced with fresh fuel when the reactors are shut-down every 18 months to two years.

When the reactor is shut down, the spent fuel being removed contains a myriad of radioactive isotopes with different half-lives including longer lived radioisotopes, notably cesium- 137 (half-live=30 years), along with very long-lived fission products (i.e. iodine-129, Technetium-99, Cs-135) and actinides (plutonium-239, americium-241) that have half-lives ranging from tens of thousands to millions of years. The most immediate and severe form of harm is direct exposure to a spent nuclear fuel assembly at a near distance. For instance, a freshly discharged spent fuel assembly would give off more than 10,000 rems per hour (100 Sv/hr) in the form of external penetrating radiation.[40] A person standing within 3 feet of this assembly would receive a lethal dose within minutes. For the next 100 years, it would give off life threatening doses at this distance. Long-term damage from lower doses includes cancers, other diseases, and lasting genetic damage, including congenital abnormalities, chromosomal disorders, and range of diseases, which could span generations.[41]

Within one year the heat output of the spent fuel diminishes by about ten times. After 10 years it drops by another factor of ten. By 100 years the decay heat has dropped another five times, but still gives off significant heat. However, the decay heat remains high throughout the operation of the reactors and well after they are closed.

Control of decay heat is a key safety factor for spent fuel storage and its final disposal in a geological repository. Storage of spent nuclear fuel in pools requires continuous cooling for an indefinite period to prevent decay heat from igniting the zirconium cladding and releasing large amounts of radioactivity into the environment. At all times, spent fuel is handled underwater following placement in dry casks.

Maintenance and operation of spent nuclear fuel involves more than 60 steps to remove spent fuel from the irradiated core for pool storage and to add new fuel. [42] Removal of the spent fuel for pool storage usually takes 2-3 days.[43](See Figure 2)

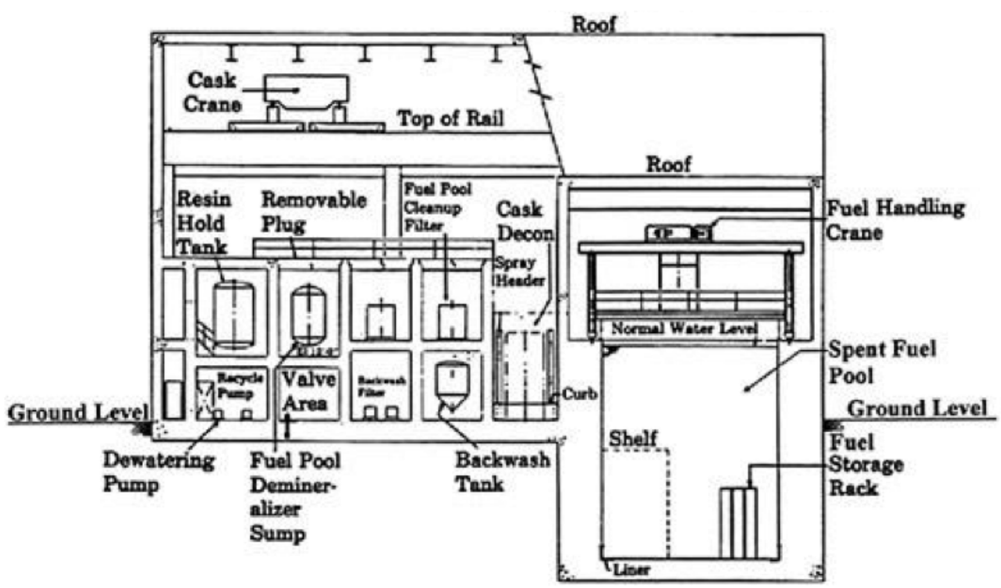


Figure 2PWR Spent Fuel System

Source: http://www.nap.edu/books/11263/xhtml/images/p2000e296g43001.jpg

The spent fuel pool for each Diablo Canyon reactor has a capacity to store 1,324 assemblies.[44] The pools operate several systems to: (a) remove residual decay heat with heat exchangers; (2) circulate cooled water with pumps; (3) maintain clarity and purity of the water with filters and debris removal equipment; and (4) to mitigate potential nuclear criticality risks.

Dry Cask Storage

Since June 2009, PG&E has installed 34 Holtec HI-STORM 100 storage casks each containing 32 assemblies at the Diablo Canyon Independent Spent Fuel Storage Installation (ISFSI). The

ISFSI currently consists of two large concrete storage pads that can hold 20 anchored casks each. The ISFSI protected area was designed to hold a total of seven pads, each holding 20 anchored casks. By 2025, the ISFSI is planned for the storage of 79 casks. PG&E estimates that each canister with over pack costs $1.5 million with an additional $1 million for labor and overhead.

Also, each spent fuel storage pool will have its inventory of used fuel reduced from slightly over 1,200 assemblies currently to slightly fewer than 800 in 2025.

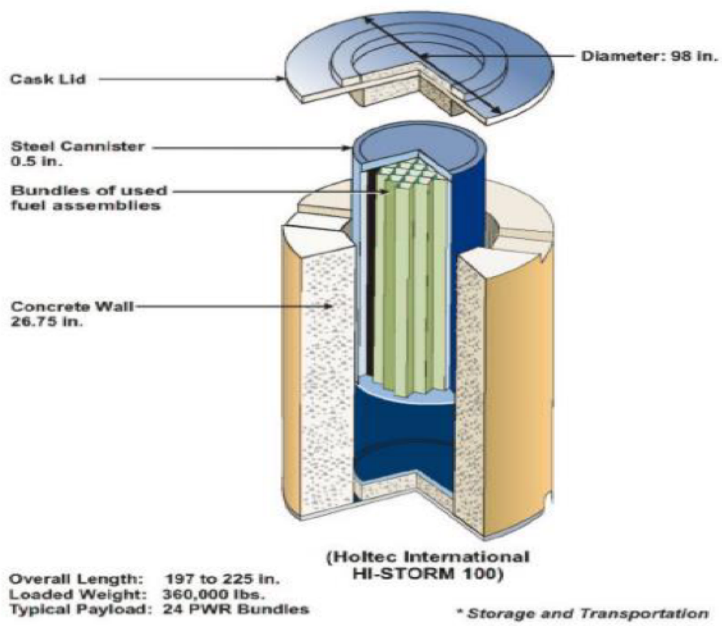
Current dry storage casks can accommodate a uniform loading of spent fuel below 45,000 MWd/t; or regional loading in which high burnup assemblies, with higher decay heat, are mixed with lower burnup assemblies, as long as the heat load limited by NRC regulation is not exceeded.[45] If only high burnup SNF can be placed in a cask reducing the number of assemblies in a cask (known as "short-loading), this may not meet NRC peak temperature requirements.

If all lower burnup assemblies are placed in dry casks, without regional loading of high burnup SNF, then pool storage times are likely to increase to allow for the greater decay heat to diminish. However, casks that do allow for regional loading also has limits on where the high burnup assemblies can be loaded without exceeding temperature requirements.

The HI-STORM100 system is a vertical storage module that is made up three pieces; a steel canister holding spent fuel assemblies; an air flow channel to allow for passive air circulation; and an external into a steel-lined concrete over-pack (see figures 4 and 5). The loaded casks each weigh approximately 178 tons. [46]

If a 20-year license extension in granted by the NRC, by 2045 an additional 43.42 Mt (2,194 assemblies) of spent fuel will be generated. By that date, given that the U.S. Department of Energy projects an opening date of 2048 for a spent fuel disposal site, an additional 65 dry casks will be required.

Figure 5 Typical Holtec Hi Storm 100 Vertical Storage Module


Cask Lid
Diameter: 98 in.
Steel Cannister
0.5 in.
Bundles of used
fuel assemblies
Concrete Wall
26.75 in.
(Holtec International
HI-STORM 100)
Overall Length: 197 to 225 in.
Loaded Weight: 360,000 lbs.
Typical Payload: 24 PWR Bundles
* Storage and Transportation

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