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Spent Fuel and Waste Disposition

Technical & Programmatic Solutions for Direct Disposal of DPCs: Draft Outline and Staffing Plan

Spent Fuel and Waste Disposition

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Table of Contents

Acronyms

BUC	Burnup credit
BWR	Boiling water reactor
CSF	Consolidated Storage Facility
DOE	U.S. Department of Energy
DOJ	U.S. Department of Justice
DPC	Dual-purpose canister
DWF	Defense Waste Fund
FEP	Features, events and processes
ISG	Interim Staff Guidance
NRC	U.S. Nuclear Regulatory Commission
NWF	Nuclear Waste Fund
ORNL	Oak Ridge National Laboratory
PWR	Pressurized water reactor
R&D	Research and development
SRNL	Savannah River National Laboratory
SNF	Spent nuclear fuel
SNL	Sandia National Laboratories
THMC	Thermal-hydrologic-mechanical-chemical
TSLCC	Total system life cycle cost
TSPA	Total system performance assessment

Technical & Programmatic Solutions for Direct Disposal of DPCs – Draft Outline and Staffing Plan

WBS: 1.08.01.03.05
Work Package: SF-18SN01030505 Technical and Programmatic Solutions for Direct Disposal of DPCs – SNL
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This is a work planning document that describes technical and programmatic goals for disposition of spent nuclear fuel (SNF) that is currently in dry storage in dual-purpose canisters (DPCs), or will be in the foreseeable future. It then describes how those goals can be promoted by a research and development (R&D) program. The needed R&D is compared to the ongoing work supported by the U.S. Department of Energy in FY18, and planned for FY19 and beyond. Some additional R&D activities are recommended, and plans are presented for technical integration activities that address the efficacy of the Direct Disposal of DPCs program (WBS 1.08.01.03.05), and integration with the overall Disposal Research program (WBS 1.08.01.03).

The planned deliverable for this work package in FY19 (M2SF-19SN010305051-*Analysis of Solutions for DPC Disposal*; 6/19/19) will be the product of this workplan. The deliverable will evaluate technical options for DPC direct disposal, taking into account the range of past and current DPC designs in the existing fleet. It will describe a set of goals for successful disposition of spent fuel in DPCs. It will analyze the scope and timing of needed R&D activities (R&D Plan), and discuss the uses of generic and site-specific analyses. Where appropriate, it will use alternative management cases to represent how DPC direct disposal could be incorporated in the overall geologic disposal program, given uncertainties in program direction and funding.

Staffing will be provided to ensure success of this integration effort, with support from Oak Ridge National Laboratory (ORNL) and Savannah River National Laboratory (SRNL), specialty contractor support, and technical staff and management support from Sandia National Laboratories.

1. Objectives for DPC R&D Plan

The report generated by the Technical & Programmatic Solutions work package will include a summary of R&D and long-term activities, needed to implement disposal of commercial SNF in DPCs. That report is referred to here as the R&D Plan, and its content will include the following topics:

- **Develop Plans to Address Two Scenarios Using DPCs for Disposal** – The "Base Case" to which the two DPC scenarios will be compared is that for which only purpose-designed, standardized storage, transport and disposal (STAD) canisters are used, and100% of the DPCs are re-packaged into STAD canisters. The two DPC scenarios (major options) are:
  - **100% of the DPCs are Directly Disposed**: This will result in the least number of STAD canisters, which would be used for a subset of the spent fuel, primarily bare fuel being shipped directly from reactor spent fuel pools.

- **Partial Use of DPCs for Disposal**: This scenario is based on the assumption that only some DPCs could be qualified for direct disposal, and that those not qualified for disposal would be re-packaged into STAD canisters. A significant portion of the R&D in the Plan described below is directed at determining which DPCs could be qualified for disposal "as is" and options for increasing the number of DPCs that could be qualified for disposal.

- **Describe High-Level Goals for DPC R&D Work** – Identify and describe the main goals: minimize overall worker and public health risks (both radiological and non-radiological); avoid introducing potentially insurmountable difficulties in the ability to demonstrate compliance with applicable U.S. Nuclear Regulatory Commission (NRC) regulations (e.g., 10 CFR 63); minimize additional time to repository opening; and minimize overall costs to the Nuclear Waste Fund (NWF), the U.S. Department of Justice (DOJ) Judgment Fund, and to taxpayers.

  The primary goal of near-term R&D work should answer the following question: *Does the cost saving from not having to re-package, justify the additional costs of: 1) redesign and additional licensing for one or more geologic repositories; 2) extending cooling time prior to disposal; 3) developing one or more special overpacks; 4) developing filling systems (if needed); and 5) developing systems to handle heavier waste packages.*

- **Compare the Role of DPC Direct Disposal (versus re-packaging into STAD canisters) in Meeting High-Level Goals** – Evaluate whether high-level goals are sensitive to the differences between major options identified above: 1) near-100% direct DPC disposal (avoiding almost all re-packaging), partial DPC disposal to reduce but not eliminate re-packaging, and 100% use of STAD canisters. The primary differences discussed are relative improvements or degradation of meeting the high-level goals for each option. Many of the differences described require additional R&D to better evaluate the risks and benefits of each of the three options.

- **Identify the Major R&D Efforts** – The major R&D efforts to determine the feasibility of full or partial DPC direct disposal are:

  - Evaluate the ability of DPCs to maintain subcriticality in a reasonable range of disposal environments, and conversely, identify those DPCs that cannot be demonstrated to maintain subcriticality with a sufficient confidence.
  - Determine postclosure criticality consequences, which may include thermal, hydrologic, mechanical, and chemical (THMC) process changes, and must include any significant short- and long-term health consequences.
  - Develop and test potential DPC filler options to ensure subcriticality or limit criticality consequences, while also limiting impacts from the fillers (cost, toxicity, gas generation, radionuclide mobility, long-term degradation).
  - Identify new or modified approaches to licensing that are needed to implement full or partial DPC disposal along with the risks and costs of developing these approaches.

- Evaluate the scope of design or redesign of surface facilities for DPC disposal, compared to alternative concepts (e.g., the Yucca Mountain License Application design), needed to include temporary lag storage of DPCs to help meet worker dose and thermal requirements, packaging and handling systems for sealing DPCs into appropriate disposal overpacks, transport of DPC-based waste packages into the underground disposal facility, and emplacement of the waste packages in disposal settings.
- Evaluate the scope of design or redesign of underground facilities to accommodate larger diameter, heavier, and hotter waste packages compared to purpose-design systems (e.g., the Yucca Mountain License Application design).
- Identify and evaluate any differences in overall worker and public health risks compared to previous assessments, during handling and disposal of DPCs, including receipt, packaging, storage, transport, and repository underground operations through monitoring and closure.
- Identify and provide working outlines for any additional licensing and permitting documents needed, and supporting analyses.
- Calculate changes in costs for replacing 100% STAD canister disposal (re-packaging) with full or partial DPC disposal. Estimate the break-even cost, that is, the minimum number of DPCs that would need to be disposed of directly, to keep the total system life-cycle cost (TSLCC) approximately the same as disposal of 100% STAD canisters.

The required additional R&D should address the following high-level requirement: *Direct disposal of DPCs **must** reduce overall costs without increasing overall health risk and without undue negative effects on licensing and the time to final repository closure.* While health risk reduction would be seen as a benefit, it might not be much of a selling point. On the other hand, DPC disposal should not increase worker and public health risk. It would also be less risky if it can be demonstrated that criticality of any kind is essentially impossible.

The R&D Plan will also include a discussion of the necessary human and laboratory resources to conduct the above R&D activities and a rough-order-of-magnitude cost estimate for these R&D activities. Cost information will be general, but broken down to a level that supports high-level decision making, for example, fillers R&D will be separated from other direct disposal R&D activities.

Given the programmatic implications of introducing full or partial direct disposal of DPCs, the R&D Plan will also provides a description of:

- Issues that would need to be discussed between the DOE and other federal organizations such as the U.S. Congress, the U.S. Department of Justice, and the U.S. Nuclear Regulatory Commission. The R&D Plan will also describe issues specific to DPC operations and disposal that would be taken up with other stakeholders such as affected States.
- Aspects of DPC designs and operations used by industry that affect the potential for postclosure criticality in DPC-based waste packages. From a technical standpoint, it

would be useful to discuss such designs and operations with industry to determine the feasibility of changes that could reduce the possibility of postclosure criticality. The R&D Plan will focus on *potential* issues that could arise when engaging industry in such discussions, to support DOE decisions on *whether and how* to engage.

2. DPC Direct Disposal High-Level Goal – Minimize Overall Health Risk

Health risks can be divided into worker and public health risks, and there are both radiological and non-radiological health risks. Products from the Technical & Programmatic Solutions work package will include analysis of health risks specific to the major options defined above.

Worker radiological risk examples that are affected by use of DPCs for direct disposal rather than re-packaging of commercial SNF are:

- At-reactor pool operations to qualify spent fuel for loading into DPCs or into bare fuel transportation systems; loading into DPCs for initial dry storage; fuel and DPC inspections; transfer to transportation overpacks; and possible re-packaging into STAD canisters.
- Transportation dose, which is a function of the surface dose rate from the transportation overpack, the distance from the driver, and the total number of shipments. This would include possible radiological releases from accidents.
- Worker dose from operation of a Consolidated Storage Facility (CSF) or lag storage at a disposal facility. Operations include receipt, inspection (direct and skyshine doses), transfer, possible re-packaging into STAD canisters at a CSF, and potential radiological releases.
- Worker dose from operation of disposal surface facilities, including fuel receipt, lag storage, storage, inspection, possible re-packaging, facility maintenance, waste transfer underground, and potential radiological releases (e.g., release of fission gases from failed spent fuel pins or due to accidents).
- Worker dose during underground operations, including exposure from handling and transporting waste packages, exposure to Rn-222 from mining and underground operations, and dose and release consequences from off-normal events (e.g., tunnel collapse or seismic activity).

Non-radiological health risks to workers that are potentially affected by DPC direct disposal include: at-reactor lifting accidents, traffic or train accidents that cause harm to workers, surface facility lifting accidents, and surface and subsurface construction accidents.

Examples of health risk to the public involving radiation would be:

- For at-reactor and consolidated storage, exposure from direct radiation or skyshine, and accidental radiological releases.
- For waste transportation, exposure from direct radiation or skyshine, and accidental radiological releases;

- Rn-222 releases from repository construction and ventilation, and risk from releases caused by normal loading operations or off-normal events such as tunnel collapse or seismic activity.
- For surface handling facilities, exposure from direct or skyshine, and release of fission gases from failed spent fuel pins or due to accidents.
- For subsurface facilities: potential radiological releases during normal loading operations or off-normal events such as tunnel collapse or seismic activity, or very long-term doses from released radionuclides transported through groundwater and air pathways.

One example of a health risk to the public not involving radiation would be transportation accidents including not just shipments involving spent fuel, but also shipments of construction materials and other types of accidents that could occur in the public domain during construction and repository operations.

3. DPC Direct Disposal High-Level Goal – Minimize TSLCC

The primary goal for a scenario involving direct disposal of DPCs is to reduce TSLCC, primarily those costs incurred by the DOE. The sections presented below will discuss spent fuel management costs that could be affected by use of DPCs for direct disposal as opposed to 100% re-packaging.

It may be useful at this point to consider the sources of funding for commercial SNF management and disposal. At present, the costs for managing SNF from the time it is generated in the reactors until it is disposed of are borne by different groups:

- Electricity ratepayers via utility contributions to the Nuclear Waste Fund (NWF).
- Utility costs borne partially by the ratepayers and partially by the utility shareholders, including:
  - Storage prior to 1/31/98.
  - Storage expenses not reimbursable by the government (see below).
  - Spent fuel pool operations (including spent fuel inspection to qualify for storage and transportation).
- Taxpayer costs:
  - DOJ Judgment Fund for utility damage awards (Congressional mandatory funding).
  - Defense waste management costs may only be marginally impacted by direct disposal of commercial SNF in DPCs.
  - Potential additional funding in the future if the NWF is inadequate, which may occur if contributions do not resume, or future production of nuclear power is insufficient to generate needed additional NWF funds.
  - Other Congressional discretionary spending (e.g., from the NWF or Defense Waste Fund).

In order to minimize the TSLCC (i.e., total over all payers or potential payers) it might mean that funding from some of these groups may actually increase or the timing of the need for funding may be altered.

4. Other High-Level Goals

Additional high-level goals for direct disposal of commercial SNF in DPCs include:

- Direct disposal must be both technically and politically acceptable. While the R&D Plan discussed here will focus on technical issues, the program will necessarily be subject to national policies and funding availability. Hence, the R&D Plan will be subject to revision as more is learned and developed technically and as funding and policies evolve.
- All waste management facilities and operations must be licensable. Hence, new regulatory issues that arise due to direct disposal of DPCs must be identified, a strategy for addressing those issues (including possible licensing risks) must be developed, and development of licensing documents and regulatory support must also be considered.
- Minimize the amount of time prior to disposal initiation and final repository closure. This goal is listed for a combination of cost, technical and policy reasons.
- Reduce or limit future impacts on the existing utility-DOE contracts.

5. Potential Effects of DPC Direct Disposal on High-Level Goals – Required R&D

This section discusses the influence of implementing direct disposal of commercial SNF in DPCs on a large scale, compared to re-packaging, on meeting the high-level goals described above. The differences associated with DPC disposal may be relative improvement or degraded ability to meet the goals. Many of the differences listed below would require additional R&D for more useful understanding.

- Health risks:
  - Direct disposal of DPCs might or might not reduce the amount of subsurface excavation and ventilation (Rn-222 to workers/public; mining accidents). While DPCs are somewhat larger than purpose-design canisters and the number of waste packages would be fewer, the size of the disposal drifts could increase, and the spacing between disposal packages could increase to manage greater decay heating.
  - Direct disposal of DPCs would reduce receipt facility handling operations (both radiological and non-radiological risks) because less re-packaging would be needed.
  - Accordingly, avoiding re-packaging through the use of DPCs would reduce the likelihood and possibly the magnitudes of onsite and off-site radiological releases.
  - If re-packaging into STAD canisters is done “upstream” either at the utility site (in spent fuel pools or other facilities at or near power plants), or at a CSF, this would increase the number of shipments if STAD canisters are smaller, although it would reduce the amount of re-packaging required at repository surface

facilities. In addition, re-packaging costs could be borne by different funding entities depending on where the re-packaging is done.

- Costs:
  - Direct disposal of commercial SNF in DPCs would produce *cost savings* because: 1) the number of new STAD canisters would be less; 2) the number of disposal overpacks would be less (with larger canisters); 3) the number of re-packaging operations would be reduced; 4) DPC canister hulls would not need disposal as low-level waste; 5) the size of repository surface facilities would be reduced; and 6) potentially fewer SNF shipments. Some re-packaging capacity would still be needed to deal with SNF in DPCs that could not be qualified for disposal, so the surface facility would still need the necessary space and equipment, and capacity to handle DPC hulls, although at reduced scale.
  - Direct disposal of commercial SNF in DPCs would increase costs because: 1) greater licensing costs due to the introduction of additional issues related to direct DPC disposal; 2) pre-disposal DPC storage costs could increase due to longer thermal aging prior to disposal, and 3) repository construction, operation, monitoring, and closure costs could be greater if larger drift diameters and waste package spacings (total excavated volume) are needed. Note that if the aging times for DPCs are very long, re-packaging may be required anyway due to degradation of the DPC shell during storage.[1]
  - The potential use of a "filler" material to eliminate the possibility of post-disposal criticality or to reduce the effects of such a criticality is part of this R&D Plan. Fillers, if used, would increase costs compared to not using fillers, and would also increase worker dose during filler operations.
  - For some costs it is unclear if they would increase or decrease such as: 1) the total length of disposal drifts needed for thermal management; 2) the amount of land required for a repository; and 3) the disposal overpack total cost which could be greater depending on the design requirements for DPC direct disposal.
  - Who is affected by the cost changes?
  - The utility ratepayer might not be affected if the amount collected from ratepayers for the NWF is not changed.
  - Costs paid by the utilities would likely only increase if they change their loading operations to facilitate DPC disposal in some way.[2] If this were to occur, the utilities could negotiate with the DOJ to determine whether the additional expenses would be reimbursable.

[1] Evaluation of the longevity of DPCs and their dry storage systems, and methods for mitigation of such degradation is an active area of R&D – some of which is funded by DOE separately. Hence the spent fuel storage R&D plan is not covered here.

[2] For example, if the utilities were to select different spent fuel or relocate the same spent fuel assemblies differently inside the DPC to reduce the likelihood or consequences of a post-disposal criticality, this could incur additional operating costs (qualifying spent fuel for disposal, additional licensing calculations) and additional worker dose.

  - Outlays by the DOJ Judgment Fund for utility management of SNF, which are essentially borne by taxpayers, could increase or decrease if DPC direct disposal is implemented on a large scale. For example, the amount of Judgment Fund disbursements could be reduced if the use of DPCs for disposal meant that at least some SNF were transferred from utilities earlier;
  - Taxpayer and Congressional discretionary spending (NWF/DWF) could be less if the TSLCC can be lowered.

- Technical feasibility: The technical feasibility of disposal of DPCs has already been partially evaluated. In principle, it appears that at least some DPCs can be disposed of directly without introducing unworkable technical complications. Technical feasibility for disposal of other DPCs is possible, but more complicated in some instances. This is addressed in the discussion of near-term R&D needs below.
- There will be additional licensing issues if DPCs are used for disposal. This is especially important if criticality consequence screening is used in screening of features, events and processes for performance assessment (PA). It will be necessary to develop robust technical and regulatory analyses to demonstrate compliance with the relevant disposal regulations.
- The time at which disposal of spent fuel could be started may be earlier or later than a system that only uses STAD canisters. For example, some DPCs might be qualified for disposal relatively easily. Since DPCs do not require a surface handling facility that includes the re-packaging capabilities, disposal of this DPC subset could occur prior to the commissioning of the entire surface handling facility. Hence, initiation of disposal could occur earlier than for the case of re-packaging. This assumes there is no significant change in the length of the licensing process for a scenario involving DPC disposal.
- The time at which the disposal facility is completely loaded might be later for the scenarios involving DPC disposal, if additional thermal aging time is needed to meet disposal thermal criteria.
- The exact policy impacts of DPC direct disposal will need to be determined by DOE and other decision makers. In the sense that use of DPCs for direct disposal does not alleviate the need for storage, transportation, or disposal, there may be little policy effect. Obviously, if use of DPCs can be shown to be safe, feasible, and less expensive than re-packaging, this would be a major benefit. The policy implications of who would benefit from the cost savings would need to be determined. There could also be value in the ability to initiate disposal earlier if this can be shown for at least some DPCs. The direct disposal of DPCs that were not designed for disposal will introduce the need to evaluate whether DPCs can remain subcritical and if no, whether the consequences of any criticality are no more than minor. There may be a policy concern about introducing the possibility of criticality events in the public and licensing arena.

Conclusion: *Direct disposal of DPCs **must** reduce overall costs without undue negative effects on licensing and the time to final repository closure. It would also be less risky from both a health* *and regulatory standpoint if it can be demonstrated robustly that criticality of any kind is essentially impossible, or has negligible consequences.*

Proceeding to research and implement DPC direct disposal will require significant expenditures of both financial and "political" capital. R&D should be prioritized to assist DOE in making short-term and long-term policies and spending plans.

Thus, the goal of the nearer-term work must address four sets of issues, postclosure criticality related, engineering, preclosure safety assessment and PA, and cost. These are addressed separately in the following sections.

6. Needed R&D Tasks – Criticality-Related

As discussed in various sections above, the postclosure criticality aspect of DPC direct disposal requires several actions:

- Determine which DPCs can be demonstrated to remain subcritical under long-term disposal conditions, with acceptable analysis effort and regulatory risk.
- For those DPCs that cannot be demonstrated to remain subcritical, determine the consequences of a potential criticality events in the repository.
- With respect to DPCs loaded in the future, consider discussing with utilities the possibility of loading some DPCs differently to reduce the likelihood and/or consequences of a postclosure criticality event(s).
- Determine whether and how to continue to investigate options for injecting filler material into some DPCs to address criticality, using the canister fill/vent ports and not cutting lids off, bearing in mind the potential complexity and costs of doing so.

Discussion

As discussed above, no matter what disposal system is used, it is necessary to evaluate the probability of a criticality event that could occur during the first 10,000 years of repository operation (see 10CFR63 and Hardin et al. 2015 for assumptions and context). If the probability of the event is sufficiently low, it is not necessary to calculate any consequences of a criticality event should it occur. For the Yucca Mountain License Application the probability was demonstrated to be sufficiently low that consequence analysis was not necessary. The Yucca Mountain TADs were designed with different criteria than the existing and planned DPCs with respect to criticality issues. Specifically, the Yucca Mountain transport-aging-disposal (TAD) canister was specified to contain a corrosion-resistant neutron poison material that could perform its function throughout the postclosure regulatory period. Since DPCs were only designed to last for several decades under dry storage conditions, the additional expense of corrosion-resistant neutron poison material was not warranted. To determine which of the many DPC basket designs could be critical in a repository, considering the fuel actually loaded into each DPC and the possibility of misloads, would be a major analysis task. This deterministic approach has been an ongoing effort and has proceeded as relevant industry data on basket designs and fuel characteristics has been made available. The effort to increase the number of analyzed DPCs continues, but the results already show that a majority of existing (and future) DPCs will not have sufficient reactivity margin to be demonstrated subcritical by this approach. The goal of DPC direct disposal could be served effectively using other strategies possibly in combination with this approach.

Starting in FY18, the focus on criticality work has expanded to include initiation of work on criticality consequences for all DPCs (not just those that cannot be demonstrated to remain subcritical using the approach discussed above). Consequence screening (with reference to FEP screening) involves modeling how the repository source term would change with the occurrence of criticality events. A bounding approach is preferred for simplicity, and would be sufficient for comparison to results without criticality, to determine whether criticality events are "significant by omission" (10CFR63.114(a)) in which case they could be excluded from PA.

Modeling criticality consequences in a repository means discerning how many waste packages could eventually achieve criticality, and when during the repository evolution. Much of the modeling insight that can be used does not depend on criticality, for example, the incidence and timing of waste package (overpack) breaches that admit ground water into a DPC. Bounding the source term in the event that a criticality event occurs, will greatly simplify the implementation of consequence analysis in PA. Probabilistic consequence screening analysis of this type is the main thrust of the current R&D program because it could in principle be used for any DPC, is insensitive to misloads, and integrates closely with other features and processes typically represented in repository PA models.

On the other hand, mechanistic modeling of the detailed physics and chemistry of a criticality event sequence would involve mathematical models for degradation of the fuel rods, fuel assemblies, fuel basket, DPC and overpack layers, and the near-field environment. Mechanistic modeling is important for understanding postclosure criticality events, for example the type of event, the energy produced, duration, damage to the waste form and packaging, and effect on the near field. It will define the processes that degrade the fuel and basket so that criticality shuts off. For FY18 and FY19, modeling sensitivity studies will be conducted to identify which submodels and processes could have the greatest impact on probabilistic consequence screening. Depending on the results of that work, additional simulation development and validation may be supported.

The following items are a list of criticality-related tasks that are either largely complete, partially completed, initiated, or not yet started. All those listed that are not complete are proposed for FY19 and beyond (note that all statements about future work are subject to availability of funding).

Planned Activities

- As-loaded DPC criticality analysis (*Ongoing in FY18 and planned to continue as long as DPCs are being loaded).* Continue to gather design information and "as-loaded" fuel characteristics, in a comprehensive DPC database, for analysis of criticality under disposal conditions (Work Packages SF-18OR01030501 Rev. 3 and SF-19OR01030501 Rev. 0). Stylized configurations (loss of absorber; basket degradation with loss of absorber) are used to identify DPCs that are relatively unlikely to achieve criticality (compared to other DPCs). This analysis could be useful in the future to stratify the existing fleet of DPCs, to evaluate which should be included in a consequence screening strategy.

- As-loaded analysis with misloads (*Ongoing in FY18 and planned to continue as long as DPCs are being loaded).* Perform criticality evaluations assuming DPCs were misloaded by selecting the correct fuel but inserting it in the wrong cells in the fuel basket (Work Packages SF-18OR01030501 Rev. 3 and SF-19OR01030501 Rev. 0). Cases where incorrect fuel was selected are not considered.

- Consequence screening analysis (*FY18–20 and beyond).* Investigate how criticality events affect repository regulatory dose, for generic (non-site specific) cases. Include the incidence and timing of waste package breaches, and the availability of water or moisture to degrade or flood DPC internals. Define criticality features, events and processes (FEPs; SNL 2008) as appropriate for the screening strategy (Work Packages SF-18SN01030506 Rev. 0 and SF-19SN01030506 Rev. 0).

- Neutronic-thermal-hydraulic-mechanical coupled simulations (*FY19 and beyond as needed*). Steady-state and transient criticality events will be investigated by numerical simulation (Work Packages SF-18OR01030501 Rev. 3 and SF-19OR01030501 Rev. 0). Sensitivity studies will evaluate whether criticality varies in different DPC types with fuel of different characteristics.

- Fuel/basket degradation analysis *(FY18–19 and beyond as needed)*: Simulate the degradation of DPCs to project the degradation and displacement of neutron absorbers, and the progression of fuel and basket degradation leading to failed configurations (Work Packages SF-18SN01030507 Rev. 0 and SF-19SN01030507 Rev. 0).

- BWR burnup credit model development (*FY19 and beyond*). At present, NRC has only granted partial burnup credit (BUC) for DPCs containing PWR fuel. The database of BUC data for BWR fuel is not considered adequate at this time. Hence, subcriticality for DPCs containing BWR fuel must be demonstrated with limited reliance on BUC. Historically, work was initiated on BWR BUC more than a decade ago but stopped, but is planned to resume in FY19 (Work Packages SF-18OR01030501 Rev. 3 and SF-19OR01030501 Rev. 0). It is anticipated that this task could rely on existing data, however, an assessment will be made to identify any needed data gaps and what sort of testing would be needed to fill them.

- Changes to fuel loading, and other modifications to future DPCs to facilitate postclosure criticality control (*FY19 and beyond).* The following topics are planned and are covered in a companion workplan (Hardin 2018; Work Packages SF-18SN01030505 Rev. 1 and SF-19SN01030505 Rev. 0):

  – Change DPC fuel loading schema (*FY19*). Identify examples of existing "as-loaded" DPCs that are shown to go critical with degradation on exposure to disposal conditions, but which could remain subcritical with changes in fuel loading.

  – Add neutron poisons (*FY19*). Identify examples of existing "as-loaded" DPCs that have been shown to go critical with degradation on exposure to disposal conditions, but which remain subcritical if additional, durable neutron poisons were loaded with the fuel. Review possible DPC modifications (e.g., disposal control rods) with rough cost estimates, and review of impacts on fuel pool operations.

- DPC filler investigations (*FY18–19*). Proceed with planned fillers investigations to evaluate the viability of a strategy involving pumpable fillers (Work Packages SF-18SN01030502 Rev. 1, SF-18OR01030501 Rev. 3, SF-19SN01030502 Rev. 0, and SF-18OR01030501 Rev. 0). Fillers should be cost effective and meet future requirements related to storage, transportation, and future disposal requirements related to structural, thermal, criticality, and retrievability performance.

Unplanned Future R&D

Other R&D not currently planned (as of 9/19/18) to be planned, funded, and performed as needed:

- Cs-133 burnup credit *(FY19 and beyond).* Cs-133 is a high-yield fission product (6.8%), a stable isotope, and a relatively strong neutron absorber. Hence, it could be a more effective burnup credit isotope than many of those currently credited. As long as fuel pins are intact, there is no path for release of Cs-133, and it remains effective as an absorber of neutrons. Credit for Cs-133 is already accepted for storage and transportation. It is proposed to conduct analyses and develop documentation to support NRC approval for Cs-133 credit for criticality calculations. An assessment of existing data will first be completed to evaluate if additional Cs-133 testing is needed.
- Changes to fuel loading, and other modifications to future DPCs to facilitate postclosure criticality control (*FY19 and beyond).* The following topics are proposed:
  - Utility interaction (*FY20 or beyond*). Based on the review and analysis of fuel loading schema and neutron poisons described above, to be completed in FY19, the DOE may choose to discuss loading changes with the utilities.
  - Disposability specification (*FY20 or beyond*). Develop general specifications for future DPCs that could be used to increase the number of that can be shown to be subcritical. Work with vendors to develop ROM costs and market implementation information.
- Develop burnup verification tool *(multi-year effort starting as soon as FY19).* Per ISG-8 Rev. 3 (NRC 2012) burnup confirmation would eliminate misload considerations from deterministic storage and transportation applications, which is one of the most significant vulnerabilities in the current "as-loaded" analysis approach. This instrumentation development work would be especially useful if the applicability of consequence screening is limited. Would require phased development and testing with irradiated fuel in a spent fuel pool.
- Validation and confirmatory testing *(FY19–22*). Develop and perform validation experiments for neutronics models, and confirmatory testing of conditions at which prompt criticality could occur.
- Overpack reliability (*FY19 to FY22).* Develop methods to mitigate human error in manufacturing and testing of disposal overpacks, to reduce the probability of early failure. Define failure rigorously to include classes of defects and partial-performance.
- Environmental review (*FY19*). Determine which DPCs contain potentially significant amounts of lead.

- Confirmatory experiments for consequence screening. Key confirmatory data will be identified by the consequence analysis team, followed by investigation of how experiments could be used to acquire that data.

7. Needed R&D Tasks – Engineering Design

The following R&D tasks are currently unplanned (as of 9/19/18) and are recommended to support high-level decisions on viability of DPC direct disposal and most effective R&D:

- Surface handling concepts. Develop a design concept for a surface handling facility that could add disposal overpacks to DPCs. The facility should be relatively simple to license, build, and qualify for operation. Such a facility could allow increased throughput of DPCs and potentially less re-packaging. The design should be sufficiently detailed such that a rough order-of-magnitude (ROM) cost can be developed.
- Overpack concepts. Develop appropriate DPC disposal overpack concepts with improved reliability of manufacture and implementation.
- Generic repository concepts of operation. DOE is currently funding generic work on development of disposal facilities in four types of geologic media. Key challenges in implementation should be investigated for at least two of these geologic media types, so that technical maturity can be evaluated and improved repository cost estimates can be developed if needed. These challenges could include heavy shaft hoist development and operational safety analysis, underground transfer equipment (e.g., shaft to emplacement machine), and emplacement equipment. They could also include layouts and mine plans, emplacement configurations, and concepts and safety/reliability for remotely operated equipment (especially that to be used for emplacing unshielded packages, and backfilling around unshielded packages).

8. Needed R&D Tasks – Postclosure Performance Assessment and Preclosure Operational Safety Analysis

The following PA activity is underway, and is planned in future years to be the principal thrust of consequence screening (Work Packages SF-18SN01030506 Rev. 0 and SF-19SN01030506 Rev. 0):

- Total system performance assessment (TSPA). Long-term waste isolation behavior of the repository system, including disposed DPCs, will be analyzed to determine if dose projections would comply with regulatory standards. TSPA will also be used to determine if dose is significantly changed when internal waste package criticality is included—this is the crux of the consequence screening strategy.

This activity would supplement postclosure TSPA with operational safety considerations:

- Generic preclosure safety analysis. Key features of a generic repository for DPC-based packages, such as the underground waste transporter, package emplacement machine, and shaft hoist for heavy waste packages, will be analyzed to evaluate whether they can be implemented safely and in compliance with applicable regulations.

9. Needed R&D Tasks – Cost Analyses

The following efforts are planned in FY19 for the Technical & Programmatic Solutions work package:

- Improved cost estimates are needed to better determine the economic value of DPC disposal compared to re-packaging in STAD canisters. While preliminary cost analyses for geologic disposal systems are available, they generally don't consider all relevant major cost items, at least not explicitly. This is most important for high-cost items that would be different for disposal of SNF in DPCs vs. STAD canisters. Such cost differences could be important with respect to disposal overpacks, surface handling and packaging facilities, and utility facilities. Some costs are controlled by hardware vendors and service contractors, which should be engaged.
- Where is the "break-even" point at which the additional costs for R&D and program changes to facilitate DPC direct disposal, are exactly offset by the lower costs from avoiding re-packaging? Break-even could be expressed in terms of the total amount of SNF that is disposed of in DPCs relative to STAD canisters. Program changes for DPC direct disposal include design changes to surface and underground facilities, new packaging specifications, extended aging time for some DPCs, development of one or more specialized overpacks, and development of filler materials and delivery systems.
- Cost projections should include the "no-action" alternative, that is the cost of continued long-term storage and the possibility that aged canisters would be remediated at some uncertain time in the future (e.g., by sleeving). Logistics simulations can be used to determine when cooling criteria are met for DPCs (Hardin et al. 2015).
- Develop cost estimates for pump-able fillers, including raw materials, delivery systems, fixturing, canister ovens, etc.
- Develop cost estimates for near-term and long-term R&D, including any larger-scale, longer-term tests. Organize R&D cost estimates around the R&D needed to promote specific strategies. For example, isolate R&D program costs for strategies such as "as-loaded" analysis with BUC and burnup verification, or consequence screening combined with "as-loaded" analysis to the extent practical, or a fillers strategy.
- Develop cost estimates for technical analysis and documentation, and licensing activities, to implement DPC direct disposal.

10. Technical Integration

In FY19, work will be undertaken under this Work Package, to review and integrate all aspects of the current DPC disposal R&D program, and to integrate with other Disposal R&D work under WBS 1.08.01.03 (Disposal Research). To ensure its success, the DPC disposal R&D program needs the benefit of work conducted in other areas of the Disposal Research program. For example, development of TSPA models and coding of new features for PFLOTRAN software, are potentially important for DPC consequence screening applications if technically integrated. Work plans and work products for elements of the Disposal Research program will be evaluated for missing scope, that could support DPC disposal efforts. If appropriate, recommendations will be made for planning work to achieve better overall program integration.

Peer Review Panel

Preparations will begin for an encompassing independent expert peer review panel, to be planned for FY20 or FY21. The peer review will address readiness for each of the major options (defined in Section 1): full re-packaging, 100% DPC direct disposal, or partial DPC direct disposal (with partial re-packaging). The technical approaches being investigated for DPC direct disposal will be the focus of readiness review including fillers, "as-loaded" criticality analysis, and consequence screening. The scope of the review will reach across the DPC Direct Disposal WBS (1.08.01.03.05), and apply the criteria discussed in Sections 2 through 4. An evaluation of the readiness and trajectory of the work to support potential future licensing will be a major component of the review. Note that it is neither necessary nor appropriate to initiate licensing preparations for DPC direct disposal, and that no date for doing so will be considered. Rather, the peer review will focus on whether potentially important licensing issues are being considered in R&D, and on the strength of a potential licensing case. Any shortcomings in the R&D completed or planned will be identified and solutions will be proposed.

11. Summary

This planning deliverable presents high-level goals for DPC direct disposal, and a general discussion of how uncertainty with respect to SNF disposal options could impact achievement of those goals. It then summarizes the scope of ongoing and future R&D, distinguishing activities that are currently underway, or due to be started in FY19, and possible future R&D. Ongoing activities cover the topical areas of criticality FEP analysis and TSPA, supporting multi-physics modeling, engineering alternative studies, and cost analysis. Additional, possible future R&D activities are identified in the areas of criticality modeling and validation, engineering concept development, and preclosure safety analysis.

The assessment of planned R&D is current as of 9/19/18, recognizing that more work planning is underway to program additional budget for FY19. The recommended (unplanned) R&D activities in this report could serve as a basis for FY19 planning.

This report serves as an outline for R&D studies that will identify and analyze alternative disposition strategies for commercial SNF in DPCs. A "no action" alternative will be included in which DPCs are monitored and replaced or supplemented with new canisters when necessary for continued storage. A full re-packaging option, and a partial re-packaging option that combines waste packages based on STAD canisters with DPC-based packages in a repository, will also be considered. This assessment of DPC disposition pathways and R&D opportunities is likely to change as new data are acquired, or program priorities are changed by policy, while based on available funding.

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