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The Potential of Using Commercial Dual Purpose Canisters for Direct Disposal

Prepared for:
U.S. Department of Energy
Office of Civilian Radioactive Waste Management
1000 Independence Avenue, SW
Washington, DC 20585

Prepared by:
Bechtel SAIC Company, LLC
1180 Town Center Drive
Las Vegas, Nevada 89144

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Prepared by: Barrie McLeod
Barrie McLeod
Date: 11/12/03

E. J. Benz for
Ralph Best
Date: 11/12/03

Reviewed by: E. J. Benz
Ed Benz
Date: 11/12/03

Reviewed by:
D. Siefken
Program Integration Manager
Date: 11/12/03

Concurrence: N Williams
N. Williams
Repository Development Manager
Date: 11-12-03

Approved by:
J. Mitchell, Jr.
Manager (Acting)
Transportation and Integration
Date: 14 Nov 03

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ACRONYMS, ABBREVIATIONS, SYMBOLS, AND UNITS

ACRONYMS AND ABBREVIATIONS

BWR	Boiling Water Reactor
CRWMS	Civilian Radioactive Waste Management System
CSNF	Commercial Spent Nuclear Fuel
CoC	Certificate of Compliance
DOE	U.S. Department of Energy
DPC	Dual Purpose Canister (for storage and transport)
DU	Depleted Uranium
MPC	Multi-Purpose Canister (for storage, transport, and disposal)
NRC	U.S. Nuclear Regulatory Commission
PWR	Pressurized Water Reactor
QA	Quality Assurance
SNF	Spent Nuclear Fuel
TSPA	Total System Performance Assessment
UMS	Universal MPC System (NAC International)
U.S.	United States
WP	Waste Package

SYMBOLS AND UNITS

^{o}C	Degrees Centigrade
cm	Centimeter [one-hundredth of a meter (10^{-2} m)]
cc	Cubic centimeters
g	Grams
GWd	Gigawatt-days
in.	inches
kg	Kilograms (1000 grams)
kW	Kilowatt (1000 watts)
kWhe	Kilowatt Hours Electric
m	meter

MTHM	Metric Tons Heavy Metal (1000 kg)
MTU	Metric Tons of Uranium
MWd	Megawatt day
W	Watts

EXECUTIVE SUMMARY

Purpose and Contents of Report

This report evaluates the potential for directly disposing of licensed commercial Dual Purpose Canisters (DPCs) inside waste package overpacks without reopening. The evaluation considers the principal features of the DPC designs that have been licensed by the Nuclear Regulatory Commission (NRC) as these relate to the current designs of waste packages and as they relate to disposability in the repository. Where DPC features appear to compromise future disposability, those changes that would improve prospective disposability are identified.

Principal Characteristics of Currently-Licensed Commercial DPCs

The principal characteristics of DPC canisters that are important to disposal are summarized in Table ES-1 for five currently licensed DPC designs. Three of these designs, the Holtec, NAC, and Transnuclear designs are in continuing use at multiple reactor sites. The Yankee MPC is a single-application DPC for Yankee Rowe reactor fuel. There are only 16 of these DPCs; 15 contain spent fuel and one contains Greater-than-Class-C wastes. To date, there are only seven BNFL Fuel Solutions DPCs; they hold 64 Big Rock Point fuel assemblies. BNFL Fuel Solutions has also obtained certification for a 21-PWR transportable storage system, but has no current orders for this system.

Principal Conclusions

The principal conclusions of this evaluation of current DPC disposability are:

1. Post-closure criticality is the principal issue that can impact the direct disposability of DPCs. The other issues discussed in this report need to be addressed by additions and/or changes in equipment, facilities and/or operations, but if addressed would not impact the disposability of DPCs.

2. Some fraction of DPCs would be disposable if DPCs receive criticality credit for fuel assembly burnup under the same conditions being assumed and used for the design and licensing of waste packages for the disposal of commercial spent nuclear fuel (CSNF) assemblies. The development of realistic estimates of the fraction of DPCs that would be disposable using burnup credit, would require a substantial analysis effort, which was not within the scope of this evaluation. The criticality design of all currently-licensed DPC systems is based on the assumption of fresh fuel without burnup credit. Therefore, these designs require extensive use of neutron absorbers, principally Boral. However, in the postclosure period, after the loss of waste package integrity, there will be a loss of the structural integrity of the Boral, because Boral is not designed for very-long-term corrosion resistance. As a result it must be assumed that the neutron absorbers would be transported elsewhere. Under the resulting analysis condition of a compact array of fresh fuel assemblies, without significant neutron absorbers, evaluations would likely show that criticality would occur. Thus, it will be necessary to have burnup credit in order to directly dispose of any current DPCs, or those soon to be loaded. In that regard, in order to use

burnup credit *in transport and storage*, NRC requires a confirmatory measurement of burnup prior to loading. However, few of the current DPC loadings included such prior measurements because they do not rely on burnup credit. This lack of measurements would not be a concern for DPC disposal if using reactor records of assembly burnup is ultimately licensed as the basis for burnup credit, as is being assumed and used for waste package design and in the license application for disposal.

3. There are physical compatibility issues between DPCs and waste packages that need to be addressed. Specifically, none of the commercial DPCs could be accommodated in the largest waste package currently designed for CSNF assemblies. However, the Long Naval waste package could accommodate three of the five DPCs, assuming that the excess length of the Long Naval waste package, relative to the DPC lengths, could be appropriately filled, and center-of-gravity issues addressed. The Holtec DPC will not fit any current waste package: its diameter is about one inch too large for the Long Naval package, and it is about 9 inches too long for the Long Co-Disposal waste package. Since more than 200 of these DPCs are anticipated, an additional waste package design for the Holtec DPC might be justified if dimensions were the only factor preventing disposal. Although the short NAC Yankee MPC will fit into the Long Co-Disposal waste package, it will have a diametral clearance of over 3 inches and will leave almost 60 inches of unoccupied length, so it is not a particularly good fit. Because there are only 15 of the Yankee spent fuel DPCs, an evaluation of three alternatives is needed: (i) use the Long Co-Disposal waste package, (ii) design and license a new waste package to fit the Yankee DPC, and (iii) unload the DPCs and dispose of the assemblies in PWR waste packages. Except for the NUHOMS 32 PT DPC variant (not currently certified for transport), the weights of loaded DPCs for all five of the DPC designs are less than the maximum weight for loaded Long Naval canisters (43,000 kg, 47.3 tons). A single new DPC Waste Package design that would accommodate the Holtec DPC outer diameter, and would have an internal length of about 193 inches, would handle all DPC types except the Yankee DPC. It would also accommodate the NUHOMS 32PT canister without exceeding the maximum loaded weight of the Long Naval waste package.

4. There is one handling issue that needs to be resolved. The Transnuclear (NUHOMS) DPC is designed only for horizontal transfer once it is loaded. As a result, this DPC does not include features designed to allow it to be lifted vertically using attachments to its top cover, i.e., to be removed from a shipping cask by lifting from the top, and loaded into a compatible waste package. Regardless of direct disposability, the CRWMS Requirements Document (DOE 2001b) requires that methods of unloading all DPCs be incorporated into repository design and such methods are being developed for the NUHOMS DPCs. If the NUHOMS DPCs are also to be directly disposable, the method of loading them into waste packages will also need to be developed.

5. The current waste package decay heat limit of 11.8 kW at emplacement is considerably below the typical decay heat limits for DPC storage, which are in the range of 20 to 26 kW. Substantial cooling will occur at reactor sites. DPC deliveries will not be made until DPCs cool at least to their transportation license limits, which are between storage and current waste package limits. If delivered DPCs require additional cooling after delivery, on-site storage would be needed to meet the waste package heat limit for disposal. Given the

availability of the surface storage option, thermal issues alone would not preclude DPC disposability.

Changes That Would Improve DPC Disposability

From a technical perspective, the prospects for future DPC disposability can be considerably improved. DPC designs would be modified to use control rods and/or plates containing neutron absorber materials with acceptable long-term performance characteristics in the disposal environment. Even in the most favorable circumstances, the necessary changes could not be implemented for several years, and would then be effective for only about half of the total number of DPCs expected. However, the disposability of the modified DPCs could approach 100%.

In order that correctable current DPC dimensional and handling incompatibilities not impact DPC disposability, at least one new waste package design will be needed, and a method of loading the NUHOMS DPC into a waste package needs to be developed. Because DPC decay heat can affect the timing of DPC disposal, it can influence the economics of DPC disposal, but does not otherwise impact DPC disposability.

Remediation of DPCs at Disposal Time

Although this assessment focused on DPC disposability "without reopening", remediation of DPCs at the time of disposal will always be an option, regardless of current decisions. The specific remediation approach and its viability would be based on the technologies, materials, regulatory requirements, and costs at the time of disposal, which are not foreseeable at the present time. Among the remediation possibilities that have been considered in the past are 1) opening the DPC and inserting long-lived neutron absorbers or 2) using a filler with characteristics favorable to long-term disposal, including criticality control. Difficulties were identified for both of these, and would have to be addressed if either were to be usable in any future remediation. A DPC opened for remediation may not need resealing except to the extent necessary for containment of the DPC contents, prior to insertion into a waste package.

Additional Considerations

The hypothesis that future DPCs will be disposable is valid to the degree and extent that the necessary current expenditures are made for the required modifications to DPC designs, and for their implementation. However, all such incremental current expenditures for future DPC disposability would be at risk in the sense that DPC disposability many years in the future depends to some extent on future circumstances and future regulations that cannot be foreseen. Consequently, the level of current expenditures to ensure disposability of DPCs should be related to the present value of potential future savings and other system benefits from DPC disposal. It was not within the scope of the current work to make estimates of the net economic benefits of the direct disposal of DPCs, or of the impact of the various uncertainties on those estimates. Unless design changes are made soon to address the long-term disposal criticality requirements, the fraction of DPCs that are disposable are unlikely to change significantly from present levels.

Table ES-1. Summary of Dual Purpose Canister Design Characteristics

	Holtec HI-STAR 100 MPC	**NAC Universal MPC System**	**Transnuclear NUHOMS MP-187/197**	**NAC Yankee MPC And STC**	**BNFL Fuel Solutions W21/W74**
Assembly Capacity, PWR BWR	24/32[1] 68	24 56	24/32[a] 61	36	21[b] 64 BRPt[c]
Canister Outer Diameter, in Maximum Length, in	68.375 190.31	67.06 191.75	67.19 192.2	70.64 122.5	66 192.3
Maximum Loaded Weight, lbs	89,765	75,896	101,380 (32P) 81,120	55,590	81,363
Maximum Thermal Output in Storage, kW	28.2	20	24	12.5	24.8
Design Basis Burnup(MWd/MTU)/Age(yr)	40,000/5 (8 yr, 32P)	45,000/10	40,000/16	36,000/8	40,000/10
Requires Burnup Credit ?	No(Yes-32P)	No	No(Yes-32P)	No	No
Material, Canister Internal Structures	316/304 SS[d] 316/304 SS	304L SS SS,Al - P SS,CS,Al -B	SS CS,SS	304L SS SS, Al	316 SS SS,CS
Neutron Absorber Material	SS-enclosed Boral	SS-enclosed Boral	SS-enclosed Boral	SS-enclosed Boral	SS-Boral (W21 P) Boron-SS(W74 B)
Shield Plug Material	SS	SS	CS-FO[e] Lead-FC,FF	SS	Coated CS or Encased DU

[a] The 32P canister has been licensed for storage but not yet for transport

[b] There are no current commitments to purchase the W21 (PWR) system using this DPC

[c] Big Rock Point assemblies

[d] SS is Stainless Steel, CS is Carbon Steel, Al is aluminum, DU is depleted uranium, P is PWR, B is BWR

[e] FO is Fuel Only, FC is Fuel with Control Components inserted, FF is Failed Fuel

1. INTRODUCTION

1.1 PURPOSE

The purpose of this report is to evaluate the potential for directly disposing of currently-approved commercial Dual Purpose Canisters (DPCs), without reopening, as the internal portions of current Waste Package (WP) designs. This report provides an update of DPC data in an earlier evaluation of DPCs (CRWMS M&O 1997), but has a different purpose. Specifically, this evaluation addresses whether the commercial DPCs could be loaded directly into the waste package without being opened, and then emplaced in the repository for disposal. The evaluation considers size, material selection, criticality control design, thermal design, structural design, and repository surface facility handling and operations. Because some of the DPCs have variants with respect to canister length and contents, the most constraining configurations are used in the evaluation. To the extent that DPCs are not found suitable for direct disposal in the waste package, areas where changes would be needed, both for existing and future DPCs, are identified. The remainder of this section summarizes the general background of potential DPC disposal, and outlines the structure of the remainder of the report.

1.2 BACKGROUND

Ever since utilities began purchasing canister-based storage systems in the mid-1980s, there has been a general recognition that, once CSNF assemblies are loaded and sealed in multi-assembly canisters, significant system operational advantages could be realized if those canisters could also be transported and disposed of, without reopening. These advantages included the prospect of handling fewer large, radiologically clean canisters, rather than many individual fuel assemblies with significant surface contamination, which may become more dispersible with long-term storage, followed by transportation. With respect to disposal costs, it was also recognized that the direct disposal of DPCs would avoid several costs associated with the alternative of loading bare fuel assemblies into the baskets of waste packages. These costs include:

1. Purchase of a waste package basket
2. Opening and unloading the DPC, and reloading assemblies into waste packages
3. Disposal of the empty DPC

Most DPCs contain more PWR or BWR fuel assemblies than the corresponding disposal waste packages. To the extent that the CSNF assembly capacity of a DPC exceeded that of the CSNF waste package that would be used, the cost of more than one waste package per DPC would be avoided. In addition, there would be savings in the avoided costs of waste package internals. On the negative side, however, there would be a number of early costs for waste package design and for the licensing of all DPCs for disposal, with the benefits not being realized until the time of disposal, many years in the future. Also, the repository license is expected to limit how high the thermal output of a waste package can be to maintain temperatures in the fuel cladding and repository environment within prescribed limits for both the pre-closure and post-closure timeframes. Thus, having more assemblies in a waste package could have detrimental aspects.

It is significant that the timing of DPC deliveries to DOE will be determined by the owners of the commercial facilities. Because plant owners are very likely to give priority to deliveries of pool-stored assemblies over deliveries of DPCs, at least until a comfortable storage margin is reached in pools, the majority of DPCs are likely to be delivered later in the repository's operations phase. It is likely that most early DPC deliveries will be from shutdown reactors whose owners have emptied their pools into transportable canister-based dry storage.

Table 1 lists the numbers of both single purpose and dual purpose canisters containing CSNF currently in storage at commercial sites and the numbers projected to be in storage for each year through 2020. The table lists 259 dual-purpose and 210 single-purpose canisters currently in storage at 22 sites; these contain about 4,700 MTHM of CSNF. The single-purpose canisters are included because it is possible that commercial plant operators could develop approaches to allow one-time transport of single-purpose canisters. Note that most of the projected loadings of canister-based systems are dual purpose canisters rather than single purpose canisters. The peak rate of acquisition of new DPCs is shown to be around 2010, the year repository operations are scheduled to begin. After 2014, the rate at which commercial owners will acquire new DPCs is projected to decline substantially, as the repository pickup rate begins to exceed the discharge rate, thereby gradually eliminating the need for additional dry storage. The projection shows that few additional DPCs will be needed after 2015 when there will be about 1,013 dual and 265 single purpose canisters containing a total of about 14,400 MTHM. As noted above, it is possible that the single purpose canisters with their CSNF contents will also be delivered to DOE for transport to the repository.

Initially, all dry storage was in metal casks and canister-based systems not licensed for transport. However, once transportable metal casks and canister-based storage systems became available in the late 1990s, utilities have shown a preference for these systems. All recent dry storage commitments are for transportable systems, including utilities previously committed to storage-only systems. Also, because the economics of dry storage favor the largest possible units, the canister capacities have been increasing, and the largest are now 32 PWR and 68 BWR assemblies. However, the 32 PWR canisters have only been approved by NRC for use in storage, and may require burnup credit to be used in transport systems. Also, because of increasing burnups, the current design targets for acceptable decay heat levels are approaching 40 kW. Because of these storage industry trends, progressively longer DPC cooling periods are going to be necessary in order to reach the acceptable maximum waste package decay heat levels currently anticipated for disposal.

Table 1. Projected Dual and Single Purpose Canisters at Commercial Nuclear Plants – 2003 through 2020[1]

YEAR	CANISTERS				ASSEMBLIES			MTU	SITES
	Annual	Cumulative	Dual Purpose	Single Purpose	Total	PWR	BWR		
2003		469	259	210	14720	9045	5675	4668.4	22
2004	16	485	273	212	15481	9301	6180	4863.7	22
2005	40	525	310	215	17519	9821	7698	5308.3	26
2006	96	621	399	222	21568	11614	9954	6367.4	37
2007	73	694	462	232	24919	12974	11945	7235.2	40
2008	102	796	556	240	29929	14654	15275	8476.2	41
2009	86	882	633	249	34058	16166	17892	9549.8	44
2010	89	971	714	257	38196	17518	20678	10619.1	44
2011	91	1062	802	260	42727	18766	23961	11746.7	45
2012	73	1135	873	262	46207	19854	26353	12642.5	45
2013	59	1194	929	265	49087	20790	28297	13395.0	45
2014	50	1244	979	265	51256	21702	29554	14014.7	45
2015	34	1278	1013	265	52724	22246	30478	14411.8	45
2016	13	1291	1026	265	53076	22598	30478	14564.3	45
2017	3	1294	1029	265	53148	22670	30478	14595.5	45
2018	13	1307	1042	265	53536	22990	30546	14745.0	47
2019	9	1316	1051	265	53900	23150	30750	14848.3	47
2020	4	1320	1055	265	54028	23278	30750	14901.2	47

[1] NOTE: Based on DBWI discharges and waste acceptance beginning in 2010 – 400, 600, 1200, 2000, 3000 MTHM/yr (BSC 2003b)

1.3 CONTENTS OF REPORT

The remainder of this report addresses the various factors affecting DPC disposability. Section 2 summarizes the five DPC types. Section 3 identifies the provisions for handling DPCs, and their dimensional compatibility with the current waste package designs. Section 4 addresses the nuclear criticality considerations for the Postclosure period, which imposes requirements and assumptions not addressed in certifying DPCs for transport and storage. Included are assumptions concerned with deterioration and ultimate loss of effectiveness of materials of construction (including neutron absorbers and structural supports) of DPCs. Section 5 addresses preclosure considerations including decay heat limits for storage and disposal of DPCs and the impact of these limits on the timing of DPC disposal. Sections 3, 4, and 5 discuss the consequences of changes in the factors evaluated that could improve or make feasible disposability of DPCs. Section 6 presents conclusions.

2. COMMERCIAL DPC DESIGN FEATURES

2.1 INTRODUCTION

This section summarizes the designs of five commercial DPCs with NRC-docketed license applications for transportation (10 CFR 71) and storage (10 CFR 72). The DPC systems described are the:

- Holtec HI-STAR 100 [Holtec 2000, Holtec 2002]
- NAC Universal MPC System (UMS) [NAC 2002a, 2002b]
- NAC Yankee MPC System [NAC 2001a, 2001b]
- Transnuclear NUHOMS/MP-187/197 System [Transnuclear 2001, 2002a, 2002b]
- BNFL Fuel Solutions W21/W74 Canisters [BNFL 2002, 2003)

This report refers collectively to all of the large commercial SNF canister designs used in these storage-transport systems as Dual-Purpose Canisters or DPCs, even though some of the designers have indicated their intention of making their canisters multi-purpose, and some of the designs include MPC in their name. The use of the term "DPC" in this report is purely a matter of descriptive convenience. The general design, size and configuration, and nuclear criticality design features of each DPC design are summarized in the following sections.

Thermal design features and material selection are discussed in later sections of the report.

2.2 GENERAL DESIGN

The general layout of a typical DPC is shown in Figure 1. The basic features are:

- The outer containment shell, which provides the primary isolation and containment.

- The basket, typically of box and spacer plate design. The box holds the fuel and is supported at many locations along its axis by spacer plates, which also provide heat transfer from the fuel to the exterior of the canister.

- Two pipes for draining and venting the interior of the canister.

- The top shield plug, which reduces radiation for lid welding, draining, drying and inerting.

- Two top lids, the first with drain and vent penetrations, the second with no penetrations.

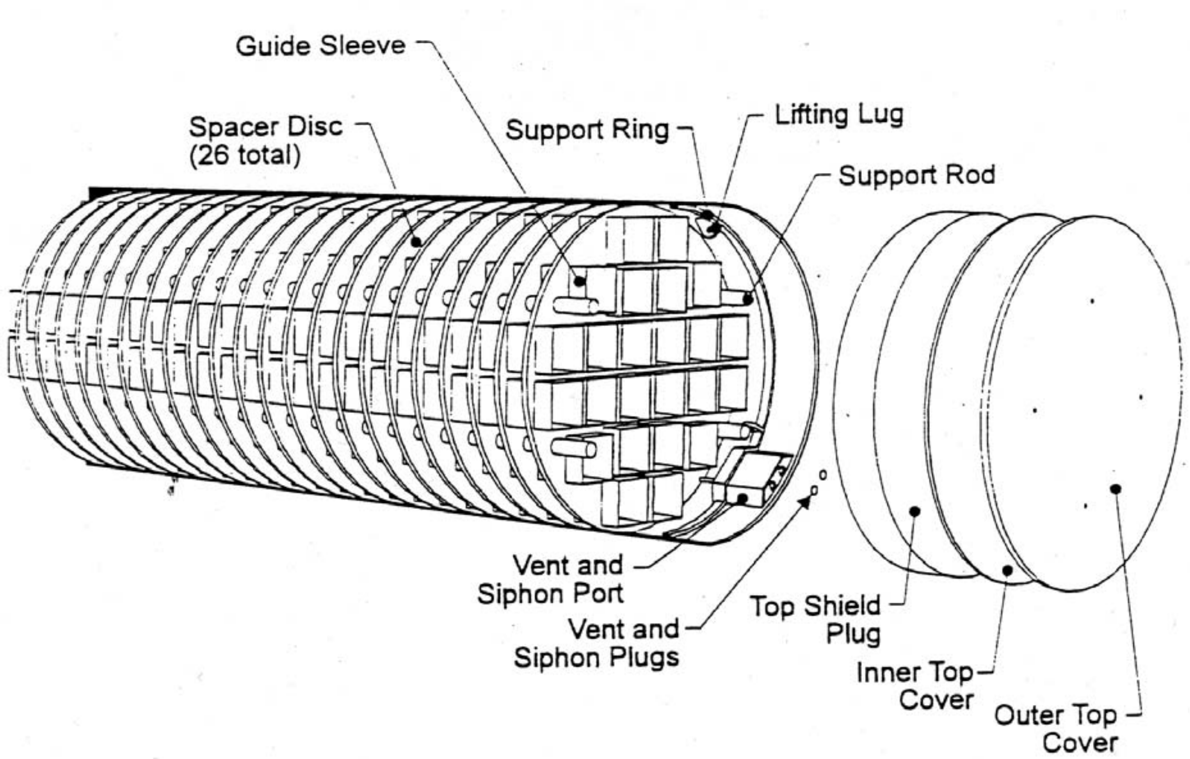

Figure 1. Typical Features of a Dual-Purpose Canister

The principal characteristics of the five commercial DPC designs are shown in Table 2. One of these designs, the Yankee MPC, is a single-application cask, for the unique, short (112 in.) fuel of the Yankee Rowe reactor. There are only 15 of these canisters that contain spent fuel, plus one canister containing Greater-than-Class-C wastes. A second design, the BNFL Fuel Solutions DPC has to date sold one system, the special canister that holds 64 Big Rock Point fuel assemblies. There are only seven of these canisters that hold spent fuel. BNFL Fuel Solutions has also obtained NRC approval for a 21-PWR transportable storage system, but has no current orders for this system. The other three DPC designs are for general usage. The PWR versions of these general usage DPCs all have a capacity of 24 PWR assemblies, all assume no burnup credit, and all make significant use of flux traps for criticality control. Holtec also offers a 32 PWR canister, which does not have flux traps and will need to assume burnup credit for transport. It has not yet been approved for use in transport. Transnuclear has also received storage certification for a 32 PWR NUHOMS canister, but this system has also not yet been approved for use in transport. The BWR DPCs have assembly capacities ranging from 56 to 68. The BWR canisters do not assume burnup credit, and do not make significant use of flux traps. The loaded canister weights range up to 90,000 lb., except for the 32 PWR NUHOMS canisters that have a maximum weight of 101,380 lb. The thermal capabilities of the three general usage DPCs range from 20 to 28 kW maximum loading for storage, which is limited by long-term fuel cladding temperatures. All of the designs use stainless steel for the canister, and most use stainless steel for the structures, with some use of carbon steel and in one case, aluminum, particularly for the spacer plates that provide axial support to the fuel boxes. The neutron absorber material is predominantly Boral, positioned, but not sealed by stainless steel sheet. Stainless or carbon steel is used as shield plug material in most of the designs, with one usage of encased depleted uranium. The NUHOMS design, which requires end shields at both the top and bottom of its canisters, uses lead in its versions that accommodate assemblies with control components (FC), or failed fuel (FF).

2.3 SIZE-RELATED DESIGN FEATURES

The characteristics of commercial DPCs that are related to size are summarized in Table 2. The largest diameter of the three general-purpose DPCs is the 68.375-in diameter of the Holtec canister. Because some of the vendors offer canisters of different lengths, the maximum lengths are shown. The loaded canister weights depend upon a number of factors, including the type and number of fuel assemblies, and whether or not non-fuel assembly hardware is attached to, or inserted in the fuel assemblies. The maximum loaded canister weights shown in Table 2 are for the heaviest of the fuel-plus-hardware types, with every assembly holding the heaviest of the non-fuel hardware, normally control rod assemblies for PWRs and channels for BWRs.

Table 2. Summary of Dual Purpose Canister Design Characteristics

	Holtec HI-STAR 100 MPC	**NAC Universal MPC System**	**Transnuclear NUHOMS MP-187/197**	**NAC Yankee MPC And STC**	**BNFL Fuel Solutions W21/W74**
Assembly Capacity, PWR BWR	24/32[1] 68	24 56	24/32[a] 61	36	21[b] 64 BRPt[c]
Canister Outer Diameter, in Maximum Length, in	68.375 190.31	67.06 191.75	67.19 192.2	70.64 122.5	66 192.3
Maximum Loaded Weight, lbs	89,765	75,896	101,380 (32P) 81,120	55,590	81,363
Maximum Thermal Output in Storage, kW	28.2	20	24	12.5	24.8
Design Basis Burnup(MWd/MTU)/Age(yr)	40,000/5 (8 yr, 32P)	45,000/10	40,000/16	36,000/8	40,000/10
Requires Burnup Credit for Transport	No(Yes-32P)	No	No(Yes-32P)	No	No
Material, Canister Internal Structures	316/304 SS[d] 316/304 SS	304L SS SS,Al - P SS,CS,Al -B	SS CS,SS	304L SS SS, Al	304 or 316 SS SS,CS
Neutron Absorber Material	SS-enclosed Boral	SS-enclosed Boral	SS-enclosed Boral	SS-enclosed Boral	SS-Boral (W21, P) Boron-SS(W74, B)
Shield Plug Material	SS	SS	CS-FO[e] Lead-FC,FF	SS	Coated CS or Encased DU

[a] The 32P canister has been licensed for storage but not yet for transport
[b] There are no current commitments to purchase the system using this DPC
[c] Big Rock Point assemblies
[d] SS is Stainless Steel, CS is Carbon Steel, Al is aluminum, DU is depleted uranium, P is PWR, B is BWR
[e] FO is Fuel Only, FC is Fuel with Control Components inserted, FF is Failed Fuel

2.4 CRITICALITY CONTROL DESIGN FEATURES

This section summarizes the criticality design features of commercial DPCs. Table 3 summarizes the principal characteristics of each design, including their usage of burnup credit, flux traps, and neutron absorbers. The assumption that water can intrude into and fully flood a canister, even though designed to exclude water, dictates the design features of DPCs provided to prevent nuclear criticality during transport. This assumption is also made when analyzing nuclear criticality for waste packages. One of the other key assumptions impacting criticality design is the assumption as to burnup credit. Because the use of burnup credit had not received regulatory approval at the time of certification for transport, the commercial DPC designers decided to design for fresh fuel, without credit for burnup. This means that the canisters are designed for a fairly high level of fresh fuel initial enrichment, which in turn requires a significant usage of both neutron absorbers, and, because of the large size of PWR assemblies, the use of flux traps in the PWR designs. Table 3 shows the average spacing (pitch) between assembly centerlines, a value that reflects both the canister inner diameter and the assembly capacity of the design. After subtracting the thickness of fuel tubes and neutron absorbers and the fuel assembly width, the remainder, as shown, is the resultant water thickness between assemblies, in effect a measure of flux trap potential and an indicator of potential over-moderation. The data show that the general-purpose PWR designs have flux traps of about 1.5-in. thickness. The BWR designs do not use flux traps, although as can be seen in Table 3, the NAC UMS BWR has considerable space for water between assemblies.

All of the 24-PWR designs use flux traps, which include neutron absorbers on each side of the water gap. Thus, every PWR assembly tube has a neutron absorber plate on each of its four faces. As a result, there are two absorber plates between each PWR assembly, and with the separation space between the two absorber plates, these make up the flux trap between each assembly. None of the BWR designs, nor the two 32P designs, use flux traps, and therefore separate each assembly with a single neutron absorber plate. This is accomplished with absorber plates on four faces of most of the assembly tubes for the BWR (and Holtec 32P) designs. Except for borated stainless steel used in the W74 canister, all of the neutron absorber materials are stainless-enclosed Boral. This neutron absorber does not qualify as a Long-Term Performance Neutron Absorber, because the stainless steel typically covers, but does not seal the Boral, and Boral would degrade and the boron neutron absorber would be lost following waste package failure. As a consequence, the benefit of these neutron absorbers cannot be included in the determination of postclosure criticality for demonstrating compliance with the criticality shutdown margins in the disposal environment.

In contrast, the CSNF waste package designs avoid the use of flux traps, use long-term performance neutron absorber materials, and assume the availability of principal isotope burnup credit, which includes burnup credit for the principal actinides and fission products. A fraction of the PWR waste packages also need additional long-term neutron absorbers, which are inserted into the control rod locations of their assemblies. Qualitatively, this shows that even with long-term neutron absorbers and substantial burnup credit, there are still some assemblies that, in degraded CSNF waste package configurations, do not have sufficient criticality safety margins without additional long-term absorbers. A greater fraction of degraded DPCs would not have adequate criticality safety margins in disposal, even with burnup credit, because their neutron absorber materials are not long-term performance materials, and could be substantially removed by degradation, following failure of the waste package.

Table 3. Summary of DPC Criticality Design Features

	Design	Burnup Credit (Y/N)	Average assembly square pitch, in.	Average[a] water between assemblies, in.	Neutron Absorbers
Holtec HISTAR-100 Cask System	32 P[c] 24 P 68 B	Y N N	9.16 10.81 6.43	0.25 1.52 0.55	SS-enclosed Boral, not sealed 24 P: all 4 faces 32 P: 2 faces 68 B: between all assemblies
NAC Universal MPC System(UMS)	24 P 56 B	N N	10.32 6.94	1.60 1.25	SS-enclosed Boral, not sealed PWR: 0.025 gB^{10}/cm^2 on all 4 faces of the tubes BWR: 0.011 gB^{10}/cm^2 between all assemblies
NAC Yankee MPC With STC	36 Yankee	N	9.07	1.17	SS-enclosed Boral plates of 0.01 gB^{10}/cm^2 minimum loading on all 4 faces of the tubes
Transnuclear NUHOMS MP-187/197	24 P 32 P[c] 61 B	N Y N	10.43 9.08 6.55	1.71 0.26 0.56	SS-enclosed Boral on 4 faces of inner 12 tubes, on 2 faces of outer 12 tubes. 32 P does not enclose Boral in SS.
BNFL Fuel Solutions W21/W74	21 P 64 BRPt[b]	N	11.08	2.31	SS-enclosed Boral PWR: 0.02 gB^{10}/cm^2 on 4 faces of the tubes BWR: 1.5% Boron-SS between all assemblies

[a] Assembly pitch, minus box and neutron absorber thickness, minus 8.44 in. (PWR) or 5.44 in. (BWR)
[b] This canister has two layers of 32 assemblies each, of Big Rock Point fuel.
[c] Not yet licensed for transport

3. HANDLING AND LOADING DPCS INTO WASTE PACKAGES

This section addresses the physical compatibility of the various DPCs with the current waste package sizes, and DPC handling capability for unloading DPCs from transport casks and loading DPCs into appropriate waste packages. The section also identifies changes to the designs regarding handling and loading into waste packages that would improve the disposability of future DPCs.

3.1 COMPATIBILITY WITH WASTE PACKAGES

The key dimensions and loaded weight limits of the principal candidate waste packages for use with DPCs are as follows:

Table 4. Candidate Waste Package Dimensions and Weights

Package	Inner Shell ID, in	Cavity Length, in	Package Weights, kg	
			Empty	Loaded
21 PWR	56.06	180.51	27,000	43,000
44 BWR	57.24	180.51	27,000	43,000
Long Naval	67.68	213.19	30,000	73,000
Long Co-Disposal	74.02	181.38	33,000	57,000

[BSC 2001 a through d]

A comparison of the above waste package inner dimensions with the outer dimensions of the five DPC types in Table 1 shows that the DPC outer diameters, in the range from 66 to 70.64 inches, all exceed the inner shell diameter of the largest civilian fuel waste package, 57.24 inches for the 44 BWR waste package. This precludes the use of the current civilian waste packages for DPC disposal. However, the Long Naval waste package will accommodate three of the five DPC types with at most about a 1-inch gap. Accommodation of the Holtec canisters would require a waste package with about a 1-inch larger diameter than the Long Naval package or a waste package with about 10 inches more length than the Long Co-Disposal waste package. Since more than 200 of these DPCs are anticipated, an analysis of the feasibility of an additional waste package design for the Holtec DPC might be justified if dimensions were the only factors preventing disposal. Although the short NAC Yankee MPC could fit into the Long Co-Disposal waste package, it would have a diametral clearance of over 3 inches and would leave almost 60 inches of unoccupied length, so it would not be a particularly good fit. Because there are only 15 of the Yankee spent fuel DPCs, an evaluation of three alternatives would be needed if dimensions were the only factors preventing disposal: (i) use the Long Co-Disposal waste package, (ii) design and license a new waste package to fit the Yankee DPC, and (iii) unload the DPCs and dispose of the assemblies in PWR waste packages. It is noted that there are only seven of the BNFL Fuel Solutions DPCs (Big Rock Point), and there are no other current commitments to this licensed DPC type.

With respect to the limiting weight of the loaded waste package, the heaviest (Long Naval) package has an allowance of 43,000 kg, (94,800 lb) for its loaded DPC. None of the loaded

DPCs would cause the 43,000 kg maximum weight to be exceeded, except the NUHOMS 32P variant which would exceed that limit by about 7%. It might be necessary to provide spacers to locate DPCs within a Long Naval waste package to prevent movement and to adjust the center of gravity of the package for handling.

If a decision were made to design a new waste package with an internal diameter to accommodate the Holtec DPC, consideration should be given to using an internal canister length of about 193 inches. That would allow the new design to accommodate all of the other DPCs except the Yankee DPC. The use of this waste package would avoid using the Long Naval waste package for the NAC, NUHOMS and BNFL DPCs, including avoidance of having to accommodate the 20 inches of unused length in the Long Naval waste package. This would be a less expensive waste package because of the shorter length and weight, and possibly because it might use the Alloy 22 barrier thickness of 20 mm that is used in the CSNF waste packages, rather than the 25 mm thickness used for the defense waste packages. Also, these weight savings appear sufficient to enable the NUHOMS 32PT DPC to be loaded without exceeding the maximum 73,000 kg (80.5 tons) loaded weight of the Long Naval waste package.

3.2 OPERATIONAL HANDLING OF DPCs

The CRWMS Requirements Document (CRD) Section 3.2.1.E requires the repository to be able to handle all DPCs (DOE 2001b). Four of the five DPC types (except the Transnuclear NUHOMS) are designed for vertical storage and transport cask loading and unloading. As a result, each incorporates features for lifting via attachments to their tops. Consequently, it will be possible for repository surface facilities to unload these types of DPCs from transport casks and load them directly into appropriate waste packages. Because the non-fixed contamination on the external surfaces of DPCs is limited to low levels and the surfaces are expected to remain clean during storage, additional decontamination should not be required during repository handling or prior to emplacement into waste packages.

Although it will be necessary for the repository to be capable of receiving and unloading about 400 NUHOMS canisters (about 25% of all DPCs), NUHOMS DPCs are not designed to be lifted using attachments to their top plates as currently envisioned for emplacing canisters into waste packages. The lid of the NUHOMS DPC is a relatively thin plate covering a shield plug. Although this lid is seal-welded to the outer shell of the NUHOMS canister to provide containment, the seal-weld it is not designed to provide structural support for lifting a canister with its CSNF contents. Also, the shield plug that is located under the lid is not structurally attached to the DPC basket, shell, or top plate and thus could not be used as a structure for lifting. For storage and transport the slight structure of the top lid is not a factor because the canisters are transferred into and from transfer/transport casks and storage modules horizontally by pushing or pulling from a bottom fitting that is accessed through ports in the transfer and transport cask bottoms. If this DPC is also to be directly disposable, it will be necessary to develop a method of waste package loading that is compatible with the approach that is being developed for receiving and unloading these DPCs from the transport overpacks at the repository.

For all five DPCs, the maximum contents are less than 36 PWR fuel assemblies, which is the amount of CSNF the LA accident analysis assumes will fail in a surface facility handling accident. The analysis demonstrates that failure of this amount of CSNF in an accident would not result in doses to the public that would exceed repository license conditions. Thus, although designs and operations will be selected to prevent drop accidents, it is likely that DPCs will not be required to provide containment following a drop accident while being handled in repository surface facilities.

3.3 SUMMARY OF HANDLING AND LOADING DPCS

The following summarizes the waste package compatibility and handling characteristics of each of the five DPC types:

DPC Type	Comment
Holtec HI-STAR	Does not fit any current waste package. An evaluation of the feasibility of providing a new waste package designed for the Holtec DPC would be required for direct DPC disposal.
NAC UMS	Closely fits the diameter Long Naval waste package, with about 20 inches of unoccupied length for the longest of the variants of this DPC.
Transnuclear NUHOMS	Closely fits the diameter Long Naval waste package, with about 20 inches of unoccupied length. The 32PT variant exceeds the maximum weight for the contents of a Long Naval package by about 7%. Because there is no current provision for vertical lifting and handling, a method of loading the DPC into a waste package needs to be developed.
NAC Yankee MPC	Loosely fits the Long Co-Disposal package with about a 3-inch diametral gap, and almost 60 inches of unused length. Because there are only 15 of these DPCs, alternatives of a new waste package design or unloading into standard PWR waste packages also need to be considered
BNFL Fuel Solutions	Fits the Long Naval waste package, with about 1.5 inches of diametral clearance and about 20 inches of unoccupied length. There are only seven of the Big Rock Point DPCs loaded with fuel, and there are no other current commitments to either the BWR or PWR versions of this design.

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4. POSTCLOSURE CONSIDERATIONS

This section reviews the postclosure aspects of using DPCs as the internals of waste packages, for direct repository disposal. The principal difference between the preclosure period, where DPC materials are assumed to maintain their structural integrity, and the post closure period is that the waste package is assumed to fail and the DPC materials are assumed to corrode and lose their integrity. Corrosion data indicate that, although it will take time after failure of the waste package, the structural integrity of the DPC basket materials would be lost, inter-assembly spaces would collapse, and the fuel assemblies would be reconfigured. Similarly, neutron absorber plates would deteriorate and the neutron absorbers could be transported out of the fuel array.

The following subsection summarizes the principal structural materials used in each of the currently-approved DPCs and the subsequent subsection discusses the consequences of the material failures on waste package criticality and related implications on DPC disposability. This section also addresses the impacts that DPC materials might have on long-term repository isolation performance: with one or two exceptions, the quantities and types of materials used are similar enough to other waste package materials that a significant effect on long-term performance analysis results would not be expected. For example, lead is used in the shield plug in the NUHOMS FC variant, and is not in the current waste packages, but is not expected to adversely impact the performance of the waste package barrier materials. Finally, the section discusses changes in designs for future DPCs and changes that might be introduced into existing DPCs to improve or enhance the feasibility of their use in disposal.

4.1 PRINCIPAL DPC MATERIALS

The principal material selections made for each of the five DPC design types are summarized in Table 5, and are as follows:

1. The three Holtec designs utilize stainless steel plates, interlocked and welded, to form their baskets, and a canister of the same material. The specific type of stainless steel used (named “Alloy X” in the HI-STAR 100 FSAR) can be selected from among four suitable ASTM stainless steels. Holtec provides this flexibility in canister materials to allow selection of the material that is “the most suitable for disposal.” In the interim, design and regulatory approval are sought for an envelope of stainless steels. Stainless steels support the flux traps that are used in the 24P design. The neutron absorber is Boral, positioned but not sealed by stainless steel sheet, and is not a Long-Term Performance neutron absorber.

2. The NAC UMS and Yankee designs use Type 304 stainless steel for the canister, the fuel assembly tubes, and the shield plugs. Several other types of stainless are used for the basket including precipitation-hardened Type 17-4 for PWR support disks, SA-533 for BWR support disks, and aluminum for heat transfer disks. Stainless steels support the flux traps that are used. Neutron absorber materials are stainless-enclosed Boral, which is not a Long-Term Performance neutron absorber.

Table 5. Summary of DPC Materials

	Canister	Basket	Shield Plugs	Neutron Absorbers
Holtec International HISTAR-100 Cask System	Alloy X[a]	Alloy X SS supports flux traps in 24P design	Alloy X	SS-enclosed Boral, 4 faces24P 2 faces 32P, 1 or 2 faces B
NAC Universal MPC System(UMS)	SS Type 304L	Support Discs - SS Type 17-4 PH(P) - CS SA 533(B) Heat Xfer Disks - Al Type 6061-T6 Fuel Tubes - SS Type 304 (P&B) SS supports Flux traps	SS Type 304L	SS-enclosed Boral PWR: 0.025 gB^{10}/cm^2 on all 4 faces of the tubes BWR: 0.011 gB^{10}/cm^2 between all assemblies
NAC International NAC-Storable Transport Cask (MPC - Yankee)	SS Type 304L	Same as UMS	SS Type 304L	SS-enclosed Boral plates of 0.01 gB^{10}/cm^2 minimum loading on all 4 faces of the tubes
Transnuclear NUHOMS MP187/MP197	SS Type 304	Spacer Discs - Carbon Steel, Al coated Fuel tubes - SS Type 304 CS Supports flux traps	CS, FO Lead, FC and FF	SS-enclosed Boral on 4 faces of inner 12 tubes, on 2 faces of outer 12 tubes
BNFL Fuel Solutions W21/W74 Canisters[b]	SS 316 or 316L	Spacer Disks- SS, 316 or 316L, and CS, SA-517 Grade P Fuel tubes SS 316 or 316L SS supports Flux Traps	Coated CS or Encased DU	SS-enclosed Borated Al PWR: 0.02 gm B^{10}/cm^2 on 4 faces of the tubes BWR: 1.5%Boron-SS between all assemblies

[a] Alloy X is one of four stainless steel materials, one of which Holtec expects will be acceptable for disposal in the Monitored Geological Repository (DOE 1998). The four ASTM materials that meet the requirements for Alloy X are: 316, 316LN, 304, and 304L

[b] Material information is not available in the non-proprietary SAR but was found in the Dual-Purpose SNF Transportation and Storage Systems Interface Information for the ISF.

3. The Transnuclear NUHOMS system uses Type 304 stainless steel in its canister. Within its basket, aluminum-coated carbon steel supports its flux traps. For its shield plugs, carbon steel is used in its Fuel-Only (FO) design; steel-encased lead is used for its Fuel-plus-Component (FC) and Failed Fuel (FF) designs. Because lead serves as a functional component of the DPC, it would not be classified as a RCRA waste and therefore is not expected to affect the disposability of FC and FF canisters. Although lead corrosion could possibly impact the corrosion of other materials, it would not do so until after waste package failure. The neutron absorber material is stainless-enclosed Boral, which is not a Long-Term Performance material.

4. In the BNFL Fuel Solutions DPCs, stainless steel (304 or 316) is used for the canister, and either stainless steel or nickel-coated carbon steel can be used for the basket components, depending upon customer preferences. The neutron absorber

material is either sealed Borated aluminum for PWRs or boron stainless steel for BWRs. Its shield plugs can be of either encased Depleted Uranium or coated carbon steel. Stainless steel supports its significant flux traps.

As a generalization, it is noted that all commercial DPC designs use a stainless steel canister, all 24-PWR DPCs use flux traps and (with the exception of Transnuclear and the optional exception of BNFL Fuel Solutions) structurally support those flux traps with stainless steel. Furthermore, except for the BNFL BWR DPC, none of the designs use a Long-Term Performance Neutron Absorber Material, meaning that credit cannot be taken for these neutron absorbers for long-term criticality control following loss of waste package integrity.

4.2 DPC CRITICALITY FOLLOWING WASTE PACKAGE FAILURE

Prior to waste package failure, DPCs would retain the preclosure integrity of their internal structure, neutron absorbers, and criticality safety margins. The preclosure, critically-safe configurations are the result of the design for storage and transportation. The required design assumption for transportation regulatory compliance is that, even though the fuel in the canisters is to be stored and transported dry, it and the fuel support structure must be assumed to be in its most reactive state, which includes flooding with water. Furthermore, because the use of burnup credit was not yet accepted by NRC at the time of licensing, all five of the currently-approved DPCs were designed to prevent criticality without taking credit for burnup of spent fuel contents. Thus, the designs were developed assuming that the enrichment of all fuel assemblies in a DPC is the pre-irradiation enrichment. In this regard, BWR fuel has some advantage over PWR fuel because BWR assemblies are smaller, permitting more effective use of (and different materials for) fixed neutron absorbers in DPC baskets. In contrast, the most effective means available to DPC designers to control the reactivity of the larger PWR assemblies with relatively high initial enrichments and no burnup credit, is to use both neutron absorbers and flux traps. Flux traps are spaces with neutron absorber plates on each side placed between each fuel assembly in a basket array. When flooded with water these traps increase the effectiveness of the neutron absorber plates thereby working with the neutron absorbers to prevent nuclear criticality.

However, in the postclosure period, after the loss of waste package integrity, the neutron absorbers and the stainless steels in the current DPCs would degrade. The neutron absorbers used in the basket (which are Boral, a boron-carbide powder dispersed in an aluminum matrix that is typically held in position, but not sealed, by stainless steel plates) would be lost, and the structural integrity of flux traps would also be lost. Using stainless steel corrosion data, results of long-term performance analysis indicates that stainless steel structures would fail a few thousand years after waste package failure (BSC 2003a). The integrity and functional effectiveness of exposed Boral would likely be lost before complete failure of the stainless structure. Boral that is encapsulated in stainless steel (as in the BNFL W21 canister) could be lost relatively soon after failure of its stainless steel encapsulation. (Only 1% of waste packages are estimated to fail before 25,000 years (Mean estimate, Figure 4-92 of DOE 2001a)). A few early waste package failures could occur during the first 10,000 years. A result of the loss of stainless steel integrity would be reconfiguration of the DPC's CSNF contents. The reconfiguration could be, effectively, a compact array of fresh fuel assemblies without significant interspersed neutron absorbers. With the assumption of flooding, this reconfiguration could initiate a nuclear criticality. To demonstrate otherwise it would be necessary to perform case-by-case analyses that would include credit for fuel burnup to demonstrate the CSNF contents could not become critical after loss of fuel support structures and fixed neutron absorbers. Absent such an analysis and burnup credit, the potential for a nuclear criticality, along with the potential for early waste package failures could preclude disposal of any of the five current DPC types.

Given the foregoing, the disposability of any current DPC will depend upon being able to take credit for the burnup of the CSNF contents, and whether or not such burnup credit is enough to provide the required level of criticality safety. Principal isotope burnup credit (principal actinides plus principal fission products) is being assumed in the waste package design and licensing for assemblies being loaded into CSNF waste packages at the repository. If the same burnup credit were to be authorized for disposal of DPCs, the disposability of specific DPCs would further depend upon how each DPC was loaded (i.e., initial enrichment and burnup of each loaded fuel assembly). Some of these data could be based on actual discharges, but most of it would have to be for projected future discharges and future DPC loadings. The required analysis is somewhat analogous to the determination that must be made as to whether PWR assemblies should be loaded into absorber plate or control rod type waste packages. The development of realistic estimates of the fraction of DPCs that would be disposable using burnup credit, would therefore require a substantial analysis effort, which was not within the scope of this evaluation. If such an estimate were developed assuming burnup credit for DPCs on the same basis as for CSNF waste package design and licensing, it is reasonable to expect that a fraction of current DPCs would be disposable.

With respect to eligibility for burnup credit, the current waste package design and licensing assumption is that principal isotope burnup credit will be licensed on the basis of using utility plant operating records of individual assembly discharge burnups, provided to DOE at the time of delivery. Current regulatory guidance for *storage and transportation* of spent nuclear fuel (Regulatory Guide 3.71) states that “credit for fuel burnup may be taken only when the amount of burnup is confirmed by physical measurements that are appropriate for each type of fuel assembly in the environment in which it is to be stored.” However, because no current DPCs rely on burnup credit, few of the current DPC loadings included such prior measurements. This lack of assembly burnup measurements would not be a concern for DPC disposal if using reactor records of assembly burnup as the basis for burnup credit is ultimately licensed, as is being assumed and used for waste package design and in the license application for disposal.

With respect to criticality-related changes that would improve the disposability of future DPCs, the licensing and use of long-term performance neutron absorber plates, instead of Boral, would be the most beneficial improvement. In addition, PWR control rod assemblies using long-term performance materials would be made available as required for insertion and mechanical locking into selected PWR assemblies at the time of DPC loading. If access through the top fitting could be obtained, neutron poison rods might also be used in BWR assemblies. These rods would be made of, or encased in long-term performance materials, such as boron carbide pellets in zircaloy tubes. The number of these control rod assemblies or rods per DPC could be varied to control the amount of criticality shutdown margin, and if desired to provide additional margin to offset regulatory uncertainty. In the limit, the judicious use of long-term performance absorber materials could result in close to 100% disposability of the so-modified DPCs. The costs of design, licensing, and the procurement and installation of these long-term performance absorbers would likely be the majority of current costs that would be expended in expectation of the larger, future benefits of DPC disposal. Also, and regardless of current decisions, there will always be the future operational option of opening and modifying DPCs at the repository to incorporate long-life fixed neutron absorbers or other features that would limit the potential for criticality. This could be accomplished without removing the spent fuel contents, would allow use of the canister as a component of the waste package, and would eliminate the need to dispose of empty DPCs separately. Ultimately, the kinds of modifications that may be possible would depend on the DPC design, the regulatory requirements and available technologies at that time, associated costs, and difficulty of making such modifications. These factors are not within the scope of this analysis.

4.3 OTHER POSTCLOSURE ISSUES

The prospective replacement of some CSNF waste packages with a lesser number of DPC waste packages raises the question of possible impacts on TSPA. In that regard, it is noted that the same assemblies are being put into the repository in both cases, and therefore the source terms are identical. Similarly, since the disposal would occur at approximately the same times, the decay heats, energy deposition, and undergound drift length/areal usage will be essentially the same. Second-order differences might occur if the larger DPCs require more surface cooling prior to disposal, but these are of essentially no significance to TSPA. There will be small quantity differences in the structural materials emplaced underground. The materials themselves are the same or similar, except for a few NUHOMS 24 FC and FP variants, which have an encased lead shield lid, and the aluminum in some DPC spacer plates and in the Boral neutron absorber plates. It will need to be confirmed that the generally-small differences in material types and quantities between DPCs and the CSNF waste package materials do not significantly impact corrosion rates to the extent of altering repository performance assessment.

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5. PRECLOSURE OPERATIONAL AND REGULATORY ASPECTS

Many of the disposal requirements for DPCs have been met via the design features needed for DPC functionality and certification for transport and storage. This section addresses those preclosure requirements for disposal that are different from, or in addition to transport and storage requirements. Specifically, the remainder of this section discusses acceptable levels of decay heat output at the time of disposal, which are generally less for disposal than storage and transport. It also reviews the possibility of encountering structural issues that could arise if there are operational or accident conditions that are more severe than in transport or storage operations. Finally, it discusses the potential impact of safeguards and accountability requirements associated with the level of verification that may be associated with final disposal.

5.1 IMPACT OF WASTE PACKAGE THERMAL LIMITS

Assuming the repository could remain open until heat levels decayed, waste package thermal limits would not directly affect ultimate DPC disposability. However, the heat output rates for DPC contents do impact the timing of disposal, thereby affecting the timing of operational and financial benefits that would arise. The timing of such benefits can be an important consideration in evaluating the tradeoff between spending current funds to facilitate future DPC disposability, and the present value of the future benefits from DPC disposal. The two principal factors affecting the timing of DPC disposal which are discussed in the remainder of this section are 1) the timing of DPC deliveries from the utilities, and 2) the time it takes for the DPC to cool down to the maximum acceptable waste package heat level, currently 11.8 kW. Basically DPC disposal takes place at the longer of these two time periods. To the extent that utilities deliver CSNF in DPCs that have not cooled to the waste package heat limit, because of their high fuel assembly capacities, it would be necessary to store the DPCs longer than if the contents were removed and placed in waste packages. Thus, it is possible that disposing DPCs could delay termination of repository operations beyond that of removing CSNF from the DPCs and loading it into waste packages.

<u>The Timing of DPC Delivery from the Utilities:</u> As noted earlier, the timing of DPC delivery is a utility decision. Because initially, deliveries of pool-stored assemblies at operating facilities are very likely to have a much higher priority than deliveries of DPCs, the majority of DPC deliveries are likely to occur later in reactor operating lifetimes. However, for shut-down plants, and possibly when storage pool inventories have been drawn down to a comfortable level, reactor plant operators may elect to deliver DPCs to eliminate dry storage that requires additional oversight and security operations at their sites. Most early deliveries of DPCs would be expected from shut down reactors whose owners have emptied their pools into transportable canister-based dry storage. The 2002 Design Basis Waste Input Report (BSC 2002) is based on the assumption that all 104 operating reactors will receive 20-year operating license extensions, and the additional assumption that utilities will only deliver DPCs when they have no pool-stored fuel that is older than five years. This analysis shows a few early DPC deliveries from shutdown reactors, but the majority of DPC deliveries could occur in the period from 2032 to 2046, which is on the order of 30 years from their time of loading.

The Cooling Period Needed to Reach the Waste Package Heat Limit: An estimate of the cooling time between DPC loading and the time of emplacement at the waste package decay heat limit can be developed using the maximum decay heat limits for DPCs at the time of loading, and the decay characteristics of spent fuel. Table 6, below summarizes the maximum DPC heat outputs for transport and storage conditions.

Table 6. Thermal Characteristics of DPC Designs

DPC Design Type	Design Capacity Ass'ys	Thermal Output, Storage kW	Thermal Output, Transport kW
Holtec International HI-STAR-100 Cask System	24 P 32 P 68 B	28.2 28.2 28.2	13.7* N/A 13.7*
NAC Universal MPC System (UMS)	24 P 56 B	23	16*
Transnuclear, NUHOMS MP-187/ MP197	24P 32P 61B	24 24 18.3	13.6* N/A 13.1*
NAC Yankee MPC and STC	36 Yankee	12.5	12.5**
BNFL Fuel Solutions W21/W74	21 P 44 B	22 24.8	22** 22**

* Thermal limit is the approximate cask thermal output at the cask transport radiological limit

** Thermal limit in license, based on maximum thermal level of analysis, not at the radiological limit

The above table shows higher heat limits for storage, which are based on thermal license limits, as compared to those for transport, which for the first three (general purpose) systems in the table, are the estimated thermal outputs at the licensed radiological limits. This difference is related to the fact that the contents of storage casks tend to be limited by fuel temperature, which is directly related to total heat output, whereas the contents of transport casks tend to be limited by external radiation dose levels, which generally result in lower heat output than for storage.

Figure 3 for PWR CSNF and Figure 4 for BWR show the relationships of the decay of fuel assembly heat to the heat limits of the contents of DPCs listed above and for waste packages. By way of illustration, the PWR graph of watts/assembly versus cooling age includes horizontal lines at a DPC storage limit of 24 kW and the current waste package limit of 11.8 kW for a 32PWR DPC (triangles) and a 24PWR DPC (diamonds). For the 24PWR DPC, the graph shows that 50 GWd/MTU fuel having a decay heat of 1000 W/assembly (24 kW DPC limit) at about eight years from discharge, would decay to the 490 W/assembly waste package limit (11.8 kW total) at about 36 years from discharge, a net of 28 years in DPC storage. The same 50 GWd/MTU fuel, if loaded into the 32PWR DPC could be loaded after about 16 years cooling and would reach the waste package limit for 32 PWRs at about 56 years after discharge, for a net DPC storage period of 40 years.

Figure 3. PWR Assembly Thermal Output, W/475 kg Ass'y

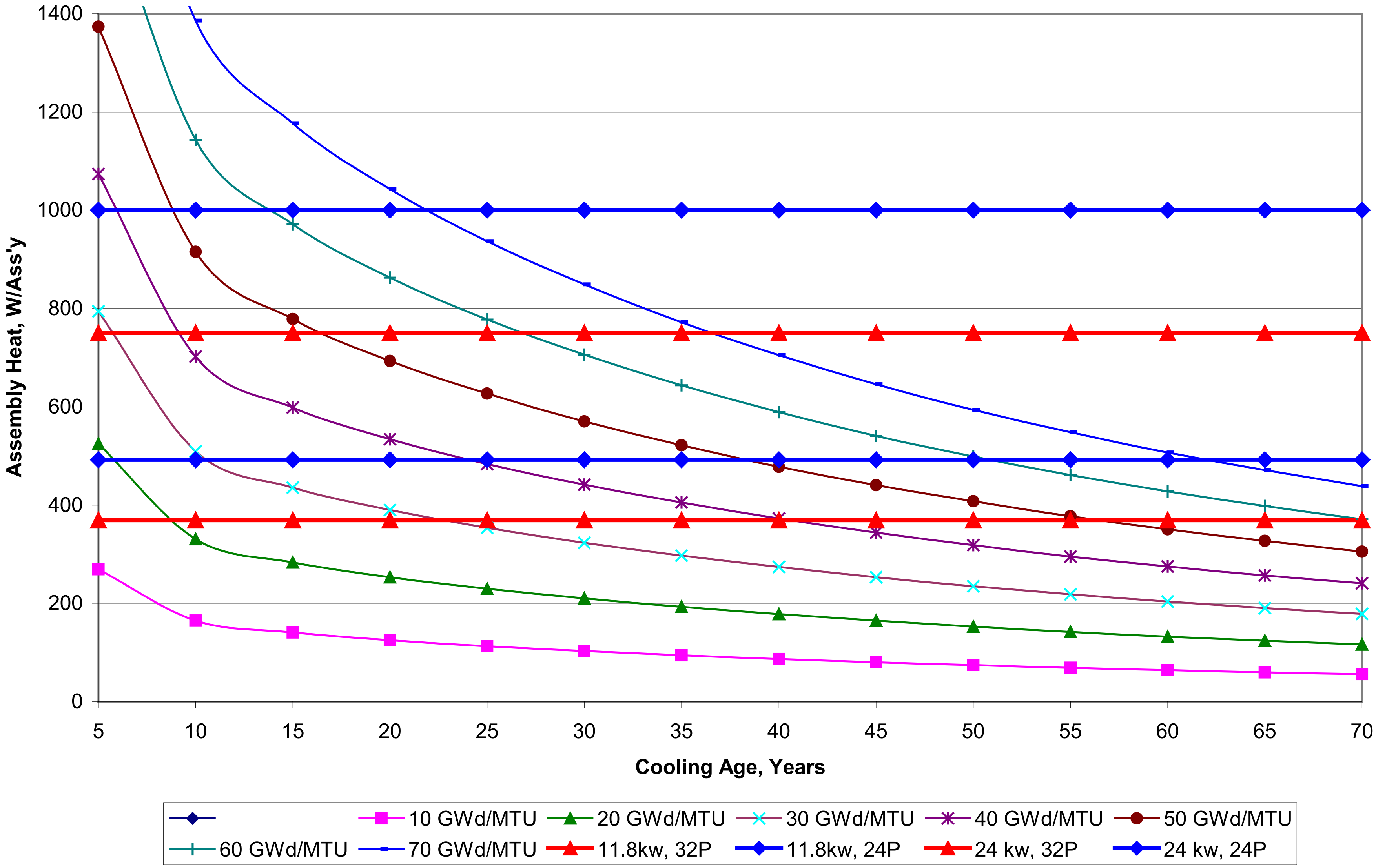
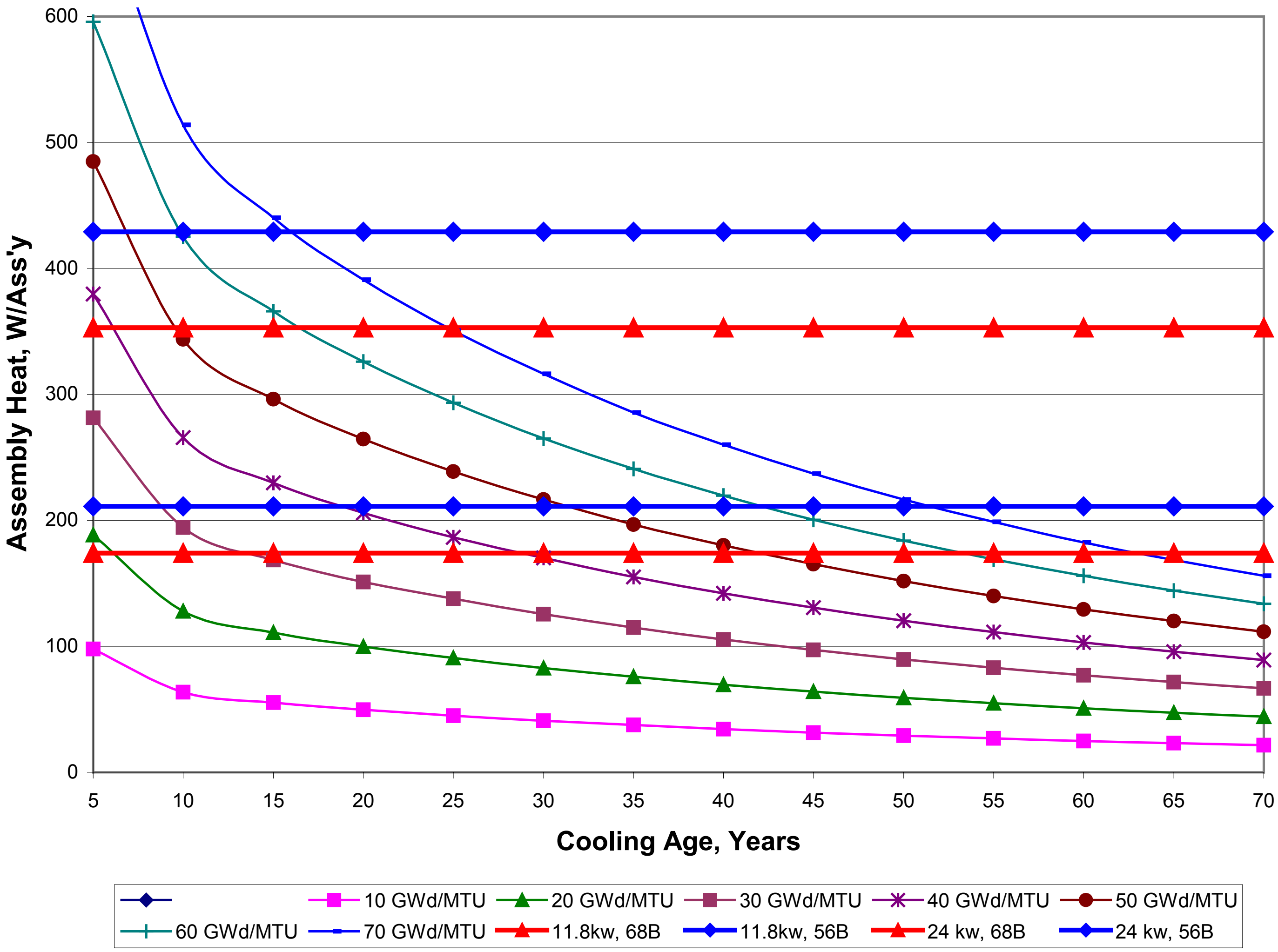


Figure 4. BWR Assembly Thermal Output, W/200 kg Ass'y



If the plant operator selected a mix of shorter cooled, hotter SNF and longer cooled, colder SNF to meet DPC heat limits, the time for the contents of the DPC to decay to the waste package limits could be longer. To the extent that DPCs were loaded below their thermal limits the required DPC storage periods could be correspondingly less. Similar results are obtained with BWR fuel, except that the required time for DPC storage would be five to eight years less than for DPCs containing PWR fuel. Since storage cask licenses are for 20 years from the date of issue, a necessary assumption in this section, is that the required license renewals will be requested by the licensee and granted by NRC.

The basic conclusion that is reached from the foregoing is that the storage periods for the three general purpose DPC types at commercial facilities, before being transportable to the repository, are roughly comparable to the cooling periods required for DPC contents to meet waste package heat limits, and are in the range of 25-40 years. This is fortuitous in the sense that if DPCs were deliverable much earlier and waste package heat limits were not increased, DPCs would have to be stored at the repository for additional cooling, relative to the cooling required for the DPC's contents if unloaded into standard waste packages. This basic conclusion as to a 25-40 year delay in DPC disposal also indicates that the realization of the principal benefits of being able to directly dispose DPCs would be deferred for that period. However, if waste package heat limits were increased from the current level of 11.8 kW, the cooling period requirements for disposal of both DPCs and the same CSNF in standard waste packages would be correspondingly less, and the cooling period required for transportability might determine the delivery and disposal times.

It should also be noted that the issue of DPC disposability has, at most, only small impacts on the thermal aspects of waste package emplacement, underground energy deposition, and usage of the underground area. If the DPCs are sufficiently cool to be emplaced when they arrive at the repository, the thermal impacts are essentially identical to the those encountered if the DPCs were to be unloaded into standard CSNF waste packages. There may be fewer, hotter DPC waste packages, but they would be spaced further apart, and the total drift usage, which is based on a constant kW per meter of drift, would be identical because the aggregate CSNF contents are the same assemblies, emplaced at the same time. If the DPCs were too hot for immediate emplacement, but their CSNF contents could be immediately emplaced, the DPCs would subsequently require somewhat less drift length (and underground area). They would also deposit slightly less aggregate total energy into the underground, than if they were unloaded for immediate emplacement in standard CSNF waste packages. In actual practice, there would be second-order differences created by operational practices, such as assembly blending in waste packages, which could result in different disposal times for some assemblies, relative to their disposal in DPCs.

Current storage trends are being driven by the fact that, as burnups increase, the current DPC heat limits are becoming too low for the fuel that needs to be stored. Therefore the vendors are developing new variants within the existing DPC envelope, but with higher heat limits. Target heat limits for these newer designs are as much as 40 kW (NOTE: 40 kW is approximately the decay heat produced by 32 PWR fuel assemblies having a burnup of 60 GWd/MTU and cooled for 10 years.). These higher storage heat limits for DPCs would require almost 40 years of cooling prior to emplacement in the repository if the waste package limit were 20 kW, but the cooling needed to meet the radiological limit of the transport cask might determine the minimum time to delivery. Much longer times (on the order of 70 years) would be required prior to emplacement to allow the contents to decay to the current 11.8 kW waste package limit. It is anticipated that as these DPCs initially come into use, they will be loaded with available CSNF that, in general, produces less heat than the limits allow. However, as burnups increase, fuel assembly heat rates can be expected to approach the limits specified in CoCs. As these DPCs start to be delivered for disposal, depending upon their heat output at their radiological limits, they may require additional cooling at the repository before they could be loaded into a waste package for disposal. The basic problem associated with any DPCs that need additional cooling and storage after they have been delivered, is their large assembly capacity. The same assemblies loaded into the standard 21 PWR or 44 BWR waste packages would be disposable considerably earlier. Thus there are additional costs for the cooling-related DPC storage, beginning from the later of 1) the time of delivery, or 2) the time at which their assemblies could have been loaded into a standard waste package. Such additional DPC storage costs reduce the benefits of DPC disposal, but delay the direct costs of disposal, and this should be recognized in any financial or business risk assessment of DPC disposal.

5.2 OTHER POTENTIAL PRECLOSURE ISSUES

A DPC waste package drop accident, DPC canister drop accident, seismic event, or other design basis accident would not result in the release of radioactive material greater than would result from the failure of 36 PWR assemblies assumed as the basis for the repository surface facility accident analysis. Also, regardless of whether DPCs were disposed in waste packages or opened to remove CSNF, in accordance with the CRD, they must be appropriately handled at the repository. Thus, it is unlikely that preclosure safety issues/requirements associated with handling would be different, regardless of the disposition of the DPCs.

It is likely that the NRC will allow DOE to accept accountability records for DPCs provided by NRC licensed facilities. These records along with unique serial numbers affixed to DPCs will provide chain-of-custody documentation including the identity of the contents of each canister and the information necessary to determine the identity and location of specific fuel assemblies within the canister. It should not be necessary to open canisters to verify the identity of contents.

6. CONCLUSIONS

The five currently-approved DPC design types have been reviewed for direct disposability as the internal portions of current waste package designs. The evaluation considers size, material selection, criticality control design, thermal design, structural design, and repository surface facility handling and operations. To the extent that DPCs are not found suitable for direct disposal in waste packages, areas where changes to existing and future DPCs would be needed are identified. The conclusions of this evaluation are summarized below.

Postclosure Materials Performance and DPC Criticality Potential

Without credit for burnup, no current DPCs, nor those soon to be loaded, will be directly disposable. All licensed commercial DPCs assume fresh fuel (no burnup credit), utilize neutron absorber materials, primarily Boral, that are not long-term performance materials, and use flux traps in PWR configurations. The DPCs use stainless steel structural materials for basket internals, including support of neutron flux traps for criticality control in PWR DPCs. Stainless steel is also used to position, but not to seal the Boral neutron absorber plates used for criticality control in most PWR DPCs. Results of the repository long-term performance analyses indicate that failure of such stainless steel supports would occur a few thousand years after waste package failure, including early failures (NOTE: Only 1% of waste package failures are estimated to occur prior to 25,000 years). With failure of the waste package, boron criticality control materials would be lost, and eventual stainless steel failure would result in collapse of flux traps in PWR DPCs. Ultimately, the resulting unpoisoned degraded array of fresh fuel materials, when flooded with water, could support a nuclear chain reaction – a nuclear criticality. Thus, because of their construction and neutron absorption materials, the design assumption of fresh fuel, and the potential for waste package failures, such DPCs would not be disposable. In contrast, CSNF waste packages are designed with credit for burnup, and the materials used in waste package internals are selected (and positioned) to remain intermingled with the spent fuel contents in a way that limits the potential for nuclear criticality to very low levels, over the long periods of time following failure of the waste package.

It is expected that some DPCs, those containing highly burned CSNF, would not go critical even with the loss of neutron absorbers. In order that such DPCs be disposable, they need to evaluated with credit for burnup. Principal isotope burnup credit, based on operating reactor records of assembly burnups, is being assumed in the design and licensing of CSNF waste packages. Assuming the same basis for DPC burnup credit, estimates could be developed for the fraction of DPCs that would be disposable, but the substantial analysis effort that would be required is beyond the scope of this report. Nonetheless, it is reasonable to expect that a fraction of current DPCs would be disposable. As a condition for using burnup credit for transportation and storage, current NRC regulatory guidance requires confirmatory assembly burnup measurements prior to loading. Because DPCs have been designed and licensed without the need for burnup credit, such measurements have not been made for the contents of all but a few of the DPCs loaded to date. However, if reactor assembly burnup records are approved by NRC as the basis for burnup credit, the lack of a burnup measurement would not affect DPC disposability. It will be some time until regulatory requirements for burnup credit for disposal are confirmed by actual licensing. If disposal of DPCs is not addressed in initial licensing, it will take additional time to resolve any burnup credit issues that are unique to DPCs.

DPC Compatibility with Current Waste Package Designs and Handling Issues

All of the DPCs are too large to fit into the current CSNF waste packages, but three of the five would fit into the Long Naval waste package. The Holtec DPC does not fit any of the current waste packages, and would require a waste package inside diameter one-inch larger than that of the Long Naval package. The NAC Yankee DPC could fit loosely into the Long Co-Disposal package. Because there are only 15 of these DPCs, the alternatives of using the Long Co-Disposal package, providing a new package, or unloading these DPCs into 26 standard PWR waste packages would need to be evaluated. All of the DPC types could be loaded within the 43,000 kg weight limit for the loaded Long Naval canister, except for the NUHOMS 32PT variant, which would exceed that weight by about 7%. One of the five DPC types, the Transnuclear NUHOMS, cannot be lifted by attaching to its top. Although it will be necessary for the repository surface facilities to be capable of handling this type of DPC, for disposal it would also be necessary to develop means for loading the canister into a waste package without damaging it. The other four DPC types are designed to be lifted vertically using attachments on their tops, and thus could be loaded into a compatible waste package using available attachments.

Changes That Would Improve DPC Disposability

From a technical perspective, the prospects for future DPC disposability can be considerably improved. DPC designs would be modified to use control rods and/or plates containing neutron absorber materials with acceptable long-term performance characteristics in the disposal environment. Even in the most favorable circumstances, the necessary changes could not be implemented for several years, and would then be effective for only about half of the total number of DPCs expected. However, the disposability of the modified DPCs could approach 100%.

In order that correctable current DPC dimensional and handling incompatibilities not impact DPC disposability, at least one new waste package design will be needed, and a method of loading the NUHOMS DPC into a waste package needs to be developed. Because DPC decay heat can affect the timing of DPC disposal, it can influence the economics of DPC disposal, but does not otherwise impact DPC disposability.

Thermal Limitations and Interaction with Utility Delivery Timing

The large and increasing heat limits, currently in the range of 25 kW for storage of DPCs, will require cooling of 25 to 40 years prior to disposal in waste packages, which have a current heat limit of 11.8 kW. It is expected that, for operating nuclear plants, much of the cooling will take place at the plant sites. Utilities are likely to continue storing DPCs at operating plants as long as there are deliverable fuel assemblies in their pools. Thus, most of the DPC deliveries are expected in the 2032 to 2046 time period. The resultant cooling time at utility sites is therefore expected to be on the order of 30 years, which for most will probably be sufficient to meet waste package heat limits. For DPCs delivered before they have cooled sufficiently for disposal, storage capability would need to be provided at the repository site.

Based on current disposal planning, because of the large number of assemblies contained and the fixed heat rate limit for waste packages, the average time for storage would be greater than that required to store the DPCs' spent fuel contents prior to emplacement into waste packages, which have less capacity. This disadvantage could begin to appear sooner than 2032 when DPCs from shut-down plants are delivered. Provisions would need to be made at the repository to store these DPCs (possibly in the same storage area used to cool spent fuel) until their contents had cooled enough for emplacement in waste packages. Because of the availability of this surface storage option, the greater heat output of DPCs does not provide a technical basis that would preclude DPC disposability.

Potential Regulatory Issues

Repository operational or accident situations involving DPCs that would be more severe than the accident being analyzed for the repository license application are unlikely. Although an NRC regulatory position has not been established, nuclear material accountability information provided by the operators of nuclear facilities licensed by the NRC should be sufficient to meet repository accountability, operational safety, and disposal requirements.

Remediation of DPCs at Disposal Time

The scope of this work was to evaluate DPC disposability "without opening", and this precluded an evaluation of remediation alternatives. However, remediation of DPCs at the time of disposal will always be an option for future system operators, and is thus an alternative for DPC disposal, regardless of current decisions. The specific remediation approach and its viability would be based on the technologies, materials, regulatory requirements, and costs at the time of disposal, which are not forseeable at the present time. Among the remediation possibilities that have been considered in the past are 1) opening the DPC and inserting long-lived neutron absorbers or 2) using an ideal filler with characteristics favorable to long-term disposal, including criticality control. Difficulties were identified for both of these, and would have to be addressed if either were to be usable in any future remediation. A DPC opened for remediation may not need resealing except to the extent necessary for containment of the DPC contents, prior to insertion into a waste package.

Additional Considerations

The hypothesis that future DPCs will be disposable is valid to the degree and extent that the necessary current expenditures are made for the required modifications to DPC designs, and for their implementation. However, all such incremental current expenditures for future DPC disposability would be at risk in the sense that DPC disposability many years in the future depends to some extent on future circumstances and future regulations that cannot be foreseen. Consequently, the level of current expenditures to ensure disposability of DPCs should be related to the present value of potential future savings and other system benefits from DPC disposal. It was not within the scope of the current work to make estimates of the net economic benefits of the direct disposal of DPCs, or of the impact of the various uncertainties on those estimates. Unless design changes are made soon to address the long-term disposal criticality requirements, the fraction of DPCs that are disposable will not change significantly from present levels.

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