DOE Advisory and Assistance Services Contract

Task Order 18: Generic Design for Small Standardized Transportation, Aging and Disposal Canister Systems

UPDATED FINAL REPORT

May 14, 2015

Prepared by

ENERGYSOLUTIONS
We're part of the solution

NAC INTERNATIONAL

Exelon
Nuclear Partners

TALISMAN
INTERNATIONAL, LLC

PETERSEN
INCORPORATED
"A Winning Combination."

Revision History

Revision	Date	Reason for Revision	Originator
Draft	**April 1, 2015**	**Draft Final Report for DOE Review**	**I. Thomas**
Final	**May 4, 2015**	**Final Report**	**I. Thomas**
Updated Final	**May 14, 2015**	**Section 4.3.2.3 – Updated thermal analysis results for the BWR STAD canister.**	**I. Thomas**

Executive Summary

Per the requirements of the Task Order 18: *Generic Design for Small Standardized Transportation, Aging, and Disposal Canister Systems*, Statement of Work (SOW), Energy*Solutions* and its team partners: NAC International, Exelon Nuclear Partners, Talisman International, and Petersen Incorporated, hereafter referred to as "the Team", is providing the U.S. Department of Energy (DOE) a Final Report, which documents a generic design of a small capacity Standardized Transportation, Aging and Disposal (STAD) canister system for four Pressurized Water Reactor (4-PWR) Spent Nuclear Fuel (SNF) assemblies or nine Boiling Water Reactor (9-BWR) SNF assemblies.

The Team has developed an integrated transfer, storage and loading process for the small STAD canisters, which utilizes a first-of-a-kind carrier to allow four small STAD canisters to be loaded, welded, dried and handled in parallel from the spent fuel pool through to storage or transportation. Figure ES-1 provides an overview of the system components.

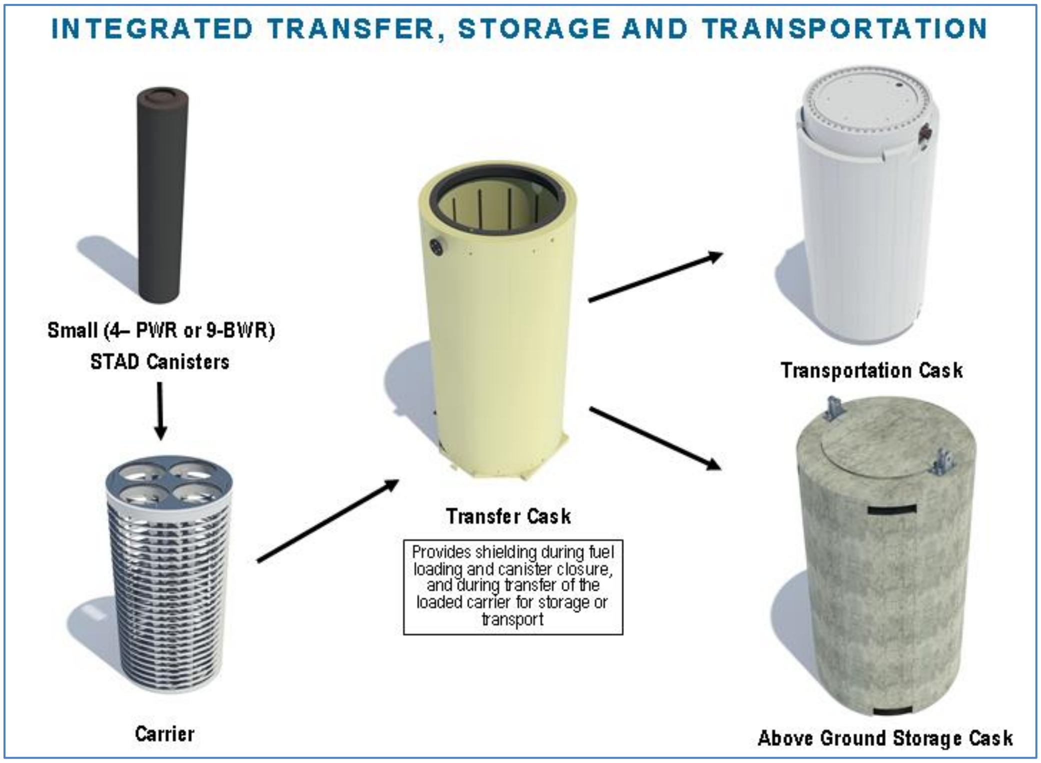


Figure ES-1. Overview of the Small STAD Canister System

The STAD canisters have been developed in accordance with the DOE *Performance Specification for Small and Medium Transportation, Aging and Disposal Canister Systems*, FCRD-NFST-2014-000579. The proposed STAD designs which can be handled with the 125 ton pool crane found at most nuclear power station sites can accommodate the entire US spent PWR and BWR fuel inventory, with the exception of South Texas Project fuel and Combustion Engineering (CE) 16×16 fuel with control components (whose length exceeds that of the cask cavity). Some future assembly types, including AP1000 fuel, will also be too long for the proposed cask and basket design. Longer versions of the proposed STAD designs, which can be used with a 150 ton plant crane, could be designed; with the South Texas Project site, as well as the AP1000 plant design, having 150 ton pool cranes.

The proposed system will require a plant spent fuel pool crane capacity of 125 tons. Most US nuclear plant sites have a crane capacity of 125 tons or more. Some sites, however, have crane capacities between 100 and 125 tons. Plants with 100 ton crane capacities may be accommodated by designing transfer casks with less shielding, or by placing three (vs. four) STAD canisters inside the transfer and storage casks (should shielding analyses show that acceptable exterior dose rates cannot be obtained with a transfer cask with a loaded hook weight under 100 tons). Noting that loading three STAD canisters will require the use of a different carrier design, in order to avoid balance problems.

A fact sheet detailing the key features of the system is provided in Appendix H, and datasheets detailing the key parameters for the system are provided in Appendix F. A summary of the work performed by the Team and the results obtained are provided below.

DESIGN CONCEPT

STAD Canisters

Two different STAD canister assembly designs have been developed, one for the 4-PWR and one for the 9-BWR SNF assemblies. Figure ES-2 shows an expanded view of the STAD canister assembly and, with the exception of the internal basket, identifies the major features discussed below.

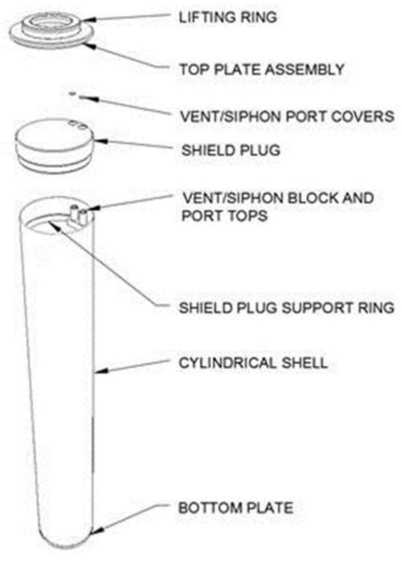


Figure ES-2. Expanded View of STAD Canister Assembly

Both STAD canister designs consist of a shell assembly (identical for both) and an internal basket assembly (different designs). The shell assembly includes an opened-top shell body assembly that contains the internal basket assembly. After SNF is placed inside the STAD canister, a shield plug is placed into the top end of the STAD canister body assembly to provide radiation shielding for workers during the subsequent canister closure operations. The shell body assembly includes a vent/siphon block and ports that are used to drain and dry the SNF and inside of the canister during loading operations. The shell body also includes a ring at the top end that is used to temporarily support the shield plug within the canister shell prior to welding the shield plug to the canister shell. The shield plug has two holes through which the vent and siphon port tops fit. After a small amount of water is drained from the STAD canister cavity, the shield plug is welded to the canister shell and the vent and siphon port tops to form the inner closure pressure boundary. Following canister draining and drying operations, small circular covers are welded over the vent and siphon port tops to complete the inner confinement boundary. The top plate assembly, which includes an integral lifting ring, is then placed on the shield plug and welded to the canister shell, forming a second redundant seal boundary.

Canister Transfer System

The canister transfer system utilizes a “carrier” type STAD canister basket. The carrier design locates and supports four small STAD canisters, during loading operations, storage conditions, or transport conditions. Use of the carrier is based on reducing the number of primary loading and handling operations and it also provides opportunities for parallel welding, non-destructive examination, and drying operations to be performed. In this role, the carrier is the primary transfer component when loading the STAD canisters. Transfer cask equipment, similar to that used for the ultra-high capacity canister based systems, is used to load, process, and transfer the STAD canisters. Figure ES-1, above, provides an overview of how the carrier is integrated into the processes of loading, storage and transportation.

The STAD canister carrier provides operational alignment, multi-unit handling and shielding during fuel loading operations. The STAD canister carrier is also a multipurpose frame which functions as a heat transfer device and structural component during storage and transportation. The STAD carrier may be preloaded into a transfer cask or staged with STAD canisters and then loaded into the transfer cask.

The transfer cask contains supports and shields the STAD canisters and STAD carrier during fuel loading, lid welding, closure operations, and subsequent transfer to storage or transport casks. The transfer cask has integrated pneumatic seals at the top and bottom to provide a boundary for clean water to be maintained within the transfer cask during fuel loading. The transfer cask is also equipped with multiple inlet and outlets whereby the clean water boundary can be filled/drained. It is expected that the canisters will be filled with pool water (particularly PWR loading) and the interstitial area within the transfer cask filled with clean water prior to placing the system in the fuel pool. The seals are to be inflated after the carrier and STAD canisters are properly loaded and positioned within the transfer cask. The seals are inflated with air or inert gas and expand to make contact with the upper shield disk and the lower support plate of the carrier. This develops the boundary for the clean water fill. To ensure adequate contamination control, the clean water system can be over-pressured, wiper rings could be used in the carrier to provide seal around each canister or a sealing ring assembly can be installed on the carrier that uses inflatable seals for each STAD canister. Inherent in the clean water boundary is the ability to provide auxiliary cooling to the STAD canisters if the need is determined. Recirculation of the water through the upper and lower ports can be routed through a heat exchanger or cooler and returned to the transfer cask.

For storage in an overpack, a concrete cask is positioned and a transfer adapter is placed over the cask opening. This adapter is used to both position the transfer cask and provide the actuation of the transfer cask doors (located at the bottom of the transfer cask). The transfer cask containing the STAD canisters is positioned on the transfer adapter (stack-up) on the top of the concrete cask. Once the carrier has been lowered into the storage overpack and the rigging removed, the transfer adapter is removed and the concrete cask lid is placed and bolted down. The process of transferring a loaded carrier to a Transportation Cask is very similar and both transfer operations can be seen in Figure ES-3.

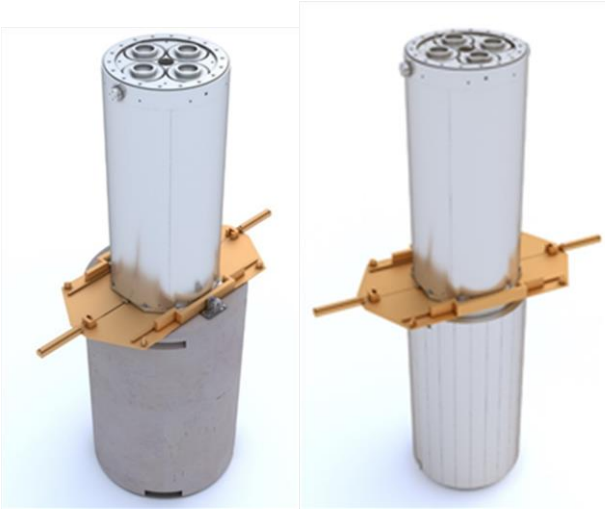


Figure ES-3. Transfer Stack-up to Storage or Transport

Although the STAD canister carrier is primarily designed for handling small STAD canisters in groups of four, each STAD canister remains independently accessible. Development of additional STAD canister handling equipment can allow for single STAD canister removal and placement for variations in transport and storage configurations. Figure ES-4 describes systems for loading and unloading single STAD canisters from both storage and transportation casks. Note that a single STAD canister transfer cask can be designed to be capable of being laid down, transported and positioned for potential horizontal placement.

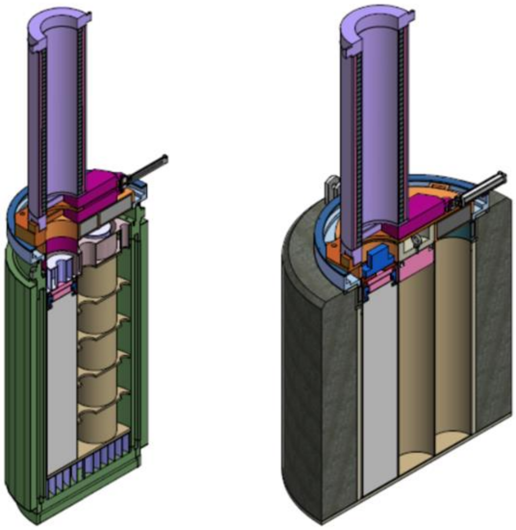


Figure ES-4. Single STAD Transfer Concept for Transport and Storage

Storage Options

For storing the loaded STAD carrier in an above-ground vertical concrete cask, a design concept has been developed based on the

MAGNASTOR ultra-high capacity fuel canister licensed technology. Utilization of a horizontal storage option may require further design modifications to accommodate the horizontal bearing of a loaded carrier into the storage module. Currently licensed technology utilizes a combination of lubrication and a material resistant to galling for both the transfer cask and the storage module horizontal structural supports. For the transfer of a single full canister, this is adequate. For the STAD carrier design approach presented in this report, the intermittent disks could be problematic in a horizontal transfer if there is a gap greater than the thickness of a support disk. Possible alternatives to resolve this issue would require the carrier to be positioned and controlled in a predetermined orientation in which continuous supports can be incorporated over the entire length of the carrier assembly. The current horizontal technology is based on a canister wall contact with a twin rail support system. A similar concept may be developed if a horizontal system is determined to be more effective for the package.

Utilization of an in-ground or above ground bunker storage option can address either the carrier concept or the individual STAD canister concept. Either option can be designed to utilize the STAD carrier or the individual STAD canister approach for storage. Shielding is predominantly provided by the embedment materials with the axial “skyshine” component controlled by the cover or lid. The in-ground application is essentially the same as an above ground component with respect to materials.

Transportation Options

With the utilization of the multi-STAD carrier concept, the transportation cask will be a rail transport sized component. The transportation cask for the STAD would utilize similar transport cask technology as that developed for the Task Order 17 SNF Transportation Cask Design Study. The significant difference in the two transport casks would be the cavity diameter (78″ Inside Diameter (ID) for the STAD transport cask versus 70″ ID) and the cavity length (194″ versus 180″). The increased size of the cask cavity drives the outside diameter and subsequently the weight. The length increase is required to compensate for the STAD canisters shield plugs, closure lids and canister bases. In addition to the increase in cask weight, the increased diameter of the transportation cask impacts the transport package’s accident performance by reducing the stroke distance of the package impact limiters. This is because the impact limiter Outside Diameter (OD) is limited to a maximum of 128″. Figure ES-5 shows a carrier loaded into a transportation cask, which does not have the impact limiters installed.

Figure ES-5. Cutaway Transportation Cask with STAD Canisters and Carrier

DESIGN AND ANALYSIS

Shielding, criticality, thermal, and structural analyses have been performed for the design concepts. Key points from this work are provided below noting that, in addition to the regulatory storage and transportation requirements pertaining to the STAD canister, the carrier will also be subject to these same requirements due to it being utilized to support and retain the STAD canisters in both storage and transportation modes.

- Investigative structural and thermal analyses for both the storage and transport of a loaded carrier in a vertical concrete cask or a transportation cask, respectively, have been performed and documented within this Final Report. Although the use of a carrier is seen as a first-of-a-kind for dry cask storage, the design is reflective of earlier dry cask storage basket designs termed “tube-and-disk” baskets.

  The current carrier design is essentially the blending of a typical dry cask storage design and the tube and disk fuel basket design. Instead of an array of fuel assemblies, there are essentially four (4) vertical casks (sleeves), one for each of four Small STAD canisters, integrated into a single package. These four sleeves are bound together by upper and lower plates and supported radially by additional gusset type supports. The current design addresses the requirements for shielding, lifting, processing, storage and transportation and is the current representation of an iterative path of inspection, balancing the structural and thermal needs of the STAD canister itself and integration into a safe operational package.
- The thermal analyses performed for the STAD canisters during storage concluded that acceptable fuel rod cladding and STAD canister fuel basket structure temperatures will occur for payloads of four PWR or BWR STAD canisters within the storage cask, given that the STAD canister heat load does not exceed 8.0 kW/STAD canister.
- The thermal analyses performed for the STAD canisters during transportation concluded that the fuel cladding and STAD canister basket structures meet their respective temperature limits by wide margins, assuming a STAD canister heat generation level of 6.0 kW/STAD canister. This corresponds to heat generation levels of 1.5 kW per PWR assembly and 0.667 kW per BWR assembly, and an overall transportation cask heat generation level of 24 kW.
- The results of the small STAD canister shell assembly structural analysis demonstrate that the small STAD canister shell assembly will satisfy the allowable stress design criteria for storage conditions.
- A structural evaluation was performed of the small STAD canister for a postulated vertical free drop of 23 feet onto an essentially unyielding horizontal surface. Two impact orientations were considered: (1) Flat bottom end impact, and (2) 4-degree rotation from vertical. The purpose of this evaluation was to provide results that DOE can use for

comparison to drop analyses that have been performed for other proposed canister designs, including the Transportation, Aging and Disposal (TAD) canister.

- For STAD canisters in the transportation cask, the shielding analysis results show that all cask exterior dose rates are under the applicable 10 CFR 71 limits (for any assembly payload that meets the cooling time requirements shown in Table 4-4 (on Page 54)).
- The shielding analyses for STAD canisters during storage determined that the peak dose rates on the cask side surface are between 80 and 90 mrem/hr, for PWR and BWR fuel. This is not significantly higher than that of other storage cask systems, given the bounding nature of the analyzed (62.5 GWd/MTU, 5 year cooled) assembly payload. The 25 mrem/year limit at the site boundary is the only 10 CFR 72 limit that applies for the storage cask. The maximum cask side surface dose rate necessary to meet this limit will be a function of the number of casks in the Independent Spent Fuel Storage Installation (ISFSI), the ISFSI arrangement, the actual fuel payload (and source terms) loaded into the casks, and the distance to the site boundary. For transfer operations, the shielding analysis results show peak dose rates under 1.0 Rem/hr on the cask side surface under dry conditions, and dose rates under 100 mrem/hr on the cask side surface when the cask and STAD canister cavities are filled with water. The peak dose rates occur at the axial elevation of the peak burnup region of the fuel. These dose rates are acceptable and in line with industry experience.
- It is likely that moderator exclusion will be employed as the primary means of criticality control for the transportation cask system. The double seal weld of the STAD canisters would be credited as the second barrier to water ingress (an approach for which there is precedent in cask system licensing). The transport cask containment boundary would be the first barrier to water ingress. However, criticality analyses that model water within the STAD canister interiors as well as between the STAD canisters have been performed. The purpose of these analyses is to provide a backup (defense in depth) to moderator exclusion. The criticality analyses model the STAD canisters inside the transportation cask and as the (outer) cask configuration does not significantly affect reactivity, and the transfer cask and transport cask materials are similar, the results of the criticality analyses are applicable for the transfer (loading) configuration as well.

  For PWR fuel, three different configurations were modeled, which reflect different licensing contingencies: (1) Intact PWR assemblies, (2) Optimum pitch cladded PWR rod arrays and (3) Optimum PWR fuel pellet (rubble) array. For configurations (1) and (2), it was concluded that the STAD canister could accommodate the entire U.S. spent PWR assembly inventory, without any need for payload reduction. Configuration (3) presents a challenge in that the initial results under these (extreme) assumptions (interior is completely filled with water with an optimum array of Westinghouse 15×15 PWR fuel pellets) concluded that the STAD canister would not be able to accommodate a significant fraction of the U.S. spent

PWR assembly inventory. Another analysis was performed, which involved modifying the fuel basket design to control reactivity under such extreme conditions. It assumed that borated stainless steel is placed around the periphery of the four basket cells and also that the central “cruciform” stainless steel plates are extended out to the STAD canister cavity edge. With these modifications, it was concluded that the entire U.S. spent PWR assembly inventory could be accommodated, without any need for payload reduction, even if it were assumed that all the pellets escape the fuel rods and that water enters the cask and STAD canister interiors. Such a borated stainless steel configuration would significantly increase the cost and weight of the STAD canisters, however.

For BWR fuel, the same three different configurations were again modeled, which reflect different licensing contingencies: (1) Intact BWR assemblies, (2) Optimum pitch cladded BWR rod arrays and (3) Optimum BWR fuel pellet (rubble) array. For configuration (1), it was concluded that four BWR STAD canisters inside a transportation cask, each with a payload of nine BWR assemblies, will meet 10 CFR 71 criticality requirements for (planar average) enrichment levels up to 5.0%; this covers the entire U.S. spent BWR assembly inventory. Thus, even if water ingress into the cask and STAD canister interiors were deemed credible, the BWR STAD canister configuration will be able to ship the entire U.S. spent BWR assembly inventory, with no need for payload reduction, if the BWR assemblies can be assumed to remain intact under 10 CFR 71 hypothetical accident conditions (HAC). For configuration (2), it was concluded that a reduction in the payload from nine to eight BWR assemblies for each STAD canister would be required for BWR fuel assemblies with planar average initial enrichment levels between 4.3% and 5.0%. That may constitute a significant fraction of the US spent BWR fuel inventory in the future. If borated stainless steel plates were placed around the periphery of the BWR STAD basket, payload reduction would only be necessary for BWR assemblies with initial enrichment levels over 4.75%, which is a very small fraction of the current (or future) U.S. spent BWR assembly inventory. Thus, if such a change to the BWR STAD canister basket design were made, payload reductions would be insignificant. However, such a design change would significantly increase the cost and weight of the STADs. For configuration (3), it was concluded that the BWR STAD canister would only be able to accommodate BWR assemblies with initial enrichment levels of 3.6% or less. It is also unlikely that any plausible STAD design changes could significantly increase that allowable enrichment. In the future, most of the BWR assembly inventory is expected to have initial enrichment levels over 3.6%.

REGULATORY COMPLIANCE

It was concluded that, subject to the considerations described below, U.S. Nuclear Regulatory Commission (NRC) approval of the STAD system design for both the initial 10 CFR 71 transport Certificate of Compliance (CoC) and the initial 10 CFR 72 storage CoC would be anticipated. The considerations that may present complexities to the applicant and to the NRC staff review are:

- Aging Management - To satisfy the DOE design specification, FCRD-NFST-2014-000579, that the design lifetime of the STAD canister under both 10 CFR 72 and 10 CFR 71 should be “licensable” for 150 years, the applicant for the STAD canister system design should consider developing and including in the initial application an aging management program as described in NRC NUREG-1927, *Standard Review Plan for Renewal of Spent Fuel Dry Cask Storage System Licenses and Certificates of Compliance*. The aging management program should be in place starting at day one in the lifetime of the STAD canister system design to support and provide the future basis for possible renewal up to the 150-year design lifetime. The implemented aging management program would provide the technical basis for future renewal application consideration.

- High Burnup Fuel – The STAD canister system design includes transport and storage of high burnup fuel with burnup up to 62.5 GWd/MTU. The NRC has much experience with review and approval of applications for the dry cask storage of high burnup spent fuel, and has for the past decade approved multiple dry cask storage systems for storage of high burnup spent fuel. The storage of high burnup fuel in the STAD canister is not anticipated to be a significant challenge in the NRC review. However, the topic of transport of high burnup fuel is presently under much study and analysis by both the NRC and the industry. The NRC review of transport applications for high burnup fuel is presently conducted on a case-by-case review basis with the applicant demonstrating to the satisfaction of the NRC the safety justification for assumptions on high burnup fuel reconfiguration under accident conditions. Further development of NRC’s review guidance for transport of high burnup fuel is anticipated over the next few years. The applicant will need to confirm that the application is consistent with the then current NRC guidance on transport of high burnup fuel. The applicant should anticipate that the technical basis and the assumptions for transport of high burnup fuel will receive close NRC scrutiny. Depending on the status of the NRC and industry studies at the time of application, perhaps further study/supporting analysis may be necessary to justify the technical basis and assumptions for transport of high burnup fuel.

- Multiple Storage Configurations - The STAD canister storage system design requirements provides for storage at a utility site in accordance with 10 CFR 72 in either a horizontal or vertical orientation. Typically, storage applications identify and analyze one storage configuration, vertical or horizontal. The inclusion of both a vertical and horizontal storage system configuration does not necessarily present a technical review challenge, but represents an added level of complexity to the NRC review and possibly added NRC review resources to review the structural, thermal, materials, shielding, operational, and accident considerations for the two separate vertical and horizontal storage systems.

The additional STAD canister storage design requirement added by the SOW to address an above or below grade vault storage system clearly adds an additional level of complexity to the STAD canister system design and application, with an increase in the NRC review resources needed for the review. The NRC has prior experience with the review of an underground vault storage system, and therefore there may not necessarily be technical challenges but the vault storage system design adds to the review complexity and needed resources.

- Multiple STAD Canisters in Storage and Transport Overpacks - The transport and storage STAD canister overpack designs will allow for the storage and/or transport of either a single STAD canister or 4 STAD canisters. The applicant and the NRC review must analyze the performance of the storage system and the transport package under accident conditions with a transport overpack and storage overpack containing either a single STAD canister or 4 STAD canisters. While there do not appear to be any technical challenges for this aspect of the NRC review, the complexity of the overpack and internal contents and design may represent an added level of NRC review time and resources.

- Moderator Exclusion - The STAD canister system design includes use of moderator exclusion to demonstrate the capability of the STAD to maintain subcriticality under accident conditions. Consideration and use of ISG-19, *Moderator Exclusion*, has been successfully demonstrated in other spent fuel transport applications. The use of ISG-19 in the STAD canister system application should not introduce any new technical challenges. However, the complexity of the analysis and justification for demonstrating moderator exclusion may require an added level of NRC resources for the review.

ABILITY TO FABRICATE

An evaluation of the ability to fabricate the small STAD canister system components has been performed by a member of the Team: Petersen Incorporated, who operate a 600,000 sq. ft. state-of-the-art precision machining and fabrication facility, has been in business for over 53 years, and has fabricated components for the nuclear industry as a core business for the last 15 years. They have provided NQA-1 compliant components for a wide range of customers in the nuclear industry, including supplying canister and cask systems to the designs of Energy*Solutions* and NAC International for the last 15 years. The evaluation concluded that the components are able to be fabricated within current facilities and capabilities. They also have features that allow for uncomplicated manufacturing, which were arrived at following a “fabricability” review during a Team workshop, which resulted in some changes to the STAD canister fuel basket designs.

COST ESTIMATES

Utilizing cost estimating assumptions provided by the DOE (see Section 3.3), cost estimates (for planning purposes only) have been developed for the structures and components of the small STAD canister system and are summarized in Table ES-1, below.

Table ES-1. Cost Estimates for Small STAD Canister System Structures and Components

Quantity	Description	Price/Each ($)	Totals ($)
300(5)	4-PWR STAD Canister	91,273	27,381,900
300(5)	9-BWR STAD Canister	116,717	35,015,100
150(5)	STAD Canister Carrier	355,657	53,348,550
150(5)	Vertical Concrete Storage Cask	300,000(1)	45,000,000
10(6)	Transfer Cask	687,157(2)	6,871,570
30(7)	Transportation Cask	2,517,513(3)(4)	75,525,390

Notes:

1. Price is comprised of $120,000 for the liner and supporting structure and an estimate of $180,000 for the labor and materials to construct the concrete shielding.
2. Price includes an estimated $147,000 to cover the procurement and installation of the neutron shielding, which is an epoxy resin (NS-4-FR).
3. Price excludes impact limiters.
4. Price includes an estimated $175,000 to cover the procurement and installation of the neutron shielding, which is an epoxy resin (NS-4-FR).
5. Per year over a 30 year period.
6. Per year over a 3 year period.
7. Per year over a 5 year period.

TABLE OF CONTENTS

FIGURES

TABLES

Acronyms

A&AS	Advisory and Assistance Service
ALARA	As Low As Reasonably Achievable
AMP	Aging Management Programs
ASME	American Society of Mechanical Engineers
BWR	Boiling Water Reactor
CDS	Cool-Down System
CFR	Code of Federal Regulations
CoC	Certificate of Compliance
CSI	Criticality Safety Index
CWCS	Circulating Water Cooling System
DBS	Drain and Blow Down System
DOE	U.S. Department of Energy
DPC	Dual Purpose Canister
EPS	Equivalent Plastic Strain
HAC	Hypothetical Accident Condition
GWd/MTU	Gigawatt-days/Metric Tons Uranium
ISF	Interim Storage Facility
ISG	Interim Staff Guidance
ISFSI	Independent Spent Fuel Storage Installation
kW	Kilowatt
LLNL	Lawrence Livermore National Laboratory
MTIHM	Metric Tons of Initial Heavy Metals
MTU	Metric Tons Uranium
MSLD	Helium Mass Spectrometer Leak Detector
NCT	normal conditions of transport
NDE	Non-Destructive Examination
NRC	U.S. Nuclear Regulatory Commission
PT	Liquid Penetrant Testing
PWR	Pressurized Water Reactor
SAR	Safety Analysis Report
SNF	Spent Nuclear Fuel
SSC	Structures, Systems, and Components (important to safety)
SOW	Statement of Work
STAD	Standardized Transportation, Aging and Disposal
TAD	Transportation, Aging and Disposal
TI	Transport Index
TLAA	Time Limited Aging Analyses

1 INTRODUCTION

On September 16, 2014, under the U.S. Department of Energy (DOE) Advisory and Assistance Services (A&AS) contract, an integrated team headed by Energy*Solutions* was the sole awardee for Task Order 18: *"Generic Design for Small Standardized Transportation, Aging, and Disposal (STAD) Canister Systems".* This task order assists the DOE Office of Nuclear Energy to develop a generic design of small capacity STADs for four Pressurized Water Reactor (4-PWR) Spent Nuclear Fuel (SNF) assemblies or nine Boiling Water Reactor (9-BWR) SNF assemblies. The generic design developed under this procurement will provide important information to system analysts and planners on the storage and transportation attributes of small STAD canister system designs, including operational impacts and limitations and estimated costs.

The background to Task Order 18 (TO 18) is that in 2012, the DOE issued Task Order 12 under the existing A&AS contract to study the feasibility of developing and licensing STAD canister systems for generic disposal media. The purpose of Task Order 12 was to provide technical ideas and recommendations, supported by evaluations/system analyses, on approaches to better integrate STAD canister concepts into the nuclear waste management system. The DOE awarded contracts to two teams led by AREVA and Energy*Solutions*. Based on comprehensive analyses and industry/utility input, detailed reports were produced, by both teams, presenting feasible STAD canister design concepts and recommendations for a path forward:

- AREVA – *Standardized Transportation, Aging, and Disposal Canisters Feasibility Study A&AS DE-NE-0000291*
- Energy*Solutions – Standardized Transportation, Aging, and Disposal Canisters Feasibility Study A&AS DE-NE-0000293*

Task Order 18 is required to further develop the design for the small 4-PWR or 9-BWR STAD canister; focusing on the unique and novel aspects of the canister and its associated multi-canister storage and transportation overpack configurations.

The Energy*Solutions* team assembled for this task consists of the following members:

- **Energy*Solutions*** - Full nuclear fuel cycle company with interests in Federal and commercial nuclear waste treatment, clean-up and disposition, nuclear reactor and legacy facility decommissioning, SNF treatment, storage and disposition, and SNF recycling.

- **NAC International** - Specialties include nuclear materials transport, and spent fuel storage and transport technologies. NAC has provided transportable SNF storage canisters and casks for a significant proportion of the commercial nuclear reactor utilities in the U.S.

- **Exelon Nuclear Partners** - A business unit of Exelon Generation. Operates 22 nuclear units and two retired units, with 11 Independent Spent Fuel Storage Installations (ISFSIs) at both BWR and pressurized water reactor (PWR) sites. Maintains over 10,000 Metric Tons Uranium (MTU) of SNF in pool storage and has moved over 3,500 MTU of SNF into approximately 320 dry cask systems.

- **Talisman International** - A consulting company specializing in nuclear regulatory issues, covering safety and security of nuclear facilities, regulation and classification of nuclear facilities and the wastes they produce. Talisman has a number of former senior U.S. Nuclear Regulatory Commission (NRC) managers on its staff.

- **Petersen Incorporated** - Operates a 600,000 sq. ft. state-of-the-art precision machining and fabrication facility, has been in business for over 53 years, and has fabricated components for the nuclear industry as a core business for the last 15 years. Has provided NQA-1 compliant components for a wide range of customers in the nuclear industry, including supplying canister and cask systems to the designs of Energy*Solutions* and NAC International for the last 15 years.

2 PURPOSE AND SCOPE

The purpose of this report is to document the generic design of a 4-PWR or 9-BWR capacity STAD[1] canister system, which has been developed by Energy*Solutions* and its team partners: NAC International, Petersen Incorporated, Talisman International, and Exelon Nuclear Partners; hereafter referred to as “the Team”.

The Task Order 18 Statement of Work (SOW) provided by the DOE is provided in Appendix I. To meet the SOW requirements, the Team has followed a five-phase approach to develop the generic design for the 4-PWR or 9-BWR STAD canister system. The five phases are:

- **Phase 1** - As a prerequisite to a first facilitated workshop, past work on the design of small STAD canister systems and information from ongoing Used Fuel Disposition (UFD) campaign work was reviewed. In addition, the requirements of the *DOE Performance Specification for Small and Medium Standardized Transportation, Aging, and Disposal Canister Systems*, FCRD–NFST–2014–000579, were evaluated and, together with the SOW requirements, were used to create a technical framework. At the workshop, which was held from October 30 - 31, 2014, following a process of identification (brainstorming), evaluation and down-selection, a shortlist of options, ideas and recommendations was produced. This shortlist was used as the basis for the development of initial design concepts, including concepts of operation, storage,

---

[1] In this report the terms “STAD” and “STAD canister”, and “STADs” and “STAD canisters” are used interchangeably.

transportability, and equipment, which were presented at the 30% Task Completion Review meeting with the DOE.

- **Phase 2** – The design concepts were further developed ahead of a second facilitated workshop, including the development of a STAD canister loading process flow sheet and an animation of the STAD canister load process. At the workshop, which was held from January 27 - 28, 2015, the design concepts for the STAD canister (including the loading process) and the storage and transportation equipment were reviewed by the team, including a cross-check against the requirements of the technical framework and a preliminary review of the ability to fabricate the equipment. The approaches, assumptions and constraints for the criticality and shielding analyses were also agreed upon.

- **Phase 3** – The end goal of this phase was the production of a Draft Final Report. Design drawings were developed for the 4-PWR and 9-BWR STAD canisters and the storage and transportation equipment, including a carrier system for the STAD canisters. Structural, thermal, criticality, and shielding analyses were performed to underpin the designs and a review of the ability to fabricate the equipment was performed, in conjunction with developing unit cost estimates for the canister, storage and transportation overpacks, and all associated components. The concept of operations was finalized in conjunction with the loading process flow sheet and the loading process animation. Phase 3 culminates in the 90% Task Completion Review meeting with the DOE.

- **Phase 4** – The purpose of this phase was to address DOE comments on the Draft Final Report, address any remaining work, and issue the Final Report and provide a Final Report Briefing to the DOE.

- **Phase 5** – The purpose of this phase was to develop and issue to the DOE a Closeout report for Task Order 18.

This report documents the output from the above approach and is structured, as follows.

- **Section 3, Systems Engineering Approach**, outlines the process which has been followed to complete the requirements of the Task Order 18 SOW and includes discussion on the design concepts and concepts of operation management that have been developed and evaluated.

- **Section 4, Description of Small (4-PWR/9-BWR) STAD Canister System,** describes the designs for the canister, transfer, storage and transportation elements of the system and addresses the SNF parameters and loading specifications. The approaches and results for the structural, thermal, shielding and criticality analyses are also described in this section.

- **Section 5, Concept of Operations**, describes the loading process for the STAD canister and describes how the loaded STAD canisters are transferred to/from storage and transportation overpacks, including describing how the STAD canisters may be loaded and unloaded in groups of four utilizing a carrier system, or individually.
- **Section 6, Concept of Fabrication,** documents an assessment of the ability to fabricate the system equipment within current facilities and capabilities.
- **Section 7, Usability,** documents an assessment of the ability of the system equipment to be used by nuclear utilities within their various physical and operational constraints.
- **Section 8, Regulatory Compliance**, documents an assessment of the ability to license the system equipment through the NRC.
- **Section 9, Cost Estimates,** documents the unit cost estimates for the canister, storage and transportation equipment and all associated components.
- **Section 10, Research and Development Recommendations,** includes a discussion on the potential use of square STAD canisters versus the right circular cylinder shape, which is the basis for the STAD canister design provided in this report. This section also discusses features to facilitate aging management monitoring activities.
- **Section 11, Conclusion**, provides the key results from the study.

3 SYSTEMS ENGINEERING APPROACH

As indicated in the Technical Proposal submitted to the DOE on August 6, 2014, the intent was to follow a five phase approach in order to perform the scope of work to develop a generic design for small STAD canister systems. Figure 3-1 shows a logic diagram of the systems engineering approach used by the Team.

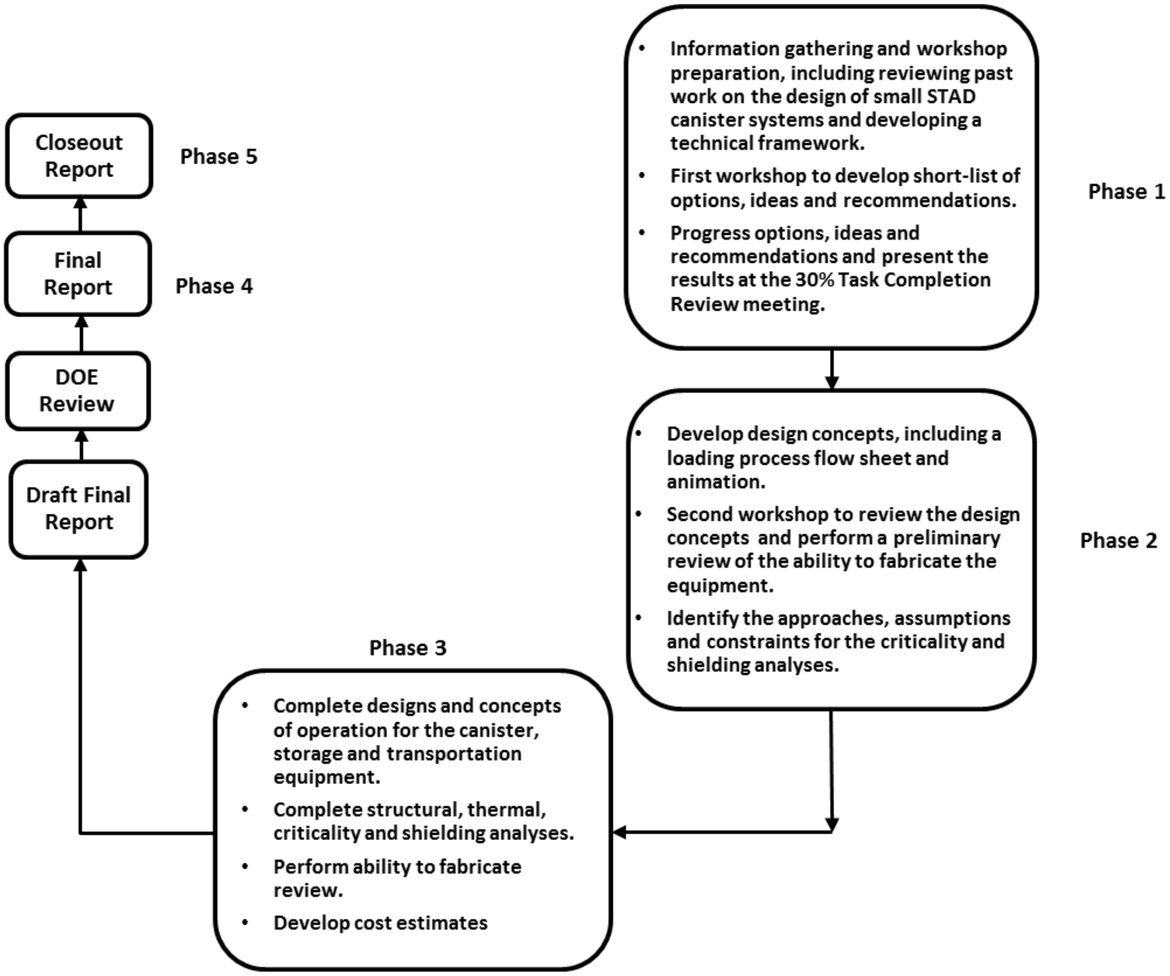


Figure 3-1. Logic Diagram Showing Systems Engineering Approach

3.1 PHASE 1

Subsequent to the award of Task Order 18 on September 16, 2014, the Team prepared for Workshop # 1 by reviewing past work on developing design concepts for small STAD canisters by AREVA[2] and Energy*Solutions*[3] and information from ongoing used fuel disposition(UFD) work. The requirements of the *DOE Performance Specification for Small and Medium Standardized Transportation, Aging, and Disposal Canister Systems*, FCRD–NFST–2014–000579, were also evaluated and, together with the SOW requirements, were used to create a technical framework; the most current version of which is provided in Appendix D.

---

[2] Task Order 12 - AREVA – *Standardized Transportation, Aging, and Disposal Canisters Feasibility Study A&AS DE-NE-0000291, Task Order 12*

[3] Task Order 12 - Energy*Solutions – Standardized Transportation, Aging, and Disposal Canisters Feasibility Study A&AS DE-NE-0000293, Task Order 12*

A facilitated workshop was held October 30 - 31, 2014, which was attended by representatives from each company within the Team and the DOE Task Order 18 Technical Monitor. A description of the workshop results is provided in Appendix A and the key outputs from the workshop are described below:

- From the information gathering, expected regulatory issues are:
    - The NRC will likely expect that the Aging Management Plan implementation would provide assurance for safe transport, after a period of extended storage;
    - Material condition of cladding and assembly;
    - Maintaining cover gas inventory (for the duration of the DOE Performance Specification-required 150-year design life);
    - Package design for damaged fuel.
- Regarding Aging Management, there needs to be a forward looking program for the 150 year design life that is required by the DOE Performance Specification. An example of such a program is *Guidance for Operations-Based Aging Management for Dry Cask Storage,* NEI 14-03, which was submitted to the NRC in September 2014. It proposes a tollgate approach to take advantage of advanced inspection technologies and operation experience as they become available in the future. One example of using operation experience is the extended storage application for Calvert Cliffs, which offers a good source of data for how issues have been addressed and the lessons learned. Additional information on review of aging management considerations can be found in NRC NUREG- 1927, *Standard Review Plan for Renewal of Spent Fuel Dry Cask Storage System Licenses and Certificates of Compliance*.
- During the review of the technical framework, items requiring additional input from the DOE were identified and the following inputs were subsequently received:
    - The current STAD canister design will be for undamaged fuel only.
    - For the fuel length it was agreed that the following A&AS contract Task Order 17 DOE guidance will be used: *The STAD canister concepts will be able to accommodate fuel assemblies with an assumed post-irradiation fuel assembly length of up to 180 inches without non-fuel components (NFCs). STAD canister concepts will also be capable of accommodating shorter length fuel assemblies containing NFCs which do not require special handling, provided the total post irradiation length (assembly with NFC) does not exceed 180 inches.*

  - The loaded STAD canisters need to be capable of being handled in both the vertical and horizontal orientation. They also need to be capable of being loaded into storage modules both horizontally and vertically. DOE is willing to accept engineering judgment where appropriate; however, analyses should be performed for areas having greater uncertainty, such as thermal performance. The Contractor may focus analyses on vertical storage in a multi-canister storage overpack and on horizontal storage of individual STAD canisters in an above-grade vault. Demonstrating the capability for horizontal vault storage of a multi-canister carrier system, in lieu of individual canisters, is also acceptable.

  - Requirement 3.5.7, Item 3C, in the DOE Performance Specification, which addresses trunnion locations, is basically to ensure maximum As Low As Reasonably Achievable (ALARA) benefits. If a different location is more suitable from operational considerations, it will be acceptable as long as ALARA benefits are ensured and dose levels are justifiable.

- A shortlist of options was confirmed, which is detailed in Appendix A, Table A-2, and can be summarized as follows:

  - For the STAD canisters, it was confirmed that they need to be packaged, i.e., loaded, welded, dried, and transferred, in parallel in multiples of up to four using a purpose-built transfer system. It was also noted that changing their shape from the "regular" right circular cylinder to an "irregular" shape (e.g., square) offers benefits regarding packing efficiencies.

  - The designs for the storage overpacks and transportation casks need to be fully integrated with the equipment that is used to package the multiple STAD canisters in parallel. Thus, the transfer system will allow STAD canisters to be transferred to a storage overpack in groups of up to four. The transfer will also allow STAD canisters in groups of up to four to be transferred from a storage overpack to a transportation cask. In addition, the transfer system will provide the capability for STAD canisters to be individually extracted from a storage overpack and transferred to a transportation cask.

Following the workshop, the team developed the design concepts ahead of the 30% Task Completion Review meeting with the DOE on January 6, 2015, which concluded Phase 1. For this review meeting, meeting notes were issued to the DOE; however, due to the in-progress work presented during this meeting being subsequently advanced and presented in the main body of this report, they are not reproduced in this report. An item of note was that the results from an evaluation of square STAD canisters were presented, which showed that square STADs were feasible; albeit with double the shell thicknesses of the right circular cylinder STAD canisters. The increased shell thickness for the square STAD canister is required to maintain the shell stresses and deformations within allowable limits, given that the square shape is less efficient in resisting internal pressure loading that the cylindrical shape. It was agreed with the DOE that for square STAD canisters, the results of the evaluation would be documented in the final report and they can be found in Section 10 (Research and Development).

3.2 PHASE 2

Subsequent to the 30% task completion review meeting, the design concepts were further developed, including the development of a loading process flow sheet, which is provided in Appendix G and is termed the “STAD-in-Carrier” loading process flow sheet, and an animation of the STAD-in-Carrier canister loading process. A second facilitated workshop was held January 27 - 28, 2015, which was attended by representatives from each company within the Team and the DOE Task Order 18 Technical Monitor. A description of the workshop results is provided in Appendix B and the key outputs from the workshop are described below:

- The Technical Framework provided in Appendix D was reviewed and the following points noted:
  - For aging management, as long as the inert atmosphere is maintained inside the canister then there should be no galvanic or corrosion issues. Weld treatments, in order to remove stresses, are a requirement and for a majority of the welds this will be performed in the fabrication facility. The exceptions are the closure welds for the canister shield plugs, vent and drain port covers, and the top plate, which will be performed in the field.
  - The loaded transfer cask will be subject to the maximum capacity of the facility spent fuel pool crane, e.g., >75% of operating facilities have 125 ton cranes. However, the transportation cask does not have the same weight restrictions.
- The STAD canister design concepts were reviewed and the following key points noted:
  - The vent and drain ports are made as large as possible, in order to achieve optimum drying.
  - The maximum weight of a loaded canister is around 14,000 lbs.
  - The internal pressure loads that are used for design are driven by regulatory requirements, and blowdown and reflood pressures must be considered.
- The STAD canister transfer, storage, and transportation design concepts were reviewed and the following key points noted:

  - Regarding above-grade vault storage it was agreed that storing single STAD canisters in a Transnuclear Inc. NUHOMS® type system will not be a challenge and the canisters will be designed to be pushed and pulled. What is of particular interest to the DOE is the concept of operations for how individual canisters can be extracted from a carrier and placed horizontally into a storage module, noting that for vertical storage the canisters will be stored in the carrier.
  - It was agreed that storing four STAD canisters in a carrier within a vertical overpack is the path forward, but making this configuration work for transportation will be a challenge due to the cavity size that is required for the carrier. The maximum width for the impact limiters around the circumference of the cask is restricted to 12 in. and, as the thickness of the shielding around the cavity is reduced, and hence, the amount of stroke (linear distance) to reduce impact is reduced, the size restricted impact limiters have to be designed to absorb more impact.

- For the criticality analyses, the main configuration was four small STADs (4-PWR STADs or 4-BWR STADS) in a transportation cask and four small STADs in a carrier in a storage module. The NAC MAGNATRAN burnup curves were used for the PWR analyses and fresh fuel were used for the BWR analyses. The subject of what assumptions should be made regarding the state of the fuel was also discussed and the design basis that was agreed subsequent to the workshop is detailed in Section 3.3.
- For the shielding analyses the same storage and transportation configurations as for the criticality analyses were assumed. It was determined that the storage overpack can take 32 kW, which, for 62.5 GWd/MT 5-year cooled PWR fuel that has a heat load of 2 kW per assembly, translates to 16 such PWR assemblies being capable of being loaded into a storage overpack. For the transportation cask, the maximum allowable heat load is 24 kW. The analyses were also done using uniform loading because the STAD canisters can be placed in any position within the carrier, such that there is no control of where hotter assemblies are placed. The dose from the storage overpack is required to meet 10 CFR 72 and the dose from the transportation cask is required to meet 10 CFR 71 however, the dose from the transfer cask is required to be ALARA.
- A discussion took place on the ability to fabricate the STAD canisters and some changes were made to the fuel basket designs in order to address input received from Petersen Incorporated’s Chief Engineer. There was also a discussion on the basis, e.g., expected order quantities, procurement approach, etc., for the cost estimate as Petersen advised that there were real benefits to moving from a job shop type of procurement to a mass production type of procurement. DOE could also place orders under different approaches, such as advanced material procurement and purchasing the tooling for mass

production, noting that large production runs can benefit from labor that has climbed the learning curves, tooling set up and robotic welding. The basis of estimate was confirmed subsequent to the workshop and is described in Section 3.3.

The completion of the second facilitated workshop concluded the work on Phase 2.

3.3 PHASE 3

The end goal of Phase 3 was the production of the Draft Final Report. During this period of time the design concepts (Sections 4.1) and design drawings (Appendix E) for the small STAD canister system were produced and are provided in Appendix E. Structural (Section 4.3.1), thermal (Section 4.3.2), shielding (Section 4.3.3), and criticality (Section 4.3.4) analyses were also completed to underpin the designs. A review of the ability to fabricate the equipment was performed (Section 6), in conjunction with developing unit cost estimates (Section 9) for the canister, storage and transportation overpacks and all associated components. The concept of operations (Section 5.1) was finalized in conjunction with the loading process flow sheet (Appendix G) and the loading process animation (supplied separately to the DOE).

Bi-weekly status calls were held with the DOE and resulted in the following key inputs to the work performed:

- Regarding criticality and the subject of the fuel being subjected to high *g* loads due to the transportation cask, potentially, having a reduced stroke as a result of the cavity diameter that is needed to load the carrier, there were discussions on fuel reconfiguration and moderator exclusion. It was noted that two other cask vendors: AREVA (MP-197 HB) and Holtec (HiStar 180), have both made double containment (moderator exclusion) arguments. The MP-197 relies on the SNF being contained within an inner welded canister, which is contained within a cask with a single lid, and the HiStar 180 relies on a double-bolted lid enclosure to contain the SNF. It was also noted that the HiStar 180 approval assumed (through structural analyses) that the fuel baskets would retain their integrity, but that the fuel may reconfigure. It was agreed that a moderator exclusion approach will be followed by performing the necessary structural analyses and that this would be a low risk and defendable (with regards to licensing) approach, versus not using moderator exclusion and relying on the criticality analyses and assumptions regarding whether the fuel is intact, partially reconfigured or rubble. Criticality analyses were performed for defense-in-depth, noting that the HiStar 180 and the MP-197 HB criticality analyses were also performed for defense-in-depth.

- The DOE provided a basis for the cost estimate, which is provided below, together with the interpretation that was provided to Petersen Incorporated.

Cost Estimating assumptions provided by the DOE

1. The transportation system of the nuclear waste management system accommodates a receipt rate from reactor sites of approximately 3000 MTIHM/yr on average for at least a few decades.

2. To support this throughput rate, approximately 1800 4P/9B-STAD canisters would be needed annually, on average.

3. These canisters, along with associated overpacks, are produced at three manufacturing plants to increase overall system reliability. Thus each manufacturing plant produces 600 canisters and 150 storage overpacks annually on average. (Notes: At some point, the amount per year would decrease based on current out-year inventory projections, but that would be decades down the line. Also, this assumption doesn't take into account re-usability of the storage overpacks once disposal starts. Although re-usability at that downstream point could reduce required quantities, our primary interest with TO18 is on costs associated with meeting the initial system need.)

4. For transportation overpacks, assuming they are re-usable for a certain lifetime, the initial overall system need would be approximately 450 overpacks (or 150 per manufacturing plant). Assume each manufacturing plant completes this order in no longer than five years (it could be less). (Notes: This assumption does not include spares, as that is probably too fine of a detail for this exercise. Also, at some point downstream, approximately equal to the lifetime of the transportation overpacks, there may be an additional jump in manufacturing to satisfy a need for fleet replacements; however our primary interest for TO18 is on costs associated with meeting the initial system need.)

Additional assumptions made by Energy*Solutions*:

i) Assume that Petersen is one of the three manufacturers.
ii) Assume "at least for a few decades" equals 30 years.
iii) Assume that Petersen will make 300 4-PWR and 300 9-BWR STAD canisters each year.
iv) Assume that Petersen will make 150 storage overpacks each year.
v) Assume that 150 transportation overpacks could be made over a five year period.

- It was agreed that the Energy*Solutions* team would perform a drop analysis for the small STAD canister, in order to provide a couple of points of comparison with work that was previously completed for the Transportation, Aging, and Disposal (TAD) canister. The required points of comparison were a 23ft drop at a 4-degree angle and a 23ft flat bottom drop. Other inputs to be accounted for were:

- For the contents of the STAD canister, the elastic modulus will be adjusted to simulate the response frequency (fundamental mode) of the contents.
- The drop will be onto an infinitely unyielding surface.
- The maximum strains within the canister shell should be reported; report the maximum equivalent plastic strain (EPS).
- The nominal dimensions of the STAD canisters shall be assumed.
- There was a discussion on what to do in the event that the drop analyses identified problems with the design. It was agreed that in this event the Team will make recommendations regarding addressing the problems in the detailed design.

Phase 3 culminated in the 90% Task Completion Review meeting with the DOE to present the Draft Final Report.

3.4 PHASES 4 AND 5

During Phase 4, DOE comments on the Draft Final Report were addressed and all remaining work was completed; culminating in the Final Report being issued to the DOE.

During Phase 5, in accordance with the requirements of the SOW, the Closeout Report was prepared and issued to the DOE.

4 DESCRIPTION OF SMALL STAD CANISTER SYSTEMS

4.1 DESCRIPTION OF DESIGN CONCEPT

4.1.1 Canister

Two different small STAD canister assembly designs are provided for PWR and BWR used fuel assemblies; the 4-PWR (4P) and 9-BWR (9B) STAD canister assemblies. Figure 4-1 shows an expanded view of the 4P canister assembly and identifies the major features discussed below. Both STAD canister designs consist of a shell assembly and an internal basket assembly. The shell assembly includes an opened-top shell body assembly that contains the internal basket assembly. After spent fuel is placed inside the STAD canister, a shield plug is placed into the top end of the STAD canister body assembly to provide radiation shielding for workers during the subsequent canister closure operations. The shell body assembly includes a vent/siphon block and ports that are used to drain and dry the canister during loading operations. The shell body also includes a ring at the top end that is used to temporarily support the shield plug within the canister shell prior to welding the shield plug to the canister shell. The shield plug has two holes through which the vent and siphon port tops fit. After a small amount of water is drained from the STAD canister cavity, the shield plug is welded to the canister shell and the vent and siphon port tops are attached to form the inner closure pressure boundary. Following canister draining and drying operations, small circular covers are welded over the vent and siphon port tops to complete the inner confinement boundary. The top plate assembly, which includes an integral lifting ring, is then placed on the shield plug and welded to the canister shell, forming a second redundant seal boundary.

As their canister designations indicate, the 4P and 9B STAD canister assemblies are designed to accommodate four PWR and nine BWR fuel assemblies, respectively. Both the 4P and 9B STAD canister assemblies use the same canister shell assembly design, which provides a common interface that allows the use of common overpack designs and auxiliary equipment, and simplifies operations. The STAD canister shell assembly, which is fabricated entirely from Type 316L austenitic stainless steel, is a right circular cylinder with a 29.0-inch outside diameter and a 193.0-inch overall length (not including the lifting ring on the top end). The canister shell assembly consists of a 2-inch thick bottom plate, ¼-inch thick cylindrical shell, 9-inch thick shield plug, and 2-inch thick top plate. An integral lifting ring assembly is attached to the canister shell top plate to allow the STAD canister to be handled remotely using a grapple assembly. The lifting ring assembly has a 19.5-inch outside diameter and a 3.0-inch overall height. Thus, the overall length of the STAD canister shell assembly, including the lifting ring, is 196.0 inches.

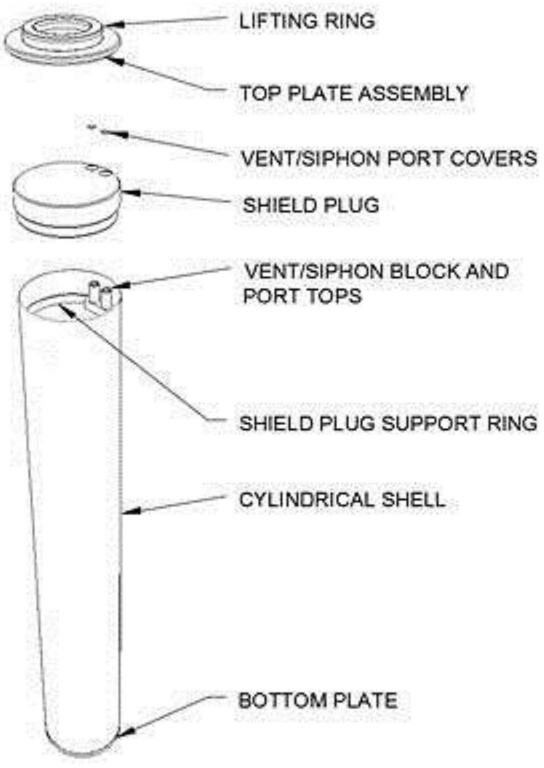


Figure 4-1. Expanded View of 4P STAD Canister Assembly

Both the 4P and the 9B basket assemblies are tube-and-disk style designs, consisting of a series of spacer plates that are supported and positioned axially by four (4) austenitic stainless steel support bars, as shown in Figure 4-2. Each spacer plate is connected to each of the four (4) support bars by fillet welds on both sides of the support bar and both faces (i.e., top and bottom surfaces) of the spacer plate. The 4P and 9B basket assemblies are identical with respect to the support bar designs and the number, thickness, and axial spacing of the spacer plates. For both the 4P and 9B basket assemblies, the top end spacer plate is fabricated from a 2-inch thick plate and all other spacer plates are fabricated from a ¾-inch thick plate. Both the 4P and 9B baskets have a spacer plate pitch (axial spacing) of 7.5-inches over the majority of the length, with a slightly smaller spacing at the top and bottom ends.

The 4P and 9B spacer plate designs differ in the number, size, and arrangement of the holes for the basket cells, as well as the cross-section dimensions of the guide tubes that line each basket cell, as shown in Figure 4-3. Each 4P spacer plate includes four 9.15-inch square holes that are separated by 0.75-inch wide ligaments, whereas each 9B spacer plate includes nine 6.15-inch square holes that are separated by 0.5-inch wide ligaments. Guide tubes, which are inserted through the stack of spacer plates and welded to the top spacer plate, line each basket cell. As their name indicates, the primary function of the guide tubes is to guide the fuel assemblies into the basket assembly during loading operations. The guide tubes also capture the poison plate egg crates within the basket assembly and support them for transverse loads, such as a side drop.

The guide tubes for both the 4P and 9B basket assemblies are constructed from 16-gauge (0.0595-inch thick) stainless steel sheet material. The guide tubes for the 4P and 9B basket assemblies are designed with 8.85-inch and 5.85-inch square openings to accommodate the widest PWR and BWR fuel assembly types, respectively. Both the 4P and 9B spacer plate designs include additional holes around the edges. These edge holes provide access to route the siphon tube from the top to the bottom end of the canister shell assembly. In addition, the edge holes minimize the overall weight of the STAD canister assemblies and reduce the horizontal surfaces within the basket on which water can collect, such that the time required for vacuum drying during canister loading operations is minimized.

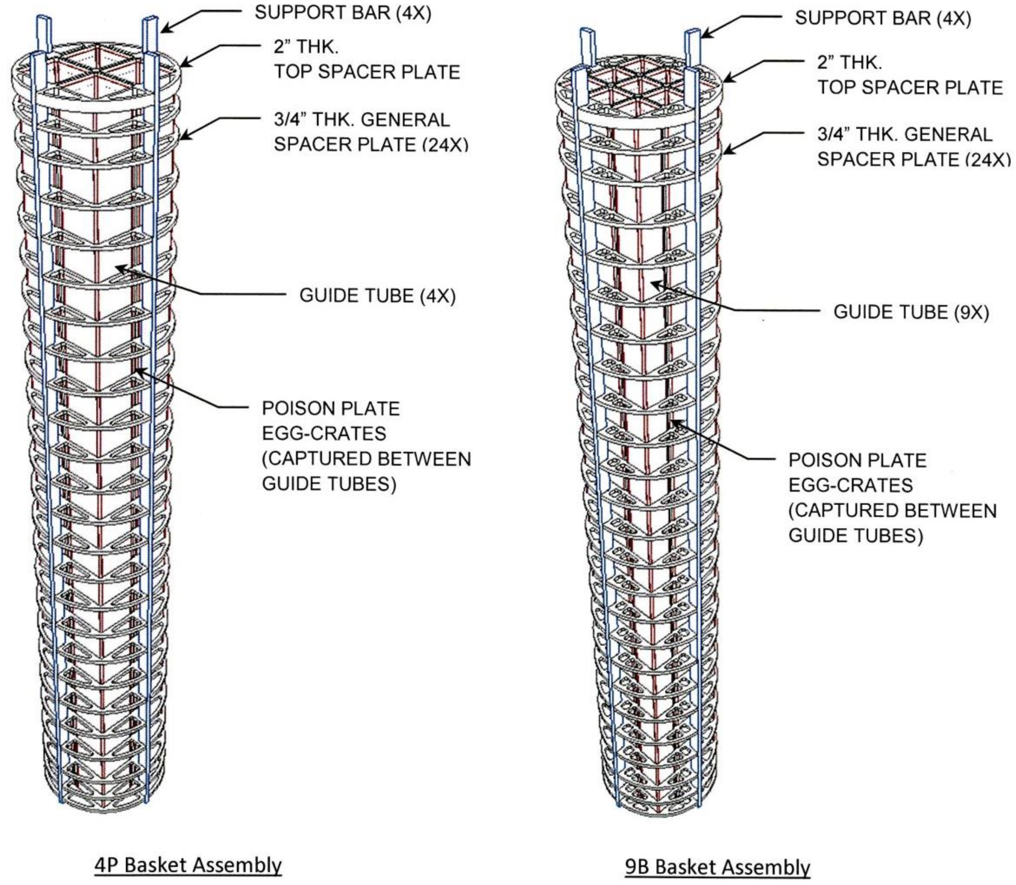
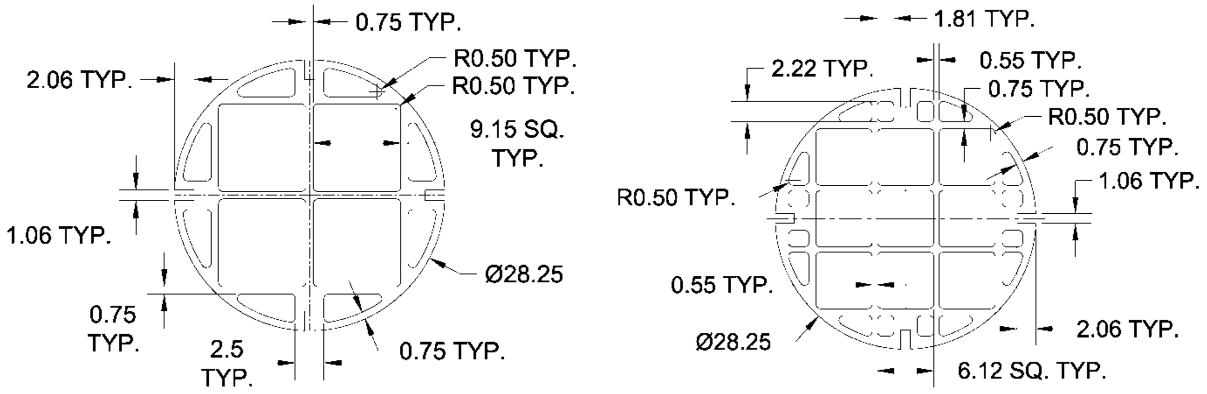


Figure 4-2. Perspective Views of 4P and 9B STAD Basket Assemblies



4P Spacer Plate Dimensions

9B Spacer Plate Dimensions

Figure 4-3. 4P and 9B Spacer Plate Dimensions

The weights of the major subassemblies that comprise the 4P and 9B STAD canister assemblies are summarized in Table 4-1 for both the loaded-dry and loaded-wet configurations. In the loaded-dry configuration, both the 4P and 9B STAD canisters weigh less than 14,000 pounds each with the heaviest spent fuel payloads. The maximum canister weights for the loaded-wet configuration are 15,900 pounds and 16,335 pounds for the 4P and the 9B STADs respectively.

Table 4-1. STAD Canister Weight Summary

Configuration	**Subassembly/Component**	**Weight (lb.)**	
		4P	**9B**
Loaded-Dry	Canister Body Subassembly	1,730	1,730
	Basket Assembly	2,650	3,720
	Shield Plug(1)	1,540	1,540
	Top Plate Assembly(1)	460	460
	Spent Fuel(2)	6,900	6,354
	Totals	**13,280**	**13,804**
Loaded-Wet(3)	Canister Body Subassembly	1,730	1,730
	Basket Assembly	2,650	3,720
	Shield Plug(1)	1,540	1,540
	Spent Fuel(2)	6,900	6,354
	Water(4)	3,080	2,991
	Totals	**15,900**	**16,335**

Notes:

(1) Includes weight allowance for closure welds.

(2) Based on the maximum PWR and BWR fuel assembly weights of 1,725 pounds and 706 pounds, respectively.

(3) The loaded wet configuration occurs when the loaded STAD canister is lifted out of the spent fuel pool. In this configuration, the shield plug is placed into the canister, but the top plate assembly is not installed in the canister. The free volume inside the canister shell is filled with water.

(4) Weight includes water inside the free volume of the canister cavity and in the free volume above the shield plug. The water weight is calculated using displaced volumes for PWR and BWR fuel assemblies of 5,500 in^3 and 2,250 in^3, respectively.

4.1.2 Canister Transfer System

The canister transfer system is proposed with the use of a “carrier” type STAD basket. The carrier design locates and supports four STAD canisters, either 4-P or 9-B, during loading operations, storage condition or transport conditions. Use of the carrier provides the advantage of reducing the number of primary loading and handling operations. In this role, the carrier is the primary transfer component when loading the STADs. Transfer equipment, similar to that used for the ultra-high capacity canister based systems, is used to load, process, and transfer the STADs.

The STAD carrier is essentially a four opening support disk system with intermittent heat transfer disks. Further analytical evaluation is required to accurately determine the number of support disk and thermal fins to meet the proposed thermal target of 32 kW. Currently thermal convection analysis will determine the performance of the carrier during storage in a vertical concrete cask. In support of this performance, there are openings in each disk and gaps developed at each STAD to allow natural convection air circulation to remove decay heat from each of the STAD canisters. Figure 4-4 shows the top view of a loaded STAD carrier in a transfer cask. Figure 4-5 shows a side-view of the STADs in the carrier without the transfer cask.

Figure 4-4. Loaded STAD Carrier in Transfer Cask – Top View

The top shield plate is thicker than the balance of plates used and provides increased structural support for the STAD shield plug mass during transport and storage conditions. The shield plate is also functional in loading operations as an occupational shield. The thickness is balanced with the STAD shield plugs to provide commensurate shielding during welding and inspection operations.

Loading operations for the STAD canister requires the use of a transfer cask. Each group of four STADs requires a single carrier be loaded into the transfer cask. Following the placement of the carrier, four STAD canisters are loaded without closure lids and prepared for loading by filling with pool water. Inflatable seals in the transfer cask allow for the interstitial space between the canisters and the transfer cask to be filled with clean demineralized water. This provides additional occupational shielding and keeps the outsides of the canister clean during loading operations. To ensure there is no in-leakage of pool water, the water system can be over-pressurized slightly to ensure clean water flow out of the cask, wipers can be installed in each of the STAD openings at the top shield plate or a sealing ring assembly can be installed on the carrier that uses inflatable seals for each STAD canister. Once loaded into the transfer cask, the STADs in the transfer cask are removed from the fuel pool using a similar lifting yoke as that used for a transport cask. Following this, the STADs are welded closed as explained in Section 4.1.1. Figure 4-6 shows a loaded carrier in a transfer cask with the lifting equipment. Figure 4-7 shows the transfer stack-up to storage or transport casks. Figure 4-8 depicts the transfer of a loaded carrier to storage.

Figure 4-5. STADs in Carrier

Figure 4-6. Loaded Carrier in Transfer Cask with Lifting Equipment

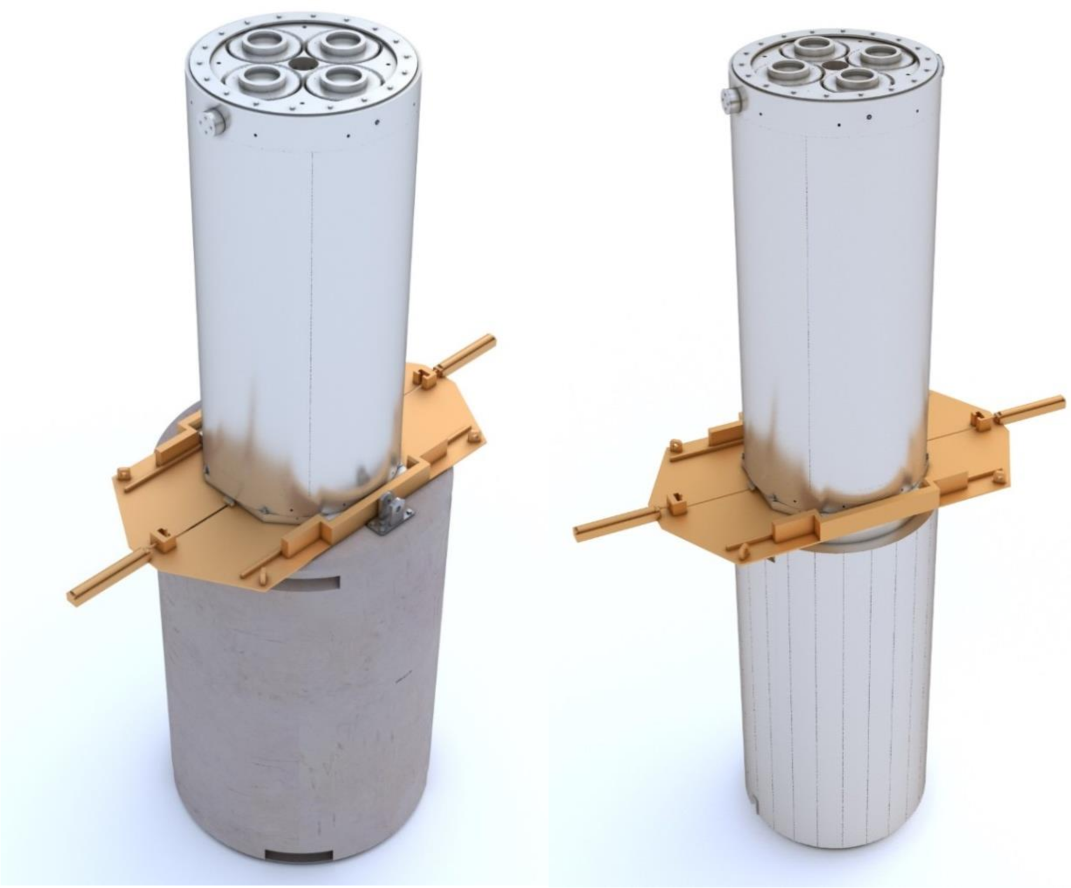


Figure 4-7. Transfer Stack-up to Storage or Transport

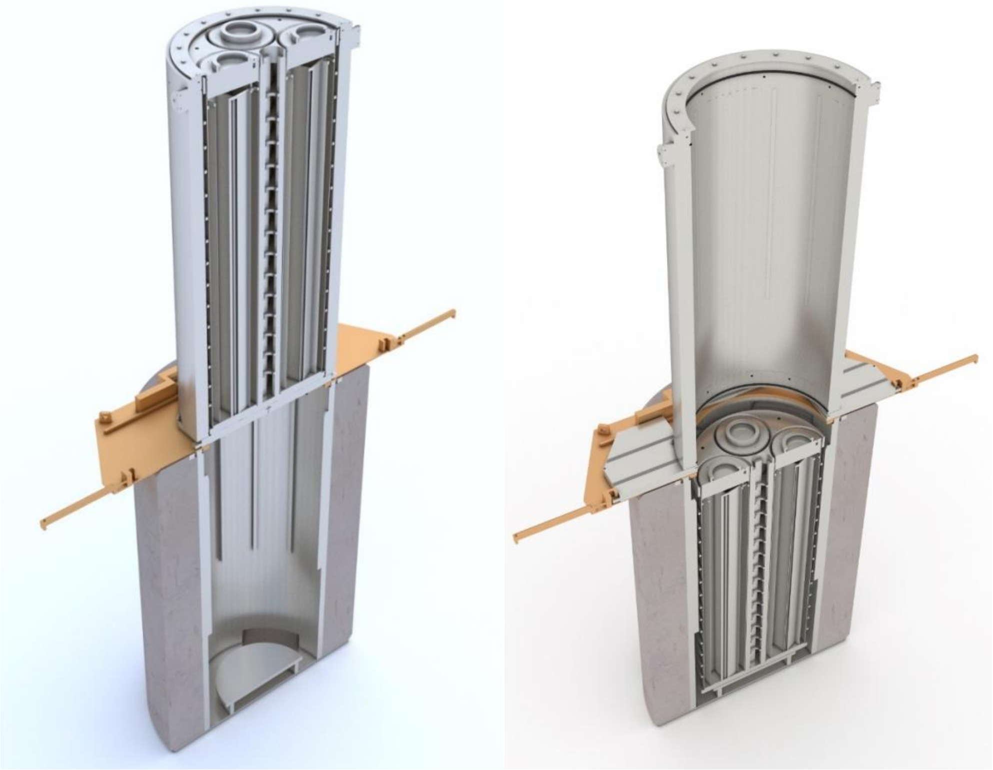


Figure 4-8. Transfer of Loaded Carrier to Storage

Although the STAD carrier is primarily designed for multiple STAD handling activities, each STAD remains independently accessible. Development of additional STAD handling equipment can allow for single STAD removal and placement for variations in transport and storage configurations. Figure 4-9 depicts systems for the loading and unloading of single STAD canisters from both storage and transportation casks. The system shown on the left demonstrates a transfer either into or from a STAD transport cask configuration. The system on the right demonstrates a transfer either into or from a STAD vertical concrete cask configuration. Similarly, a single STAD transfer can be performed from or into individual in-ground caisson type storage or horizontally into bunker type storage.

Lifting and handling of the individual STAD canisters is by the engineered lid interface described in Section 4.1.1. The STAD lifting system, as well as the transfer cask handling interface, will be designed to be single-failure proof.

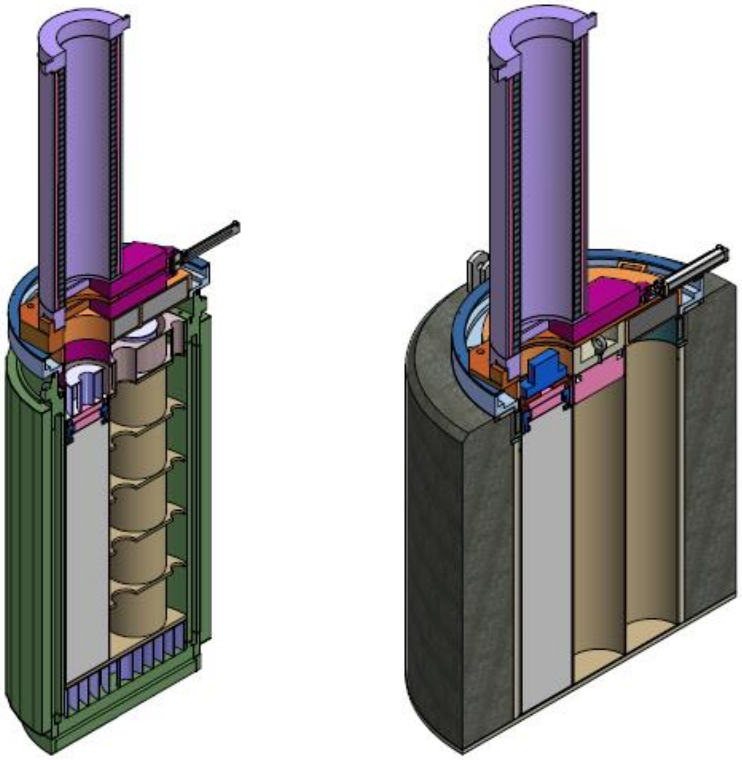


Figure 4-9. Single STAD Transfer Concept for Transport and Storage

4.1.3 Storage Options

4.1.3.1 Vertical Concrete Cask Storage

The proposed vertical concrete cask implementation of the STAD storage concept is based upon MAGNASTOR ultra-high capacity fuel canister licensed technology (see Figure 4-10).

The Vertical Concrete Cask (VCC) is a reinforced concrete structure with a structural steel inner liner and base. The reinforced concrete wall and steel liner provide the neutron and gamma radiation shielding for the stored SNF. Inner and outer reinforcing steel (rebar) assemblies are encased within the concrete. The reinforced concrete wall provides the structural strength to protect the STADs and their contents in natural phenomena events such as tornado wind loading and wind-driven missiles and during non-mechanistic tip-over events. The concrete surfaces remain accessible for inspection and maintenance over the life of the cask, so that any necessary restoration actions may be taken to maintain shielding and structural conditions.

The concrete cask body also provides an annular air passage to allow the natural circulation of air around the STAD carrier to remove the decay heat from the contents. The lower air inlets and upper air outlets are steel-lined penetrations in the concrete cask body. Each air inlet/outlet is covered with a screen. A weldment baffle directs the air upward and around the pedestal that supports the STAD carrier. Decay heat is transferred from the fuel assemblies to the STAD wall by conduction, convection, and radiation. Heat is removed by conduction and convection from the STAD shell to the air flowing upward through the annular air passage and exhausting out through the air outlets. The passive cooling system is designed to maintain the peak fuel cladding temperature below acceptable limits during long-term storage, in accordance with NUREG-1536, Rev.1. The VCC thermal design also maintains the bulk concrete temperature below the American Concrete Institute (ACI) limits under normal operating conditions. The inner liner of the VCC also incorporates standoffs that provide lateral support to the STADs in the carrier in side impact accident events.

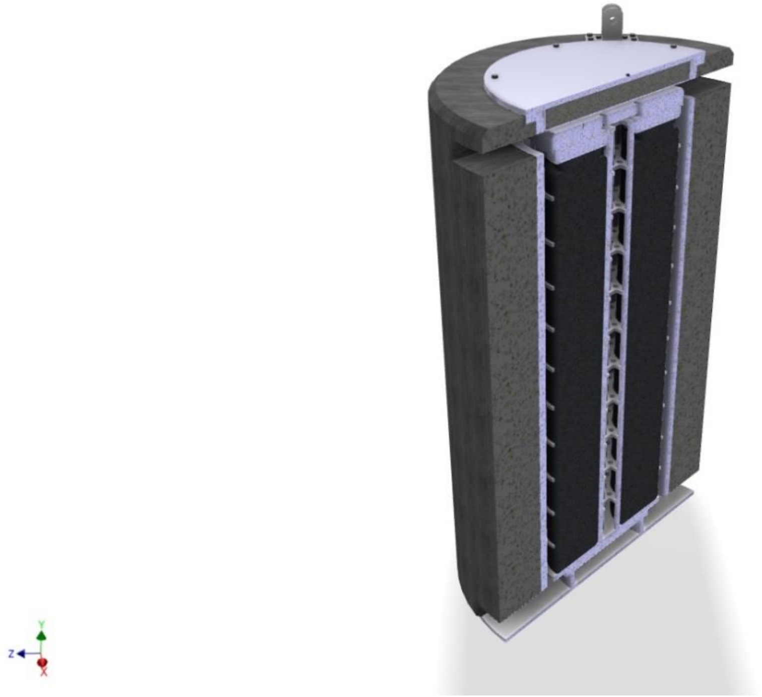


Figure 4-10. Vertical Concrete Cask Storage

A carbon steel and concrete lid is bolted to the top of the concrete cask. The lid reduces skyshine radiation and provides a cover to protect the STAD carrier from the environment and postulated tornado missiles.

Fabrication and construction of the VCC requires no unique or unusual forming, concrete placement, or reinforcement operations. The concrete portion of the cask is constructed by placing concrete between a reusable, exterior form and the steel liner. Reinforcing bars are used near the inner and outer concrete surfaces to provide structural integrity.

Operationally, daily visual inspection of the air inlet and outlet screens assures that airflow through the cask meets licensed requirements. As an alternative to daily visual inspections, the loaded concrete cask in storage may include the capability to measure air temperature at the four outlets. Each air outlet may be equipped with a remote temperature detector mounted in the outlet air plenum. The air temperature-monitoring system, which provides verification of heat dissipation capabilities, can be designed for remote or local read-out capabilities. The temperature-monitoring system can be installed on all or some of the concrete casks at the ISFSI facility. Figure 4-11 and Figure 4-12 show an ISFSI facility.

Figure 4-11. An Independent Spent Fuel Storage Installation Facility

Figure 4-12. An Independent Spent Fuel Storage Installation Facility – Distant View

Provided within this report is a preliminary analysis of the tube and disk carrier concept within a vertical ventilated concrete cask. The evaluation was used to provide confidence in a naturally convection system's ability to adequately cool the STADs with heat loads as high as 32 kW.

4.1.3.2 Horizontal Concrete Cask Storage

Utilization of a horizontal storage option may require further design modifications to accommodate the horizontal bearing of a loaded carrier into the storage module. Currently licensed technology utilizes a combination of lubrication and a material resistant to galling for both the transfer cask and the storage module horizontal structural supports. For the transfer of a full single canister, this is adequate.

For the STAD carrier design approach presented in this report, the intermittent disks could be problematic in a horizontal transfer if there is a gap greater than the thickness of a support disk. Possible alternatives to resolve this issue would require the carrier to be positioned and controlled in a predetermined orientation in which continuous supports can be incorporated over the entire length of the carrier assembly. The current horizontal technology is based on a canister wall contact with a twin rail support system. A similar concept may be developed if a horizontal system is determined to be more effective for the package. A further development of this concept, and described in Section 4.1.2, is the ability to transfer single STADs. The ability to handle the STADs individually may be more optimal for placement horizontally.

Similar to the VCC, the horizontal storage cask is constructed of reinforced concrete, providing shielding and protection for the contents. As opposed to the VCC's construction approach, however, the horizontal storage modules are typically precast and transported to the site. Assembly at the site is limited to placement of the modules onto the pad in a row of predetermined length and installing the end shield walls.

Placement of the STAD carrier would follow loading similarly to that of the vertical approach, except the transfer cask has an upper and lower closer plate and is handled horizontally. Incorporated into the transfer cask handling device is a large hydraulic ram which, following alignment procedures to the horizontal storage module, drives the transfer cask contents into the storage module. Figure 4-13 shows a horizontal concrete cask storage operation.

Figure 4-13. Horizontal Concrete Cask Storage

4.1.3.3 In Ground Concrete Silo/Bunker

Utilization of an in-ground or above ground bunker storage option can address either the carrier concept or the individual STAD concept. Either option can be designed to utilize the STAD carrier or the individual STAD approach for storage. Shielding is predominantly provided by the embedment materials with the axial "skyshine" component controlled by the cover or lid. The in-ground application is essentially the same as an above ground component with respect to materials.

Thermal performance can be either conduction/convection into the earth or convection out thru vent risers at the installation surface. Figure 4-14 shows in-ground storage at Bruce Power, located in Canada.

Figure 4-14. In Ground Storage at Bruce Power

Development of an in ground storage approach can require a significant amount of excavation, installation of engineered fill and construction. Figure 4-15 shows excavation activities at the Callaway Nuclear Site.

Figure 4-15. Excavation Activities at Callaway Nuclear Site

4.1.4 Transportation Options

With the utilization of the multi-STAD carrier concept, the transport cask would be a Rail/Barge sized component. The transportation cask for the STAD would utilize similar transport cask technology as the bare fuel transport cask developed for Task Order 17. The significant difference in the two transport casks would be the cavity diameter (78″ ID versus 70″ ID) and the cavity length (194″ versus 180″). The increased size of the cask cavity drives the outside diameter and subsequently the weight. The length increase is required to compensate for the shield plug, closure lid and canister base of the STAD, as well as the carrier base. In addition to the increased cask weight, the increased diameter of the transportation cask impacts the transport package's drop accident performance by reducing the radial thickness of the impact limiters. The radial thickness is reduced due to the increased diameter of the transportation cask and the fixed outside diameter (128″) of the limiters. (See Figure 4-16 and Figure 4-17). Further details are provided in Section 5.3.

Figure 4-16. Cutaway Transport Cask with STADs and Carrier Installed

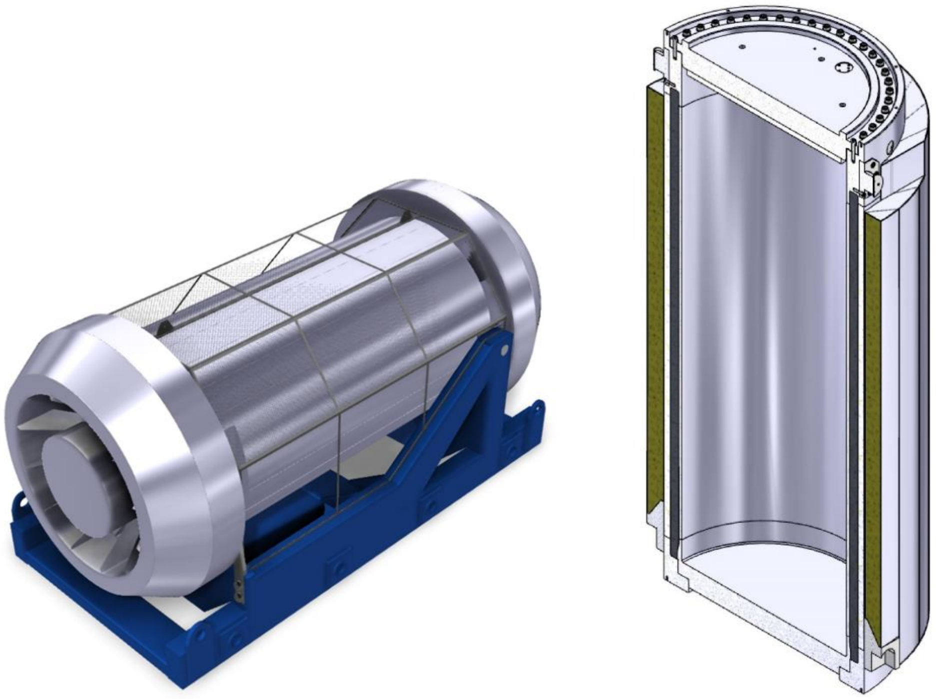


Figure 4-17. Task Order 17 Concepts

4.1.5 Handling Weights for Operations

Table 4-2 provides weights for both 4P and 9B STAD designs with respect to loading operations, storage operations and transport operations.

Table 4-2. Estimated STAD Package Weights

Estimated STAD Package Weights (lbs)	**STAD Configurations**							
Components	PWR-4 Transport Cask	PWR-4 Storage Cask	PWR-4 Transfer Cask	BWR-9 Transport Cask	BWR-9 Storage Cask	BWR-9 Transfer Cask	PWR STAD Carrier	BWR STAD Carrier
Cask Body	202,841	257,520	147,500	202,841	257,520	147,500		
Cask Lid	9,425	9,480		9,425	9,480			
Impact Limiters (2)	19,000			19,000				
Yoke/Lifting Rig	5,500		5,500	5,500		5,500	1,200	1,200
STAD Carrier	23,800	23,800	23,800	23,800	23,800	23,800	23,800	23,800
STAD Canister PWR-4 (4) Dry	53,120	53,120	53,120				53,120	
STAD Canister BWR-9 (4) Dry				55,216	55,216	55,216		55,216
STAD Canister PWR-4 (4) Wet	63,600	63,600	63,600					
STAD Canister BWR-9 (4) Wet				65,340	65,340	65,340		
Transfer Cask Interstitial Water			11,193			11,193		
Crane Hook/Lift Weight	294,686	343,920	251,593	296,782	346,016	253,333	78,120	80,216
Transport Weight	313,686			315,782			76,920	79,016

Table 4-2 illustrates the different loading configurations (transfer/fuel loading, storage and transport) for both the 4P and 9B STAD options. The critical weight for the STAD is the loading/transfer operations where the package is limited to the 125 ton site crane. In both of the configurations, the loaded package(s) with water slightly exceed the crane capacity. Further development of the system and finer shielding models should be able to provide some additional latitude in shielding and allow for a slight reduction in transfer cask weight. A reduction of ¼″ of lead, radially, would reduce the transfer cask weight by approximately 5,500 lbs.

4.2 PACKAGE CONTENTS

The PWR and BWR STADs described in Section 4.1 can accommodate all US PWR and BWR assembly types with the exception of South Texas PWR assemblies, (future) AP1000 assemblies, and Combustion Engineering 16×16 assemblies with inserted control components, whose lengths exceed that of the 180-inch cask cavity.

Specific allowable fuel assembly parameters and dimensions are discussed in the subsections below and are summarized in Table 4-3.

Table 4-3. STAD Assembly Loading Specifications

	Storage		**Transportation**	
	PWR	**BWR**	**PWR**	**BWR**
Allowable US Assembly Types	All[1]	All	All[1]	All
Overall Assembly Length (in.)[2]	≤ 178.5	≤ 178.5	≤ 178.5	≤ 178.5
Assembly Width (in.)	≤ 8.6	≤ 8.6	≤ 5.6	≤ 5.6
Overall Assembly Weight (lbs)[3]	≤ 1,725	≤ 1,725	≤ 706	≤ 706
Maximum Assy Heat Generation (kW)	≤ 2.0	≤ 0.889	≤ 1.5	≤ 0.667
Assembly Burnup (GWd/MTU)	≤ 62.5	≤ 62.5	≤ 62.5	≤ 62.5
Assembly Cooling Time (yr.)	≥ 5	≥ 5	Varies[4]	Varies[4]
Initial Enrichment (w/o U-235)[5]	Varies[6]	≤ 5.0	Varies[6]	≤ 5.0[7]

Notes:

1. With the exception of South Texas and AP1000 assemblies. CE 16×16 assemblies may not be loaded with inserted control components.
2. Nominal, pre-irradiation-growth length including any inserted control components.
3. Including any inserted control components (PWR) or flow channels (BWR).
4. The required minimum assembly cooling time varies with assembly burnup level. The required cooling times are shown as a function of burnup level in Table 4-4.
5. Limits refer to maximum planar average initial enrichment (at any axial elevation).
6. The maximum allowable initial enrichment varies with assembly burnup level, as shown in Table 4-5.
7. This allowable enrichment limit is based upon the assumption that the currently proposed approach of relying on moderator exclusion for the BWR STAD cask system is successful. Even in the case of water ingress, the maximum allowable enrichment is still 5.0% if the BWR assemblies can be shown to remain intact under all transportation conditions. Unlikely scenarios where both water ingress and BWR assembly reconfiguration are assumed to occur are evaluated in Section 4.3.4.2.

4.2.1 Fuel Parameters

The minimum opening for the PWR STAD basket cells is 8.85 inches. This is wide enough to accommodate all US PWR fuel, as the maximum US PWR assembly width is 8.54 inches.[4] The 5.85 inch minimum cell opening width for the BWR basket cells is wide enough to accommodate all US BWR fuel, as the maximum US BWR assembly width is 5.52 inches.[4]

The maximum lengths for US PWR and BWR fuel assemblies (with the exception of South Texas fuel, AP1000 fuel, and CE 16×16 fuel with control components) are 178.3 inches and 176.2 inches, respectively[4]. Thus, all such PWR and BWR fuel can be shipped in the PWR and BWR STADs; both of which have a cavity length of 180 inches. If 1.5 inches is not sufficient to account for both thermal and irradiation growth, then the STAD cavity would have to be slightly increased to accommodate CE 16×16 (Sys 80) fuel.

The cask system weight calculations and the Section 4.3.1 structural evaluations cover PWR and BWR assembly weights of up to 1725 lbs. and 706 lbs., respectively. Thus, individual assemblies with weights equal to or lower than those values may be loaded. Note that the weight of any inserted control components must be included in the overall assembly weight.

4.2.2 Loading Specifications

Loading specifications (i.e., limits on assembly burnup, cooling time, and heat generation, etc.), are discussed, for transport and storage operations, in the following sections.

4.2.2.1 Transportation Cask Loading Specifications

The Section 4.3.2 thermal analyses qualify PWR and BWR assemblies with heat generation levels of 1.5 kW/assembly and 0.667 kW/assembly, respectively, for loading into the transportation cask described in Section 4.1.4.

However, for the transportation cask, minimum required assembly cooling times are governed by shielding (as opposed to thermal) design considerations. The combinations of assembly burnup levels and cooling times that are qualified for loading (within STADs) in the transportation cask are shown in the titles of Table 4-24 through Table 4-36 (starting on page 150). The required (minimum) cooling times are conservatively based on upper-bound assembly uranium loadings and lower-bound initial enrichment levels for each corresponding burnup level. The minimum required cooling times are presented as a function of assembly burnup level for PWR and BWR assemblies in Table 4-4.

---

[4] MAGNATRAN Transport Cask SAR, Revision 12A, October 2012, NRC Docket No. 71-9356, NAC International.

Table 4-4. Minimum Required Cooling Times for PWR and BWR Assemblies Loaded into the STAD Transportation Cask System

Assembly Burnup Level (GWd/MTU)	Minimum Required Cooling Time (years)	
	PWR	BWR
40	-	5
45	5	6
50	6	9
55	8	13
60	10	18
62.5	11	20

Table 4-5. PWR Fuel Allowable Initial Enrichment vs. Burnup for the PWR STAD[1,2]

Assembly ID	Zero (0) Burnup Max. Enr. (wt %)	Max Initial Enrichment (wt% ^{235}U) = C_4 × Burnup (GWd/MTU) + C_5					
		Burnup (GWd/MTU) < 18		18 ≤ Burnup (GWd/MTU) ≤ 30		Burnup (GWd/MTU) > 30	
		C_4	C_5	C_4	C_5	C_4	C_5
BW 15×15	1.9	0.0501	1.69	0.0693	1.65	0.0748	1.60
BW 17×17	1.9	0.0502	1.72	0.0687	1.70	0.0742	1.66
CE 14×14	2.1	0.0473	2.04	0.0675	2.03	0.0759	1.93
CE 16×16	2.1	0.0464	2.03	0.0657	2.06	0.0733	1.99
WE 14×14	2.2	0.0496	2.08	0.0672	2.21	0.0725	2.29
WE 15×15	1.9	0.0494	1.74	0.0683	1.72	0.0742	1.67
WE 17×17	1.9	0.0494	1.71	0.0685	1.68	0.0749	1.61

Notes:

1. These requirements only apply if water ingress into the cask is deemed to be credible. The proposed licensing approach for the PWR STAD transport system is to rely on moderator exclusion.

2. The presented maximum initial enrichment requirements are taken directly from the MAGNATRAN transport cask system SAR[5]. These requirements are conservative for the PWR STAD transport cask configuration, which is demonstrated in Section 4.3.4.1 to be less reactive than the MAGNATRAN cask configuration. These requirements are also applicable for the transfer cask configuration.

---

[5] MAGNATRAN Transport Cask SAR, Revision 12A, October 2012, NRC Docket No. 71-9356, NAC International.

The currently proposed approach for the STAD transportation cask system criticality licensing evaluation is to rely on moderator exclusion for 10 CFR 71 hypothetical accident conditions (HAC). Burnup credit will still be relied upon to qualify intact PWR assemblies for loading, but assembly reconfiguration that could occur under HAC would not have to be modeled in the burnup credit analysis, if moderator exclusion is successfully used. The BWR criticality analysis will not rely on burnup credit. The BWR HAC analyses would, however, have to assume water ingress, along with any assembly reconfiguration that may occur under HAC, if moderator exclusion cannot be relied upon.

As discussed in Section 4.3.4, burnup credit will be used to qualify intact PWR assemblies for transportation during the licensing phase of the STAD cask system, and may be used to qualify reconfigured assemblies under HAC, if water ingress is deemed credible. Thus, "burnup curves" would be established which specify maximum assembly initial enrichments as a function of assembly burnup level for each PWR assembly type. The Section 4.3.4 criticality evaluation demonstrates that, even if water ingress is assumed, the PWR STAD and cask configuration, containing intact PWR fuel, is less reactive than a MAGNATRAN transportation cask system containing intact PWR fuel. As discussed in Section 4.3.4, the PWR STAD system is less reactive than MAGNATRAN even if partial or full reconfiguration of the PWR assemblies occurs (although an extended borated stainless steel plate configuration would have to be employed within the PWR STAD if full reconfiguration is deemed credible). Thus, the enrichment vs. burnup requirements given for intact PWR assemblies in the MAGNATRAN Safety Analysis Report (SAR)[4] are applicable (or conservative) for the PWR STAD and transportation cask system. The maximum allowable initial enrichment levels are presented as a function of assembly burnup level, for each major U.S. PWR assembly type, in Table 4-5.

Analyses are presented in Section 4.3.4 that determine the maximum allowable BWR assembly planar average enrichment levels that would apply if water ingress into the transportation cask and STAD interiors is assumed. Those analyses show that the BWR STAD can accommodate BWR assembly initial enrichment levels up to 5.0% if the assemblies are assumed to remain intact (under transportation hypothetical accident conditions). If partial assembly reconfiguration (along with water ingress) is assumed to be credible, then the allowable enrichment falls to 4.3%. If the STAD payload is reduced to eight BWR assemblies, the allowable initial enrichment would be 5.0%, even assuming partial BWR assembly reconfiguration. Alternative STAD basket configurations that place borated stainless steel plates around the periphery would allow a full payload of partially reconfigured BWR assemblies with enrichments up to 4.75%. If full BWR assembly reconfiguration is deemed credible, than moderator exclusion must be relied upon (for HAC), in which case the allowable BWR assembly initial enrichment is 5.0%.

The overall requirements for PWR and BWR assemblies to be loaded into the transportation cask (within STADs) are summarized in Table 4-3.

4.2.2.2 Transfer and Storage Cask Loading Specifications

The Section 4.3.2 thermal analyses qualify PWR and BWR assemblies with heat generation levels of 2.0 kW/assembly and 0.889 kW/assembly, respectively, for loading (within STADs) into the transfer and storage casks described in Sections 4.1.2 and 4.1.3. These assembly heat generation levels allow the loading of PWR and BWR fuel assemblies with a burnup level up to 62.5 GWd/MTU and a cooling time as low as 5 years.

The Section 4.3.3 shielding analyses also show that full payloads of 62.5 GWd/MTU, 5 year cooled PWR and BWR fuel (within the PWR and BWR STADs described in Section 4.1.1) produce acceptable dose rates outside the transfer and storage casks.

The overall requirements for PWR and BWR assemblies to be loaded into the transfer and storage casks (within STADs) are summarized in Table 4-3. The criticality related requirements determined for the transportation cask are also applicable for the transfer and storage cask configurations. Note that BWR assembly enrichment limits discussed in Section 4.3.4, that are associated with HAC assembly reconfiguration (along with water ingress) do not apply for transfer and storage since the STADs will be transported in the future, and the transport configuration bounds the storage and transfer configurations, with respect to criticality.

4.3 DESIGN AND ANALYSIS APPROACH

4.3.1 Structural Analyses

The STAD carrier was originally conceived as a multi-disc structure with longitudinal stringers for STAD canister support (See Figure 4-18). As a concept, the design allowed further investigation with respect to the structure’s ability to perform as a passive convective heat rejection component in a standard vertical concrete storage cask. The results of those thermal investigations are documented in Section 4.3.2.

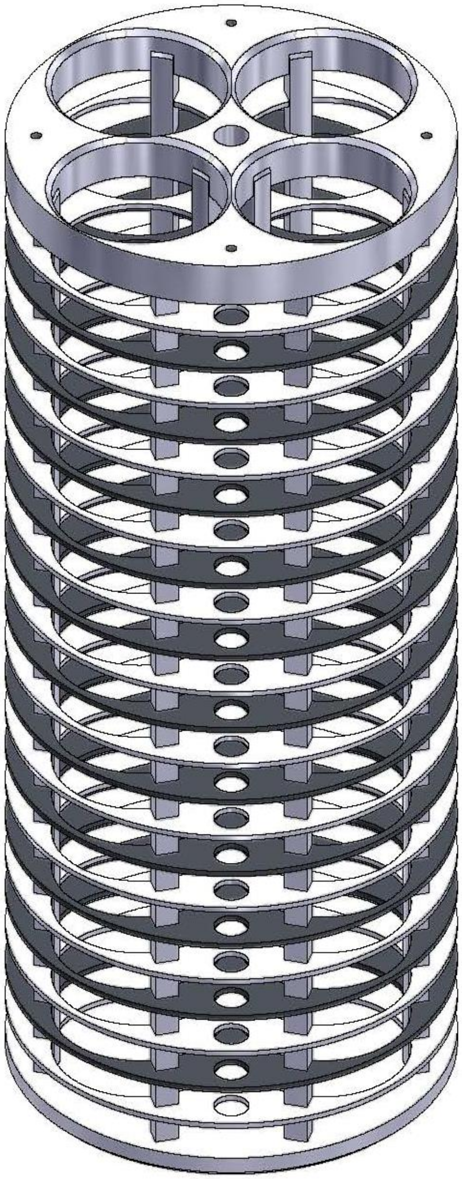


Figure 4-18. Baseline STAD Carrier Design

In parallel to the thermal evaluations, scoping evaluations and discussions within the Team on the STAD design initiated several informational assessments with respect to the performance of the multi disc arrangement structurally, and options to enhance the STAD canister support structure design. Specifically, discussions within the Team indicated the three longitudinal supports presented in the baseline design would impose too much load on the STAD canisters. A direct solution would have been to increase the number of supports for better distribution of loads, but the weight impact was significant. The alternative was to develop a “sleeve” design. The first two initial designs, Version 1 and Version 2, (See Figure 4-19) are both based on the use of a continuous sleeve located in support discs. The current sleeve design (See Figure 4-20) is essentially 4 sleeves in contact, with a developed bearing width of 3.25″. The 2×2 array develops a tangent diameter of 77″.

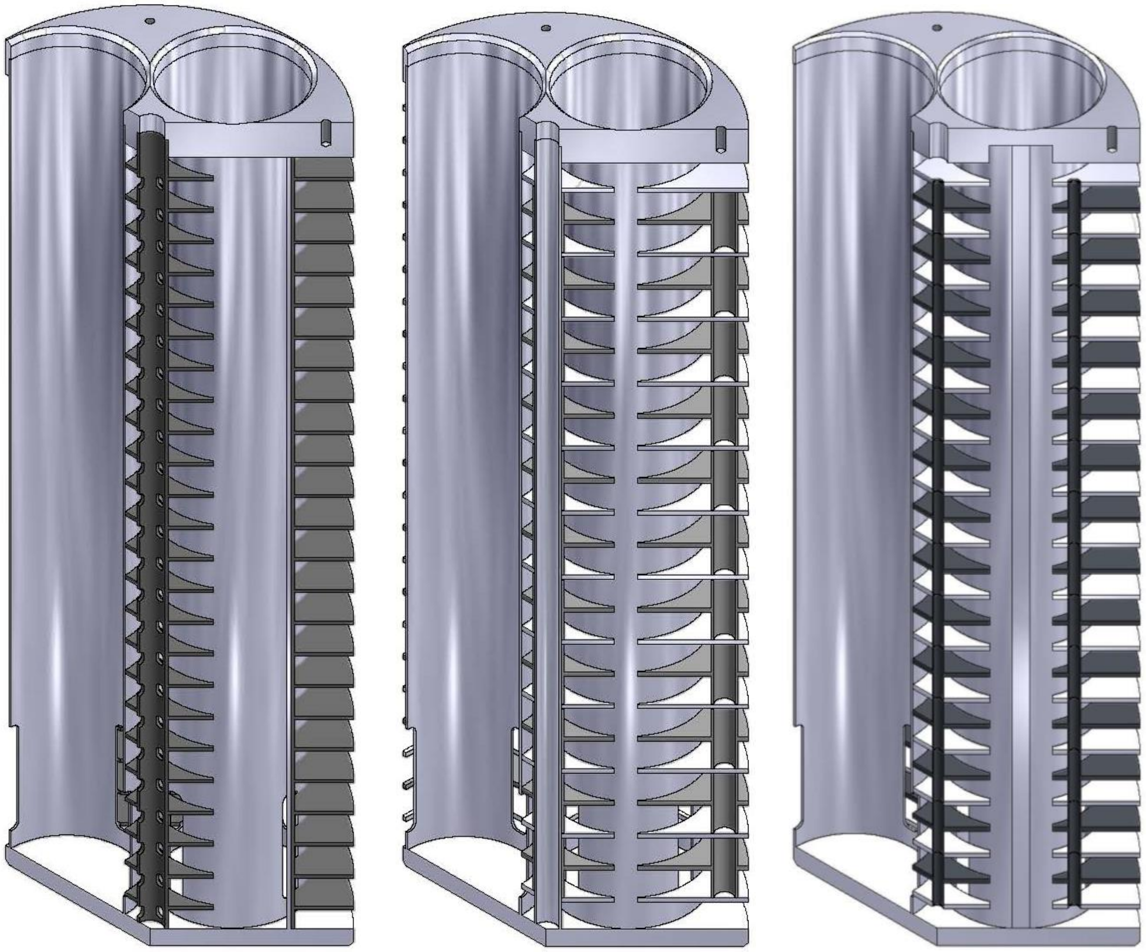


Figure 4-19. STAD Carrier Design – Evolution of Carrier Sleeve Design Version 1, Version 2 and Current

Support discs assemblies are used in the regions between the sleeves, one in the center and four between the sleeves (see Figure 4-20). These areas will ultimately be used to attach thermal shunts for transport thermal conduction. Figure 4-21 shows the integration of the sleeves and supports.

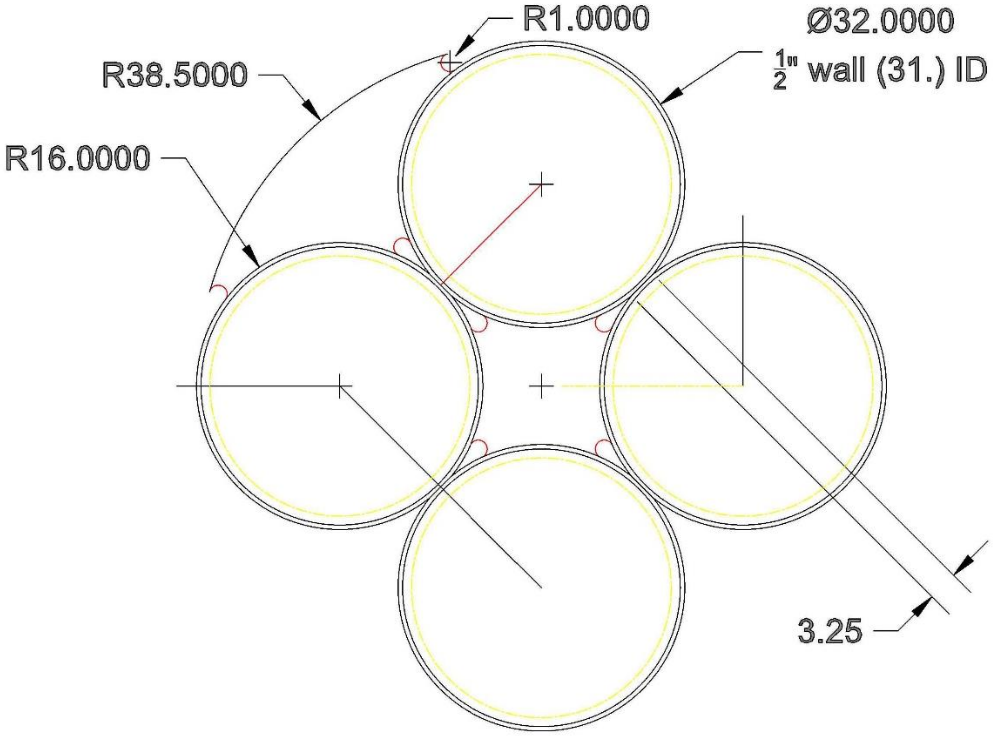


Figure 4-20. Geometry of the Current Sleeve Design

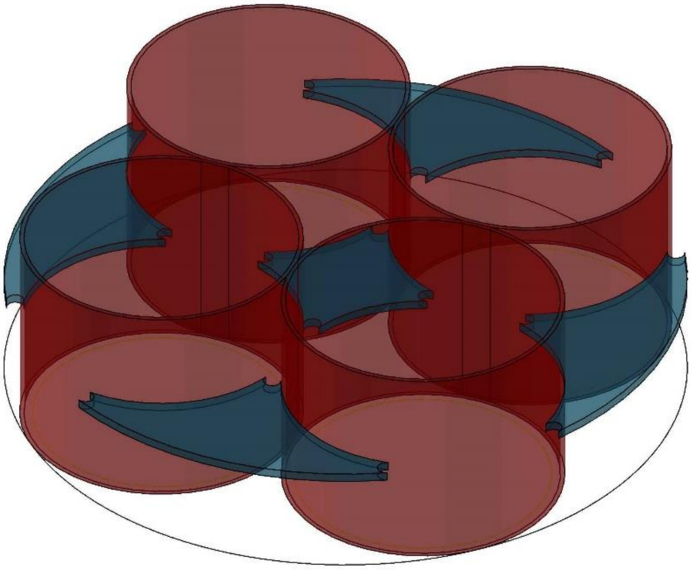


Figure 4-21. Relationship of Supports and Sleeves

Although the current 4 sleeve design is based on a tangent diameter of 77″, the sleeve to STAD gap has yet to be optimized and may result in the reduction of the cask(s) inside diameter. This reduction should offset the weight penalty of the continuous sleeves. Figure 4-22 through Figure 4-28 demonstrates the structural effectiveness of the current design. Analyses for 0, 22.5 and 45 degree orientations were performed with only local stresses coming close to allowable limits.

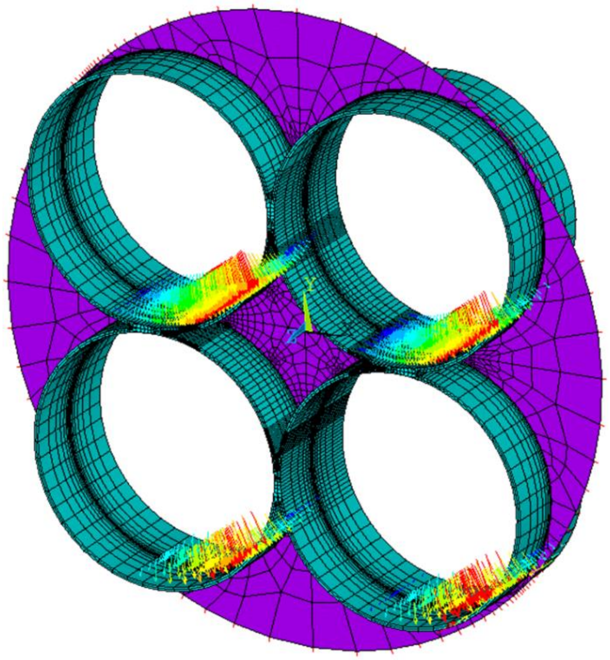


Figure 4-22. 45^0 Model With Loads Imposed

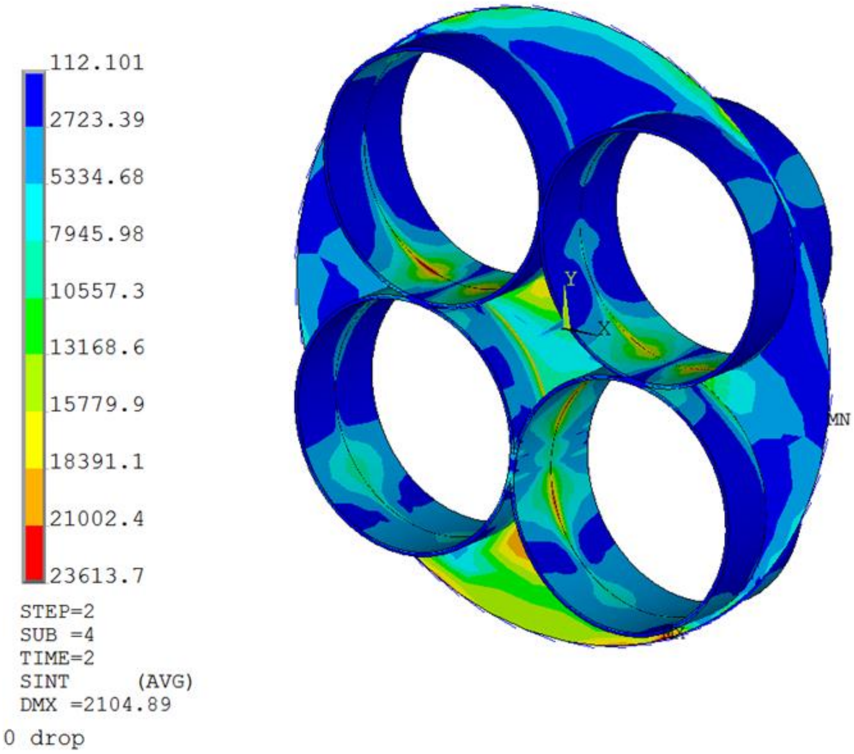


Figure 4-23. Stress Contours at 0^0 for Sleeve to Support Disc Interface

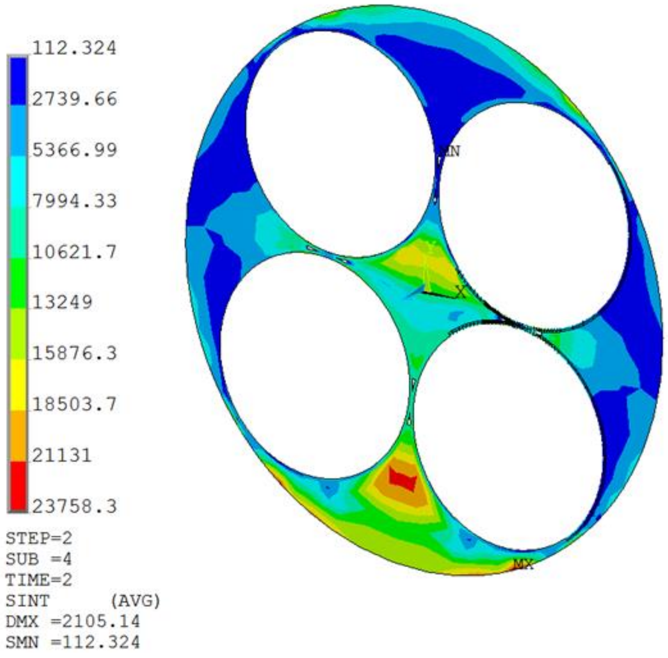


Figure 4-24. Stress Contours at 0^0 for Support Disc

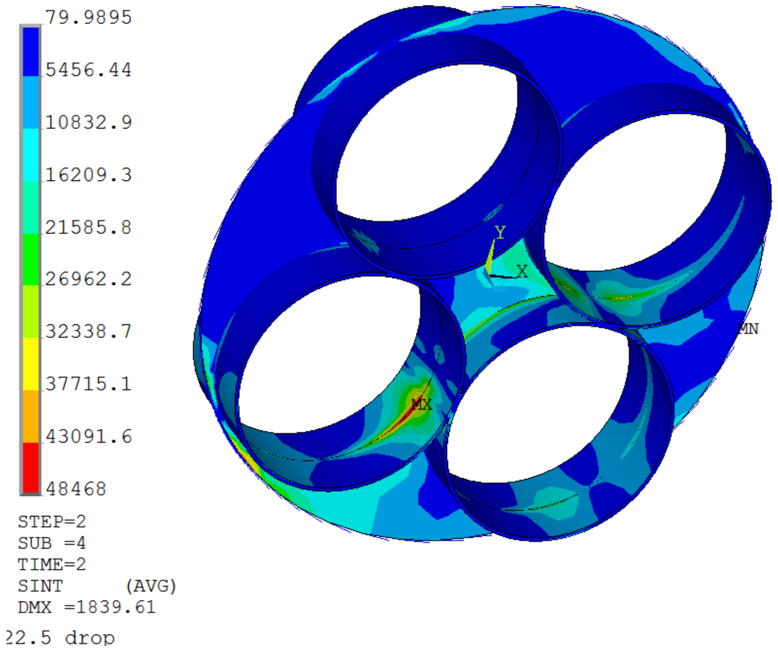


Figure 4-25. Stress Contours at 22.5^0 for Sleeve to Support Disc Interface

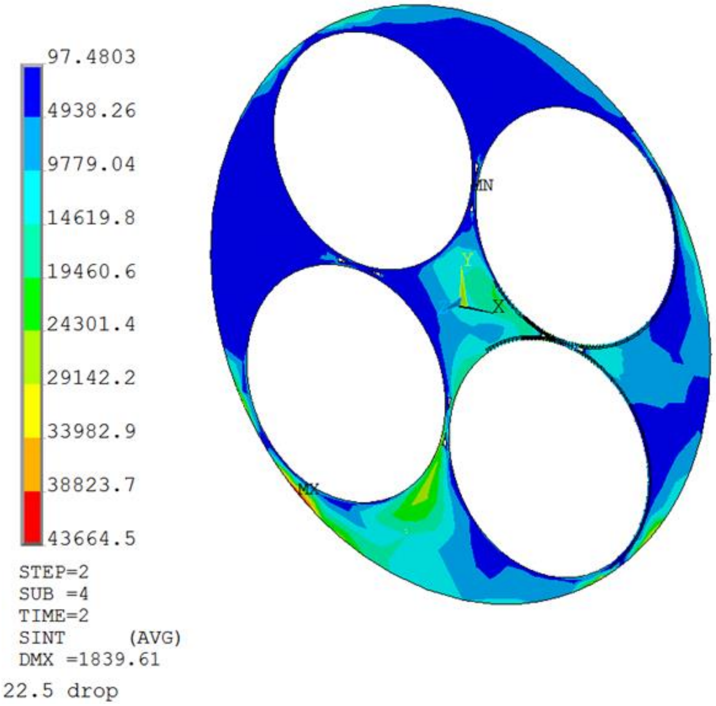


Figure 4-26. Stress Contours at 22.5^0 for Support Disc

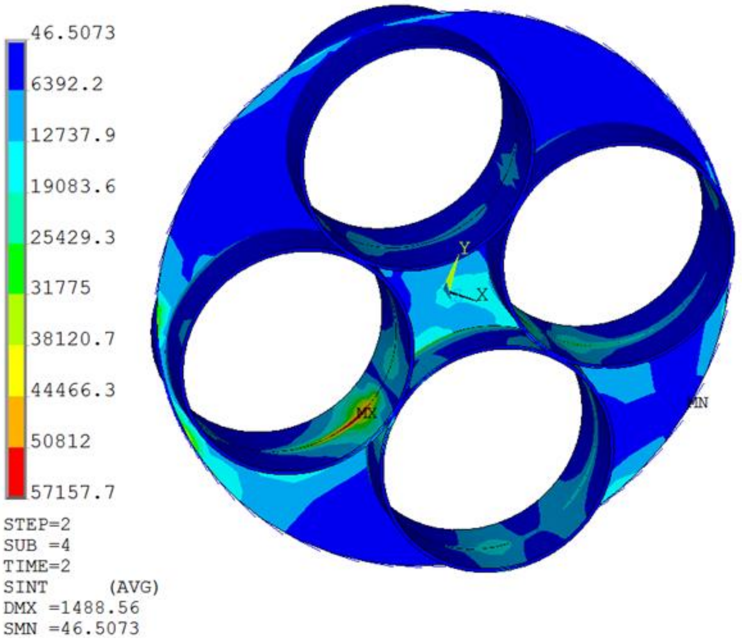


Figure 4-27. Stress Contours at 45^0 for Sleeve to Support Disc Interface

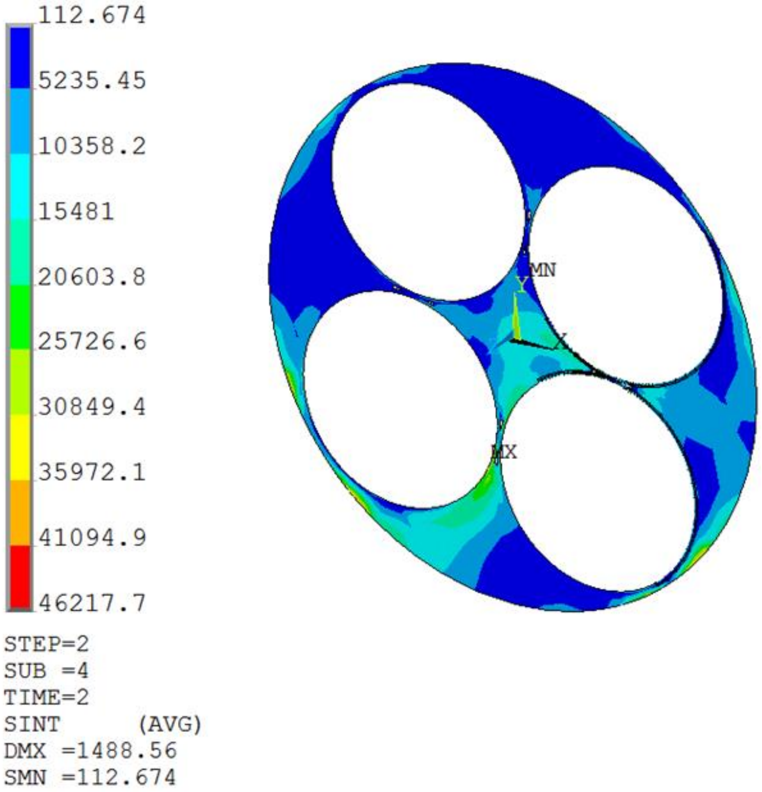


Figure 4-28. Stress Contours at 45^0 for Support Disc

Analyses bases:

- Acceleration: 70*g*’s
- STAD Load: 1,500 lb (Reflects periodic analysis)
- Support spacing: 15 in. (175/15=11.7)
- Support thickness: 1 in.
- Support diameter: 77 in.
- Support material: SS Type 304
- Allowable Stress corresponds to material properties @ 500^{0}F

Radial gap elements were modeled at the basket outer radius to represent the interaction with the cask cavity shells. Fuel loading was represented by pressure loadings consistent with all previous models evaluated. Table 4-6 presents the results of the modeling.

Table 4-6. Drop Combinations and Margins

Basket Drop Orientation	**Allowable Support Stress Su @ 500^{0}F (SS Type 304)**	**Peak Stress at Sleeve to Support**	**Peak Stress in Supports**	**Effective Safety Margin**
0^{0}	63.4 ksi	23.6		2.7
0^{0}	63.4 ksi		23.8	2.7
22.5^{0}	63.4 ksi	48.4		1.30
22.5^{0}	63.4 ksi		43.6	1.45
45^{0}	63.4 ksi	57.2		1.08
45^{0}	63.4 ksi		46.2	1.37

The earlier versions of the carrier used between a ¼″ to ½″ thick sleeve (essentially a tube) resulting in nominal weight impact. Primary advantages of the sleeve design are continuous structural support of the STAD canisters and the ability to match up with the airflow gaps developed thru the initial thermal evaluations performed on the support discs. As the sleeve is a continuous boundary for gas flow (the lower end of the sleeve has inlets, 4″×24″ openings in a 4 position, 90° pattern), it is expected that the efficiency of the heat transfer will be equivalent or better than that of the support discs.

Structural evaluations were performed on each of the evolving concepts of the carrier. ANSYS models, shown in Figure 4-29 and Figure 4-30, looked explicitly at support disc performance with both exhibiting overstress conditions. Version 1 was based on a sleeve inserted into a fully connected support disc. Version 2, focused on removing the highly stressed areas, indicated in the Version 1 analysis, and resulted in overstressed areas at the transition regions of the sleeve to support disc.

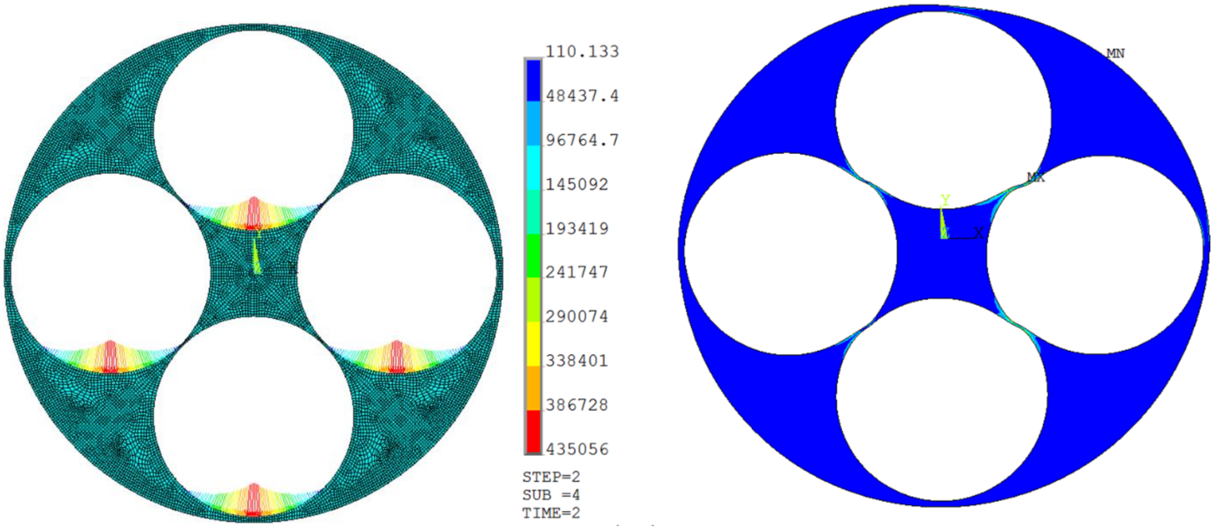


Figure 4-29. Sleeve and Support Disc Version 1

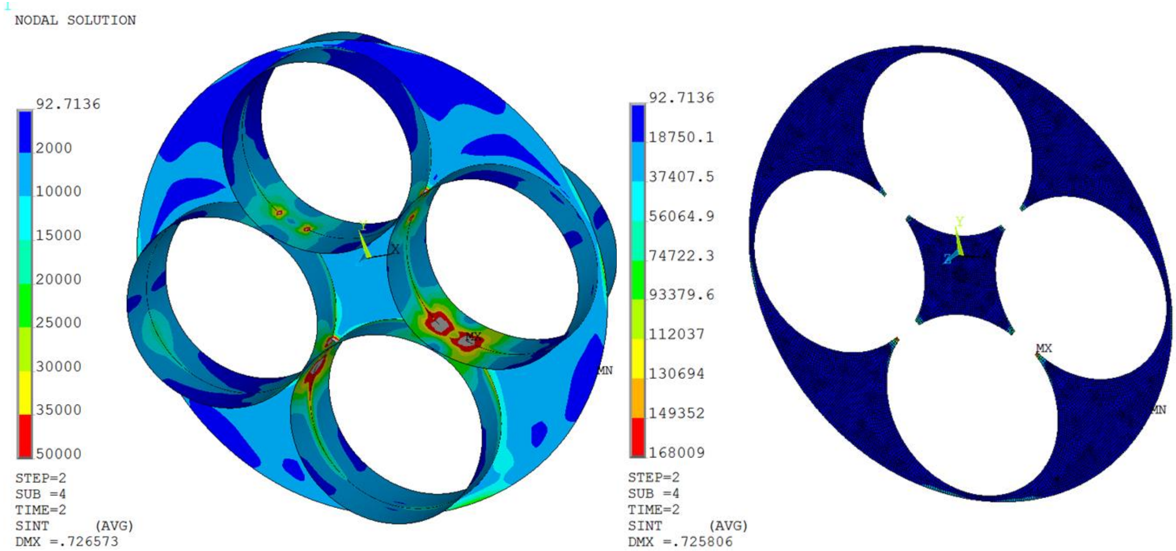


Figure 4-30. Sleeve and Support Disc Version 2

4.3.1.1 STAD Canister

Structural analyses of the 4P and 9B STAD canister assemblies were performed to demonstrate that they are capable of satisfying the applicable structural design criteria when subjected to the most severe design loads for storage, and transportation conditions. The following sections describe the structural analyses of the STAD canisters for these conditions as well as the unmitigated response if the canister were to be dropped during handling operations at an interim storage facility (ISF) or repository.

Section 4.3.1.1.1 describes the structural analysis of the STAD canister for the 10 CFR 71 transportation conditions. For the purposes of this report, the most limiting transportation condition was assumed to be a HAC 30-foot side drop, for which an equivalent static acceleration load of 75*g* was assumed. The analyses of the STAD canisters for the 75*g* HAC side drop load demonstrate that the main structural members of the 4P and 9B STAD canisters satisfy the applicable structural design criteria. This analysis demonstrates with a high likelihood that the 4P and 9B STAD canister designs are structurally adequate for the full range of transportation loading conditions and combinations.

Section 4.3.1.1.2 describes the structural analysis of the STAD canister for the storage conditions of 10 CFR 72. The STAD canister shell assembly was evaluated for a range of normal, off-normal, and accident load conditions and load combinations for storage. The storage loading conditions and load combinations used for this evaluation were based on those used for similar canister-based vertical and horizontal storage systems. The results of this analysis demonstrate the structural adequacy of the 4P and 9B STAD canister shell assembly for the governing storage conditions and provide a high level of assurance that these designs could be approved in the future by NRC under 10 CFR 72.

Section 4.3.1.1.3 describes the structural analysis of the STAD canister for a handling mishap condition. Specifically, the STAD canister was evaluated for a postulated free drop from a height of 23-feet onto a horizontal essentially unyielding surface. This analysis was provided to allow DOE to compare the response of the small STAD canister to that of the large transportation, aging and disposal (TAD) canister that was evaluated for the same drop condition previously.

4.3.1.1.1 Transportation Side Drop Analysis

The maximum stresses in the most heavily loaded 4P and 9B spacer plates for the 75*g* HAC side drop loading were determined using plastic system Finite Element Analysis (FEA), as discussed in the following subsections. The 4P and 9B spacer plate designs were evaluated for a range of side drop impact orientations to determine the maximum stress intensities.

The 4P and 9B STAD canister shell and internal basket assemblies are designed in accordance with the requirements of the AMSE Code, Subsections NB[6] and NG,[7] respectively. Per Regulatory Guide 7.6[8], the design criteria for HAC are similar to those for Level D Service

---

[6] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB, *Class 1 Components*, 2004 Edition.

[7] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NG, *Core Support Structures*, 2004 Edition.

[8] Regulatory Guide 7.6, *Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels*, Revision 1, U.S. Nuclear Regulatory Commission, Office of Standards Development, March 1978.

Limits. In accordance with Subsection NG, Article NG-3225, the rules of Appendix F[9] of the American Society of Mechanical Engineers (ASME) Code may be used for evaluating Service Loadings for which Level D limits are designated. Specifically, the acceptance criteria of F-1340 for plastic system analysis were applied. In accordance with F-1341.2, the maximum general primary membrane stress intensity (P_m) and maximum primary stress intensity ($P_L + P_b$) within the basket were demonstrated to not exceed $0.7S_u$ and $0.9S_u$, respectively.

Plastic system analyses of 4P and 9B spacer plate designs were also performed to demonstrate that they satisfy the applicable design criteria for buckling under the HAC side drop loading. In accordance with F-1331.5, the maximum compressive loading was limited to 2/3 of the buckling load determined by a comprehensive plastic instability analysis. For the 75*g* HAC side drop loading, this buckling design criterion is satisfied provided that the plastic instability load is shown to be greater than 150% of the design load (i.e., greater than 112.5*g*).

The structural analyses of the 4P and 9B STAD canister assemblies for the 75*g* side drop load were performed using the ANSYS general-purpose finite element analysis program. The three-dimensional finite element (FE) models shown in Figure 4-31 were used for both the stress and plastic instability analyses. The FE models represent periodic axial segments of the full 4P and 9B STAD canister assemblies at the mid-length of the canister where the spacer plate pitch is largest (i.e., 7.5-inch). As such, the models represent the most heavily loaded spacer plates within the basket (i.e., the spacer plate supporting the largest tributary weight) and, therefore, the structural analysis results obtained from these models are bounding for all spacer plates within the 4P and 9B basket assemblies. The same finite element models were used to evaluate three (3) different circumferential impact orientations for the HAC side drop; 0°, 23°, and 45° relative to the basket centerlines. Symmetry boundary displacement constraints were modeled at the axial ends of the model. This modeling approach was used to account for the possibility of lateral buckling of the spacer plates and support bars in the plastic instability analysis.

The finite element models used 3-D 8-node solid brick elements to represent the spacer plate, support bars, and canister shell. The fuel assemblies, guide tubes, and poison plates were not explicitly modeled; instead the loading on the basket assembly structure from these items was modeled as uniform pressure loads on the supporting spacer plate ligaments. The analyses were performed using bounding PWR and BWR fuel assembly line loads of 10.0 pounds/inch and 4.0 pounds/inch, respectively. The line loads used for each PWR and BWR guide tube were 0.61 pounds/inch and 0.40 pounds/inch, respectively. Thus, the combined tributary weights of the fuel assembly and guide tube within each cell of the 4P and 9B spacer plates were 80 pounds (= 7.5″ × 10.61 pound/inch) and 33 pounds (= 7.5″ × 4.40 pound/inch), respectively. This tributary weight was modeled as a uniform pressure load over the flat surface area of each of the supporting spacer plate ligament(s). In addition, the neutron absorber plates that form the poison

---

[9] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Appendix F, *Rules for Evaluation of Service Loadings with Level D Service Limits*, 2004 Edition.

egg-crates located between the spacer plates are supported by the guide tubes. The total tributary weight of the PWR and BWR poison egg-crates are 32 pounds and 64 pounds, respectively. The weight of the poison egg-crates are supported by the guide tubes, which transfer the loads to the supporting cell edges of the spacer plate. Thus, for the 4P design, the tributary weight of the poison egg-crates is applied to the edges of two cells for each component of loading (i.e., along the model X and Y axes). A summary of the applied pressure loads for the spent fuel, guide tubes, and poison egg-crates is provided in Figure 4-32.

The coincident nodes of the support bars and spacer plate at the locations of the connecting fillet welds are coupled in all three translational degrees of freedom. The non-linear interfaces between the spacer plate and canister shell were modeled using surface-to-surface contact elements and target elements. In addition, 2-D contact elements were used to model the non-linear interface between the outside of the canister shell and the eight 2-inch wide stringers of the carrier that supports the canister.

The plastic behavior of the 4P spacer plate and canister shell Type 316 stainless steel material was modeled using multi-linear isotropic hardening at a bounding design temperature of 600°F, as summarized in Table 4-7. This is considered to be conservative because the peak temperatures throughout the 4P canister are lower than 600°F for all conditions. All canister assembly components were modeled with a nominal density of 0.286 lb/in^3 and Poisson's ratio of 0.29. The support bars, which support only their own weight under side drop loading, were modeled using linear-elastic material properties of Type 316 stainless steel at 600°F.

Table 4-7. Plastic Material Properties for Type 316 Stainless Steel at 600 °F

Strain (%)	**Stress (ksi)**
0.273	21.4
0.3	21.5
0.8	25.0
1.0	37.5
40	71.8

Note:

Properties from Figure 8(d) of NUREG/CR-0481, SAND77-1872, R-7, "An Assessment of Stress-Strain Data Suitable for Finite Element Analysis of Shipping Containers."

For each of the three side drop impact orientations evaluated, a non-linear large deflection plastic-system analysis was performed. The 75*g* side drop design load was gradually applied to determine the maximum stresses. The loading was then increased to 112.5*g* (i.e., 150% of the design load) and beyond to demonstrate compliance with the plastic instability buckling design criteria.

The results of the 4P and 9B STAD canister 75*g* side drop stress analyses, which are summarized in Table 4-8, demonstrate that both the 4P and 9B STAD canisters satisfy the plastic-system analysis design criteria of ASME Appendix F, Article F-1341.2 for all impact orientations evaluated. The maximum primary membrane (P_m) stress intensity, which occurs in the lower end of the center ligament, results from the 0° impact orientation. The maximum general primary ($P_L + P_b$) stress intensity results from the 45° impact orientation. Stress intensity contour plots of the 4P and 9B spacer plates for all impact orientations are shown in Figure 4-33 and Figure 4-36, respectively.

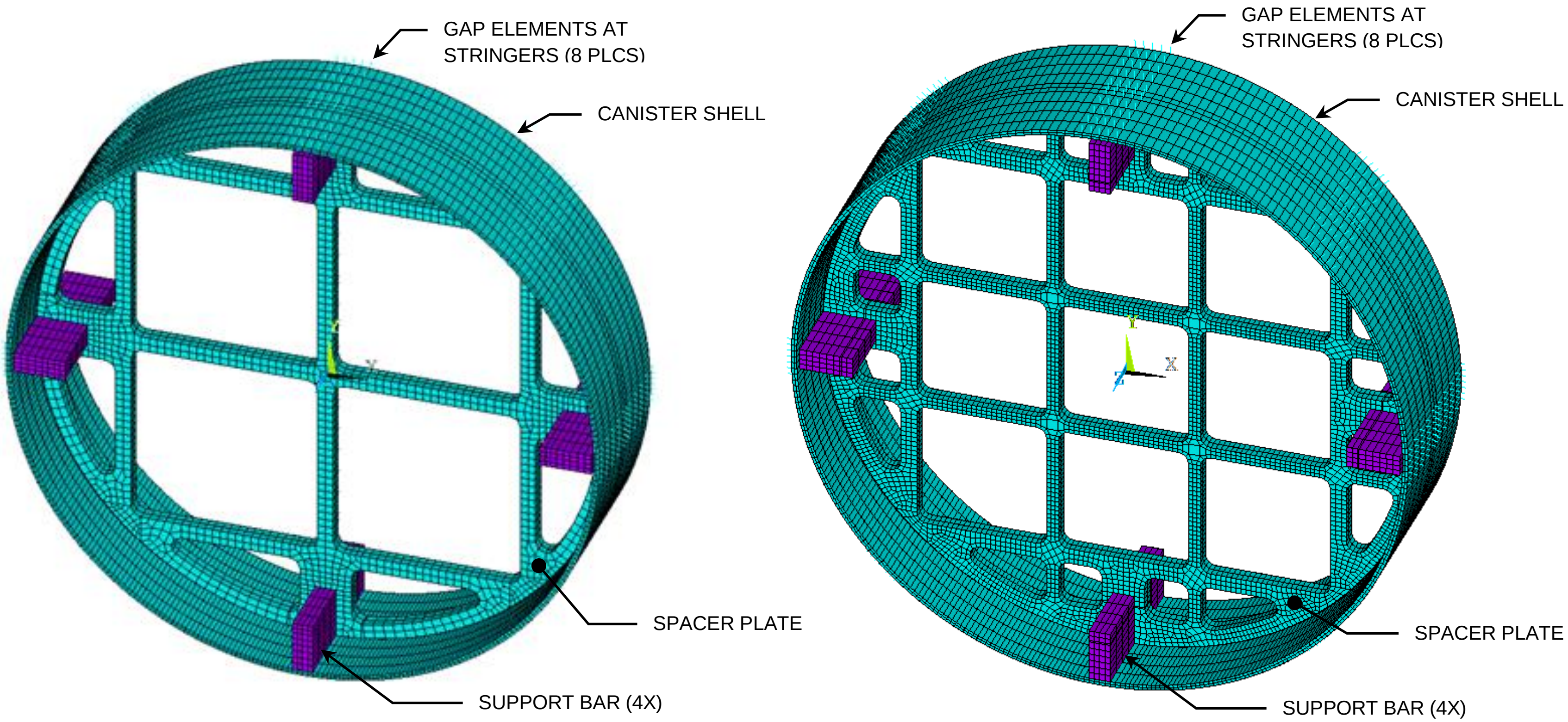
Table 4-8. STAD Canister 75g Side Drop Stress Analysis Results

Impact Angle	Stress Type	Maximum S.I. (ksi)				Allowable S.I.(1) (ksi)
		4P STAD		9B STAD		
		Spacer Plate	Canister Shell	Spacer Plate	Canister Shell	
0°	P_m	21.8	8.4	22.9	15.8	50.3
	$P_L + P_b$	27.9(2)	23.3(2)	39.0(2)	26.5(2)	64.6
23°	P_m	19.6	15.4	5.1	5.1	50.3
	$P_L + P_b$	32.4(2)	23.6(2)	23.5(2)	23.5(2)	64.6
45°	P_m	16.2	13.5	11.0	11.0	50.3
	$P_L + P_b$	33.5(2)	21.0(2)	22.6(2)	22.6(2)	64.6

Notes:

(1) For plastic-system analysis, P_m and $P_L + P_b$ shall not exceed $0.7S_u$ and $0.9S_u$, respectively. The allowable stress intensities are conservatively based on Type 316 material properties at 600°F.

(2) The highest stress intensity occurring anywhere in the spacer plate is conservatively reported as the maximum membrane plus bending stress intensity.



4P STAD Model

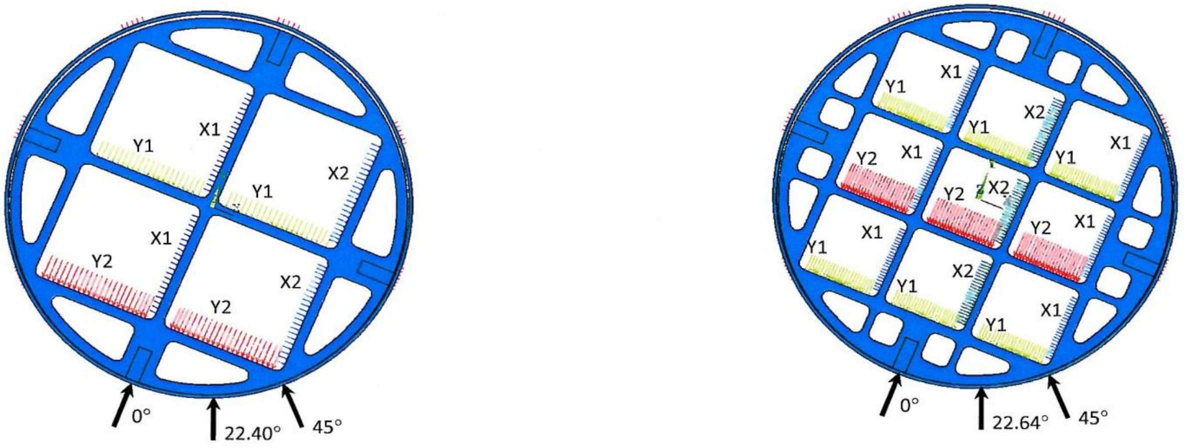
9B STAD Model

Figure 4-31. 4P and 9B STAD Canister Side Drop Finite Element Models

STAD Design	Impact Angle[1]	Applied Pressure Load at 75G (psi)			
		Y1	Y2	X1	X2
4P	0.00	976	1376	0	0
	22.40	903	1272	372	524
	45.00	690	973	690	973
9B	0.00	645	1062	0	0
	22.64	595	981	248	409
	45.00	456	751	456	751

Notes:

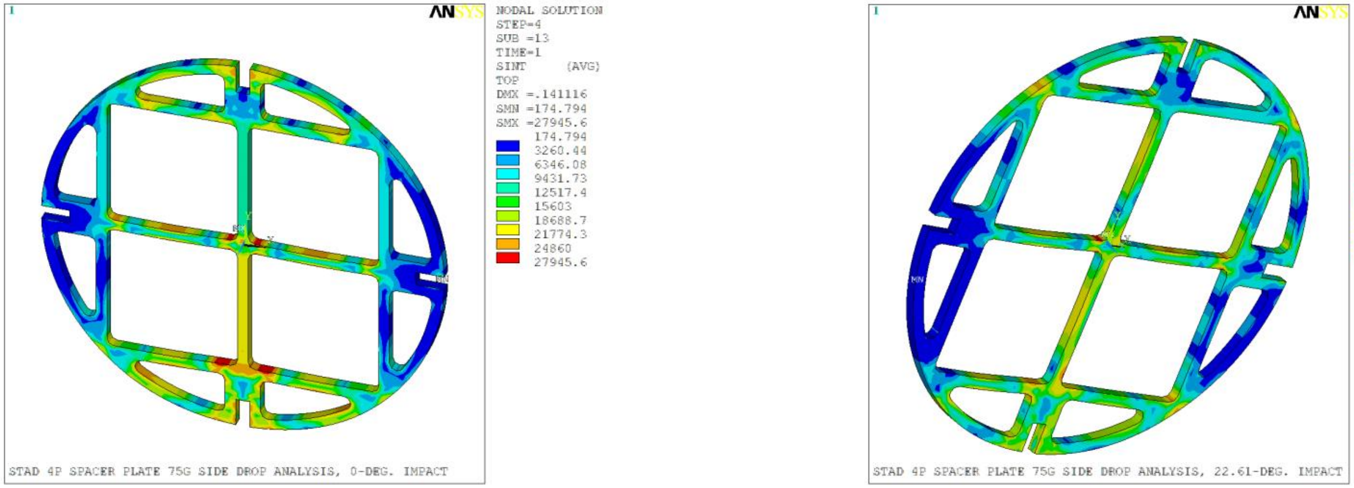
[1] Impact angles and applied pressure loads shown in diagrams below.



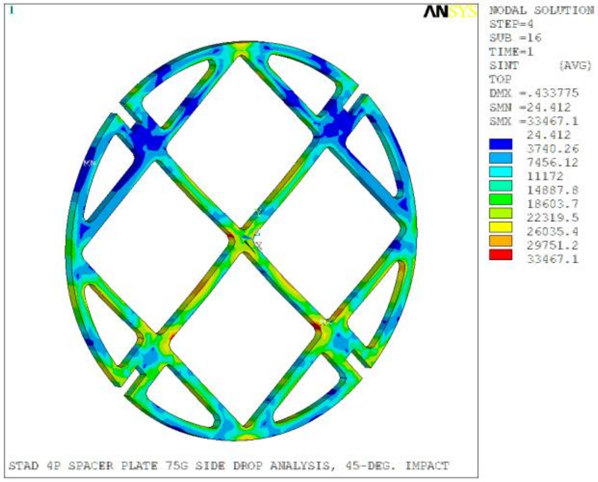
4P STAD

9B STAD

Figure 4-32. Applied Pressure Loads for 75*g* Side Drop



0° Impact **23° Impact**



45° Impact

Figure 4-33. 4P Spacer Plate S.I. Contour Plots – 75*g* Side Drop

The results of the 4P and 9B STAD canister HAC side drop plastic instability analyses demonstrate that both the 4P and 9B STAD canisters remain structurally stable for side drop loads greater than 150% of the 75*g* side drop loading for all the impact orientations evaluated. The lateral deflection of the controlling 4P and 9B spacer plate ligament for each impact orientation is plotted as a function of the side drop acceleration load in Figure 4-34. This figure shows that the spacer plate deformations were fairly linear up to the 75*g* design load, as indicated by the slope of the curves. However, as the loading was increased beyond 75*g*, the slopes increase significantly due to formation of plastic hinges within the spacer plates. In all cases, plastic instability of the spacer plate occurs at 150*g* or higher (two times the design load), as fully-plastic moments were developed within the spacer plate members. The deformed shape of the 4P and 9B spacer plates for each impact orientation at the final load step prior to plastic instability are shown in Figure 4-35 and Figure 4-37, respectively. The figures show significant in-plane deformation of the ligament, indicating the onset of buckling. In conclusion, the results demonstrate that the 4P and 9B STAD canister assemblies both satisfy the applicable plastic instability design criteria for the 75*g* side drop design load.

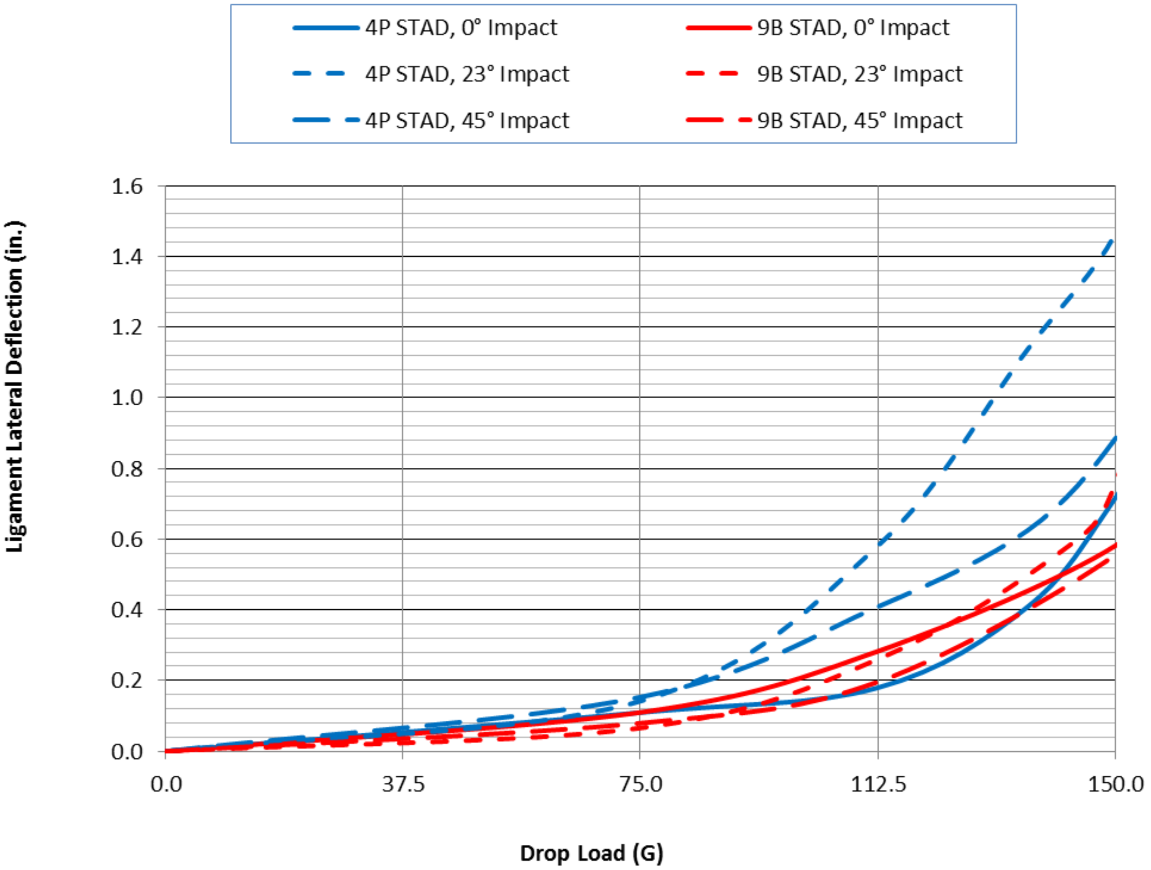
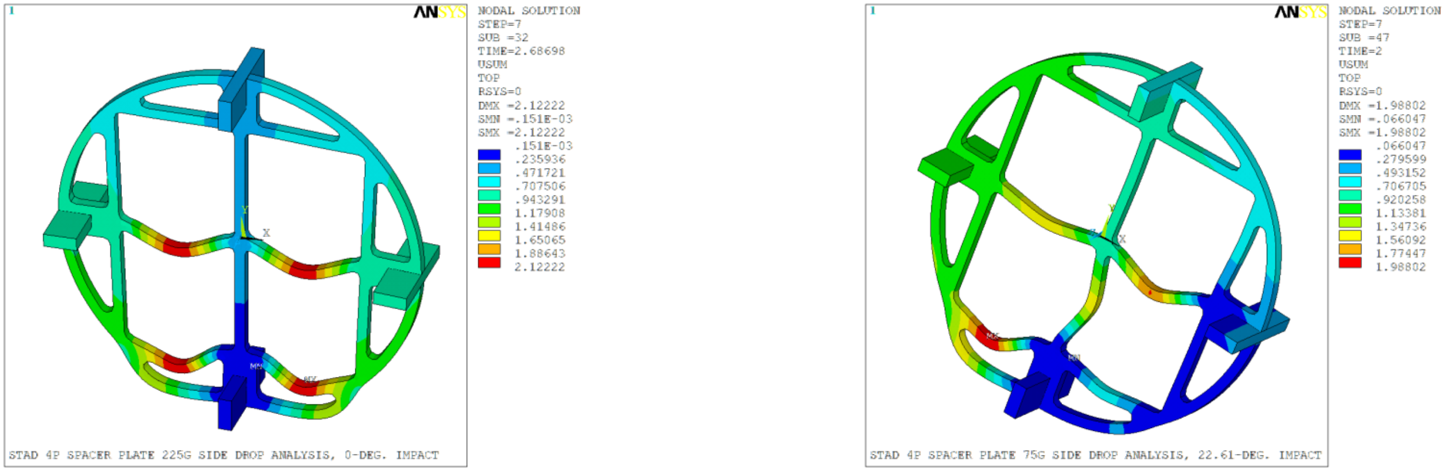
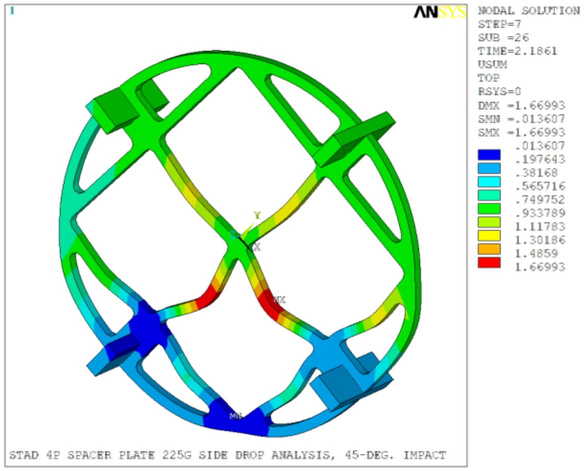


Figure 4-34. 4P and 9B Spacer Plate Plastic Instability Analysis – Ligament Lateral Deformations



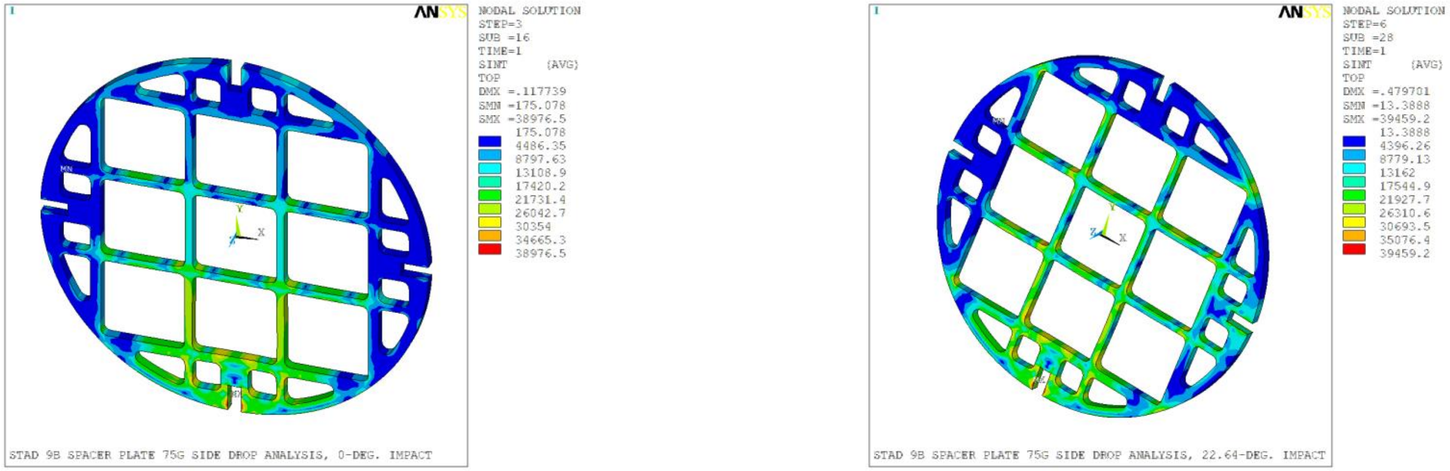
0° Impact

23° Impact



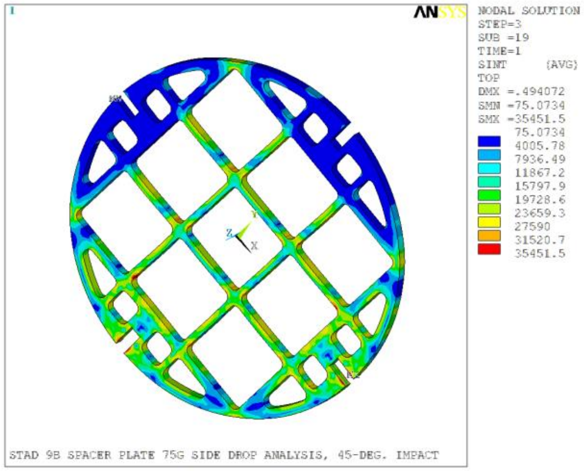
45° Impact

Figure 4-35. 4P Spacer Plate Buckling Deformations – HAC Side Drop



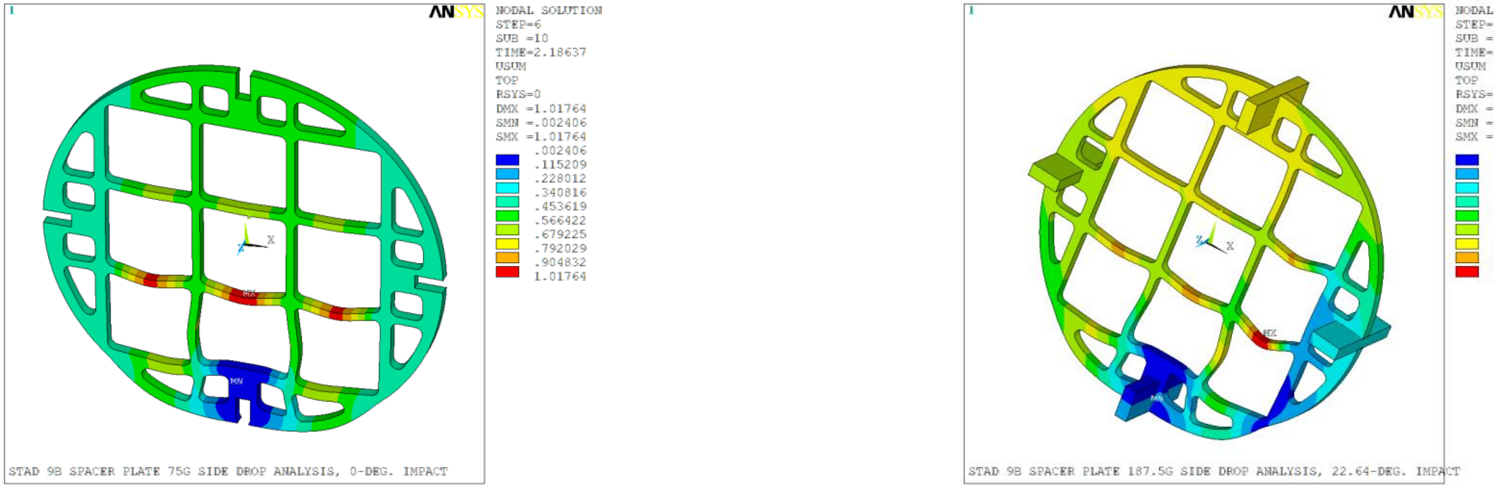
0° Impact

23° Impact



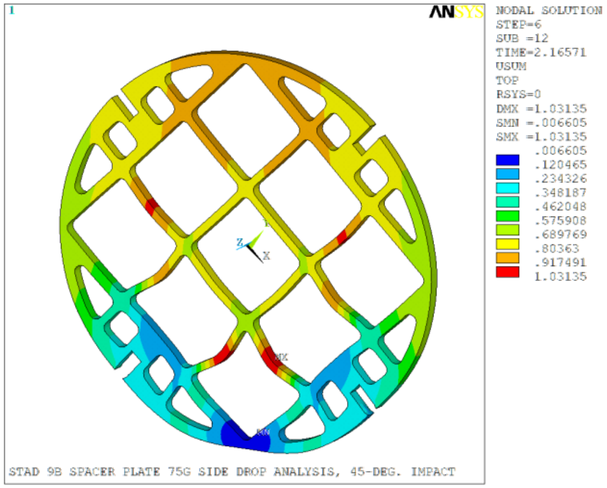
45° Impact

Figure 4-36. 9B Spacer Plate S.I. Contour Plots – 75*g* Side Drop



0° Impact

23° Impact



45° Impact

Figure 4-37. 9B Spacer Plate Buckling Deformations – HAC Side Drop

4.3.1.1.2 Storage Condition Analyses

The stresses in the canister shell assembly used for both the 4P and 9B small STAD designs were evaluated for a range of storage condition loading combinations using FEA. This section describes the design criteria for the canister assembly for storage conditions, the finite element model used for the structural evaluation, and the results of the evaluation.

Design Criteria

The structural components of the small STAD canister include the internal basket assembly and the shell assembly. The internal basket assembly is designed and fabricated as a core support structure in accordance with the applicable requirements of Section III, Subsection NG[10] of the ASME Code, to the maximum extent practicable. The shell assembly is designed and fabricated as a Class 1 component pressure vessel in accordance with Section III, Subsections NB[11] and NF[12] of the ASME Code, to the maximum extent practicable. The principal exception is the top end inner and outer closure plate welds to the canister shell. The top end closure design complies with guidance provided in NRC Interim Staff Guidance #4 (ISG-4).[13] In addition, the grapple ring that is attached to the top end outer closure plate is designed in accordance with the requirements of ANSI N14.6[14] for critical lifts to facilitate vertical canister transfer.

The canister top end inner and outer closure welds are partial penetration welds that are structurally qualified by analysis, as discussed below. The inner and outer closure welds are inspected by performing a liquid penetrant examination of the root pass and final weld surfaces. The integrity of the inner closure welds is verified by performing a pneumatic pressure test, and a helium leak test. This weld non-destructive examination (NDE) is in compliance with ISG-4. The associated critical flaw size must be determined by evaluation to support the NDE acceptance basis. The structural analysis of the small STAD canister, in conjunction with the redundant closures and nondestructive examination, pneumatic pressure testing, and helium leak testing performed during canister fabrication and canister closure, provides assurance of canister closure integrity in lieu of the specific weld joint requirements of Subsection NB.

The small STAD canisters are designed for all normal, off-normal, and postulated accident condition loadings. For the purposes of this report, the design loadings are based in part upon

---

[10] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NG, *Core Support Structures*, 2004 Edition.

[11] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB, *Class 1 Components*, 2004 Edition.

[12] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division I, Subsection NF, *Supports*, 2004 Edition.

[13] ISG-4, *Cask Closure Weld Inspections*, Spent Fuel Project Office Interim Staff Guidance-4, United States Nuclear Regulatory Commission, Revision 1, May 21, 1999.

[14] ANSI N14.6, *Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4,500 kg) or More*, American National Standards Institute, 1993.

the Fuel*Solutions*™ Storage System, which is designed for both vertical and horizontal canister transfer. The design loadings assumed for the structural analysis of the small STAD canister are as follows:

Dead Load: The dead weight of the canister assembly and its contents in either the vertical (D_v) or horizontal (D_h) orientation. For the purposes of this report, only vertical dead load was evaluated.

Handling Loads: For normal conditions, this load includes normal handling loads associated with vertical or horizontal transfer of the canister between overpacks (i.e., transfer, storage, and transportation.) For vertical canister transfer (L_{hv}), the handling load is equal to a hoist motion factor of 30% of the maximum loaded canister weight, based on CMAA #70.[15] This load was applied as a pulling force on the inside of the grapple ring that is attached to the canister top plate.

For horizontal canister transfer between a storage cask, transfer cask, or transportation cask, the handling load (L_{hh}) is defined as a pushing or pulling axial force of 10,000 pounds acting on the outer closure plate of either end of the canister due to friction forces that developed between the canister shell and cask rails. This is equivalent to a sliding coefficient of friction greater than 0.7, which is conservative for mild steel-on-mild steel. However, for the purposes of this report, the horizontal canister transfer load condition was not evaluated.

In addition to the normal handling loads described above, an off-normal canister misalignment loading condition (L_m) is postulated during horizontal transfer of the canister. This load is defined as a pushing or pulling axial force of 50,000 pounds, acting on the grapple ring or outer closure plate. Although this load condition is postulated to occur only for horizontal transfer conditions, it was conservatively evaluated for the vertical transfer condition in this report to demonstrate the structural adequacy of the canister.

Internal Pressure: The small STAD canister was evaluated for a range of internal pressure loadings associated with normal, off-normal, and accident conditions. The normal condition internal pressure (P) for the canister during dry storage was based on the initial canister helium backfill pressure, normal condition canister temperatures, and an assumed failure of 1% of the fuel rods with complete release of their associated fill gases and 30% of their fission gases to the canister cavity. The design basis internal pressure for this condition was assumed to be equal to the design basis value of 10 psig used for the Fuel*Solutions*™ canisters.

The off-normal condition internal pressure for storage was based on the initial canister helium backfill pressure, the off-normal condition canister temperatures, and an assumed

---

[15] CMAA #70, *Specifications for Electric Overhead Traveling Cranes*, Crane Manufacturers Association of America (CMAA), 1988.

failure of 10% of the fuel rods with complete release of their associated fill gases and 30% of their fission gases to the canister cavity. The design basis internal pressure for this condition (P_o) was conservatively assumed to be 20 psig, which is higher than the 16 psig off-normal internal pressure loading used for the Fuel*Solutions*™ canisters.

The postulated accident condition internal pressure for the canister was based on the initial canister helium backfill pressure, the off-normal condition canister temperatures, and the assumed failure of 100% of the fuel rods with complete release of their associated fill gases and 30% of their fission gases. The design basis internal pressure for this condition (P_a) was assumed to be equal to the design basis value of 70 psig used for the Fuel*Solutions*™ canisters.

Normal condition internal pressure during draining of the canister cavity after the inner closure weld between the shield plug and canister shell was completed, but prior to attaching the outer closure plate, a.k.a. blowdown pressure (P_b), was also evaluated. This load was conservatively assumed to be a 50 psig internal pressure.

In the unlikely event of a canister reopening, the canister cavity is reflooded with water. Depending on the temperatures inside the canister, the water may flash to steam resulting in internal pressures in the canister during reflood. This load (P_r) was defined as an internal pressure of 100 psig.

Thermal: The normal (T), off-normal (T_o and T_r), and accident (T_a) thermal loading conditions ambient conditions for the canister are those associated with the ambient conditions during normal, off-normal, and accident conditions for fuel loading, closure, transfer, and dry storage. Thermal stresses are classified as secondary stresses by the ASME code because they are self-limiting in nature. Experience shows that thermal stresses generally do not control the design of the canister, and therefore, thermal stresses were not evaluated in this report.

Earthquake: The canister was evaluated for the effects of seismic accelerations with the canister in the storage cask or the transfer cask. The design basis seismic acceleration for this event was assumed to be a peak horizontal ground acceleration of 0.75*g*, based on input from DOE. For the purpose of this report, the vertical seismic acceleration load (E) was conservatively assumed to be equal to 0.75*g*.

Drop: The postulated drop accident conditions include free drops of a loaded storage cask or transfer cask, and a non-mechanistic storage cask tipover. Only the storage cask free drop, which is a vertical drop onto the bottom end of the storage cask, was evaluated in this report. An equivalent static bottom end drop load (A_s) of 100*g* was conservatively used for the structural evaluation of the canister.

Flood: The canister is designed for an enveloping design basis flood, postulated to result from natural phenomena such as a tsunami or a seiche (surface water movement on an enclosed body of water, such as a lake, usually caused by intense storm activity). For the purpose of this bounding generic evaluation, the 50-foot flood height was used. The canister was conservatively evaluated for a 50 foot hydraulic head of water (F), which corresponds to an external pressure of 21.7 psi. Since the canister shell confinement boundary is designed to prevent water intrusion under the postulated flood condition, criticality safety during the flood event is assured. In addition, the small STAD canisters include fixed borated neutron absorbers and are designed for fresh water optimum moderation for transportation, which provides defense-in-depth for criticality safety under the postulated flood condition.

The canister is designed for the load combinations shown in Table 4-9. These combinations are categorized based on the ASME service level criteria for evaluation against the associated allowable values.

Table 4-9. Storage Loading Conditions and Combinations

	Load Combinations																	
	Normal Operating Conditions					Off-Normal Conditions					Postulated Accident Conditions							
Load Condition	A1	A2	A3(1)	A4	A5(1)	B1	B2	B3(1)	B4	C1	D1	D2(1)	D3	D4(2)	D5(2)	D6(3)	D7(4)	D8(5)
Dead Weight	D_v	D_v	D_h	D_v	D_h	D_v	D_v	D_h	D_h	D_v	D_v	D_h				D	D	D_v
Handling				L_{hv}	L_{hh}		L_{hv}	L_{hh}	L_m		L_{hv}	L_{hh}						
Internal Pressure	P_b	P	P	P	P	P_o	P_o	P_o	P	P_r	P_a	P_a	P_o	P_o	P_o	P_o	P_o	P
Thermal(6)		T	T	T	T	T_o	T_o	T_o	T	T_r	T_o	T_o	T	T	T	T	T_a	T
Earthquake																E		
Drop													A_s	A_t	A_{s1}			
Flood																		F

Notes:

(1) Horizontal load combinations are not evaluated in this report, but are not expected to control the design.

(2) Horizontal side drop and tip-over loading conditions are expected to be bounded by the HAC side drop evaluated previously.

(3) Bounded by load combination D3.

(4) Bounded by load combination B1.

(5) Load combination D8 is not evaluated in this report because it is not expected to control the design.

(6) Thermal loads are not included in the load combinations evaluated in this report because they are classified as secondary stresses, which are not expected to control the design.

Legend:

D_v: Dead weight in vertical orientation (1*g* applied to canister shell and contents).

D_h: Dead weight in horizontal orientation (not evaluated in this report).

L_{hv}: Vertical transfer load (30% hoist motion factor).

L_{hh}: Horizontal transfer load (not evaluated in this report).

L_m: Horizontal transfer misalignment load (50,000 lb. ram pulling force).

P_b: Blowdown internal pressure (50 psig).

P: Normal internal pressure (10 psig).

P_o: Off-normal internal pressure (20 psig).

P_a: Accident internal pressure (70 psig).
P_r: Reflood internal pressure (100 psig).
A_s: Vertical canister drop load (100*g*).
E: Earthquake load (0.75*g*).
F: Flood external pressure load due to 50-foot head of water (21.7 psig).

Model Description

The structural analysis of the small STAD canister shell assembly for storage loading conditions was performed using the axisymmetric finite element model shown in Figure 4-38. The model included the canister shell bottom plate, cylindrical shell, shield plug support ring, shield plug, top plate, grapple ring, and all structural welds that connect these members. However, the model did not include the vent/drain port body and tops, because the model is axisymmetric and these features are not. As shown in Figure 4-38, the finite element model mesh was refined in the regions of the welds where stress concentrations are expected to occur.

The finite element model of the small STAD canister shell assembly was constructed from 2-D solid axisymmetric elements (PLANE182). For all load combinations, contact behavior between the shield plug and top cover plate and between the shield plug and the top surface of the shield plug support ring was modeled using 2-D surface-to-surface contact elements (CONTA171 and TARGE169). Finally, for those load combinations where the canister rests on its bottom end (as opposed to being supported by the grapple ring), contact behavior between the bottom surface of the canister and the supporting surface of the overpack (i.e., "ground") was modeled using 2-D node-to-node gap elements for those loads. The basket assembly and spent fuel payload were not explicitly modeled. Instead, the effects of their mass acting on the bottom plate of the canister shell for the vertical conditions evaluated was represented by a uniform pressure load on the inside surface of the bottom plate.

The applied loading for each of the loading conditions was as follows:

> Dead Load, Vertical Handling, Earthquake, and Drop Loads: The magnitude of the pressure loading on the canister bottom plate from the basket assembly and spent fuel payload due to the vertical dead weight, vertical handling, and the storage cask drop loads were calculated based on a bounding weight of 10,500 pounds for the basket assembly and spent fuel applied over the entire inside surface area of the bottom plate and multiplied by the corresponding accelerations. The inertia of the canister shell assembly due to the vertical dead load and vertical handling load was accounted for by applying the corresponding accelerations loads to the model. For the load combinations that include vertical handling (L_{hv}), the canister assembly was restrained vertically at the mid-radius of the grapple ring end plate. However, for the load combination that includes horizontal transfer misalignment (L_m), the canister was restrained axially at the bottom of the cylindrical shell and a uniform pressure load due to the 50,000 pound pull force was applied to the inside surface of the grapple ring end plate.

Internal Pressure: Internal pressure loads associated with normal (P), off-normal (P_o), and accident (P_a) conditions were applied as a uniform surface pressure load on the inside surfaces of the canister shell confinement boundary. For each of the load combinations that include these pressure loads, evaluations were performed for internal pressure acting on both the inner closure (i.e., shield plug and inner closure weld) and outer closure (i.e., top plate and outer closure weld), because these are two pressure boundaries were credited for redundancy.

For the blowdown pressure (P_b) the pressure load was applied to the inner closure and the top plate was not modeled because it is installed after the canister is drained and vacuum dried. For the reflood pressure (P_r) the pressure load was applied to the inner closure, but the top plate was included in the model because it is not removed until the canister reflood operation is complete.

Flood: The 21.7 psig hydrostatic pressure load due to the design-basis 50-foot flood was applied as a uniform surface pressure load to the outer surfaces of the canister assembly.

Stresses were calculated for all of load combinations identified in Table 4-9, except for those that are shaded (i.e., all thermal loads and all loading conditions corresponding to a horizontal canister orientation, except for the misalignment load, which is discussed above). Thermal loads were not considered because general thermal stress is classified as secondary stress in accordance with the ASME code, and secondary stress is not anticipated to be limiting for the canister shell assembly.

Summary of Results

For each load combination, the individual loads were applied in combination to determine the resulting stresses within each of the canister shell components and connecting welds. The primary membrane (P_m) and membrane plus bending (P_L+P_b) stress intensities were determined at each of the 15 critical stress sections identified in Figure 4-38 using the ANSYS stress linearization commands. The resulting stress intensities were tabulated and compared to the corresponding allowable stress design criteria (See Table 4-10 through Table 4-18). The lowest margins of safety for each stress type at each section are summarized in Table 4-19.

The results show that the lowest overall design margin of safety is 0.06 (6%) for membrane plus bending stress intensity in the lift plate (stress section 16) due to load combination D1 ($D_v + L_{hv} + P_a$). For this load combination, the allowable membrane plus bending stress in the lift ring is taken as the lesser of $S_y/6$ and $S_u/10$ in accordance with the requirements of ANSI N14.6 for non-redundant critical lifting devices. The lowest margin of safety elsewhere in the canister shell assembly, excluding the lift ring and lift plate, is 1.11 (111%) for membrane plus bending stress intensity in the outer closure weld due to load combination B4 ($D_v + L_m + P$). The results of the small STAD canister shell assembly structural analysis demonstrate with a high level of confidence that the small STAD canister shell assembly will satisfy the allowable stress design criteria for storage conditions.

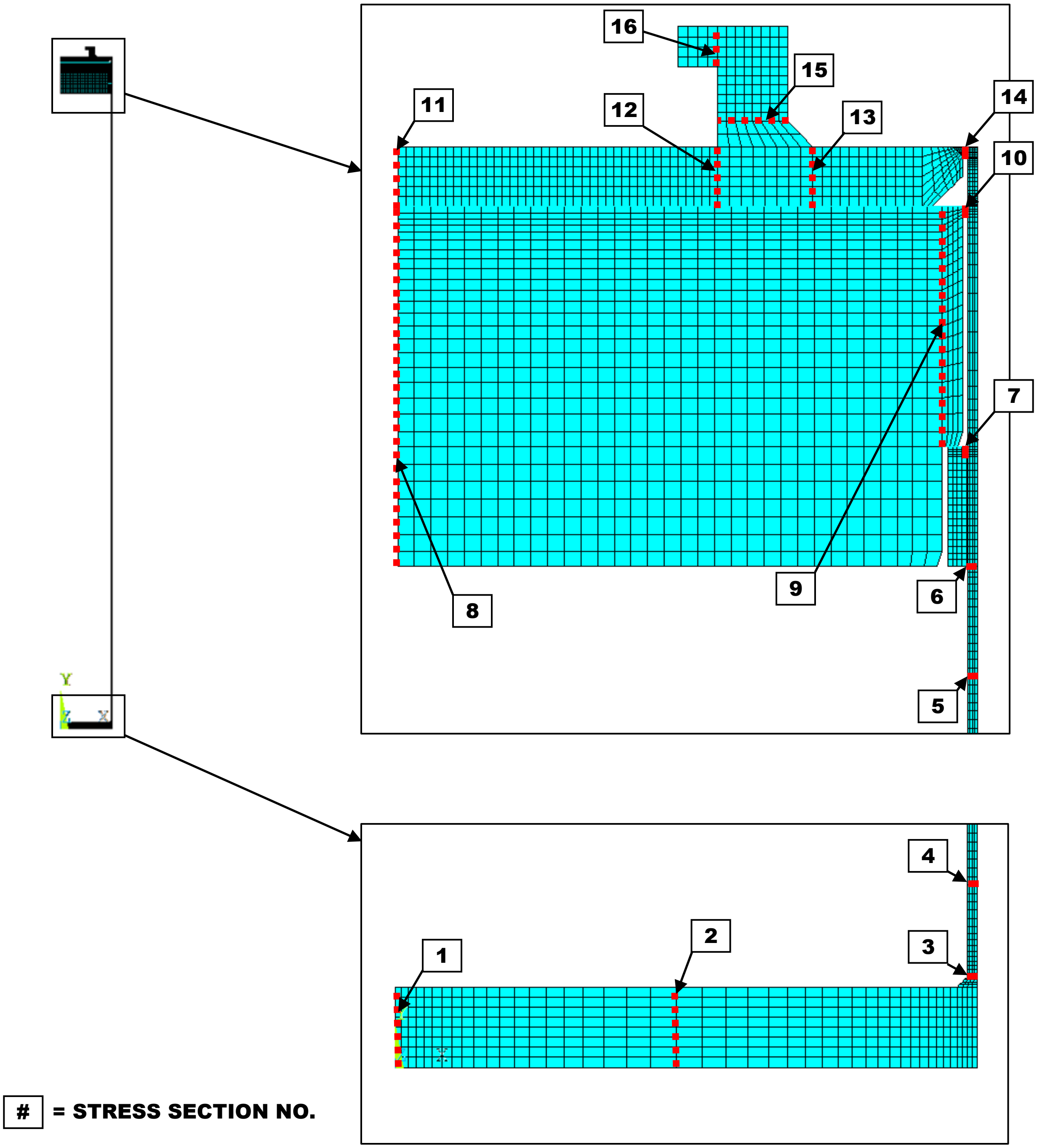


Figure 4-38. Small STAD Canister Shell Assembly Axisymmetric Finite Element Model

Table 4-10. Load Combination A1 ($D_v + P_b$) Canister Shell Assembly Stress Results

Section No.	Component	Stress Type	Calculated S.I. (ksi)	Allowable S.I. (ksi)	Margin of Safety[1]
1	Bottom Plate	P_m	0.8	20.0	24.77
		P_l+P_b	1.5	30.0	19.49
2	Bottom Plate	P_m	0.1	20.0	>100
		P_l+P_b	1.4	30.0	20.57
3	Shell-to-Btm Pl. Weld	P_m	2.2	20.0	7.94
		P_l+P_b	6.7	30.0	3.46
4	Cylindrical Shell	P_m	1.3	20.0	14.24
		P_l+P_b	1.8	30.0	16.12
5	Cylindrical Shell	P_m	2.9	20.0	5.89
		P_l+P_b	2.9	30.0	9.32
6	Cylindrical Shell	P_m	1.2	20.0	15.38
		P_l+P_b	2.1	30.0	13.38
7	Shield Plug Support Ring Weld	P_m	1.8	20.0	10.19
		P_l+P_b	3.8	30.0	6.88
8	Shield Plug	P_m	0.0	20.0	>100
		P_l+P_b	0.2	30.0	>100
9	Shield Plug	P_m	0.2	20.0	>100
		P_l+P_b	0.3	30.0	92.17
10	Inner Closure Weld	P_m	3.2	16.0	4.03
		P_l+P_b	5.9	24.0	3.05
11	Top Plate	P_m	N/A	20.0	N/A
		P_l+P_b	N/A	30.0	N/A
12	Top Plate	P_m	N/A	20.0	N/A
		P_l+P_b	N/A	30.0	N/A
13	Top Plate	P_m	N/A	20.0	N/A
		P_l+P_b	N/A	30.0	N/A
14	Outer Closure Weld	P_m	N/A	16.0	N/A
		P_l+P_b	N/A	24.0	N/A
15	Lift Ring	P_m	N/A	20.0	N/A
		P_l+P_b	N/A	30.0	N/A
16	Lift Plate	P_m	N/A	20.0	N/A
		P_l+P_b	N/A	30.0	N/A

Notes: (1) Margin of Safety = (Allowable S.I./Calculated S.I.) - 1.0.

Table 4-11. Load Combination A2 (D_v + P) Canister Shell Assembly Stress Results

Section No.	Component	Stress Type	Calculated S.I. (ksi)		Allowable S.I. (ksi)	Margin of Safety[1]
			Inner	Outer		
1	Bottom Plate	P_m	0.1	0.1	20.0	>100
		P_l+P_b	0.1	0.2	30.0	>100
2	Bottom Plate	P_m	0.0	0.0	20.0	>100
		P_l+P_b	0.1	0.1	30.0	>100
3	Shell-to-Btm Pl. Weld	P_m	0.3	0.3	20.0	62.29
		P_l+P_b	0.9	0.9	30.0	31.29
4	Cylindrical Shell	P_m	0.3	0.3	20.0	61.89
		P_l+P_b	0.3	0.3	30.0	86.98
5	Cylindrical Shell	P_m	0.6	0.6	20.0	33.31
		P_l+P_b	0.6	0.6	30.0	50.37
6	Cylindrical Shell	P_m	0.2	0.2	20.0	84.11
		P_l+P_b	0.5	0.4	30.0	62.56
7	Shield Plug Support Ring Weld	P_m	0.4	0.4	20.0	53.50
		P_l+P_b	0.7	0.8	30.0	37.22
8	Shield Plug	P_m	0.0	0.0	20.0	>100
		P_l+P_b	0.0	0.0	30.0	>100
9	Shield Plug	P_m	0.0	0.0	20.0	>100
		P_l+P_b	0.0	0.0	30.0	>100
10	Inner Closure Weld	P_m	0.5	0.4	16.0	32.47
		P_l+P_b	0.9	1.0	24.0	24.21
11	Top Plate	P_m	0.0	0.1	20.0	>100
		P_l+P_b	0.0	0.4	30.0	83.27
12	Top Plate	P_m	0.0	0.0	20.0	>100
		P_l+P_b	0.0	0.2	30.0	>100
13	Top Plate	P_m	0.0	0.1	20.0	>100
		P_l+P_b	0.0	0.5	30.0	61.37
14	Outer Closure Weld	P_m	0.0	0.6	16.0	23.96
		P_l+P_b	0.1	1.3	24.0	17.46
15	Lift Ring	P_m	0.0	0.2	20.0	>100
		P_l+P_b	0.0	0.4	30.0	75.14
16	Lift Plate	P_m	0.0	0.3	20.0	67.49
		P_l+P_b	0.0	0.3	30.0	97.04

Notes: (1) Margin of Safety = (Allowable S.I./Calculated S.I.) - 1.0.

Table 4-12. Load Combination A4 ($D_v + L_{hv} + P$) Canister Shell Assembly Stress Results

Section No.	Component	Stress Type	Calculated S.I. (ksi)		Allowable S.I. (ksi)	Margin of Safety[1]
			Inner	Outer		
1	Bottom Plate	P_m	0.1	0.1	20.0	>100
		P_l+P_b	2.0	2.0	30.0	14.18
2	Bottom Plate	P_m	0.1	0.1	20.0	>100
		P_l+P_b	1.7	1.7	30.0	17.12
3	Shell-to-Btm Pl. Weld	P_m	2.0	2.0	20.0	9.22
		P_l+P_b	4.4	4.4	30.0	5.85
4	Cylindrical Shell	P_m	1.2	1.2	20.0	15.22
		P_l+P_b	1.3	1.3	30.0	22.55
5	Cylindrical Shell	P_m	1.0	1.0	20.0	19.41
		P_l+P_b	1.0	1.0	30.0	29.09
6	Cylindrical Shell	P_m	0.9	0.9	20.0	22.15
		P_l+P_b	1.0	1.0	30.0	29.58
7	Shield Plug Support Ring Weld	P_m	0.7	0.7	20.0	29.03
		P_l+P_b	1.4	1.4	30.0	20.46
8	Shield Plug	P_m	0.0	0.0	20.0	>100
		P_l+P_b	0.0	0.0	30.0	>100
9	Shield Plug	P_m	0.0	0.0	20.0	>100
		P_l+P_b	0.0	0.0	30.0	>100
10	Inner Closure Weld	P_m	0.8	0.8	16.0	19.36
		P_l+P_b	1.2	1.6	24.0	14.11
11	Top Plate	P_m	0.3	0.4	20.0	49.38
		P_l+P_b	0.8	1.2	30.0	23.57
12	Top Plate	P_m	0.2	0.2	20.0	80.97
		P_l+P_b	0.9	1.1	30.0	26.73
13	Top Plate	P_m	0.5	0.6	20.0	31.89
		P_l+P_b	1.9	2.4	30.0	11.29
14	Outer Closure Weld	P_m	2.0	2.7	16.0	4.98
		P_l+P_b	4.0	5.4	24.0	3.46
15	Lift Ring	P_m	0.6	0.8	4.3	4.26
		P_l+P_b	1.3	1.7	4.3	1.58
16	Lift Plate	P_m	1.5	1.8	4.3	1.42
		P_l+P_b	2.0	2.3	4.3	0.87

Notes: (1) Margin of Safety = (Allowable S.I./Calculated S.I.) - 1.0.

Table 4-13. Load Combination B1 ($D_v + P_o$) Canister Shell Assembly Stress Results

Section No.	Component	Stress Type	Calculated S.I. (ksi)		Allowable S.I. (ksi)	Margin of Safety[1]
			Inner	Outer		
1	Bottom Plate	P_m	0.2	0.2	22.0	99.92
		P_l+P_b	0.2	0.3	33.0	>100
2	Bottom Plate	P_m	0.1	0.1	22.0	>100
		P_l+P_b	0.2	0.2	33.0	>100
3	Shell-to-Btm Pl. Weld	P_m	0.7	0.7	22.0	30.43
		P_l+P_b	2.1	2.1	33.0	14.94
4	Cylindrical Shell	P_m	0.6	0.6	22.0	34.54
		P_l+P_b	0.7	0.7	33.0	48.92
5	Cylindrical Shell	P_m	1.2	1.2	22.0	17.90
		P_l+P_b	1.2	1.2	33.0	27.33
6	Cylindrical Shell	P_m	0.5	0.5	22.0	44.93
		P_l+P_b	0.8	0.8	33.0	37.92
7	Shield Plug Support Ring Weld	P_m	0.7	0.7	26.6	35.09
		P_l+P_b	1.5	1.6	40.0	24.32
8	Shield Plug	P_m	0.0	0.0	26.6	>100
		P_l+P_b	0.1	0.0	40.0	>100
9	Shield Plug	P_m	0.1	0.0	26.6	>100
		P_l+P_b	0.1	0.0	40.0	>100
10	Inner Closure Weld	P_m	1.0	0.7	17.6	16.05
		P_l+P_b	1.9	1.8	26.4	12.98
11	Top Plate	P_m	0.0	0.2	22.0	>100
		P_l+P_b	0.0	0.7	33.0	44.14
12	Top Plate	P_m	0.0	0.1	22.0	>100
		P_l+P_b	0.0	0.4	33.0	77.01
13	Top Plate	P_m	0.0	0.3	22.0	79.29
		P_l+P_b	0.0	1.0	33.0	32.20
14	Outer Closure Weld	P_m	0.2	1.3	17.6	12.23
		P_l+P_b	0.4	2.7	26.4	8.81
15	Lift Ring	P_m	0.0	0.4	26.6	72.68
		P_l+P_b	0.0	0.8	40.0	48.20
16	Lift Plate	P_m	0.0	0.6	26.6	43.04
		P_l+P_b	0.0	0.6	40.0	62.29

Notes: (1) Margin of Safety = (Allowable S.I./Calculated S.I.) - 1.0.

Table 4-14. Load Combination B2 ($D_v + L_{hv} + P_o$) Canister Shell Assembly Stress Results

Section No.	Component	Stress Type	Calculated S.I. (ksi)		Allowable S.I. (ksi)	Margin of Safety(1)
			Inner	Outer		
1	Bottom Plate	P_m	0.2	0.2	22.0	>100
		P_l+P_b	2.6	2.6	33.0	11.91
2	Bottom Plate	P_m	0.2	0.2	22.0	>100
		P_l+P_b	2.1	2.1	33.0	14.43
3	Shell-to-Btm Pl. Weld	P_m	2.6	2.6	22.0	7.45
		P_l+P_b	6.1	6.1	33.0	4.40
4	Cylindrical Shell	P_m	1.4	1.4	22.0	15.01
		P_l+P_b	1.4	1.4	33.0	22.72
5	Cylindrical Shell	P_m	1.3	1.3	22.0	16.36
		P_l+P_b	1.3	1.3	33.0	24.11
6	Cylindrical Shell	P_m	1.0	1.0	22.0	20.80
		P_l+P_b	1.4	1.4	33.0	22.35
7	Shield Plug Support Ring Weld	P_m	1.0	1.0	26.6	24.78
		P_l+P_b	2.2	2.2	40.0	17.43
8	Shield Plug	P_m	0.0	0.0	26.6	>100
		P_l+P_b	0.0	0.0	40.0	>100
9	Shield Plug	P_m	0.1	0.0	26.6	>100
		P_l+P_b	0.1	0.0	40.0	>100
10	Inner Closure Weld	P_m	1.3	1.1	17.6	12.13
		P_l+P_b	2.3	2.4	26.4	9.80
11	Top Plate	P_m	0.3	0.5	22.0	45.22
		P_l+P_b	0.8	1.6	33.0	19.68
12	Top Plate	P_m	0.2	0.2	22.0	88.43
		P_l+P_b	0.9	1.3	33.0	24.44
13	Top Plate	P_m	0.5	0.7	22.0	28.49
		P_l+P_b	1.9	3.0	33.0	10.17
14	Outer Closure Weld	P_m	2.1	3.4	17.6	4.23
		P_l+P_b	4.1	6.8	26.4	2.90
15	Lift Ring	P_m	0.6	1.0	4.3	3.29
		P_l+P_b	1.3	2.0	4.3	1.11
16	Lift Plate	P_m	1.5	2.1	4.3	1.09
		P_l+P_b	2.0	2.6	4.3	0.66

Notes: (1) Margin of Safety = (Allowable S.I./Calculated S.I.) - 1.0.

Table 4-15. Load Combination B4 (D_h + L_m + P) Canister Shell Assembly Stress Results

Section No.	Component	Stress Type	Calculated S.I. (ksi)		Allowable S.I. (ksi)	Margin of Safety[1]
			Inner	Outer		
1	Bottom Plate	P_m	0.1	0.1	22.0	>100
		P_l+P_b	1.7	1.7	33.0	18.94
2	Bottom Plate	P_m	0.1	0.1	22.0	>100
		P_l+P_b	1.4	1.4	33.0	22.81
3	Shell-to-Btm Pl. Weld	P_m	2.6	2.7	22.0	7.29
		P_l+P_b	5.1	5.1	33.0	5.48
4	Cylindrical Shell	P_m	2.5	2.5	22.0	7.85
		P_l+P_b	2.6	2.6	33.0	11.55
5	Cylindrical Shell	P_m	2.4	2.4	22.0	8.12
		P_l+P_b	2.4	2.4	33.0	12.64
6	Cylindrical Shell	P_m	2.3	2.3	22.0	8.38
		P_l+P_b	2.6	2.6	33.0	11.57
7	Shield Plug Support Ring Weld	P_m	1.3	1.3	26.6	19.80
		P_l+P_b	2.7	2.7	40.0	13.89
8	Shield Plug	P_m	0.0	0.0	26.6	>100
		P_l+P_b	0.0	0.0	40.0	>100
9	Shield Plug	P_m	0.0	0.0	26.6	>100
		P_l+P_b	0.1	0.1	40.0	>100
10	Inner Closure Weld	P_m	1.4	1.5	17.6	10.94
		P_l+P_b	1.8	2.4	26.4	9.80
11	Top Plate	P_m	0.9	1.0	22.0	21.99
		P_l+P_b	2.4	2.7	33.0	11.08
12	Top Plate	P_m	0.7	0.7	22.0	32.28
		P_l+P_b	2.4	2.6	33.0	11.61
13	Top Plate	P_m	1.3	1.4	22.0	14.28
		P_l+P_b	5.3	5.9	33.0	4.63
14	Outer Closure Weld	P_m	5.6	6.3	17.6	1.81
		P_l+P_b	11.2	12.5	26.4	1.11
15	Lift Ring	P_m	1.8	1.9	26.6	12.68
		P_l+P_b	3.6	4.0	40.0	9.04
16	Lift Plate	P_m	4.1	4.3	26.6	5.12
		P_l+P_b	5.6	5.8	40.0	5.85

Notes: (1) Margin of Safety = (Allowable S.I./Calculated S.I.) - 1.0.

Table 4-16. Load Combination C1 ($D_v + P_r$) Canister Shell Assembly Stress Results

Section No.	Component	Stress Type	Calculated S.I. (ksi)	Allowable S.I. (ksi)	Margin of Safety(1)
1	Bottom Plate	P_m	2.0	24.0	10.83
		P_l+P_b	5.9	36.0	5.13
2	Bottom Plate	P_m	0.2	24.0	>100
		P_l+P_b	3.5	36.0	9.34
3	Shell-to-Btm Pl. Weld	P_m	5.3	24.0	3.53
		P_l+P_b	15.4	36.0	1.34
4	Cylindrical Shell	P_m	2.7	24.0	7.78
		P_l+P_b	3.6	36.0	9.13
5	Cylindrical Shell	P_m	5.8	24.0	3.13
		P_l+P_b	5.8	36.0	5.19
6	Cylindrical Shell	P_m	2.4	24.0	8.80
		P_l+P_b	4.2	36.0	7.52
7	Shield Plug Support Ring Weld	P_m	3.6	30.0	7.33
		P_l+P_b	7.7	45.0	4.87
8	Shield Plug	P_m	0.0	30.0	>100
		P_l+P_b	0.3	45.0	>100
9	Shield Plug	P_m	0.3	30.0	86.21
		P_l+P_b	0.6	45.0	78.51
10	Inner Closure Weld	P_m	5.5	19.2	2.50
		P_l+P_b	9.8	28.8	1.94
11	Top Plate	P_m	0.0	24.0	>100
		P_l+P_b	0.0	36.0	>100
12	Top Plate	P_m	0.0	24.0	>100
		P_l+P_b	0.1	36.0	>100
13	Top Plate	P_m	0.1	24.0	>100
		P_l+P_b	0.3	36.0	>100
14	Outer Closure Weld	P_m	1.4	19.2	13.02
		P_l+P_b	2.7	28.8	9.61
15	Lift Ring	P_m	0.1	30.0	>100
		P_l+P_b	0.2	45.0	>100
16	Lift Plate	P_m	0.1	30.0	>100
		P_l+P_b	0.1	45.0	>100

Notes: (1) Margin of Safety = (Allowable S.I./Calculated S.I.) - 1.0.

Table 4-17. Load Combination D1 ($D_v + L_{hv} + P_a$) Canister Shell Assembly Stress Results

Section No.	Component	Stress Type	Calculated S.I. (ksi)		Allowable S.I. (ksi)	Margin of Safety[1]
			Inner	Outer		
1	Bottom Plate	P_m	0.4	0.4	48.0	>100
		P_l+P_b	5.5	5.5	72.0	12.19
2	Bottom Plate	P_m	0.3	0.3	48.0	>100
		P_l+P_b	4.6	4.6	72.0	14.80
3	Shell-to-Btm Pl. Weld	P_m	5.9	5.9	48.0	7.18
		P_l+P_b	15.0	15.0	72.0	3.80
4	Cylindrical Shell	P_m	2.6	2.6	48.0	17.17
		P_l+P_b	3.0	3.0	72.0	22.69
5	Cylindrical Shell	P_m	4.1	4.1	48.0	10.82
		P_l+P_b	4.1	4.1	72.0	16.69
6	Cylindrical Shell	P_m	1.8	1.8	48.0	25.16
		P_l+P_b	3.5	3.6	72.0	19.16
7	Shield Plug Support Ring Weld	P_m	2.8	2.9	30.0	9.49
		P_l+P_b	6.0	6.1	45.0	6.43
8	Shield Plug	P_m	0.0	0.0	30.0	>100
		P_l+P_b	0.2	0.0	45.0	>100
9	Shield Plug	P_m	0.3	0.0	30.0	>100
		P_l+P_b	0.4	0.0	45.0	>100
10	Inner Closure Weld	P_m	4.6	3.0	48.0	9.53
		P_l+P_b	7.8	6.7	72.0	8.25
11	Top Plate	P_m	0.3	0.9	48.0	54.11
		P_l+P_b	0.8	3.5	72.0	19.73
12	Top Plate	P_m	0.2	0.3	48.0	>100
		P_l+P_b	0.9	2.4	72.0	29.32
13	Top Plate	P_m	0.5	1.4	48.0	32.17
		P_l+P_b	1.9	5.5	72.0	12.05
14	Outer Closure Weld	P_m	2.2	6.8	38.4	4.64
		P_l+P_b	4.3	13.7	57.6	3.20
15	Lift Ring	P_m	0.6	1.9	4.3	1.23
		P_l+P_b	1.3	3.9	4.3	0.10
16	Lift Plate	P_m	1.5	3.5	4.3	0.23
		P_l+P_b	2.0	4.0	4.3	0.06

Notes: (1) Margin of Safety = (Allowable S.I./Calculated S.I.) - 1.0.

Table 4-18. Load Combination D3 (P_o + A_s) Canister Shell Assembly Stress Results

Section No.	Component	Stress Type	Calculated S.I. (ksi)		Allowable S.I. (ksi)	Margin of Safety[1]
			Inner	Outer		
1	Bottom Plate	P_m	7.3	10.8	48.0	3.43
		P_l+P_b	8.4	15.7	72.0	3.58
2	Bottom Plate	P_m	1.7	2.2	48.0	20.69
		P_l+P_b	3.6	5.3	72.0	12.68
3	Shell-to-Btm Pl. Weld	P_m	13.2	13.3	48.0	2.62
		P_l+P_b	14.3	15.2	72.0	3.74
4	Cylindrical Shell	P_m	14.0	13.8	48.0	2.43
		P_l+P_b	15.2	15.1	72.0	3.73
5	Cylindrical Shell	P_m	9.9	9.9	48.0	3.84
		P_l+P_b	9.9	9.9	72.0	6.25
6	Cylindrical Shell	P_m	7.4	7.4	48.0	5.48
		P_l+P_b	8.7	8.7	72.0	7.31
7	Shield Plug Support Ring Weld	P_m	10.7	10.7	30.0	1.80
		P_l+P_b	17.7	17.7	45.0	1.54
8	Shield Plug	P_m	0.0	0.0	30.0	>100
		P_l+P_b	0.8	0.8	45.0	54.21
9	Shield Plug	P_m	0.6	0.6	30.0	49.42
		P_l+P_b	1.1	1.1	45.0	41.29
10	Inner Closure Weld	P_m	5.2	5.4	48.0	7.90
		P_l+P_b	8.5	8.8	72.0	7.22
11	Top Plate	P_m	0.1	0.1	48.0	>100
		P_l+P_b	0.2	0.2	72.0	>100
12	Top Plate	P_m	0.0	0.0	48.0	>100
		P_l+P_b	0.2	0.2	72.0	>100
13	Top Plate	P_m	0.2	0.2	48.0	>100
		P_l+P_b	0.7	0.7	72.0	97.50
14	Outer Closure Weld	P_m	1.9	1.6	38.4	19.60
		P_l+P_b	3.8	3.3	57.6	13.99
15	Lift Ring	P_m	0.2	0.2	30.0	>100
		P_l+P_b	0.4	0.5	45.0	95.36
16	Lift Plate	P_m	0.3	0.3	30.0	86.98
		P_l+P_b	0.4	0.4	45.0	>100

Notes: (1) Margin of Safety = (Allowable S.I./Calculated S.I.) - 1.0.

Table 4-19. Summary of Canister Shell Stress Results for Storage Conditions

Section No.	Component	Stress Type	Minimum M.S.[(1)]	Governing L.C.
1	Bottom Plate	P_m	3.43	D3
		P_l+P_b	3.58	D3
2	Bottom Plate	P_m	20.69	D3
		P_l+P_b	9.34	C1
3	Shell-to-Btm Pl. Weld	P_m	2.62	D3
		P_l+P_b	1.34	C1
4	Cylindrical Shell	P_m	2.43	D3
		P_l+P_b	3.73	D3
5	Cylindrical Shell	P_m	3.13	C1
		P_l+P_b	5.19	C1
6	Cylindrical Shell	P_m	5.48	D3
		P_l+P_b	7.31	D3
7	Shield Plug Support Ring Weld	P_m	1.80	D3
		P_l+P_b	1.54	D3
8	Shield Plug	P_m	>100	---
		P_l+P_b	20.00	D3
9	Shield Plug	P_m	30.00	D3
		P_l+P_b	20.00	D3
10	Inner Closure Weld	P_m	2.50	C1
		P_l+P_b	1.94	C1
11	Top Plate	P_m	21.99	B4
		P_l+P_b	11.08	B4
12	Top Plate	P_m	30.00	B4
		P_l+P_b	11.61	B4
13	Top Plate	P_m	14.28	B4
		P_l+P_b	4.63	B4
14	Outer Closure Weld	P_m	1.81	B4
		P_l+P_b	1.11	B4
15	Lift Ring	P_m	1.23	D1
		P_l+P_b	0.10	D1
16	Lift Plate	P_m	0.23	D1
		P_l+P_b	0.06	D1

Notes: (1) Margin of Safety = (Allowable S.I./Calculated S.I.) - 1.0.

4.3.1.1.3 Canister Drop Analysis

A structural evaluation was performed of the small STAD canister assembly for a postulated vertical free drop of 23-feet onto an essentially unyielding horizontal surface. Two impact orientations were considered: (1) Flat bottom end impact, and (2) 4-degree rotation from vertical. The purpose of this evaluation was to provide results that DOE can use for comparison to drop analyses that have been performed for other proposed canister designs, including the Dual Purpose Canister (DPC) and TAD canister evaluated by Lawrence Livermore National Laboratory (LLNL)[16] .

The free drop analysis of the small STAD canister assembly was performed using ANSYS LS-DYNA, an explicit dynamic finite element code. The 4P STAD canister was used for this analysis and the results are assumed to be representative for the 9B STAD canister due to the similarities in the designs. The 4P STAD canister shell assembly, basket assembly, and spent fuel payload were all modeled using solid brick elements. The ground was modeled as an infinitely rigid solid surface. Each fuel assembly was modeled as a rigid solid rectangular prism with a 8.54-inch square cross-section, 173-inch length, and a weight of 1725 pounds. The canister shell and basket assembly components were conservatively modeled using bi-linear kinematic plastic material properties to account for non-linear material behavior. This material model is conservative compared to the power law plasticity model used in the DPC evaluation in that the estimated engineering strains are linearized from the material yield to ultimate strength based upon the tangent modulus.

The stainless steel material model used for the canister shell and basket assembly was based on a yield strength of 25,000 psi, an ultimate strength of 70,000 psi, a density of 490 lb/ft^3, a Poisson ratio of 0.3, and a Young's Modulus of 29,400,000 psi. The assumed material property temperature of the canister and components was 100 °F, which is the same as the DPC evaluation. The temperature can vary over the length of the canister under normal operating conditions. Therefore, assuming an average material temperature is a simplifying assumption considering structural steel material properties do not vary significantly over the expected range of temperatures. As mentioned above, the bi-linear kinematic material model was used, which utilizes the tangent modulus to relate the stress-strain in the plastic region. The tangent modulus was calculated by the following formula:

$$E_t = \frac{\sigma_u - \sigma_y}{\varepsilon_u - \varepsilon_y} = \frac{\sigma_u - \sigma_y}{\varepsilon_u - {}^{\sigma_y}/_{E}} = \frac{70000 - 25000}{0.12 - \frac{25000}{29400000}} = 377{,}600 \text{ psi}$$

---

[16] Lawrence Livermore National Laboratory, “ Seismic and Structural Container Analysis for the PCSA”, 000-PSA-MGR0-02100-000-00A

In order to minimize solution time, the model was simplified and details that have a negligible impact upon the structural integrity were not modeled. Examples of details that were not modeled include: the neutron absorber plates, the drain vents and ports, the siphon tubes and tube fittings, the quick connects, the grapple rings and plates, etc. Mass was added to the modeled components to ensure the STAD total weight was consistent with the Computer Aided Design (CAD) models. The inner contents, which provide the bulk of the mass, were modeled. Figure 4-39 shows the inner components of the STAD which consist of: the support bars, spacer plates, fuel assemblies, support ring, the top end spacer plate, and the shield plug.

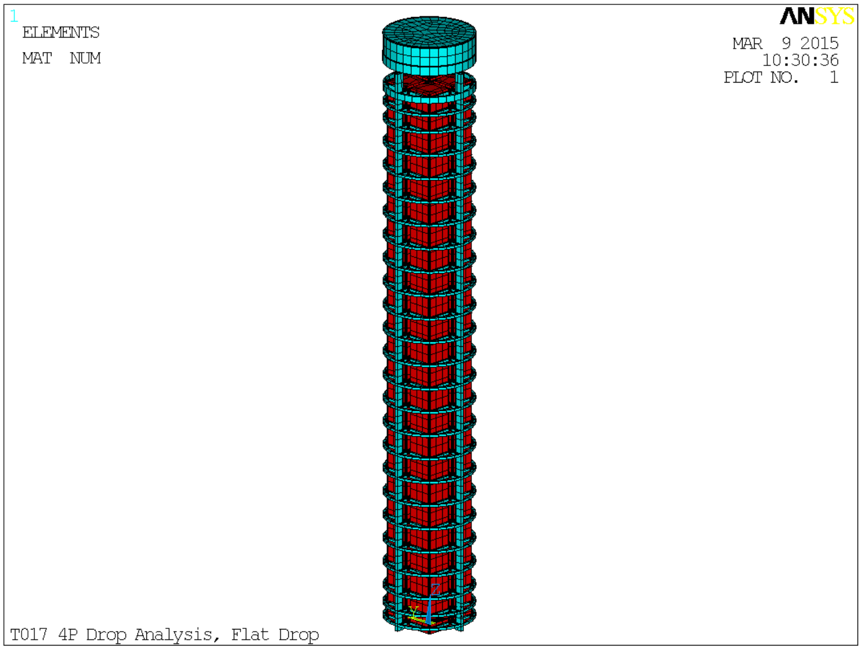


Figure 4-39. Inner Components of the STAD Canister

The outer structural contents which provide for the integrity of the assembly were modeled as well. Figure 4-40 shows the outer structural components which consist of the canister, top plate, and bottom plate.

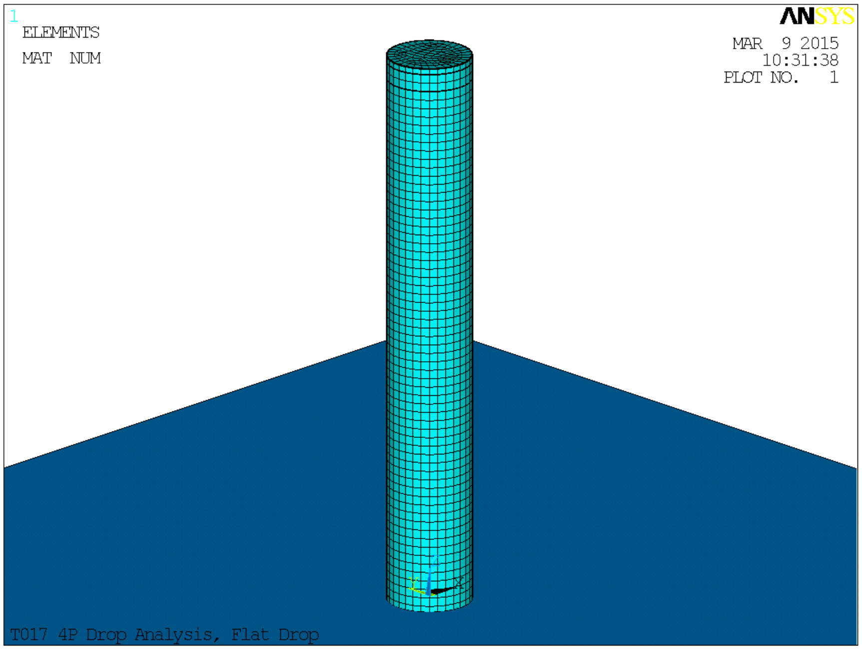


Figure 4-40. Outer Structural Components of the STAD Canister

Drop Analyses

Similar to the DPC and TAD canisters for Yucca Mountain, the STAD canister was evaluated for a flat bottom end impact orientation and a slightly angled (i.e., 4° from vertical) impact orientation. The DPC and TAD analyses utilized a Fragility curve that related strains experience to a probability of failure, which was based on as set of 204 tensile failure tests for Type 304 stainless steel.

This data is valid for axial strains, but LS-DYNA utilizes tri-axial strains. As such, an EPS must be calculated. The EPS is calculated according to the following formula:

$$EPS = \left(\frac{\sqrt{2}}{3}\right) * \sqrt{(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2 + (\varepsilon_1 - \varepsilon_3)^2 + 6(\varepsilon_{12}^2 + \varepsilon_{23}^2 + \varepsilon_{13}^2)}$$

where ε_i are the primary plastic strains and ε_{ij} are the secondary plastic strains in 3-D space.

Flat Drop Results

Similar to the TAD canister analysis, the model was dropped in a flat orientation from an elevation of 23 feet onto a rigid, unyielding surface. This produced a maximum equivalent plastic strain of 0.17, as shown in Figure 4-41.

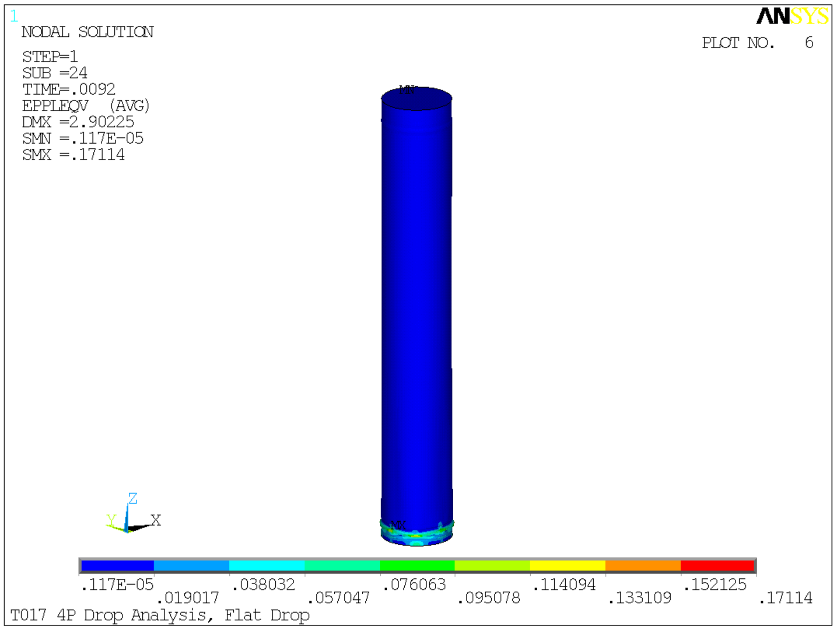


Figure 4-41. Results of the Flat Drop

Corner Drop Results

The model was also dropped in the same worst case orientation as the TAD canister, on its corner at a 4˚ angle from vertical and an elevation of 23 feet onto a rigid, unyielding surface. The canister shell buckled until the lid came into contact with the internal support bars. This corner drop produced a maximum equivalent plastic strain of 0.27, as shown in Figure 4-42.

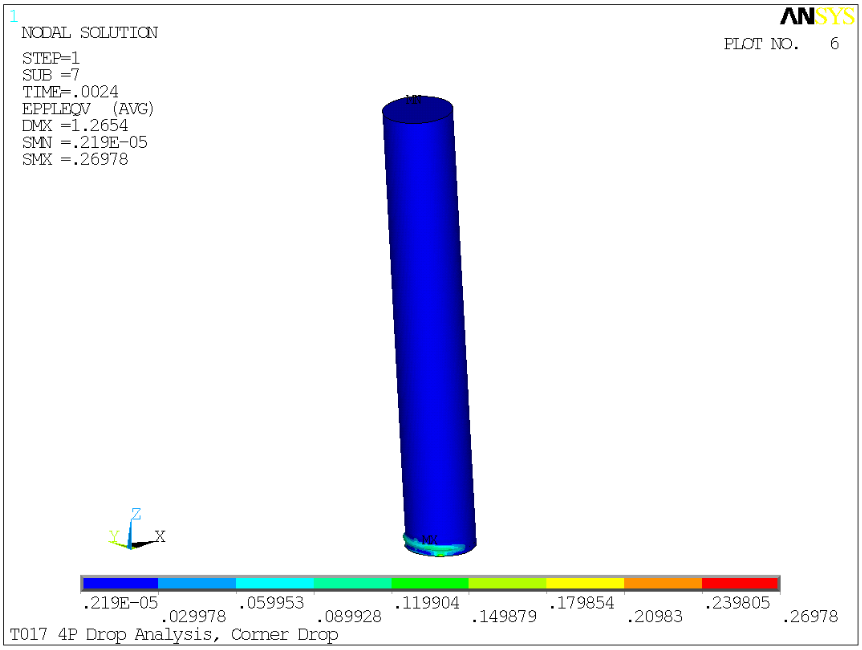


Figure 4-42. Results of Corner Drop

The STAD canister wall thickness was increased to 3/8-inch and dropped in the same orientation. This orientation is considered the worst case. Therefore, a flat end drop was not performed for the thick-walled canister. Similar to the thin-walled canister, the thick-walled canister shell buckled. The corner drop produced a maximum equivalent plastic strain of 0.29, as shown in Figure 4-43.

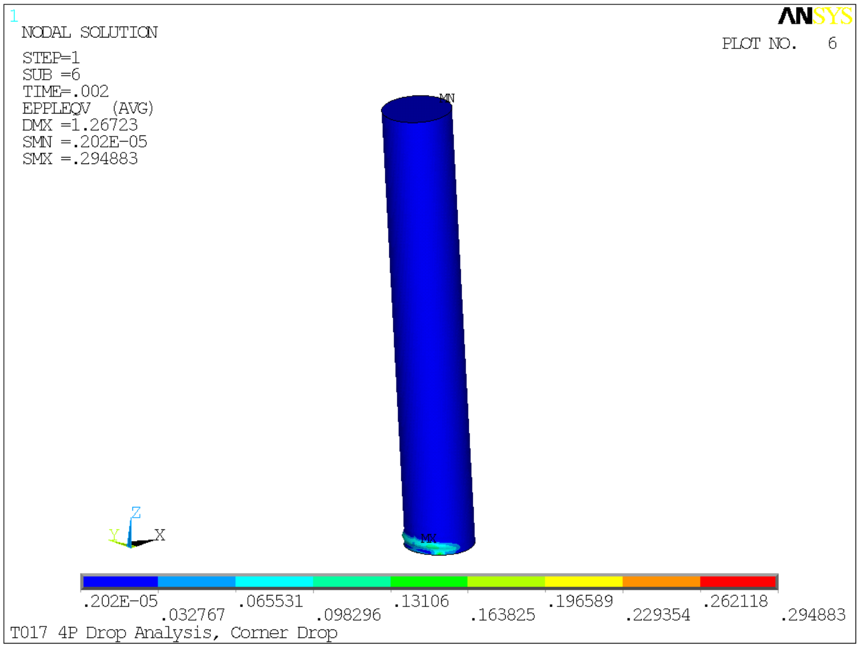


Figure 4-43. Results of Corner Drop of the Thick-Walled Canister

Conclusions

The small STAD canister maximum EPS due to a 23 foot drop onto an unyielding surface is similar to the same drop orientations of the DPC and TAD canister as discussed in the Seismic and Structural Container Analysis for the PCSA, 000-PSA-MGR0-02100-000-00A[16]. The results for the DPC/TAD 23-ft, 4° corner drop had a maximum EPS of 24.19%[16]. The results for the DPC/TAD canister end drop analysis predicted a maximum EPS of 2.13% in the canister shell. As shown in Table 4-20, the results of the small STAD canister drop analysis predict similar maximum EPS magnitudes in the canister shell although the value for the small STAD end-drop is about a factor of 8 higher than that for the DPC/TAD canister.

The scenario of a postulated 23-foot drop of a small STAD canister onto a horizontal essentially unyielding target that was evaluated in this section takes no credit for facility design features or mitigation measures that could potentially be considered in the structural evaluation to lessen the impact on the canister shell. For instance, modeling of a more realistic target, such as a reinforced concrete pad on grade, would account for some of the impact energy being absorbed by the deformation of the target and may reduce the predicted maximum plastic strain in the canister shell. An engineered pad-on-grade surface could be designed to limit the damage sustained by the canister shell under this postulated drop scenario. Other facility design features, such as engineered crash pads in the area used for canister lifts, could also be used as mitigation measures for the drop scenario. These options may be preferable to design modifications of the small STAD canister shell that would result in additional cost for each STAD assembly, and a greater overall impact on the system cost.

Table 4-20. Maximum Equivalent Plastic Strain Results

Canister Type	Corner Drop [1]	End Drop [2, 3]
Small STAD Canister	26.978%	17.11%
DPC/TAD Canisters	24.19%	2.13%

Notes:

1.0 The corner drop is the 23-ft end drop with a 4 degree off-vertical orientation. Both canisters are evaluated for this drop orientation.
2.0 The TAD Dual Purpose Canister end drop is a 32.5-ft end drop.
3.0 The STAD Canister end drop is a 23-ft.

The predicted EPS for the small STAD canister drop are considered conservative, based upon the material plasticity model choice. It is expected that if a power law plasticity material model was used for the drop analysis, the strain results would have been closer to the DPC/TAD canister strains.

A sensitivity study was performed that evaluated two different wall thicknesses for the small STAD canisters and the corner drop case. Wall thicknesses of 1/4-inch and 3/8-inch were evaluated. The maximum EPS for 1/4-inch walled canister was 0.27. The maximum EPS for the thick-walled canister (3/8-inch) was 0.29. The thick-walled canister had a larger maximum EPS. Thickening of the canister wall increases the resistance. This resistance contributes to larger strains when the canister does buckle. If the canister wall thickness was increased to the point where buckling did not occur, the strain results would be smaller than the strain results for these two different canister wall thicknesses. It was concluded that, the thinner-walled canister will be used in the design of the small STAD canisters because the overall weight consideration of the STAD canister is important.

A literature search was performed to investigate alternative strain-based acceptance criteria. There are similar strain-based criteria and methods to those discussed in PCSA, 000-PSA-MGR0-02100-000-00A. One of the strain-based acceptance criteria addressed both tension/compression strains and stress states, which seem to be applicable to strain results of the drop cases. This type of method could be used to further qualify the small STAD canister design.

4.3.2 Thermal Analyses

4.3.2.1 Thermal Analysis of the STAD Carrier in Storage

NAC performed investigative analysis on the performance of the STAD "disc" carrier in a vertical concrete cask (VCC) using natural convection for cooling. Previous applications of tube-and-disc designs were applied for conduction baskets for transport or canisterized fuel. The analysis required multiple runs to obtain reasonable results on the design's performance. Two cases were evaluated; the first case used a nominal 0.25″ gap and the second used a nominal 1.00″ gap. Both models were based on an 8 kW heat load per STAD canister with a typical PWR power distribution. Both models were based on the generic disc support design of the STAD carrier, prior to full development for structural performance (number of support discs) and of numbers of thermal heat fins (required for transport conduction heat transfer performance). For the purpose of these scoping calculations, the effects of these design attributes would be nominal.

- Geometry of the models was based on the earlier TO-18 drawings
- Two geometries modeled:
  - Case 1: canister diameter of 29.0 inch, and 0.25 inch gap between the canister surface and basket disks
  - Case 2: canister diameter of 27.5 inch (artificially increases radial gap), and 1.0 inch gap between the canister surface and basket disks
- All other dimensions of two cases were the same
- Modeled as 1/8 symmetry full axial geometry (see Figure 4-44)
- Both the VCC inlet and outlet were modeled as straight channels, with the same average cross-sectional areas as MAGNASTOR model
- Canister contents were not modeled; each of the canisters was modeled as an 8 kW canister.

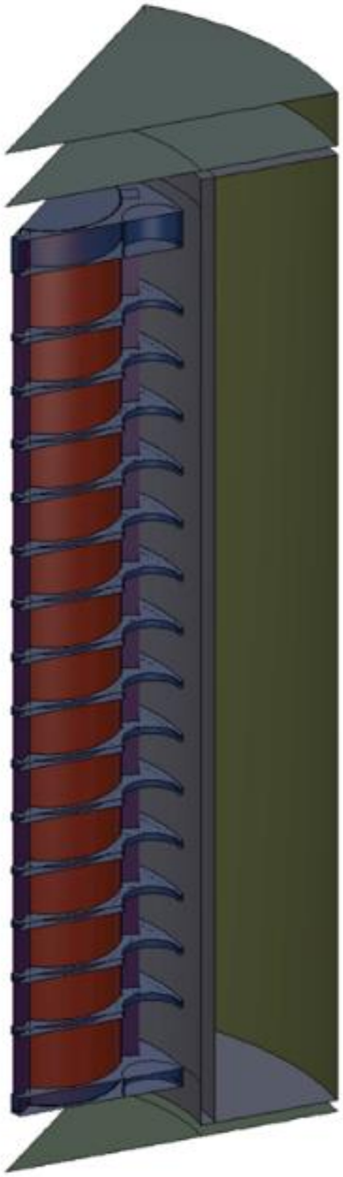
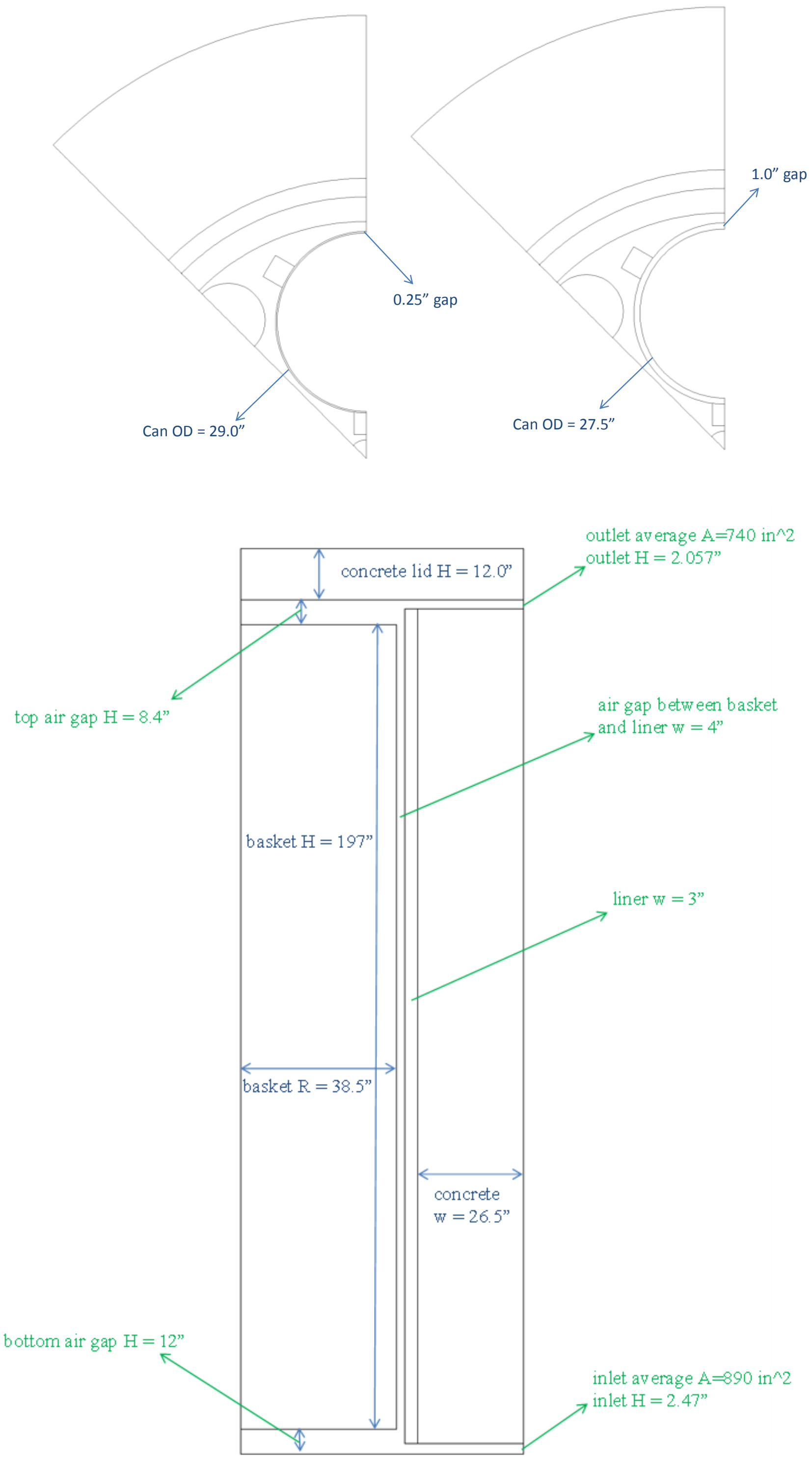


Figure 4-44. 1/8 Symmetry Model

Figure 4-45 provides some additional descriptions for the analyzed model.



Case 1 – 0.25 inch air gap

Case 2 – 1.0 inch air gap

Figure 4-45. Planar and Axial Model Descriptions

Materials:

- Material properties of stainless-steel, carbon-steel, concrete, and air were the same as that used in the MAGNASTOR model
- Surface emissivity values of solid zones were the same as that in the MAGNASTOR model
- The liner was modeled as carbon-steel and the carrier was modeled as stainless-steel; contribution of aluminum heat fins was neglected

Boundary Conditions:

- On VCC inlet, outlet, side, and top, the boundary conditions were the same as that in the MAGNASTOR model
- Ambient air temperature was 76 °F
- Heat transfer coefficients were applied to top and side of VCC
- Solar heating was included (same values as MAGNASTOR)
- On the canister surface, along the 144 inch length of active fuel location, heat flux as function of axial distance was applied with same axial profile as a typical PWR fuel assembly (see Figure 4-46). There was no attempt to model the STAD thermal flux profile.
- Total heat flux on each canister axial surface was 8.0 kW
- On the rest of the canister surfaces (i.e., top, bottom, and axial surface above and below active fuel location), heat flux is set to zero

Results

Table 4-21 shows the flowrates and peak temperatures from the analyzed model.

Table 4-21. Model Results

Feature	**Case 1 - 0.25″ gap**	**Case 2 - 1.0″ gap**
Maximum STAD canister surface temperature	557 °F	408 °F
Max concrete cask temperature	181 °F	163 °F
Total air flowrate through the storage cask	0.587 kg/s	0.587 kg/s
Air flowrate between each can and disk at bottom	0.0131 kg/s	0.0636 kg/s
Air flowrate between each can and disk at top	0.00738 kg/s	0.0628 kg/s

As shown in Figure 4-47 through Figure 4-52, FLUENT solutions for this geometry are very complex and develop a broad spectrum of air velocities. The results indicate that a nominal air gap of 1/2" is more effective in providing an airflow path for keeping the STAD canisters at lower temperatures. The smaller gap clearly indicates biased flow outside of the support discs.

At the canister midpoint, analysis shows an outer (azimuth) STAD shell temperature of approximately 340-350°F degrees, and an inner temperature just above 410°F. Both values support the canister/basket thermal analysis presented in support of Peak Clad Temperature limits.

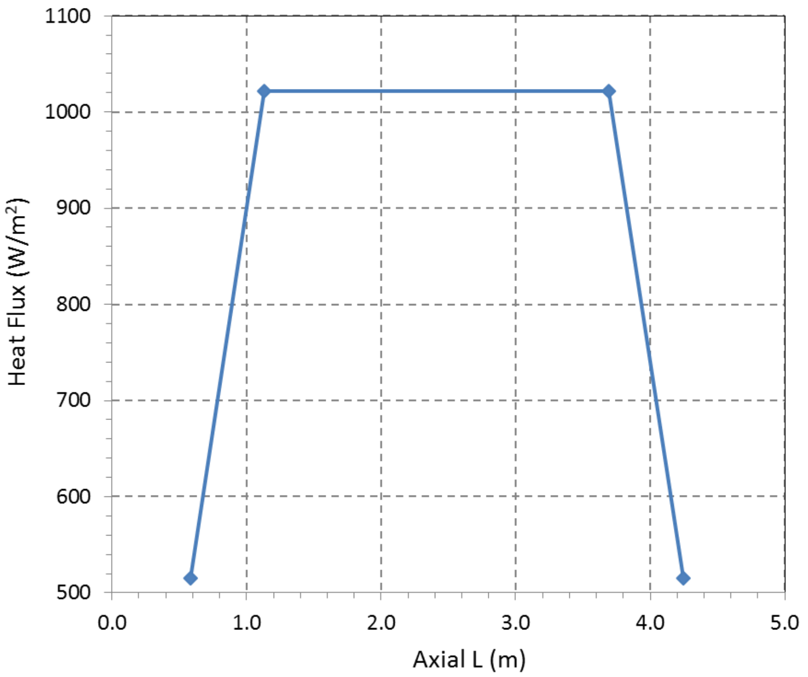
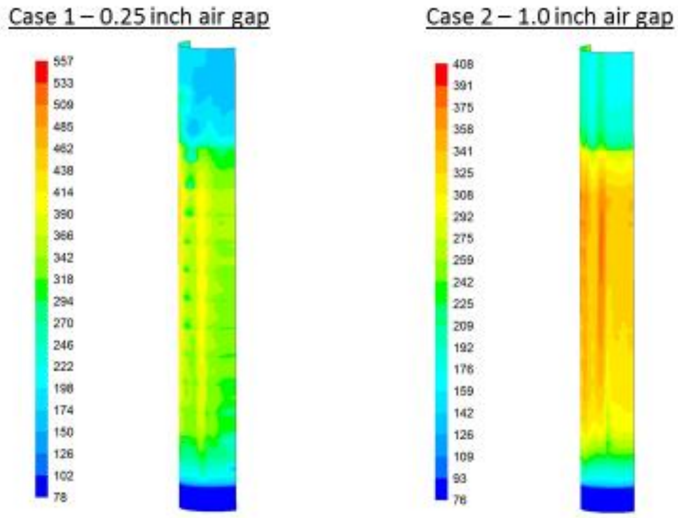


Figure 4-46. Power Profile for the Heat Flux



Case 1 – 0.25 inch air gap

Case 2 – 1.0 inch air gap

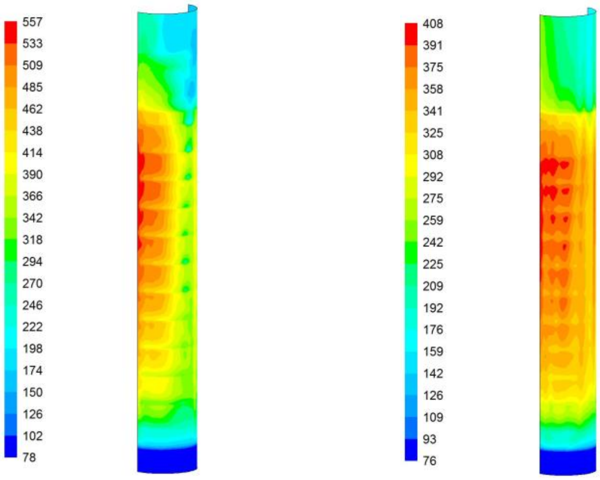


Figure 4-47. Canister Surface Temperature Profiles

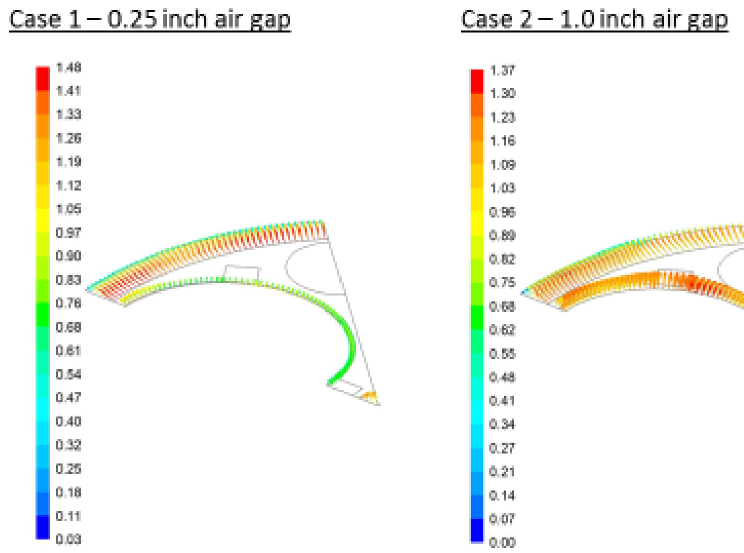


Figure 4-48. Air Velocity Profiles.
Velocity (m/s) on z=12″ Plane Through Bottom of Basket

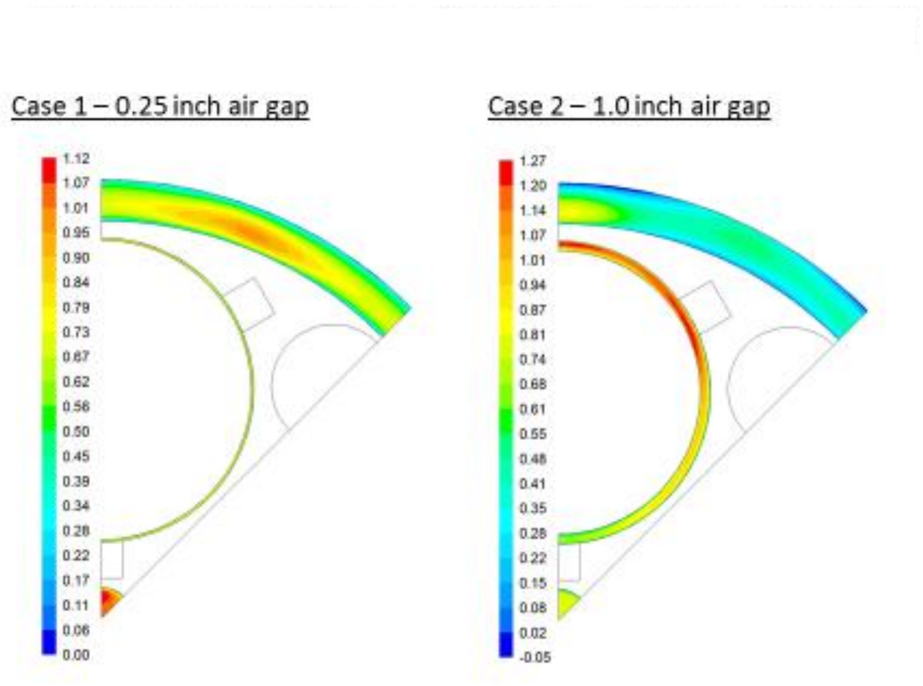
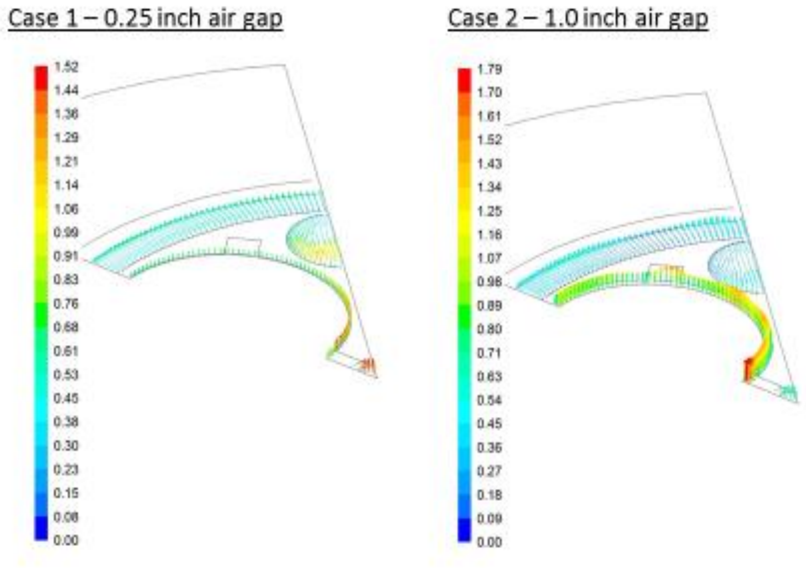
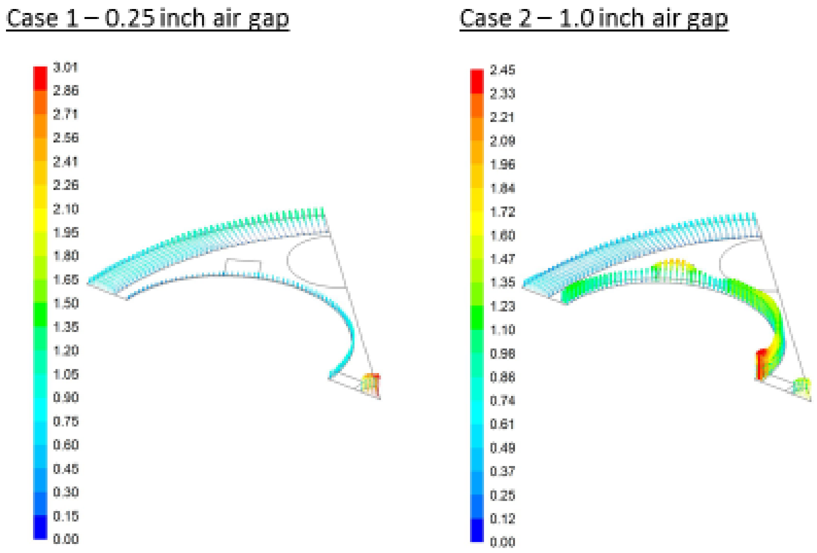


Figure 4-49. Air Velocity Profiles.
Axial Velocity (m/s) on z=12″Plane - Bottom of the Basket


Case 1 – 0.25 inch air gap

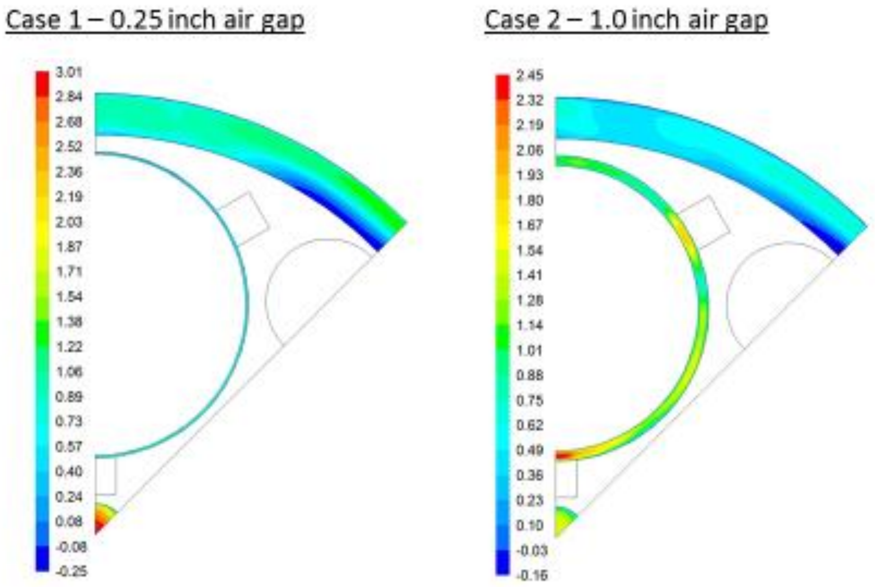
Case 2 – 1.0 inch air gap

Figure 4-50. Air Velocity Profiles.
Velocity (m/s) on z=102.5″ Plane Through Middle of Basket


Case 1 – 0.25 inch air gap

Case 2 – 1.0 inch air gap

Figure 4-51. Air Velocity Profiles.
Velocity (m/s) on z=209″ Plane Through Top of Basket


Case 1 – 0.25 inch air gap

Case 2 – 1.0 inch air gap

Figure 4-52. Air Velocity Profiles.
Axial Velocity (m/s) on z=209″Plane -Top of Basket

Subsequent to the analysis performed above, substantial changes in the structural methodology were made, however, sensitivity to the STAD to support gap was maintained. As described in Section 4.3.1, the structural support for the STAD is now conceived to be a continuous sleeve. And as noted in that same section, the design has maintained a nominal radial gap to provide for convective air flow. Also, with the implementation of the sleeve design, the cooling air flow path around the STAD is far more controlled and can be further evaluated with a 2D axisymmetric model as opposed to the sophisticated three dimensional models used for the disc to disc air flow evaluation.

Using the same boundary conditions, the sleeve design was evaluated and compared to the performance of the disc design.

2D Axisymmetric Model - Boundary Conditions

- Simplified 2D modeling used for annular air flow evaluation
- Storage cask inlet, outlet, side, and top boundary conditions were the same as those used in the MAGNASTOR analysis
- Ambient air temperature was <u>76 °F</u>
- Heat transfer coefficients were applied to the top and side of the storage cask
- Solar heating was included (same values as the MAGNASTOR analysis)

- On the canister surface, along the 144 inch length of active fuel location, heat flux as a function of axial distance was applied with same axial profile as the heat source of the MAGNASTOR analysis
- Total heat flux on each canister axial surface was 8.0 kW
- On the rest of the canister surfaces (i.e., top, bottom, and axial surface above and below active fuel location), the heat flux was set to zero
- Material properties of stainless-steel, carbon-steel, concrete, and air used were the same as those used in the MAGNASTOR analysis
- Surface emissivity values of solid zones were same as in the MAGNASTOR Analysis
- Liner is modeled as carbon-steel and carrier is modeled as stainless steel discs only

Figure 4-53 through Figure 4-56 show the results from the modeling results. Table 4-22 presents the surface temperature results from the modeling.

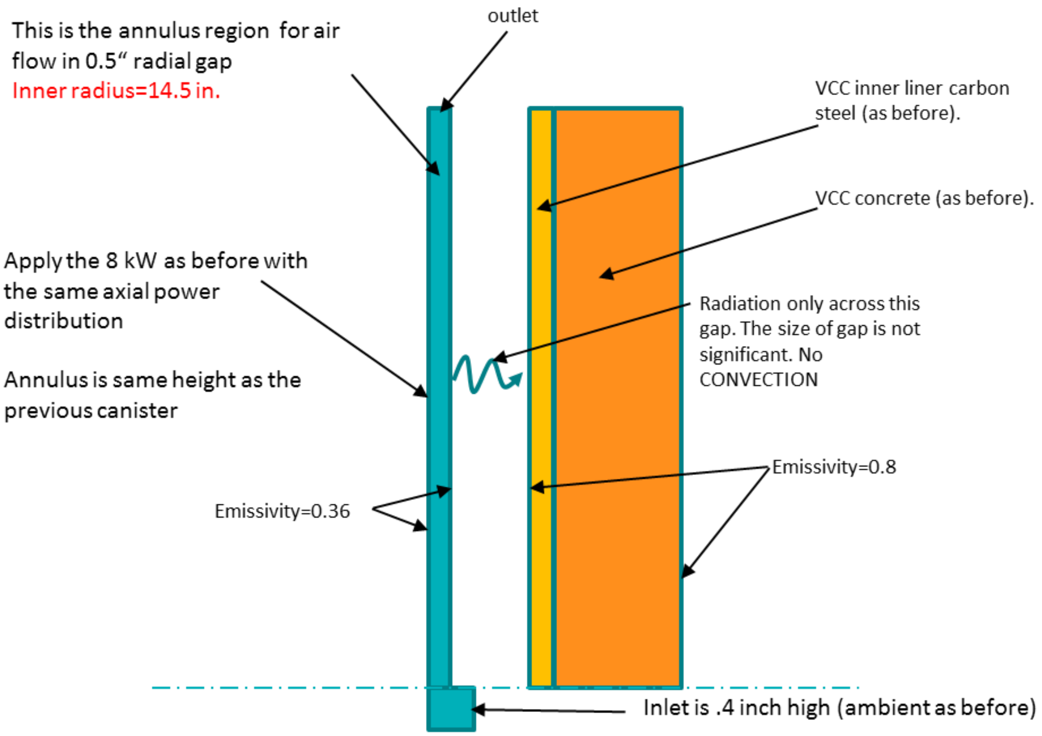


Figure 4-53. Case 1 - 2D Axisymetric Model of ½″ Annulus Region and Concrete Cask

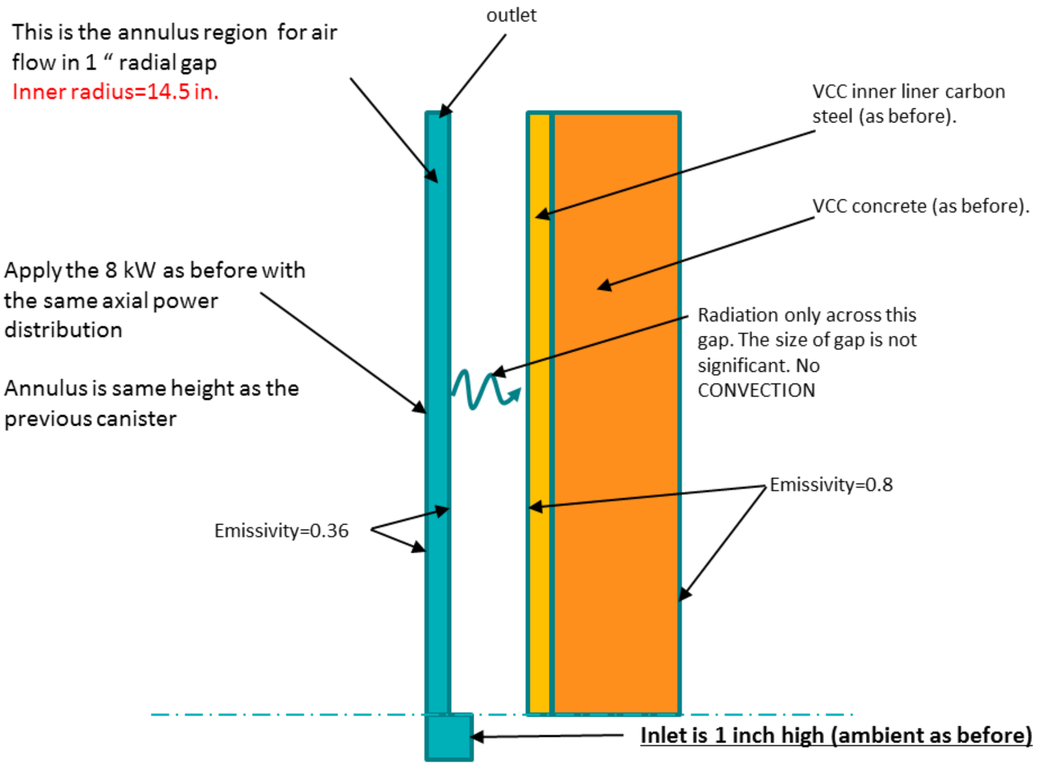


Figure 4-54. Case 1 - 2D Axisymetric Model of 1" Annulus Region and Concrete Cask

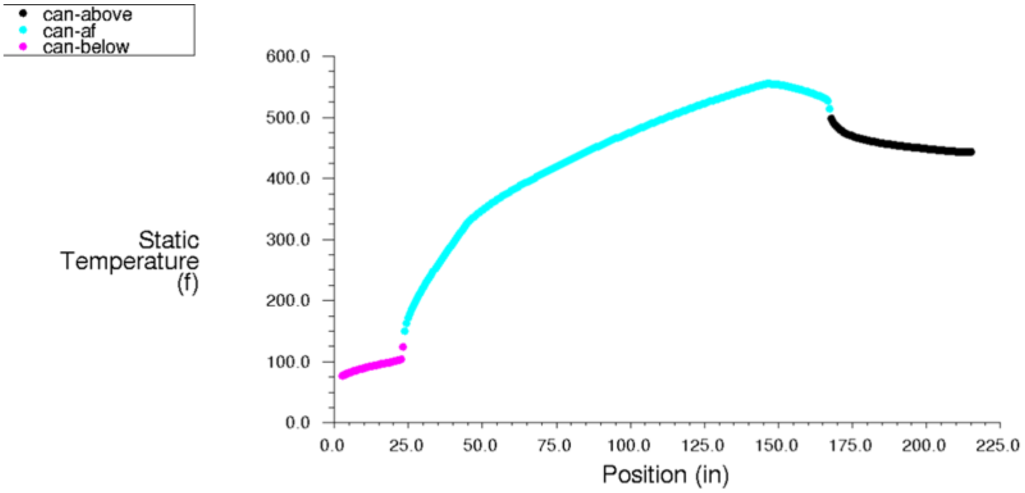


Figure 4-55. Case 1 – 1/2" Annulus Temperature Results

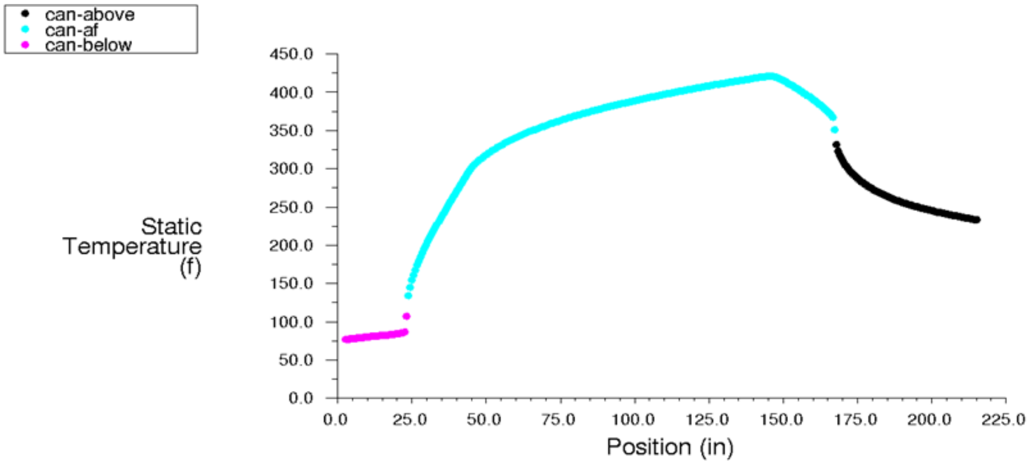


Figure 4-56. Case 1 - 1” Annulus Temperature Results

Table 4-22. Surface Temperature Results from Modeling

	3D model with disks Case 1 - 0.25” gap	3D model with disks Case 2 - 1.0” gap	2D axisymmetric smooth shell model Case 1 - 0.5” gap	2D axisymmetric smooth shell model Case 2 - 1.0” gap
Maximum canister surface temperature	557 °F	408 °F	554 °F	421 °F

The 2D axisymmetric model was a simplification of the VCC which was contained in the 3D model. The air flowing up the annulus would reduce the 2D axisymmetric temperature results, but not to the point of reducing 554 °F to 500 °F.

In transportation, the carrier will have to perform as a thermal conduction system and require aluminum heat fins to conduct decay heat from the sleeves outward to the cask inner shell. The primary design attribute is to have the aluminum fins in contact with the sleeves. For the current carrier concept, integration of the thermal fins with the sleeve support assemblies would be a reasonable design and quite capable of allowing the thermal fins to “float” a bit. The central structure (in the middle of the sleeves) could effectively be a solid piece of aluminum that would serve to stretch or distribute the thermal effects of the STAD canister the entire length of the carrier. The transport heat load is expected to be 24 kW, significantly less than the storage heat load and, although there has not been specific analysis performed for this design, correlation to a standard transport tube and disc design provides reasonable confidence that this sleeve carrier design can be made to conduct the 24 kW heat load into the transport cask body and provide adequate thermal performance for the STAD canister contents.

4.3.2.2 Thermal Analysis of the STAD Carrier in Transport

In transportation, the basket will have to perform as a conduction system and will require aluminum heat fins to conduct from the canister shells outward to the cask inner shells.

Problematic in this, is the concept that the heat fins need to be in relatively close proximity to the canister to function efficiently. This would require the thermal fins to have complex (3-4 leaf clover type) openings for the canisters allowing some of the radial area to be close to the canister and the balance open for storage. The transport heat load is expected to be 24 kW, significantly less than the storage heat load. There has not been analysis specific to this design, but correlation to a standard transport tube and disc design provides reasonable confidence that this design can be made to conduct a 24 kW heat load into the transport cask body.

4.3.2.3 STAD Canister Thermal Analyses

Thermal analyses were performed, using the ANSYS code, to calculate peak temperatures for the fuel assembly cladding and the (stainless steel or borated stainless steel) basket structures. Thermal analyses were also performed for the PWR and BWR STADs, for transportation and storage. These analyses are discussed in the sections below.

4.3.2.3.1 Transportation Analysis

Analysis Methodology

For both STADs, the analyses modeled a horizontal slice through the axial center of the basket structure, and applied adiabatic boundaries on the axial ends of the slice. Therefore, the analyses effectively modeled an infinite height basket (and assembly fuel zone) structure, and thus conservatively neglected axial heat transfer and loss. Both STAD baskets employ axially periodic spacer plates that occur at a regular axial spacing. To model these features, the (horizontal slice) basket models covered a finite axial span, extending from the axial center of a spacer plate to a point halfway between spacer plates. This effectively modeled an infinite-height basket structure with the spacer plates occurring at a regular axial interval.

The axial heat generation (in watts/assembly-inch) modeled in these infinite-height analyses equates to the overall assembly heat generation levels given above. The axial heat generation levels were multiplied by 1.07 and 1.22, for PWR and BWR fuel, respectively, to conservatively account for the assembly's axial burnup profiles.

The analyses did not model the transportation cask, or the heat transfer through the transportation cask and out to the ambient environment. Instead, the analyses applied a fixed temperature on the outer radial surface of the cask cavity, as a boundary condition. The basket analyses conservatively used the peak cask cavity wall temperature that occurs at any axial location. A series of analyses were performed that cover a range of cask cavity wall temperatures (330°F to 400 °F). Based on thermal evaluations of similar transport casks[19], it was assumed that the cavity wall temp will not exceed 400 °F.

The analyses, for both basket designs, modeled the fuel assemblies as a homogenous mass that completely fills the loading cell and has an effective (temperature dependent) radial thermal conductivity. Effective assembly thermal conductivities were taken from previous, NRC-approved cask system licensing analyses. Specifically, the effective conductivities for PWR and BWR fuel assemblies were taken from Table 4.4-2 of the MAGNASTOR FSAR[17] and from Appendix A of the VSC-24 FSAR[18], respectively.

The analyses modeled radiation heat transfer between the basket edge and the cask inner shell, based on an emissivity of 0.4 for the basket and cask shell material surfaces. The analyses conservatively neglected all convective heat transfer, within the STAD interior and within the spaces between the STADs and the cask wall.

In addition to modeling the hottest axial section of the basket and neglecting axial heat transfer, the models assumed the assemblies and basket components "float", i.e., are centered within the spaces they lie in, which results in no thermal contact between components, and evenly distributed gaps around them. Thus, the results of these analyses are conservative.

Both the PWR and BWR analyses modeled a heat generation level of 6.0 kW per STAD, which corresponds to an overall transportation cask heat load of 24 kW. This also equates to per-assembly heat loads of 1.5 kW/assembly for PWR and 0.667 kW/assembly for BWR. These per-cell heat generation levels were increased (as discussed above) by 7% and 22%, for the PWR and BWR cases, respectively, to account for the axial burnup profile of the fuel assemblies.

The analyses calculated the peak temperature within the homogenous fuel assembly mass (which corresponds to the peak fuel rod cladding temperature) and the peak temperatures that occur in the STAD basket structures, including the stainless steel spacer plates and the borated stainless steel neutron absorber plates. The calculated peak temperatures were compared to their maximum allowable values, which are 752 °F (400 °C) for the fuel rod cladding and 800 °F for the stainless steel basket structural materials.

Analysis Results

The results of the transportation case STAD thermal analyses are summarized in Figure 4-57 for both the PWR and BWR STADs. The plot shows the peak fuel cladding and peak basket material temperatures as a function of the modeled transport cask cavity wall temperature (discussed in the methodology section above).

The results show that the fuel rod cladding and the STAD basket structure materials remain under their temperature limits (of 752 °F and 800 °F, respectively) by significant margins, even with a cask cavity wall temperature of 400 °F. Cask cavity wall temperatures are expected to be

---

[17] MAGNASTOR Final Safety Analysis Report, Revision 0, February 2009, NRC Docket No. 72-1301, NAC International.

[18] Final Safety Analysis Report for the VSC-24 Ventilated Storage Cask System, Revision 5, March 2003, NRC Docket No. 72-1007, BNFL Fuel Solutions Corporation.

significantly lower[19]. Thus, the actual temperature margins are quite wide, especially considering the conservative assumptions made in the analyses, such as neglecting all convective heat transfer and all axial heat transfer.

Temperature contour plots are shown, for the PWR and BWR STADs, in Figure 4-58 and Figure 4-59, respectively. The plots present the temperatures that occur over a horizontal cross section of the PWR and BWR STAD basket configurations, at an axial location halfway between spacer plates. That is the elevation where peak temperatures occur. The temperatures that occur at other axial elevations (e.g., in the plane occupied by a spacer plate) are lower than those shown in Figure 4-58 and Figure 4-59. The temperatures shown in Figure 4-58 and Figure 4-59 correspond to a modeled cask cavity wall temperature of 330 °F which is close to the expected cavity wall temperature for a 24 kW cask heat load.

In conclusion, the transportation case STAD interior thermal analyses show that the fuel cladding and STAD basket structures meet their respective temperature limits by wide margins, assuming a STAD heat generation level of 6.0 kW/STAD. This corresponds to heat generation levels of 1.5 kW per PWR assembly and 0.667 kW per BWR assembly, and an overall transportation cask heat generation level of 24 kW. Thus, the analyses show that it is the transportation cask (and the cask neutron shield temperature limit) that limits the allowable heat generation levels for the system.

---

[19] EnergySolutions et.al., "DOE Advisory and Assistance Services Contract Task Order 17: Spent Nuclear Fuel Transportation Cask Study", March 2015

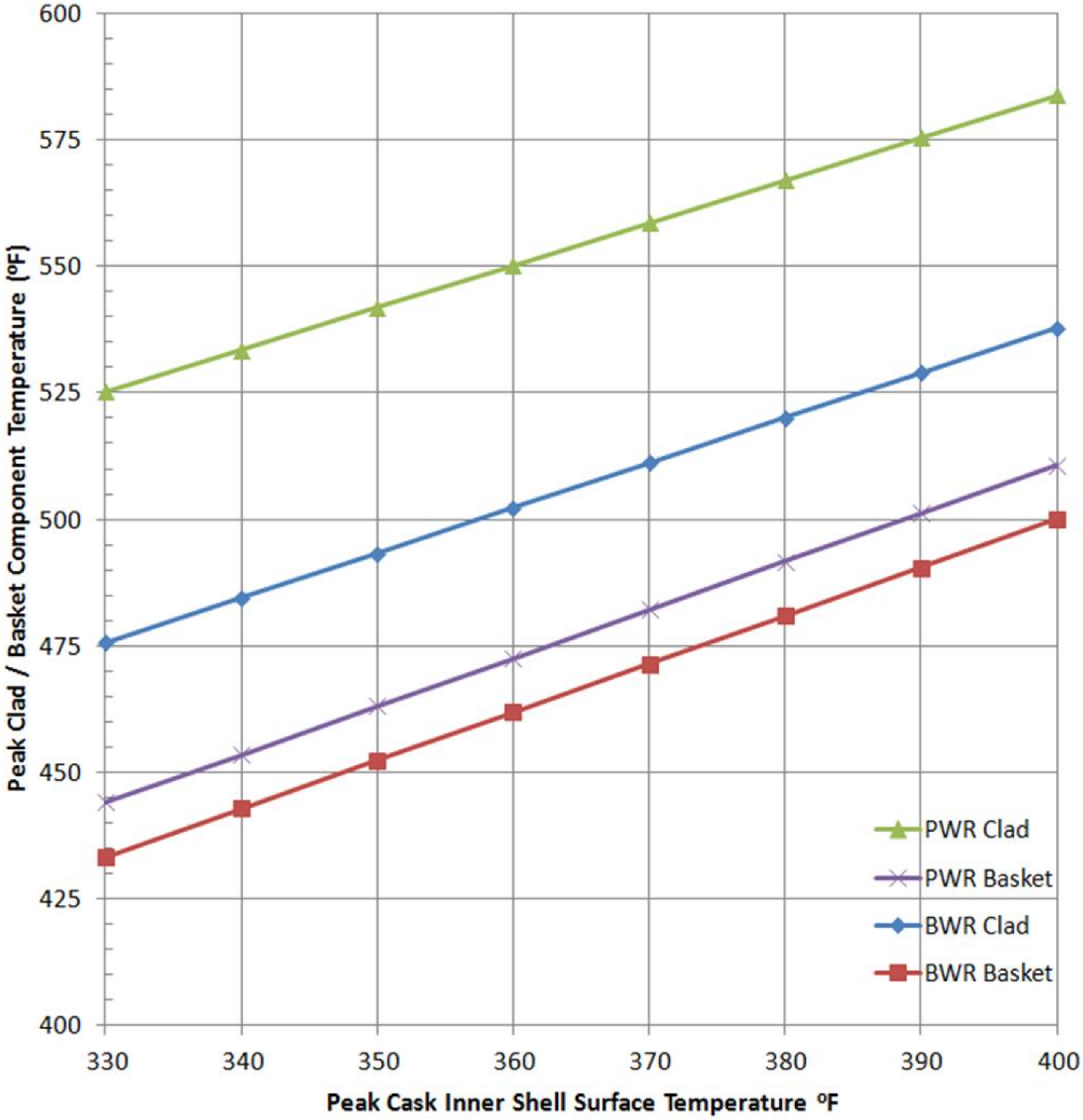


Figure 4-57. Peak Fuel Cladding and Basket Structural Component Temperatures for Four STADs in Transportation Cask – 6.0 kW/STAD Heat Generation

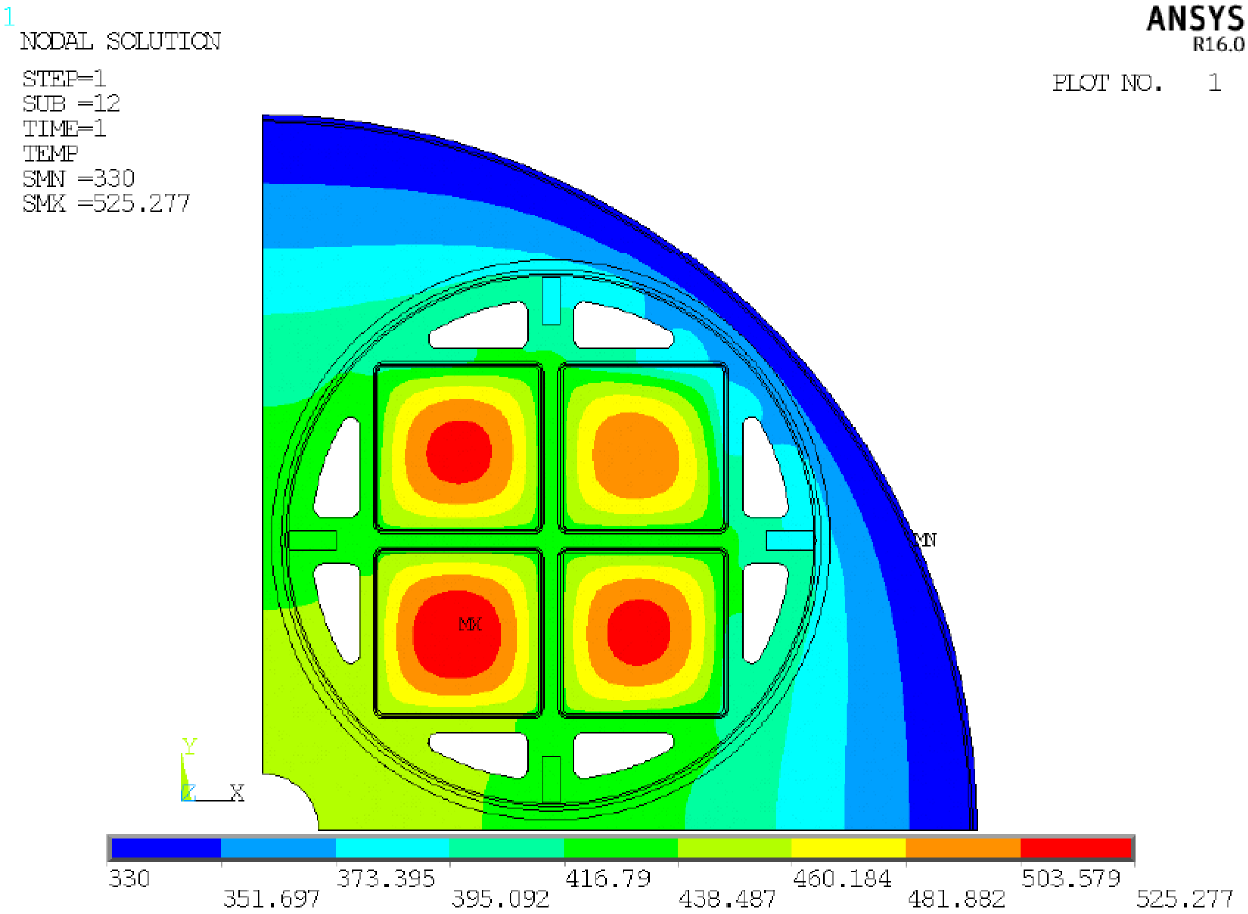


Figure 4-58. Basket and Assembly Materials Temperature Distribution for Four PWR STADs in Transportation Cask – 6.0 kW/STAD Heat Generation

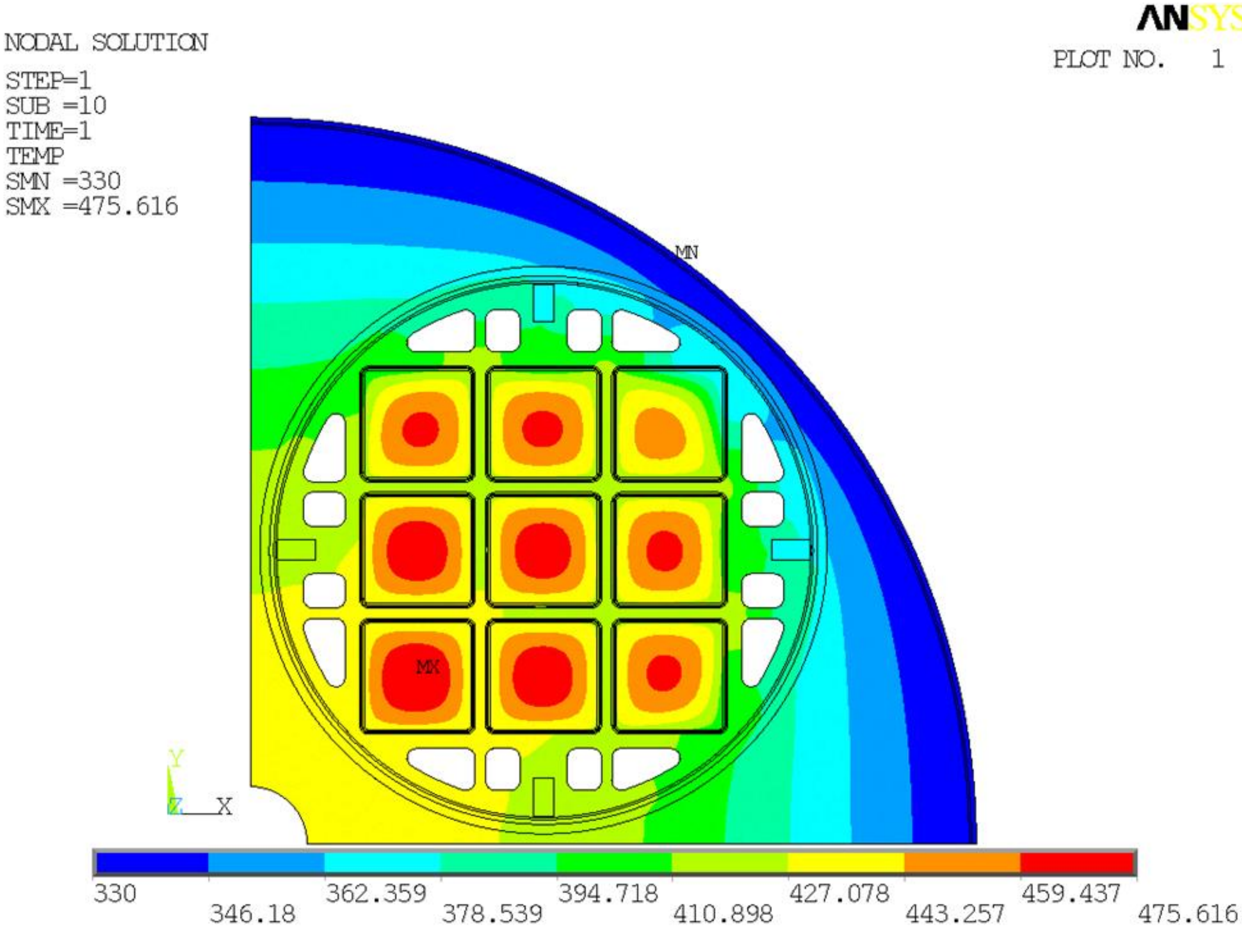


Figure 4-59. Basket and Assembly Materials Temperature Distribution for Four BWR STADs in Transportation Cask – 6.0 kW/STAD Heat Generation

4.3.2.3.2 Storage Analyses

To estimate the STAD interior temperatures that will occur during storage, the thermal models described in the previous section, for four STADs inside the transportation cask, were modified to increase the heat generation level to 8.0 kW/STAD, which corresponds to an overall storage cask interior heat load of 32 kW. No other changes are made to the models.

As with the transportation evaluation, the analyses modeled cask cavity wall temperatures that range from 330 °F to 400 °F. Figure 4-60 shows the peak fuel rod clad temperature and peak STAD interior basket structure temperature, as a function of cask cavity wall temperature, for a 8.0 kW/STAD heat load. The results show that the PWR and BWR rod cladding and basket temperatures remain under their limits (of 752 °F and 800 °F, respectively) by significant margins, for cask wall temperatures that do not exceed 400 °F.

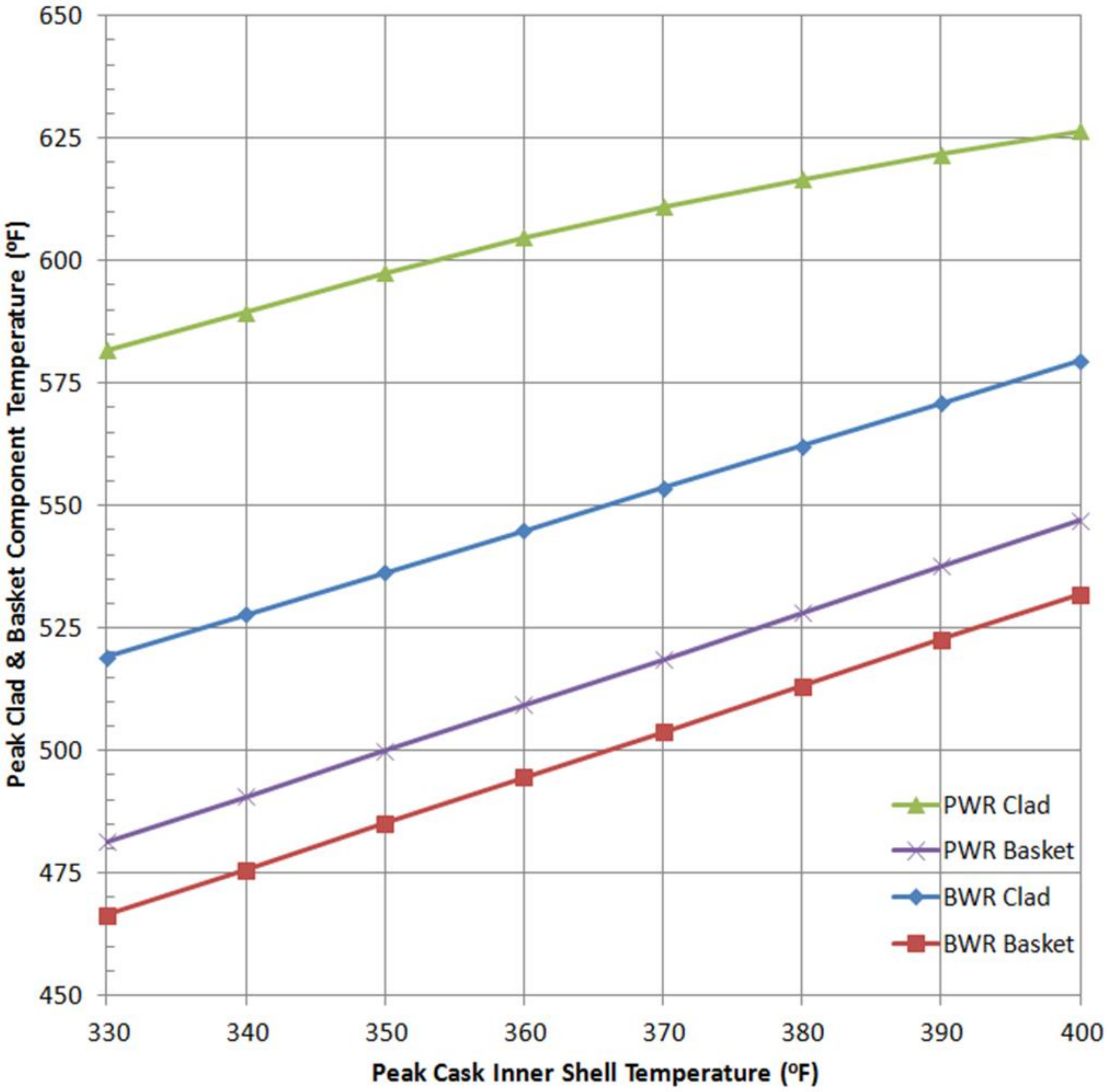


Figure 4-60. Peak Fuel Cladding and Basket Structural Component Temperatures for Four STADs in Transfer Cask – 8.0 kW/STAD Heat Generation

The STAD interior thermal analyses modeled the four STADs inside a metal cask cavity with no ventilation air flow around or between the STADs, as opposed to the actual storage cask and carrier configuration. However, the accuracy of the calculated STAD interior temperatures can be evaluated by comparing the STAD wall temperatures calculated by (and effectively modeled by) the STAD interior thermal analyses to those calculated by the Section 4.3.2.1 analyses, which do accurately model the four STADs within the storage cask and carrier configurations.

Temperature contour plots for the STAD interior, produced by the STAD interior thermal analyses, are shown in Figure 4-61 through Figure 4-64. The plots present the temperatures that occur over a horizontal cross-section of the PWR and BWR STAD basket configurations, at an axial location halfway between spacer plates. That is the elevation where peak temperatures occur. The temperatures that occur at other axial elevations (e.g., in the plane occupied by a spacer plate) are lower than those shown in Figure 4-61 through Figure 4-64. The four figures show the temperature contour plots for the PWR and BWR STAD configurations, and for the modeled boundary (cask cavity wall) temperatures of 330 °F and 400 °F (i.e., the two extremes of the analyzed range).

Examination of Figure 4-63 and Figure 4-64 shows that the 400 °F cask wall configurations yield a STAD wall temperature of approximately 420-425 °F at the outermost azimuth (i.e., at the outer edge of the four-STAD carrier configuration) and STAD wall temperatures of approximately 530-540 °F (PWR) at the innermost azimuth (i.e., the section of the STAD wall between the STADs, nearest to the center of four-STAD carrier configuration).

The Section 4.3.2.1 storage cask thermal analyses show that, for a 8.0 kW/STAD heat generation level and a 0.25 inch annular air gap around the STADs, the peak STAD wall temperature is approximately 410 °F at the outermost azimuth. This is less than the ~425 °F temperature shown for the 400 °F cask wall, PWR and BWR STAD thermal analysis cases shown in Figure 4-63 and Figure 4-64. Thus, with respect to the outer-azimuth STAD wall temperature, the STAD interior thermal analyses are shown to be conservative.

The Section 4.3.2.1 storage cask thermal analyses also show that, for a 8.0 kW/STAD heat generation level, the peak inner-azimuth STAD wall temperature is 557 °F. This is approximately 17 °F and 27 °F higher than the ~540 °F and ~530 °F values shown for the 400 °F cask wall, PWR and BWR STAD cases in Figure 4-63 and Figure 4-64, respectively. Despite this, it is likely that the peak cladding and basket component temperatures calculated by the STAD interior thermal analyses are conservative (high). The STAD interior thermal analyses are clearly conservative as they neglect all convective heat transfer within the STAD interior. Furthermore, the 557 °F value (calculated in Section 4.3.2.1) is based on an annular air gap (around the STADs) of only 0.25 inches. For a 1.0 inch gap, the Section 4.3.2.1 analyses calculate an inner-azimuth STAD wall temperature of 408 °F, which is well below the temperatures of 530-540 °F calculated by the STAD interior thermal analyses.

Also, as shown in Figure 4-60, the peak rod cladding and STAD interior basket component temperatures, for the 400 °F cask wall case, are below their respective limits by more than 125 °F and 170 °F, for the PWR and BWR STADs, respectively. These temperature margins are far larger than the (17-27 °F) differences in inner-azimuth STAD wall temperatures, between the STAD interior thermal analyses and the Section 4.3.2.1 thermal analyses. Thus, it is very unlikely that the actual storage configuration would result in fuel rod cladding and STAD basket component temperatures in excess of their limits.

It will have to be confirmed, by detailed licensing thermal analyses, that the peak rod cladding and STAD basket temperatures are less than their respective limits, under storage conditions with an 8.0 kW/STAD heat load. As discussed in Section 4.3.2.1, there may be design changes that could be made, if necessary, that would significantly reduce the temperature of the STAD shell at the inner azimuth, which in turn would significantly reduce peak cladding and STAD basket temperatures.

Therefore, it is concluded that acceptable fuel rod cladding and STAD interior basket structure temperatures will occur for payloads of four PWR or BWR STADs within the storage cask described in Section 4.1.3, given that the STAD heat load does not exceed 8.0 kW/STAD.

During transfer operations, the transfer cask inner shell temperature will be kept below 400 °F, using methods such as circulating water. Therefore, the STAD interior temperatures will remain below their limits during transfer operations.

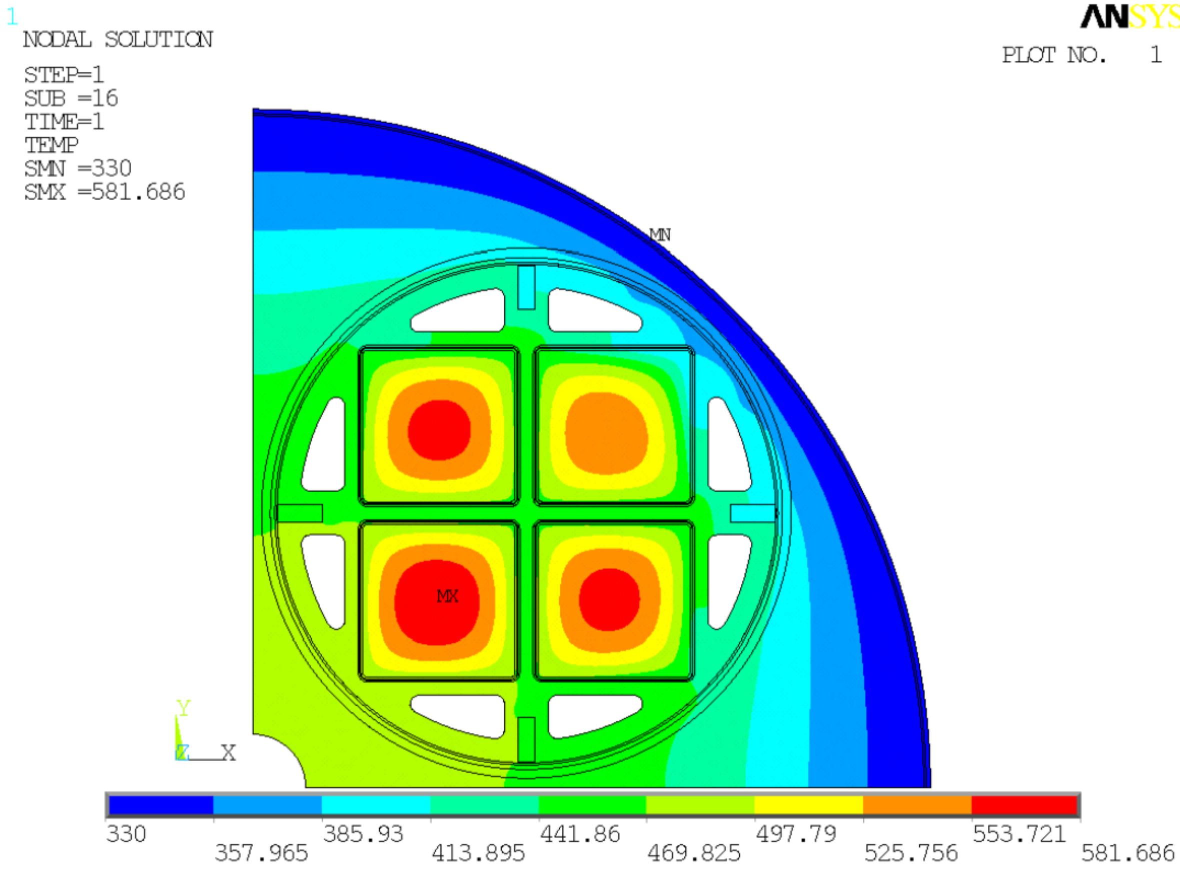


Figure 4-61. Basket and Assembly Materials Temperature Distribution for Four PWR STADs in Transfer Cask 8.0 kW/STAD Heat Generation – 330 °F Cask Cavity Wall Temperature

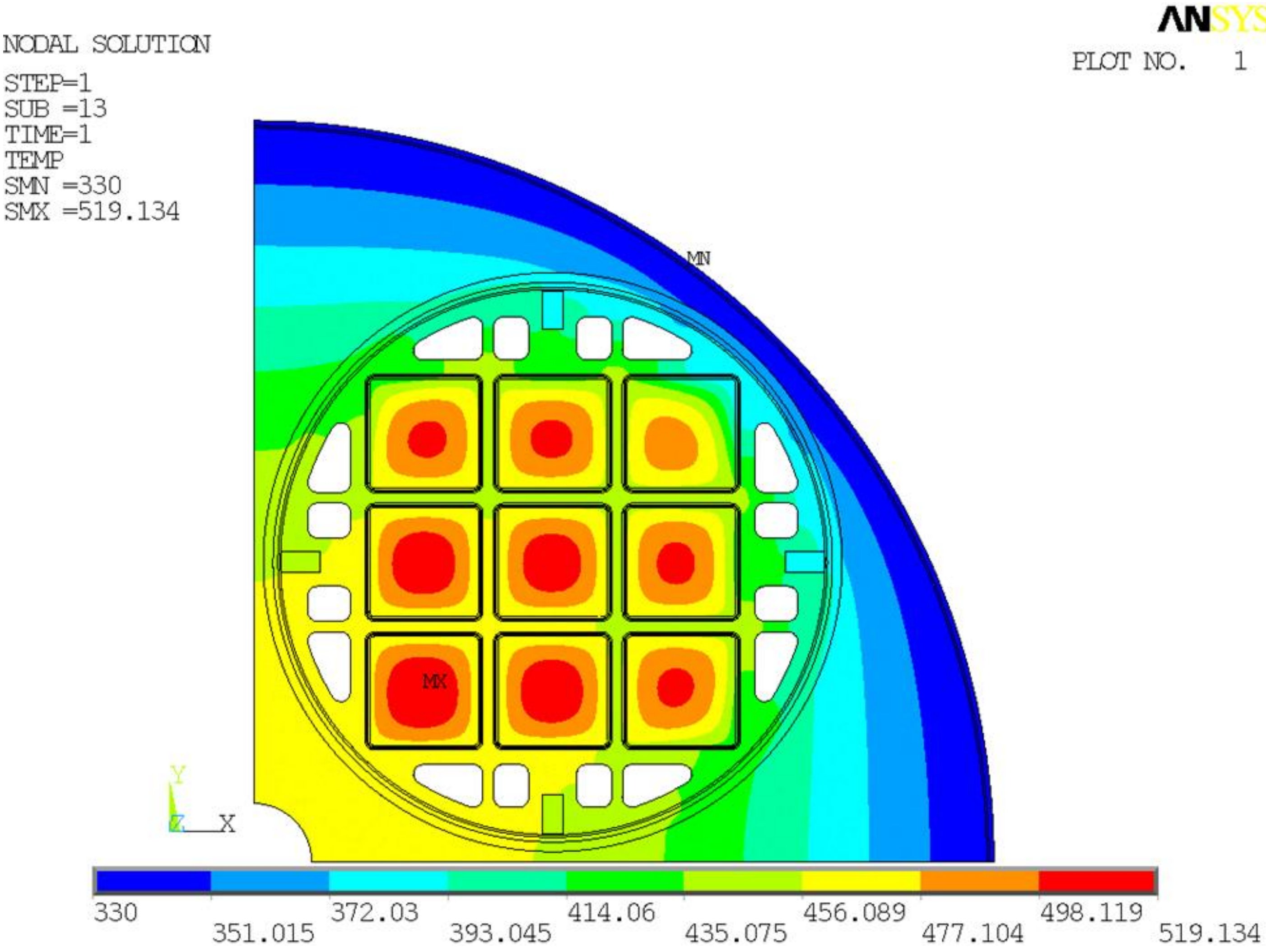


Figure 4-62. Basket and Assembly Materials Temperature Distribution for Four BWR STADs in Transfer Cask 8.0 kW/STAD Heat Generation – 330 °F Cask Cavity Wall Temperature

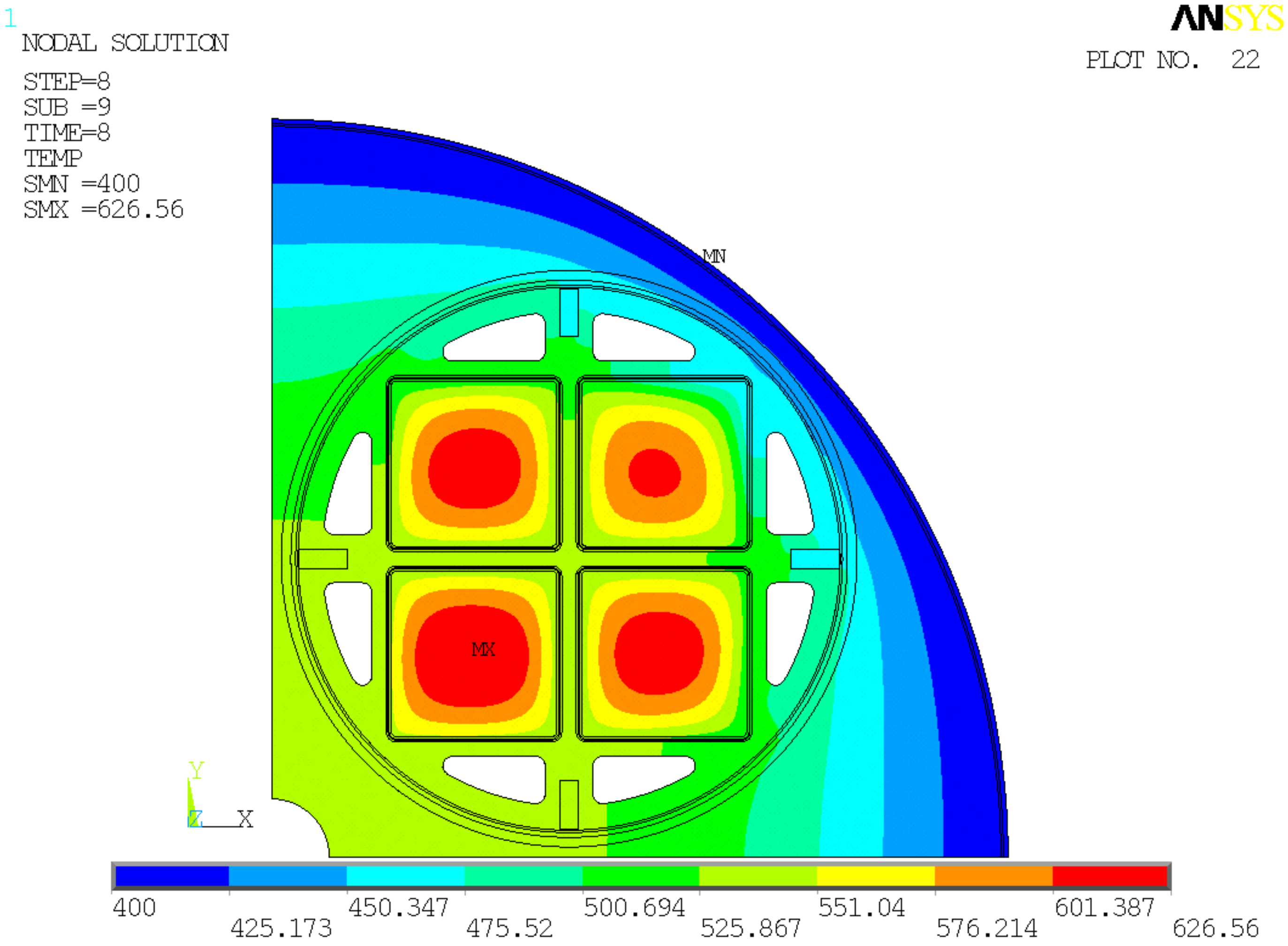


Figure 4-63. Basket and Assembly Materials Temperature Distribution for Four PWR STADs in Transfer Cask
8.0 kW/STAD Heat Generation - 400 °F Cask Cavity Wall Temperature

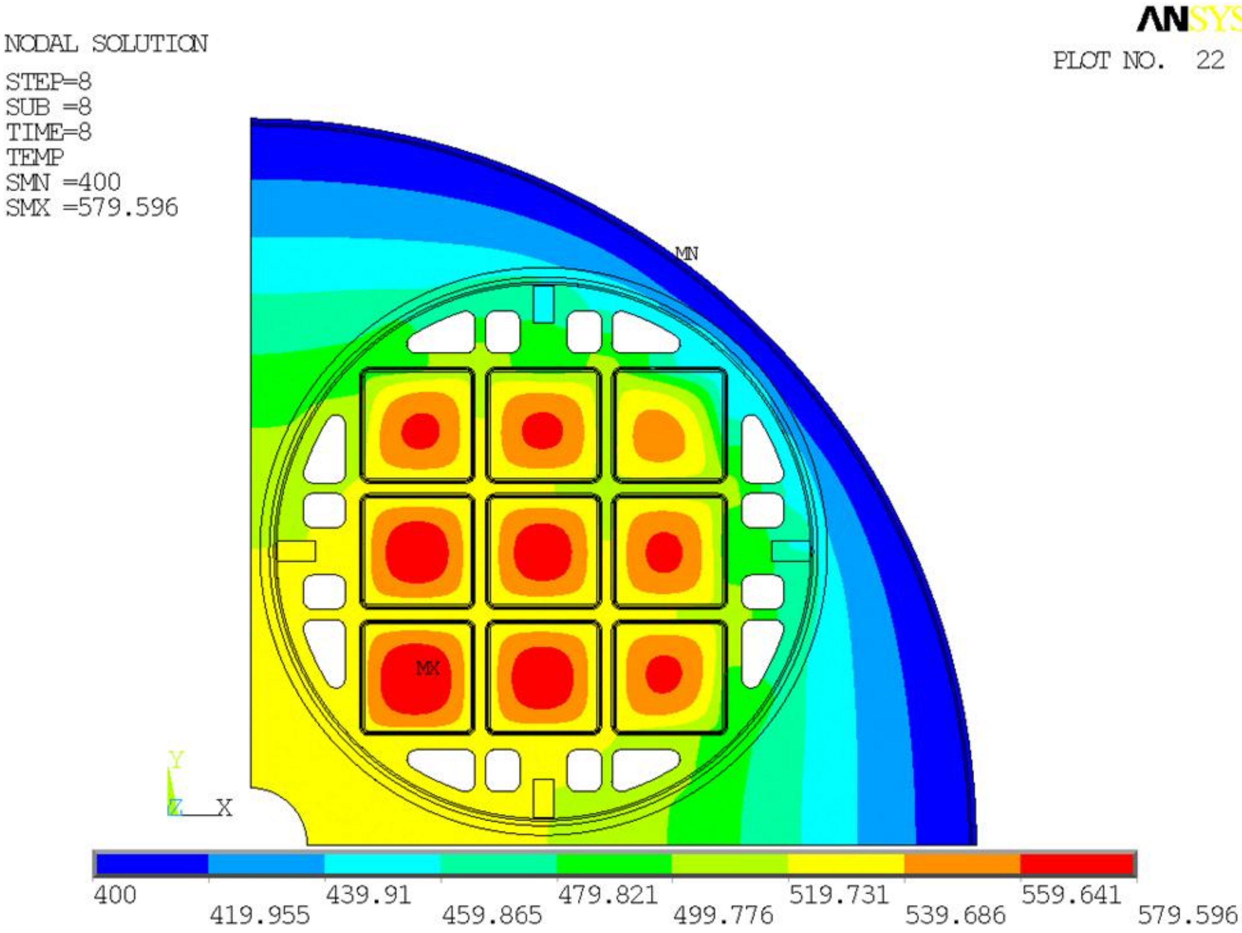


Figure 4-64. Basket and Assembly Materials Temperature Distribution for Four BWR STADs in Transfer Cask 8.0 kW/STAD Heat Generation - 400 °F Cask Cavity Wall Temperature

4.3.3 Shielding Analyses

Shielding analyses were performed on the cask and basket designs described in Section 4.1, using the industry-standard MCNP5 Monte Carlo code. Shielding analyses were performed for STADs inside a transportation cask, a transfer cask, and a storage cask. In each case, the cask contained a payload of 4 STADs. The PWR STAD contained four PWR assemblies, and the BWR STAD contained nine BWR assemblies.

The objective of the transportation shielding analyses is to determine the PWR and BWR assembly cooling times required to produce cask exterior dose rates that meet all 10 CFR 71 regulatory limits, as a function of assembly burnup level. The dose rate limits are 200 mrem/hr at any point on the accessible package surface and 10 mrem/hr at any point on a vertical plane two meters from the side of the package and/or conveyance (i.e., transport vehicle, such as a rail car).

The transfer and storage cask shielding analyses modeled bounding, 62.5 GWd/MTU, 5 year cooled fuel assemblies in every STAD-interior location. Peak dose rates were determined on the exterior surfaces of the transfer and storage casks.

4.3.3.1 Shielding Model Configurations

Illustrations of the transport, transfer and storage cask shielding models are shown in Figure 4-65 through Figure 4-73. In all cases, the shielding analyses used a quadrant (one quarter) model of the overall cask configuration. Thus, the (quadrant) models contained a single STAD. Reflective boundaries on the quadrant interior boundaries (i.e., the X and Y axes) were employed to effectively model the entire cask with a four STAD payload. The radial and axial shielding thicknesses modeled in the shielding analyses are shown in Table 4-23

For all the shielding analyses, the assembly materials were “smeared” into a homogenous mass that fills a square cross-sectioned area that extended out to the inner surfaces of the outermost guide tube walls within the STAD interior basket. The source region was divided into four axial sections, representing the assemblies’ fuel zone, gas plenum zone, and top and bottom nozzle zones. Each of the four axial zones had a different homogenous material composition. The modeled fuel zones (which contain the modeled fuel gamma or neutron source) were 144 and 150 inches high, for PWR and BWR fuel, respectively.

The modeled densities within each axial zone were calculated based on the material masses present in one assembly, divided by the volume of the interior of one guide tube. Those material densities were modeled over the entire source region, i.e., were extended over the regions occupied by other components such as guide tube walls or borated stainless steel neutron absorber plates. As the homogenized assembly material densities were far lower than the densities of those other STAD basket components (i.e., far lower than the ~8 g/cc density of steel) this modeling approach is conservative.

A single 0.06-inch thick steel wall, that represents the outer walls of the outer guide tubes, was modeled around the entire (square cross-sectioned) source area. Outside the source region, the STAD radial shell and top and bottom plates were rigorously modeled. Void was modeled between the source/guide tube region and the STAD radial shell. Thus, the spacer plate edge materials that occupy that region were conservatively neglected. Also, outside the STADs, the steel spacer plates of the carrier (which is present during transport, transfer and storage) were conservatively neglected (and replaced by air).

Neglecting the STAD interior and carrier spacer plates probably resulted in significant overestimation of peak package end gamma dose rates, as it results in axial gamma streaming within the STAD interior edge region and between the STADs that would actually have been significantly attenuated by those spacer plates. (The spacer plates would not significantly reduce cask side dose rates.) Despite this, the calculated package end gamma dose rates are extremely low.

Table 4-23. Modeled Cask Configuration Shielding Thicknesses (inches)

Component	Material	Thickness
STAD Basket Outer Guide Tube Walls	Stainless Steel	0.06
STAD Radial Shell	Stainless Steel	0.25
STAD Bottom Plate	Stainless Steel	2.0
STAD Lid	Stainless Steel	9.0
STAD Carrier Top Shielding Plate	Stainless Steel	9.0
STAD Carrier Bottom Plate	Stainless Steel	4.0
Transport Cask Inner Liner	Stainless Steel	1.25
Transport Cask Radial Lead Shield	Lead	4.25
Transport Cask Outer Shell	Stainless Steel	2.25
Transport Cask Radial Neutron Shield	NS-4FR[1]	6.0
Transport Cask Radial Neutron Shield Structure	Stainless Steel	0.25
Transport Cask Bottom Plate	Stainless Steel	9.0
Transport Cask Top Lid	Stainless Steel	6.0
Impact Limiter End Steel Shielding	Stainless Steel	2.0
Transport Model Total Top Steel[2]	Stainless Steel	17.0
Transport Model Total Bottom Steel[3,6]	Stainless Steel	17.0
Impact Limiter Side Wood	Redwood	17.25
Impact Limiter End Foam	Polyurethane	28.563
Transfer Cask Inner Shell	Carbon Steel	0.75
Transfer Cask Radial Lead Shield	Lead	4.0
Transfer Cask Radial Neutron Shield	NS-4FR[1]	4.0
Transfer Cask Outer Shell	Carbon Steel	1.25
Transfer Cask Bottom Doors	Carbon Steel	5.0
Transfer Model Total Top Steel[4]	Carbon Steel	9.0
Transfer Model Total Bottom Steel[5,6]	Carbon Steel	11.0
Storage Cask Radial Inner Liner	Carbon Steel	3.0
Storage Cask Radial Concrete	Concrete	26.5
Storage Cask Top Lid Steel[7]	Carbon Steel	1.0
Storage Cask Top Lid Concrete	Concrete	5.75

Notes:

1. The transport cask NS-4FR neutron shield material also contains copper (heat transfer fins) at a 3.1% volume fraction. The same material mixture is modeled in the transfer cask analysis.
2. This overall thickness includes the 9.0-inch STAD lid (or carrier top plate), the 6.0-inch cask lid, and the 2.0-inch impact limiter end steel.
3. This overall thickness includes the 2.0-inch STAD bottom plate, the 4.0–inch carrier bottom plate, the 9.0-inch cask bottom plate, and the 2.0-inch impact limiter end steel.
4. The modeled overall thickness consists solely of the 9.0-inch STAD lid (or carrier top plate).
5. This overall thickness includes the 2.0-inch STAD bottom plate, the 4.0–inch carrier bottom plate, and the 5.0-inch transfer cask bottom doors.
6. The 2.0-inch STAD bottom plate steel is not present between STADs. Thus, some radiation will stream around the STAD bottom plates.
7. This includes a 0.25-inch bottom plate and a 0.75-inch top plate.

4.3.3.1.1 Transportation Cask Configuration

The transportation cask shielding model is illustrated in Figure 4-65 through Figure 4-67. The shielding thicknesses associated with the cask configuration are listed in Table 4-23.

For the transportation cask analyses, the modeled cask and impact limiter configurations and materials are similar to that of the transport cask configuration defined in the DOE Task Order 17 bare fuel cask report[19]. While the configurations are qualitatively the same, various parameters like cavity diameter and length, and shielding thicknesses are different. The STAD cask has a larger modeled cavity diameter of 78 inches. The radial lead shield extends 3.0 inches past the top and bottom ends of the STAD interior cavity (i.e., the source region). In the neutron shield region, neutron shield material and the copper fins were "smeared" for the model into a homogenous mixture that fills the annular neutron shield region. The distances between the ends of the neutron shield structure and the top and bottom impact limiters was the same as that modeled for the Task 17 cask.[19] As with the Task Order 17 cask, the impact limiter sides (which extend out from the cask body to a diameter of 128 inches) consisted of 0.5 g/cc redwood, while 0.2 g/cc polyurethane foam was modeled for the impact limiter ends and corners (as illustrated, in purple, in Figure 4-66 and Figure 4-67).

The modeled radial transportation cask configuration consisted of a 1.25-inch thick inner liner, a 4.25-inch thick lead shield, a 2.25-inch thick outer shell, a 6.0-inch thick NS-4FR neutron shield, and a 0.25-inch thick steel neutron shield structure shell. The overall thickness of the radial shielding structure is limited to 14 inches, based on the cask cavity diameter and the needed impact limiter stroke (with an impact limiter outer diameter that is limited to 128 inches). The thicknesses listed above for the radial steel shells are necessary for structural reasons. That leaves a total 10.25 inches for lead and neutron shielding. Infinite height scoping analyses showed that, within the overall thickness constraint, 4.25 inches of lead and 6.0 inches of neutron shielding yielded minimum cask side exterior dose rates. Note that these dimensions are slightly different from those shown in Section 4.1 (which have 1/4-inch more lead and ¼-inch less neutron shield). As the modeled shielding configuration has the same overall thickness and a lower weight, there shouldn't be any problems associated with changing the Section 4.1 radial shielding configuration during the final design phase, to match the optimum configuration analyzed in this section.

A total of 17 inches of steel was modeled above and below the source region in the STAD transport cask configuration. On the cask top end, that overall thickness is the sum of the 9.0 inch thick STAD lids (and the 9.0-inch thick carrier top plate that lies between the STAD lids), the 6.0-inch thick transport cask lid, and an additional two inches of steel shielding that are placed on the impact limiter end. On the cask bottom, that total thickness is the sum of the 2.0-inch STAD bottom plate, the 4.0-inch carrier bottom plate, the 9.0-inch cask bottom plate, and 2.0 inches of additional steel shielding on the bottom impact limiter end. Between the STADs, the overall shielding is 15.0 inches, and some radiation will stream around the 2.0-inch steel STAD bottom plates.

A 9.0-inch-high, 3/8-inch wide annular gap exists between the STAD lids and the carrier top shielding plate (that lies between the STAD lids). Also, a 0.5 inch radial gap exists between the edge of the carrier top and bottom shield plates and the inside of the cask cavity. These gaps were not modeled in the transportation shielding analysis as it was assumed that any gamma radiation streaming up those gaps would be greatly attenuated by the 8.0 inches of cask top lid and impact limiter steel shielding, and would be largely diffused by the time it reached the (distant) top impact limiter end surface, where the 200 mrem/hr 10 CFR 71 dose rate limit applies. Also (as shown in Section 4.3.3.4), the gamma dose rates on the top and bottom impact limiter surfaces are extremely small; orders of magnitude lower than the 200 mrem/hr limit. In the case of the gap between the carrier top and bottom plates and the cask inner liner, radiation is not traveling at an angle parallel to the gap, since the STAD interior source zones lie a significant distance from the cask cavity edge (as shown in Figure 4-66 and Figure 4-67).

The analyses did not model any penetrations in the radial lead or neutron shielding, such as those that may occur around top trunnions or bottom rotation trunnions. Analyses presented for a very similar transport cask configuration in the DOE Task Order 17 report[19] showed that any significant shielding penetrations cause significant increases in cask side dose rates and result in dose rates in excess of regulatory limits. Thus, any significant penetrations will have to be "patched" with local shielding, either in the cask interior or outside the cask, over the penetrations. Those conclusions are assumed to be applicable for a transport cask containing STADs as well.

A large volume of air was modeled around the cask to address air scattering effects. Within that air mass, a cylindrical surface is defined two meters off the side surface of the (128 inch diameter) impact limiters (i.e., a cylinder with a radius of 362.56 cm). This conservatively represents the vertical surface (2 meters from the "conveyance") where the 10 mrem/hr dose rate limit applies. Dose rates calculated on the cylindrical surface would correspond to the dose rates on the vertical surface at the elevation where peak dose rates would occur (directly across from the cask centerline).

Dose rates were tallied on that cylindrical surface, as well as the 128 inch diameter surface that corresponds to the radial surfaces of the impact limiters and personnel barrier (i.e., the radial surfaces of the "package", as defined by regulation). Dose rates were also calculated on the package ends (i.e., the top and bottom end surfaces of the impact limiters). Finally, dose rates were tallied on the radial surface of the cask body, between the impact limiters. The radial surfaces were subdivided into a large number of axial tally segments, to determine the axial dose rate profile on those surfaces, and to determine the peak dose rates that occur on those surfaces. Similarly, the axial (end) surfaces were subdivided into several radial segments.

The calculated peak cask side dose rates account for azimuthal variations in cask exterior dose rates that occur due to the azimuthal asymmetries in the within the cask interior (i.e., the square cross-section source region within each STAD and the STADs themselves, which do not azimuthally fill the cask interior). The calculated peak dose rates also account for potential variations of the azimuthal orientation of the STAD and source region within the cask (i.e., potential rotation of the STADs within the cask).

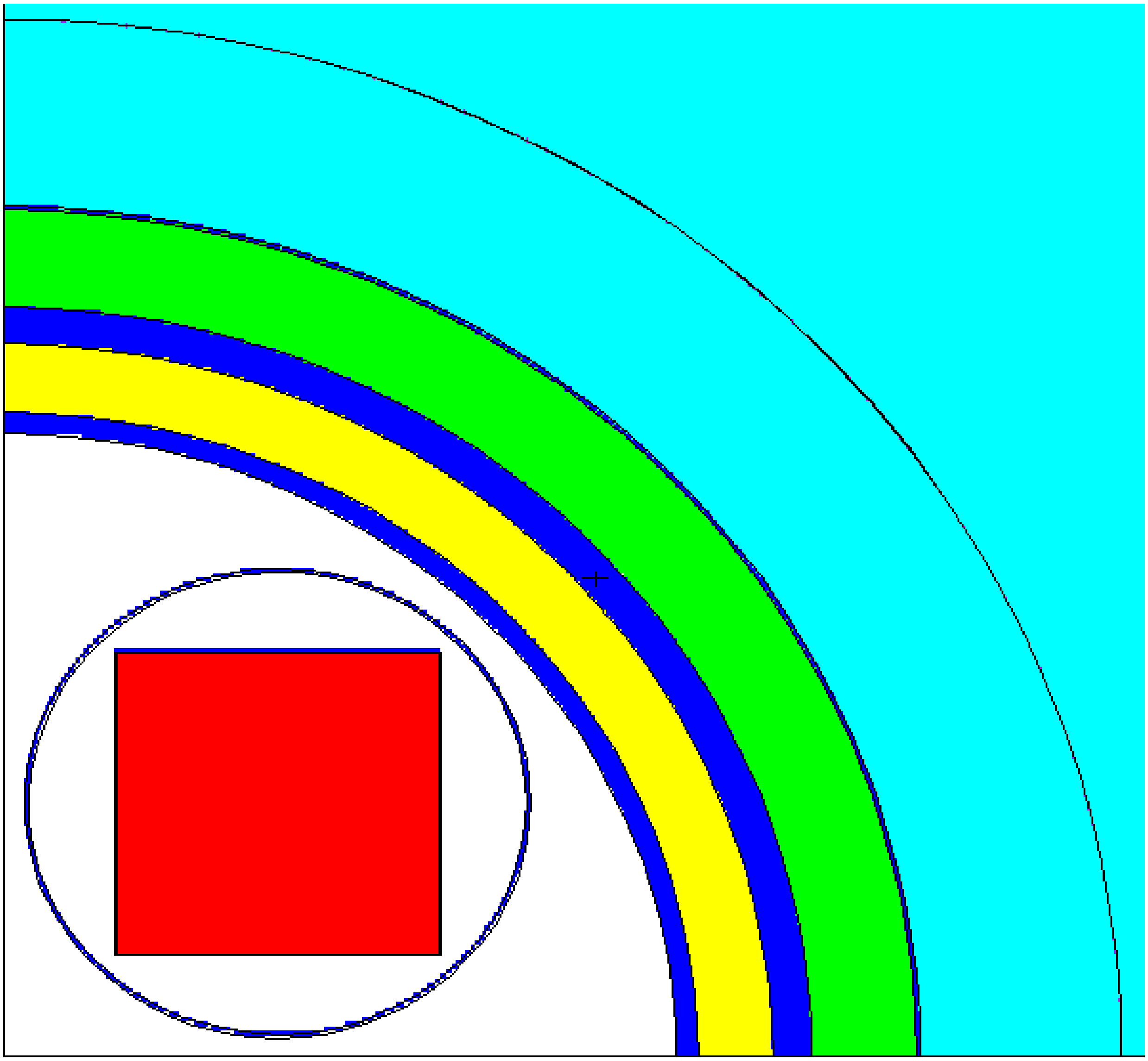


Figure 4-65. Transport Cask Shielding Model – Horizontal Cross-Section View

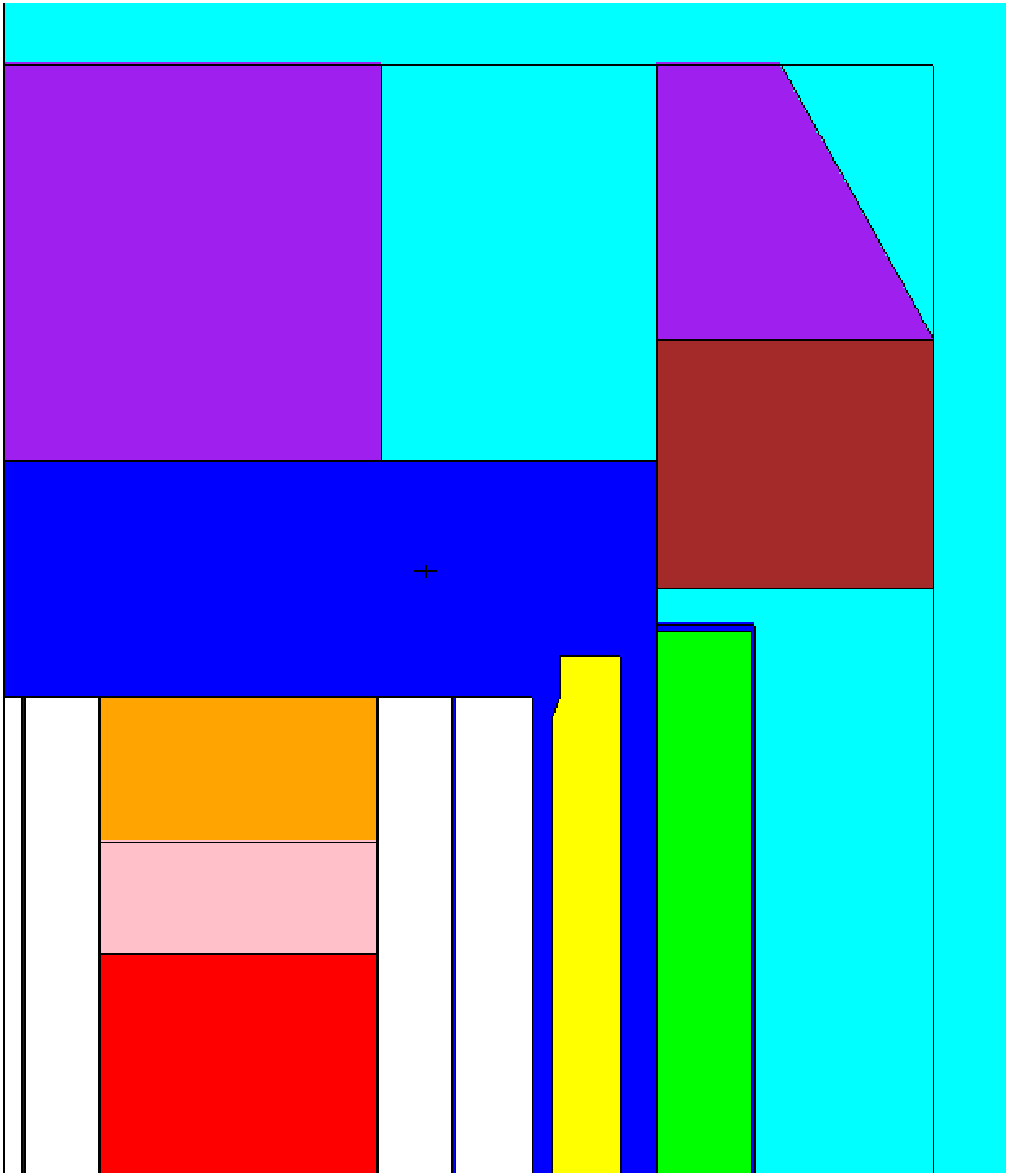


Figure 4-66. Transport Cask Shielding Model – Vertical Chord-Section View – Top End

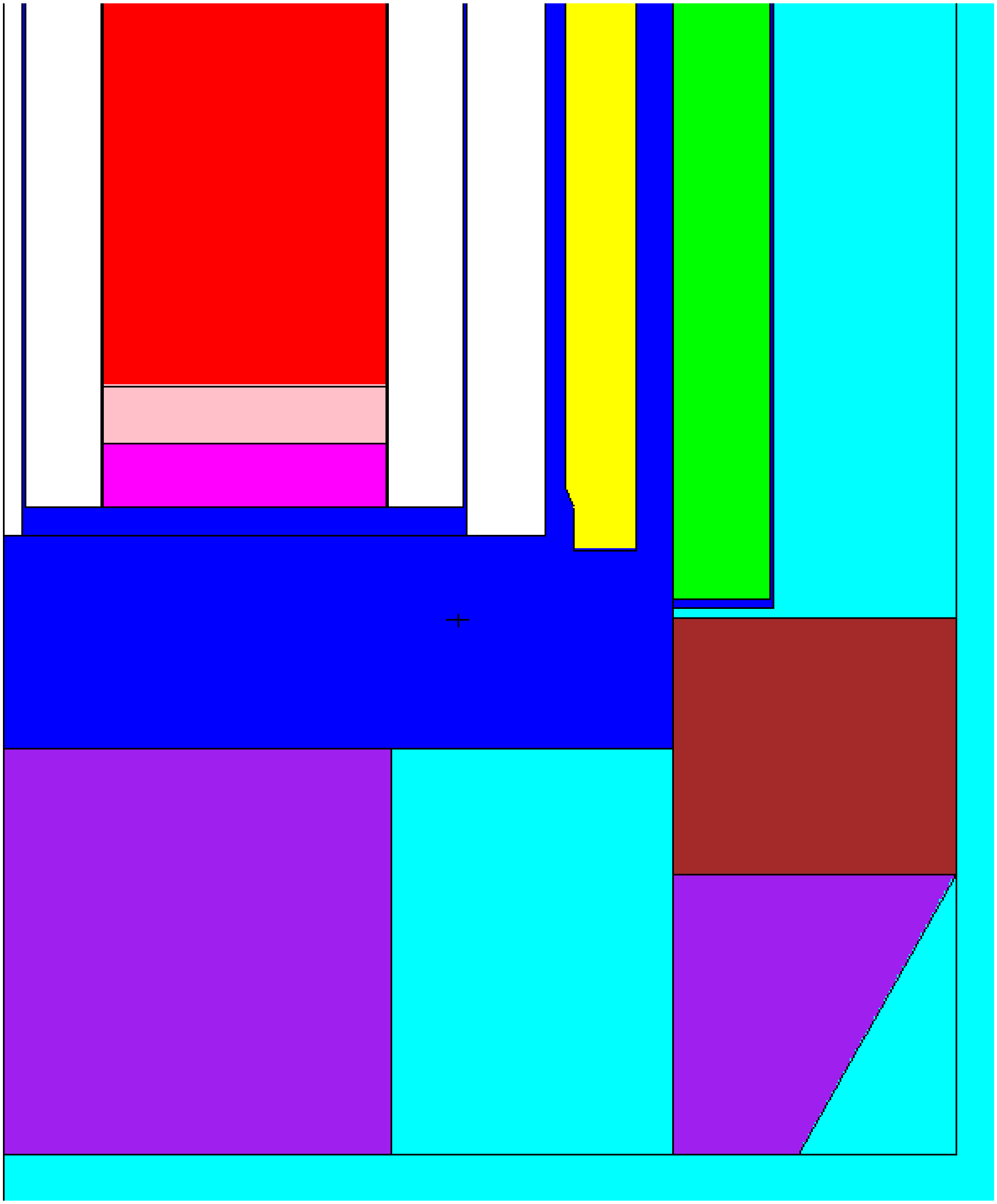


Figure 4-67. Transport Cask Shielding Model – Vertical Chord-Section View – Bottom End

4.3.3.1.2 Transfer Cask Configuration

The transfer cask shielding model is illustrated in Figure 4-68 through Figure 4-70. The shielding thicknesses associated with the transfer cask configuration are listed in Table 4-23.

The transfer cask (described in Section 4.1) has a 0.75-inch thick steel inner radial shell and a 1.25-inch thick steel outer radial shell. Between these shells lie a 4.0-inch thick radial lead shield and a 4.0-inch thick NS-4FR neutron shield. The transfer cask also has 5.0-inch thick steel doors on the bottom. It is open on the top (and thus provides no additional top end shielding).

Thus, there is a total of 11 inches of steel shielding on the transfer cask bottom end, including the 2.0-inch STAD bottom plate, the 4.0-inch carrier bottom plate, and the 5.0-inch thick transfer cask doors. Between the STADs, there is 2.0 inches less steel shielding (for radiation streaming downward between the STADs). On the top end, there is a total of 9.0 inches of shielding, which consists of the 9.0-inch STAD top lids (or the carrier's 9.0-inch top plate, between STADs).

The transfer cask shielding analyses modeled the 3/8-inch annular gap between the STAD lids and the carrier top plate, and evaluated the impacts of gamma streaming up those gaps.

Dose rates were tallied on the transfer cask side surface and the bottom surface of the transfer cask bottom steel doors. As the transfer cask is open at the top, dose rates were also tallied on the top surfaces of the STAD lids and the carrier top shielding plate. Dose rates immediately above the annular gaps between the STAD lids and the carrier top shielding plate were also tallied.

For some of the loading operations that occur when the STADs (and carrier) lie inside the transfer cask, water will be present within the STADs (and between them) in order to reduce doses. Therefore, dose rates were calculated for a wet and dry transfer configuration. In the dry configuration, no water was present anywhere within the transfer cask interior (either inside the STADs or between them). In the wet configuration, water was assumed to fill all non-occupied volumes within the transfer cask cavity, both inside the STADs and between the STADs. As the STAD interior and carrier spacer plates were (conservatively) not modeled, their volumes were also modeled as water in the wet case. For the four source zones that contain a homogenous material mixture that represents the fuel zone, plenum zone, top nozzle zone and bottom nozzle zone of the assemblies, a water density was determined based on estimated free volume fractions for each assembly region, and was added to the overall material mixture for the wet case.

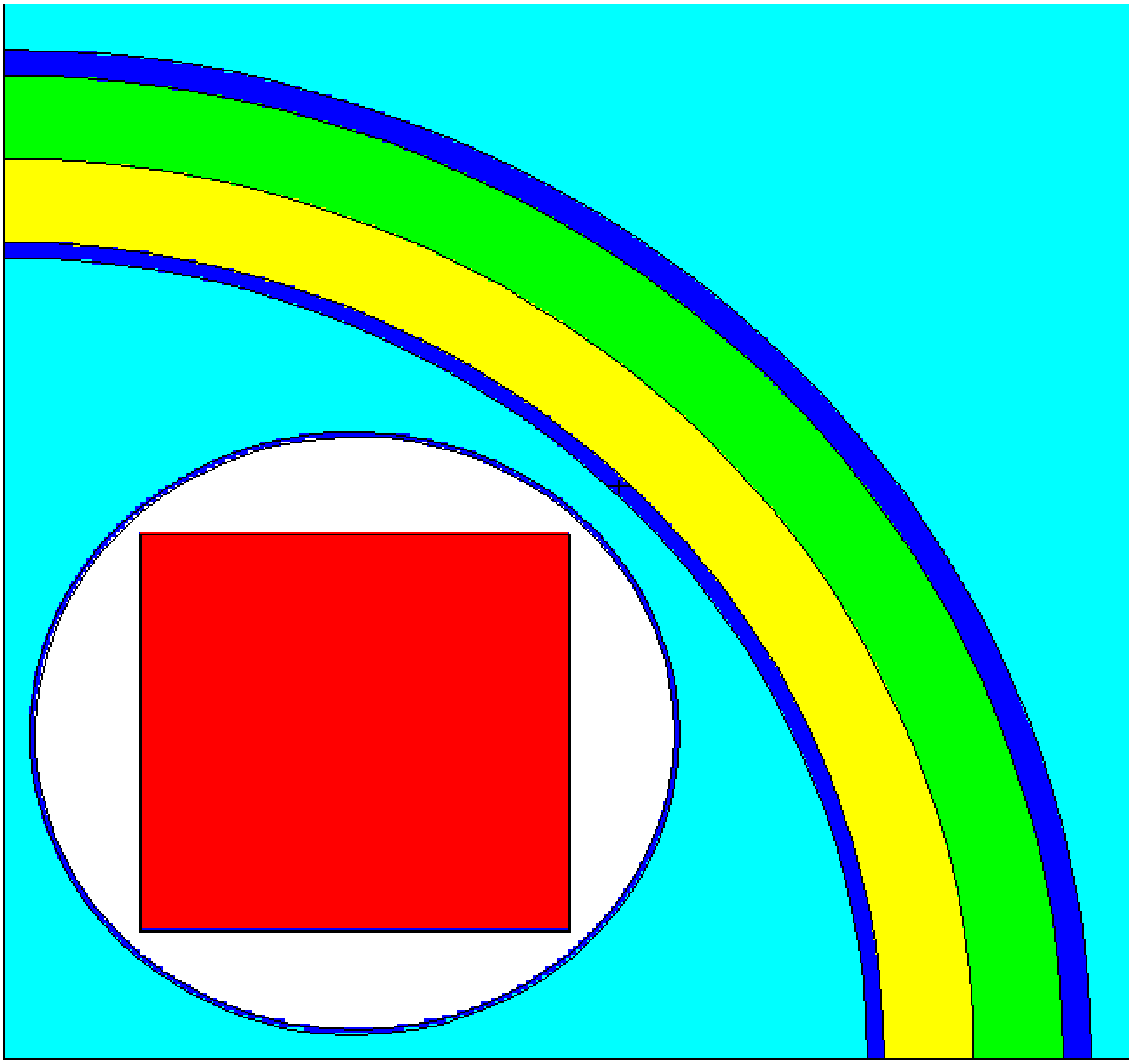


Figure 4-68. Transfer Cask Shielding Model – Horizontal Cross-Section View (air filled configuration)

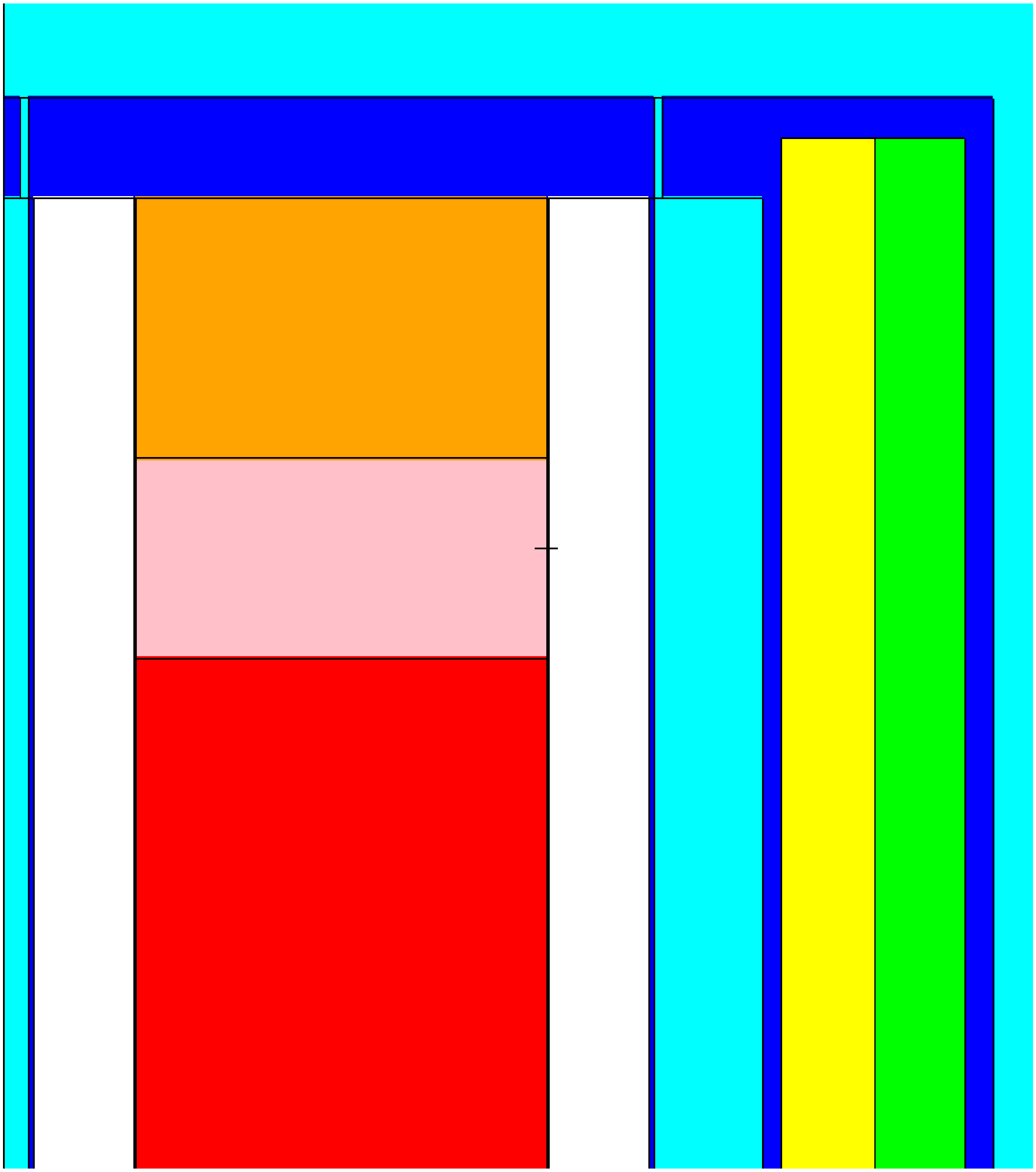


Figure 4-69. Transfer Cask Shielding Model – Vertical Chord-Section View – Top End

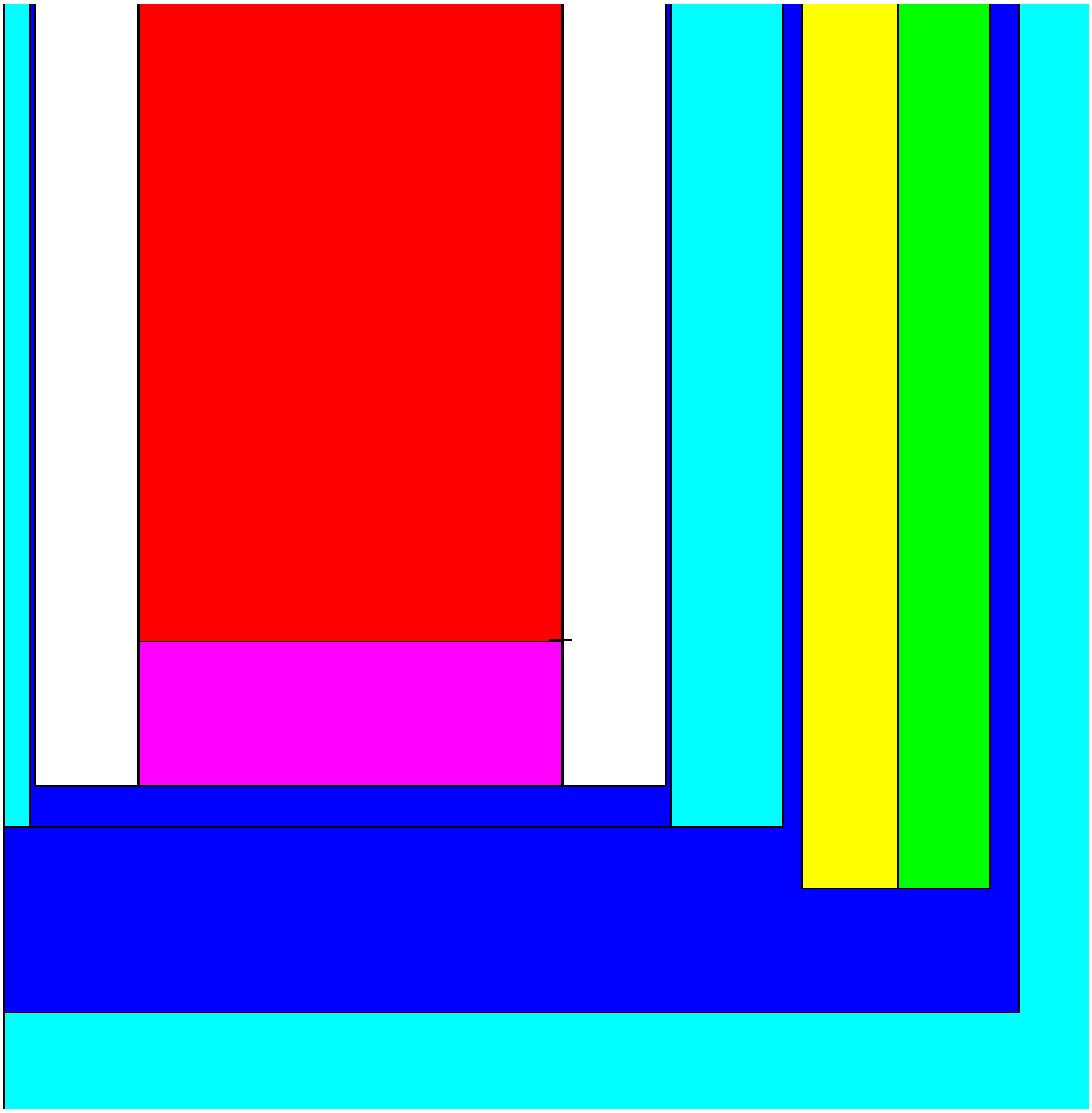


Figure 4-70. Transfer Cask Shielding Model – Vertical Chord-Section View – Bottom End

4.3.3.1.3 Storage Cask Configuration

The storage cask shielding model is illustrated in Figure 4-71 through Figure 4-73. The shielding thicknesses associated with the storage cask configuration are listed in Table 4-23.

The storage cask (described in Section 4.1) has a cavity diameter of 85 inches, a 3.0-inch thick inner steel liner, and 26.5 inches of radial concrete (which results in a cask outer diameter of 144 inches). A 14.25 inch high air-filled gap lies above the top of the STADs and carrier top plate steel. Above that is a lid that consists of a 0.25-inch steel bottom plate, 5.75 inches of concrete, and a 0.75 inch steel top plate.

A representative storage cask configuration consisting of a thick steel bottom plate and a thick (~2 foot) layer of concrete were modeled at the bottom end of the cask. The cask bottom configuration does not significantly impact the calculated dose rates, as dose rates on the bottom end were not tallied. (The end configuration only has a small impact related to scattering effects.)

The inlet and outlet duct structures of the storage cask were not modeled (and have not been designed as part of this task order). The inlet and outlet vent configurations will be similar to those employed by existing storage cask designs, and the (localized) inlet and outlet duct dose rates are expected to be similar to those of other casks. It should be noted that the only regulatory (10 CFR 72) dose rate limit governing storage casks is a 25 mrem/year limit at the plant site boundary. Due to the small affected area, the localized dose rates at the cask inlet and outlet vents do not significantly impact the annual dose from the cask array at the site boundary. The site boundary dose is primarily a function of the average dose rates over the storage cask side and (to a lesser extent) top surfaces.

It should also be noted that the difference between the four-STAD configuration and typical large canister configurations will not lead to any difficulties with respect to inlet/outlet vent design and radiation streaming. The STAD source regions are completely enveloped by the source region of a large canister. (i.e., large canister configurations have source material in all locations that the four STADs do, along with locations where the STADs do not). Thus, no streaming issues (from source at a specific location within the cask interior) will arise for the four STADs that would not arise for the large canister configuration. In fact, designing an inlet/outlet vent configuration should be easier for the four STAD configuration (and should result in lower inlet/outlet duct dose rates) because the STAD source zones only occupy parts of the cask interior. For example, inlet and outlet ducts could be placed at the azimuths that lie between the four STADs, resulting in significantly reduced vent dose rates (assuming that the azimuthal orientation of the STAD carrier within the cask can be controlled).

As with the transportation cask analyses, the 3/8-inch annular gaps between the STAD lids and the carrier top shielding plate were not modeled in the storage cask analyses. Gammas streaming up those gaps will be attenuated by the thick storage cask top shield lid, and will spread out over the distance between the carrier top plate and the storage cask lid top surface. As personnel will not be in the immediate vicinity of the section of the cask top lid surface directly over the gaps, occupational exposure from localized peaking in the storage cask lid dose rate is not a significant concern. Dose rates at the site boundary are affected by the overall average dose rate on the cask top surface, as opposed to local peak dose rates. The 3.0 inch wide, annular ventilation duct was rigorously modeled by the shielding analysis. Thus, the effects of radiation streaming up the ventilation duct were accounted for in the analyses.

Dose rates were tallied on the side (radial) and top surfaces of the storage cask. Peak dose rates were calculated on both the side and top surfaces. On the cask top, the surface average dose rate was also calculated (as variations in the cask top surface dose rate have no effect on dose rates far away from the cask, e.g., at the site boundary). As cask side dose rates do not vary significantly, the side surface average dose rate should not be significantly less than the calculated peak dose rate.

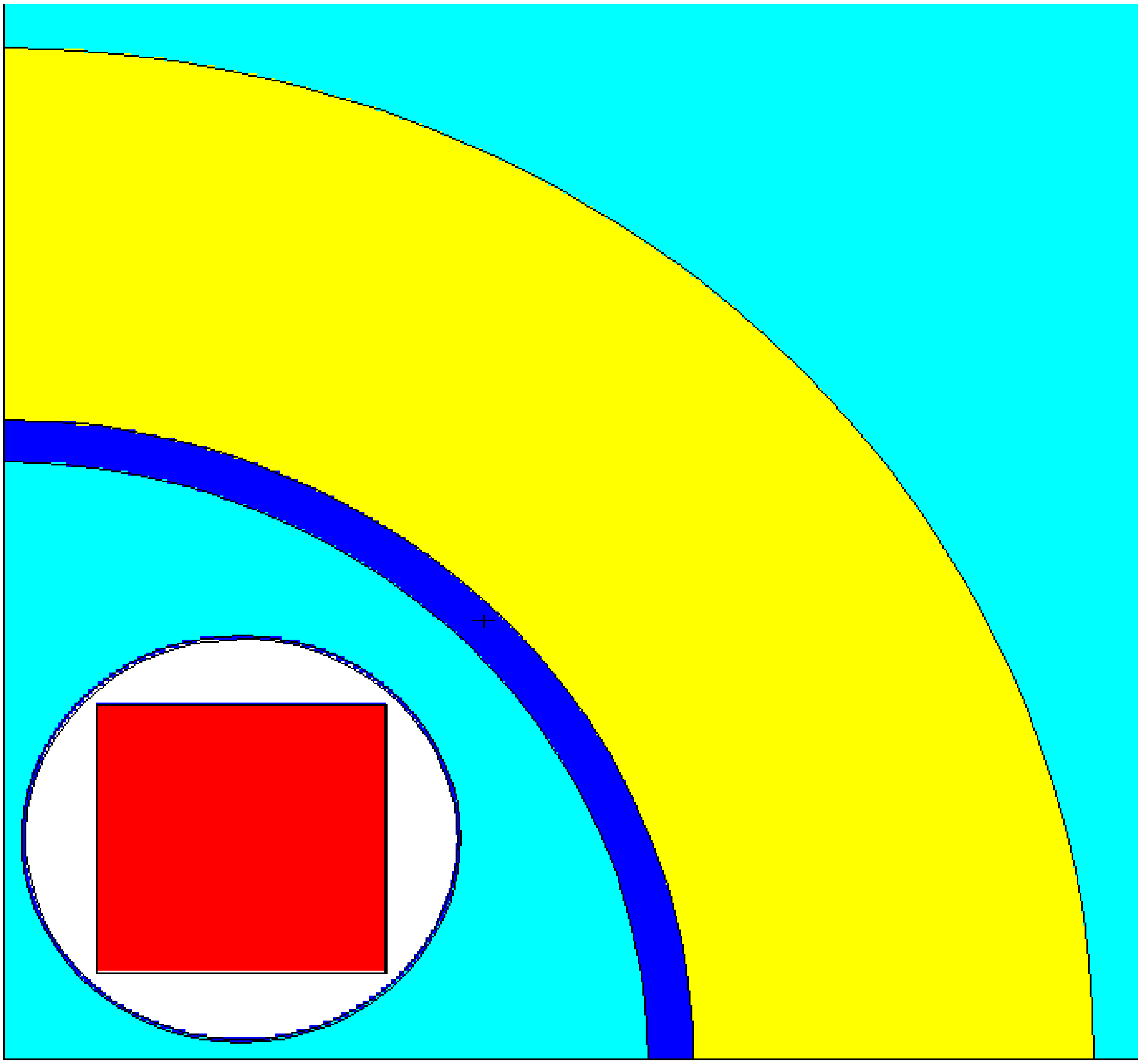


Figure 4-71. Storage Cask Shielding Model – Horizontal Cross-Section View

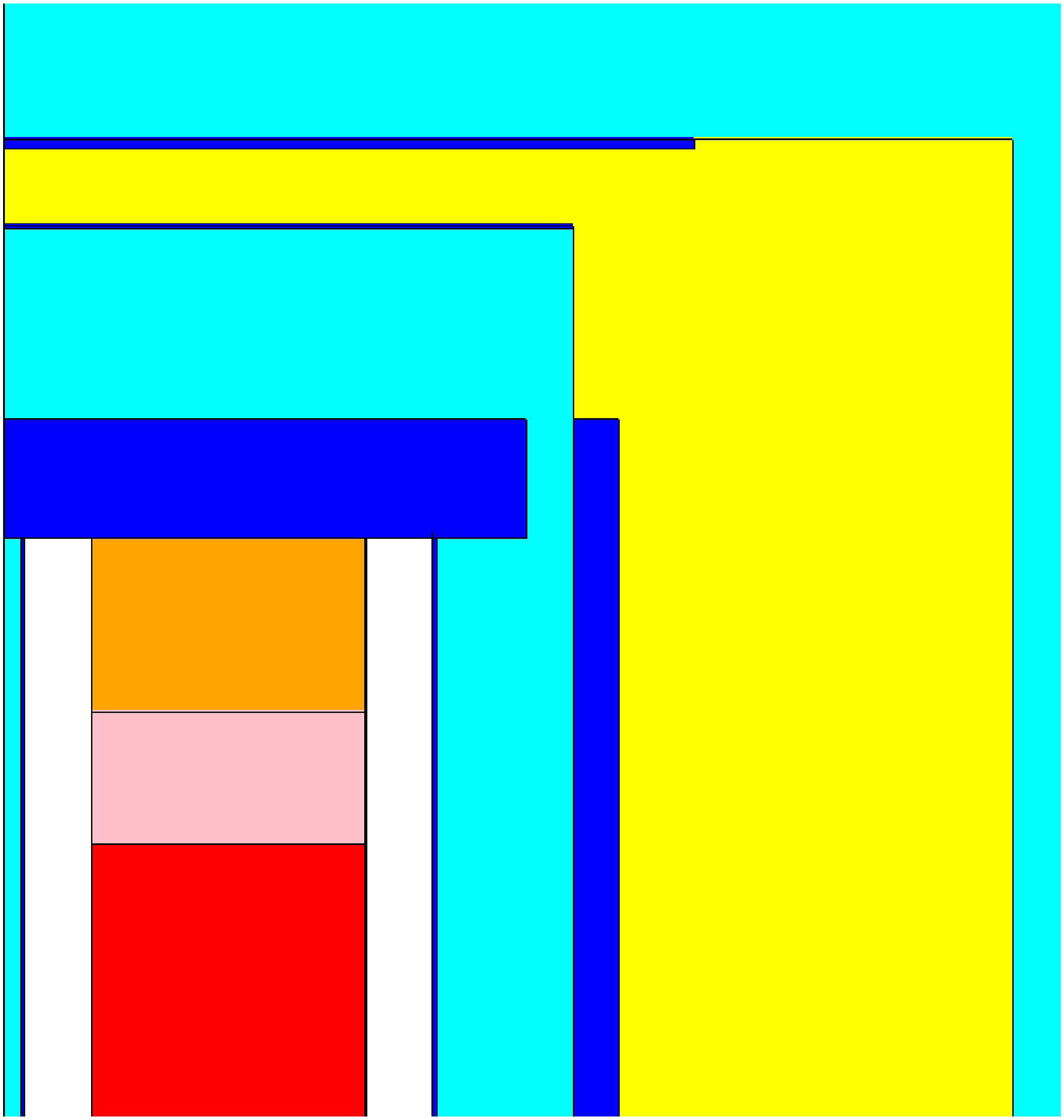


Figure 4-72. Storage Cask Shielding Model – Vertical Chord-Section View – Top End

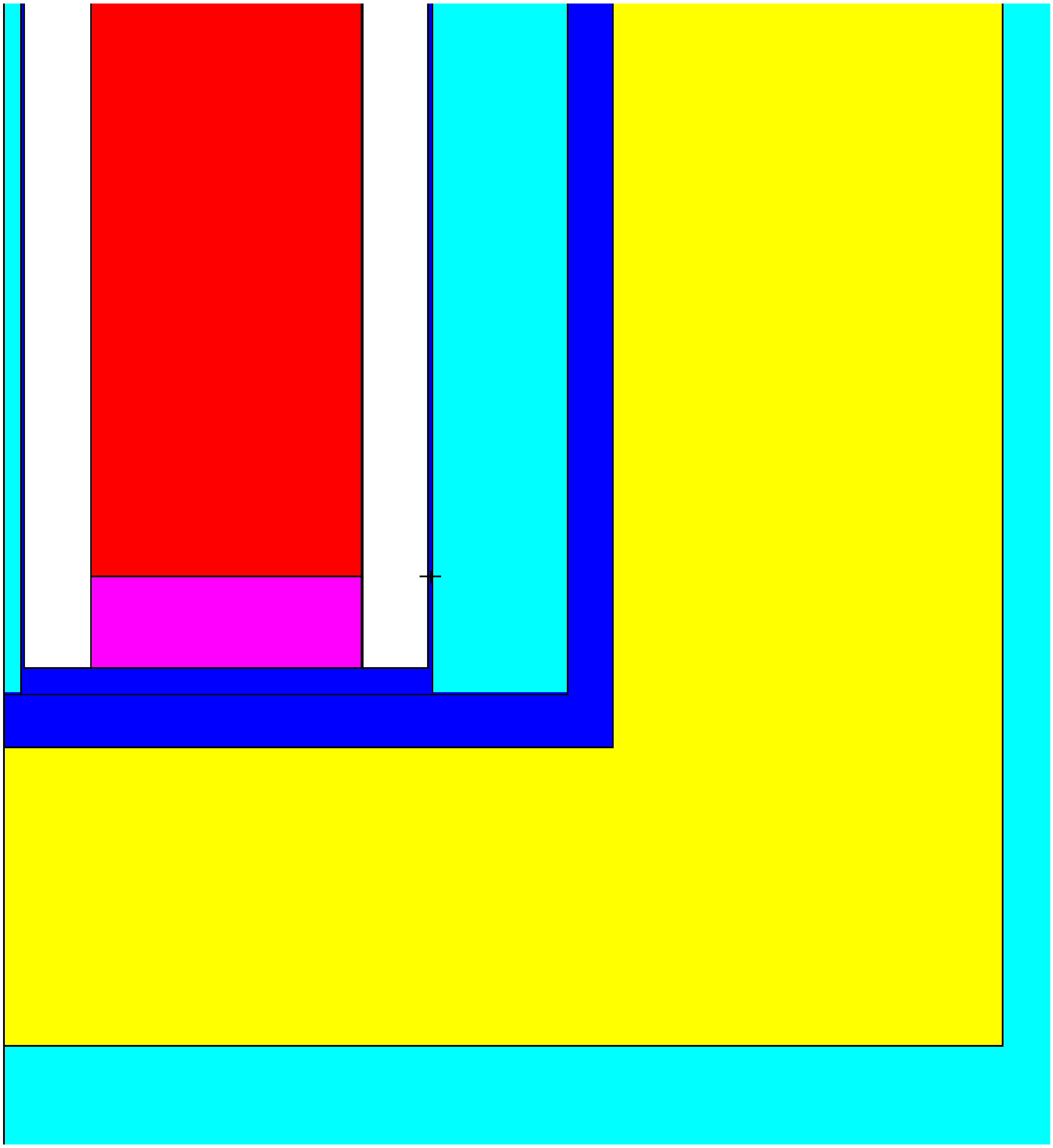


Figure 4-73. Storage Cask Shielding Model – Vertical Chord-Section View – Bottom End

4.3.3.2 Source Strength Determination

ORIGEN2 fuel depletion code results were used to determine assembly gamma and neutron source strengths, and heat generation levels, as a function of assembly burnup (GWd/MTU) initial enrichment (w/o U-235) and post-irradiation cooling time (years).

4.3.3.2.1 Determination of Evaluated Fuel Parameters

For the transportation cask shielding evaluations, PWR and BWR assembly burnup levels ranging from 40 GWd/MTU to 62.5 GWd/MTU were evaluated. Scoping evaluations show that lower initial enrichment levels produce higher cask exterior dose rates, for a given assembly heat generation level (in large part due to higher neutron source strengths). Thus, the evaluations modeled lower-bound initial enrichment levels for each evaluated burnup level. The initial enrichment levels modeled for each burnup level are shown in the titles of Table 4-24 through Table 4-37. The US spent fuel demographic data shown in Section 4.3.4 shows that the modeled initial enrichment levels are conservative (low) initial enrichment values for each assembly burnup level.

Once the assembly burnup and initial enrichment level were determined (for each evaluated case), the minimum cooling time that yields cask exterior dose rates within applicable 10 CFR 71 limits was determined.

For the storage and transfer cask shielding evaluations, 62.5 GWd/MTU, 4.1% enriched, 5 year cooled fuel was analyzed, for both PWR and BWR fuel.

It is known from extensive shielding evaluation experience that cask exterior gamma dose rates do not vary significantly with assembly uranium loading (where the per-MTU source strengths remain constant). As the assembly uranium loading (in MTU/assembly) is increased, gamma and neutron source strengths scale up directly with the uranium loading, but increased self-shielding almost entirely offsets the effects of the increased source strengths. Nonetheless, for a given assembly burnup, initial enrichment and cooling time, a higher uranium loading yields slightly higher cask exterior dose rates. Therefore, upper bound uranium loadings of 0.47 MTU/assembly and 0.2 MTU/assembly were modeled for PWR and BWR fuel, respectively.

4.3.3.2.2 Modeled Sources

Once the burnup, initial enrichment and cooling time values for each evaluated case were determined, the corresponding assembly fuel zone gamma and neutron source strengths were determined using ORIGEN2. ORIGEN2 directly outputs energy-dependent gamma source strengths. A Cm-244 spontaneous fission energy spectrum was modeled for the neutron source. The ORIGEN2 gamma and neutron source strengths, which are output on a per MTU of fuel basis, were multiplied by the assembly uranium loadings shown above, and the number of assemblies in the shielding model. As discussed above in Section 4.3.3.1, the shielding models covered one quarter of the overall cask configuration, and thus included a single STAD. Thus, the per-assembly gamma and neutron source strengths were multiplied by modeled payloads of four PWR assemblies and nine BWR assemblies, respectively.

The shielding analyses address the effects of the axial burnup profiles present in the assemblies by directly modeling axially-varying assembly fuel zone gamma and neutron source strengths (i.e., by modeling gamma and neutron source strength profiles). The analyses modeled a PWR axial burnup profile that is bounding for burnup levels over 35 GWd/MTU. A representative profile was also modeled for BWR fuel.

Gamma source strengths from activated assembly metal hardware in fuel, gas plenum bottom nozzle and top nozzle axial zones of the PWR and BWR fuel assemblies were calculated and modeled in the shielding analyses. In each axial zone, the assembly hardware gamma source strength was calculated based on an assumed initial cobalt quantity (present in the assembly before irradiation), and on the level of cobalt activation (i.e., curies of Co-60 per initial gram of cobalt present), which was calculated as a function of assembly burnup, initial enrichment and cooling time.

Cobalt activation levels for the assembly core zone, at the time of assembly discharge, have been calculated in previous licensing evaluations. PWR core Co-60 activation levels are presented as a function of assembly burnup in Table 5.2-6 of the FuelSolutions^{TM} W21 Canister Transportation SAR[20]. Table 5.2-3 of the FuelSolutions^{TM} W74 Canister Transportation SAR[21] shows the BWR assembly core zone for a single burnup level. Comparison of the PWR and BWR values, at similar burnup levels, shows that BWR activation levels are not higher than PWR activation levels. Thus, the burnup-dependent core zone Co-60 activation levels shown in Table 5.2-6 of the W21 canister SAR are applied for BWR fuel as well. Once the initial assembly fuel zone Co-60 activation level, at discharge, is known as a function of assembly burnup (and lower-bound initial enrichment level), the core zone hardware activation level (curies of Co-60 per initial gram of cobalt) can be determined for each assembly burnup and cooling time combination.

Due to reduced neutron fluences, the Co-60 activation levels in the plenum and nozzle regions of the assembly are lower than those that apply in the assembly core (fuel) zone. Activation scaling factors for each PWR and BWR assembly non-fuel axial zone have been determined in previous licensing evaluations, and are presented in the FuelSolutions^{TM} W21 and W74 canister SARs. For the gas plenum region, the scaling factor is 0.2 for both PWR and BWR fuel. For the bottom nozzle zone, the scaling factors are 0.2 and 0.15 for PWR and BWR fuel, respectively. For the top nozzle zone, the scaling factor for BWR fuel is 0.1. For PWR fuel, a scaling factor of 0.1 applies for most assembly top nozzles, but a factor of 0.05 applies for the CE 16×16 assembly top nozzle. This analysis modeled the CE 16×16 top nozzle, since it has the highest initial cobalt

---

[20] Fuel*Solutions*^{TM} W21 Canister Transportation Cask Safety Analysis Report, Revision 3, April 2002, NRC Docket No. 71-9276, BNFL Fuel Solutions Corporation.

[21] Fuel*Solutions*^{TM} W74 Canister Transportation Cask Safety Analysis Report, Revision 3, April 2002, NRC Docket No. 71-9276, BNFL Fuel Solutions Corporation.

content and is the assembly top nozzle that will be closest to the top of the cask cavity (and the top of the lead shield), and thus will yield the highest dose rates around the cask top end.

After the Co-60 activation levels (in curies of Co-60 per initial gram of cobalt) were determined for each of the four PWR and BWR assembly axial zones, the Co-60 activity levels, in curies, were determined by multiplying those activation levels by upper-bound assembly zone cobalt quantities. Assembly axial zone cobalt masses were calculated based on assembly-type-specific stainless steel, Inconel and Zircaloy masses given in DOE (OCRWM) references[22]. Cobalt concentrations of 10 ppm and 800 ppm were assumed for Zircaloy and stainless steel, respectively. A cobalt concentration of 4800 ppm was assumed for Inconel-718, whereas a concentration of 6500 ppm was conservatively assumed for all other types of Inconel.

Cobalt masses of 11 grams and 1.5 grams were assumed for PWR and BWR fuel, respectively. These are upper bound values for modern LWR assemblies (that do not employ large amounts of stainless steel hardware in the assembly core zone). Any (very old) assemblies with higher core zone cobalt quantities will have lower source terms despite the higher cobalt quantities, as they will all have very long cooling times at the time of shipment. For each of the non-fuel axial assembly zones, the highest initial cobalt quantity, that occurs for any assembly type, was conservatively modeled. Thus, hardware zone cobalt quantities from different (bounding) assembly types were conservatively assumed to simultaneously exist. For PWR fuel, the bottom nozzle, plenum and top nozzle zones were assumed to have initial cobalt quantities of 12.76 grams, 7.71 grams, and 39.09 grams, respectively. For BWR fuel, the bottom and top nozzle zones were assumed to have initial cobalt quantities of 3.63 grams and 3.5 grams, respectively. BWR assembly gas plenum zones do not have significant quantities of cobalt-bearing metal.

The available ORIGEN2 reference data, as well as the Co-60 activation level data presented in the Fuel*Solutions*™ canister SARs, covers a burnup range up to 60 GWd/MTU. For the (energy-dependent) gamma source strengths, 62.5 GWd/MTU values were determined through extrapolation of the source term data, and its associated burnup dependence. The neutron source strength was scaled up based on a 4th power dependence of neutron source strength on burnup (which is observed in the existing data). Given the small degree of extrapolation (from 60 to 62.5 GWd/MTU), these extrapolations should not be a source of significant error.

4.3.3.3 Adjustments to Calculated Neutron Dose Rates

Three adjustments were made to the raw, calculated neutron dose rates, which account for sub-critical neutron multiplication within the assemblies, axial burnup profile effects, and neutron streaming through the heat transfer fins present within the cask neutron shield.

---

[22] DOE/RW-0184, "Characteristics of Spent Fuel, High-Level Waste, and Other Radioactive Wastes Which May Require Long-Term Isolation", Appendix 2A, Volume 3 of 6, U.S. Department of Energy, Office of Civilian Nuclear Waste Management, December 1987.

4.3.3.3.1 Sub-Critical Neutron Multiplication

Even in the absence of water within the cask cavity, primary neutron sources can cause fissions within the fuel material, resulting in an increase to the overall neutron source. To estimate the magnitude of this effect, the PWR and BWR STAD criticality models (described in Section 4.3.4) were run with the cask interior water density set to zero.

The primary neutron source strengths calculated by ORIGEN2 were based upon burned fuel material isotopic compositions that were also determined by the code. In the dry criticality models, the modeled fuel isotopic composition was the same isotopic composition (output by ORIGEN2) that the primary neutron source strengths were based upon.

The dry criticality analyses show maximum k_{eff} values of ~0.23 and ~0.20 for the PWR and BWR STAD cases, respectively. The relative increase in neutron source strength, due to sub-critical neutron multiplication, was determined by the equation: $1 / (1-k_{eff})$. Thus, the above dry k_{eff} values correspond to sub-critical multiplication source increase factors of ~1.3 and ~1.25, for PWR and BWR fuel, respectively. The sub-critical neutron multiplication factors calculated for the PWR and BWR four-STAD configurations were somewhat lower than those calculated for large PWR and BWR casks/baskets (such as the bare fuel cask evaluated in the DOE Task Order 17 report[19]), due to the lower amount of MTU in the overall payload, and increased neutron leakage out of the STADs, which were relatively small and spread apart.

Water-filled configurations were evaluated for the transfer cask shielding analyses. Criticality analyses similar to those described above, but with water present within and between the STADs were performed to estimate the sub-critical neutron multiplication factors that were applicable for the wet transfer cask configuration. Those analyses estimated sub-critical neutron multiplication factors of ~2.4 and ~2.0 for the PWR and BWR STADs, respectively.

4.3.3.3.2 Axial Profile Effects

Whereas gamma source strengths scale roughly linearly with fuel burnup level, for a given initial enrichment and cooling time, neutron source strengths scale with burnup in a strong, non-linear fashion. Per-MTU neutron source strengths scale roughly as the burnup to the 4th power. Thus, an axial variation (or profile) in assembly burnup not only changes the axial distribution of the neutron source, but it also increases the overall neutron source for a given assembly-average burnup level (due to the non-linear dependence on burnup). In other words, assembly average burnup does not correspond to assembly-average neutron source strength. Since the assembly neutron source strengths were determined using ORIGEN2 on the basis of the assembly-average burnup level, the overall neutron source strength had to be adjusted upward to account for this effect.

The axial burnup profile modeled for this preliminary shielding evaluation, which is bounding for PWR fuel with burnup levels over 35 GWd/MTU, was also modeled in previous cask licensing evaluations. Thus, the neutron source strength increase factor determined for that profile in those licensing evaluations can be used for these evaluations as well. Based on those previous licensing evaluations, “profile effect” increase factors of 15% and 41% were applied for the PWR and BWR fuel analyses, respectively.

4.3.3.3.3 Neutron Streaming Though Neutron Shield Heat Transfer Fins

Copper plates extend through the radial neutron shielding material from the cask outer shell to the outer radial steel skin (that encases the neutron shield). These plates, or fins, are necessary to transfer heat through the neutron shield material to the ambient environment. The fins are placed at angles relative to the cask surface (as opposed to extending out directly in the radial direction) so that neutrons do not have a direct streaming path. Due to the fact that the neutrons are not all moving in a purely radial direction there is still some streaming effect, however.

Many existing cask system licensing evaluations did not directly (rigorously) model the heat transfer fin configuration within the cask neutron shield region. Instead, the primary shielding analyses “smeared” the fins into the neutron shield material, and modeled the resulting homogenous material throughout the annular neutron shield region (as was done for these shielding evaluations). For this report, a supplementary streaming analyses was performed to estimate the increase in cask exterior radial neutron dose rates that will occur due to the heat transfer fin streaming effect.

Table 5.4-1 of the TS125 transportation cask SAR[23] presents the results of a neutron shield heat transfer fin neutron streaming evaluation that was performed for the TS-125 cask (whose metal heat transfer fin configuration is similar to that of the cask described in Section 4.1 of this report). The evaluation showed a 4% increase in neutron dose rates on the plane two meters from the package side. Larger increases were shown for closer-in surfaces, such as the package (personnel barrier) surface and the cask body surface. However, even with the larger streaming effect, the peak dose rates on those surfaces remain below their regulatory limits by far larger margins than the peak dose rate on the plane two meters from the package surface.

Based on these existing licensing evaluations that have been performed for similar cask systems, the neutron dose rates calculated in this shielding evaluation were adjusted upward by 4% to account for any neutron streaming that may occur through the copper heat transfer fins that extend through the cask radial neutron shield.

---

[23] FuelSolutions^{TM} TS125 Transportation Cask Safety Analysis Report, Revision 3, April 2002, NRC Docket No. 71-9276, BNFL Fuel Solutions Corporation.

4.3.3.4 Shielding Evaluation Results

The results of the shielding analyses are presented in Table 4-24 through Table 4-37.

4.3.3.4.1 Transport Cask NCT Shielding Analysis Results

For each evaluated case, the applicable assembly burnup, initial enrichment and cooling time are presented in the Table 4-24 through Table 4-37 titles. The peak dose rates that occur on each of the surfaces where regulatory dose rate limits apply are then presented. These include the vertical surface two meters from the package side, the radial package surface, the top package surface, the bottom package surface, and the cask body radial surface (between the impact limiters and under the personnel barrier). For each surface, the applicable regulatory dose rate limit is also listed. For each peak total dose rate, the contributions from the fuel gamma source, the fuel neutron source, from activated assembly metal hardware sources, and from secondary gamma sources (produced from neutron absorption in hydrogen-bearing materials) are also presented. The presented neutron and gamma dose rate contributions are those that apply at the location of peak total dose rate. Their relative contributions may vary significantly over the surface.

The peak NCT (normal conditions of transport) dose rates on both the vertical plane 2 meters from the package side and the radial package surface occur near the axial center of the cask for all cases (i.e., all burnup levels and for PWR and BWR fuel). This indicates that significant gamma and neutron streaming over the axial ends of the gamma and neutron shield is not occurring. In all cases, the vertical plane 2 meters from the package side is the controlling location, where dose rates are closest to their regulatory limits.

On the package (i.e., impact limiter) end surfaces, gamma dose rates are extremely small, due to the very thick steel that exists on both the top and bottom ends of the cask configuration. Gamma dose rates from the assembly top and bottom nozzles are less than 1 mrem/hr by a wide margin, at all package end surface locations, for all evaluated burnup level cases. The gamma dose rate contributions from the fuel are even smaller (< 0.1 mrem/hr). One mrem/hr is added to the package end total dose rates to conservatively account for any primary gamma dose rate contributions. The peak dose rates on the NCT package end surfaces lie over the annular gap in the impact limiter foam (shown in Figure 4-66 and Figure 4-67) for all cases. That is the expected location for the peak dose rate, since the foam material attenuates neutron much more than gammas, and gammas are an insignificant fraction of the total dose rate.

On the cask body radial surface (underneath the personnel barrier, between the impact limiters), the peak NCT dose rate always occurs at the location of the gap between the top of the neutron shield and the bottom of the top impact limiter, directly across from the assembly top nozzles (see Figure 4-66 and Figure 4-67). In all cases, the neutron dose rate is the dominant contributor to the total dose rates at that location, which is expected as the location is over a gap in the radial neutron shielding. Also, that location does not lie directly over any gamma source regions, such as the assembly top nozzle region.

The transport cask dose rate results, presented in Table 4-24 through Table 4-34, show dose rates under the regulatory limit at all locations for all analyzed cases. Therefore, it is concluded that fuel with the minimum cooling times shown the tables will meet the 10 CFR 71 requirements with respect to shielding. It should be noted that the dose rate margin is fairly small (~0.5 mrem/hr) at the peak 2-meter side plane location for some of the evaluated cases. Thus, it is possible that the required cooling time for some assembly burnup levels may increase by one year during the formal licensing of the cask system.

4.3.3.4.2 Evaluation of Reduced Cavity Diameter Cask Configuration

The evaluated cask configuration (and associated shielding materials) is not limited by weight, as the cask is not placed on the plant fuel pool crane. The outer radius of the main cask structure (i.e., the outer surface of the neutron shield structure) is limited however, based on the needed impact limiter stroke (crush depth) and the impact limiter diameter limit of 128 inches. Thus, the overall thickness of the radial shielding configuration is limited to a given value, based on the radius of the cask cavity. However, if the cask cavity radius could be reduced by a given amount, the thickness of the radial gamma and/or neutron shielding could be increased by the same amount (i.e., on an inch for inch basis).

To evaluate the impact of reducing the cask cavity radius on shielding (i.e., on required assembly cooling times), a case was considered where the cask cavity radius is reduced by 2.0 inches (i.e., a case where the cask cavity diameter is 74 inches as opposed to 78 inches). This allows the addition of 2.0 inches of radial gamma and/or neutron shielding. Based on scoping analysis results, a case where 0.5 inches of lead and 1.5 inches of NS-4FR neutron shielding is added was selected for analysis.

The dose rate results of that evaluation are shown in Table 4-35 and Table 4-36 (on pages 155 and 156), for PWR and BWR fuel, respectively. The results show that the 10 CFR 71 dose rate limits are met, by a wide margin, even for a bounding payload of 62.5 GWd/MTU, 5 year cooled fuel. Note that such a payload would actually have a heat generation level as high as 32 kW, which significantly exceeds the 24 kW the heat generation limit of the transport cask. However, a payload of 62.5 GWd/MTU assemblies would produce 24 kW at a cooling time of 6-7 years, which is still significantly below the required cooling times of 11 and 20 years calculated in Section 4.3.3.4.1 for PWR and BWR fuel, respectively. Thus, shielding limitations are significantly increasing the required cooling times.

Thus, these results show that the required assembly cooling times are extremely sensitive to the cask cavity diameter. As lower required assembly cooling times for transportation may be important to the DOE fuel management program, reducing the diameter of the transport cask cavity may be an important consideration in the final cask design phase.

It is likely that a 4-STAD carrier can be developed during the final design and licensing phase that allows a smaller transportation cask diameter. As discussed above, a 74-inch cask cavity diameter would allow enough shielding to pass 10 CFR 71 shielding requirements with a full payload of 62.5 GWd/MTU, 5 year cooled fuel. However, unless the heat generation limit for the transport cask is also increased, thermal constraints will require a cooling time of 6-7 years for 62.5 GWd/MTU fuel. A somewhat larger final cask cavity diameter (i.e., 75-76 inches) would likely accommodate any fuel that the transport cask's 24 kW heat generation limit would allow. That is, a 75-76 inch cask cavity would be able to accommodate all fuel, with a cooling time of 10 years or less (with the required cooling time likely to be closer to 6-7 years). It is very likely that a 4-STAD carrier can be designed that will allow a transport cask cavity of 75-76 inches. A 74-inch cavity may also be possible.

Another alternative would be to design and license a 3-STAD carrier and transport cask, as well as a 4-STAD cask. That configuration would be used to ship very high burnup assemblies, after cooling times of only 5 years. The 4-STAD carrier and transport cask would still be used for the great majority of fuel shipments. A 3-STAD carrier configuration would be able to fit into a transport cask cavity with a diameter of less than 70 inches. Thus, the 3-STAD transport cask can be designed with enough shielding to allow shipment of 62.5 GWd/MTU, 5-year cooled PWR or BWR fuel. Due to the lower cask capacity, the STAD payload would also have an overall heat generation level of approximately 24 kW or less. It should be noted that a 3-STAD carrier configuration may need to be designed and licensed in any event, in order to accommodate plants with 100 ton pool cranes. It should also be noted that, given the scale of the DOE spent fuel shipping program, designing and licensing an additional 3-STAD carrier and cask option would not have a significant effect on overall program cost.

4.3.3.4.3 Transport Cask Hypothetical Accident Condition Shielding Results

Table 4-24 through Table 4-36 also present dose rates for the HAC cask configuration. The peak dose rates that occur on the planes one meter from the cask body radial, top and bottom surfaces are presented. The results show that the dose rates are under the 1000 mrem/hr limit, at all locations and for all evaluated cases, by a significant margin.

The cask configuration changes (for HAC vs. NCT) are consistent with those modeled in previous licensing evaluations[5]. Axial gaps (0.87 inches high) on the top and bottom ends of the radial lead shield were modeled to account for potential effects of axial lead slump that may occur as a result of a cask end drop. The radial thickness of the lead was reduced by 0.5 inches, over the entire axial length of the shield, to account for potential effects of horizontal lead slump that may occur after a cask side drop. All moisture (i.e., all hydrogen and oxygen) was removed from the radial neutron shield material, to account for (complete) water vapor off-gassing that may occur during the fire event. The impact limiter wood and foam materials were completely removed (i.e., conservatively neglected) in the HAC shielding model.

For all cases, the peak one meter plane dose rate occurs on the radial surface, near the axial center of the cask, over the peak burnup section of the fuel. This is expected, since the neutron dose rate is the dominant contributor. This is due to the fact that, due to the complete loss of hydrogen in the neutron shield, the radial neutron dose rates increase much more than the radial gamma dose rates or the axial gamma or neutron dose rates. Secondary gamma dose rate contributions are not presented in the results tables. As there are no hydrogen-bearing materials in the HAC cask configuration, secondary gamma production will be insignificant.

4.3.3.4.4 Transfer Cask Shielding Results

The results of the transfer cask shielding evaluation are presented in Table 4-37. The analyses are based on a transfer cask containing four STADs, each of which are loaded with four 62.5 GWd/MTU, 5 year cooled PWR assemblies or nine 62.5 GWd/MTU, 5 year cooled BWR assemblies. Peak dose rates for the side, top and bottom surfaces are presented. Note that since the transfer cask has an open top, the top surface dose rates correspond to those that occur on the top surfaces of the STAD lids and the STAD carrier top shielding plate.

The localized dose rates that may occur immediately above the 3/8-inch annular gaps between the STAD lids and the carrier top shielding plate were also estimated and are presented. It should be noted that the gap dose rate estimates were very conservative, since both the STAD interior spacer plates and the carrier spacer plates (between STADs) were conservatively neglected in the shielding models. As those plates would significantly reduce upward gamma streaming, they would significantly reduce the localized dose rate that occurs over the gaps.

As discussed in Section 4.3.3.1.2, dose rates are presented for a dry configuration (where no water is present anywhere) and a wet configuration, were both the STAD interiors and the space between the STADs is filled with water.

Secondary gamma dose rate contributions are expected to be negligible for the transfer cask configuration, as those soft gammas will be almost completely absorbed within the 1.25 inch thick cask outer steel shell. The cask configuration has no hydrogen-bearing materials on the top and bottom ends.

The calculated cask side surface dose rates represent azimuthal-average dose rates (i.e., they do not account for azimuthal variations due to the square source zone within each STAD, or potential variations in STAD azimuthal orientation). Such variations are expected to be on the order of ~10%.

The results show peak dose rates under 1.0 Rem/hr on the cask side surface under dry conditions, and dose rates under 100 mrem/hr on the cask side surface when the cask and STAD cavities are filled with water. The peak dose rates occur at the axial elevation of the peak burnup region of the fuel. These dose rates are acceptable and in line with industry experience.

For the dry PWR configuration, a peak dose rate of ~2.5 Rem/hr occurs on the top surface over the center of the STAD lid. A local dose rate as high as ~50 Rem/hr may occur directly over the annular gap between the STAD lid and the carrier top plate. A peak dose rate of ~2.0 Rem/hr occurs at the center of the transfer cask door bottom surface.

For the wet PWR configuration, a peak dose rate of ~1.0 Rem/hr occurs on the top surface over the center of the STAD lid. A local dose rate as high as ~10 Rem/hr may occur directly over the annular gap between the STAD lid and the carrier top plate. A peak dose rate of ~300 mrem/hr occurs on the transfer cask door bottom surface, directly below the STAD centerline.

For the dry BWR configuration, a peak dose rate of ~2.0 Rem/hr occurs on the top surface over the center of the STAD lid. A local dose rate as high as ~25 Rem/hr may occur directly over the annular gap between the STAD lid and the carrier top plate. A peak dose rate of ~4.0 Rem/hr occurs at the center of the transfer cask door bottom surface.

For the wet BWR configuration, a peak dose rate of ~500 mrem/hr occurs on the top surface over the center of the STAD lid. A local dose rate as high as ~4 Rem/hr may occur directly over the annular gap between the STAD lid and the carrier top plate. A peak dose rate of ~100 mrem/hr occurs on the transfer cask door bottom surface, directly below the STAD centerline.

Although the localized dose rate directly over the annular STAD lid / carrier plate gap may be a concern (and may require temporary shielding), the transfer cask top and bottom surface dose rates are acceptable, and not significantly above those which occur for cask systems in commercial use today. It must be noted that the presented dose rates correspond to bounding, 62.5 GWd/MTU, 5 year cooled fuel. Most loaded fuel will have significantly lower radiological source terms, and dose rates will be significantly lower.

4.3.3.4.5 Storage Cask Shielding Results

The results of the concrete storage cask shielding evaluation are presented in Table 4-37. The peak dose rates on the storage cask side and top surfaces are presented, along with the cask top surface average dose rate.

The calculated cask side surface dose rates represent azimuthal-average dose rates (i.e., they do not account for azimuthal variations due to the square source zone within each STAD, or potential variations in STAD azimuthal orientation). Such variations are expected to be on the order of ~10%.

The peak dose rates on the cask side surface are between 80 and 90 mrem/hr, for PWR and BWR fuel. This is not significantly higher than that of other storage cask systems, given the bounding nature of the analyzed (62.5 GWd/MTU, 5 year cooled) assembly payload. The 25 mrem/year limit at the site boundary is the only 10 CFR 72 limit that applies for the storage cask. The maximum cask side surface dose rate necessary to meet this limit will be a function of the number of casks in the ISFSI, the ISFSI arrangement, the actual fuel payload (and source terms) loaded into the casks, and the distance to the site boundary. If lower dose rates on the storage cask side surface are needed or desired, more radial concrete can always be added, or the thickness of the steel inner liner can be increased (if space is a concern). No real weight limits apply to the concrete cask.

Even with the high payload source term (bounding fuel), the top surface average dose rate is approximately 300 mrem/hr for PWR and BWR fuel. This is fairly similar to allowable top surface average dose rates that are specified for existing storage cask systems. The dose rate at the site boundary is affected by the top surface average dose rate, as opposed to any local peak dose rates that may occur on the cask top. As with the cask side shielding configuration, additional shielding can be added to the storage cask top, if lower dose rates are desired.

The peak (local) dose rate on the storage cask top surface is ~2.0 rem/hr, and occurs directly over the ventilation duct (see Figure 4-72 and Figure 4-73). This is not a significant concern, as local dose rate peaks do not affect the site boundary dose rate significantly, and personnel are not near that area for significant time periods. If reduction of that local dose rate is desired, concrete could be replaced by steel in the section of the cask lid that lies directly over the ventilation duct. Many existing storage cask designs employ thick, steel shielding rings directly over the duct in order to reduce dose rates.

4.3.3.4.6 Applicability to Other Storage Cask Configurations

The storage cask shielding results presented above in Section 4.3.3.4.5 show the (acceptable) dose rates that correspond to the shielding thicknesses and materials given in Table 4-23. Those required thicknesses and corresponding dose rates should be fairly applicable for other storage configurations, such as horizontal cask modules or vault storage. External dose rates produced by the same shielding materials thicknesses will not significantly differ from those presented in Section 4.3.3.4.5 for the vertical cask system. Also, with respect to bulk shielding, there are no size and weight constraints on the storage system, vertical or horizontal, so additional shielding can always be added if necessary.

As with the vertical system, it is clear that an inlet and outlet duct (airflow) structure can be designed that will yield acceptable dose rates, especially given that such local dose rates do not significantly affect the dose rate at the plant site boundary; the only location where (10 CFR 72) regulatory dose rate limits apply. There is significant industry experience designing horizontal storage modules that have adequate bulk shielding and inlet/outlet vent structure design for large canisters. Differences between a typical large canister source configuration and the four-STAD configuration will not cause any unique difficulties with respect to vent design or the resulting (local) dose rates.

In summary, it is clear that horizontal module or vault storage systems with adequate (bulk and vent) shielding performance can be designed for the four-STAD payload configuration. There is nothing unique about the four-STAD payload that would cause significant difficulty with respect to shielding design. The Table 4-23 shielding thicknesses and Section 4.3.3.4.5 dose rates indicate (roughly) how much shielding would be necessary for adequate shielding performance, for any storage system configuration.

Table 4-24. Peak Transport Cask Exterior Surface Dose Rates (in mrem/hr) for 45 GWd/MTU, 3.25% enriched, 5 Year Cooled PWR Fuel

	Primary Fuel Gamma*	**Assembly Hardware Gamma***	**Neutron***	**Secondary Gamma***	**Total**	**10CFR71 Limit**
NCT 2-meter Vertical Side Plane	4.1	1.7	3.0	0.9	9.6	10
NCT Package Radial Surface	12	3	10	3	28	200
NCT Package Bottom Surface	<<1	<1	22	1	24	200
NCT Package Top Surface	<<1	<1	12	1	14	200
NCT Cask Body Radial Surface	2	15	168	13	198	1000
HAC 1-meter Radial Surface	11	3	138	-	152	1000
HAC 1-meter Bottom Surface	<<1	<1	56	-	57	1000
HAC 1-meter Top Surface	<<1	<1	29	-	30	1000

*Presented values are those that occur at the location of peak total dose rate on the surface in question

Table 4-25. Peak Transport Cask Exterior Surface Dose Rates (in mrem/hr) for 50 GWd/MTU, 3.5% enriched, 6 Year Cooled PWR Fuel

	Primary Fuel Gamma*	**Assembly Hardware Gamma***	**Neutron***	**Secondary Gamma***	**Total**	**10CFR71 Limit**
NCT 2-meter Vertical Side Plane	3.1	1.6	3.9	1.1	9.6	10
NCT Package Radial Surface	9	3	13	4	29	200
NCT Package Bottom Surface	<<1	<1	29	1	31	200
NCT Package Top Surface	<<1	<1	15	1	17	200
NCT Cask Body Radial Surface	2	13	219	18	252	1000
HAC 1-meter Radial Surface	8	3	180	-	192	1000
HAC 1-meter Bottom Surface	<<1	<1	73	-	74	1000
HAC 1-meter Top Surface	<<1	<1	38	-	39	1000

*Presented values are those that occur at the location of peak total dose rate on the surface in question

Table 4-26. Peak Transport Cask Exterior Surface Dose Rates (in mrem/hr) for 55 GWd/MTU, 3.75% enriched, 8 Year Cooled PWR Fuel

	Primary Fuel Gamma*	Assembly Hardware Gamma*	Neutron*	Secondary Gamma*	Total	10CFR71 Limit
NCT 2-meter Vertical Side Plane	2.1	1.3	4.5	1.3	9.2	10
NCT Package Radial Surface	6	2	16	5	29	200
NCT Package Bottom Surface	<<1	<1	34	2	37	200
NCT Package Top Surface	<<1	<1	18	1	20	200
NCT Cask Body Radial Surface	1	11	257	74	343	1000
HAC 1-meter Radial Surface	6	2	211	-	219	1000
HAC 1-meter Bottom Surface	<<1	<1	85	-	86	1000
HAC 1-meter Top Surface	<<1	<1	44	-	45	1000

*Presented values are those that occur at the location of peak total dose rate on the surface in question

Table 4-27. Peak Transport Cask Exterior Surface Dose Rates (in mrem/hr) for 60 GWd/MTU, 4.0% enriched, 10 Year Cooled PWR Fuel

	Primary Fuel Gamma*	Assembly Hardware Gamma*	Neutron*	Secondary Gamma*	Total	10CFR71 Limit
NCT 2-meter Vertical Side Plane	1.8	1.0	5.1	1.5	9.3	10
NCT Package Radial Surface	5	2	17	5	30	200
NCT Package Bottom Surface	<<1	<1	38	2	41	200
NCT Package Top Surface	<<1	<1	20	1	22	200
NCT Cask Body Radial Surface	1	9	288	23	321	1000
HAC 1-meter Radial Surface	5	2	237	-	244	1000
HAC 1-meter Bottom Surface	<<1	<1	95	-	96	1000
HAC 1-meter Top Surface	<<1	<1	49	-	50	1000

*Presented values are those that occur at the location of peak total dose rate on the surface in question

Table 4-28. Peak Transport Cask Exterior Surface Dose Rates (in mrem/hr) for 62.5 GWd/MTU, 4.1% enriched, 11 Year Cooled PWR Fuel

	Primary Fuel Gamma*	Assembly Hardware Gamma*	Neutron*	Secondary Gamma*	Total	10CFR71 Limit
NCT 2-meter Vertical Side Plane	1.9	0.9	5.3	1.5	9.6	10
NCT Package Radial Surface	6	2	18	5	31	200
NCT Package Bottom Surface	<<1	<1	40	2	43	200
NCT Package Top Surface	<<1	<1	21	1	23	200
NCT Cask Body Radial Surface	1	8	301	24	334	1000
HAC 1-meter Radial Surface	5	2	248	0	255	1000
HAC 1-meter Bottom Surface	<<1	<1	56	0	57	1000
HAC 1-meter Top Surface	<<1	<1	29	0	30	1000

*Presented values are those that occur at the location of peak total dose rate on the surface in question

Table 4-29. Peak Transport Cask Exterior Surface Dose Rates (in mrem/hr) for 40 GWd/MTU, 2.75% enriched, 5 Year Cooled BWR Fuel

	Primary Fuel Gamma*	Assembly Hardware Gamma*	Neutron*	Secondary Gamma*	Total	10CFR71 Limit
NCT 2-meter Vertical Side Plane	3.2	0.5	4.0	1.2	8.9	10
NCT Package Radial Surface	9	1	15	4	30	200
NCT Package Bottom Surface	<<1	<1	34	2	37	200
NCT Package Top Surface	<<1	<1	12	1	14	200
NCT Cask Body Radial Surface	1	4	173	14	192	1000
HAC 1-meter Radial Surface	4	1	189	-	193	1000
HAC 1-meter Bottom Surface	<<1	<1	85	-	86	1000
HAC 1-meter Top Surface	<<1	<1	31	-	32	1000

*Presented values are those that occur at the location of peak total dose rate on the surface in question

Table 4-30. Peak Transport Cask Exterior Surface Dose Rates (in mrem/hr) for 45 GWd/MTU, 3.0% enriched, 6 Year Cooled BWR Fuel

	Primary Fuel Gamma*	Assembly Hardware Gamma*	Neutron*	Secondary Gamma*	Total	10CFR71 Limit
NCT 2-meter Vertical Side Plane	2.5	0.5	5.1	1.5	9.6	10
NCT Package Radial Surface	8	1	19	5	33	200
NCT Package Bottom Surface	<<1	<1	43	2	46	200
NCT Package Top Surface	<<1	<1	16	1	18	200
NCT Cask Body Radial Surface	1	4	220	18	243	1000
HAC 1-meter Radial Surface	3	0	240	-	243	1000
HAC 1-meter Bottom Surface	<<1	<1	109	-	110	1000
HAC 1-meter Top Surface	<<1	<1	39	-	40	1000

*Presented values are those that occur at the location of peak total dose rate on the surface in question

Table 4-31. Peak Transport Cask Exterior Surface Dose Rates (in mrem/hr) for 50 GWd/MTU, 3.25% enriched, 9 Year Cooled BWR Fuel

	Primary Fuel Gamma*	Assembly Hardware Gamma*	Neutron*	Secondary Gamma*	Total	10CFR71 Limit
NCT 2-meter Vertical Side Plane	1.6	0.3	5.8	1.7	9.5	10
NCT Package Radial Surface	5	1	22	6	34	200
NCT Package Bottom Surface	<<1	<1	50	2	53	200
NCT Package Top Surface	<<1	<1	18	1	19	200
NCT Cask Body Radial Surface	1	3	253	20	276	1000
HAC 1-meter Radial Surface	2	0	275	-	278	1000
HAC 1-meter Bottom Surface	<<1	<1	125	-	126	1000
HAC 1-meter Top Surface	<<1	<1	45	-	46	1000

*Presented values are those that occur at the location of peak total dose rate on the surface in question

Table 4-32. Peak Transport Cask Exterior Surface Dose Rates (in mrem/hr) for 55 GWd/MTU, 3.5% enriched, 13 Year Cooled BWR Fuel

	Primary Fuel Gamma*	Assembly Hardware Gamma*	Neutron*	Secondary Gamma*	Total	10CFR71 Limit
NCT 2-meter Vertical Side Plane	1.2	0.2	6.3	1.8	9.6	10
NCT Package Radial Surface	4	0	23	7	34	200
NCT Package Bottom Surface	<<1	<1	54	3	58	200
NCT Package Top Surface	<<1	<1	19	1	21	200
NCT Cask Body Radial Surface	0	2	272	79	353	1000
HAC 1-meter Radial Surface	1	0	297	-	299	1000
HAC 1-meter Bottom Surface	<<1	<1	134	-	135	1000
HAC 1-meter Top Surface	<<1	<1	48	-	49	1000

*Presented values are those that occur at the location of peak total dose rate on the surface in question

Table 4-33. Peak Transport Cask Exterior Surface Dose Rates (in mrem/hr) for 60 GWd/MTU, 4.0% enriched, 18 Year Cooled BWR Fuel

	Primary Fuel Gamma*	Assembly Hardware Gamma*	Neutron*	Secondary Gamma*	Total	10CFR71 Limit
NCT 2-meter Vertical Side Plane	0.9	0.1	6.4	1.9	9.3	10
NCT Package Radial Surface	3	0	24	7	33	200
NCT Package Bottom Surface	<<1	<1	55	3	59	200
NCT Package Top Surface	<<1	<1	20	1	22	200
NCT Cask Body Radial Surface	0	1	278	22	301	1000
HAC 1-meter Radial Surface	1	0	303	-	304	1000
HAC 1-meter Bottom Surface	<<1	<1	137	-	138	1000
HAC 1-meter Top Surface	<<1	<1	49	-	50	1000

*Presented values are those that occur at the location of peak total dose rate on the surface in question

Table 4-34. Peak Transport Cask Exterior Surface Dose Rates (in mrem/hr) for 62.5 GWd/MTU, 4.1% enriched, 20 Year Cooled BWR Fuel

	Primary Fuel Gamma*	Assembly Hardware Gamma*	Neutron*	Secondary Gamma*	Total	10CFR71 Limit
NCT 2-meter Vertical Side Plane	0.7	0.1	6.6	1.9	9.3	10
NCT Package Radial Surface	2	0	24	7	34	200
NCT Package Bottom Surface	<<1	<1	56	3	60	200
NCT Package Top Surface	<<1	<1	20	1	22	200
NCT Cask Body Radial Surface	0	1	284	23	307	1000
HAC 1-meter Radial Surface	1	0	309	-	310	1000
HAC 1-meter Bottom Surface	<<1	<1	140	-	141	1000
HAC 1-meter Top Surface	<<1	<1	50	-	51	1000

*Presented values are those that occur at the location of peak total dose rate on the surface in question

Table 4-35. Peak Transport Cask Exterior Surface Dose Rates (in mrem/hr) for Reduced Cask Cavity Diameter Configuration 62.5 GWd/MTU, 4.1% enriched, 5 Year Cooled PWR Fuel

	Primary Fuel Gamma*	Assembly Hardware Gamma*	Neutron*	Secondary Gamma*	Total	10CFR71 Limit
NCT 2-meter Vertical Side Plane	1.9	0.6	1.4	1.5	5.5	10
NCT Package Radial Surface	6	1	5	5	17	200
NCT Package Bottom Surface	<<1	<1	50	2	53	200
NCT Package Top Surface	<<1	<1	26	1	28	200
NCT Cask Body Radial Surface	1	6	77	6	90	1000
HAC 1-meter Radial Surface	5	1	232	-	239	1000
HAC 1-meter Bottom Surface	<<1	<1	125	-	126	1000
HAC 1-meter Top Surface	<<1	<1	65	-	66	1000

*Presented values are those that occur at the location of peak total dose rate on the surface in question

Table 4-36. Peak Transport Cask Exterior Surface Dose Rates (in mrem/hr) for Reduced Cask Cavity Diameter Configuration
62.5 GWd/MTU, 4.1% enriched, 5 Year Cooled BWR Fuel

	Primary Fuel Gamma*	Assembly Hardware Gamma*	Neutron*	Secondary Gamma*	Total	10CFR71 Limit
NCT 2-meter Vertical Side Plane	1.6	0.2	2.4	2.7	6.8	10
NCT Package Radial Surface	5	0	9	10	24	200
NCT Package Bottom Surface	<<1	<1	98	5	104	200
NCT Package Top Surface	<<1	<1	35	2	38	200
NCT Cask Body Radial Surface	1	2	102	8	112	1000
HAC 1-meter Radial Surface	2	0	405	-	408	1000
HAC 1-meter Bottom Surface	<<1	<1	140	-	141	1000
HAC 1-meter Top Surface	<<1	<1	50	-	51	1000

*Presented values are those that occur at the location of peak total dose rate on the surface in question

Table 4-37. Peak Transfer and Storage Cask Exterior Surface Dose Rates (in mrem/hr) 62.5 GWd/MTU, 4.1% enriched, 5 Year Cooled BWR Fuel

		Primary Fuel Gamma[1]	Assembly Hardware Gamma[1]	Neutron[1]	Total
Transfer Cask Radial Surface [2]	Dry PWR	324	1	303	628
	Wet PWR	64	0	5	70
	Dry BWR	265	0	569	834
	Wet BWR	52	0	8	61
Transfer Cask Top Surface[3,4]	Dry PWR	73	1771	702	2547
	Wet PWR	4	1142	0	1146
	Dry BWR	45	819	1079	1943
	Wet BWR	1	462	0	463
Transfer Cask Bottom Surface	Dry PWR[5]	134	108	1846	2088
	Wet PWR[6]	7	281	0	288
	Dry BWR[5]	99	45	3646	3790
	Wet BWR[6]	2	92	0	94
Storage Cask Radial Surface[2]	PWR	77	0	10	88
	BWR	64	0	18	82
Storage Cask Top Surface[7]	PWR	1866	252	51	2169
	BWR	1535	73	89	1696
Storage Cask Top Surface Average Dose Rate	PWR	281	56	20	357
	BWR	210	17	36	263

Notes:

1. Presented values are those that occur at the location of peak total dose rate on the surface in question.
2. Peak dose rates on cask side occur near the axial center of the cask, over the peak burnup section of the fuel.
3. Without considering the annular gap between the STAD lid and the carrier top shielding plate, the peak top surface dose rate occurs directly over the STAD centerline for all cases.
4. A very localized, high dose rate occurs directly over the 3/8-inch annular gap between the STAD lid and the carrier top shielding plate. This dose rate is ~50 Rem/hr, ~10 Rem/hr, ~25 Rem/hr, and ~4 Rem/hr for the dry PWR, wet PWR, dry BWR, and wet BWR configurations, respectively.
5. The peak dose rate occurs at the center of the transfer cask bottom (doors) surface.
6. The peak dose rate occurs directly under the STAD centerline.
7. The peak dose rate occurs directly over the ventilation annulus (see Figure 4-72 and Figure 4-73). The dose rate at the lid center is ~100 mrem/hr.

4.3.4 Criticality Analyses

Criticality analyses were performed on the cask and basket designs described in Section 4.1, using the industry-standard MCNP5 Monte Carlo code.

It is likely that moderator exclusion will be employed as the primary means of criticality control under 10 CFR 71 HAC for the STAD transport cask system. The double seal weld of the STADs would be credited as the second barrier to water ingress (an approach for which there is precedent in cask system licensing). The transport cask containment boundary would be the first barrier to water ingress. However, analyses that model water ingress will have to be used to qualify the nominal, “as loaded” configuration (containing intact fuel), per the requirements of 10 CFR 71.55(e).

Criticality analyses that model water within the STAD interiors as well as between the STADs were performed. The purpose of these analyses is to qualify the “as loaded” cask configuration, and provide backup (defense in depth) to moderator exclusion for the NCT and HAC configuration. Also, they demonstrate sub-criticality for cask loading operations, thus eliminating the need to rely on soluble boron as a means of criticality control. Soluble boron is not present in BWR spent fuel pools, so the use of soluble boron credit would present difficulties for the BWR cask loading process.

The criticality analyses model the STADs inside the transportation cask described in Section 4.1. As the (outer) cask configuration does not significantly affect reactivity, and the transfer and transport cask materials are similar, the results of these criticality analyses are applicable for the transfer (loading) configuration as well.

The focus of the criticality analyses performed for this report is to determine if the PWR and BWR STAD and carrier configurations offer adequate criticality performance in the case of water ingress, and to estimate the fraction of the US PWR and BWR used fuel inventory that can be accommodated by the cask system. The analyses performed model the configurations known to be the limiting configurations that govern basket criticality performance (e.g., an infinite array of casks with full density water completely filling the cask interior).

The overall analysis methodology for the PWR and BWR basket differ significantly, due to the fact that burnup credit criticality evaluations could be performed in support of the PWR basket licensing evaluation, whereas simple, unburned fuel criticality analyses would be performed to qualify the BWR baskets. The analysis methodology, and results, for the preliminary PWR and BWR criticality evaluations are presented in the sub-sections below.

4.3.4.1 PWR Criticality Evaluation

The (future) criticality licensing evaluations for the PWR STAD payload will have to employ burnup credit criticality analyses. Such analyses are quite involved and time consuming, and have therefore not been performed as part of this DOE report.

Therefore, to estimate the criticality performance of the PWR STAD and carrier configuration described in Section 4.1, criticality analyses were performed to estimate their reactivity *relative* to NAC International's MAGNATRAN system, an existing PWR basket for which burnup credit licensing evaluations have been performed. The MAGNATRAN transportation (10 CFR 71) SAR[4] presents maximum allowable assembly initial enrichment values as a function of assembly burnup, for each major US PWR assembly type. If these relative reactivity analyses show that the PWR STAD configuration is no more reactive than the MAGNATRAN basket, then the applicable burnup curves (i.e., maximum allowable initial enrichment levels for given burnup levels) will be similar to or better than those presented in the MAGNATRAN SAR.

4.3.4.1.1 MAGNATRAN Criticality Models

The first step in the process is to develop a criticality model of the MAGNATRAN basket configuration, as described in the MAGNATRAN SAR, to determine a raw k_{eff} value which corresponds to that configuration. There are actually two basket configurations for which the MAGNATRAN SAR presents burnup curves (for each PWR assembly type), an intact PWR assembly basket, and a damaged PWR fuel basket, for which damaged assembly arrays inside damaged fuel cans are modeled in four corner cells of the (37-assembly) basket.

The MAGNATRAN intact and DFC basket burnup curves (for the W 15×15 assembly) are presented in Figure 4-74. The burnup and initial enrichment levels of the US PWR spent fuel inventory are also shown in Figure 4-74 for comparison. This allows the fraction of the US PWR fuel inventory that can be accommodated by each of the MAGNATRAN burnup curves to be estimated.

For the intact assembly slots, the MAGNATRAN licensing analyses modeled spent fuel isotopic compositions that correspond to the assembly average burnup and initial enrichment values along their specified burnup curves. For each analysis, 18 axial zones were defined within the fuel, each with its own modeled fuel isotopic composition, to model the effects of the assembly axial burnup profile. For the four damaged assemblies in the corner locations of the damaged fuel basket, a very conservative isotopic composition that corresponds to ~4.0% enriched, 45 GWd/MTU fuel was modeled, over the entire axial length of the assembly.

For this evaluation, the intact and damaged fuel MAGNATRAN basket configurations were modeled with W 15×15 Std., Zircaloy-clad fuel assemblies. The intact basket configuration was modeled with a fuel material composition which corresponds to spent fuel with an 18-axial-zone set of isotopic compositions that correspond to 5.0% enriched, 45 GWd/MTU fuel. (This corresponds to the right end of the intact fuel MAGNATRAN burnup curve shown in

Figure 4-74.) The damaged fuel basket configuration modeled the same fuel compositions (as the intact model) in all but the four corner cells, where a 4.0% enriched, 45 GWd/MTU fuel composition was modeled over the entire axial span. No fuel depletion analyses were performed to determine the fuel isotopic compositions that correspond to 5.0% enriched, 45 GWd/MTU fuel. The 18-axial-zone set of isotopic compositions used in the MAGNATRAN licensing evaluation were directly provided by NAC International, for use in this evaluation.

It is assumed that if the PWR STAD configuration is shown to be no more reactive than MAGNATRAN, for 5.0% enriched, 45 GWd/MTU W 15×15 fuel, then the burnup curves presented in the MAGNATRAN SAR, for all PWR assembly types, are likely to be very similar to the burnup curves that would apply for the PWR STAD configuration.

It should be noted that k_{eff} values calculated using the above (MAGNATRAN) criticality models are raw k_{eff} values that do not correspond to the final k_{eff} values determined by burnup credit licensing evaluations. With burnup credit criticality evaluations, several k_{eff} penalties are applied to account for biases and uncertainties in both the fuel depletion and criticality codes, and effects such as radial burnup variations in the fuel rod arrays, assembly component dimensional tolerances, and potential misleading of under-burned assemblies. Thus, the k_{eff} values are somewhat lower than typical maximum allowable k_{eff} values. It should also be noted that the objective of these criticality evaluations is not to estimate system absolute k_{eff} values, but to estimate the relative impact, on k_{eff}, of the changes in basket geometry between the MAGNATRAN and PWR STAD configurations. This is done through a comparison of raw k_{eff} values.

The raw k_{eff} values for the intact and DFC MAGNATRAN basket configurations (for the W 15×15 assembly) are presented in Table 4-38. The k_{eff} values are 0.891 and 0.915, for the intact and DFC configurations, respectively.

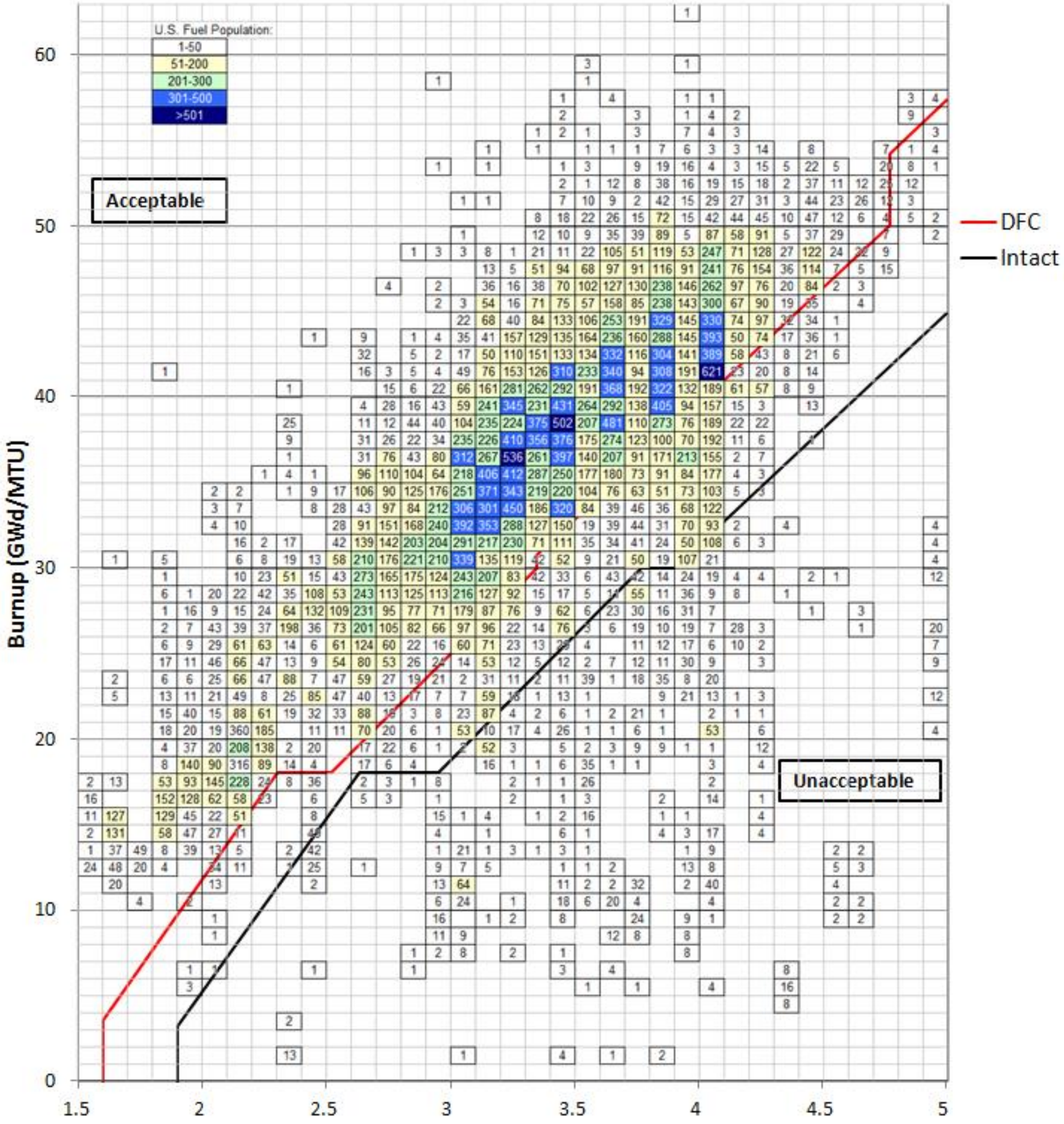


Figure 4-74. MAGNATRAN Intact Fuel and DFC Burnup Curves vs. US PWR Fuel Inventory

4.3.4.1.2 PWR STAD Models

Once the raw k_{eff} values were determined for the MAGNATRAN configurations, the PWR STAD and transport cask configurations described in Sections 4.1 were rigorously modeled, and similar raw k_{eff} values were determined for comparison.

The criticality model covered one quadrant of the overall cask configuration. Thus, a single STAD lay within the model. Reflective boundaries were applied on the bottom and left boundaries of the model (i.e., on the X and Y axes). This effectively modeled the entire cask, with a four STAD payload.

As discussed in Section 4.1.1, a 7/16-inch thick cross of borated stainless steel plates was placed between the four assembly cells within the PWR STAD interior. A boron concentration of 1.1 wt% was modeled within the stainless steel material, in accordance with STAD specifications. The B-10 concentration was then reduced by 10% to account for variations in B-10 concentration within the plates (as is required by NRC). Borated stainless steel plates are not present around the periphery of the STAD interior basket.

Three different configurations were modeled for the PWR STAD configuration, which reflect different licensing contingencies. The evaluations of these alternative cases allow the impacts of various licensing contingencies (concerning how high burnup and/or damaged fuel are treated, for example) will affect system performance. These specific evaluations are described in the sections below.

4.3.4.1.3 Intact PWR Assemblies

This configuration evaluated an intact assembly payload, which applies for the “as loaded” configuration, and is also considered to be the configuration most likely to be applicable for NCT and HAC. It modeled intact (W 15×15) PWR fuel assemblies in the four cells of the PWR STAD interior. With respect to fuel pellet composition, the analysis modeled the 45 GWd/MTU, 5.0% enriched composition described above in Section 4.3.4.1.1. The assemblies were shifted (within their cells) towards the center of the STAD, as that maximizes reactivity.

A horizontal cross-section view of the intact PWR criticality model is shown in Figure 4-75 and Figure 4-76. The illustration corresponds to elevations between the steel spacer plates. At the spacer plate elevations, ordinary stainless steel (as opposed to borated stainless steel) occupies the space between the guide tubes (assembly cells). The spacer plates also replace water around the edges of basket, at the spacer plate elevations.

The results of the intact PWR assembly criticality evaluation are presented in Table 4-38. The raw k_{eff} value for the intact PWR STAD configuration is 0.786, which is much lower than the raw k_{eff} value of 0.891 calculated for the intact PWR MAGNATRAN configuration.

Thus, it is concluded that the four STADs in a transport cask, loaded with four intact PWR assemblies, is less reactive than a MAGNATRAN basket fully loaded with intact PWR assemblies. Although the reactivity comparison analysis was performed modeling W 15×15 assemblies (for both the STAD and MAGNATRAN cases), it is concluded that the STAD configuration is less reactive than MAGNATRAN for all PWR assembly types, as the assembly configuration should not significantly affect the relative reactivity of the different basket configurations.

Therefore, it is concluded that the burnup curves presented (for each PWR assembly type) in the MAGNATRAN SAR for their fully loaded intact PWR assembly basket are applicable (or conservative) for the PWR STAD, even if water ingress is assumed. The MAGNATRAN burnup curves for other PWR assembly types are similar to or lower than the W 15×15 assembly burnup curve presented graphically in Figure 4-74 . Thus, the percentage of the PWR fuel inventory that can be accommodated by the cask system, that is estimated based on the W 15×15 burnup curve and fuel population data shown in Figure 4-74, will be similar (or conservative) for all US PWR assembly types.

As shown in Figure 4-74, the MAGNATRAN intact PWR fuel burnup curve would accommodate the overwhelming majority of US PWR spent fuel. Based on experience at the Zion plant, it is assumed that shutdown plants would have more than enough control rod assemblies (CRAs) to insert into the few assemblies underneath that curve. Thus, the PWR STAD configuration described in Section 4.1 should be able to accommodate the entire US PWR spent fuel inventory, without the need to reduce payload capacity for any shipments.

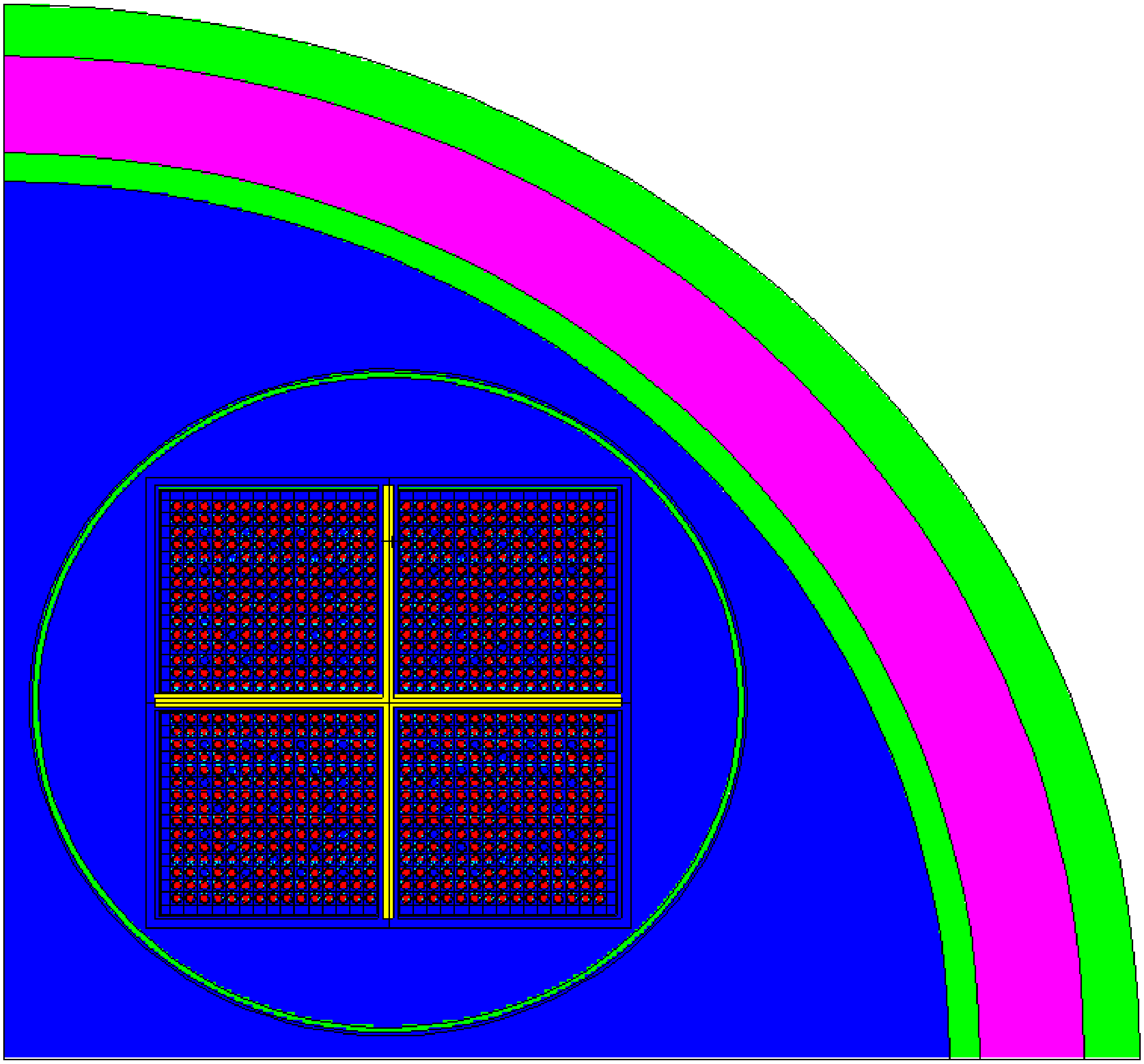


Figure 4-75. PWR STAD – Intact Fuel Criticality Model (horizontal cross-section view – between spacer plates)

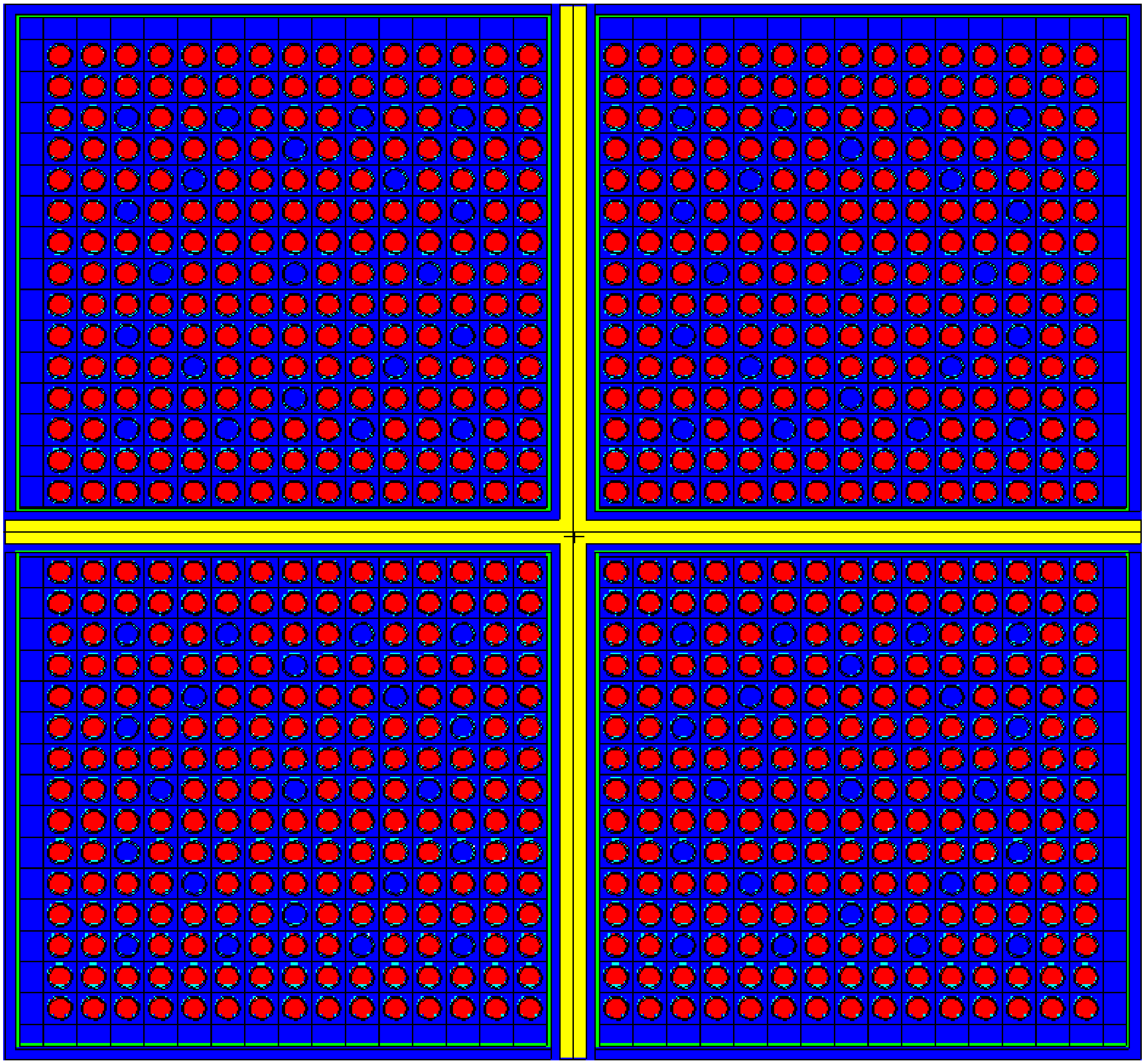


Figure 4-76. PWR STAD – Intact Fuel Criticality Model – Fuel Region Close Up View (horizontal cross-section view – between spacer plates)

4.3.4.1.4 Optimum Pitch Cladded PWR Rod Arrays

This configuration is similar to the configuration evaluated in the above section, except that the rod array pitch of the PWR assemblies is varied to yield the maximum k_{eff} value. This configuration was modeled to represent a contingency where the NRC requires that partial assembly reconfiguration (where the fuel rod array pitch may change) must be considered for (initially intact) high burnup fuel.

The cladding was not removed from the assemblies and the guide and instrument tubes of the W 15×15 assembly were still modeled. The only difference in the array is that the pitch was varied. It was assumed that no fuel pellets leave the fuel rods, and that the fuel rods do not break into rod fragments that can travel between one axial zone of the fuel assembly to another. Thus, the number of fuel rods in the array (204) was retained, and the fuel rods (including their cladding) did not shift out past the cell walls.

Analyses performed in support of the DOE Task 17 report[19] show that maximum PWR assembly reactivity occurs when the fuel rods are separated as much as possible, so that the outer rows of fuel rods are in contact with the cell walls. That configuration is modeled for this evaluation.

A horizontal cross-section view of the optimum-pitch PWR criticality model (between spacer plates) is shown in Figure 4-77.

The results of the optimum PWR assembly rod pitch evaluation are presented in Table 4-38. The raw k_{eff} value for a PWR STAD loaded with optimum pitch (W 15×15) PWR assemblies is 0.822, which is still less than the raw k_{eff} value (of 0.891) calculated for the intact PWR fuel MAGNATRAN basket.

Thus, it is concluded that even if it is assumed that the rod pitch of the loaded PWR assemblies could change to the most reactive possible value (under HAC), and it is also assumed that water enters the cask, the PWR STAD configuration could still accommodate the entire US spent PWR assembly inventory, without any need for payload reduction.

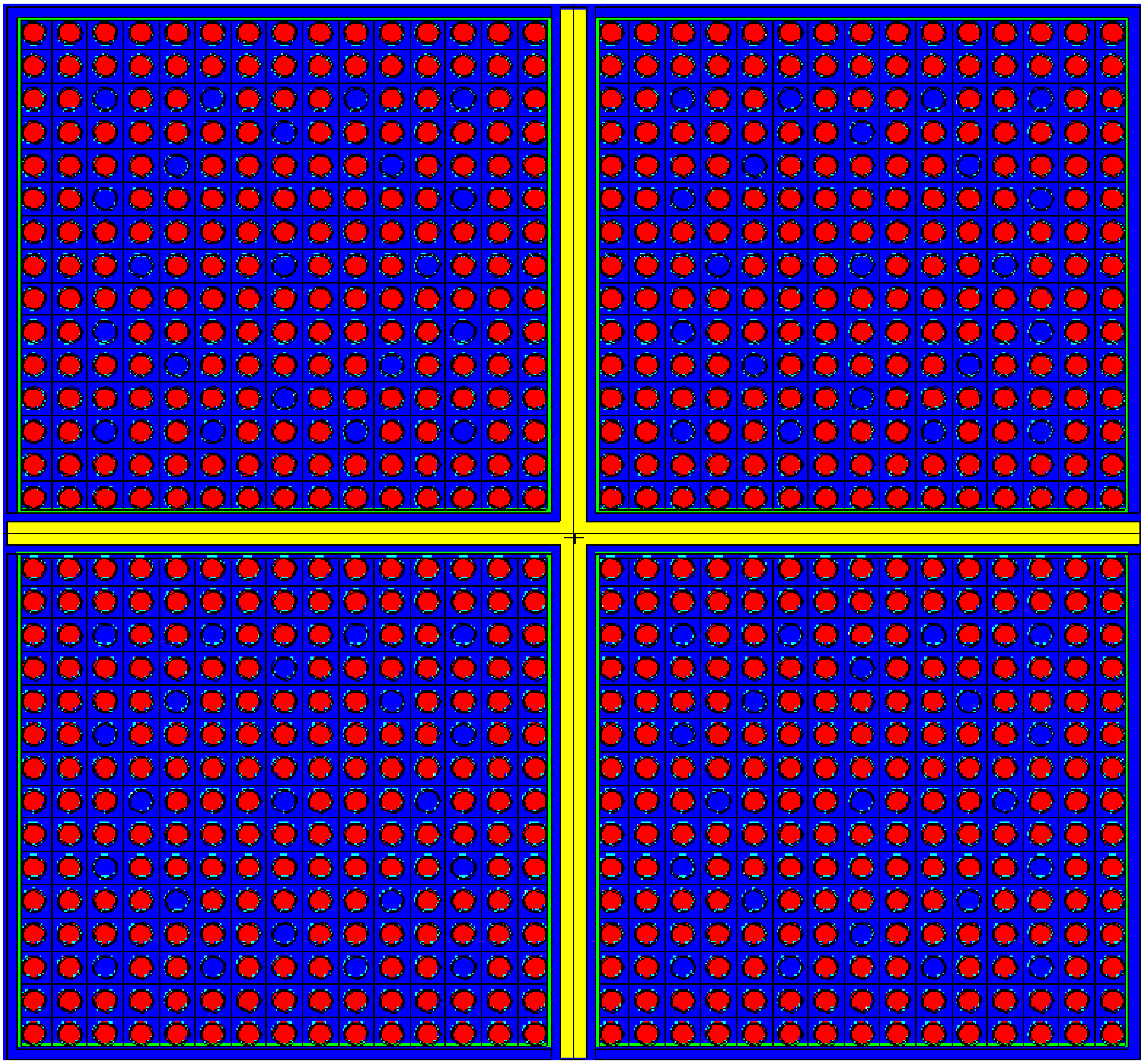


Figure 4-77. PWR STAD – Optimum Pitch Array Criticality Model -Fuel Region Close Up (horizontal cross-section view – between spacer plates) (rest of model identical to that shown in Figure 4-75)

4.3.4.1.5 Optimum PWR Fuel Pellet (rubble) Array

Finally, an extreme case was considered where not only does water fill the cask and STAD interiors (despite the fact that the system is licensed for moderator exclusion), but it was also assumed that all the fuel pellets escape the fuel rods and freely move about the STAD interior. As the basket guide sleeves will not be sealed off, and thus will not provide any pellet confinement, the pellets are not restricted to the four assembly cell volumes. The pellets may move into any axial section of the STAD interior, and may also occupy the large region around the edge of the STAD interior (outside the four guide sleeves). Since the pellets may congregate in one axial section of the STAD interior, and axial leakage is not significant for an array covering any significant fraction of the STAD interior, it was conservatively assumed that there is no limit on the fissile mass (number of pellets) that may occupy the STAD interior.

The analysis conservatively removed all cladding material. The primary material modeled in the STAD interior, other than the fuel pellets, was the central cross of borated stainless steel. Optimum (maximum reactivity) fuel pellet arrays were determined as part of the criticality evaluation presented in the DOE Task Order 17 report[19]. The optimum fuel pellet pitch determined in those evaluations was assumed for this evaluation. A fuel pellet array, with that (optimum) pitch, was then modeled throughout the STAD interior, with the exception of the volume occupied by the borated stainless steel neutron absorber plates. The modeled configuration is illustrated in Figure 4-78.

The results of the optimum PWR assembly rod pitch evaluation are presented in Table 4-38. The raw k_{eff} value for a PWR STAD whose interior is completely filled with an optimum array of (W 15×15) PWR fuel pellets is 0.943. The configuration is more reactive than both the intact and DFC MAGNATRAN baskets, which have raw k_{eff} values of 0.891 and 0.915, respectively, so a burnup curve determined for that configuration would be higher than both MAGNATRAN burnup curves shown in Figure 4-74. Thus, under those (extreme) assumptions, the PWR STAD would not be able to accommodate a significant fraction of the US spent PWR fuel inventory.

The above results would not present an issue if either water ingress or the large scale release of fuel pellets into the STAD interior under HAC can be excluded as a credible possibility. Another possibility would be changing the design of the STAD basket to control reactivity under such extreme assumptions. An additional analysis is performed which assumed that borated stainless steel is placed around the periphery of the four basket cells. Also, the borated stainless steel plates are extended out to the STAD cavity edge. This results in separated areas around the basket periphery that have a cross-sectional area smaller than that of the four assembly cells. This configuration is illustrated in Figure 4-79.

The possibility of placing fixed neutron absorbers in the STAD carrier structure was also considered as a means of criticality control. This was modeled by placing a 1/8-inch thick layer of borated aluminum (with a high B-10 areal density) around the outside of the STAD shell. However, analysis results showed that such a feature has little impact on reactivity. The results appear to show that the four STADs present in a transport cask are very neutronically isolated (even without placing neutron absorbers between them). Criticality (k_{eff}) is almost entirely driven by neutronic communication between the cells within each STAD. Thus, placing neutron absorbers between the STADs has little effect. Placing borated stainless steel plates around the periphery of the STAD basket has somewhat more of an effect, since the close contact with the assemblies reduces water reflection (as well as any inter-STAD neutron communication) and because absorber material near the assemblies (in each STAD) creates a wide flux trap between the STADs. That effect, however, is still small.

The result of the analysis of the "additional borated stainless steel configuration" described above is presented in Table 4-38. The raw k_{eff} value for the analyzed configuration is 0.881, which is less than the raw k_{eff} value (of 0.891) calculated for the intact PWR fuel MAGNATRAN basket. Thus, it is concluded that if the borated stainless steel neutron absorber structure were extended to resemble the configuration illustrated (in yellow) in Figure 4-79 the entire US spent PWR assembly inventory could be accommodated, without any need for payload reduction, even if it were assumed that all the pellets escape the fuel rods and that water enters the cask and STAD interiors (under HAC). Such a borated stainless steel configuration would significantly increase the cost and weight of the STADs, however.

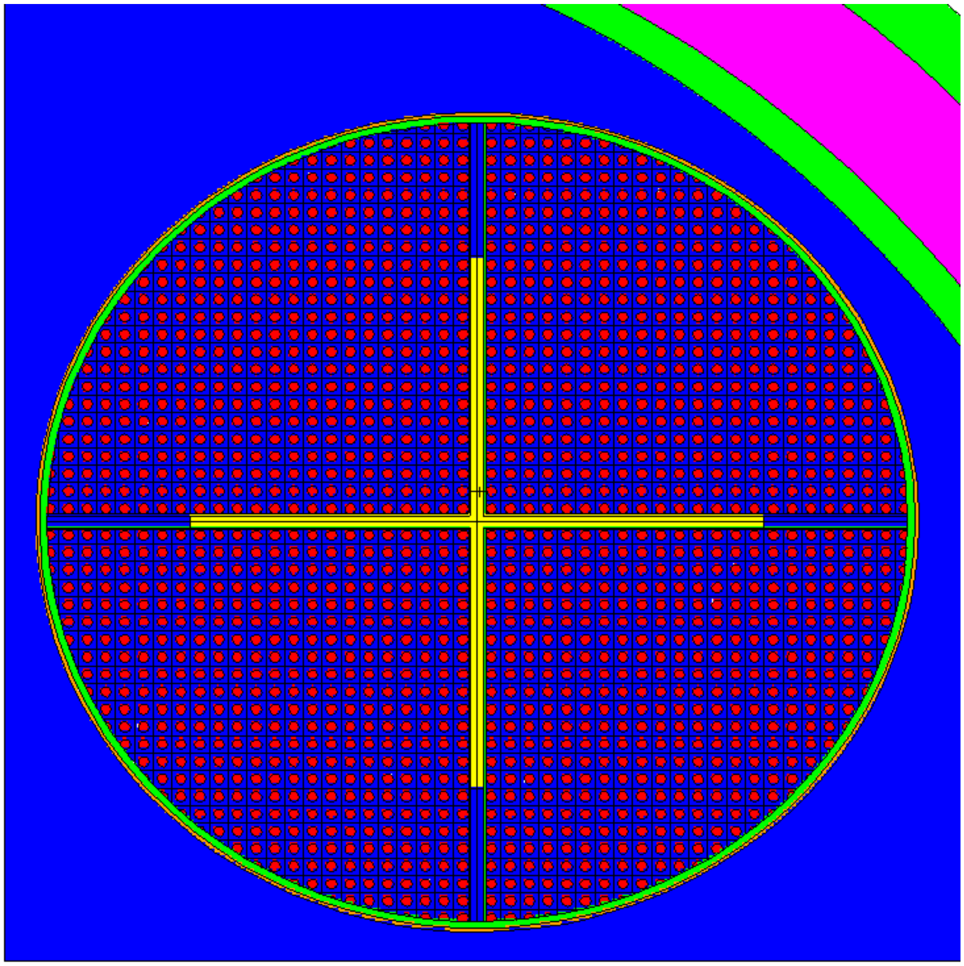


Figure 4-78. PWR STAD – Optimum Fuel Pellet (rubble) Array Criticality Model (current borated stainless steel plate configuration) (horizontal cross-section view – between spacer plates)

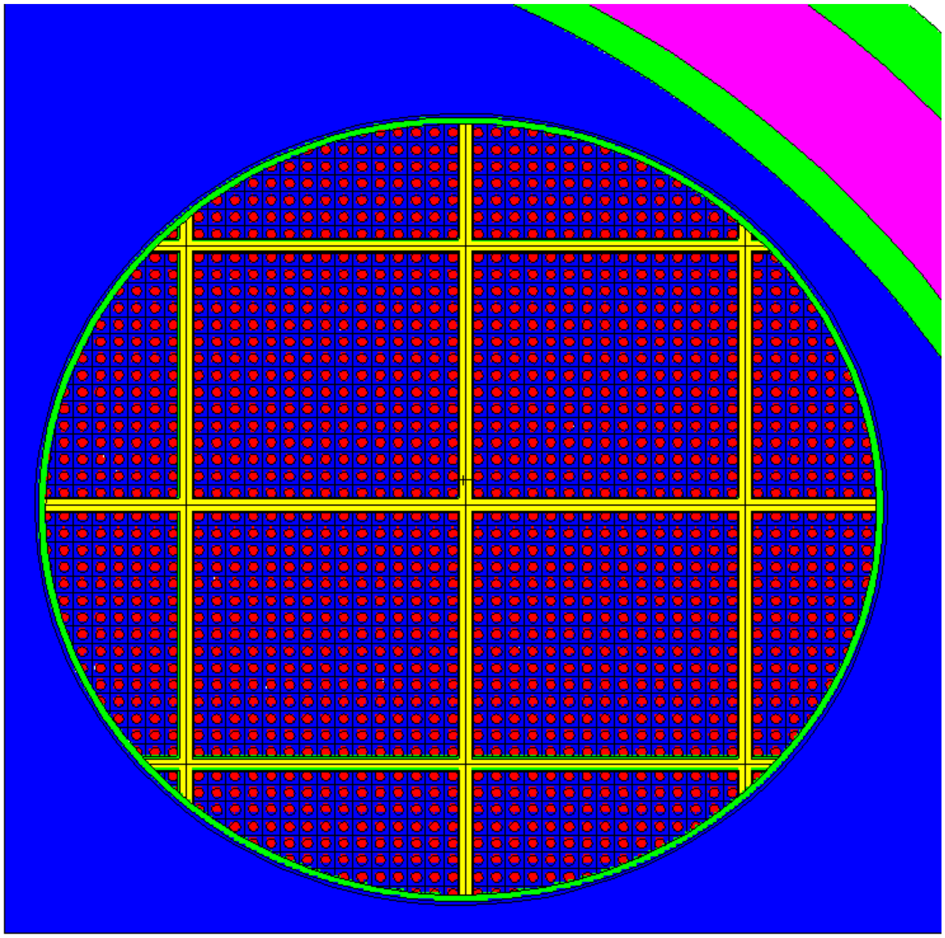


Figure 4-79. PWR STAD – Optimum Fuel Pellet (rubble) Array Criticality Model (extended borated stainless steel plate configuration) (horizontal cross-section view –between spacer plates)

4.3.4.2 BWR Criticality Evaluation

There is no licensing precedent for using burnup credit criticality analyses to license BWR assembly payloads. For many reasons, burnup credit criticality analyses would be much more difficult for BWR fuel. Also, due to the smaller size of BWR assemblies, they can be qualified for loading in a non-flux-trap basket, without crediting burnup. This removes most of the need for burnup credit analyses. Thus, it is assumed that any future licensing evaluation for the BWR STADs would not involve burnup credit.

Since unburned fuel criticality analysis is much simpler than burnup credit analysis, such analyses can be performed in support of this DOE report. Thus, instead of performing analyses which estimate the reactivity of the BWR STAD configuration relative to that of an existing system (as was done for PWR fuel), analyses can be performed which directly calculate absolute

k_{eff} values. The results of these analyses are maximum allowable BWR assembly initial U-235 enrichment values, for the basket configurations that were evaluated.

One thing that was not done in this report was an extensive criticality code benchmarking evaluation that determines the code bias and uncertainty penalties that must be applied to raw, calculated k_{eff} values. Instead, a maximum allowable raw k_{eff} value of 0.9376 was taken from the SAR for the MAGNATRAN cask system, for which licensing criticality analyses (for BWR fuel) have been performed. These evaluations used the same criticality code (MCNP5) that was used in the MAGNATRAN licensing evaluations, so the same code bias and uncertainty penalties should apply.

4.3.4.2.1 BWR STAD Models

The criticality model covered one quadrant of the overall cask configuration. Thus, a single STAD lay within the model. Reflective boundaries were applied on the bottom and left boundaries of the model (i.e., on the X and Y axes). This effectively modeled the entire cask, with a four STAD payload.

As discussed in Section 4.1.1, an egg crate structure consisting of 7/16-inch thick borated stainless steel plates was placed between the nine assembly cells within the BWR STAD interior. A boron concentration of 1.1 wt% was modeled within the stainless steel material, in accordance with STAD specifications. The B-10 concentration was then reduced by 10% to account for variations in B-10 concentration within the plates (as is required by NRC). Borated stainless steel plates were not present around the periphery of the STAD interior basket.

Three different configurations were modeled for the BWR STAD configuration, which reflect different licensing contingencies. The evaluations of these alternative cases allow the impacts of various licensing contingencies (concerning how high burnup and/or damaged fuel are treated, for example) will affect system performance. These specific evaluations are described in the sections below.

4.3.4.2.2 Intact BWR Assemblies

This configuration evaluated an intact assembly payload, which applies for the “as loaded” configuration, and is also considered to be the configuration most likely to be applicable for NCT and HAC. It modeled intact (8×8) BWR fuel assemblies in the nine cells of the BWR STAD interior. The analysis modeled fresh (unburned) UO_2 BWR fuel with an initial enrichment of 5.0%. The assemblies were shifted (within their cells) towards the center of the STAD, as that maximizes reactivity. BWR assemblies with (0.125 inch thick Zircaloy) flow channels were also modeled, as that is known to increase reactivity.

A horizontal cross-section view of the intact BWR criticality model is shown in Figure 4-80 and Figure 4-81. The illustration corresponds to elevations between the steel spacer plates. At the spacer plate elevations, the ordinary stainless steel (as opposed to borated stainless steel) occupies the space between the guide tubes (assembly cells). The spacer plates also replace water around the edges of basket, at the spacer plate elevations.

The results of the intact BWR assembly criticality evaluation are presented in Table 4-38. The raw k_{eff} value for the intact BWR STAD configuration is 0.880, which is less than the maximum allowable raw k_{eff} value of 0.9376. Given the degree of margin in the k_{eff} result, it is concluded that all US BWR assembly types would yield acceptable k_{eff} values, at an initial enrichment level of 5.0%. (Criticality results presented in the MAGNATRAN SAR show that no other BWR assembly types are significantly more reactive than the modeled 8×8 assembly.)

Thus, it is concluded that four BWR STADs inside a transportation cask, each with a payload of nine BWR assemblies, will meet 10 CFR 71 criticality requirements for (planar average) enrichment levels up to 5.0%. This covers the entire US spent BWR assembly inventory. Thus, even if water ingress into the cask and STAD interiors under NCT or HAC were deemed credible, the BWR STAD configuration will be able to ship the entire US spent BWR assembly inventory, with no need for payload reduction, if the BWR assemblies can be assumed to remain intact under 10 CFR 71 HAC.

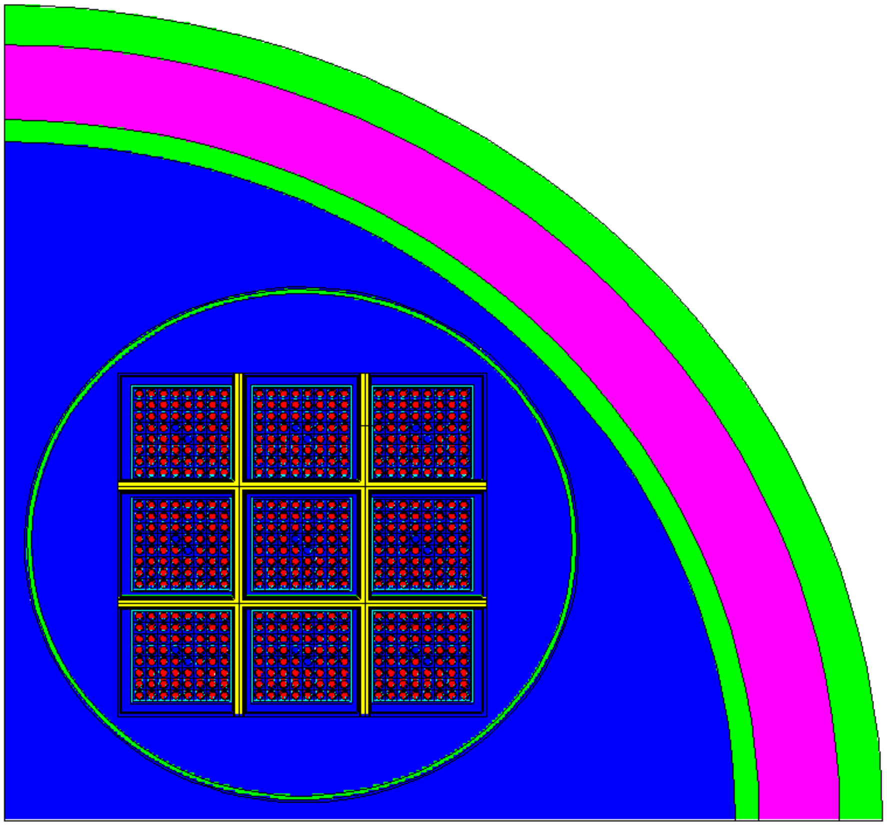


Figure 4-80. BWR STAD – Intact Fuel Criticality Model (horizontal cross-section view – between spacer plates)

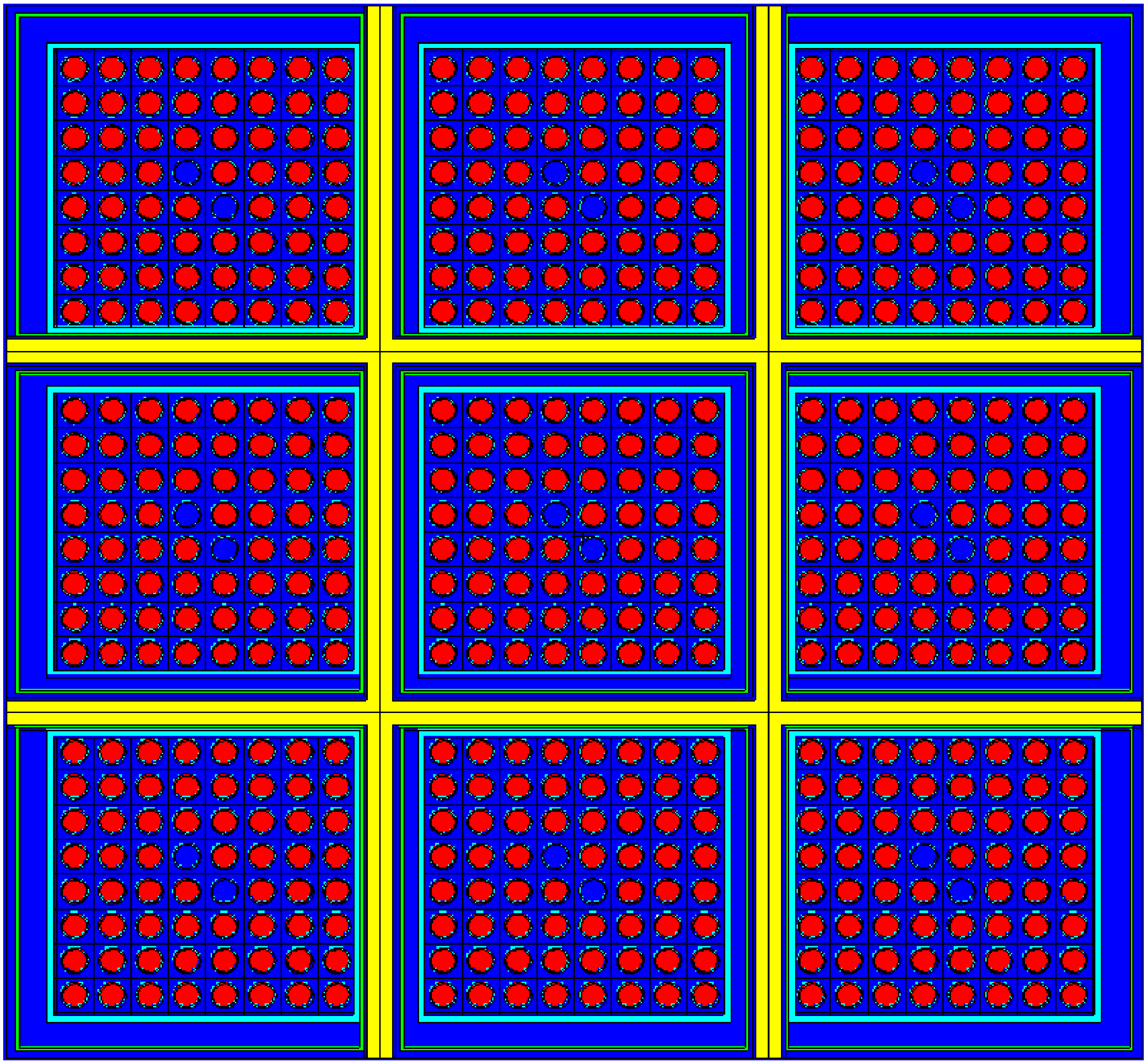


Figure 4-81. BWR STAD – Intact Fuel Criticality Model – Fuel Region Close Up (horizontal cross-section view – between spacer plates)

4.3.4.2.3 Optimum Pitch Cladded BWR Rod Arrays

This configuration is similar to the configuration evaluated in the above section, except that the rod array pitch of the BWR assemblies was varied to yield the maximum k_{eff} value. This configuration was modeled to represent a contingency where the NRC requires that partial assembly reconfiguration (where the fuel rod array pitch may change) must be considered for HAC for (initially intact) high burnup fuel.

The cladding was not removed from the assemblies and the guide tubes of the 8×8 assembly were still modeled. The only difference in the array is that the pitch was varied. The BWR assembly flow channel was also removed (since the flow channel, if present, would prevent the fuel rod pitch from increasing to its optimum value). It was assumed that no fuel pellets leave the fuel rods, and that the fuel rods do not break into rod fragments that can travel between one axial zone of the fuel assembly to another. Thus, the number of fuel rods in the array (62) is retained, and the fuel rods (including their cladding) may not shift out past the cell walls.

Analyses performed in support of the DOE Task 17 report[19] show that maximum BWR assembly reactivity occurs when the fuel rods are separated as much as possible, so that the outer rows of fuel rods are in contact with the cell walls. That configuration was modeled for this evaluation.

A horizontal cross-section view of the optimum-pitch BWR criticality model (between spacer plates) is shown in Figure 4-82.

The results of the optimum BWR assembly rod pitch evaluation are presented in Table 4-38. A fully-loaded BWR STAD with 5.0%-enriched, optimum-pitch BWR assemblies produced an unacceptably high k_{eff} value, so the modeled enrichment had to be reduced. The raw k_{eff} value for a BWR STAD loaded with optimum pitch, 4.3% enriched (8×8) BWR assemblies is 0.935, which is just under the maximum allowable raw k_{eff} value of 0.9376.

An additional analysis showed that if the BWR assembly in the center cell of the BWR STAD basket were removed (resulting in a payload of eight BWR assemblies), a BWR assembly (planar average) initial enrichment level of 5.0% yields an acceptable raw k_{eff} value of 0.873 for optimum pitch BWR fuel. That k_{eff} result is also tabulated in Table 4-38. An evaluation which modeled borated stainless steel plates around the periphery of the BWR STAD basket yielded an acceptable raw k_{eff} value of 0.934 for a full payload of nine optimum pitch (8×8) BWR assemblies with an initial enrichment level of 4.75%. The analyses showed that half thickness (7/32-inch) borated stainless steel edge plates were sufficient to yield the above k_{eff} result (of 0.934) and that full thickness plates yield roughly the same k_{eff} value (i.e., make no difference). Analyses showed that adding neutron absorbers (e.g., borated aluminum sheets) to the STAD carrier structure has little impact on reactivity. The criticality model which places half-thickness borated stainless steel plates around the STAD basket edge is illustrated in Figure 4-83.

Thus, it is concluded that if partial reconfiguration of BWR assemblies (such that the rod pitch is optimized) is assumed along with water ingress into the cask and STAD interiors, a reduction in payload, from nine to eight BWR assemblies, would be required for BWR assemblies with planar average initial enrichment levels above 4.3%. That may constitute a significant fraction of the US spent BWR fuel inventory in the future. If borated stainless steel plates were placed around the periphery of the BWR STAD basket, payload reduction would only be necessary for BWR assemblies with initial enrichment levels over 4.75%, which is a very small fraction of the current (or future) US spent BWR assembly inventory. Thus, if such a change to the BWR

STAD basket design were made, payload reductions would be insignificant. However, such a design change would significantly increase the cost and weight of the STADs.

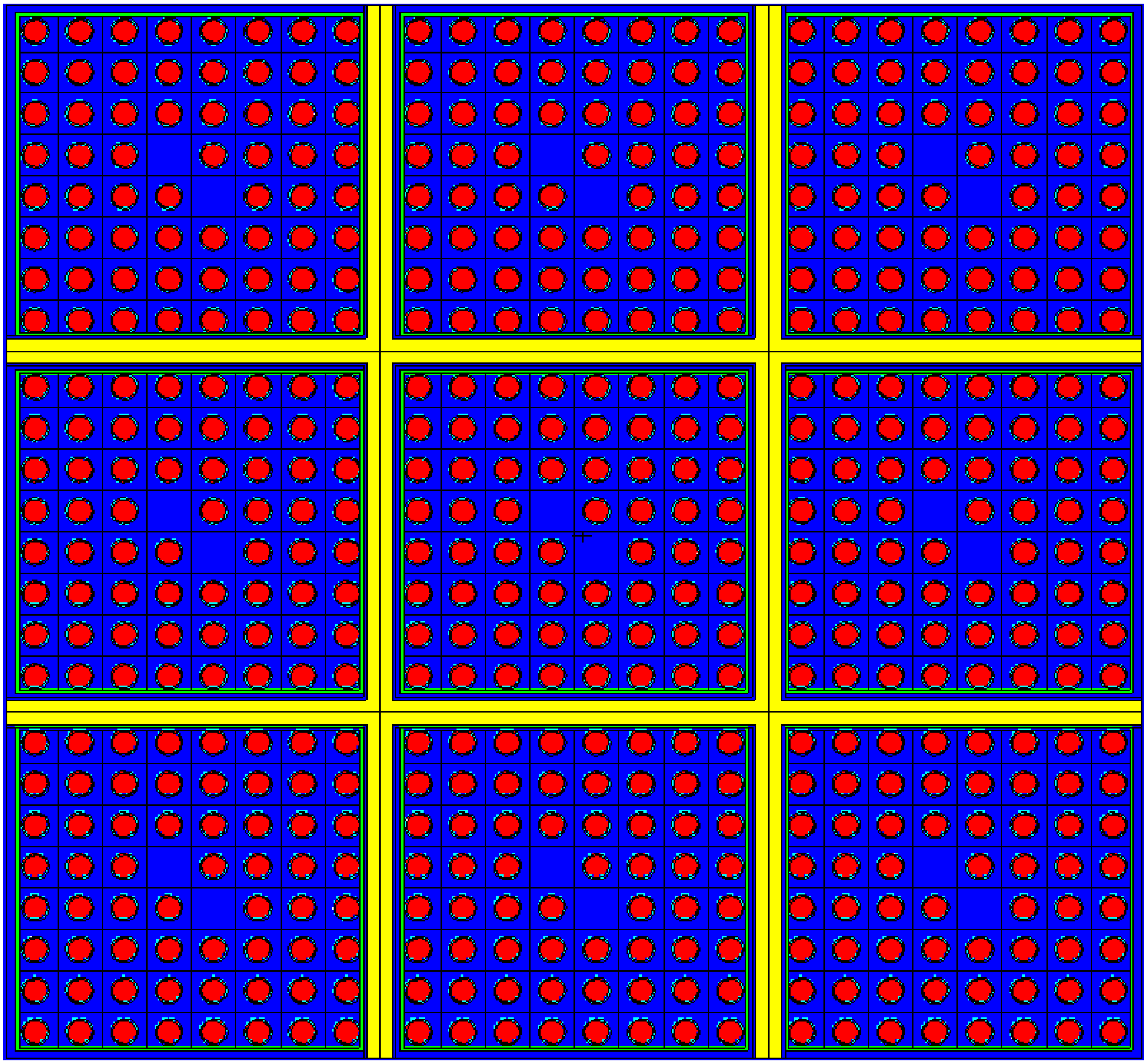


Figure 4-82. BWR STAD – Optimum Pitch Array Criticality Model -Fuel Region Close Up (horizontal cross-section view – between spacer plates)
Note: the rest of model is identical to that shown in Figure 4-80

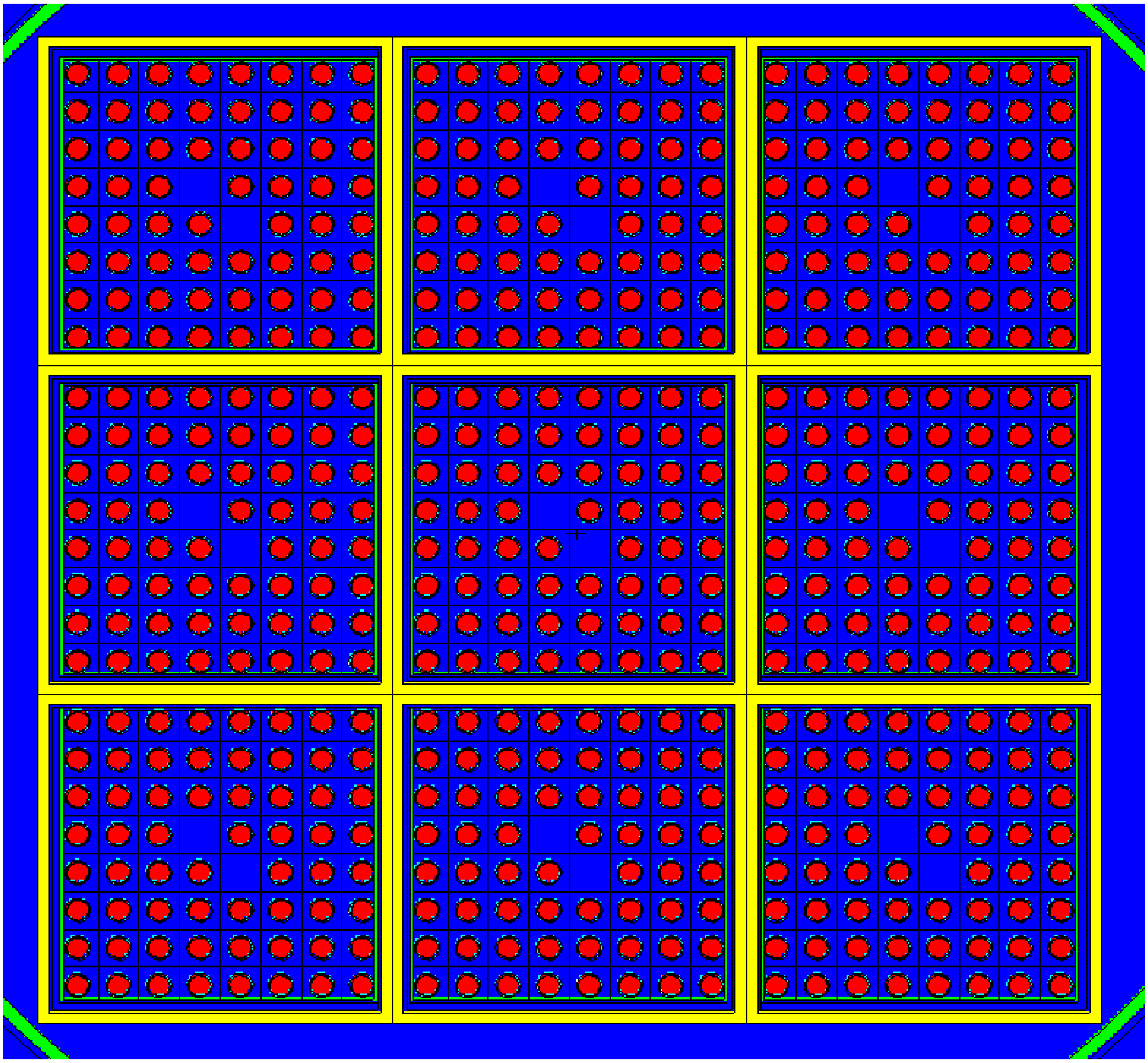


Figure 4-83. BWR STAD – Optimum Pitch Array Criticality Model -Fuel Region Close Up (horizontal cross-section view – between spacer plates) (half-thickness borated stainless steel plates around basket periphery)

4.3.4.2.4 Optimum BWR Fuel Pellet (Rubble) Array

Finally, an evaluation was performed for an optimum BWR pellet (rubble) array similar to the one described for the PWR STAD in Section 4.3.4.1.5. The fuel rod cladding was conservatively removed. The primary material modeled in the STAD interior, other than the fuel pellets, was the borated stainless steel neutron absorber plates. The (optimum) pitch of the pellet array was set based on similar evaluations presented in the DOE Task 17 report[19]. The pellet array was then modeled as filling the STAD interior.

The criticality analyses showed that the optimum BWR fuel pellet array described above yields unacceptable k_{eff} values for the current STAD basket configuration. Therefore, an analysis was performed which modeled borated stainless steel plates around the outer edges of the assembly cells, as well as borated stainless steel plates that extend out to the edge of the STAD interior. A cross-section view (between spacer plates) of that model is shown in Figure 4-84.

The results of the above analysis are tabulated in Table 4-38. The results show even with the extended borated stainless steel plate configuration shown in Figure 4-84, an acceptable k_{eff} value of 0.933 could only be attained at a BWR assembly planar average initial enrichment level of 3.6%. Reducing the STAD payload (e.g. to eight BWR assemblies) will not help in this case, since the fuel pellets (that are free to move within the STAD cavity) could still fill the STAD interior area (as illustrated in Figure 4-84) over a significant axial span. Thus, as axial leakage does not significantly affect reactivity, the removal of one or more BWR assemblies would do little to reduce the reactivity of the optimum pellet array configuration. It is also unclear if or how even more borated stainless steel could be added to the basket design in order to significantly improve STAD performance for this optimum pellet array configuration. As the STADs are already neutronically isolated from each other, placing neutron absorbing materials outside the STADs (within the STAD carrier structure) would also have little impact.

Thus, the criticality results show that if water ingress into the cask and STAD interiors is considered credible, and it is also assumed that a significant fraction of the fuel pellets could be released from the fuel rods under HAC, then the BWR STAD would only be able to accommodate BWR assemblies with initial enrichment levels of 3.6% or less. It is unlikely that any plausible STAD design changes could significantly increase that allowable enrichment. In the future, most of the BWR assembly inventory is expected to have initial enrichment levels over 3.6%.

Thus, in conclusion, the hypothetical contingency evaluated in this section is problematic for the BWR STAD. Thus, it will be necessary to classify either water ingress or large scale pellet release (or the combination of the two) under HAC as non-credible. It is likely that the combination of the two could be classified as two independent, unlikely events, which would eliminate the need to demonstrate sub-criticality under those conditions. It is possible, however, that this could be the source of a small amount of licensing risk for the BWR STAD.

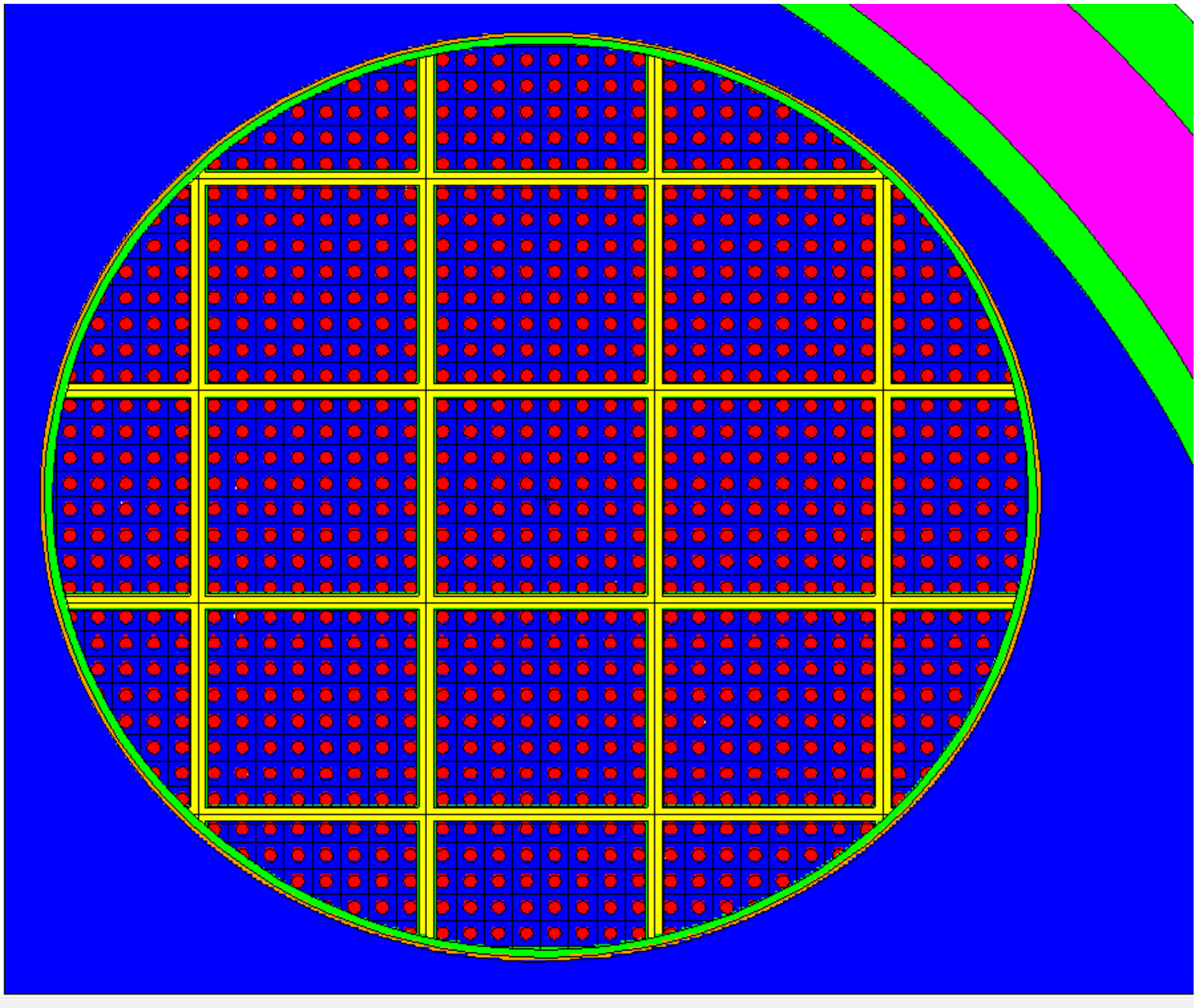


Figure 4-84. BWR STAD – Optimum Fuel Pellet (rubble) Array Criticality Model (extended borated stainless steel plate configuration) (horizontal cross-section view – between spacer plates)

Table 4-38. Summary of STAD Criticality Evaluation Results

Basket/Assembly Configuration	**MCNP5 Raw K_{eff}[2,3]**
MAGNATRAN Intact Assembly Basket[1] – 5.0%, 45 GWd/MTU PWR fuel	0.891
MAGNATRAN DFC Basket[1] - 5.0%, 45 GWd/MTU PWR fuel	0.915
PWR STAD – Intact 5.0% Enriched, 45 GWd/MTU Fuel	0.786
PWR STAD – Optimum Pitch, Cladded, 5.0% Enriched, 45 GWd/MTU Fuel	0.822
PWR STAD – Optimum Fuel Pellet (rubble) Array, 5.0% Enriched, 45 GWd/MTU Fuel - Standard Borated Stainless Steel Plate Configuration	0.943
PWR STAD – Optimum Fuel Pellet (rubble) Array, 5.0% Enriched, 45 GWd/MTU Fuel - Extended Borated Stainless Steel Plate Configuration (see Figure 4-79)	0.881
BWR STAD – Intact 5.0% Enriched Fuel	0.880
BWR STAD – Optimum Pitch, Cladded Rods, 4.3% Enriched Fuel – Full Payload Standard Borated Stainless Steel Plate Configuration	0.935
BWR STAD – Optimum Pitch, Cladded Rods, 5.0% Enriched Fuel – 8-Assembly Payload - Standard Borated Stainless Steel Plate Configuration	0.873
BWR STAD – Optimum Pitch, Cladded Rods, 4.75% Enriched Fuel – Full Payload Borated Stainless Steel Plates Also Around Outer Edges of Assembly Cells	0.934
BWR STAD – Optimum Fuel Pellet (rubble) Array, 3.6% Enriched Fuel Extended Borated Stainless Steel Plate Configuration (see Figure 4-84)	0.933

Notes:

1. Burnup curves which correspond to the intact and DFC MAGNATRAN baskets are shown (in comparison to the US PWR spent fuel inventory) in . PWR STAD basket and payload configurations with similar raw k_{eff} values are assumed to yield similar burnup curves.
2. For the PWR STAD analyses, if the raw k_{eff} value is less than the MAGNATRAN intact fuel value of 0.891, then the analyzed configuration should be able to accommodate the entire US spent PWR fuel inventory.
3. For the (unburned fuel) BWR STAD analyses, raw k_{eff} values under 0.9376 are acceptable, and will meet 10 CFR 71 criticality requirements.

5 CONCEPT OF OPERATIONS

5.1 STAD CANISTER LOADING PROCESS

This section provides general procedural guidance for the loading and unloading of the STAD canister using a 4-STAD canister carrier concept. A flow sheet showing the loading process is provided in Appendix G and an animation of the loading process was developed by the Team and will be provided to the DOE as a separate deliverable. Final equipment and operating requirements will need to be established by the designer prior to implementation. The major auxiliary equipment generally required by the user to load and close or to open and unload the system is described below.

The STAD and the supporting process equipment (transfer cask, storage cask, etc.) are designed to provide effective shielding for operations personnel; however, supplemental shielding may be used to further reduce operator radiation exposure.

The STAD and supporting process equipment may incorporate further design features to minimize the potential for contamination of the STAD during fuel loading, STAD canister preparation, and transfer.

The STAD canister concept defines loading in the spent fuel pool, but the external surfaces are protected from contact with the contaminated pool water by clean water maintained in the interstitial volume between the transfer cask and the STAD canisters. For purposes of the operating procedures, clean water is defined as demineralized, processed, or filtered pool water, or any water external to the spent fuel pool that has water chemistry compatible for use in the spent fuel pool.

Table 4-2 provides the handling weights for the major components of the unloaded and loaded STAD and the loads to be lifted during various phases of the loading and unloading operations.

5.1.1 STAD Operating Procedures

5.1.1.1 General Description for Loading the STAD Canister

The STAD canister is used to transfer, store, transport, and ultimately dispose of spent nuclear fuel. Principal components of the system are: the small STAD canister, the STAD carrier, the transfer cask, the concrete cask and the transport cask.

There are two small STAD canister designs, the PWR fuel STAD canister which contains up to four PWR fuel assemblies and the BWR fuel STAD canister which contains up to nine BWR fuel assemblies. Once loaded and welded, the STAD canisters for each are essentially physically identical.

The STAD carrier provides operational alignment, multi-unit handling and shielding during fuel loading operations. The STAD carrier is also a multipurpose frame which functions as a heat transfer device and structural component during storage and transportation. The STAD carrier may be preloaded into a transfer cask or staged with STAD canisters and then loaded into the transfer cask.

The transfer cask contains, supports, and shields the STADs and STAD carrier during fuel loading, lid welding, closure operations and subsequent transfer to storage or transport casks.

Initial system set-up requires installation of a STAD carrier into the Transfer Cask and placement of four STAD canisters into the carrier.

The transfer cask has integrated pneumatic seals at the top and bottom to provide a boundary for clean water to be maintained within the transfer cask during fuel loading. The transfer cask is also equipped with multiple inlet and outlets whereby the clean water boundary can be filled/drained. It is expected that the canisters will be filled with pool water (particularly PWR loading) and the interstitial area within the transfer cask filled with clean water prior to placing the system in the fuel pool. The seals are to be inflated after the carrier and STADs are properly loaded and positioned within the transfer cask. The seals are inflated with air or inert gas and expand to make contact with the upper shield disk and the lower support plate of the carrier. This develops the boundary for the clean water fill. To ensure adequate contamination control, the clean water system can be over-pressured, wiper rings could be used in the carrier to provide seal around each canister or a sealing ring assembly can be installed on the carrier that uses inflatable seals for each STAD canister. Inherent in the clean water boundary is the ability to provide auxiliary cooling to the STADs if the need is determined. Recirculation of the water through the upper and lower ports can be routed through a heat exchanger or cooler and returned to the transfer cask.

Each STAD is provided with a two lid closure system that is welded in place following fuel loading. A thicker shield plug is installed first and provides the primary containment boundary when welded. The second lid is also welded and provides the redundant sealing of the STAD. The second lid is thinner and incorporates the lifting interface for the loaded STAD canister.

Following fuel loading, the shield plug is installed and the transfer cask containing the loaded STADs is lifted from the bottom of the spent fuel pool. The STADs are partially drained and the shield plug is welded to the STAD canister shell. The top plate-to-shell weld is visual and progressive dye penetrant examined. The cavity is refilled and the STAD is subjected to a hydrostatic pressure test. Following hydrostatic pressure test acceptance, the STAD canister cavity water is drained and followed by completion of vacuum drying and an atmospheric helium backfill. The residual moisture or free water in the STAD canister can be removed by either vacuum drying techniques or dry gas recirculation. The STAD is then evacuated to ≤ 3 torr and backfilled with high-purity helium to 1 atmosphere providing an inert atmosphere for the safe long-term storage of the spent fuel contents. System connections to the vent and drain openings are removed and the port covers are installed, welded, dye penetrant examined, and helium leak tested. The STAD top plate, which provides both the redundant seal closure barrier and STAD handling interface, is then installed, welded, and inspected.

For storage, a concrete cask is positioned and a transfer adapter is placed over the cask opening. This adapter is used to both position the transfer cask and provide the actuation of the transfer cask doors. The transfer cask containing the STADs is positioned on the transfer adapter (stack-up) on the top of the concrete cask. For transfer of the STAD carrier, there are two methods that can be used.

The first method disconnects the primary lifting beam from the transfer cask and uses either an auxiliary crane or an alternate connection to the lift beam to connect slings long enough to lower the STAD carrier into the concrete cask. When the carrier is fully lowered, the slings are disconnected and removed. The transfer adapter is removed and the concrete cask lid is placed and bolted down.

A second method uses an integrated chain hoist to lower the STAD carrier into the concrete cask. The advantage of the second method is retention of the transfer cask on the primary crane hook during the loading. In high seismic areas, where the crane is qualified to single failure proof, this method avoids the free standing stack-up.

Downloading of the STAD carrier requires it be lifted slightly thereby allowing the door hydraulics to open the transfer cask doors. The STAD is then lowered into the concrete cask, rigging is disconnected, transfer cask doors closed and the transfer cask is removed/staged for the next loading. The transfer adapter is removed and the concrete lid assembly is installed and secured to complete the loading process. Transfer operations directly to a transport cask are very similar.

For storage operations, the loaded concrete cask is moved to an ISFSI storage pad using a site-specific transportation system where it is placed in its long-term storage location. Final radiation surveys are completed and the temperature monitoring system is installed, if used, which completes the STAD loading and transfer sequence.

For transport operations, the cask is processed for transport and loaded onto a conveyance. Final radiation surveys are completed and transport packaging installed completing the transportation transfer sequence.

Table 5-1 provides a list of the major auxiliary equipment that is used for operations.

5.1.1.2 General Fuel Loading and Closure of the STAD Canister

This section describes the sequence of operations to load and close the STAD canister(s) in preparation for transferring the STAD carrier to the concrete cask. The empty STAD canisters are assumed to be positioned inside the transfer cask located at a designated workstation.

1. Visually inspect the STAD canister and basket internals for foreign materials or debris.
2. Visually inspect the top of the STAD canister shell and shield plug weld preps.
    i. If the sealing ring assembly is implemented, installation should occur at this point of the operation.

   ii. Carefully lower the assembly over the 4 STAD canisters and ensure proper fit with the carrier shield plate.
   iii. Install mounting hardware and torque to procedure.

3. Inflate the transfer cask seals with air or nitrogen gas. Disconnect the gas supply.
4. Fill the transfer cask with clean demineralized water by filling from the bottom ports and venting from around the STAD canisters.
   i. If the sealing ring assembly is implemented, inflate the STAD canister seals with air or nitrogen gas. Disconnect the gas supply.
5. Verify that at least one lock pin is installed on each transfer cask shield door.
6. Fill the STAD canisters with clean or pool water. For PWR spent fuel contents, the soluble boron concentration in the STAD canister shall be verified and monitored in accordance with the licensed requirements.
7. Attach the lift yoke to a crane suitable for handling the loaded STAD canister, transfer cask, and yoke.
8. Position the lift yoke over the transfer cask and engage it with the two transfer cask trunnions.
9. Lift the transfer cask containing the empty STAD canisters and move it to the spent fuel pool following the prescribed load path.
10. Connect the clean water lines to the lower fill ports of the transfer cask. Ensure that any unused ports are closed or capped to prevent pool water in-leakage.
11. Lower the transfer cask to the pool surface and turn on the clean water supply lines to the lower fill ports to fill the transfer cask/STAD canister interstitial volume.
12. Spray the transfer cask and lift yoke with clean water to wet the exposed surfaces.

    Note: Wetting the components that enter the spent fuel pool and spraying the components leaving the pool will reduce the effort required to decontaminate the components.

13. Lower the transfer cask as it fills with clean water until the upper fill ports are accessible.
14. Hold this position and connect the clean water fill lines to the upper fill ports. Ensure the unused ports are closed or capped to prevent pool water in-leakage.
15. Lower the transfer cask to the bottom of the pool in the cask loading area.

16. Disengage the lift yoke and visually verify that the lift yoke is fully disengaged. Remove the lift yoke from the spent fuel pool while spraying the yoke and crane cables with clean water.
17. Load the previously selected fuel assemblies into the STAD canister basket.
18. Visually verify the fuel assembly identifications to confirm the serial numbers match the approved fuel-loading pattern.
19. Attach lifting sling to the shield plug and prepare for placement into STAD
20. Raise the shield plug and move over the spent fuel pool.
21. Carefully lower the shield plug until it enters the STAD canister and seats in the STAD canister.
22. Allow sling cables to go slack and disengage slings.
23. Repeat operations 19 through 22 for each STAD canister shield plug.
24. Lower into pool and position the lifting yoke over the transfer cask.
25. Engage the lift yoke to the trunnions, apply a slight tension, and visually verify engagement.
26. Raise the transfer cask until its top clears the pool surface. Visually verify that the shield plugs are properly seated. Rinse the lift yoke and transfer cask with clean water as the equipment is removed from the pool.
27. Rinse and flush the top of the transfer cask and STAD canister with clean water as necessary to remove any radioactive particles. Survey the top of the STAD carrier, shield plugs, and the top of the transfer cask to check for radioactive particles.
28. Following the prescribed load path, move the transfer cask to the designated workstation for STAD canister closure operations.

    Note: STAD canister closure operations may be performed with the transfer cask partially submerged in the spent fuel pool, cask loading pit, or an equivalent structure. Each commercial site will have specific needs in this operation.

29. Disengage the lift yoke from the transfer cask trunnions. Place lift yoke in storage/lay-down area.

30. If required, connect the transfer cask circulating water cooling system (CWCS), or alternative flush/cooling system, to the lower and upper fill lines. Unused fill lines are to be closed or capped.

31. Initiate clean water flow into the transfer cask lower fill lines with water discharging through the upper fill lines. Ensure water flow is maintained to keep the outlet water temperature ≤ specification limits.

    Note: CWCS operations are determined in detailed analysis for thermal transient conditions and have been in the range of 30-60 gallons per minute (GPM). Typical flow control is based on the outlet water temperature.

    Note: With an CWCS operating, there are no time limits through initiation of the draining of the STAD canister(s).

32. Using a portable suction pump, remove any standing water from the STAD shield plug recess and weld grooves, and the vent and drain ports.

33. Decontaminate the top of the transfer cask and STAD canister shield plug to allow installation of the welding equipment. Decontaminate external surfaces of the transfer cask and install any temporary shielding.

34. Verify quick-disconnects are installed in both the vent and drain port openings in each of the four STAD canisters.

35. Connect the drain and blow down system vent lines with the STAD quick-connector(s).

36. Install a venting device to the vent port quick-disconnect to prevent combustible gas or pressure buildup below the top plate.

37. At the discretion of the user, establish foreign material exclusion controls to prevent objects from being dropped into the STAD canister.

38. Install the welding system, including supplemental shielding, to the top of the carrier shield plate.

    Note: At the discretion of the user, supplemental shielding may be installed around the transfer cask to reduce operator dose. Use of supplemental shielding shall be evaluated to ensure its use does not adversely affect the safety performance of STAD processing.

39. Connect a suction pump to the drain port quick-disconnect and verify venting through the vent port quick-disconnect.

40. Operate the suction pump to remove approximately 6 inches (3-5 gallons) of water from the STAD canister. Disconnect the suction pump.

    Note: The radiation level will increase as water is removed from the STAD canister cavity, as shielding material is being removed.

    Note: Fuel rods will not be exposed to air during the 3-5 gallon pump-down.

41. Attach a hydrogen detector to the vent line. Ensure that the vent line does not interfere with the operation of the weld machine.

42. Sample the gas volume below the shield plug and observe hydrogen detector for H_2 concentration prior to commencing shield plug welding operations. Monitor H_2 concentration in the STAD canister until the root pass of the shield plug-to-shell weld is completed.

    Note: If H_2 concentration exceeds 2.4% prior to or during root pass welding operations, immediately stop welding operations. Evacuate the STAD canister gas volume or purge the gas volume with helium. Verify H_2 levels are <2.4% prior to restarting welding operations.

    Note: In place of continuous H_2 monitoring, continuous gas purging of the volume below the lid may be used in concert with initial (prior to start of welding) and intermittent H_2 monitoring (upon termination of gas purging and prior to re-starting welding operations).

43. Install shims into the shield plug-to-STAD canister shell gap, if required, to establish a uniform gap for welding. Tack weld the shield plug and shims.

44. Operate the welding equipment to complete the shield plug-to-STAD canister shell root pass weld in accordance with the approved weld procedure.

45. Perform visual examinations and liquid penetrant testing (PT) of the root pass and record the results.

46. Remove the H_2 detector from the vent line while ensuring the STAD canister cavity vent line remains installed and allows venting of gases from the cavity.

47. Operate the welding equipment to perform the shield plug-to-shell weld to the mid-plane between the root and final weld surfaces. Perform visual examinations and liquid penetrant testing (PT) for the mid-plane weld pass, and record the results.

48. Complete welding through the completion of the final pass of the shield plug weld, perform final visual examinations and PT, and record the results.

49. Perform a hydrostatic test of the STAD canister as follows:

    i. Connect a drain line to the vent port and a pressure test system to the drain port.

    ii. Refill the STAD canister with clean water until water is observed flowing from the vent port drain line. Close the vent line isolation valve. Ensure continuing compliance with the boron concentration requirements of Limiting Condition of Operation (LCO) 3.2.1.

    iii. Pressurize the STAD canister to design pressure requirements and isolate the STAD canister.

        a) Maintain the STAD canister pressure for a minimum 10-minute hold period. At the end of the 10-minute hold period, visually examine the shield plug-to-STAD canister shell weld for leakage of water, while maintaining the test pressure. The test pressure shall be maintained until the completion of the visual inspection of the shield plug-to-STAD canister shell weld.

        b) The hydrostatic test is acceptable if there is no visible water leakage from the shield plug-to-STAD canister shell weld based on a visual examination of the weld after a minimum 10-minute hold period, while maintaining the test pressure.

        c) Vent the STAD canister cavity and remove the pressure test system from the drain port and the drain line from the vent line. Reinstall a vent line to the vent port to prevent pressurization of the STAD canister.

50. Remove the water from the STAD canister using one of the following methods: drain down using a suction pump with a pressurized helium cover gas; or blow down using pressurized helium gas.

    Note: Fuel rods shall not be exposed to air during STAD canister draining operations.

51. Connect a drain line with or without suction pump to the drain port connector.

52. Connect a regulated helium gas supply to the vent port connector.

53. Open gas supply valve and start suction pump, if used, and drain water from the STAD canister until water ceases to flow out of the drain line. Close gas supply valve and stop suction pump.

54. At the option of the user, disconnect suction pump, close discharge line isolation valve, and open helium gas supply line. Pressurize STAD canister to approximately 25 psig and

open discharge line isolation valve to blow down the STAD canister. Repeat blow down operations until no significant water flows out of the drain line.

> Note: Time used for system draining and blow down is considered part of the vacuum drying time.

55. Disconnect the drain line and gas supply line from the drain and vent port quick-disconnects.
56. Dry the STAD canister cavity using vacuum drying methods as follows.

    > Note: Ensure heat load dependent vacuum drying time limits are not exceeded so that fuel cladding temperatures are maintained below 752ºF.

    i. Connect the vacuum drying system to the vent and drain port openings.

    ii. Operate the vacuum pump until a vapor pressure of ≤ 10 torr is achieved in the STAD canister.

    iii. Isolate the vacuum pump from the STAD canister and turn off the vacuum pump. Observe the vacuum gauge connected to the STAD canister for an increase in pressure for a minimum period of 10 minutes. If the STAD canister pressure is ≤ 10 torr at the end of 10 minutes, the STAD canister is dry of free water.
57. Upon satisfactory completion of the dryness verification, evacuate the STAD canister cavity to a pressure of ≤ 3 torr. Isolate and turn off the vacuum pump, and backfill and pressurize the STAD canister cavity with 99.995% (minimum) pure helium as follows:

    i. Set the helium bottle regulator to 90 (+5,-0) psig.

    ii. Slowly open the helium supply valve and backfill the STAD canister to 1 atmosphere (0 psig).
58. Disconnect the vacuum drying helium backfill system from the vent and drain openings.
59. Install and weld the port cover on the drain port opening.
60. Install and weld the port cover on the vent port opening.
61. Perform visual and PT examinations of the final surface of the port cover welds and record the results.
62. Perform helium leak test on each of the port cover welds to verify the absence of helium leakage past the port cover welds.

63. Install closure plate within the STAD canister recess and tack the closure plate in position.

64. Weld the closure plate to the STAD canister shell. Perform visual and PT examinations of the final surfaces of the welds and record the results.

65. Using an appropriate crane, remove the weld machine and any supplemental shielding.

66. If the CWCS has been in operation throughout the STAD canister closing operations up to helium backfill is achieved, initiate draining of the STAD canister/transfer cask by stopping CWCS flow to the cask and connecting one or more drain lines to the lower fill ports. Once the cask is drained, deflate the top and bottom seals.
    i. If the sealing ring assembly is implemented, removal should occur at this point of the operation.
    ii. Remove attachment hardware and rig the shield ring assembly for lifting.
    iii. Carefully raise the assembly over the 4 STAD canisters.
    iv. Position shield ring assembly for next loading operation.

67. Install carrier retaining blocks or retention ring depending on the final design.

68. Install the four (4) swivel hoist rings into the four (4) threaded holes in the top plate of the STAD canister carrier. Carrier transfer to storage will be performed by two sets of 2 leg slings.

69. Torque the hoist rings to the manufacturer’s recommended value.

    Note: Utilize high temperature-resistant slings (≤ 350°F).

    Note: As noted in the introduction, alternative site-specific STAD canister lifting systems and equipment may be used for lowering and lifting the STAD canister in the transfer cask. The lifting system design must comply with the user’s heavy load program and the applicable requirements of ANSI N14.6, NUREG-0612, and/or ASME/ANSI B30.1, as appropriate.

70. Complete final decontamination of the transfer cask exterior surfaces. Final STAD canister contamination surveys may be performed after STAD canister transfer following Step 21 in Section 5.1.1.3 when STAD canister surfaces are more accessible.

71. Proceed to Section 5.1.1.3.

5.1.1.3 Transferring the STAD Carrier to the Concrete Cask

This section describes the sequence of operations required to complete the transfer of a loaded STAD carrier from the transfer cask into a concrete cask, and preparation of the concrete cask for movement to the ISFSI pad.

1. Position an empty concrete cask with the lid assembly removed in the designated STAD carrier transfer location.

   Note: The concrete cask can be positioned on the ground, or on a de-energized air pad set, roller skid, heavy-haul trailer, rail car, or transfer cart. The transfer location can be in a truck/rail bay inside the loading facility or an external area accessed by the facility cask handling crane.

2. Inspect all concrete cask openings for foreign objects and remove if present; if required, install supplemental shielding in four outlets.
3. Install a four-legged sling set to the lifting points on the transfer adapter.
4. Using the crane, lift the transfer adapter and place it on top of the concrete cask ensuring that the guide ring sits inside the concrete cask lid flange. Remove the sling set from the crane and move the slings out of the operational area.
5. Connect a hydraulic supply system to the hydraulic cylinders of the transfer adapter.
6. Verify the movement of the connectors and move the connector tees to the fully extended position.
7. Connect the lift yoke to the crane and engage the lift yoke to the transfer cask trunnions. Ensure all lines, temporary shielding and work platforms are removed to allow for the vertical lift of the transfer cask.
8. Raise the transfer cask and move it into position over the empty concrete cask.
9. Slowly lower the transfer cask into the engagement position on top of the transfer adapter to align with the door rails and engage the connector tees.
10. Following set down, remove the lock pins from the shield door lock tabs.
11. Install a stabilization system for the transfer cask, if required by the facility heavy load handling or seismic analysis programs.
12. Disengage the lift yoke from the transfer cask trunnions and move the lift yoke from the area.

13. As appropriate to the STAD carrier lifting system being used, move the lifting system to a position above the transfer cask. If redundant sling sets are being used, connect the sling sets to the crane hook.

14. Using the STAD carrier lifting system, lift the STAD carrier slightly (approximately ½ -1 inch) to remove the STAD carrier weight from the shield doors.

    Note: The lifting system operator must take care to ensure that the STAD carrier is not lifted such that the retaining blocks or the retaining ring is engaged by the top of the STAD carrier.

15. Open the transfer cask shield doors with the hydraulic system to provide access to the concrete cask cavity.

16. Using the cask handling crane in slow speed (or other approved site-specific handling system), slowly lower the STAD carrier into the concrete cask cavity until the STAD carrier is seated on the pedestal.

    Note: The transfer adapter and the standoffs in the concrete cask will ensure the STAD carrier is appropriately centered on the pedestal within the concrete cask.

    Note: The completion of the transfer of the STAD carrier to the concrete cask (i.e., the top of the STAD carrier is in the concrete cask cavity) completes the STAD carrier transfer evolution time.

17. When the STAD carrier is seated, disconnect the slings (or other handling system) from the lifting system, and lower the sling sets through the transfer cask until they rest on top of the STAD carrier.

18. Retrieve the lift yoke and engage the lift yoke to the transfer cask trunnions.

19. Remove the seismic/heavy load restraints from the transfer cask, if installed.

20. Close the shield doors using the hydraulic system and reinstall the lock pins into the shield door lock tabs.

21. Lift the transfer cask from the top of the concrete cask and return it to the cask preparation area for next fuel loading sequence or to its designated storage location.

22. Disconnect hydraulic supply system from the transfer adapter hydraulic cylinders.

23. Remove redundant sling sets, swivel hoist rings, or other lifting system components from the top of the STAD carrier, if installed.

24. Verify all equipment and tools have been removed from the top of the STAD carrier and transfer adapter.

25. Connect the transfer adapter four-legged sling set to the crane hook and lift the transfer adapter off the concrete cask. Place the transfer adapter in its designated storage location and remove the slings from the crane hook. Remove supplemental shielding from outlets.

26. Install three swivel hoist rings into the concrete cask lid and attach the three-legged sling set. Attach the lifting sling set to the crane hook.

27. Lift the concrete cask lid and place it in position on the top of the flange.

28. Remove the sling set and swivel hoist rings and install the concrete cask lid bolts. Torque to the value specified.

29. Move the loaded concrete cask into position for access to the site-specific transport equipment.

30. Transport loaded concrete cask to the storage pad.

5.1.1.4 Transferring the STAD Carrier to the Transport Cask

This section describes the sequence of operations required to complete the transfer of a loaded STAD carrier from the transfer cask into a transport cask.

1. Position an empty transport cask with the lid removed in a site designated STAD carrier transfer location.

   Note: The transport cask can be positioned on the ground, roller skid, heavy-haul trailer, rail car, or transfer cart. The transfer location can be in a truck/rail bay inside the loading facility or an external area accessed by the facility cask handling crane.

2 Inspect transport cask cavity for foreign objects and remove if present.

3. Install a four-legged sling set to the lifting points on the transfer adapter.

4. Using the crane, lift the transfer adapter and place it on top of the concrete cask ensuring that the guide ring sits inside the transport cask lid recess. Remove the sling set from the crane and move the slings out of the operational area.

5. Install and torque adapter retainer bolts.

6. Connect a hydraulic supply system to the hydraulic cylinders of the transfer adapter.

7. Verify the movement of the connectors and move the connector tees to the fully extended position.

8. Connect the lift yoke to the crane and engage the lift yoke to the transfer cask trunnions. Ensure all lines, temporary shielding and work platforms are removed to allow for the vertical lift of the transfer cask.

9. Raise the transfer cask and move it into position over the empty transport cask.

10. Slowly lower the transfer cask into the engagement position on top of the transfer adapter to align with the door rails and engage the connector tees.

11. Following set down, remove the lock pins from the shield door lock tabs.

12. Install a stabilization system for the transfer cask, if required by the facility heavy load handling or seismic analysis programs.

13. Disengage the lift yoke from the transfer cask trunnions and move the lift yoke from the area.

14. As appropriate to the STAD carrier lifting system being used, move the lifting system to a position above the transfer cask. If redundant sling sets are being used, connect the sling sets to the crane hook.

15. Using the STAD carrier lifting system, lift the STAD carrier slightly (approximately ½ -1 inch) to remove the STAD carrier weight from the shield doors.

    Note: The lifting system operator must take care to ensure that the STAD carrier is not lifted such that the retaining blocks or the retaining ring is engaged by the top of the STAD carrier.

16. Open the transfer cask shield doors with the hydraulic system to provide access to the concrete cask cavity.

17. Using the cask handling crane in slow speed (or other approved site-specific handling system), slowly lower the STAD carrier into the transport cask cavity until the STAD carrier is seated.

    Note: The transfer adapter is aligned with the transport cask to ensure the STAD carrier is transferred without impacting the cask lid seal surface.

    Note: The completion of the transfer of the STAD carrier to the transport cask (i.e., the top of the STAD carrier is in the transport cask cavity) completes the STAD carrier transfer evolution time.

18. When the STAD carrier is seated, disconnect the slings (or other handling system) from the lifting system, and lower the sling sets through the transfer cask until they rest on top of the STAD carrier.
19. Retrieve the lift yoke and engage the lift yoke to the transfer cask trunnions.
20. Remove the seismic/heavy load restraints from the transfer cask, if installed.
21. Close the shield doors using the hydraulic system and reinstall the lock pins into the shield door lock tabs.
22. Lift the transfer cask from the top of the transport cask and return it to the cask preparation area for next fuel loading sequence or to its designated storage location.
23. Disconnect hydraulic supply system from the transfer adapter hydraulic cylinders.
24. Remove redundant sling sets, swivel hoist rings, or other lifting system components from the top of the STAD carrier, if installed.
25. Verify all equipment and tools have been removed from the top of the STAD carrier and transfer adapter.
26. Connect the transfer adapter four-legged sling set to the crane hook and lift the transfer adapter off the transport cask. Place the transfer adapter in its designated storage location and remove the slings from the crane hook.
27. Attach the transport cask lid handling slings, ensuring levelness, to crane hook and raise the lid for seal inspection.
28. Inspect the transport cask closure lid O-ring(s) and replace if damaged.

    Note: If the closure lid seals are damaged and require replacement, closure operations will require the new seal be tested to the leak tight requirements typically performed during maintenance operations.

29. Following the inspection of the closure lid O-rings, lift the closure lid and place it on the transportation cask ensuring proper lid seating and orientation. Visually verify proper lid position.
30. Connect drain and vent lines to the cask port quick-disconnects.
31. Install the closure lid bolts and torque all bolts to the torque value specified in the sequence indicated on the closure lid.

32. Connect a vacuum pump and helium gas backfill system to the lid port quick-disconnect valve. Evacuate the cask cavity to a vacuum pressure of < 3 torr and backfill the cavity with helium gas to a pressure of 1 atmosphere.

33. Disconnect all hoses

34. Install the drain and vent port coverplates. Torque the bolts to specified values.

35. Perform closure lid O-ring leakage testing as follows:

    i. Perform the preshipment leakage rate test to confirm no detected leakage to a test sensitivity of 1×10^{-3} ref cm^3/sec by pressurizing the O-ring annulus to 15 (+2, 0) psig and isolating for a minimum of 15 minutes. There shall be no loss in pressure during the test period.

    ii. For O-rings that have been field installed due to damage or failed leakage testing (a), use a leak detector connected to the interseal test port to verify the total leakage rate is $\leq 9.3\times10^{-5}$ cm^3/sec (helium) (1) with a minimum test sensitivity of 4.7×10^{-5} cm^3/sec (helium).

36. Install the test port plug for the lid interseal test port and torque the plug to the value specified.

37. Perform port cover O-ring leakage testing as follows:

    i. Perform the preshipment leakage rate test to confirm no detected leakage to a test sensitivity of 1×10^{-3} ref cm^3/sec by pressurizing the O-ring annulus to 15 (+2, 0) psig and isolating for a minimum of 15 minutes. There shall be no loss in pressure during the test period.

    ii. For O-rings that have been field installed due to damage or failed leakage testing (a), use a leak detector connected to the interseal test port to verify the total leakage rate is $\leq 9.3\times10^{-5}$ cm^3/sec (helium) (1) with a minimum test sensitivity of 4.7×10^{-5} cm^3/sec (helium).

38. Install the test port plug for the port cover interseal test ports and torque the plug to the value specified.

39. Perform final external decontamination and perform survey to verify acceptable level of removable contamination to ensure compliance with 49 CFR 173.443.

40. Perform final radiation survey. Record the survey results.

41. Perform final visual inspection to verify assembly of the transportation cask in accordance with the Certificate of Compliance (CoC).

42. Verify that the loading documentation has been appropriately completed and signed off.

5.1.1.5 Preparation for Transport

1. Engage the lift yoke to the cask lifting trunnions and move the cask to the cask loading area.

2. Load the cask onto the transport vehicle by gently lowering the rotation trunnion recesses into the rear support. Rotate the cask to horizontal by moving the overhead crane in the direction of the front support. Maintain the crane cables vertical over the lifting trunnions.

3. Using a lifting sling, place the tiedown assembly over the cask upper forging between the top neutron shield plate and front trunnions. Install the front tiedown hardware to each side of the front support.

4. Remove cask lifting trunnions and install/torque lifting trunnion cask body coverplate.

5. Complete a health physics removable contamination survey of the cask to ensure compliance with 49 CFR 173.443. Complete a health physics radiation survey of the entire package to ensure compliance with 49 CFR 173.441.

6. Using the designated lifting slings and a crane of appropriate capacity, install the top impact limiter. Install the impact limiter retaining hardware and torque to the value specified.

7. Repeat the operation for the bottom impact limiter installation.

8. Install security seals through holes where provided and record the security seal identification numbers in the cask loading report.

9. Install the personnel barrier/enclosure and torque all attachment bolts to the prescribed torque value. Install padlocks on all personnel barrier/enclosure accesses.

10. Complete a health physics radiation survey of the entire package to ensure compliance with 49 CFR 173.441.

11. Complete a health physics removable contamination survey of the transport vehicle to ensure compliance with 49 CFR 173.443.

12. Determine the transport index (TI) corresponding to the maximum dose rate at 1 meter from the cask. Record on the shipping documents.

13. Determine the appropriate Criticality Safety Index (CSI) assigned to the package contents in accordance with the CoC, and indicate the correct CSI on the fissile material labels applied to the package.

14. Apply placards to the transport vehicle in accordance with 49 CFR 172.500 and provide special instructions to the carrier/shipper for an Exclusive Use Shipment.

15. Complete the shipping documentation in accordance with 49 CFR Subchapter C.

Table 5-1. Major Auxiliary Equipment

Table 5-1. Major Auxiliary Equipment	
ITEM	**DESCRIPTION**
Air Pad Rig Set	Optional device consisting of four air pads, a controller, and an air supply source that allows lifting and moving the concrete cask using air supplied at a high volume.
Transfer Cask Fill System	System that supplies clean/filtered spent fuel pool water through the transfer cask/STAD carrier interstitial volume using the lower and upper transfer cask fill lines. The system maintains a positive clean water flow to minimize the exposure of the STAD canister external surfaces to contaminated spent fuel pool water.
Circulating Water Cooling System (CWCS)	The system provides a circulating water flow through the transfer cask to maintain STAD shell temperatures during welding and drying evolutions. The system includes appropriate circulating pump, pressure gauges, and inlet and outlet water thermometer.
Annulus Seals	Inflatable seals provided at the top and bottom of the transfer cask/STAD carrier for use with the transfer cask fill and circulating water cooling systems.
Cask Transporter	A heavy-haul trailer, a rail car, a vertical cask transporter, or other specially designed equipment used onsite to move the concrete cask. The loaded concrete cask is transported vertically resting on its base (requiring a flat-bed transporter) or it is transported vertically suspended from its lifting lugs (requiring a vertical cask transporter).
Closure Lid Lifting Sling System	Sling system used to install the shield plug and top plates into the STAD canisters.
Cool-down System (CDS)	Introduces nitrogen, helium, and cooling water to the STAD canister cavity to cool-down the internals and stored spent fuel to allow the return of the STAD canister to the spent fuel pool for potential unloading of the fuel assemblies. This system would only be required in the highly unlikely event that a loaded STAD canister had to be unloaded.
Drain and Blow Down System (DBS)	System used to pump out and/or blow down the water from the STAD canister cavity prior to the start of welding operations, drying operations and to refill the cavity for hydrostatic testing the shield plug weld. The system includes the appropriate suction pump, piping/hoses, helium cover gas supply, pressure gauges, and valves to connect to the STAD canister vent and drain port connections to complete the draining and hydrostatic testing.
Hydrogen Detection System	System that detects increased concentration of H_2 in the canister cavity resulting from any possible material reactions during shield plug root pass welding operations and for shield plug weld removal operations.
Sealing Ring Assembly	A system with inflatable seals used to minimize fuel pool contamination of the STAD canisters during fuel loading operations. Attaches to the carrier shield plate. Requires an alternate design carrier (shorter by 4-5”) to allow the seals to be located far enough below the STAD tops to avoid thermal damage during welding
Helium Mass Spectrometer Leak Detector (MSLD)	A system utilized to perform the helium leakage testing of the vent and drain port cover welds.
Lift Yoke (with Crane Hook Extension, if required)	Device for lifting and moving the transfer cask by engaging the lifting trunnions.

Table 5-1. Major Auxiliary Equipment

ITEM	DESCRIPTION
Loaded STAD carrier Sling System	Redundant sling system (two 2-legged slings) used to transfer/handling a loaded STAD carrier into a concrete cask or a transfer cask and meeting the requirements of ANSI N14.6 and the facility crane. Alternative STAD canister handling systems that meet site-specific or client requirements and comply with the facility's heavy lift program developed per NUREG-0612 may be utilized.
Remote/Robotic Welding System	System that completes the shield plug, top plate and port cover welds with minimal operator assistance. The system may include video cameras and a recording device to remotely observe the welding activities and to videotape the results of the top plate PT examinations.
Supplemental Weld Shield	Optional steel plate installed on the transfer cask to provide additional shielding to the operators during STAD canister closure welding, preparation, and test activities. The supplemental weld shield may be installed separately or as an integrated base plate for the welding system.
Vacuum Drying and Helium Backfill System	The system used to vaporize and remove free water, water vapor, and oxidizing gases from the STAD canister cavity prior to backfilling with helium. The system includes the appropriate vacuum pump(s), vacuum and pressure gauges, helium supply connections and valves, and hoses to connect the system to the vent and drain connections.

5.2 STORAGE/AGING IN MULTI-CANISTER OVERPACKS AND VAULT SYSTEMS

The STAD canister, carrier and storage overpack will be capable of receiving approval for use by the NRC under 10 CFR 72 regulations. In accordance with U.S. federal regulations contained in 10 CFR 72.42, the initial term of a site-specific license for an ISFSI must not exceed 40 years (originally 20 years but increased to 40 years in 2011). In addition, a site-specific license can be renewed for a period of up to 40 additional years provided the renewal application contains Time Limited Aging Analyses (TLAAs) and Aging Management Programs (AMPs) and is submitted at least two years prior to the initial term's expiration date. An alternative approval method to a site-specific license is a CoC. The terms and applications for a CoC are similar in scope to an application and renewal of a cask site-specific license with the exception of the renewal submittal date, which must be at least 30 days prior to the initial term's expiration date. These requirements are the same for both vertical concrete casks and for horizontal storage modules. In order to operate the storage system for a potential 150 year life, the license or CoC holder for the storage system will have to initiate renewal actions with the NRC prior to expiration of their initial license or CoC term to support continued storage. Renewals are currently limited to a term not to exceed 40 years. Therefore with a 40-80 year initial term and a 40 year extension limit, the current approval term for a storage application is 40-80 years. As renewal actions and aging management programs develop and mature, there may be future opportunities for the package to reach a 150 year life or maybe longer.

Licensee applications for ISFSI site-specific license and CoC renewals must include the following:

- TLAAs that demonstrate that structures, systems, and components (SSCs) important to safety will continue to perform their intended function for the requested period of extended operation and
- A description of the AMP for addressing any issues associated with aging that could adversely affect SSCs important to safety.

The NRC issued NUREG-1927, "Standard Review Plan (SRP) for Renewal of Spent Fuel Dry Cask Storage System Licenses and Certificates of Compliance" in March 2011. NUREG-1927 is in the process of being revised to address issues with submittals received to this date (Calvert Cliffs, Prairie Island and ES VSC-24, etc.). Identified application issues were:

- Inadequate aging management reviews
- AMP lack of details
- Confusion on lead system inspection requirements

Management of the aging effects on dry cask storage systems for extended long term storage, e.g. greater than 40 years, and subsequent transportation of the fuel "begins" when the used fuel assemblies are loaded into a canister. Following welding of the canister closure lid, the canister is drained, evacuated/dried, and back filled with helium. The fuel is then transferred to the concrete storage cask/module and positioned on the storage pad. The first aging management threshold is the proper handling and processing of the fuel for storage. For example, proper drying a leak tight canister backfilled with high purity helium protects the fuel from aging effects.

For long term storage, following the initial 20 year term, an AMP is implemented to substantiate the condition of the storage cask and canister. A properly developed program can provide an additional 40 years of storage time. The key point is that for the AMP to be effective, AMP programs and AMP inspection methods need to be capable of detecting issues prior to failure. Managing aging effects on dry cask storage systems for extended long term storage and subsequent transportation of used fuel depends on AMPs to prevent, mitigate, and detect aging effects on the SSCs early with active and effective system monitoring.

Aging effects should be detected before there is a loss of any structural or functional performance and includes aspects such as defining methods, inspection frequency, sample definition, operational experience, data collection and timing of inspections. The difficulty associated with monitoring storage components like the STAD are accessibility and dose. The

STAD carrier has the ability to allow access to a single STAD canister for removal and inspection. In can be argued that with a programmed inspection of a complete STAD in combination with other AMPs, the status of all 4 STADs, perhaps several storage systems, can be ascertained. Visual inspections of the carrier and internal concrete storage system should be reasonably performed and sufficient for approval term extension requests. External assessment of the storage casks can be scheduled on a regular basis as a typical ISFSI has some degree of inspection performed.

5.3 TRANSPORTATION AND ASSOCIATED TRANSPORTATION COMPONENTS

The transportation cask for the STAD will utilize the same transport cask technology as that developed for Task Order 17 (See Figure 5-1). Cask materials, closure methods, impact limiter design/attachment and general handling features are very similar to the Task Order 17 design. The primary difference is the cavity size.

The transportation casks have a cavity diameter of 78” and cavity length of 194″. The increased size of the cask cavity (compared to the Task Order 17 transportation cask) drives the outside diameter and subsequently the weight. Of more significance, the size drives the outside diameter of the cask with respect to the impact limiters. The increased diameter of the cask impacts the transport package’s accident performance by reducing the stroke distance (radial gap from OD of limiter to surface of neutron shield shell) for the impact limiters. This increased cask OD, in combination with the fixed impact limiter maximum diameter of 128″, requires a stiffer material to stop the cask more quickly (shorter stroke) and thereby results in higher *g*-loads on the package and contents. Preliminary estimates indicate the impact limiter design can meet approximately 80*g*. Minor changes from the Task Order 17 design include longer impact limiter overlap of the transport cask (10″ to 14″) and a slightly stronger limiter material for the radial sections of the limiter. Corner and end drop are not as challenging and can be addressed with modified foam characteristics and geometry.

Another difference is the increase in length of the cask cavity. This is required to compensate for the inclusion of the STAD canister which includes in the axial build a thick plate bottom and the thicker shield plug and closure lid. The canister components alone add 14″ to the additional length. The implementation of the STAD carrier adds another 4″ to the length due to the base plate. Based on the STAD canister’s inside dimension of 181″ clear length for fuel, the net STAD/Carrier length is 197.0″ with the STAD lifting rings being just beyond the top of the upper shield plate resulting in an overall loaded height of 200.0″.

For the transport cask to adequately support the added mass of the shield plate and STAD shield plugs, the lead shield is stopped at a length of 186”. The lead shield starts just below the STAD carrier bottom plate upper surface at 3” off the bottom of the transport cask. This shielding geometry results in an overlap of the lead shield to the effective fuel length providing slightly better shielding than the Task Order 17 design. There is a minor weight penalty for this shielding, but due to the transfer cask being the in-pool loaded component, the transport cask is not limited to the 125 tons of the fuel pool crane.

The closure lid will be reduced in thickness from that of the Task Order 17 cask as the predominant axial shielding for the STADs is provided by the STAD shield plug and the carrier upper support disk (approximately 9″). The primary function of the lid will be resistance to puncture.

The carrier's function in the transportation evaluation is to provide support and conduction heat transfer of the STADs during the transport conditions.

Figure 5-1. Transportation Cask

6 CONCEPT OF FABRICATION

An evaluation of the ability to fabricate the small STAD canister system components has been performed by a member of the Team: Petersen Incorporated, who operate a 600,000 sq. ft. state-of-the-art precision machining and fabrication facility, has been in business for over 53 years, and has fabricated components for the nuclear industry as a core business for the last 15 years. They have provided NQA-1 compliant components for a wide range of customers in the nuclear industry, including supplying canister and cask systems to the designs of Energy*Solutions* and NAC International for the last 15 years. The evaluation concluded that the components are able to be fabricated within current facilities and capabilities. They also have features that allow for uncomplicated manufacturing, which were arrived at following a "fabricability" review during a Team workshop, which resulted in some changes to the STAD canister fuel basket designs. As part of the work on evaluating the ability to fabricate the STAD canisters, fabrication sequences were produced by Petersen Incorporated, and these are provided in Appendix J.

7 USABILITY

The proposed STAD designs can accommodate the entire US spent PWR and BWR fuel inventory, with the exception of South Texas fuel and CE 16×16 fuel with control components (whose length exceeds that of the cask cavity). Some future assembly types, including AP1000 fuel, will also be too long for the proposed cask and basket design. Longer versions of the proposed STAD designs, which can be used with a 150 ton plant crane, could be designed. The South Texas site, and the AP1000 plant design sites, have 150 ton pool cranes.

The proposed STADs and cask systems can store any fuel assembly payload with fuel burnup levels up to 62.5 GWd/MTU and cooling times over 5 years. For transportation, shielding limitations require longer assembly cooling times, which are shown as a function of assembly burnup level in Table 4-4 (on Page 54). With respect to criticality, the system will be able to accommodate the entire US spent fuel inventory, the only qualification being that a slight reduction in payload capacity may be required for a very small fraction of shipments, if moderator exclusion cannot be relied upon. (Note. If release of the fuel pellets from the BWR assembly fuel rods under HAC is deemed credible, then moderator exclusion must be relied upon).

The proposed cask system would be able to accept partial, stainless steel clad and MOX fuel assemblies. The STADs are not designed, at this time, to accept damaged fuel assemblies. The small amount of US stainless clad and MOX fuel is very old (resulting in low gamma and neutron source strengths). All such fuel would physically fit into the proposed cask and baskets. Accommodating stainless clad and MOX fuel may not be necessary, however, as all such fuel may already be in dry storage. The cask systems will be able to accommodate all partial fuel assemblies (i.e., intact assemblies with one or more fuel rods missing).

The proposed STAD and cask designs, described in Section 4.1, will require a plant spent fuel pool crane capacity of 125 tons. Most US nuclear plant sites have a crane capacity of 125 tons or more. Some sites, however, have crane capacities between 100 and 125 tons. Plants with 100 ton crane capacities may be accommodated by designing transfer casks with less shielding, or by placing three (vs. four) STADs inside the transfer and storage casks (should shielding analyses show that acceptable exterior dose rates cannot by obtained from a transfer cask with a loaded hook weight under 100 tons).

As discussed in Section 4.1, the STADs are placed into a carrier, which is then handled, in lieu of handling the individual STADs. The carrier is pre-loaded in the transfer cask, and is subsequently loaded into the storage and transportation casks. Thus, once the STADs are sealed and loaded into the carrier, transfer, storage and transport operations are very similar to those associated with large canister dry-storage systems, for which there is substantial operating experience.

The primary difference in operations is the fact that multiple STADs will have to be drained, vacuum dried and backfilled with helium, as opposed to doing this with a single large canister. Also, four STAD lids (vs. one larger canister lid) will have to be welded on. While the number of operations will be larger for the STAD system, the type and complexity of the operations will be very similar to those currently performed for large canister based dry storage systems. Efforts to reduce loading operation times by doing certain operations (e.g., vacuum drying or lid welding) in parallel may introduce some changes (and increased complexity) to typical dry storage system loading operations.

The transportation cask described in Section 4.1, that can accommodate four STADs, is similar in size and weight to the transportation casks that have been designed for large canister dual-purpose (storage and transportation) systems. The cask will fit on a typical US railcar and has a package width of 128 inches, which meets the Association of American Railroads standard width requirement. The weight of the loaded cask (on the railcar) is well under 150 tons, and can therefore be accommodated by typical railcars.

8 REGULATORY COMPLIANCE

8.1 Applicable Requirements

The SOW for Task Order 18 requires that the design of a STAD canister system must ultimately be licensable; that is, there is should be reasonable assurance that the design could be approved and certified by the NRC for transport and storage of spent fuel.

The NRC regulations governing the review and approval of the STAD canister system design for transport and storage are 10 CFR Part 71 - *Packaging and Transportation of Radioactive Material*, and 10 CFR Part 72 – *Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High Level Radioactive Waste, and Reactor –Related Greater Than Class C Waste*.

Both 10 CFR 71 and 10 CFR 72 have common primary goals and objectives to:

- Prevent the loss of radioactive contents
- Provide shielding and heat dissipation
- Prevent nuclear criticality (maintain sub-criticality)

Likewise, both 10 CFR 71 and 10 CFR 72 set forth very specific requirements for the content of an application for NRC review and approval including:

- Detailed description of the design, including materials of construction
- Evaluation of the design demonstrating that the design satisfies the various conditions of use including accident conditions, including in the case of spent fuel storage natural phenomena such as earthquakes and floods.
- Quality assurance program, or reference to a previously approved quality assurance program
- Operating controls and procedures for use

Guidance to assist in the preparation of a 10 CFR 71 spent fuel transport application is provided in two NRC general guidance documents:

- NRC Regulatory Guide (RG) 7.9 - *Standard Format and Content of Part 71 Applications for Approval of Packages for Radioactive Material*
- NRC NUREG–1617 - *Standard Review Plan (SRP) for Transportation Packages for Spent Nuclear Fuel*

Guidance to assist in the preparation of a 10 CFR 72 spent fuel storage application is provided in the following NRC general guidance documents:

- NRC RG 3.61 – *Standard Format and Content for a Topical Safety Analysis Report for a Spent Fuel Dry Storage Cask*
- NRC NUREG – 1536 rev 1 - *Standard Review Plan (SRP) for Spent Fuel Dry Storage Systems at a General License Facility*
- NRC NUREG – 1927 - *Standard Review Plan for Renewal of Spent Fuel Dry Cask Storage System Licenses and Certificates of Compliance* (NUREG-1927, rev 1 is presently in final draft for ACRS review with publication expected in mid to late 2015)

In addition to the NRC Regulatory Guides and NRC NUREG documents, the NRC has issued Interim Staff Guidance (ISG) documents that provide augmented staff review guidance on new and evolving issues involving spent fuel transportation and storage. Almost all of the ISGs that have been issued by the NRC Division of Spent Fuel Storage and Transportation (and its predecessor organization the Spent Fuel Project Office) are applicable to the STAD canister system design considered in Task Order 18. The list of ISGs is provided below, and the guidance documents can be accessed online at http://www.nrc.gov/reading-rm/doc-collections/isg/spent-fuel.html.

- ISG 1 - Classifying the Condition of Spent Nuclear Fuel for Interim Storage and Transportation Based on Function (*formerly entitled “Damaged Fuel”)*
- ISG-2 - Fuel Retrievability
- ISG-3 - Post Accident Recovery and Compliance with 10 CFR 72.122(l)
- ISG-4 - Cask Closure Weld Inspections
- ISG-5 - Confinement Evaluation
- ISG-6 - Establishing minimum initial enrichment for the bounding design basis fuel assembly(s)
- ISG-7 - Potential Generic Issue Concerning Cask Heat Transfer in a Transportation Accident
- ISG-8 - Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transportation and Storage Casks
- ISG-9 - Storage of Components Associated with Fuel Assemblies
- ISG-10 - Alternatives to the ASME Code
- ISG-11 - Cladding Considerations in the Transportation and Storage of Spent Fuel
- ISG-12 - Buckling of Irradiated Fuel Under Bottom End Drop Conditions
- ISG-13 - Real Individual
- ISG-14 - Supplemental Shielding
- ISG-15 - Materials Evaluation
- ISG-16 - Emergency Planning
- ISG-17 - Interim Storage of Greater Than Class C Waste
- ISG-18 - The Design and Testing of Lid Welds on Austenitic Stainless Steel Canisters as the Confinement Boundary for Spent Fuel Storage
- ISG-19 - Moderator Exclusion Under Hypothetical Accident Conditions and Demonstrating Subcriticality of Spent Fuel Under the Requirements of 10 CFR 71.55 (e)

- ISG-20 - Transportation Package Design Changes Authorized Under 10 CFR Part 71 Without Prior NRC Approval
- ISG-21 - Use of Computational Modeling Software
- ISG-22 - Potential Rod Splitting Due to Exposure to an Oxidizing Atmosphere During Short-Term Cask Loading Operations in LWR or Other Uranium Oxide Based Fuel
- ISG-23 - Application of ASTM Standard Practice C1671-07 when Performing technical reviews of spent fuel storage and transportation packaging licensing actions
- ISG-24 - The Use of a Demonstration Program as a Surveillance Tool for Confirmation of Integrity For Continued Storage of High Burnup Fuel Beyond 20 Years
- ISG-25 - Pressure and Helium Leakage Testing of the Confinement Boundary of Spent Fuel Dry Storage Systems

The topic of high burnup spent fuel has been the subject of much study and analysis by both the NRC and the industry. Dry cask storage of high burnup fuel has been authorized by NRC in many storage applications. However, NRC review of applications for the transport of high burnup fuel continues to be considered on a case-by-case basis. ISG-11 - *Cladding Considerations in the Transportation and Storage of Spent Fuel*, is currently applicable to spent fuel storage; however, the ISG-11 cladding temperature limits at time of cask loading should also be considered for transport cask design. The NRC has recently approved two applications for transport of high burnup fuel (Holtec Hi-Star 180 and NUHOMS 197HB). For the two cases, the applicants were able to demonstrate and justify the acceptability of their assumptions on possible high burnup fuel reconfiguration and the ability to maintain subcriticality. Further development of NRC’s review guidance for high burnup fuel is anticipated over the next few years. At the time of license application, the applicant for the STAD system design considered in this report will need to confirm that the application is consistent with the then current NRC guidance on high burnup fuel.

NRC approval of a 10 CFR 71 application for a CoC for a transportation package is typically issued for a 5-year term, with possible renewal for additional 5-year terms. NRC approval of a 10 CFR 72 application for a site specific license or for a CoC for a dry cask storage system is typically issued for a 40-year term, with possible renewal for a 40-year term.

An additional requirement for the STAD canister system design is that the STAD transport package must be able to be transported by rail which requires that the rail transport package with impact limiters must not exceed the maximum width restriction of 128 inches as specified in the AAR Standard, *S-2043 Performance Specification for Trains Used to Carry High Level Radioactive Materials*.

8.2 DOE Guidance on Cask Design Specifications and Assumptions

DOE provided the general design requirements for the STAD canister system design that are contained in:

> *Performance Specification for Small and Medium Standardized Transportation, Aging, and Disposal Canister Systems, FCRD–NFST–2014–000579*

The Task Order 18 SOW and the design criteria from FCRD-NFST-2014-000579 identify a few STAD system design requirements that may add complexity to the development of the transport and storage applications and add complexity to the NRC's regulatory compliance review. A few examples of the design criteria from FCRD-NFST-2014-000579 and Task Order 18 SOW that may add complexity to the applications and review are listed below:

<u>Aging Management</u>

- Criteria 12 - The design lifetime of the STAD canister shall be 150 years from the time the canister is loaded with SNF to the time the canister is loaded into a waste package.
- Criteria 14 - The 150 years lifetime should be licensable (along with an associated storage overpack, module, vault, etc.) under both 10 CFR 72 and (along with a transportation cask) under 10 CFR 71.

<u>High Burnup Fuel</u>

- Criteria 21 - A STAD canister for PWR assemblies shall be limited to accepting SNF with initial enrichment up to 5 wt % U-235 and burnup up to 62.5 GWd/MTU. Required cooling (decay) time can be variable based on enrichment, burnup, and assembly design.
- Criteria 22 - A STAD canister for BWR assemblies shall accept SNF with initial enrichment up to 5 wt % U-235 and burnup up to 62.5 GWd/MTU. Required cooling (decay) time can be variable based on enrichment, burnup, and assembly design.

<u>Multiple Storage Configurations</u>

- Criteria 26 - The STAD canister shall be designed to store SNF at a utility site in accordance with 10 CFR 72 in either a horizontal or vertical orientation.
- The SOW for Task Order 18 requires an additional configuration for spent fuel storage in a vault, an above or below grade storage system designed as a hardened reinforced concrete structure with an above grade structure providing an operating area.

Multiple STAD Canisters in Storage and Transport Overpacks

- Criteria 66 - Overpacks/modules may be designed to handle single or multiple STAD canisters.
- Criteria 72 - The transportation overpack cavity shall accommodate a STAD canister or canisters (potentially in a multi-canister fixture).

In addition to the design criteria in FCRD-NFST-2014-000579, DOE provided guidance that the STAD design should not consider damaged fuel or damaged fuel cans to be included in the STAD design.

8.3 NRC Review Considerations

New applications for a spent fuel transportation cask design and for a spent fuel dry cask storage system design as presented in this report would typically be considered by the NRC to involve multiple technical review disciplines requiring approximately two-years of staff review time for review of each application. If the NRC reviews are conducted in parallel, there may be some efficiencies and reduction in NRC review effort recognizing, for example, the STAD canister design that would be common to both the transportation and storage applications. However, based on some of the design complexities discussed in Section 8.2, additional NRC staff reviewers, contractor support and NRC review time may be required. The review of both the transport and storage applications will involve multiple technical disciplines including structural, materials, thermal, shielding, and criticality. The two-year estimate of NRC review time for each application, transport and storage, includes time for the initial NRC review of the application and time for NRC review of applicant responses to requests for additional information. The estimate does not include the time for the applicant to review and respond to NRC requests for additional information.

The NRC presently has in place the regulatory framework to conduct the review of the two STAD system applications for transport and storage, and to reach a regulatory determination for issuing an initial 5-year term Part 71 transport CoC and an initial 40-year term Part 72 storage CoC.

However, there are a number of STAD design considerations that may present complexities to the applicant and to the NRC staff review. The potential issues are discussed below:

- Aging Management - To satisfy the DOE design specification, FCRD-NFST-2014-000579, that the design lifetime of the STAD under both 10 CFR 72 and 10 CFR 71 should be "licensable" for 150 years, the applicant for the STAD system design should consider developing and including in the initial application an aging management program as described in NRC NUREG-1927, *Standard Review Plan for Renewal of Spent*

Fuel Dry Cask Storage System Licenses and Certificates of Compliance. The aging management program should be in place starting at day one in the lifetime of the STAD system design to support and provide the future basis for possible renewal up to the 150-year design lifetime. The implemented aging management program would provide the technical basis for future renewal application consideration.

- High Burnup Fuel - The STAD design includes transport and storage of high burnup fuel, with burnup up to 62.5 GWd/MTU. The NRC has much experience with review and approval of applications for the dry cask storage of high burnup spent fuel, and has for the past decade approved multiple dry cask storage systems for storage of high burnup spent fuel. The storage of high burnup fuel in the STAD is not anticipated to be a significant challenge in the NRC review.

  However, the topic of transport of high burnup fuel is presently under much study and analysis by both the NRC and the industry. The NRC review of transport applications for high burnup fuel is presently conducted on a case-by-case review basis with the applicant demonstrating to the satisfaction of the NRC the safety justification for assumptions on high burnup fuel reconfiguration under accident conditions. Further development of NRC's review guidance for transport of high burnup fuel is anticipated over the next few years. The applicant will need to confirm that the application is consistent with the then current NRC guidance on transport of high burnup fuel. The applicant should anticipate that the technical basis and the assumptions for transport of high burnup fuel will receive close NRC scrutiny. Depending on the status of the NRC and industry studies at the time of application, perhaps further study/supporting analysis may be necessary to justify the technical basis and assumptions for transport of high burnup fuel.

- Multiple Storage Configurations - The STAD storage system design requirements provides for storage at a utility site in accordance with 10 CFR 72 in either a horizontal or vertical orientation. Typically, storage applications identify and analyze one storage configuration, vertical or horizontal. The inclusion of both a vertical and horizontal storage system configuration does not necessarily present a technical review challenge, but represents an added level of complexity to the NRC review and possibly added NRC review resources to review the structural, thermal, materials, shielding, operational, and accident considerations for the two separate vertical and horizontal storage systems.

  The additional STAD storage design requirement added by the SOW to address an above or below grade vault storage system clearly adds an additional level of complexity to the STAD system design and application, with an increase in the NRC review resources needed for the review. The NRC has prior experience with the review of an underground vault storage system, and therefore there may not necessarily be technical challenges, but the vault storage system design adds to the review complexity and needed resources.

- Multiple STAD Canisters in Storage and Transport Overpacks - The transport and storage STAD overpack design will allow for the storage and/or transport of either a single STAD canister or 4 STAD canisters. The applicant and the NRC review must analyze the performance of the storage system and the transport package under accident conditions with a transport overpack and storage overpack containing either a single STAD canister or 4 STAD canisters. While there do not appear to be any technical challenges for this aspect of the NRC review, the complexity of the overpack and multiple internal contents and design may represent an added level of NRC review time and resources.

- Moderator Exclusion - The STAD canister system design includes use of moderator exclusion to demonstrate the capability of the STAD to maintain subcriticality under accident conditions. Consideration and use of ISG-19, *Moderator Exclusion,* has been successfully demonstrated in other spent fuel transport applications. The use of ISG-19 in the STAD application should not introduce any new technical challenges. However, the complexity of the analysis and justification for demonstrating moderator exclusion may require an added level of NRC resources for the review.

Countering some of the added complexity of the STAD applications, there are some design considerations that do not push or challenge the margins of previously NRC approved designs and these attributes of the STAD system design should facilitate the NRC review. Examples include:

- Lower capacity of 4 or 16 PWR and 9 or 36 BWR assemblies depending on STAD overpack loading compared to NRC certified transportation packages and dry cask storage systems with 37 PWR and 69 BWR assemblies.
- Lower transport package heat load of approximately 24 kW compared to NRC certified transportation packages with 32 kW or higher heat load.
- STAD canister structural design is similar to canister designs previously reviewed and approved by NRC.

8.4 Regulatory Conclusion

The applicant for the STAD design developed under Task Order 18 should anticipate a detailed NRC review involving multiple technical disciplines requiring approximately two-years of staff review time for the application 10 CFR 71 transport application and approximately two-years of staff review time for the 10 CFR 72 storage application. There may be some efficiencies to be gained in both review resources and review time if the NRC transport and storage reviews are conducted in parallel taking into account the common STAD canister design in both the transport and storage applications. However, these potential efficiencies will most likely be more than offset by some of the complexities in the review discussed in Section 8.3.

The design specification that the STAD should have a licensable 150-year lifetime does present a challenge to the applicant to develop an aging management program at the time of the initial application. The applicant should consider engaging early with the NRC in pre-application meetings to discuss design considerations and plans for an aging management program that would be initiated at the very outset of the STAD system deployment. Early NRC engagement and gaining NRC perspectives on aging management, including new developments with regard to evolving regulatory guidance on aging management (e.g., NUREG-1927 revisions) are important and very relevant to address the150-year lifetime design specification for the STAD system design.

Testing and/or modeling and analysis would be necessary to demonstrate the acceptability of the STAD transportation package to satisfy the routine, normal, and hypothetical accident conditions. Likewise modeling and analysis would be necessary to demonstrate the acceptability of the STAD dry cask storage system and its multiple storage configurations under accident conditions. The applicant will also need to confirm that the application is consistent with the then current NRC guidance on transport of high burnup fuel.

The NRC presently has in place the regulatory framework to conduct the review of the STAD applications for the initial 5-year term Part 71 transport CoC and 40-year term Part 72 storage CoC. The complexities of the review to address the issues identified in Section 8.3 may add to the required NRC review time and resources. The NRC also has in place the regulatory framework to conduct the Part 71 transport and Part 72 storage CoC renewal reviews. With the exception of the issues involving aging management to support the 150-year lifetime for the STAD system design, there do not appear to be any new or novel technical issues to challenge the NRC review.

Based on the considerations summarized above, NRC approval of the STAD system design for the initial 10 CFR 71 transport CoC and the initial 10 CFR 72 storage CoC would be anticipated.

Although Task Order 18 focuses on the storage and transport aspects of the STAD canister, it should be recognized that at some point in the future the STAD canister would have to be licensed as part of a geologic repository system to support a disposal function. A STAD canister would be placed inside a disposal overpack (or waste package) to be designed at some point in the future. Since the STAD canister is entirely constructed out of corrosion-resistant materials with long-term performance characteristics (i.e., stainless steel Type 316 structural components and borated stainless steel neutron absorber plates), this should facilitate repository design and licensing.

9 COST ESTIMATES

Utilizing the cost estimating assumptions provided by the DOE, which are described in detail in Section 3.3., in conjunction with the Team's assumptions regarding the numbers of STAD carriers and transfer casks, cost estimates were developed by Petersen, Inc. for the structures and components of the small STAD canister system. These are summarized in Table 9-1 and more detail on their derivation is provided in Appendix K.

Table 9-1. Cost Estimates for Small STAD Canister System Structures and Components

Quantity	Description	Price/Each (\$)(5)	Totals (\$)
300(6)	4-PWR STAD Canister	91,273	27,381,900
300(6)	9-BWR STAD Canister	116,717	35,015,100
150(6)	STAD Canister Carrier	355,657	53,348,550
150(6)	Vertical Concrete Storage Cask	300,000(1)	45,000,000
10(7)	Transfer Cask	687,157(2)	6,871,570
30(8)	Transportation Cask	2,517,513(3)(4)	75,525,390

Notes:

1. Price is comprised of \$120,000 for the liner and supporting structure and an estimate of \$180,000 for the labor and materials to construct the concrete shielding.
2. Price includes an estimated \$147,000 to cover the procurement and installation of the neutron shielding, which is an epoxy resin (NS-4-FR).
3. Price excludes impact limiters.
4. Price includes an estimated \$175,000 to cover the procurement and installation of the neutron shielding, which is an epoxy resin (NS-4-FR).
5. See Appendix K for supporting information for cost estimates.
6. Per year over a 30 year period.
7. Per year over a 3 year period.
8. Per year over a 5 year period.

10 RESEARCH AND DEVELOPMENT RECOMMENDATIONS

10.1 NON-CIRCULAR STAD CANISTER CROSS SECTION

The current baseline concept for the small STAD canister designs has an outer envelope that is a right circular cylinder with a 29.0-inch outside diameter. The use of a right circular cylinder shape for the canister design is consistent with other dry cask storage designs that are currently used. The circular shape is used because it has many clear design advantages over non-circular shapes, such as its inherent strength and dimensional stability for internal pressure loads. However, for the small STAD canister design, the circular cross section does not provide the most efficient use of space, which results in fewer small STAD canisters, and thus fewer fuel assemblies, accommodated within each storage and transportation overpack. This is illustrated by Figure 10-1, which shows four (4) circular 4P STAD canisters and six (6) square 4P STAD canisters inside a 78-inch diameter circle (i.e., the transportation cask cavity). The difference in the packing efficiency in this example results in a 50% increase in the number of fuel assemblies accommodated within each transportation shipment.

For the reasons discussed above, a non-circular STAD canister design will require a substantially thicker canister shell to limit the shell deflections and stresses to acceptable values. It is expected that the additional thickness of a square canister shell and the different methods that will be required to form the square shell will result in increased unit costs, and perhaps higher unit weights. In order to determine these impacts, evaluations have been performed to determine the plate thickness that would be required for a square canister shell to satisfy the allowable stress criteria and displacement criteria for internal pressure loading. This analysis considered three different design configurations: (1) the baseline circular canister shell design, (2) a square canister shell design with flat walls, and (3) a square canister shell design with ribs formed into the flat sides for increased bending stiffness. The analysis of the canister shell configurations for internal pressure loading is performed using finite element methods. The 1/8th symmetry models shown in Figure 10-2 are used for these analyses. Each of these models represents an axial periodic segment of the canister shell near the mid-length of the canister where there are no stiffening effects from the canister ends. For the cylindrical and square-flat models, a unit length (1-inch) is modeled. For the square-ribbed model, a 3-inch length is modeled, assuming a 6-inch axial pitch between the formed ribs. The square-ribbed model also assumes constant rib width and depth dimensions of 1.5-inch and 3/8-inch, respectively, for all cases evaluated. For the purposes of this evaluation, only the canister shell thickness is varied. Symmetry boundary constraints are applied to all “cut” edges of the models.

These analyses were performed using elastic-plastic material properties for the canister shell. A bi-linear kinematic hardening material model was used for Type 316L stainless steel at an assumed shell temperature of 400°F. The material behavior was defined by an initial elastic modulus of 26.5×10^6 psi, a yield strength of 20.7 ksi, and a tangent modulus of 1.095×10^5 psi.

Analyses were performed for each configuration for a range of shell thicknesses to determine the stresses and deformations under both normal and accident internal pressure loads of 12 psig and 70 psig, respectively. The resulting maximum stresses and deformations were compared to the design limits to determine the required shell thickness for each configuration.

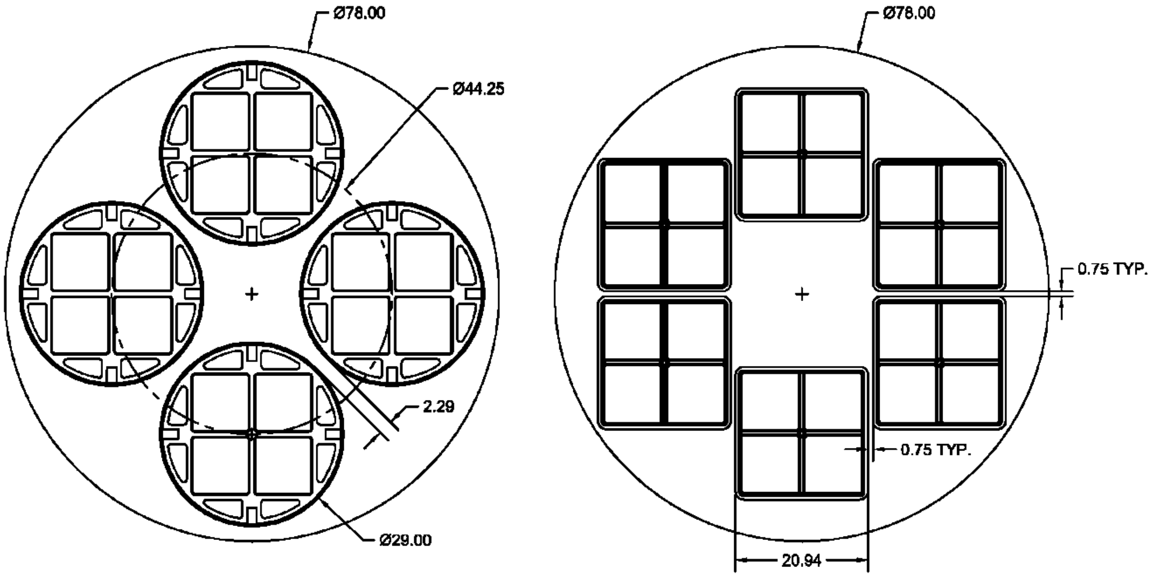
The maximum radial deformations and stresses of the cylindrical, square-flat, and square-ribbed canister shells, as a function of shell thickness, are shown in Figure 10-3 through Figure 10-5. As expected, the results show that the deformation of the cylindrical shell is very small compared to those of the square-flat and square-ribbed designs. The results also show that the maximum radial deformations of the square-flat and square-ribbed designs are not excessive under the 12 psig normal internal pressure loading for the range of shell thicknesses evaluated. However, for the 70 psig accident internal pressure loading, the maximum radial deflection of the square-flat and square-ribbed shells are too large for thicknesses less than ½-inch. This is due to the formation of plastic hinges at the shell corners and sidewall mid-spans. The results also show that the radial deflection of the square-ribbed shell is only marginally less than that of the square-flat shell for thicknesses of ½-inch or more.

The stresses in the cylindrical shell for both normal and accident internal pressure loading are much lower than the allowable stress limits for even the smallest (1/4-inch) shell thickness evaluated, and therefore the stress results for the cylindrical shell are not presented. The stress results for the square-flat and square-ribbed shell configurations shown in Figure 10-4 and Figure 10-5 show that there are significant margins of safety for even the smallest shell thickness considered (i.e., 3/8-inch) for the 12 psig normal internal pressure. However, for the 75 psig accident pressure load the results show that the maximum membrane plus bending stresses in the 3/8-inch thick square-flat and square-ribbed shells are either near or exceed the allowable stress limit. For shell thickness of ½-inch or higher, the results show that there are likely sufficient margins to account for the other load conditions that must be considered in combination with internal pressure.

In summary, the conclusions of this evaluation are as follows:

1. The cylindrical shell is the most efficient design in terms of deformations and stresses, but the least efficient for packing efficiency. A ¼-inch thick cylindrical shell appears to be sufficient for the conditions evaluated.
2. The square-flat canister shell design requires a shell thickness of approximately 9/16-inch to limit the radial deflection to acceptable values (approximately 0.1-inch) under accident internal pressure loading. At this thickness, the maximum stresses in the square-flat shell are acceptable.
3. The radial deflection of the square-ribbed canister shell is only marginally less than that of the square-flat shell, particularly for thicknesses of ½-inch or more. At these thicknesses, it is expected that ribs cannot be press-formed into plate material, and that alternate means of forming the ribs would be cost prohibitive. Therefore, a rib-stiffened canister shell is not recommended.

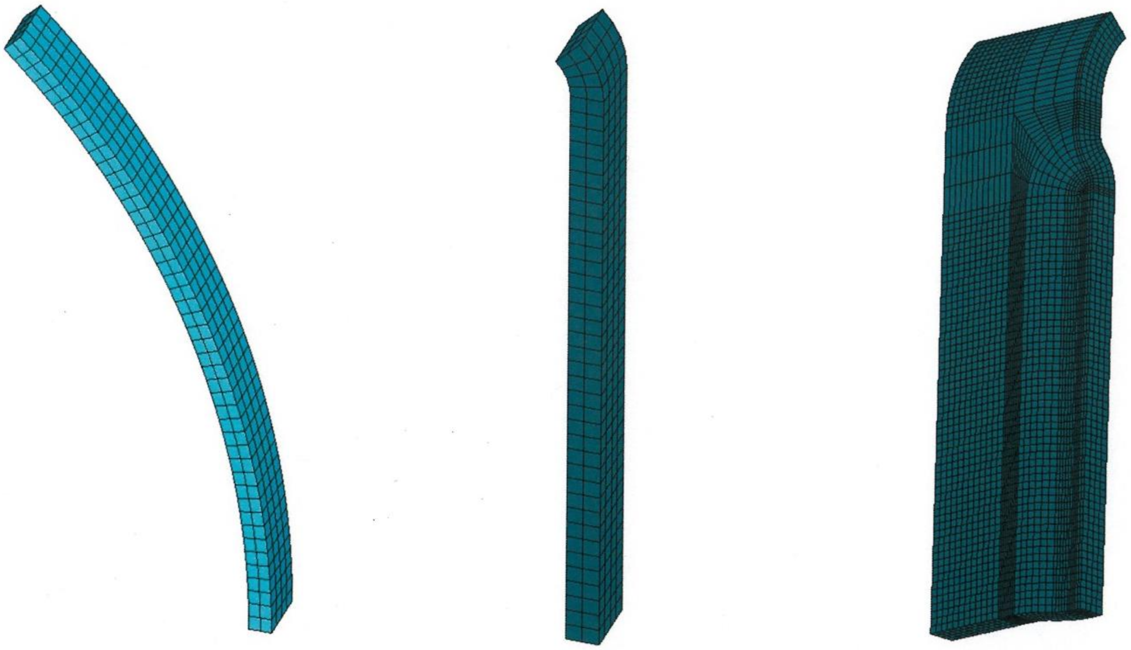
Although the unit costs of the non-circular STAD canister designs are expected to be higher than those of the circular design, the packing efficiency advantages of the non-circular designs could potentially result in overall lower system costs considering that fewer storage and transportation overpacks would be required, the overall footprint of the storage facilities would be smaller, and the throughput for operating utilities would be higher, which could make the use of small STAD canisters more viable at operating sites, thus minimizing the need for fuel repackaging at an interim storage facility or repository. Therefore, further development of non-circular small STAD canisters, along with the corresponding overpacks and transfer equipment is recommended for further consideration.



4X ARRAY OF CIRCULAR STAD CANISTERS IN TRANSPORTATION OVERPACK

6X ARRAY OF SQUARE STAD CANISTERS IN TRANSPORTATION OVERPACK

Figure 10-1. Effect of STAD Canister Shape on Packing Efficiency



Cylindrical Square-Flat Sided Square-Ribbed

Figure 10-2. Canister Shell 1/8th Symmetry Periodic Finite Element Models

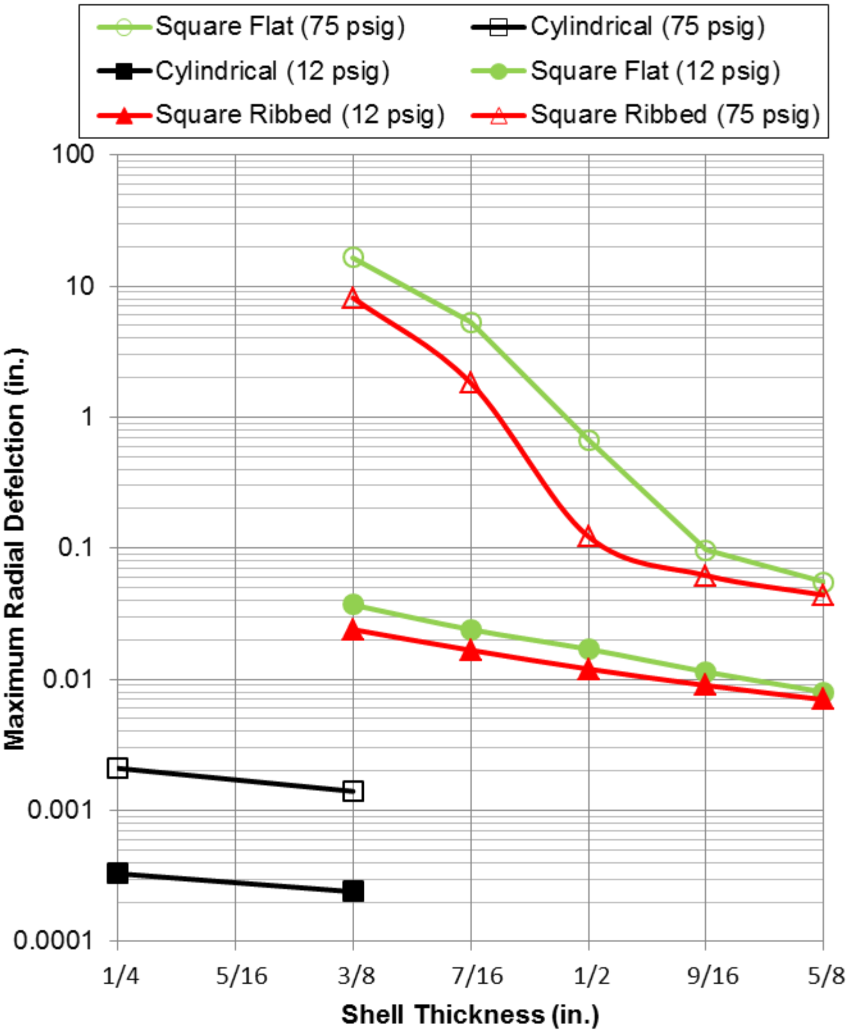


Figure 10-3. Canister Shell Maximum Radial Deflection vs. Shell Thickness

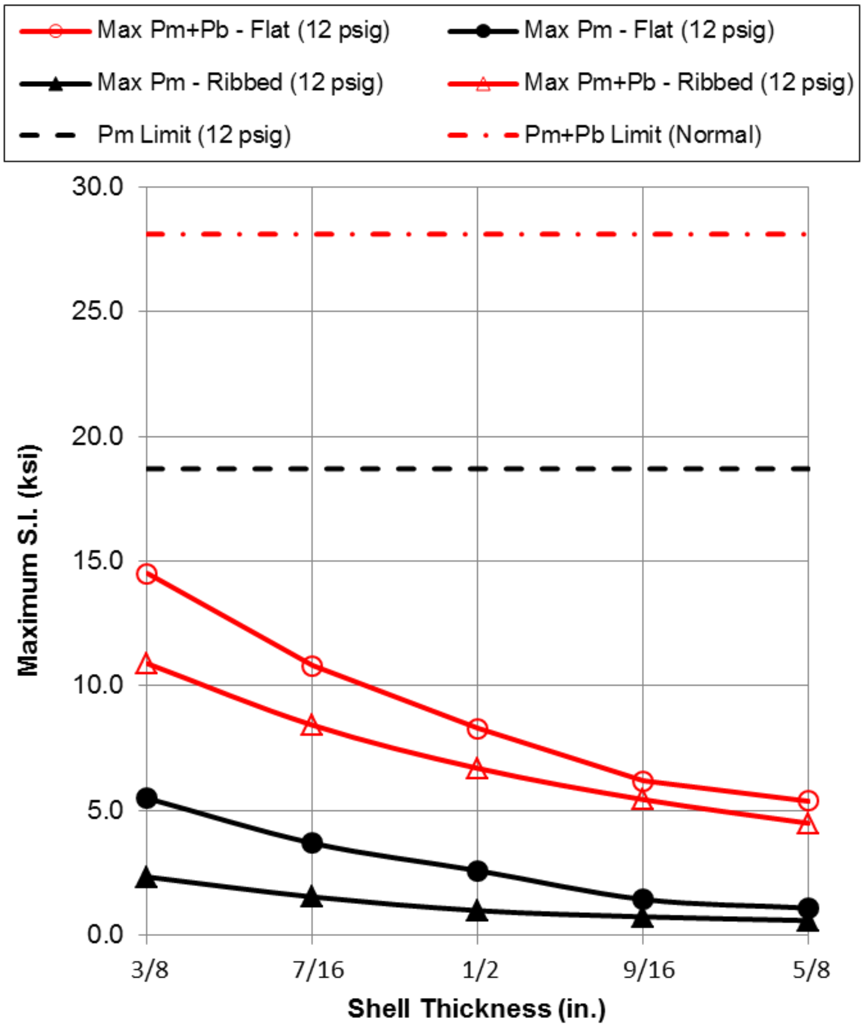


Figure 10-4. Square Canister Shell Stress Results – 12 psig Normal Internal Pressure

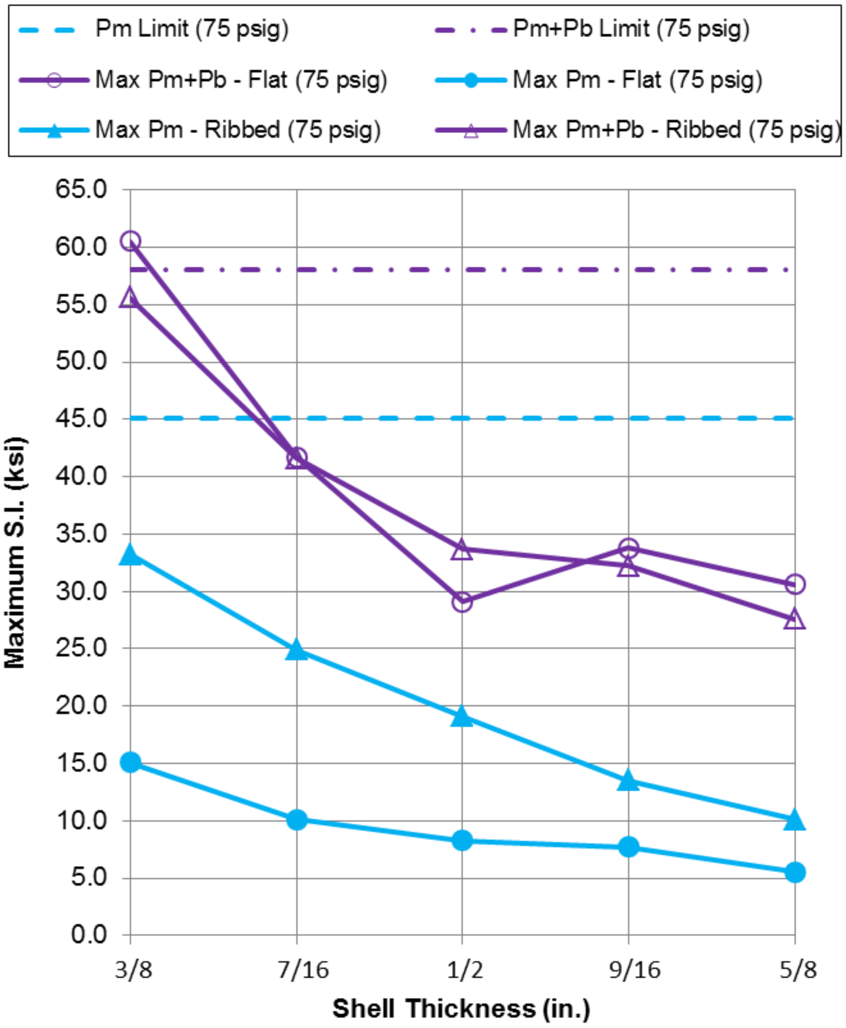


Figure 10-5. Square Canister Shell Stress Results – 70 psig Accident Internal Pressure

10.2 FEATURES TO FACILITATE AGING MANAGEMENT MONITORING ACTIVITIES

For extended storage operations (i.e., storage beyond the initial 40-year term of the Certificate of Compliance), AMPs are required to monitor the storage system components for aging effects that could prevent them from performing their intended safety functions. For canisters, the AMPs typically include remote visual examination of the accessible exterior surfaces, particularly the area of the closures weld(s). These remote visual inspections are typically accomplished using equipment that is inserted through the storage overpack ventilation ducts and routed through the annulus between the storage overpack and canister shell. However, for multiple small STAD canisters stored within a carrier inside a storage overpack, the use of traditional remote visual monitoring of in-situ canisters will not be viable because most of the canister surfaces will be obstructed by the carrier and not accessible for monitoring. Thus, alternate monitoring techniques and equipment will need to be developed for the small STAD system AMPs.

One approach that has been discussed for larger DPC storage systems is the use of an examination bell (e.g., a transfer cask equipped with the required inspection and monitoring devices) to perform inspections of the canister shell for aging effects. Although this is not the preferred method for DPC systems, it may be well suited for the small STAD canister because they are much smaller and lighter than DPCs. Similar to canister transfer operations, the examination bell could be docked on top of the storage cask and the canister could be lifted into the examination bell where the required inspections/examinations could be performed. Unlike the remote visual examination of in-situ DPCs, which may require the development of new inspection techniques and equipment, the examination bell could be equipped with fixed instrumentation that could inspect practically all of the canister exterior surfaces as it is drawn into the bell or once inside the bell. Also, there would be less need for miniaturization of existing technology with this approach. The biggest disadvantage to this approach is the need to lift and handle the canister, which is generally avoided for the larger DPC systems.

Aging effects that could compromise the confinement integrity of the canister are of primary importance during the extended storage period because the inert atmosphere inside the canister is required to prevent degradation of the fuel cladding. Bolted storage casks use a pressure monitoring system to detect leaks in the closure during storage, however, DPC-based storage rely upon redundant closure welds to assure confinement integrity, in lieu of continuous monitoring, and do not include any features to allow confirmation of the presence of inert gas within the canister. The addition of such a feature to the small STAD canister is recommended given that they are expected to maintain their storage and transportation safety functions for a period of 150 years or more. Features that allow remote monitoring for the presence of inert gas within the canister are recommended because any penetrations used to access the canister interior greatly increase the probability of leakage. Therefore, it is recommended that inspection equipment and methods be developed to allow remote monitoring of the canister confinement boundary during extended storage.

11 CONCLUSION

This Task Order 18 report has provided a generic design system for small STAD canister systems, which has been developed, analyzed and evaluated by the Energy*Solutions* Team.

The key outputs from this study are:

1. Designs for the 4-PWR and 9-BWR canisters have been developed in accordance with the DOE *Performance Specification for Small and Medium Transportation, Aging and Disposal Canister Systems,* FCRD-NFST-2014-000579. The proposed STAD designs

can accommodate all US PWR and BWR assembly types, with the exception of South Texas Project fuel, AP1000 and CE 16×16 fuel with control components (whose length exceeds that of the cask cavity). Some future assembly types, including AP1000 fuel, will also be too long for the proposed cask and basket design. Outline drawings are provided in Appendix E.

2. Central to the system design is the use of a “carrier” type STAD canister basket. The carrier design locates and supports four small STAD canisters, during loading operations, storage condition or transport conditions. Use of the carrier is based on reducing the number of primary loading and handling operations and it also provides opportunities for parallel welding, non-destructive examination, and drying operations to be performed. In this role, the carrier is the primary transfer component when loading the STAD canisters. Transfer cask equipment, similar to that used for the ultra-high capacity canister based systems, is used to load, process and transfer the STAD canisters. The STAD canister carrier provides operational alignment, multi-unit handling and shielding during fuel loading operations. The STAD canister carrier is also a multipurpose frame which functions as a heat transfer device and structural component during storage and transportation. The STAD carrier may be preloaded into a transfer cask or staged with STAD canisters and then loaded into the transfer cask.
3. Concepts for storage and transportation have been developed around the use of storing or transporting units of four STAD canisters in a carrier. Loading the carrier vertically is compatible with how DPCs are currently loaded; however, utilization of a horizontal storage option will require further design. The horizontal transfer of a single loaded STAD canister can be accomplished using technology that is akin to what is currently used in the dry cask storage industry; currently licensed technology utilizes a combination of lubrication and a material resistant to galling for both the transfer cask and the storage module horizontal structural supports. Loading a carrier loaded with four STAD canisters will require careful design to ensure that the carrier is continuously supported during placement and removal.
4. The proposed system will require a plant spent fuel pool crane capacity of 125 tons. Most US nuclear plant sites have a crane capacity of 125 tons or more. Some sites, however, have crane capacities between 100 and 125 tons. Plants with 100 ton crane capacities may be accommodated by designing transfer casks with less shielding, or by placing three (vs. four) STAD canisters inside the transfer and storage casks (should shielding analyses show that acceptable exterior dose rates cannot by obtained with a transfer cask with a loaded hook weight under 100 tons).
5. The structural, thermal, shielding and criticality analyses have been produced for the design concepts with the following outputs:

a. Thermal and structural analyses for both storage and transport have been performed for the STAD carrier to levels necessary to adequately characterize system performance in both normal and accident conditions. The analyses performed are contained in this Final Report.

b. The thermal analyses performed for the STAD canisters during storage concluded that acceptable fuel rod cladding and STAD canister fuel basket structure temperatures will occur for payloads of four PWR or BWR STAD canisters within the storage cask, given that the STAD canister heat load does not exceed 8.0 kW/STAD canister.

c. The results of the small STAD canister shell assembly structural analysis demonstrate with a high level of confidence that the small STAD canister shell assembly will satisfy the allowable stress design criteria for storage conditions.

d. A structural evaluation was performed of the small STAD canister for a postulated vertical free drop of 23 feet onto an essentially unyielding horizontal surface. Two impact orientations were considered: (1) Flat bottom end impact, and (2) 4-degree rotation from vertical. The purpose of this evaluation was to provide results that DOE can use for comparison to drop analyses that have been performed for other proposed canister designs, including the Transportation, Aging and Disposal (TAD) canister. The results from this evaluation are provided in Section 4.3.1.1.3.

e. The shielding analyses for STAD canisters during storage determined that the peak dose rates on the cask side surface are between 80 and 90 mrem/hr, for PWR and BWR fuel. This is not significantly higher than that of other storage cask systems, given the bounding nature of the analyzed (62.5 GWd/MTU, 5 year cooled) assembly payload. The 25 mrem/year limit at the site boundary is the only 10 CFR 72 limit that applies for the storage cask.

f. For transfer operations, the shielding analysis results show peak dose rates under 1.0 rem/hr on the cask side surface under dry conditions, and dose rates under 100 mrem/hr on the cask side surface when the cask and STAD cavities are filled with water. The peak dose rates occur at the axial elevation of the peak burnup region of the fuel. These dose rates are acceptable and in line with industry experience.

g. For STAD canisters in the transportation cask, the shielding analysis results show that all cask exterior dose rates are under the applicable 10 CFR 71 limits (for any assembly payload that meets the cooling time requirements shown in Table 4-4 (on Page 54).

h. It is likely that moderator exclusion will be employed as the primary means of criticality control under NCT and HAC for the transportation cask system. The double seal weld of the STADs would be credited as the second barrier to water ingress (an approach for which there is precedent in cask system licensing). The transport cask containment boundary would be the first barrier to water ingress. However, criticality analyses that model water within the STAD canister interiors as well as between the STAD canisters have been performed. The purpose of these analyses is to qualify the "as loaded" assembly and cask configuration (under 10 CFR 71.55(b)) and to provide backup (defense in depth) to moderator exclusion under HAC. The criticality analyses model the STAD canisters inside the transportation cask and as the (outer) cask configuration does not significantly affect reactivity, and the transfer cask and transport cask materials are similar, the results of the criticality analyses are applicable for the transfer (loading) configuration as well. The approaches used and the results obtained for the PWR and BWR criticality analyses are provided in Sections 4.3.4.1 and 4.3.4.2, respectively.

   For the optimum PWR fuel pellet (rubble) array configuration, it was determined that the STAD canister would not be able to accommodate a significant fraction of the U.S. spent PWR assembly inventory without an unacceptably high k_{eff}. This could be mitigated by modifying the fuel basket design to add more borated stainless steel. For the other two configurations analyzed: intact PWR assemblies and optimum pitch cladded PWR rod arrays, it was concluded that the STAD canister could accommodate the entire U.S. spent PWR assembly inventory, without any need for payload reduction or fuel basket design modifications.

   For BWR fuel, the analysis of intact BWR fuel revealed no issues. However, analysis of optimum pitch cladded BWR rod arrays concluded that a reduction in the payload from nine to eight BWR assemblies for each STAD canister would be required for BWR fuel assemblies with planar average initial enrichment levels above 4.3%. That may constitute a significant fraction of the US spent BWR fuel inventory in the future. If borated stainless steel plates were placed around the periphery of the BWR STAD basket, payload reduction would only be necessary for BWR assemblies with initial enrichment levels over 4.75%, which is a very small fraction of the current (or future) US spent BWR assembly inventory. For the analysis of an optimum BWR fuel pellet (rubble) array, it was concluded that the BWR STAD canister would only be able to accommodate BWR assemblies with initial enrichment levels of 3.6% or less. It is also unlikely that any plausible STAD design changes could significantly increase that allowable enrichment. In the future, most of the BWR assembly inventory is expected to have initial enrichment levels over 3.6%. Thus it is likely that, for this case, water moderator exclusion will need to be relied upon to establish acceptable criticality control for HAC.

6. Regarding the ability to license the STAD canister system design, it was concluded that, subject to several considerations, NRC approval of the STAD system design for both the initial 10 CFR 71 transport CoC and the initial 10 CFR 72 storage CoC would be anticipated. The considerations are described in detail in Section 8 and cover the areas of: aging management, high burnup fuel, multiple storage configurations, multiple STAD canisters in storage and transportation overpacks, and moderator exclusion.
7. Cost estimates have been developed for the systems and components of the STAD canister system, which are provided in Section 9.
8. A fact sheet detailing the key features of the system is provided in Appendix H.
9. A table detailing the key parameters for the system is provided in Appendix F.
10. The loading process for the STAD canisters utilizing a carrier is detailed in Appendix G and has been captured in an animation, which will be provided to the DOE.

12 REFERENCES

American National Standards Institute, ANSI N14.6 - 1993, *Radioactive Materials - Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4,500 kg) or More,* American National Standards Institute, New York.

American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB, *Class 1 Components*, 2004 Edition.

American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division I, Subsection NF, *Supports*, 2004 Edition.

American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NG, *Core Support Structures*, 2004 Edition.

American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Appendix F, *Rules for Evaluation of Service Loadings with Level D Service Limits*, 2004 Edition.

AREVA – *Standardized Transportation, Aging, and Disposal Canisters Feasibility Study A&AS DE-NE-0000291.*

Crane Manufacturers Association of America (CMAA), CMAA #70, *Specifications for Electric Overhead Traveling Cranes*, 1988.

DOE Performance Specification for Small and Medium Standardized Transportation, Aging, and Disposal Canister Systems, FCRD–NFST–2014–000579.

DOE/RW-0184, *Characteristics of Spent Fuel, High-Level Waste, and Other Radioactive Wastes Which May Require Long-Term Isolation*, Appendix 2A, Volume 3 of 6, U.S. Department of Energy, Office of Civilian Nuclear Waste Management, December 1987.

Energy*Solutions – Standardized Transportation, Aging, and Disposal Canisters Feasibility Study A&AS DE-NE-0000293.*

EnergySolutions et.al. *DOE Advisory and Assistance Services Contract Task Order 17: Spent Nuclear Fuel Transportation Cask Study*, March 2015.

Final Safety Analysis Report for the VSC-24 Ventilated Storage Cask System, Revision 5, March 2003, NRC Docket No. 72-1007, BNFL Fuel Solutions Corporation.

FuelSolutions^{TM} TS125 Transportation Cask Safety Analysis Report, Revision 3, April 2002, NRC Docket No. 71-9276, BNFL Fuel Solutions Corporation.

Fuel*Solutions*^{TM} W21 Canister Transportation Cask Safety Analysis Report, Revision 3, April 2002, NRC Docket No. 71-9276, BNFL Fuel Solutions Corporation.

Fuel*Solutions*^{TM} W74 Canister Transportation Cask Safety Analysis Report, Revision 3, April 2002, NRC Docket No. 71-9276, BNFL Fuel Solutions Corporation.

Lawrence Livermore National Laboratory, *Seismic and Structural Container Analysis for the PCSA*, 000-PSA-MGR0-02100-000-00A.

MAGNASTOR Final Safety Analysis Report, Revision 0, February 2009, NRC Docket No. 72 -1301, NAC International.

MAGNATRAN Transport Cask SAR, Revision 12A, October 2012, NRC Docket No. 71-9356, NAC International.

NEI 14-03, *Guidance for Operations-Based Aging Management for Dry Cask Storage*, Revision 0, September 2014, Nuclear Energy Institute, Washington, D.C.

NRC Regulatory Guide 7.6, *Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels*, Revision 1, 1978, U.S. Nuclear Regulatory Commission, Office of Standards Development.

NRC Regulatory Guide 7.9, *Standard Format and Content of Part 71 Applications for Approval of Packages for Radioactive Material*, Revision 2, 2005, U.S. Nuclear Regulatory Commission, Office of Standards Development.

NUREG-1536, 2010, Rev 1, *Standard Review Plan (SRP) for Spent Fuel Dry Storage Systems at a General License Facility,* Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, D.C.

NUREG-1617, 2000, *Standard Review Plan for Transportation Packages for Spent Nuclear Fuel,* Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, D.C.

NUREG-1927, 2011 *Standard Review Plan for Renewal of Spent Fuel Dry Cask Storage System Licenses and Certificates of Compliance,* Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, D.C.

Spent Fuel Project Office, Interim Staff Guidance, United States Nuclear Regulatory Commission, http://www.nrc.gov/reading-rm/doc-collections/isg/spent-fuel.html.

- ISG 1 - *Classifying the Condition of Spent Nuclear Fuel for Interim Storage and Transportation Based on Function* (formerly entitled *"Damaged Fuel")*
- ISG-2 - *Fuel Retrievability*
- ISG-3 - *Post Accident Recovery and Compliance with 10 CFR 72.122(l)*
- ISG-4 - *Cask Closure Weld Inspections*
- ISG-5 - *Confinement Evaluation*
- ISG-6 - *Establishing minimum initial enrichment for the bounding design basis fuel assembly(s)*
- ISG-7 - *Potential Generic Issue Concerning Cask Heat Transfer in a Transportation Accident*
- ISG-8 - *Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transportation and Storage Casks*
- ISG-9 - *Storage of Components Associated with Fuel Assemblies*
- ISG-10 - *Alternatives to the ASME Code*
- ISG-11 - *Cladding Considerations in the Transportation and Storage of Spent Fuel*

- ISG-12 - *Buckling of Irradiated Fuel Under Bottom End Drop Conditions*
- ISG-13 - *Real Individual*
- ISG-14 - *Supplemental Shielding*
- ISG-15 - *Materials Evaluation*
- ISG-16 - *Emergency Planning*
- ISG-17 - *Interim Storage of Greater Than Class C Waste*
- ISG-18 - *The Design and Testing of Lid Welds on Austenitic Stainless Steel Canisters as the Confinement Boundary for Spent Fuel Storage*
- ISG-19 - *Moderator Exclusion Under Hypothetical Accident Conditions and Demonstrating Subcriticality of Spent Fuel Under the Requirements of 10 CFR 71.55 (e)*
- ISG-20 - *Transportation Package Design Changes Authorized Under 10 CFR Part 71 Without Prior NRC Approval*
- ISG-21 - *Use of Computational Modeling Software*
- ISG-22 - *Potential Rod Splitting Due to Exposure to an Oxidizing Atmosphere During Short-Term Cask Loading Operations in LWR or Other Uranium Oxide Based Fuel*
- ISG-23 - *Application of ASTM Standard Practice C1671-07 when Performing technical reviews of spent fuel storage and transportation packaging licensing actions*
- ISG-24 - *The Use of a Demonstration Program as a Surveillance Tool for Confirmation of Integrity For Continued Storage of High Burnup Fuel Beyond 20 Years*
- ISG-25 - *Pressure and Helium Leakage Testing of the Confinement Boundary of Spent Fuel Dry Storage Systems*

13 APPENDICES

Appendix A - Results from First Facilitated Workshop, Columbia, MD – October 30 - 31, 2014

The first workshop was held from October 30 - 31, 2014, at Energy*Solutions* offices in Columbia, Maryland, and was attended by representatives from all of the companies comprising the Team, in addition to the DOE Task Order 18 Technical Monitor. The workshop was facilitated by the Task Order 18 Project Manager and followed the agenda below:

- Day 1
    - Review scope of work
    - Review and Finalize Workshop Objectives
    - Information Gathering Presentations
    - Review Technical Framework
    - Options Identification
- Day 2
    - Options Down –Select
    - Options Confirmation
    - Planning for Subsequent Phases

DAY 1

Following introductions, the Task Order 18 scope of work and the required schedule for completing it were reviewed. Key dates are, as follows:

- 30% Task Completion Review Meeting – January 6 (Note. Agreed with DOE to move from December 18).
- Workshop # 2 – January 27 to January 28
- Submit Draft Report – April 1
- 90% Task Completion Review Meeting – April 2 (Note. Subsequently agreed to move to April 7)
- Submit Final Report – April 16
- Final Report Briefing – April 16
- Submit Closeout Report – April 30

The following objectives for the workshop were reviewed and agreed to:

Phase 2 Workshop Objectives

To establish a technical framework and brainstorm and down-select options for the generic design for small STAD canister systems. The output of the Phase 2 workshop will be a shortlist of options, ideas and recommendations for the small STAD canister systems, which will be addressed with additional scrutiny in the next phase of work.

Discussion on Information Gathering

The team then reviewed, via a mixture of discussions and presentations, the results of the information gathering activities performed prior to the workshop. Key points were, as follows:

1. Syed advised that the materials must be equivalent to or better than those specified in the performance specification. AREVA have introduced a new stainless steel and Syed Bokhari will provide details to the team.

   ACTION: Provide details on the new stainless steel product, which is being marketed by AREVA for SNF canisters – **Syed Bokhari.**

   Post Meeting Note: Syed Bokhari provided information, via email on 11/3/14, which advised that AREVA is offering Duplex Stainless Steel – **Action Closed**

2. Basket materials need to last 10,000 years (criticality control).
3. GA-4 was a square truck cask. The GA-9 (single purpose) SAR was prepared, but not submitted to the NRC for review and certification.
4. A single STAD is potentially shippable by truck, but most likely as an overweight shipment.
5. Ray Termini advised that the NRC Environmental Impact Statement currently points to repackaging after 100 years.
6. Steve Sisley advised that we can move the STAD into another overpack after 150 years if the concrete integrity has deteriorated.
7. Must consider aging management.
8. The Calvert Cliffs and VSC-24 extended storage applications can be used to describe how aging management issues have been addressed and lessons learned.
9. Charley Haughney doesn’t believe that the NRC has to enter into a big rulemaking exercise for 10CFR71 for the small STAD system.
10. At Yucca Mountain, 10CFR72 didn't apply for the aging pad; 10 CFR 63 was the governing regulation for licensing.
11. Syed Bokhari will advise on the site specific g value we should use.

    ACTION: Advise on the g value to be used for the site location – **Syed Bokhari**

    Post Meeting Note: Syed Bokhari provided information, via email on 11/13/14, that the STAD will be designed for 0.75g and the storage cask will be designed for 0.25g which will be suitable for east coast ISF locations, noting that the 0.25g was subsequently revised to 0.21g at the 1/6/15 30% Task Completion Review meeting – **Action Closed**

12. Ray Termini advised that TLDs are used by Exelon for monitoring of the external dose from storage modules.

13. Steve Sisley believes that, based on experience, we have a good story for 20 to 60 years of storage, but what about 150 years?

14. Per 10 CFR 72.42, the first license issued is for a period of up to 40 years.

15. The aging management for 150 years needs to be a forward looking program.

16. Peening relaxes the heat induced stresses from welding.

17. How do we address DFCs? The STAD will get bigger and heavier.

    ACTION: Advise on how fuel in damaged fuel cans should be addressed in the generic design – **Syed Bokhari**

    Post Meeting Note: Syed Bokhari provided information, via email on 11/13/14, that the current STAD canister design will be for undamaged fuel only, in future as the need may be, a separate damaged fuel STAD design may be undertaken – **Action Closed**

18. NEI 14-03 aging management has been submitted to the NRC for acceptance.

19. Poison material has to cover the active length, but it does not specifically state in the performance specification that each cell has to be enclosed. Steve Sisley's interpretation is that a cruciform between the cells will work, i.e. poison not on all four sides.

20. The transportation cask will need a full length support structure for each STAD within it.

21. A 72" diameter cavity for the transportation cask still allows the 128" maximum width (including impact limiters) to be maintained.

22. Moderator exclusion for a single STAD is problematic - Jim Hopf to evaluate.

23. As the STAD canister is not going to be opened again, there does not seem to be any justification for loading DFCs in the STADs.

24. A storage overpack containing 4 small STAD canisters is equivalent to a standard DPC in a storage overpack.

    Post Meeting Note: The statement above refers to the physical space that 4 small STADs, compared with a standard DPC, e.g. holds 32 PWR fuel assemblies, would occupy when loaded together in a storage overpack.

25. George Carver advised that for the TAD, each cell was wrapped with poison.

26. Ray Termini advised that small STADs will not allow operating utilities to unload at an acceptable rate. Maybe single units can do it, but twin units will definitely not be able to due to operational constraints in the pool area.

27. Steve Sisley – An idea is to have a transfer cask that would be loaded with 4 empty canisters; each of which is filled individually and then, ideally, welded in parallel and dried in parallel.

Technical Framework

The meeting then switched to reviewing, and revising as necessary, a draft technical framework, which was derived from the Performance Specification and the statement of work. The revised technical framework is provided in Appendix D and the key points from the review were, as follows:

1. For requirement # 70, the site transporter, e.g. crawler, needs to be considered as part of the overall generic design.

2. Regarding requirement # 16, for the fuel length it was agreed that the Task Order 17 DOE guidance will also be used for TO18.

3. For requirement # 31 the maximum fuel temperature is 400C.

4. For requirement # 34, add a note that the 12/32 canister size is not applicable to Task Order 18.

5. For requirement # 36, Ray Termini advised that based on Exelon’s experience you can decontaminate canisters below 1000 dpm/100 cm^2 for release. He also advised that they wash the canister as it is taken out of the pool and then it is swabbed and cleaned as necessary, e.g. use wipes; a process which provides effective decontamination.

6. After filling the annulus between the pool transfer cask and the STADs with water it is then sealed off with an inflatable seal. The logic being that the pool water is prevented from entering this region.

7. For requirement # 46, there will be some code issues associated with welding.

8. If water is still present in a canister, then you will not hold a vacuum because the water vaporizes and increases the pressure inside the canister.

9. Requirement # 57 is only applicable for storage and transportation.

10. Need to consider the worse-case site environmental conditions, e.g. salt, humidity, etc.

11. **ACTION:** Provide guidance on the above ground and below ground vault storage design concepts, which the Energy*Solutions* should account for when determining that the small STAD generic design is suitable for horizontal or vertical storage in vault storage **– Syed Bokhari**

Post Meeting Note: At the 30% Task Completion Review meeting on 1/6/15, the following notes pertaining to this action were recorded. *The loaded STADs need to be capable of being handled in both the vertical and horizontal orientation. They also need to be capable of being loaded into storage modules both horizontally and vertically. DOE is willing to accept engineering judgment where appropriate, however, analyses should be performed for areas having greater uncertainty, such as thermal performance. The Contractor may focus analyses on vertical storage in a multi-canister storage overpack and on horizontal storage of individual STAD canisters in an above-grade vault. Demonstrating the capability for horizontal vault storage of a multi-canister carrier system, in lieu of individual canisters, is also acceptable* – **Action Closed**

12. Both the new Vogtle plant and Diablo Canyon use storage casks bolted to the pad to address stack up issues.

13. For requirement # 88, it is believed that this requirement is to avoid neutron hot spots during loading. The team believed that we would not be able to meet this requirement as written and the following action was placed:

    ACTION: In the Performance Specification, Requirement 3.5.7, Item 3C, states "The centerline of each trunnion set shall be outside the area of the SNF region to provide maximum ALARA benefits. Is the real requirement to ensure that maximum ALARA benefits are provided or is it where the trunnion shall be positioned, i.e. locating the trunnions in the specified area may not be the most appropriate location for them from a lifting perspective? – **Syed Bokhari**

    Post Meeting Note – Syed Bokhari advised, via email on 11/13/14, that the specification requirements regarding the trunnion location are basically to ensure maximum ALARA benefits. If a different location is more suitable from operational considerations, it will be acceptable as long as ALARA benefits are ensured and dose levels are justifiable **- Action Closed**

Options Identification

After completing the review of the technical framework the team began the process of options identification. A high level flowchart was initially created, which defined the stages in processing STAD canisters and the options of either processing STADs singularly or in groups of "N", where N could be 3 or 4. It was recognized that although processing single STADs will not allow operating utilities to unload at an acceptable rate, the team noted that the objective of Task Order 18 is to develop a generic design for a small STAD canister system and that single canisters are one component of that system. The high level flowchart is shown in Table A-1.

Table A-1: High Level Flowchart Defining Stages of STAD Canister Processing

STAD Canister Processing Stages				
POOL	**TRANSFER**	**WELD/DRY**	**STORAGE**	**TRANSPORT**
➡	➡	➡	➡	
ONE STAD	ONE STAD	ONE STAD	Load into a storage overpack that is capable of holding 3 or 4 STAD canisters. This will be achieved using a “lazy Susan” type of loading system that indexes to an empty position and shields any loaded locations.	Load into a transportation cask that is capable of holding 3 or 4 STAD canisters. This will be achieved using a “lazy Susan” type of loading system that indexes to an empty position and shields any loaded locations.
N-STAD	N-STAD	N-STAD	N-STAD single load	N-STAD Single load

Using the above table, the team identified options for each stage and the STAD canister

<u>STAD Canister</u>

a. Right circular cylinder

b. Flatten sides

a. Provides benefits (packing efficiency, material savings, weight savings)

b. Will likely be a licensing challenge that will need a full discussion at the pre-license stage

c. Will require additional demonstration of feasibility to the NRC

c. Alternative poisons

a. Enriched Boron

d. Alternative materials of construction

a. E.g. AREVA offering duplex stainless steel

e. Different lid configurations

WELD/DRY

1. For one STAD the technology is the same as DPCs, although the welding and drying times should both be shorter.
2. For N STADs we could either weld one at a time or weld N canisters at the same time.
3. For N STADs we could dry N STADs at the same time

TRANSFER

Equipment is normally provided as a system, which hangs off the spent fuel pool overhead crane and comes with its own yoke and ancillary equipment

1. For One STAD would need to use a purpose-built cask transfer system, rather than use a system that is designed for DPCs.
2. For N STADs we could use a DPC-size cask transfer system, but it would need to be a purpose-built system, rather than modifying an existing DPC system.

STORAGE

1. The above ground storage casks will be capable of storing 3 or 4 STADs. Loading will be achieved as follows:
    - Single STAD load using an indexing shielding collar and a purpose-built single STAD transfer cask.
    - Load multiple STADs at the same time using a purpose-built transfer cask.
2. .Above ground storage cask options are:
    - Round
    - Square
3. Any benefits to using alternative methods of construction for the storage casks?

TRANSPORT

1. The transportation casks will be capable of transporting 3 or 4 STADs. Loading will be achieved as follows:
    - Single STAD load using an indexing shielding collar and a purpose-built single STAD transfer cask.

- Load multiple STADs at the same time using a purpose-built transfer cask.

2. Load STADs vertically.
3. Transport STADs horizontally.

DAY 2

Options Down-Select

At the beginning of Day 2 of the workshop the team reviewed the options identified on Day 1 in order to down-select to a short list of options, which will be developed further in preparation for the 30% Task Completion Review Meeting. During the discussion the following notes were captured:

1. For configurations of the STAD canister lid, Steve Sisley has some ideas regarding a combination inner and outer lid; with the goal of reducing welding and NDE.
2. Can we save on materials if we remain cylindrical – are there opportunities for cost reduction?
3. Need to have a production mentality in designing the STAD canister system.
4. Are there any benefits to having a non-circular transfer cask?
5. An option to process a single STAD should be part of the overall system, but this should not be our prime focus.
6. The use of novel welding techniques for the STAD canister lids was discussed, but it was agreed that this area of work would be better addressed under Task Order 21.

Shortlist of Options to be Further Developed

The confirmed shortlist of options to be further developed is provided in Table A-2, below.

Table A-2: Confirmed Shortlist of Options to be Further Developed

System Component	Options	Notes
STAD CANISTER		
	Right circular cylinder	
	Flatten Sides	a. Provides benefits (packing efficiency, material savings, weight savings) b. Will likely be a licensing challenge c. Will require additional demonstration of feasibility to the NRC
	Alternative poisons	a. Provides benefits (packing efficiency, material savings, weight savings)
	Alternative materials of construction	a. AREVA offering duplex stainless steel
	Different lid configurations	a. Steve Sisley has some ideas regarding a combination inner and outer lid; with the goal of reducing welding and NDE.
	Welding	a. For one STAD the technology is the same as DPCs, although the welding time will be shorter. b. For N STADS we could either weld one at a time or weld N canisters at the same time.
	Drying	a. For one STAD the technology is the same as DPCs, although the drying time should be shorter. a. For N STADS we could dry N canisters at the same time.
TRANSFER		
	For One STAD would need to use a purpose-built cask transfer system, rather than use a system that is designed for DPCs.	Are there any benefits to a non-circular transfer cask?

System Component	**Options**	**Notes**
	For N STADs we could use a DPC-size cask transfer system, but it would need to be a purpose-built system, rather than modifying an existing DPC system.	
STORAGE		
	Load an above ground storage cask, which is capable of storing 3 or 4 STADs.	a. Load single STADs using an indexing collar and a purpose-built single STAD transfer cask. b. Load multiple STADs at the same time using a purpose-built transfer cask. c. Consider alternative materials of construction. d. Consider square versus round storage casks.
	Above ground and below ground vault storage	a. Guidance has been requested from DOE on the above ground and below ground vault storage design concepts, which the Energy*Solutions* team should account for when determining that the small STAD generic design is suitable for horizontal or vertical storage in vault storage.
TRANSPORT		
	Load a Transportation Cask, which is capable of transporting 3 or 4 STADs.	a. Load single STADs using an indexing collar and purpose-built single STAD transfer cask. b. Load multiple STADs at the same time using a purpose-built transfer cask. c. Load STADs into the transportation cask vertically. d. Transport STAD canisters horizontally.

Appendix B - Results from Second Workshop, Columbia, MD – January 27 - 28, 2015

The second workshop was held from January 27 - 28, 2015, at Energy*Solutions* offices in Columbia, Maryland, and was attended by representatives from all of the companies comprising the Team, in addition to the DOE Task Order 18 Technical Monitor a representative from the DOE support team. The workshop was facilitated by the Task Order 18 Project Manager and followed the agenda below:

- Day 1
    - Review scope of work
    - Review and Finalize Workshop Objectives
    - Review Technical Framework
    - Review STAD Canister Design Concepts
    - Review STAD Canister Transfer, Storage and Transportation Design Concepts
    - Criticality and Shielding Analyses
    - Fabrication
    - Presentation and Critique of the Process and Equipment Animation
- Day 2
    - Cost Estimating
    - STAD Canister System Fact Sheet
    - Draft Final Report Storyboard
    - Closeout

DAY 1

Following introductions, Ivan Thomas reviewed the purpose and scope of work for Task Order 18 as described in the statement of work (SOW). He then explained that the primary objectives for the workshop were:

- Review the existing technical framework and ensure that that the SOW requirements will be met;
- Review current work on the design concepts for the STAD canister, transfer cask, storage system and the transportation system;

- Discuss and agree on the approaches for the criticality and shielding analyses;
- Benefit from Petersen Incorporated's experience as a major fabricator of dry cask storage systems, including lessons learned, design features to avoid, design features to simplify fabrication and considerations for minimizing fabrication and material costs for mass production
- Agree on a clear path forward to completing the work for the Draft Final Report and presenting the results to DOE at the 90% Task Completion Review meeting.

Review Technical Framework

Ivan Thomas went through the existing Technical Framework, which was developed during Workshop # 1 and subsequently modified to capture the responses from the DOE to actions raised during Workshop #1 (See Appendix D). Key points and actions from this agenda item are provided below.

1. Aging management - Jack asked that we ensure that there is nothing that would preclude the small STAD canisters from being overpacked if aging related issues arise. Steve believes that storage overpacks will likely need to be replaced after several decades (100 years). As long as the inert atmosphere is maintained inside the canister, then there should be no galvanic or corrosion issues. Weld treatments, in order to remove stresses, are a requirement. The shop can handle this requirement, but there is a need to be careful with field welds.
2. The SOW does not include the 5 year cooling time for the 62.5 GWd/MT. We have more options with the STAD canisters to allow them to cool. The DOE wants to know if there are any thermal limits associated with our design.
3. For drying, borated stainless will not be an issue for water retention. Could we use a coating on the STAD fuel baskets to improve drying? Charley advised that there was a deflagration issue with a coating used in a spent fuel cask in the past; it was a Carboline zinc based coating, which reacted with borated pool water to evolve hydrogen into the canister. Is this concept of using a coating an option we should look at for the STAD baskets, noting that a test program would be required?
4. George advised that the design for the transportation cask is following the same method of construction as the Task Order 17 transportation cask.
5. The loaded transfer cask will be subject to the 125 ton crane capacity limit. The transportation cask does not have the same weight restriction.
6. There was a discussion on the consequences of subjecting transported SNF to excessive g forces during an accident, such that the fuel would reconfigure. You can't rely on the double lids on each of the STAD canisters for moderator exclusion if, as currently proposed for the TO18 transportation cask, you only have a single lid on the

transportation cask. The team will need to identify the extent of required testing for the transportation cask if the design stays with a single lid, noting that Holtec have implemented a solution to address this type of moderator exclusion issue.

Review STAD Canister Design Concepts

Steve Sisley gave the presentation shown in Appendix 2, and the key points and actions from this agenda item are provided below.

1. The lifting ring design is simpler than the TAD spec.
2. The lid weld sizes/configuration have been derived and provided to the TO21 team for use in the time and motion analyses.
3. The vent and drain ports are the same size as the large STADs, in order to achieve optimum drying.
4. A loaded canister weighs 14,000 lbs.
5. The internal pressure loads that you design to are driven by regulatory requirements, and you also have to consider blowdown and reflood pressures.
6. Currently have considerable design margins based on the canister structural analysis results under normal conditions. Based on these results there are opportunities to reduce some thicknesses and achieve further weight saving.

Review STAD Canister transfer, Storage and Transportation Design Concepts

George Carver led this session and the key points and actions from this agenda item are provided below.

1. Currently looking at the fluidics modeling for the air flow through a loaded carrier inside the vertical concrete cask (VCC).
2. The cover plate for the carrier is currently 8 inches thick, but the cover plate may go away and be replaced by a thicker top plate for the carrier.
3. George believes that we don't need to seal each STAD to the top plate due to having inflatable seals built into the transfer cask, which engage with the carrier top and bottom plates; together with a positive water pressure that is created by water flow into and out of the transfer cask via ports in the side of the cask.
4. The plan is to use a NAC standard type construction for the transportation cask. Currently have 25,000 lbs of margin for under the hook (125 ton) even with water in the canisters.
5. **Action - George Carver -** Look at what it would take for a loaded transfer cask to meet a 100 ton crane capacity. There is no regulatory requirement for the shielding provided by the transfer cask, as it is an ALARA consideration. George will look at what can be done

and provide input to Jim to evaluate the acceptability of the shielding provided, noting that a reduction in the lead shielding will be necessary.

6. The plan is to go with 4 small STADs in a carrier for storage.
7. The biggest issue with the transportation cask is that the current diameter (105”) of the carrier for the 4 small STADs and the need to not exceed the maximum width of 128” for the impact limiters results a reduced amount of stroke to absorb impact in an accident condition. The challenge will be finding an impact limiter design that can stop the package with the reduced stroke. As described above, excessive g loads on the fuel will result in reconfiguration of the fuel during an accident and challenges with ensuring moderator exclusion.
8. An option to reduce the carrier size and hence increase the stroke would be to decrease the pitch between the STAD canisters, however, we won’t know if this can be done until the air flow fluidics modeling has been completed.
9. It was agreed that making 4 small STADs work for transportation is the primary target, but, as described above, there will be challenges to overcome. At the moment, the challenge is making the carrier concept work for storage.
10. George believes that he has a solution for the transfer cask and confirmation of the storage and transportation overpacks will come later.
11. There was a discussion on what options the ES Team should look at for above-grade vault storage. It was agreed that storing single STAD canisters in a NUHOMS type system will not be a challenge and the canisters will be designed to be pushed and pulled. What is of particular interest to the DOE is the concept of operations for how individual canisters can be extracted from a carrier and placed horizontally into a storage module, noting that for vertical storage the canisters will be stored in the carrier. As well as developing the concept of operations, George will develop an animation for this loading process.
12. The question was asked by Ivan if the pitch of the STADs in the carrier could be reduced to allow it to be used with the current NAC MAGNASTOR system, which takes a 72" diameter DPC. Reduction in the pitch is tied in to the results of the fluidics modeling described above.

Criticality Analyses

Jim Hopf led this session and the key points and actions from this agenda item are provided below.

1. The main configuration will be 4 small STADs (4 PWR STADs or 4 BWR STADS) in a transportation cask and 4 small STADs in a carrier in a storage module. Will model 4 PWR and 4 BWR STADS in a transportation cask. If poison is required between the STADs then he will flag this requirement to George.

2. Will use the MAGNATRAN burn up curves for the PWR analysis; following a similar approach to TO 17.

3. George needs to figure out the pitch between the STAD canisters.

4. Jim asked the questions: What assumptions do we make regarding intact or reconfigured fuel? Do we assume that the pitch is optimized, but the pellets remain intact? Jack asked that the ES team provide our design basis for fuel that is initially intact and what might happen to it and what would be the process to get licensed. Jim will look at TO17 types of analyses for criticality and this subject will be discussed as needed during the bi-weekly status calls with the DOE.

5. Halim advised that for the TAD canister, the criticality analyses were for intact fuel with burn-ups under 45 GWs/MT. It did not address high burnup.

6. Halim raised the issue of how subcriticality can be assured under all future conditions. Jim advised that he will need to be selective regarding the fuel types he analyzes.

7. Jim discussed the issue of preferential draining during recovery, i.e., STADs and cask are filled with water in an accident condition and the cask is drained first. He asked the question is draining the water first in the transfer cask and leaving water in the STADs for BWRs going to be an issue? He needs to analyze this scenario.

Shielding Analyses

Jim Hopf led this session and the key points and actions from this agenda item are provided below.

1. For the shielding analyses Jim will assume 4 small STADS in a carrier in a transfer cask, storage overpack and a transportation overpack. George advised that the storage overpack can take 32 kW. For 62.5 GWd/MT/5 year cooled PWR fuel the heat load is 2 kW per assembly. Thus, a storage overpack could take 16 such PWR assemblies.

2. For transportation, George advised the we should assume an allowable heat load of 24kW.

3. Jim expressed concern about George's changes to the shielding and it was agreed that the shielding analysis will be an iterative process with the shielding design.

4. George advised that if poison material is needed between the STAD canisters for storage and transportation then we can use Boral to save weight, noting that the storage and transportation components of the system will not be loaded in the spent fuel and thus, do not need to be vacuum dried.

5. Jim will look at uniform loading and because the STAD canisters can be placed in any position within the carrier, such that there is no control of where hotter assemblies are placed, there will be no azimuthal loading of canisters.

6. Cycle 3rd year fuel equals the hottest burn-up.
7. The dose from the transfer cask is required to be ALARA.
8. For a 100 ton transfer cask, Jim can perform a shielding assessment to determine the required shielding.

Fabrication / Cost Estimating

Tom Burkland led this session and the key points and actions from this agenda item are provided below.

1. Tom presented a graphic (see Appendix 3), which highlights the differences in unit costs and production units when a job shop versus a mass manufacturer approach is taken.
2. Petersen have built 1000s of TDOPs and standard waste boxes. There are real benefits to moving from a job shop type of procurement to a mass production type of procurement. DOE could place orders under different approaches, such as advanced material procurement and purchasing the tooling for mass production. Large production runs can benefit from labor that has climbed the learning curves, tooling set up and robotic welding. As an example, the production time for the standard waste box was reduced from 72 hours labor to 18 hours
3. Steve made some changes to the basket design during this session, in order to address input from Tom.
4. Tom believes that what we have is easy to build. For cost estimating Tom needs to know such information as weld symbols, material types, thicknesses. He believes that estimating will be straight forward and he will cost materials and fabrication processes.
5. For the licensing inspections, it was agreed that these would not be included in the included in the pricing. However, we do need to include typically required fabrication inspections and tests
6. Duplex stainless does not eliminate residual stress in welds.
7. For square canisters, Tom believes that the fabrication labor would be double versus an equivalent right circular cylinder. A lot of time will be spent forming the corners and you will not be saving a lot of money regarding materials.

   ACTION - Steve Sisley – Work with Tom to come up with a ball park cost for a square STAD canister, including providing sketches as needed.
8. George needs to confirm the design details for the carrier.
9. Tom will use a Petersen standard format for providing the cost estimates. He will need at least two weeks to perform the fabricability review and cost estimating and so needs the design media around the middle of February.

10. George asked what range regarding order quantities are DOE looking for us to estimate. Josh believes that 1500 to 2000 small STADs per year will be required to replace packaging via, for example, 32-PWR DPCs. Tom advised that there are a number of ways to get to the mass manufacturing. George Carver advised that John Lydon at NAC is the storage overpack construction expert.
11. Charley advised from past NRC experience that having a fabrication shop representative involved in the licensing stage helps to head off fabrication issues. He found that a fabricator presence in a certification meeting is valuable.
12. Ivan advised that the TO 12 final report contains details on STAD canister licensing costs and licensing approaches.

Presentation and Critique of the Process and Equipment Animation

Ivan Thomas presented the animation and loading process flowsheet for the 4 STAD-in-carrier design concept, which has been developed by ES in conjunction with NAC. The key points from this agenda item are provided below.

1. Mark-ups to the flowsheet were captured and the final version will be included in the Draft Final Report.
2. When available, the animation will be updated to incorporate NACs carrier design and the ES STAD canister design noting that, as described previously, the cover plate may go away.
3. There will only be one cover (silver dollar) for each of the vent and syphon ports. The top plate will provide the redundant seal on the vent and syphon ports.
4. There will be inflatable seals at the top and bottom, which seal between the top and bottom plates and the transfer cask. These are built into the transfer cask.
5. Add labels to individual components.
6. Josh advised that there is a good video on YouTube on how spent fuel loading was performed at Diablo Canyon.
7. George will look at his archived animation files for details on the transfer cask inflatable seals.
8. Add labels for each of the checks, e.g., hydrostatic testing, NDE, Helium leak testing, etc.
9. Add a label to identify where fuel assembly serial number verification is performed.
10. The Team viewed a dry cask storage animation provided George, which reflected the use of NAC equipment in Taiwan.

DAY 2

<u>Presentation and Critique of the Process and Equipment Animation (continued)</u>

Day 2 began by going through the animation one more time and the following additional comments were captured.

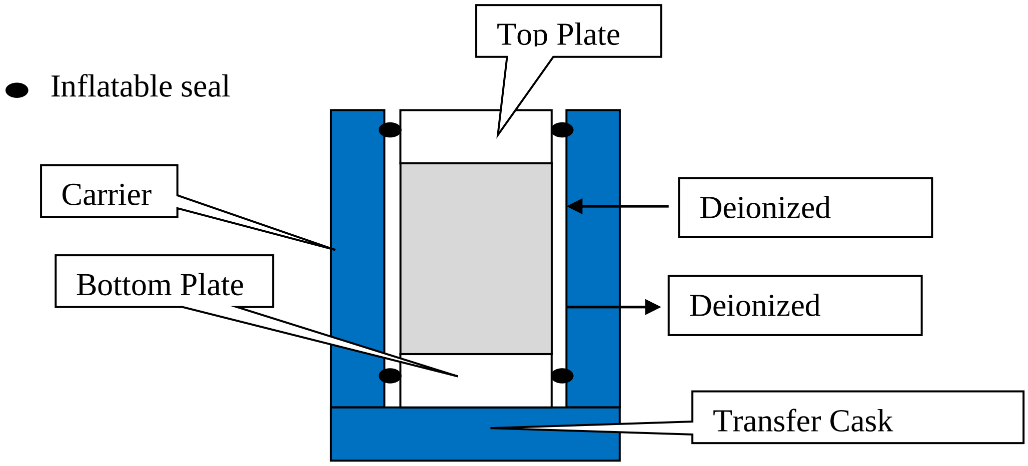
1. Need to add titles for each step and avoid using acronyms, e.g., load package, weld package, put pool water in the canisters, etc.

2. For the checks, need a check on the components at the beginning of the animation.

3. For adding water to the transfer cask and the STAD canisters, need to do the following. Fill the STAD canisters first and indicate that the water used is from the spent fuel pool. Then, using a different color, show the annulus between the transfer cask and the STAD canisters being filled and indicate that deionized water is being used.

4. Before any water is added to the STAD canisters or the transfer cask, inflatable seals that are built into the transfer cask will be inflated such that the transfer cask is sealed to the top plate and the bottom plate. The animation needs to show these seals inflating.

   After the pool water has been added to the STADs, the water will then be added to the annulus between the transfer cask and the STAD canisters (and between the upper and lower inflatable seals) by introducing it via a port in the side of the transfer cask. The sketch below shows where the seals are installed and the ports through the sides of the transfer cask, noting that when the transfer cask is placed in the pool, deionized water will be circulated via these ports in order to keep the deionized water at a positive pressure and prevent pool water from entering.



5. Need to add more fuel to the spent fuel pool.

6. Where we load the fuel into the STAD canisters, change the angle such that it shows the entry into the loading pit.

7. For the fuel loading show the crane hook for the first couple of assemblies and show them being lowered slowly. Once these are loaded we can then revert to the loading as currently shown. Verify the serial numbers of the loaded fuel bundles [for a BWR as in this animation, the serial number is on top of the fuel bundle lifting bale].

8. The water in the annulus between the transfer cask and the STAD canisters should not be removed until the STAD canisters are closed up.

9. The STAD canister design is different from the Zion design reflected in the animation. The animation should show the inner lid being welded/NDE, followed by the blowdown, drying and then Helium fill. Single covers (called silver dollars) are then welded (manually) over the vent and siphon ports. You then do the He leak check and if it passes, you then install and weld the outer lid.

10. Show the drying as a vacuum rather than a pressure. The key to this activity is that a vacuum will be held once the residual moisture has been removed.

11. George will provide a graphic for the adapter that goes between the transfer cask and the storage overage.

12. For the radiation gauge don’t show the level going up and down and instead of a graduated scale, simply show on the gauge a green segment, followed by a yellow segment, followed by a red segment. The indicator should then rise and stay in the green segment.

13. Add a person alongside the filled vertical concrete cask to give a perspective of its size.

Fact Sheet

1. For the fact sheet, which is a required deliverable for the final report, Jack requested that the ES Team provide a two page summary of the system, including schematics, 3-D models, etc.

   ACTION - Ivan Thomas – Develop a storyboard for the fact sheet for use by the team in populating the required data.

Draft Final Report

1. The agreed upon storyboard for the draft final report is provided in Appendix 4.

2. The report will need to address aging management for the system, including the carrier (if the STADs are stored in the carrier in a vertical overpack).

3. The carrier presents challenges for inspection of the store STAD canisters but, if needed, the system will allow for individual STADs to be extracted from a carrier.
4. Josh provided a data template, which he wants the ES Team to complete for just the TO18 system and include it as an appendix in the report.

90% Task Completion Briefing

The format for the briefing, which will be over ¾ of a day (assume 8:30 am to 3:00 pm, with a break for lunch), is provided below.

1. How does the Draft Final Report address the SOW requirements?
2. What does the generic design for the small STAD canister systems look like and how does it operate?
3. What were the approaches and results for the supporting analyses: structural, thermal, criticality and shielding?
4. Can the design be fabricated within current facilities and capabilities?
5. Are the systems usable by all or most nuclear utilities within their various physical and operational constraints?
6. Are there any limitations or licensing considerations of relevance?
7. What are the cost estimates for each piece of the STAD?
8. What are the key points to take away from this briefing?
9. Closeout

Appendix C - Cross-reference between Task Order 18 Statement of Work and the report for the Generic Design for Small Standardized Transportation, Aging and Disposal Canister Systems

Statement of Work Section	**Statement of Work Requirement**	**Generic Design for Small Standardized Transportation, Aging and Disposal Canister Systems**
Scope of Work		
2	The contractor shall develop a generic design of a small (4 PWR/9 BWR) STAD canister system. The STAD canister system consists of: • a canister shell; • lid(s); • internal components (e.g., basket for holding fuel assemblies, thermal shunts, and neutron absorbers, etc.);lid(s); • a canister transfer system; • storage options, including a multi-canister storage overpack, and a vault storage configuration; and • transportation options, including a multi-canister transportation overpack, and associated impact limiters.	**Section 4.1.1** **Section 4.1.2** **Section 4.1.3** **Section 4.1.4** **Appendix E**
2	The STAD canister may be loaded with commercial SNF and sealed at a reactor site, at an Interim Storage Facility (ISF), or at a repository. The loaded STAD canister may be stored in a storage overpack at a reactor site or transported (in a transportation overpack) and stored at an ISF and/or the repository. Eventually, loaded STADs will be disposed of in a waste package overpack, thus avoiding the need to open STADs once these have been sealed.	**Section 5** **Appendix G**

Statement of Work Section	**Statement of Work Requirement**	**Generic Design for Small Standardized Transportation, Aging and Disposal Canister Systems**
2	Design requirements should be derived from the performance specifications: *Performance Specification for Small and Medium Standardized Transportation, Aging, and Disposal Canister Systems, FCRD–NFST–2014–000579*	**Appendix D**
2	The contractor should provide analyses that demonstrate that the STAD can be stored in the following storage configurations: 1) multi-canister storage overpack in horizontal or vertical mode and 2) vault. In this case, a vault is an above or below grade storage system designed as a hardened reinforced concrete structure with an above grade structure providing an operating area for canister placement, storage, and removal.	**Section 4.3** **Section 5**
2	The contractor should demonstrate that the STAD can be transported in a horizontal mode in a multi-canister transportation overpack.	**Section 5.3**
2	The contractor shall perform analyses on radiation dose, heat load, criticality, and structural integrity.	**Section 4.3**
2	The contractor shall also provide cost estimates for each piece of the STAD system.	**Section 9** **Appendix K**
2	The design information to be developed by this procurement will support analyses and planning related to the waste management system. Therefore, the level of design detail required is limited to this intended usage, which requires reliable estimates of STAD canister system characteristics, such as capacity, dimensions, component masses and costs, operational characteristics and attributes, and any limitations or anticipated licensing considerations of relevance.	**Section 4.1** **Section 4.2** **Section 4.3** **Section 9** **Appendix F**

Statement of Work Section	Statement of Work Requirement	Generic Design for Small Standardized Transportation, Aging and Disposal Canister Systems
2	Design and design analyses should be sufficient to provide reasonable assurance that each STAD canister system design is viable and has the capability to meet the fundamental licensing requirements for transportation and storage, thereby providing confidence in the reliability of the provided data. At this time SAR level design is not required.	**Section 4.3** **Section 8**
2	The STAD canister systems must ultimately be NRC licensable, able to be fabricated within current facilities and capabilities, and usable by all or most nuclear utilities within their various physical and operational constraints, and able to be transported via rail. The STAD system design should have features that allow for uncomplicated manufacturing and operations.	**Section 4.2** **Section 6** **Section 7** **Section 8** **Appendix J**
2	As part of the Final Report and Briefing (Subtask 2.4 of the SOW), the contractor should develop information to communicate to decision makers and stakeholders (fact sheets, solid works representations, animation, etc.).	**Appendix E** **Appendix H** **An animation has been developed for the STAD-in-Carrier loading process.**

Statement of Work Section	Statement of Work Requirement	Generic Design for Small Standardized Transportation, Aging and Disposal Canister Systems
Applicable Codes, Standards, and Procedures		
3	The design and supporting analysis work shall be performed so that the STAD canister systems can comply with NRC regulations, applicable regulatory guides and industry standards, as appropriate.	**Section 4.3**
3	The Contractor shall prepare the STAD system designs and the final report as a Quality Rigor Level (QRL) 3 deliverable, i.e. it should receive an independent technical review by the Contractor and a quality assurance cover sheet should be provided in accordance with the Fuel Cycle Technologies Quality Assurance Program Document (FCT QAPD), Revision 2.	**Technical Review performed and documented via FCT Document Cover Sheet.**

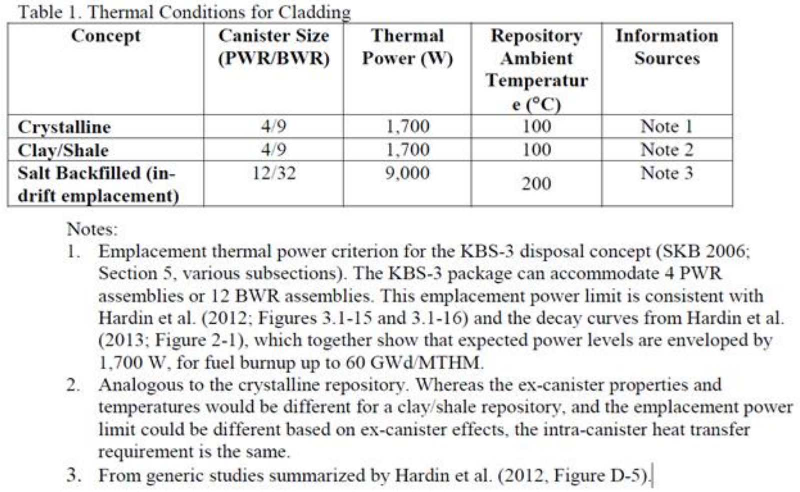
APPENDIX D – TECHNICAL FRAMEWORK

No.	Component	***Performance Specification for Small and Medium Standardized Transportation, Aging, and Disposal Canister Systems*, FCRD-NFST-2014-000579, July 2014**	Notes	Type and Section
1	STAD System	The STAD system consists of a STAD canister, aging or storage overpack/module/vault, transfer cask, site transporter, transportation overpack, and transportation skid.	Specifications for other components (e.g., disposal overpack) and equipment that are unique to the Federal SNF management system will be developed in the future.	Section 1.1, STAD System components
2	STAD Canister	The STAD canister will be loaded with commercial SNF and sealed at existing 10CFR50 facilities, existing 10CFR72 facilities, a future ISF, or a future geologic repository surface facility.		Functionality 1.2.1
3	STAD Canister	The STAD canister may be used for storage for a period of time at an Independent Spent fuel Storage Installation (ISFSI) facilities or a federal ISF and may be transported between facilities. The STAD canister storage and transportation system MUST be licensed under 10CFR Parts 71 and 72 for multiple uses (e.g., storage at an ISFSI, followed by transportation, followed by storage at and ISF, followed by transportation, followed by aging at a repository).		Requirement 1.2.1
4	STAD Overpack, Modules, and Vaults	Overpacks/modules/vaults may be designed to contain single or multiple STAD canisters and will be used to SAFELY contain loaded STAD canisters at a storage or aging facility until transported or emplaced in a repository.		Functionality 1.2.2
5	Storage Overpack	Storage overpacks that are part of a site-specific ISFSI will be designed to meet the requirements of 10CFR72.		Requirement 1.2.2
6	Shielded Transfer Cask	The Shielded Transfer Cask (STC) is used for intra-site transfer and protects the STAD canister from damage, protects workers from radiation, and allows for required heat dissipation.		Functionality 1.2.3
7	Transportation Overpack	The transportation overpack is an overpack certified under 10CFR71.		Requirement 1.2.5
8	Transportation Overpack	The transportation overpack, in conjunction with the STAD canister, provides for compliance with transportation safety functional requirements including containment, radiological protection, criticality safety, and thermal performance during normal conditions of transport (NCT) and hypothetical accident conditions (HAC).		Functionality 1.2.5
9	Support Equipment	Ancillary equipment required to operate and handle STAD system components in accordance with their certificates of compliance and other regulatory or operation requirements. Ancillary equipment to be used at reactor sites is expected to be similar to commercially available equipment in common usage.		Functionality 1.2.7
10	STAD System	Regulatory responsibilities and actions to implement this STAD specification will be limited to storage and transportation and will NOT include repository operations and disposal performance.	Because a repository geology has not been specified nor is there a specific regulation to govern repository operations and disposal performance.	Limitation 1.4
11	Applicable Documents/ References	Lists are provided of applicable regulations, DOE documents, NRC documents, codes and standards and other references.		Section 2
		GENERAL ↓		Section 3.1.1
12	STAD Canister	The design lifetime of the STAD canister shall be 150 years from the time the canister is loaded with SNF to the time the canister is loaded into a waste package.	The STAD canister, which includes a canister shell, lid, and components (e.g., basket for holding the fuel assemblies, thermal shunts, neutron absorbers, etc.), needs to perform its safety functions after storage.	Requirement 3.1.1, item 1
13	STAD Canister	The service lifetime environmental conditions shall be site appropriate for the period of deployment.		Requirement 3.1.1, item 1

No.	Component	*Performance Specification for Small and Medium Standardized Transportation, Aging, and Disposal Canister Systems*, FCRD-NFST-2014-000579, July 2014	Notes	Type and Section
14	STAD Canister	The 150 years lifetime should be licensable (along with an associated storage overpack, module, vault, etc.) under both 10 CFR Part 72 and (along with a transportation cask) under 10 CFR Part 71.	It should be assumed that the canister maybe stored at a power plant ISFSI and then transported pursuant to 10 CFR Part 71 to an ISF for storage again under 10 CFR Part 72. Storage at the ISF need not be in the same configuration of storage as the ISFSI, as long as it is licensable under 10 CFR Part 72. After interim storage, it should be assumed that the canister will be transported again under 10 Part CFR 71 to a repository where it will be subject to pre-closure safety requirements. It should be assumed that pre-closure performance requirements for repository handling and aging facilities are similar to 10 CFR Part 63. Aging management protocols necessary to ensure continued compliance with applicable requirements as well as engineered measures to control the canister storage environment are acceptable.	Requirement 3.1.1, item 1
15	STAD Canister	The STAD canister is not required to be a right circular cylinder as long as the canister, in conjunction with storage and transportation overpacks, meets all applicable requirements.	Direction was received from the DOE on 12/11/14 that right circular cylinder STADs are the default case and that irregular STAD canisters should be evaluated as an alternative approach.	Requirement 3.1.1, item 2
16	STAD Canister	The STAD canister height shall not be less than 186.0 in. and not greater than 212.0 in. including the lifting feature considering all relevant factors (e.g., tolerance stack-up, thermal expansion, internal pressure).	As agreed on 10/30/14, the Task Order 17 DOE guidance on fuel length will also be used for Task Order 18, i.e. the STAD concepts will be able to accommodate fuel assemblies with an assumed post-irradiation fuel assembly length of up to 180 inches without non-fuel components (NFCs). STAD concepts will also be capable of accommodating shorter length fuel assemblies containing NFCs which do not require special handling, provided the total post irradiation length (assembly with NFC) does not exceed 180 inches.	Requirement 3.1.1, item 3
17	STAD Canister	The canister-lifting feature shall be incorporated into the canister top lid and shall not protrude beyond the canister side walls.		Requirement 3.1.1, item 4
18	STAD Canister	The STAD canister along with its STC shall be compatible with load limits and crane-lifting capacities at existing reactor sites.		Requirement 3.1.1, item 5
19	STAD Canister	The capacity of the small STAD canister shall be either four PWR SNF assemblies or nine BWR spent fuel assemblies. The exterior dimensions of the small PWR and BWR canisters must be the same.	Syed Bokhari provided information, via email on 11/13/14, that the current STAD canister design will be for undamaged fuel only, in future as the need may be, a separate damaged fuel STAD design may be undertaken	Requirement 3.1.1, item 6
20	STAD Canister	The loaded and closed STAD canister shall be capable of being reopened while submerged in a borated or unborated pool.		Requirement 3.1.1, item 8
21	STAD Canister	A STAD canister for PWR assemblies shall be limited to accepting SNF with initial enrichment up to 5 wt % U-235 and burnup up to 62.5 GWd/MTU. Required cooling (decay) time can be variable based on enrichment, burnup, and assembly design.		Requirement 3.1.1, item 9
22	STAD Canister	A STAD canister for BWR assemblies shall accept SNF with initial enrichment up to 5 wt % U-235 and burnup up to 62.5 GWd/MTU. Required cooling (decay) time can be variable based on enrichment, burnup, and assembly design.		Requirement 3.1.1, item 10
23	STAD Canister	A STAD canister shall be capable of being loaded with SNF from all facilities that are licensed by the NRC and hold a contract with DOE for disposal of SNF.		Requirement 3.1.1, item 11
24	STAD Canister	All external edges of the STAD canister shall have a minimum radius of curvature of 0.25 in.		Requirement 3.1.1, item 12

<table>
<tr><th>No.</th><th>Component</th><th>Performance Specification for Small and Medium Standardized Transportation, Aging, and Disposal Canister Systems, FCRD-NFST-2014-000579, July 2014</th><th>Notes</th><th>Type and Section</th></tr>
<tr><td>25</td><td>STAD Canister</td><td>To the extent practicable, projections or protuberances from reasonably smooth adjacent surfaces shall be avoided or smoothly blended into the adjacent smooth surfaces.</td><td></td><td>Requirement 3.1.1, item 13</td></tr>
<tr><td>26</td><td>STAD Canister</td><td>The STAD canister shall be designed to store SNF at a utility site in accordance with 10 CFR Part 72 in either a horizontal or vertical orientation.</td><td></td><td>Requirement 3.1.1, item 14</td></tr>
<tr><td>27</td><td>STAD Canister</td><td>A STAD canister shall be designed to transport SNF in a horizontal configuration.</td><td></td><td>Requirement 3.1.1, item 15</td></tr>
<tr><td></td><td></td><td>STRUCTURAL ↓</td><td></td><td>Section 3.1.2</td></tr>
<tr><td>28</td><td>STAD Canister</td><td>A STAD canister in a storage/aging configuration shall be designed to meet the leak-tight acceptance criterion defined in ANSI N14.5-97, taking into consideration structural loads during normal operations and due to off-normal conditions and design basis accidents, including both operational events (e.g., drops) and natural phenomena events (e.g., seismic).</td><td>Note that the seismic analysis should consider the guidance in HLRWS-ISG-01.

Syed Bokhari provided information, via email on 11/13/14, that the STAD canister will be designed for 0.75g and the storage cask will be designed for 0.25g, which will be suitable for east coast ISF locations, noting that the 0.25g was subsequently revised to 0.21g at the 1/6/15 30% Task Completion Review meeting</td><td>Requirement 3.1.2, item 1</td></tr>
<tr><td>29</td><td>STAD Canister</td><td>The STAD canister structural design shall take into consideration the impact of aging on the canister based on a service lifetime of 150 years (from the time the canister is loaded with SNF to the time the canister is loaded into a waste package) that could potentially include multiple dry storage and transportation cycles.</td><td></td><td>Requirement 3.1.2, item 2</td></tr>
<tr><td>30</td><td>STAD Canister</td><td>The STAD canister is not required to have a flat bottom; the use of impact limiters (e.g., skirts, concave bottom plate), if required in the structural design, is acceptable.</td><td></td><td>Requirement 3.1.2, item 3</td></tr>
<tr><td></td><td></td><td>THERMAL ↓</td><td></td><td>Section 3.1.3</td></tr>
<tr><td>31</td><td>STAD Canister</td><td>UNF cladding temperatures in STAD canisters shall meet applicable limits established in NRC Review Plans and guidance documents.</td><td>Maximum fuel temperature is 400C</td><td>Requirement 3.1.3, item 1</td></tr>
<tr><td>32</td><td>STAD Canister</td><td>Canister cooling features and mechanisms shall be passive.</td><td></td><td>Requirement 3.1.3, item 2</td></tr>
<tr><td>33</td><td>STAD Canister</td><td>The peak thermal power output of the STAD shall not exceed the values presented in Table 1 (see Notes) at emplacement for the listed repository concepts.

NOTE. Canister size 12/32 is not applicable to Task Order 18.</td><td>
Table 1. Thermal Conditions for Cladding
<table>
<tr><th>Concept</th><th>Canister Size (PWR/BWR)</th><th>Thermal Power (W)</th><th>Repository Ambient Temperature (°C)</th><th>Information Sources</th></tr>
<tr><td>Crystalline</td><td>4/9</td><td>1,700</td><td>100</td><td>Note 1</td></tr>
<tr><td>Clay/Shale</td><td>4/9</td><td>1,700</td><td>100</td><td>Note 2</td></tr>
<tr><td>Salt Backfilled (in-drift emplacement)</td><td>12/32</td><td>9,000</td><td>200</td><td>Note 3</td></tr>
</table>
Notes:
1. Emplacement thermal power criterion for the KBS-3 disposal concept (SKB 2006; Section 5, various subsections). The KBS-3 package can accommodate 4 PWR assemblies or 12 BWR assemblies. This emplacement power limit is consistent with Hardin et al. (2012; Figures 3.1-15 and 3.1-16) and the decay curves from Hardin et al. (2013; Figure 2-1), which together show that expected power levels are enveloped by 1,700 W, for fuel burnup up to 60 GWd/MTHM.
2. Analogous to the crystalline repository. Whereas the ex-canister properties and temperatures would be different for a clay/shale repository, and the emplacement power limit could be different based on ex-canister effects, the intra-canister heat transfer requirement is the same.
3. From generic studies summarized by Hardin et al. (2012, Figure D-5).</td><td>Requirement 3.1.3, item 3</td></tr>
</table>

No.	Component	*Performance Specification for Small and Medium Standardized Transportation, Aging, and Disposal Canister Systems*, FCRD-NFST-2014-000579, July 2014	Notes	Type and Section
		DOSE AND SHIELDING ↓		Section 3.1.4
34	STAD Canister	The STAD canister shall meet the dose rate and shielding requirements for Storage and Transportation in 10 CFR Parts 71 and 72, including applicable Acceptance Criteria in associated Review Plans (NUREG-1536, NUREG-1567, and NUREG-1617), including applicable NRC SFST ISG documents.	Must address normal conditions of operation (NCT) and hypothetical accident conditions (HAC).	Requirement 3.1.4, item 1
35	STAD Canister	The combined neutron and gamma integrated average dose rate over the top surface of a loaded STAD canister shall not exceed 800 mrem/hr on contact.		Requirement 3.1.4, item 2
36	STAD Canister	The STAD canister shall be designed such that contamination on an accessible external surface shall be removable to 1,000 dpm/100 cm2 – beta.		Requirement 3.1.4, item 3
		CRITICALITY ↓		Section 3.1.5
37	STAD Canister	The STAD canister shall meet the criticality safety requirements for Storage and Transportation in 10 CFR Parts 72 and 71, including applicable Acceptance Criteria in associated Review Plans (NUREG-1536, NUREG-1567, and NUREG-1617), including applicable NRC SFST ISG documents.		Requirement 3.1.5, item 1
38	STAD Canister	The STAD canisters shall include sufficient criticality control features such as fixed neutron absorbers (plate or other form), geometry controls, moderator displacement features, or a combination of features to ensure subcriticality for the entire commercial PWR and BWR SNF inventory.		Requirement 3.1.5, item 2a
39	STAD Canister	Neutron absorber plates or tubes made from borated stainless steel produced by powder metallurgy and meeting ASTM A887-89, Standard Specification for Borated Stainless Steel Plate, Sheet, and Strip for Nuclear Application, Grade "A" alloys.		Requirement 3.1.5, item 2a (i)
40	STAD Canister	Minimum thickness of neutron absorber interstitial to fuel assemblies shall be 0.4375 in. Maximum and nominal thickness may be based on structural requirements. Multiple plates may be used if corrosion assumptions (250 nm/year) are taken into account for all surfaces such that 6 mm remains after 10,000 years.		Requirement 3.1.5, item 2a (ii)
41	STAD Canister	The neutron absorber plate shall have a boron content of 1.1 wt % to 1.2 wt %, a range that falls within the specification range for 304B4 (UNS S30464) as described in ASTM A887-89, Standard Specification for Borated Stainless Steel Plate, Sheet, and Strip for Nuclear Application.		Requirement 3.1.5, item 2a (iii)
42	STAD Canister	Neutron-absorbing material shall extend the full length of the active fuel region inclusive of any axial shifting within the STAD canister.		Requirement 3.1.5, item 2a (iv)
		CONFINEMENT AND CONTAINMENT ↓		Section 3.1.6
43	STAD Canister	The STAD canister design shall meet the applicable 10 CFR 72 requirements for a SNF storage confinement boundary. The canister design must be sufficient to address the staff review criteria in NUREG-1536, including applicable NRC SFST ISG documents.		Requirement 3.1.6, item 1
44	STAD Canister	Helium shall be the only gas used for final backfill operations.		Requirement 3.1.6, item 2
45	STAD Canister	The STAD canister shell and lid shall be designed and fabricated in accordance with ASME Boiler and Pressure Vessel Code, Section III, Division 1, Sub- section NB or NC (for Class 1 Components) to the extent practicable.		Requirement 3.1.6, item 3
46	STAD Canister	The vendor shall identify applicable code exceptions, clarifications, interpretations, and code cases.		Requirement 3.1.6, item 3

No.	Component	***Performance Specification for Small and Medium Standardized Transportation, Aging, and Disposal Canister Systems*****, FCRD-NFST-2014-000579, July 2014**	Notes	Type and Section
47	STAD Canister	In accordance with industry standards and regulatory guidance, the STAD canister shall be designed to facilitate the following: a) Draining and drying to remove water vapor and oxidizing material, b) Filling with helium, and c) Limiting maximum allowable oxidizing gas concentration within the loaded and sealed STAD canister to preclude significant corrosion of the canister internals.		Requirement 3.1.6, item 4 (a), (b) and (c)
48	STAD Canister	All proposed transportation design functions for the STAD canister pressure boundary, such as containment and/or moderator exclusion for normal transportation and hypothetical accident conditions shall be defined and explained.		Requirement 3.1.6, item 5
		OPERATIONS ↓		Section 3.1.7
49	STAD Canister	The STAD canister lid shall be designed for handling under water with the STAD canister in a vertical orientation.		Requirement 3.1.7, item 1
50	STAD Canister	The STAD canister body and lid shall have features to center and seat the lid during submerged installation. The maximum off-center value is ½ in.		Requirement 3.1.7, item 2
51	STAD Canister	A feature for lifting a vertically oriented, loaded STAD canister from the lid shall be provided. The lifting feature may be integral with the lid or mechanically attached.		Requirement 3.1.7, item 3
52	STAD Canister	An open, empty, and vertically oriented STAD canister shall have integral lifting feature(s) provided to allow lifting by an overhead handling system.		Requirement 3.1.7, item 4
53	STAD Canister	The STAD canister shall be designed with features such that draining, drying, backfill, and welding operations take advantage of "as low as reasonably achievable" (ALARA) principles.		Requirement 3.1.7, item 5
		MATERIALS ↓		Section 3.1.8
54	STAD Canister	It is suggested that, except for thermal shunts and criticality control materials, the STAD canister and structural internals (i.e., basket) be constructed of a Type 300-series stainless steel (UNS S3XXXX, such as UNS S31603, which may also be designated as type 316L) as listed in ASTM A-276-06, Standard Specification for Stainless Steel Bars and Shapes. However, other materials may be considered provided they are compatible with all other requirements in this performance specification.		Requirement 3.1.8, item 1
55	STAD Canister	General guidance for materials used in dry storage casks and transportation packages is given in NUREG-1536.		Requirement 3.1.8, item 2
56	STAD Canister	The following are design and performance requirements beyond those in NUREG-1536: a) Materials are selected to accommodate the effects of, and to be compatible with, known ISFSI site characteristics, environmental conditions, and the 150-year design life of the canister prior to placing it in a waste package, b) b) Components of the STAD should not react with one another, or with the cover gas or SNF, in a manner that may adversely affect safety. Additionally, corrosion of components inside the containment vessel should be effectively prevented, and c) Potential problems from uniform corrosion, pitting, stress corrosion cracking, or other types of corrosion should be evaluated for the environmental conditions and dynamic loading effects that are specific to the component. Because it is assumed that a waste package will be used for disposal, this refers to environmental conditions during storage or aging and transport.		Requirement 3.1.8, item 2 (a), (b) and (c)
57	STAD Canister	Weld specifications for non-closure welds are provided in the ASME Boiler and Pressure Vessel Code, Section II. Guidance for the closure welds is provided in NUREG-1536.		Requirement 3.1.8, item 3

No.	Component	***Performance Specification for Small and Medium Standardized Transportation, Aging, and Disposal Canister Systems*, FCRD-NFST-2014-000579, July 2014**	Notes	Type and Section
58	STAD Canister	Canister design shall ensure that all external STAD canister welds have the capability to be readily post-weld treated for stress mitigation at reactor sites, using methods such as thermal annealing, shot- or laser-peening, or low-plasticity burnishing.		Requirement 3.1.8, item 4
59	STAD Canister	All metal surfaces shall meet surface cleanliness classification C requirement defined in ASME NQA-1-2000 Edition, Subpart 2.1, Quality Assurance Requirements for Cleaning of Fluid Systems and Associated Components for Nuclear Power Plants.		Requirement 3.1.8, item 5
60	STAD Canister	The STAD canister and its basket materials shall be designed to be compatible with either borated or unborated pool water.		Requirement 3.1.8, item 6
61	STAD Canister	The following is a list of prohibited or restricted materials: a) The STAD canister shall not have organic, hydrocarbon-based materials of construction, b) The STAD canister shall not be constructed of pyrophoric materials, and c) The STAD canister, including the steel matrix, gaskets, seals, adhesives and solder, shall not be constructed with materials that would be regulated as hazardous wastes under the Resource Conservation and Recovery Act (RCRA) and prohibited from land disposal under RCRA if declared to be waste.		Requirement 3.1.8, item 7 (a), (b) and (c)
62	STAD Canister	The following is a list of marking requirements: a) The STAD canister shall be capable of being marked on the lid and body with an identical unique identifier prior to delivery for loading, b) The markings shall remain legible without intervention or maintenance during/after any of the following events. • The entire service life prior to being placed in a waste package • Normal operations to include loading, closure, storage, transportation, aging, and placement in a disposal waste package		Requirement 3.1.8, item 8 (a), (b) and bullets one and two
		SECURITY ↓		Section 3.1.9
63	STAD System	The STAD and its storage cask, module, vault, etc., shall be designed to permit compliance with the requirements of 10 CFR Part 73, Physical Protection of Plants and Materials, as applicable to storage of SNF at an ISFSI license under 10 CFR Part 72.		Requirement 3.1.9, item 1
		SPACE UTILIZATION ↓		Section 3.2.1
64	Storage And Aging Configuration	Storage and aging configurations shall meet 10 CFR Part 72 and shall have the capability to maintain the STAD canister for 150 years.		Requirement 3.2.1, item 1
65	Storage And Aging Configuration	Storage and aging configurations for STAD canisters include the potential use of overpacks, modules, or vault systems.		Requirement 3.2.1, item 1
66	Storage And Aging Configuration	Overpacks/modules may be designed to handle single or multiple STAD canisters.		Requirement 3.2.1, item 1
67	Storage And Aging Configuration	Vault systems will provide similar functions to storage/aging overpacks or modules but may contain active components.		Requirement 3.2.1, item 1

No.	Component	*Performance Specification for Small and Medium Standardized Transportation, Aging, and Disposal Canister Systems*, FCRD-NFST-2014-000579, July 2014	Notes	Type and Section
		SEISMIC AND ENVIRONMENTAL ↓		Section 3.2.2
68	Storage And Aging Configuration	All storage configurations should be designed to be able to meet 10 CFR Part 72. The guidance in HLWRC-ISG-01 should be considered in the seismic analysis.		Requirement 3.2.2, item 1
		SHIELDED TRANSFER CASK (STC) ↓		Section 3.3
69	Shielded Transfer Cask	The STC shall be designed in accordance with applicable 10 CFR Part 72 requirements to transfer a loaded STAD canister prior to loading into a storage/aging overpack/module/vault or transportation overpack.		Requirement 3.3, item 1
		SITE TRANSPORTER ↓		Section 3.4
70	Site Transporter	The site transporter shall be designed in accordance with applicable 10 CFR Part 72 requirements to transport loaded and unloaded STCs at an ISFSI or ISF.		Requirement 3.4, item 1
		TRANSPORTATION OVERPACK - GENERAL ↓		Section 3.5.1
71	Transportation Overpack	The transportation overpack requirements are specified in 10 CFR 71 for a SNF transportation package. The transportation overpack design must be sufficient to address the staff review criteria in NUREG-1617, including applicable SFST ISG documents.		Requirement 3.5.1, item 1
72	Transportation Overpack	The transportation overpack cavity shall accommodate a STAD canister or canisters (potentially in a multi-canister fixture).		Requirement 3.5.1, item 2
73	Transportation Overpack	The transportation overpack shall function with the STAD canister that meets the requirements of Section 3.1.		Requirement 3.5.1, item 3
74	Transportation Overpack	The loaded transportation overpack (without impact limiters) shall be designed to be lifted in a vertical orientation by an overhead crane.		Requirement 3.5.1, item 4
75	Transportation Overpack	The loaded transportation overpack (without impact limiters) shall be able to stand upright when set down upon a flat horizontal surface without requiring the use of auxiliary supports.		Requirement 3.5.1, item 5
76	Transportation Overpack	Lifting attachments and appurtenances on transportation overpacks, overpack lids, and impact limiters shall be designed, fabricated, inspected, and tested in accordance with NUREG-0612, Control of Heavy Loads at Nuclear Power Plants, particularly subsection 5.1.6 for single failure-proof lifting systems.		Requirement 3.5.1, item 6
77	Transportation Overpack	The transportation overpack shall minimize the number of transportation operations and required railcars.		Requirement 3.5.1, item 7
		TRANSPORTATION OVERPACK - STRUCTURAL ↓		Section 3.5.2
78	Transportation Overpack	A loaded STAD canister contained within a transportation overpack assembled with any other components included in the packaging, as defined in 10 CFR Part 71, shall meet the requirements as specified in 10 CFR Part 71, as evidenced by a valid Certificate of Compliance.		Requirement 3.5.2, item 1
		TRANSPORTATION OVERPACK - THERMAL ↓		Section 3.5.3
79	Transportation Overpack	During normal operations, the SNF cladding temperature in the STAD canister shall not exceed 752°F.		Requirement 3.5.3, item 1
80	Transportation Overpack	Transportation overpack cooling features and mechanisms shall be passive.		Requirement 3.5.3, item 2

No.	Component	*Performance Specification for Small and Medium Standardized Transportation, Aging, and Disposal Canister Systems*, FCRD-NFST-2014-000579, July 2014	Notes	Type and Section
		TRANSPORTATION OVERPACK - DOSE AND SHIELDING ↓		Section 3.5.4
81	Transportation Overpack	The transportation overpack impact limiters shall include design and handling features that use standardized tools and features that simplify removal operations. Standard tools are those that can be found in industrial tool catalogs.		Requirement 3.5.4, item 1
82	Transportation Overpack	Transportation overpack shall be designed such that contamination on accessible external surfaces shall be removable to: a) 1,000 dpm/100 cm2 – beta-gamma with a wipe efficiency of 0.1 and 2) 20 dpm/100 cm2 – alpha with a wipe efficiency of 0.1.		Requirement 3.5.4, items 2(a) and 2(b)
		TRANSPORTATION OVERPACK - CRITICALITY ↓		Section 3.5.5
83	Transportation Overpack	No specific requirements beyond those of 10 CFR Part 71.		Requirement 3.5.5, item 1
		TRANSPORTATION OVERPACK - CONTAINMENT ↓		Section 3.5.6
84	Transportation Overpack	The transportation overpack shall have sealed mechanical closures and meet the requirements for the containment boundary specified in 10 CFR 71 for a SNF transportation package.		Requirement 3.5.6, item 1
85	Transportation Overpack	The transportation overpack design must be sufficient to address the staff review criteria in NUREG-1617, including applicable SFST ISG documents.		Requirement 3.5.6, item 1
		TRANSPORTATION OVERPACK - OPERATIONS ↓		Section 3.5.7
86	Transportation Overpack	Normal operational procedures shall not require submergence of transportation overpack into a spent fuel pool at the repository or loading site. Transportation overpacks may be submerged in a pool in unusual or off-normal circumstances.		Requirement 3.5.7, item 1
87	Transportation Overpack	Transportation overpack shall have closures that can be bolted and unbolted using standard tools. Standard tools are those that can be found in industrial tool catalogs.		Requirement 3.5.7, item 2
88	Transportation Overpack	The transportation overpack shall have trunnions that meet the following requirements: a) There shall be two upper (lifting) trunnions with the centerline located between 8 and 24 in. from the top of the transportation overpack, b) There shall be two lower (rotation) trunnions with the centerline located less than 36 in. from the bottom of the transportation overpack, and c) The centerline of each trunnion set shall be outside the area of the SNF region to provide maximum ALARA benefits.	Syed Bokhari advised, via email on 11/13/14, that the specification requirements regarding the trunnion location are basically to ensure maximum ALARA benefits. If a different location is more suitable from operational considerations, it will be acceptable as long as ALARA benefits are ensured and dose levels are justifiable	Requirement 3.5.7, items 3(a), 3(b) and 3(c)
		TRANSPORTATION OVERPACK - MATERIALS ↓		Section 3.5.8
89	Transportation Overpack	Materials selections shall be as necessary to meet requirements of 10 CFR Part 71 and other requirements of this specification.		Requirement 3.5.8, item 1
		TRANSPORTATION OVERPACK - SECURITY ↓		Section 3.5.9
90	Transportation Overpack	The transportation overpack shall be designed to permit compliance with the applicable requirements of 10 CFR Part 73, Physical Protection of Plants and Materials, for transportation of spent nuclear fuel.		Requirement 3.5.9, item 1

No.	Component	*Performance Specification for Small and Medium Standardized Transportation, Aging, and Disposal Canister Systems*, FCRD-NFST-2014-000579, July 2014	Notes	Type and Section
		TRANSPORTATION OVERPACK - TRANSPORTATION SKID ↓		Section 3.6
91	Transportation Overpack	Transportation skid shall be designed to permit the loaded transportation overpack, without impact limiters, to be upended by rotation about its lower trunnions and removed from the transportation skid in a vertical orientation via overhead crane.		Requirement 3.6, item 1
92	Transportation Overpack	The transportation skid to be used with the STAD canister-based system shall have the following characteristics: a) secures the transportation overpack during normal conditions of transport in accordance with requirements of 10 CFR Part 71.45, b) secures to the railcar in accordance with requirements of AAR Interchange Rule 88, A.16.c.3. (AAR Field Manual 2014), and c) facilitates lifting of the loaded package in its transportation configuration, including the skid and impact limiters, and transfer of the package from one conveyance to another.		Requirement 3.6, items 2(a), 2(b) and 2c
		Task Order 18, Statement of Work, Generic Design for Small Standardized Transportation, Aging, and Disposal Canister System		
93	General	The contractor shall develop a generic design of a small (4 PWR/9 BWR) STAD canister system. The STAD canister system consists of: 1. a canister shell; 2. lid(s) 3. internal components (e.g. basket for holding fuel assemblies, thermal shunts, and neutron absorbers, etc.); 4. a canister transfer system; 5. storage options, including a multi-canister storage overpack, and a vault storage configuration; 6. transportation options, including a multi-canister transportation overpack, and associated impact limiters		Requirement 2.0

No.	Component	*Performance Specification for Small and Medium Standardized Transportation, Aging, and Disposal Canister Systems*, FCRD-NFST-2014-000579, July 2014	Notes	Type and Section
94	Storage Configurations	The contractor should provide analyses that demonstrate that the STAD can be stored in the following storage configurations: 1) multi-canister storage overpack in horizontal or vertical mode and 2) vault. In this case, a vault is an above or below grade storage system designed as a hardened reinforced concrete structure with an above grade structure providing an operating area for canister placement, storage, and removal.	At the 30% Task Completion Review meeting on January 6th, 2015, with the DOE, it was noted that the loaded STAD canisters need to be capable of being handled in both the vertical and horizontal orientation. They also need to be capable of being loaded into storage modules both horizontally and vertically. DOE is willing to accept engineering judgment where appropriate; however, analyses should be performed for areas having greater uncertainty, such as thermal performance. The Contractor may focus analyses on vertical storage in a multi-canister storage overpack and on horizontal storage of individual STAD canisters in an above-grade vault. Demonstrating the capability for horizontal vault storage of a multi-canister carrier system, in lieu of individual canisters, is also acceptable. At the second workshop from January 27th to 28th, 2015, there was a discussion on what options the ES Team should look at for above-grade vault storage. It was agreed that storing single STAD canisters in a NUHOMS type system will not be a challenge and the canisters will be designed to be pushed and pulled. What is of particular interest to the DOE is the concept of operations for how individual canisters can be extracted from a carrier and placed horizontally into a storage module, noting that for vertical storage the canisters will be stored in the carrier.	Requirement 2.0
95	Transport Configuration	The contractor should demonstrate that the STAD can be transported in a horizontal mode in a multi-canister transportation overpack.		Requirement 2.0
96	Design, Analysis and Required Data	The contractor shall perform analyses on radiation dose, heat load, criticality, and structural integrity. The design information to be developed by this procurement will support analyses and planning related to the waste management system. Therefore, the level of design detail required is limited to this intended usage, which requires reliable estimates of STAD canister system characteristics, such as capacity, dimensions, component masses and costs, operational characteristics and attributes, and any limitations or anticipated licensing considerations of relevance. Design and design analyses should be sufficient to provide reasonable assurance that each STAD canister system design is viable and has the capability to meet the fundamental licensing requirements for transportation and storage, thereby providing confidence in the reliability of the provided data. At this time SAR level design is not required.	A data template was provided by the DOE at the second workshop (1/27/15 to 1/28/15).	Requirement 2.0
97	Cost Estimate	The contractor shall provide cost estimates for each piece of the STAD system.		Requirement 2.0

No.	Component	***Performance Specification for Small and Medium Standardized Transportation, Aging, and Disposal Canister Systems*, FCRD-NFST-2014-000579, July 2014**	Notes	Type and Section
98	Licensability	The STAD canister systems must ultimately be NRC licensable.		Requirement 2.0
99	Fabricability	The STAD canister systems must be able to be fabricated within current facilities and capabilities, and have features that allow for uncomplicated manufacturing and operations.		Requirement 2.0
100	Usability	The STAD canister systems must be usable by all or most nuclear facilities within their various physical and operational constraints.		Requirement 2.0
101	Transport	The STAD canister systems must be able to be transported via rail.		Requirement 2.0
102	Marketing Material	As part of the Final Report and Briefing (Subtask 2.4 below), the contractor should develop information to communicate to decision makers and stakeholders (fact sheets, solid works representations, animation, etc.).		Requirement 2.0

Appendix E - Outline Drawings for Generic Design for STAD Canister Systems

GENERAL NOTES: (UNLESS OTHERWISE SPECIFIED)

1. ALL DIMENSIONS SHOWN IN INCHES UNLESS OTHERWISE NOTED.

2 ITEM 2 MAY INCLUDE FULL-PENETRATION SEAM WELDS.

3 WELDS SHALL RECEIVE NDE IN ACCORDANCE WITH NB-5000.

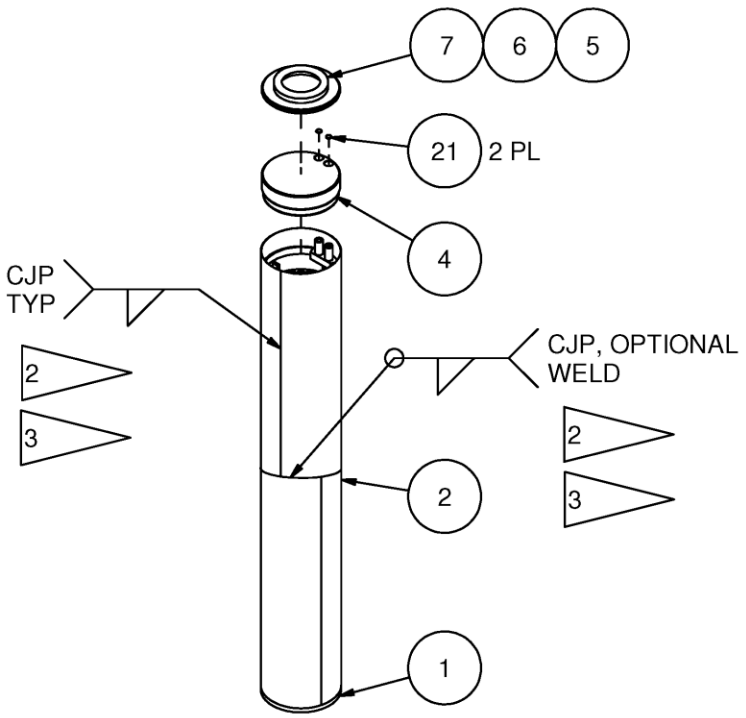
4 WELDS SHALL RECEIVE NDE IN ACCORDANCE WITH NG-5000. B

5 OPTIONALLY ITEM 4 MAY BE FABRICATED FROM TWO SEPARATE PLATES JOINED BY A 3/8 INCH PARTIAL PENETRATION GROOVE WELD ALL-AROUND.

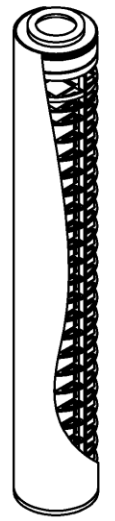
6 THE FINISHED SHELL ASSEMBLY (ITEMS 1, 2, 3, 15, & 16) SHALL BE HYDROSTATICALLY TESTED IN ACCORDANCE WITH THE REQUIREMENT OF NB-6000.

7 HELIUM LEAKAGE RATE TESTING SHALL BE PERFORMED ON ALL CANISTER SHELL PRESSURE BOUNDARY SHOP WELDS TO THE LEAKTIGHT CRITERIA OF ANSI N14.5.

QTY	NOMENCLATURE/DESCRIPTION	MATERIAL/REFERENCE	ITEM
1	BOTTOM PLATE, 2 INCH THK	ASME SA-240, TYPE 316L	1
1	CANISTER BODY, 1/4 INCH PLATE	ASME SA-240, TYPE 316L	2
1	SUPPORT RING, 1/2 INCH PLATE	ASME SA-240, TYPE 316L	3
1	SHIELD PLUG	ASME SA-240, TYPE 316L	4
1	TOP PLATE, 2 INCH PLATE	ASME SA-240, TYPE 316L	5
1	GRAPPLE RING CYLINDER, 1 3/4 INCH PLATE	ASME SA-240, TYPE 316L	6
1	GRAPPLE RING PLATE, 1 INCH PLATE	ASME SA-240, TYPE 316L	7
24	SPACER PLATE, 3/4 INCH PLATE	ASME SA-240, TYPE 316L	8
1	TOP END SPACER PLATE, 28.25 DIA X 2 INCH PLATE	ASME SA-240, TYPE 316L	9
4	SUPPORT BAR, 1 INCH THK	ASME SA-240, TYPE 316L	10
4	GUIDE TUBE, 16 GA. (0.0595 INCH THK)	ASME SA-240, TYPE 316L	11
6	NEUTRON ABSORBER PLATE #1, 7/16 INCH PLATE	ASTM A887-89, GRADE A	12
4	NEUTRON ABSORBER PLATE #2, 7/16 INCH PLATE	ASTM A887-89, GRADE A	13
40	NEUTRON ABSORBER PLATE #3, 7/16 INCH PLATE	ASTM A887-89, GRADE A	14
1	DRAIN/VENT PORT BODY	ASME SA-240, TYPE 316L	15
2	DRAIN/VENT PORT TOP	ASME SA-240 OR SA-479, TYPE 316L	16
1	SIPHON TUBE, 3/4 INCH DIA X 18 GA.	ASTM A249 OR A269, TYPE 304	17
1	TUBE FITTING, 3/4 INCH DIA NPT	SWAGELOK (SS-1210-1-2)	18
1	QUICK CONNECT BODY, 1/2 INCH MNPT	SWAGELOK (SS-QC8-B-8PMIS)	19
1	QUICK CONNECT STEM, 1/2 INCH MNPT	SWAGELOK (SS-QC8-D-8PMIS)	20
2	DRAIN/VENT PORT COVER	ASME SA-240, TYPE 316L	21



EXPANDED VIEW
SCALE: NONE



NOTE:
SHELL PARTIALLY
REMOVED FOR
CLARITY

PRELIMINARY

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

TALISMAN
PETERSEN INCORPORATED
Exelon Nuclear Partners
NAC INTERNATIONAL

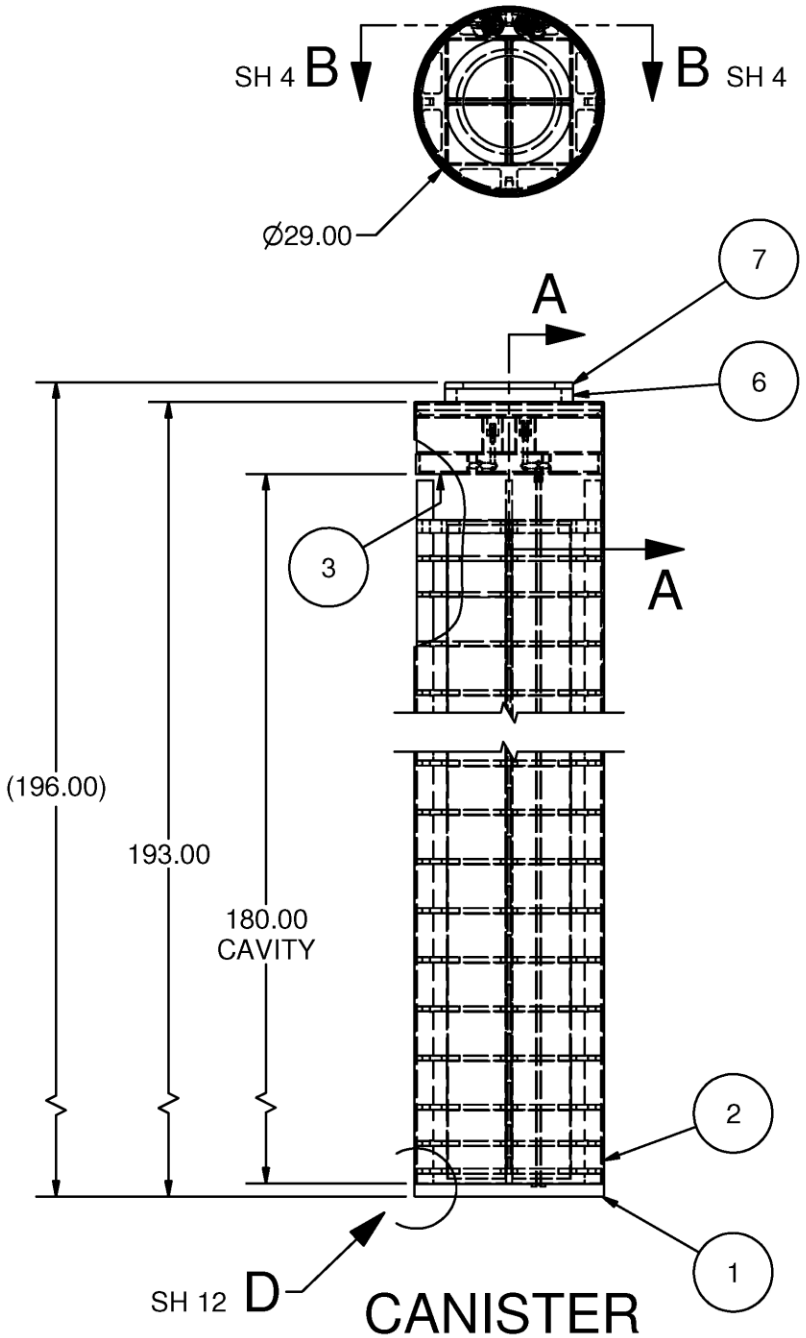
	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

CONTRACT NO. DE-NE-0000293
PROJECT NO. 205591

TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
4P ASSEMBLY AND DETAILS

SIZE B
DWG NO. DWG-205591-ME-0005
REV B
SCALE: SHOWN
SHEET: 1 OF 13

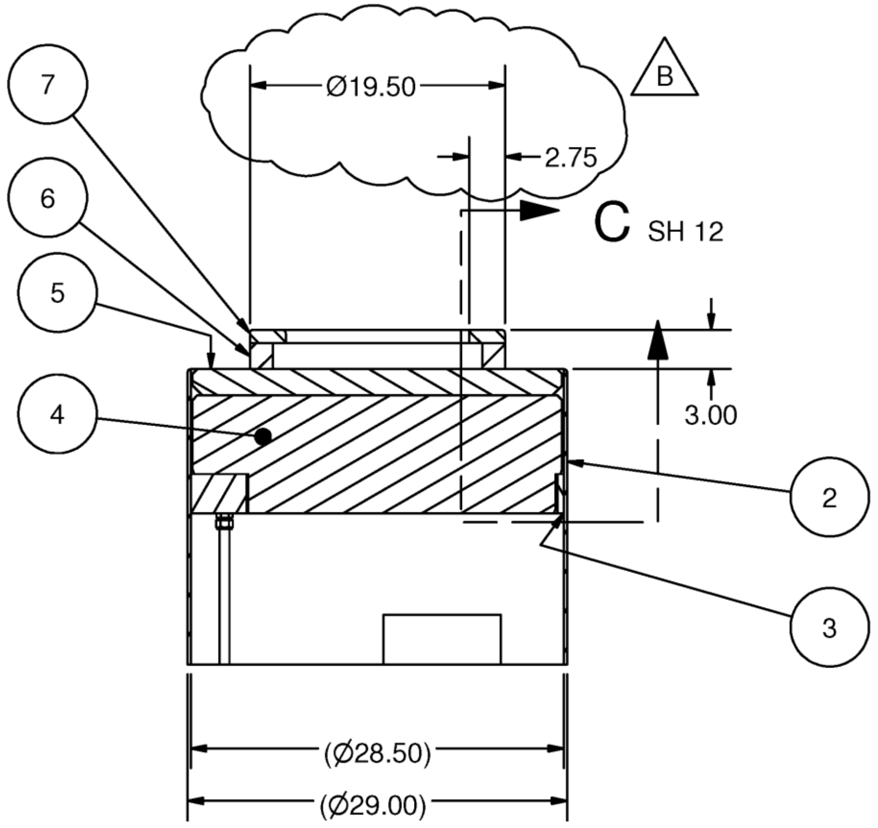


CANISTER ASSEMBLY

SCALE: 1/24

NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.



SECTION A-A

SCALE: 1/12
ITEMS REMOVED FOR CLARITY

PRELIMINARY

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

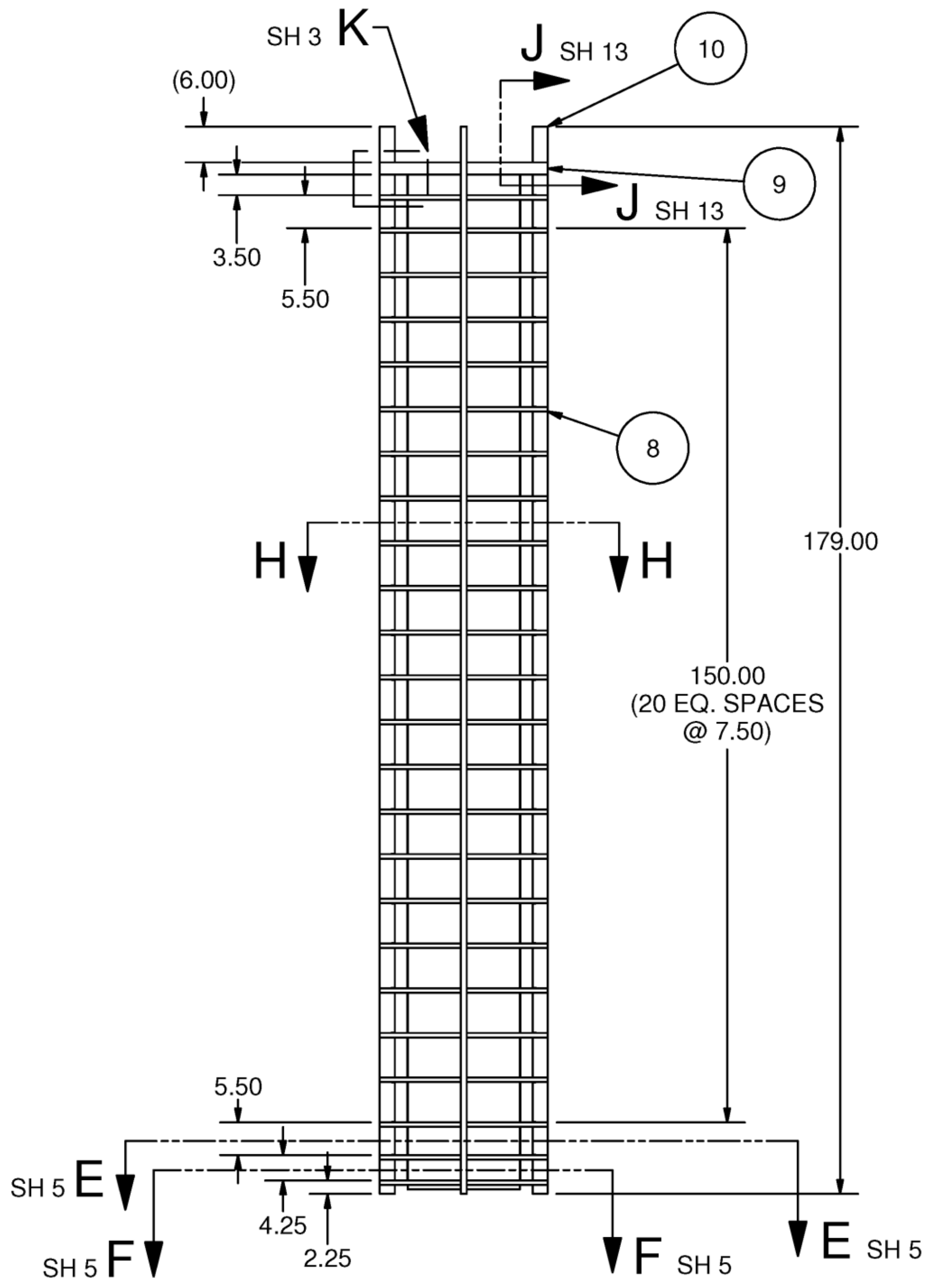
	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

CONTRACT NO. DE-NE-0000293
PROJECT NO. 205591

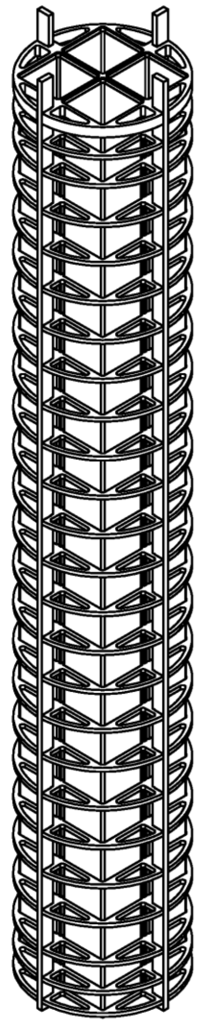
TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
4P ASSEMBLY AND DETAILS

SIZE B
DWG NO. DWG-205591-ME-0005
REV B
SCALE: SHOWN
SHEET: 2 OF 13



BASKET ASSEMBLY

SCALE: 1/24

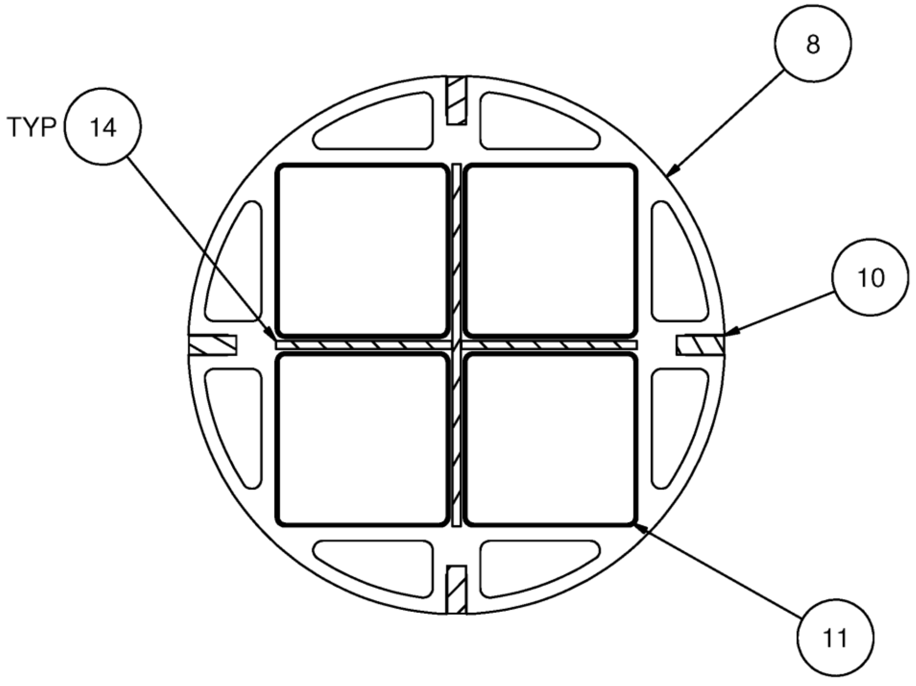


ISO VIEW

SCALE: 1/24

NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.



SECTION H-H

SCALE: 1/8

PRELIMINARY

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

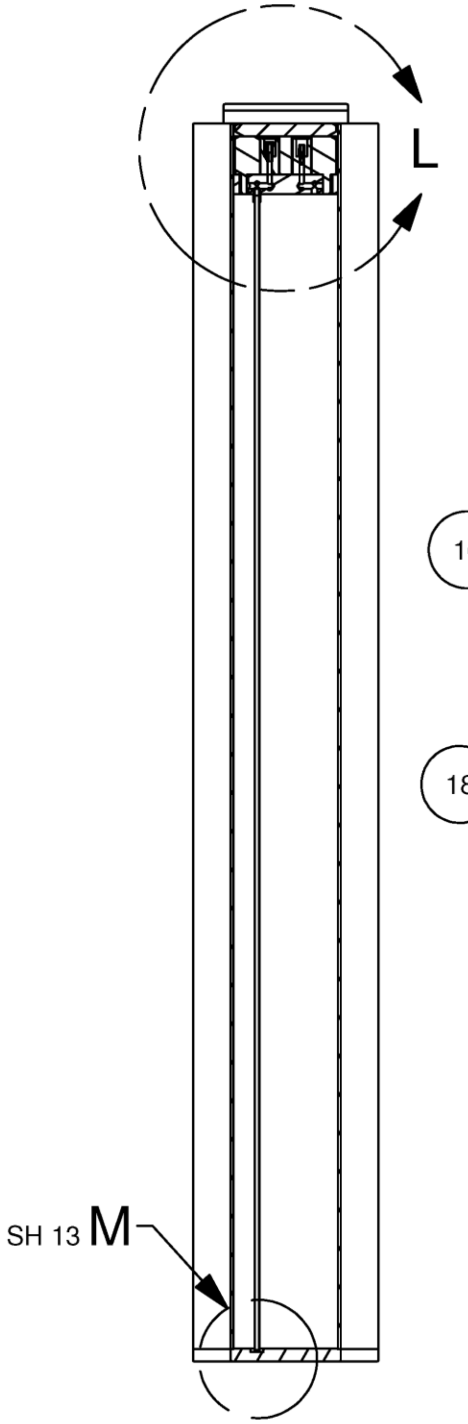
	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

CONTRACT NO. DE-NE-0000293
PROJECT NO. 205591

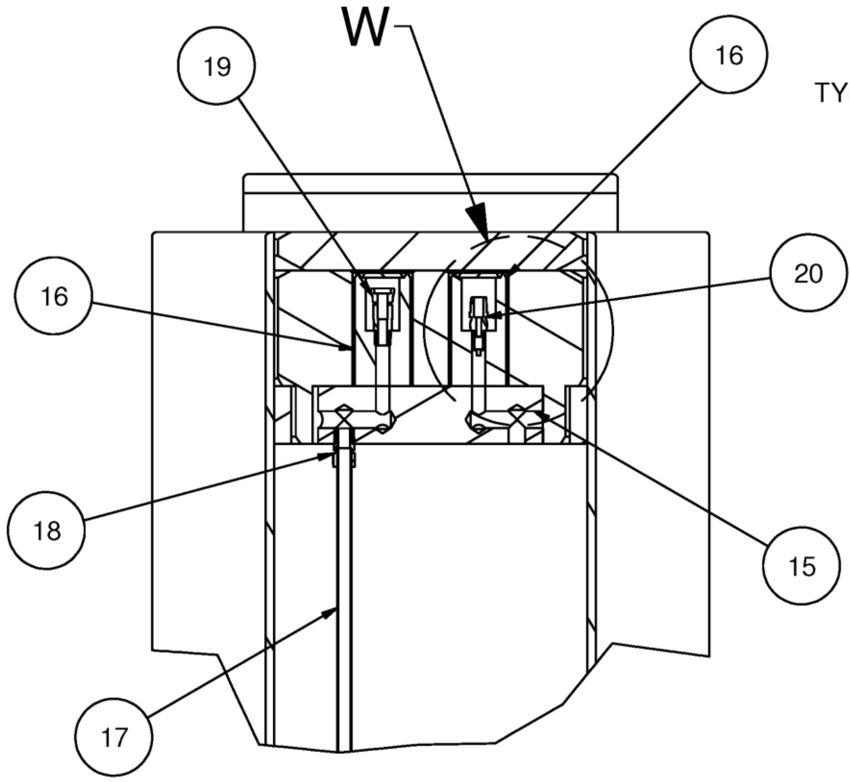
TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
4P ASSEMBLY AND DETAILS

SIZE B
DWG NO. DWG-205591-ME-0005
REV B
SCALE: SHOWN
SHEET: 3 OF 13



SECTION B-B

SCALE: 1/24
SHEET 2

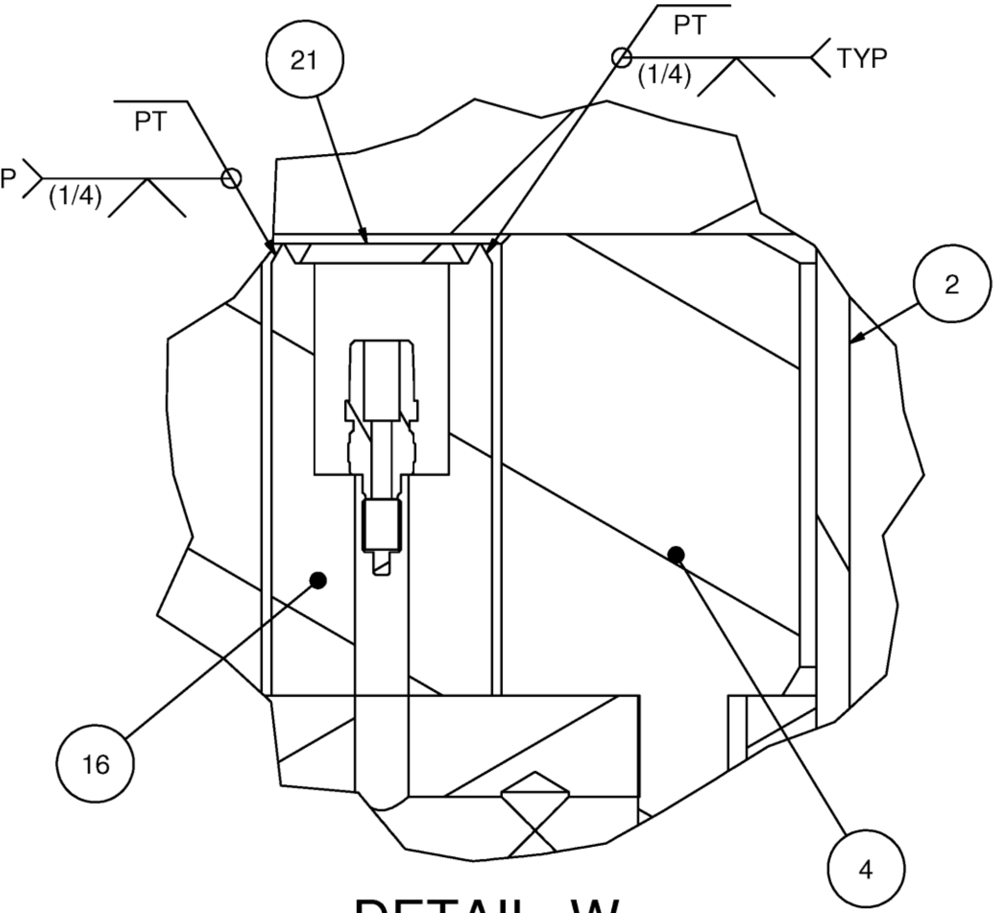


DETAIL L

SCALE: 1 / 8

NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.



DETAIL W

SCALE: 1 / 2

PRELIMINARY

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

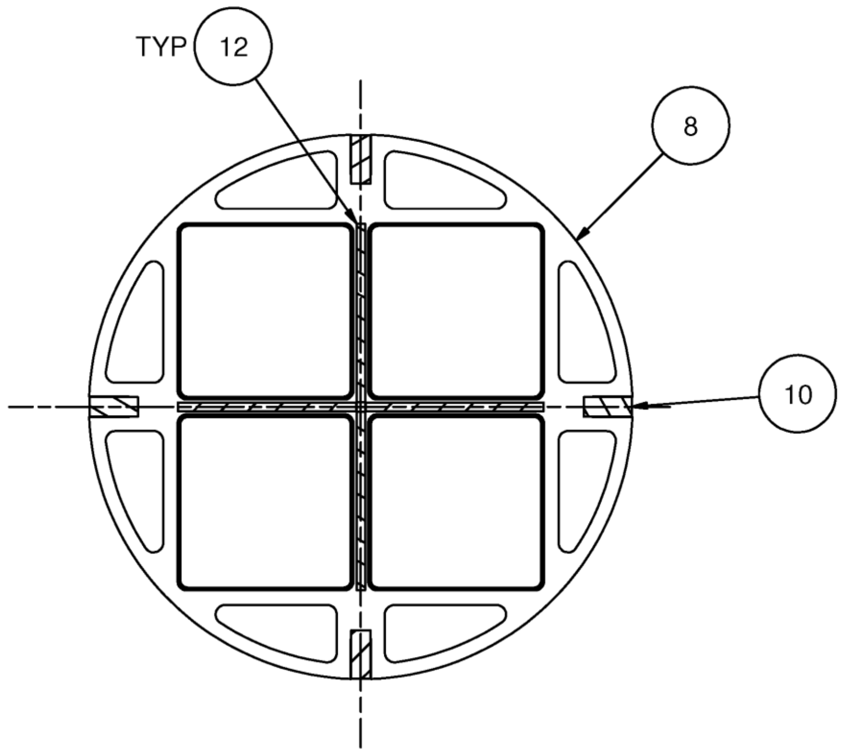
CONTRACT NO. DE-NE-0000293
PROJECT NO. 205591

TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
4P ASSEMBLY AND DETAILS

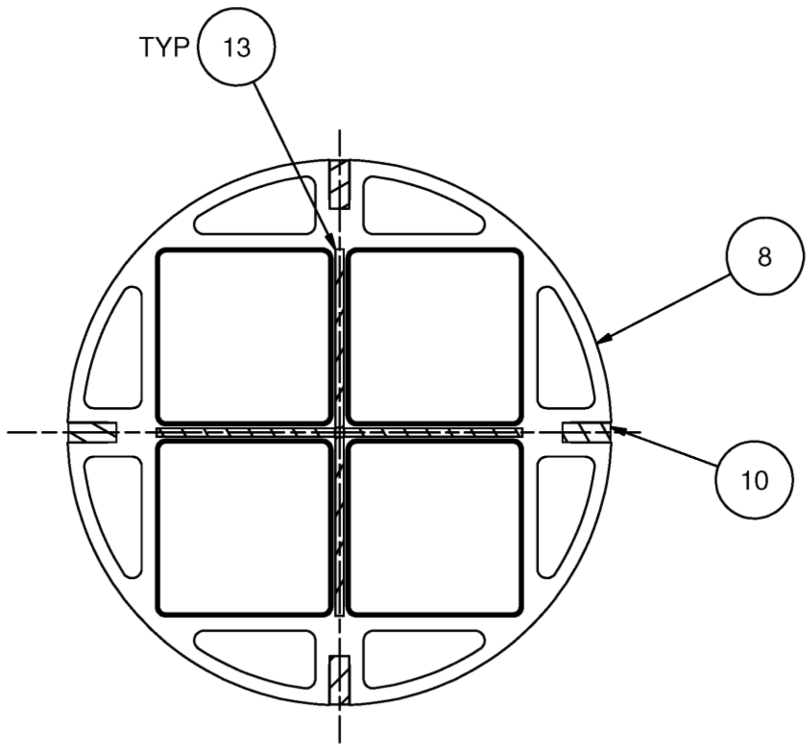
SIZE B
DWG NO. DWG-205591-ME-0005
REV B
SCALE: SHOWN
SHEET: 4 OF 13

NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.



SECTION F-F
SCALE: 1/8
SHEET 3



SECTION E-E
SCALE: 1/8
SHEET 3

PRELIMINARY

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

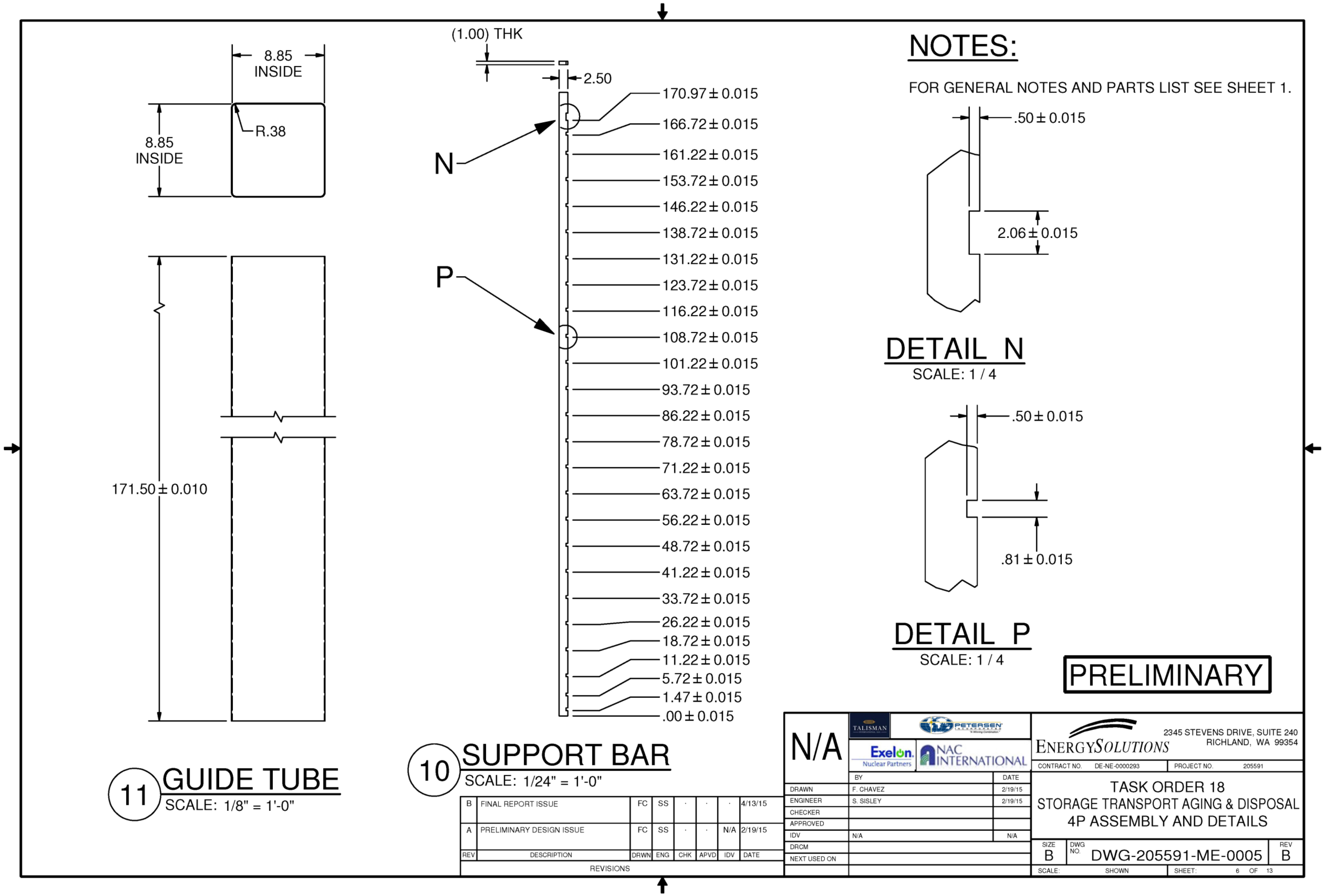
	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

CONTRACT NO. DE-NE-0000293
PROJECT NO. 205591

TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
4P ASSEMBLY AND DETAILS

SIZE B
DWG NO. DWG-205591-ME-0005
REV A
SCALE: SHOWN
SHEET: 5 OF 13



NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.

DETAIL N
SCALE: 1 / 4

DETAIL P
SCALE: 1 / 4

⑪ GUIDE TUBE
SCALE: 1/8" = 1'-0"

⑩ SUPPORT BAR
SCALE: 1/24" = 1'-0"

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

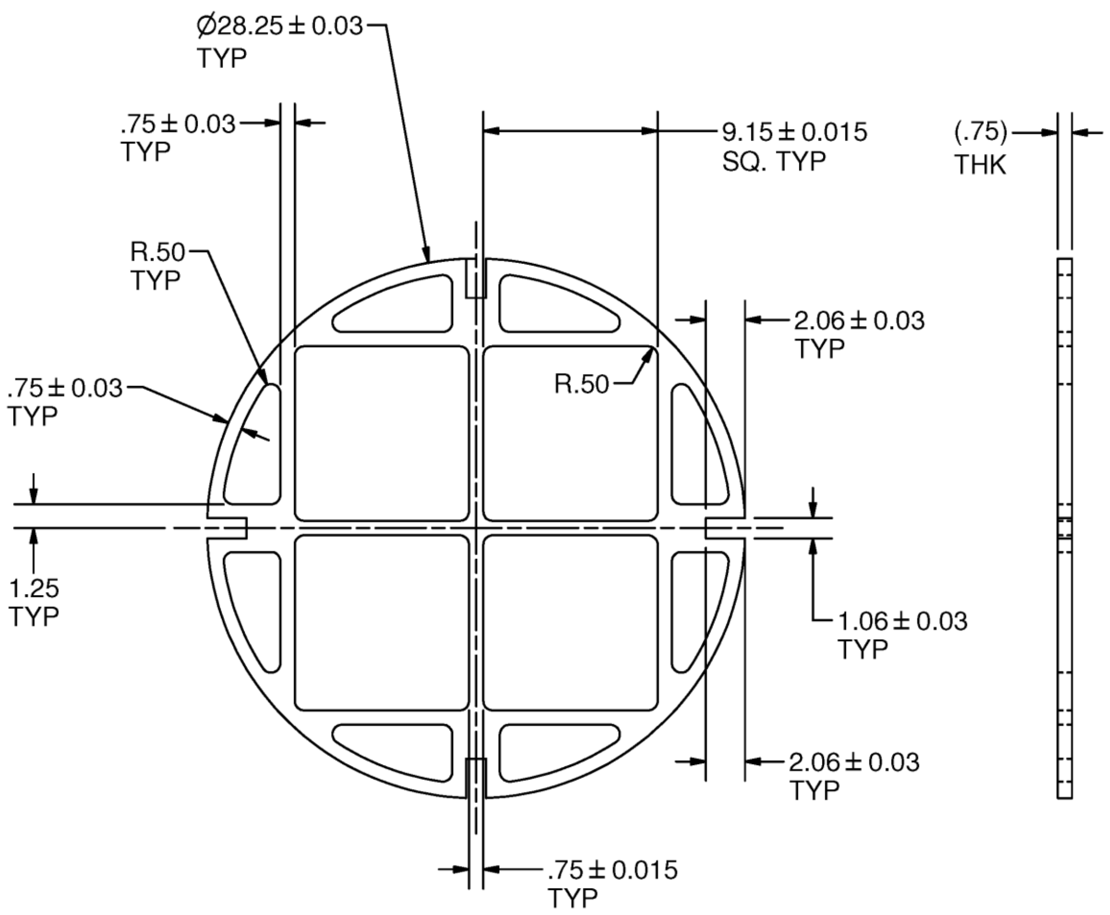
CONTRACT NO. DE-NE-0000293
PROJECT NO. 205591

TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
4P ASSEMBLY AND DETAILS

SIZE B
DWG NO. DWG-205591-ME-0005
REV B
SCALE: SHOWN
SHEET: 6 OF 13

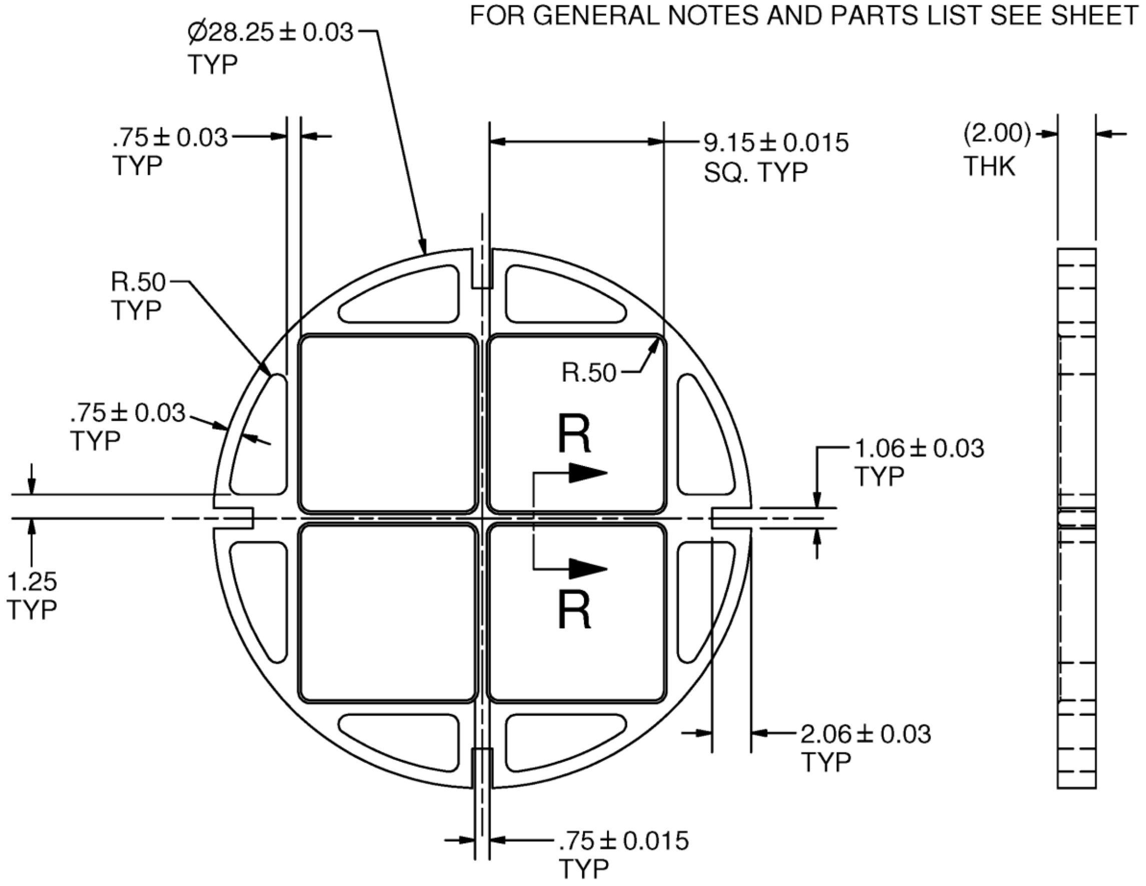
NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.



⑧ SPACER PLATE

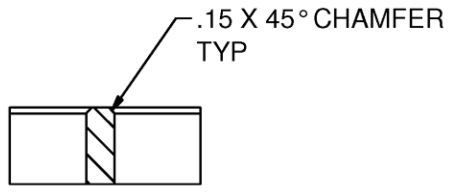
SCALE: 1/8" = 1'-0"



⑨ TOP SPACER PLATE

SCALE: 1/8" = 1'-0"

PRELIMINARY



SECTION R-R

SCALE: 1/4

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

CONTRACT NO. DE-NE-0000293 PROJECT NO. 205591

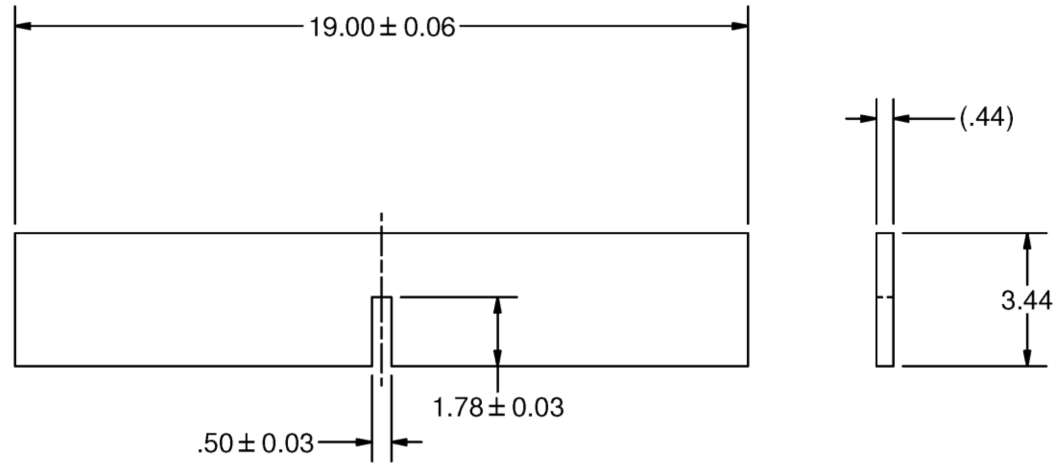
TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
4P ASSEMBLY AND DETAILS

SIZE B DWG NO. DWG-205591-ME-0005 REV B

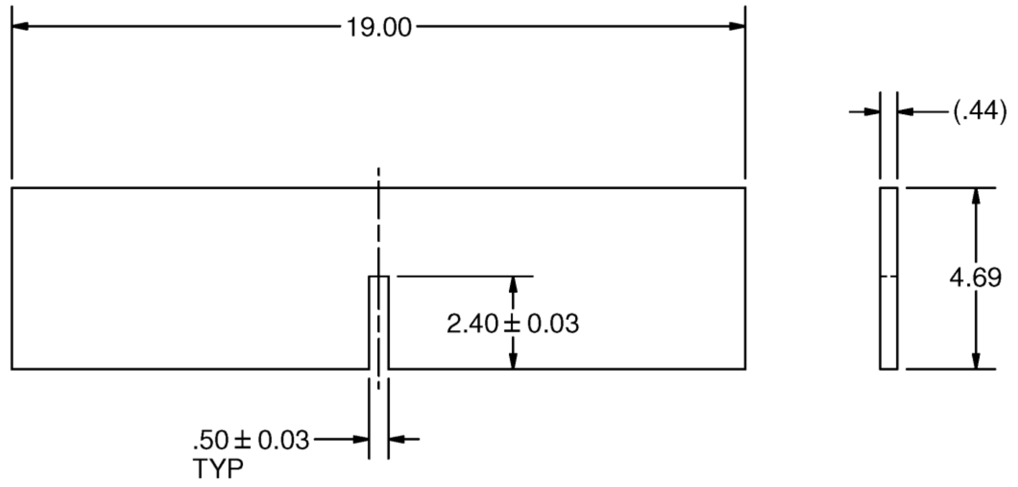
SCALE: SHOWN SHEET: 7 OF 13

NOTES:

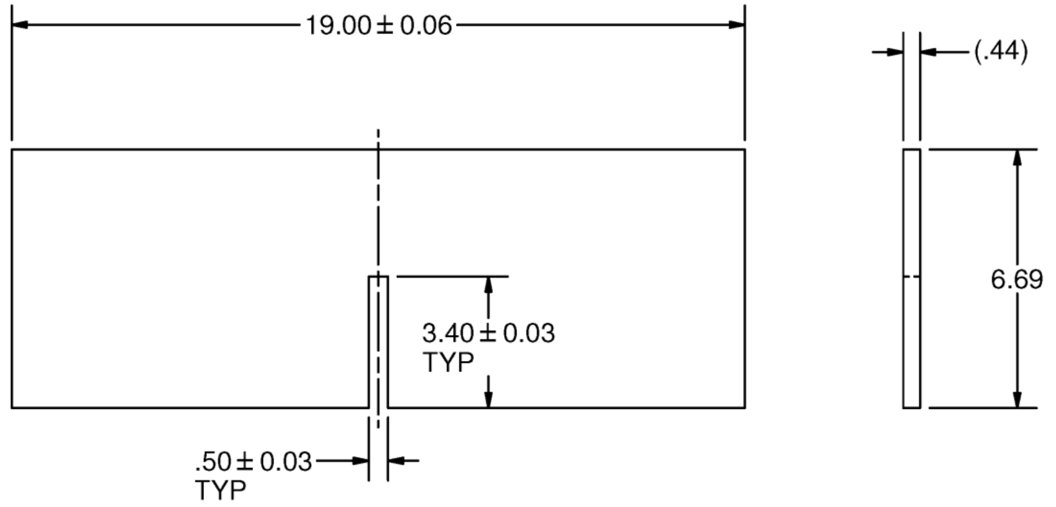
FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.



12 NEUTRON ABSORBER PLATE
SCALE: 1/4" = 1'-0"



13 NEUTRON ABSORBER PLATE
SCALE: 1/4" = 1'-0"



14 NEUTRON ABSORBER PLATE
SCALE: 1/4" = 1'-0"

PRELIMINARY

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

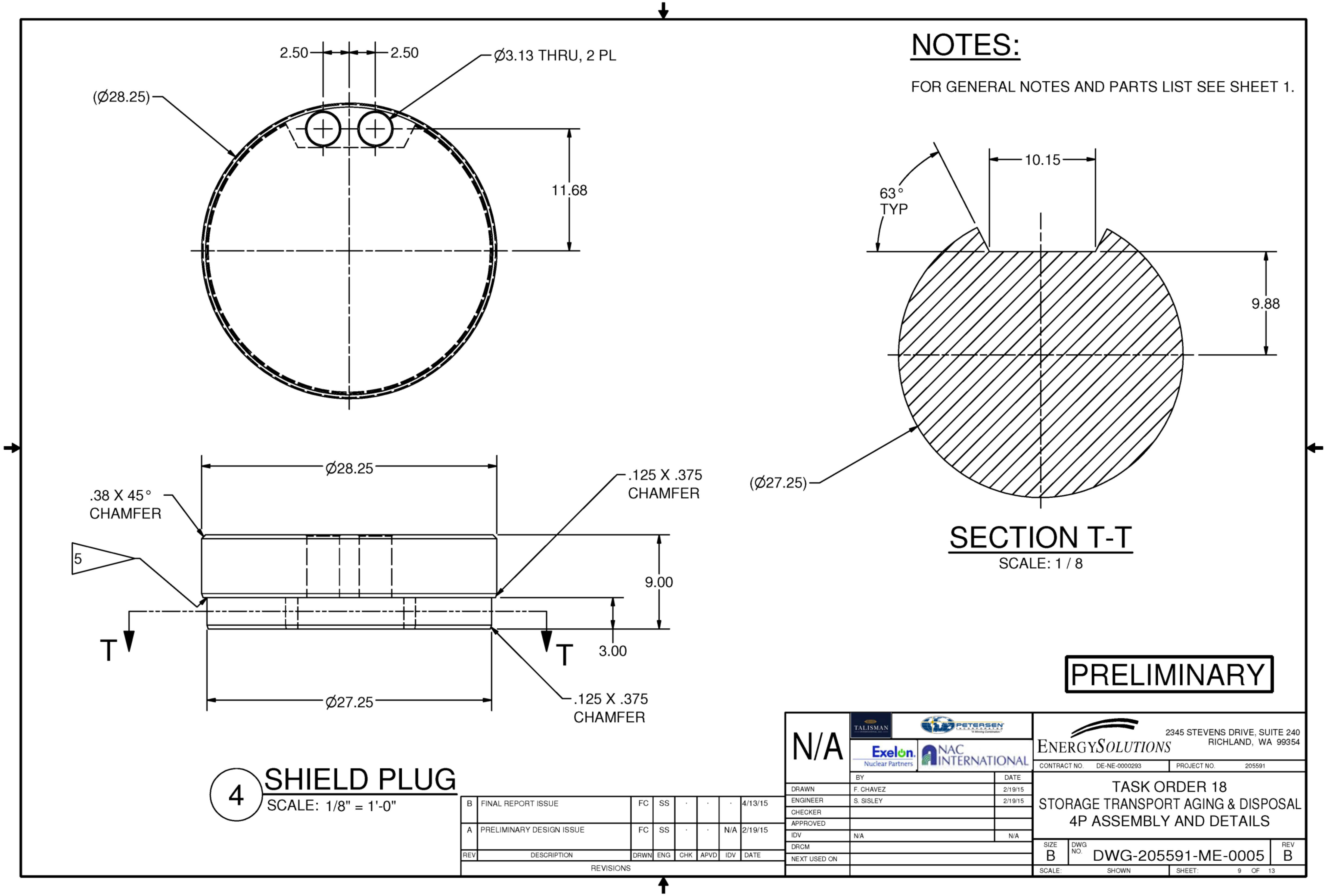
	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

CONTRACT NO. DE-NE-0000293
PROJECT NO. 205591

TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
4P ASSEMBLY AND DETAILS

SIZE B
DWG NO. DWG-205591-ME-0005
REV B
SCALE: SHOWN
SHEET: 8 OF 13



NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.

SECTION T-T

SCALE: 1 / 8

4 SHIELD PLUG

SCALE: 1/8" = 1'-0"

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

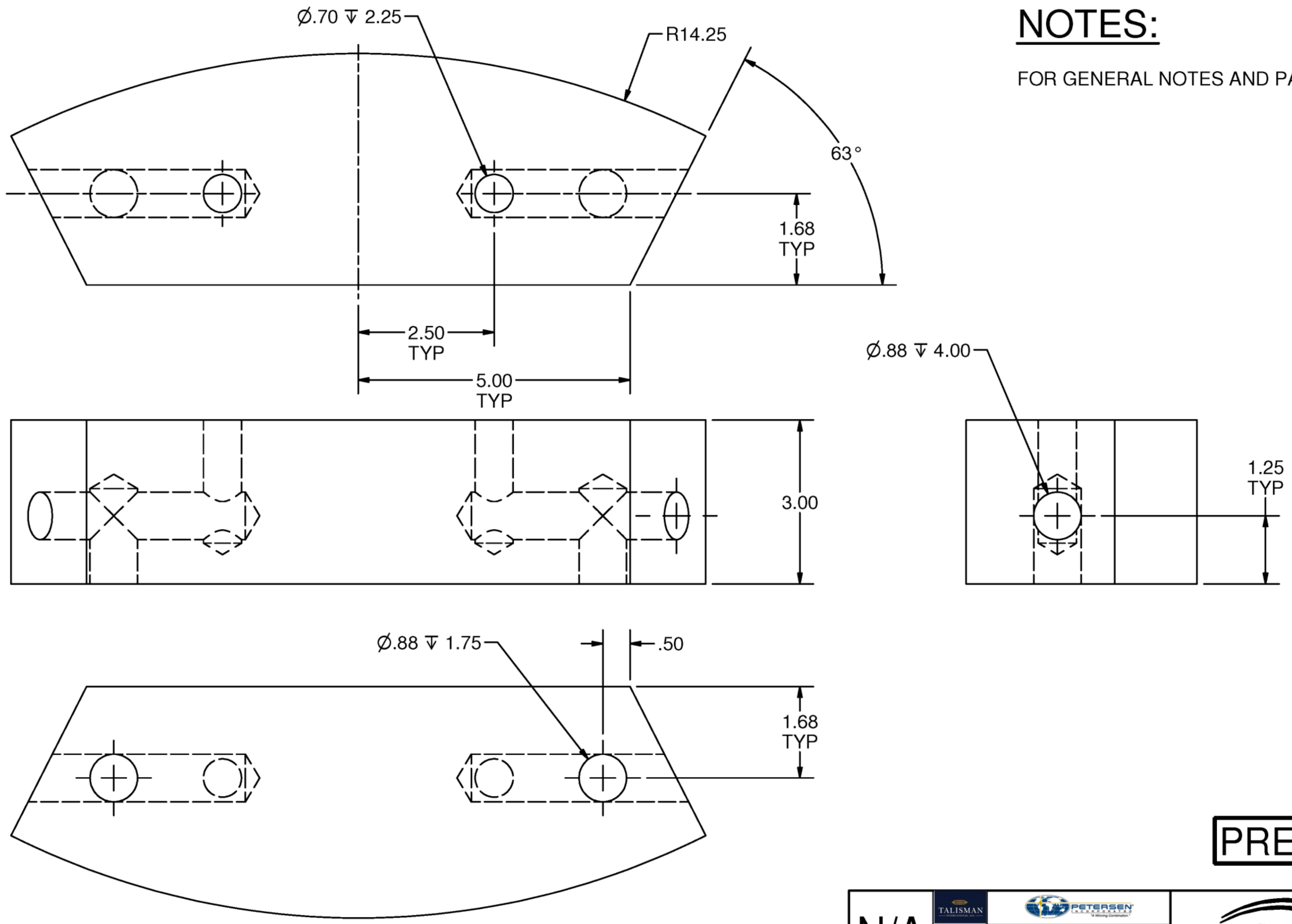
	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

CONTRACT NO. DE-NE-0000293
PROJECT NO. 205591

TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
4P ASSEMBLY AND DETAILS

SIZE B
DWG NO. DWG-205591-ME-0005
REV B
SCALE: SHOWN
SHEET: 9 OF 13



NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.

PRELIMINARY

15 DRAIN/VENT PORT BODY
SCALE: 1/2" = 1'-0"

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

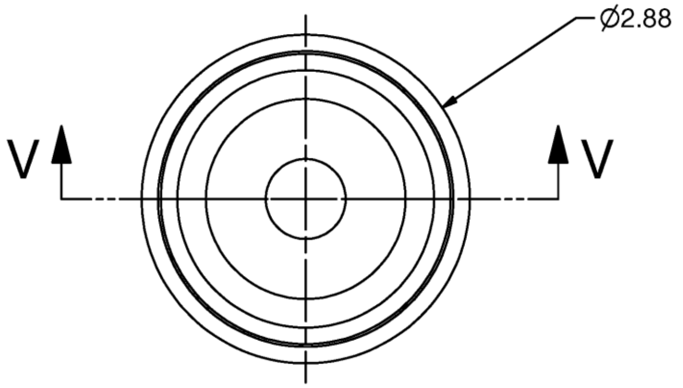
	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

CONTRACT NO. DE-NE-0000293
PROJECT NO. 205591

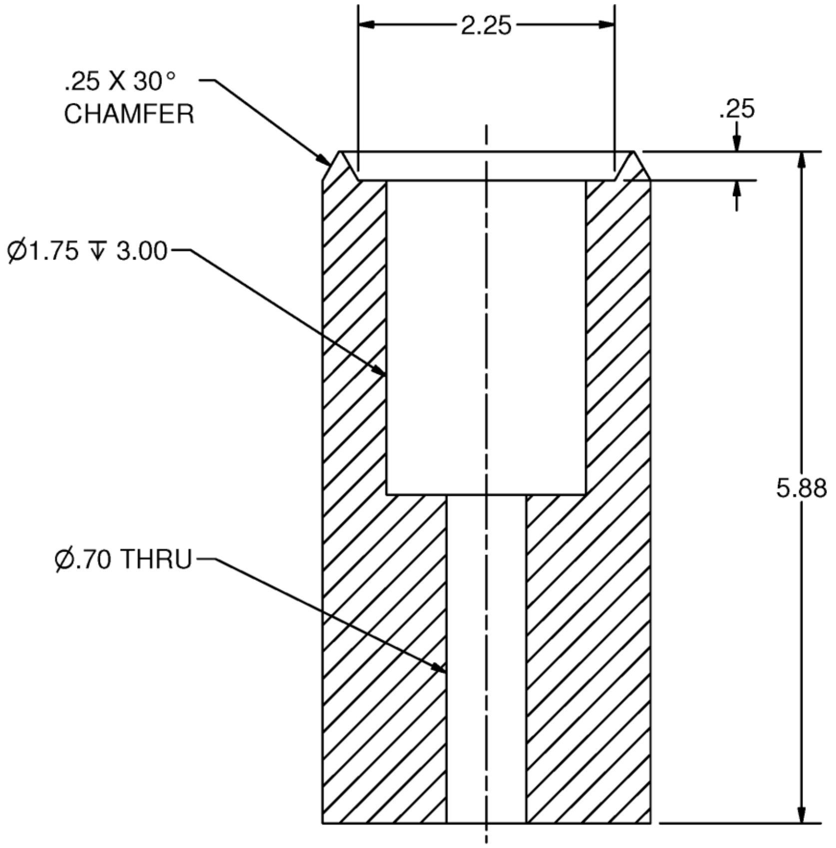
TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
4P ASSEMBLY AND DETAILS

SIZE B
DWG NO. DWG-205591-ME-0005
REV B
SCALE: SHOWN
SHEET: 10 OF 13



16 DRAIN/VENT PORT TOP

SCALE: 1/2" = 1'-0"

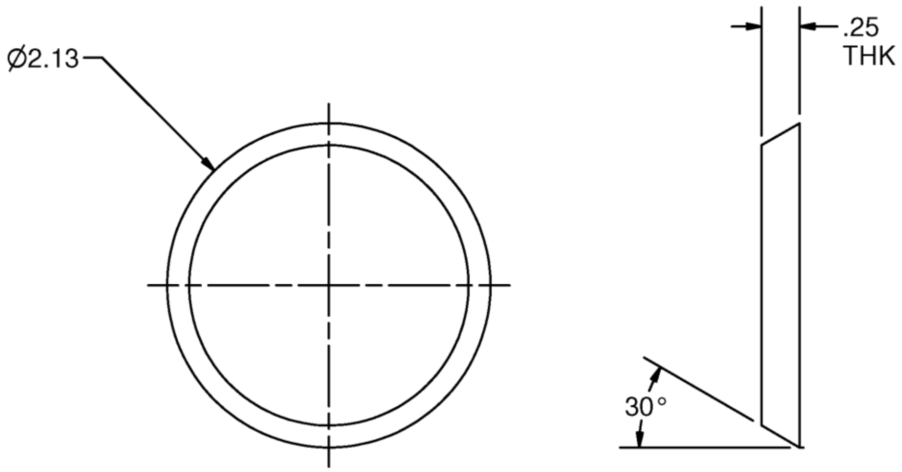


SECTION V-V

SCALE: 3/4

NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.



21 DRAIN/VENT PORT COVER

SCALE: 1" = 1'-0"

PRELIMINARY

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS

2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

CONTRACT NO. DE-NE-0000293 PROJECT NO. 205591

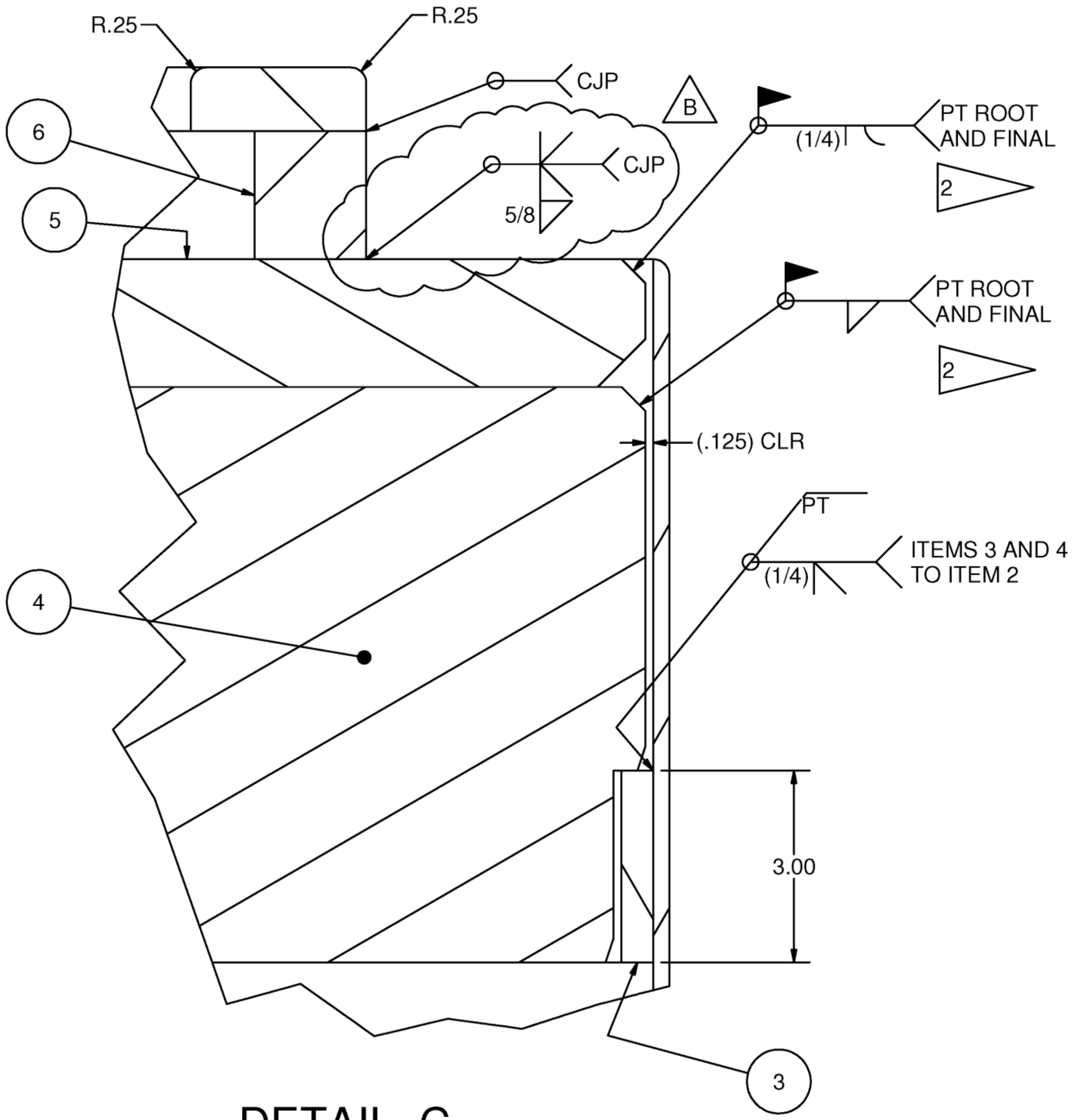
TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
4P ASSEMBLY AND DETAILS

SIZE B DWG NO. DWG-205591-ME-0005 REV B

SCALE: SHOWN SHEET: 11 OF 13

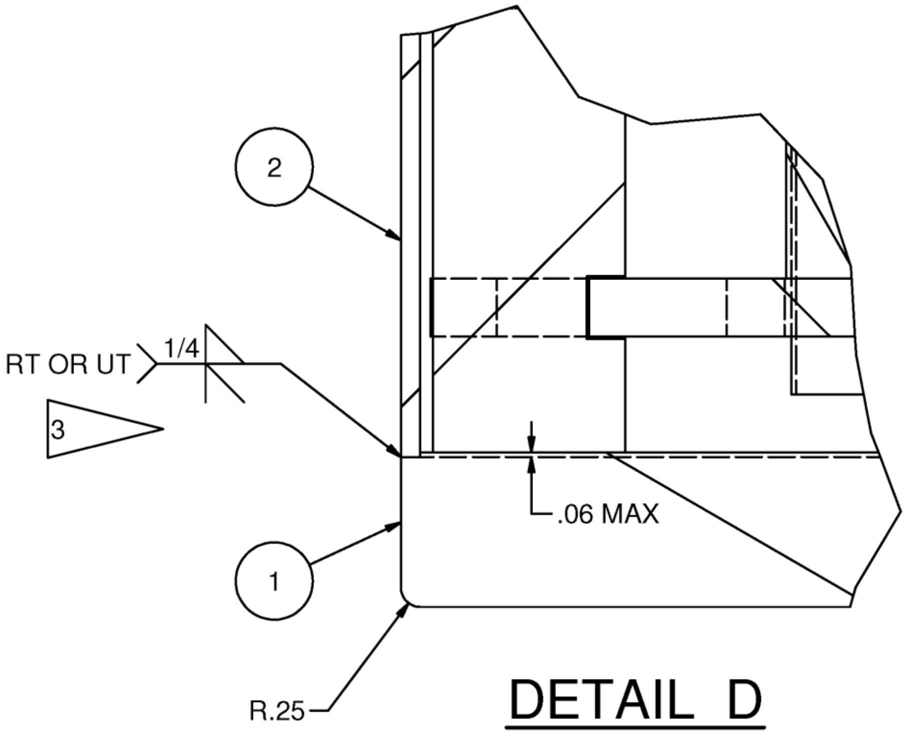
NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.



DETAIL C

SCALE: 1 / 2
SHEET 2



DETAIL D

SCALE: 1 / 2
SHEET 2

PRELIMINARY

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	-	-	-	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	-	-	N/A	2/19/15

REVISIONS

N/A

	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

CONTRACT NO. DE-NE-0000293 PROJECT NO. 205591

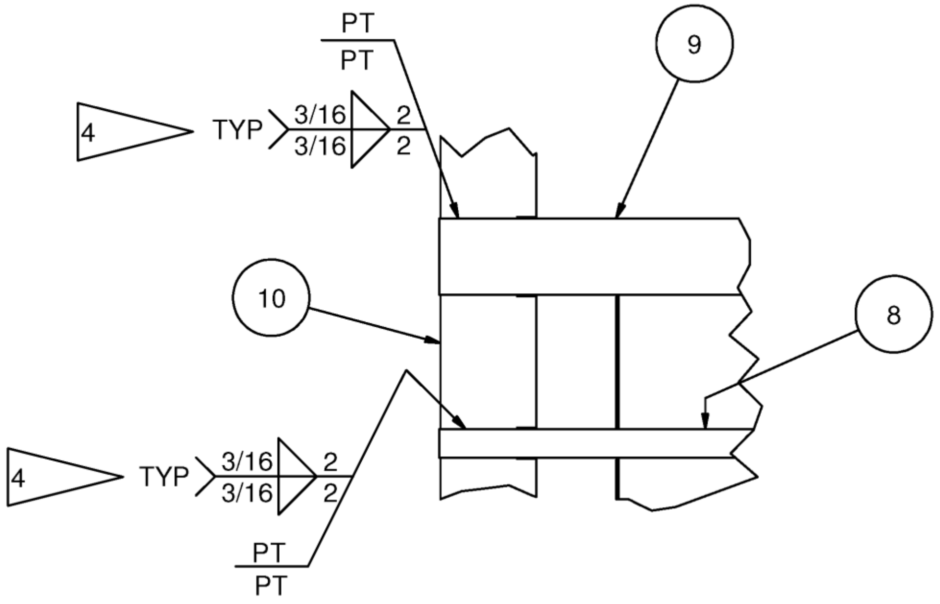
TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
4P ASSEMBLY AND DETAILS

SIZE B DWG NO. DWG-205591-ME-0005 REV B

SCALE: SHOWN SHEET: 12 OF 13

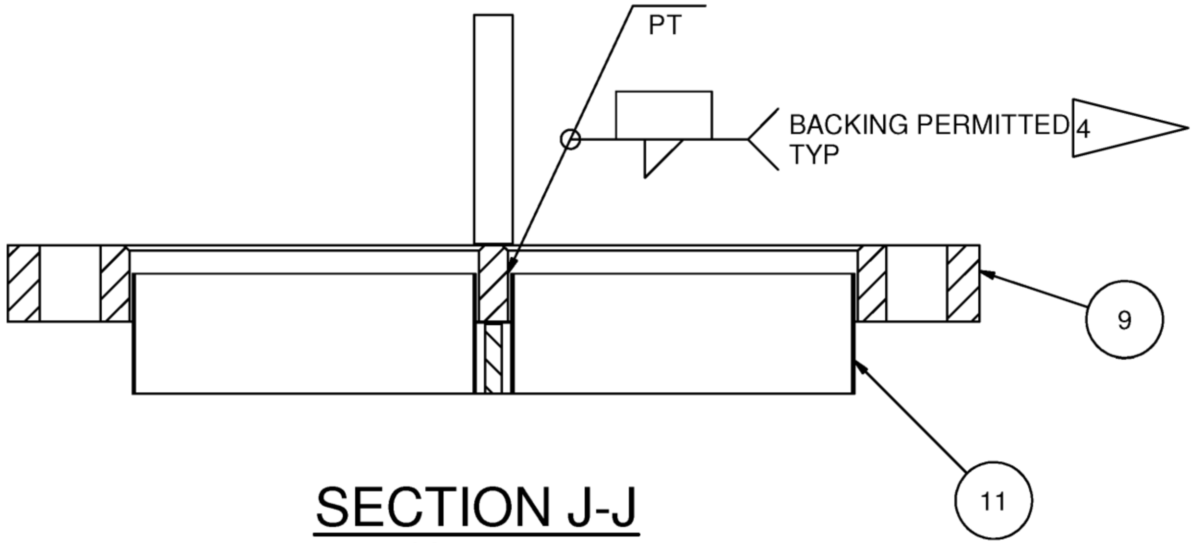
NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.



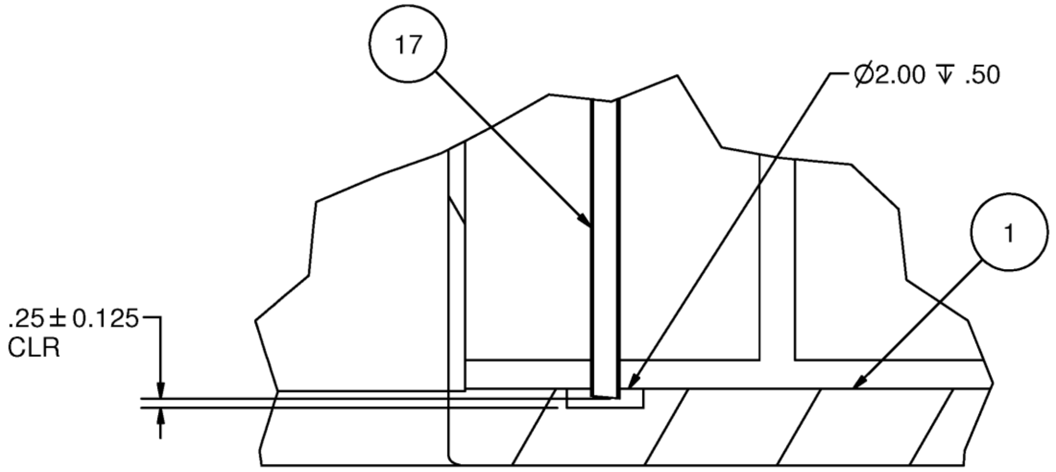
DETAIL K

SCALE: 1 / 4
SHEET 3



SECTION J-J

SCALE: 1/4
SHEET 3



DETAIL M

SCALE: 1 / 4
SHEET 4

PRELIMINARY

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	-	-	-	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	-	-	N/A	2/19/15

REVISIONS

N/A

	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

CONTRACT NO. DE-NE-0000293
PROJECT NO. 205591

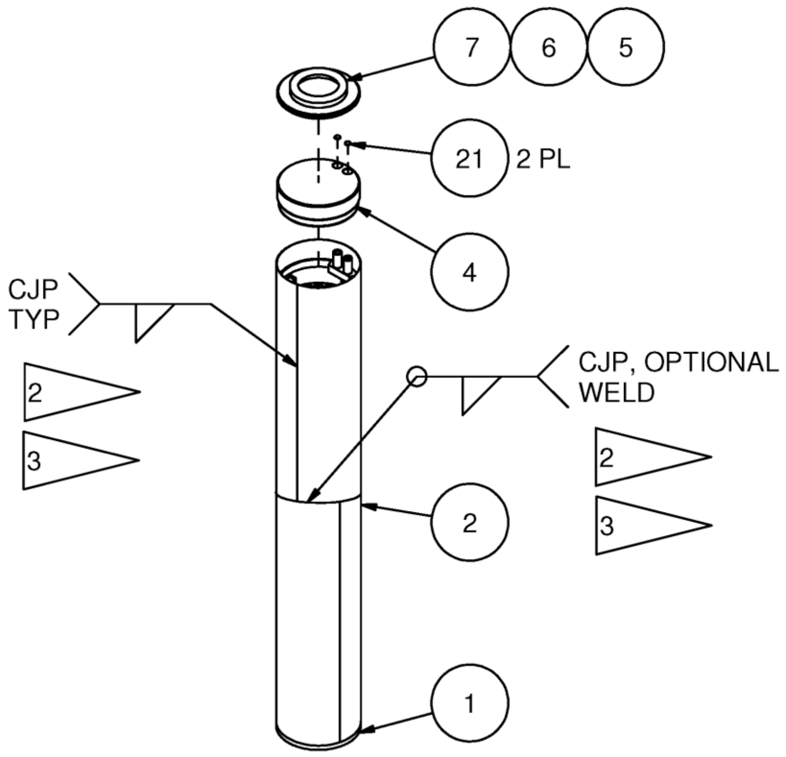
TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
4P ASSEMBLY AND DETAILS

SIZE B
DWG NO. DWG-205591-ME-0005
REV B
SCALE: SHOWN
SHEET: 13 OF 13

GENERAL NOTES: (UNLESS OTHERWISE SPECIFIED)

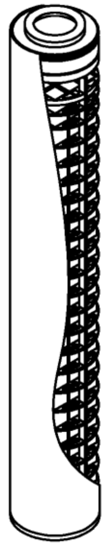
1. ALL DIMENSIONS SHOWN IN INCHES UNLESS OTHERWISE NOTED.
2. ITEM 2 MAY INCLUDE FULL-PENETRATION SEAM WELDS.
3. WELDS SHALL RECEIVE NDE IN ACCORDANCE WITH NB-5000.
4. WELDS SHALL RECEIVE NDE IN ACCORDANCE WITH NG-5000. B
5. OPTIONALLY ITEM 4 MAY BE FABRICATED FROM TWO SEPARATE PLATES JOINED BY A 3/8 INCH PARTIAL PENETRATION GROOVE WELD ALL-AROUND.
6. THE FINISHED SHELL ASSEMBLY (ITEMS 1, 2, 3, 15, & 16) SHALL BE HYDROSTATICALLY TESTED IN ACCORDANCE WITH THE REQUIREMENT OF NB-6000.
7. HELIUM LEAKAGE RATE TESTING SHALL BE PERFORMED ON ALL CANISTER SHELL PRESSURE BOUNDARY SHOP WELDS TO THE LEAKTIGHT CRITERIA OF ANSI N14.5.

QTY	NOMENCLATURE/DESCRIPTION	MATERIAL/REFERENCE	ITEM
1	BOTTOM PLATE, 2 INCH THK	ASME SA-240, TYPE 316L	1
1	CANISTER BODY, 1/4 INCH PLATE	ASME SA-240, TYPE 316L	2
1	SUPPORT RING, 1/2 INCH PLATE	ASME SA-240, TYPE 316L	3
1	SHIELD PLUG	ASME SA-240, TYPE 316L	4
1	TOP PLATE, 2 INCH PLATE	ASME SA-240, TYPE 316L	5
1	GRAPPLE RING CYLINDER, 1 3/4 INCH PLATE	ASME SA-240, TYPE 316L	6
1	GRAPPLE RING PLATE, 1 INCH PLATE	ASME SA-240, TYPE 316L	7
24	SPACER PLATE, 3/4 INCH PLATE	ASME SA-240, TYPE 316L	8
1	TOP END SPACER PLATE, 28.25 DIA X 2 INCH PLATE	ASME SA-240, TYPE 316L	9
4	SUPPORT BAR, 1 INCH THK	ASME SA-240, TYPE 316L	10
9	GUIDE TUBE, 16 GA. (0.0595 INCH THK)	ASME SA-240, TYPE 316L	11
8	NEUTRON ABSORBER PLATE #1, 7/16 INCH PLATE	ASTM A887-89, GRADE A	12
8	NEUTRON ABSORBER PLATE #2, 7/16 INCH PLATE	ASTM A887-89, GRADE A	13
80	NEUTRON ABSORBER PLATE #3, 7/16 INCH PLATE	ASTM A887-89, GRADE A	14
1	DRAIN/VENT PORT BODY	ASME SA-240, TYPE 316L	15
2	DRAIN/VENT PORT TOP	ASME SA-240 OR SA-479, TYPE 316L	16
1	SIPHON TUBE, 3/4 INCH DIA X 18 GA.	ASTM A249 OR A269, TYPE 304	17
1	TUBE FITTING, 3/4 INCH DIA NPT	SWAGELOK (SS-1210-1-2)	18
1	QUICK CONNECT BODY, 1/2 INCH MNPT	SWAGELOK (SS-QC8-B-8PMIS)	19
1	QUICK CONNECT STEM, 1/2 INCH MNPT	SWAGELOK (SS-QC8-D-8PMIS)	20
2	DRAIN/VENT PORT COVER	ASME SA-240, TYPE 316L	21



EXPANDED VIEW

SCALE: NONE



NOTE:
SHELL PARTIALLY
REMOVED FOR
CLARITY

PRELIMINARY

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

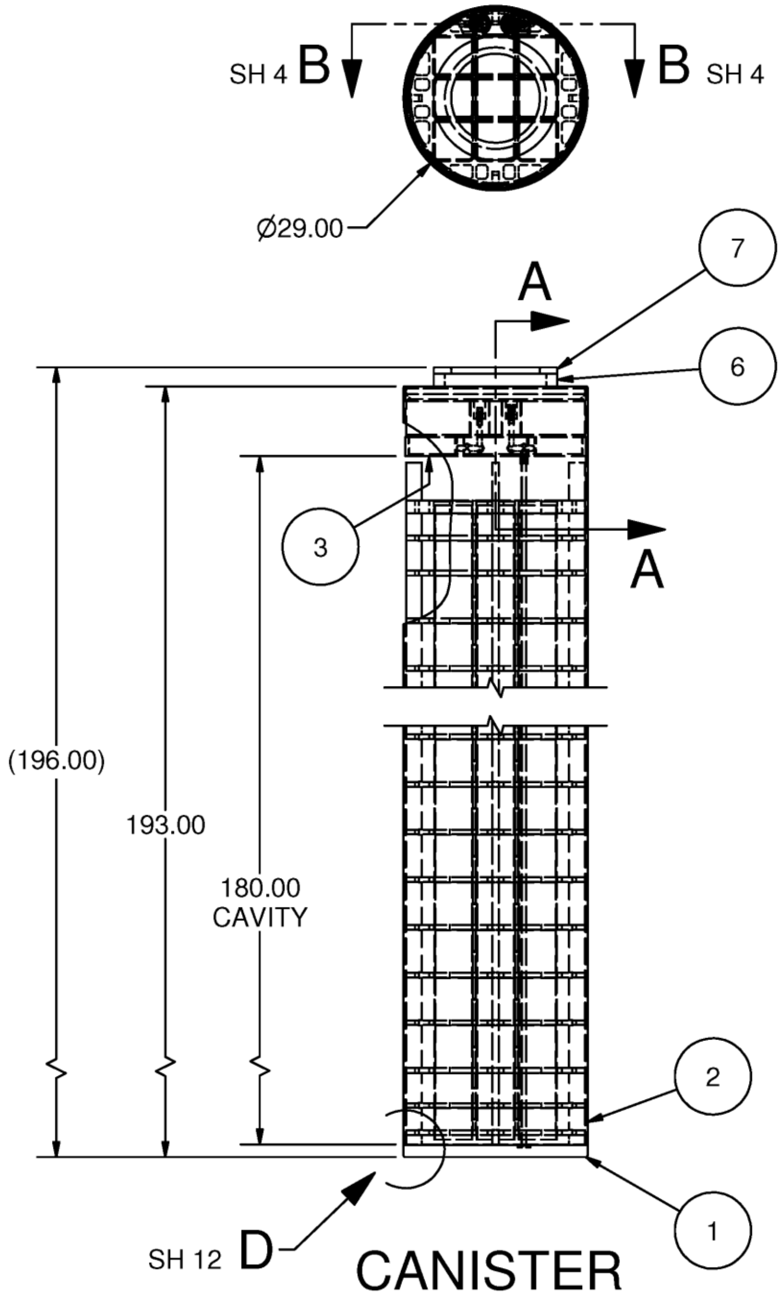
CONTRACT NO. DE-NE-0000293
PROJECT NO. 205591

TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
9B ASSEMBLY AND DETAILS

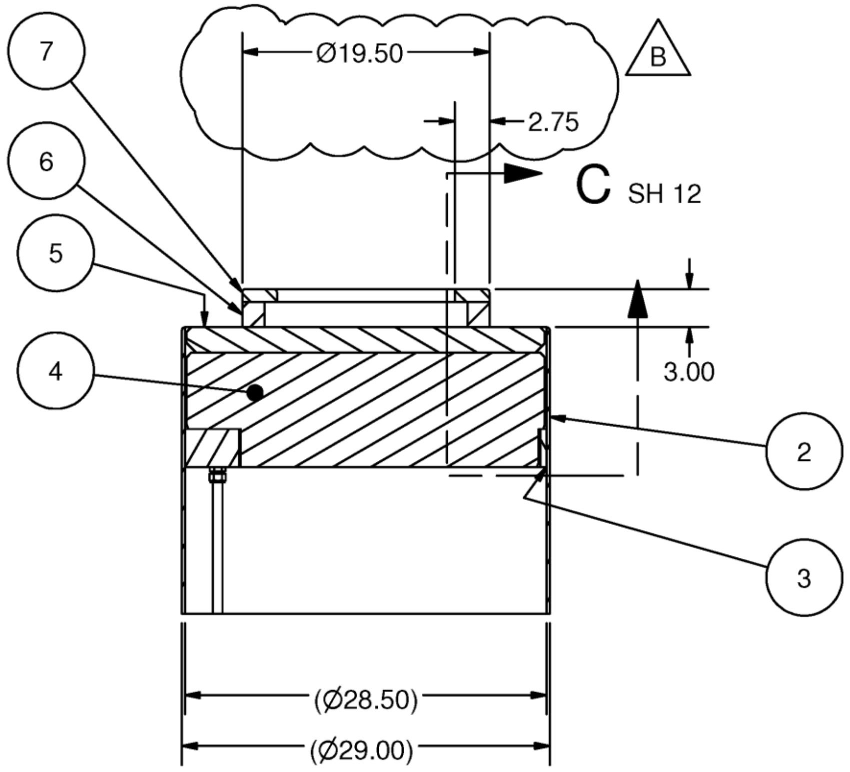
SIZE B
DWG NO. DWG-205591-ME-0010
REV B
SCALE: SHOWN
SHEET: 1 OF 13

NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.



CANISTER ASSEMBLY
SCALE: 1/24



SECTION A-A

SCALE: 1/12
ITEMS REMOVED FOR CLARITY

PRELIMINARY

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

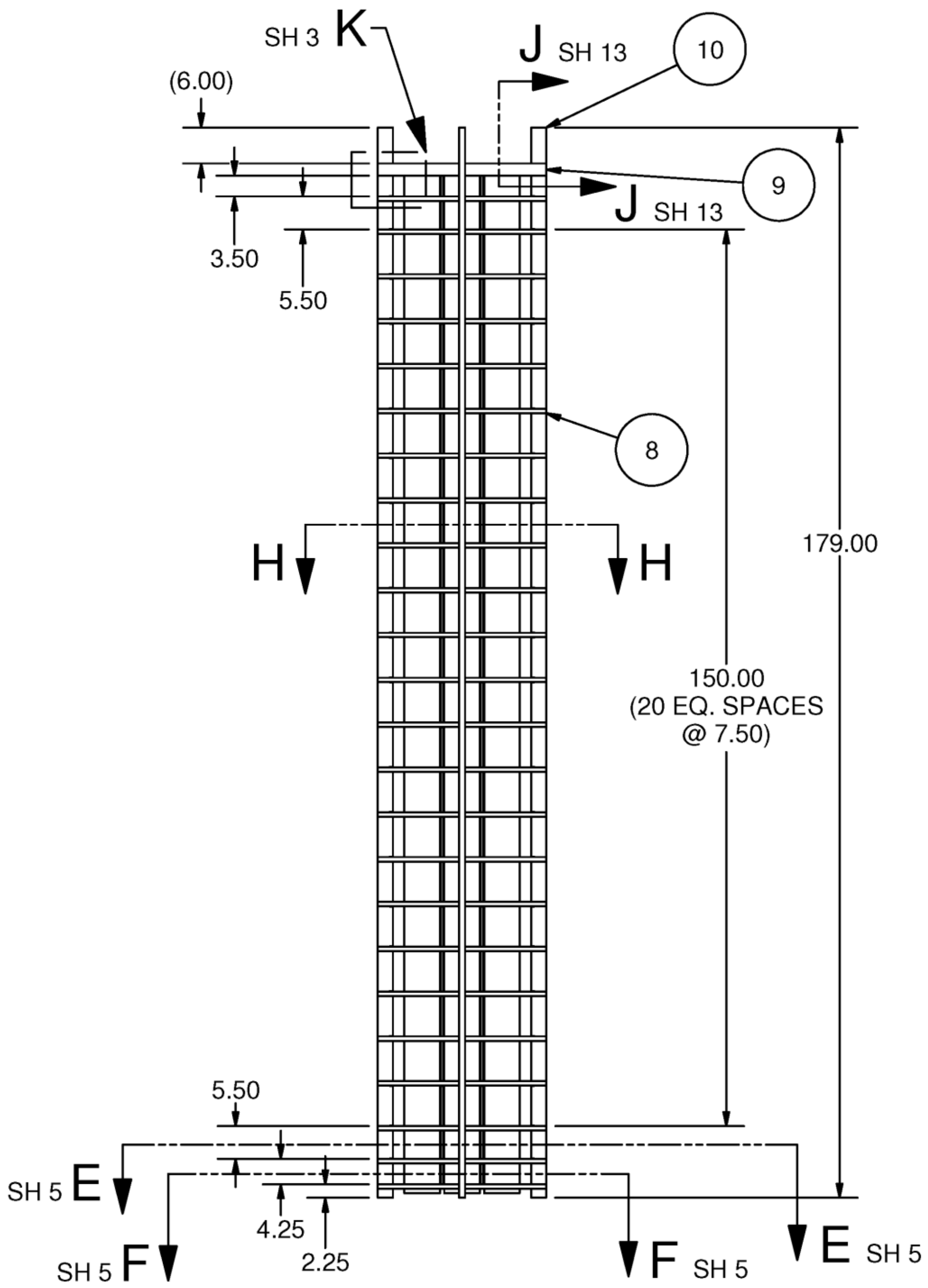
	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

CONTRACT NO. DE-NE-0000293
PROJECT NO. 205591

TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
9B ASSEMBLY AND DETAILS

SIZE B
DWG NO. DWG-205591-ME-0010
REV B
SCALE: SHOWN
SHEET: 2 OF 13



BASKET ASSEMBLY

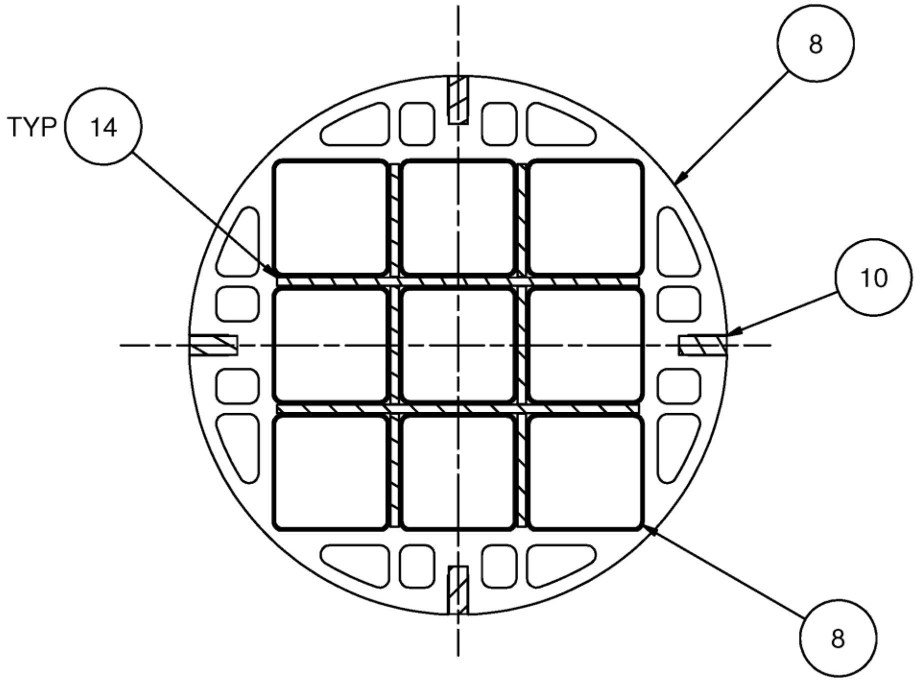
SCALE: 1/24

ISO VIEW

SCALE: 1/24

NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.



SECTION H-H

SCALE: 1/8

PRELIMINARY

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

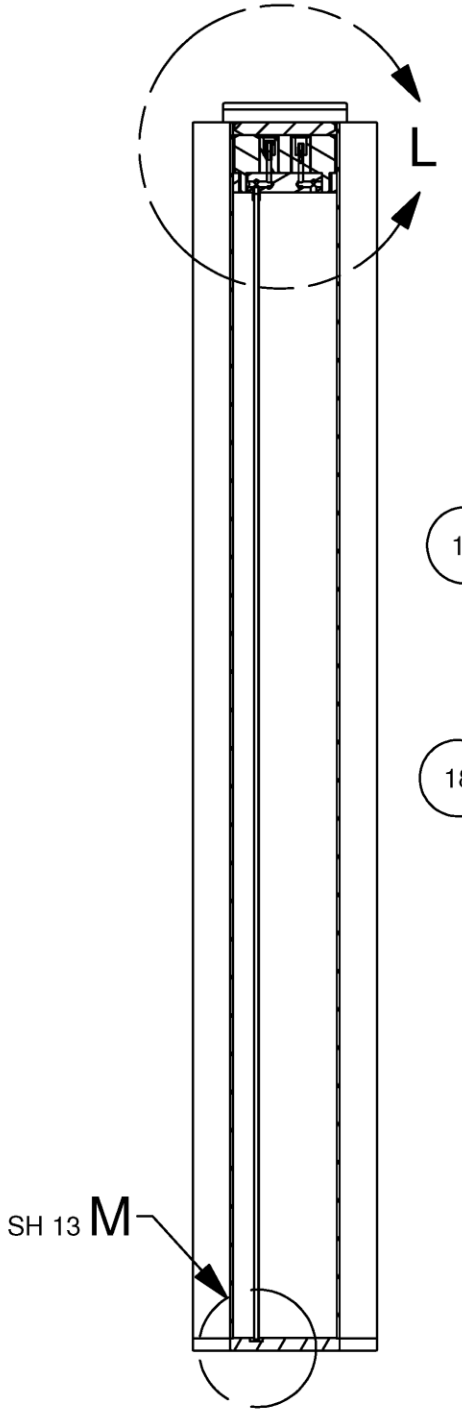
CONTRACT NO. DE-NE-0000293
PROJECT NO. 205591

TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
9B ASSEMBLY AND DETAILS

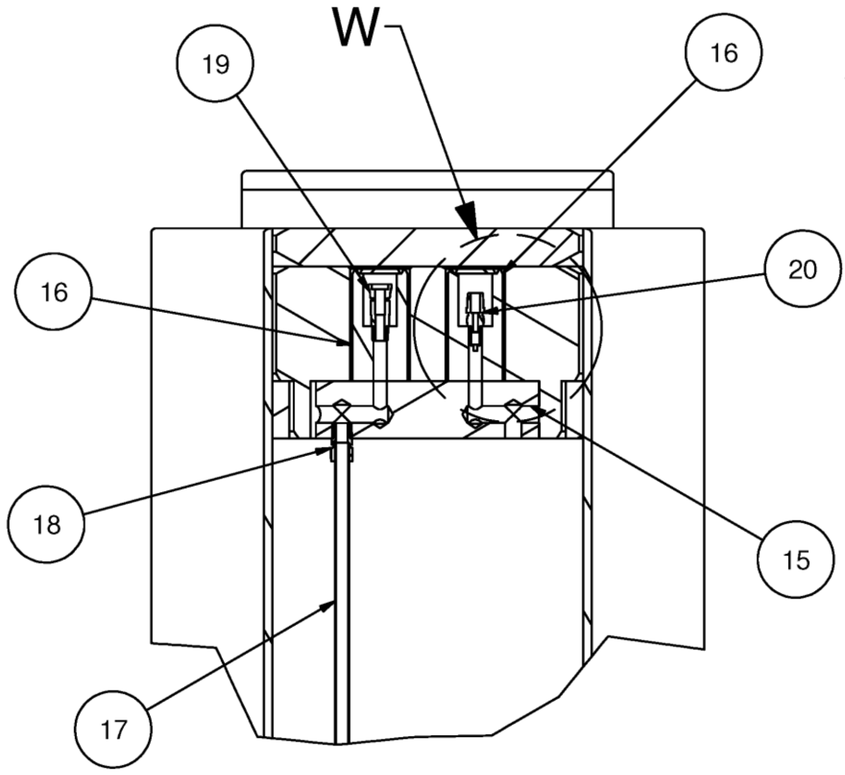
SIZE B
DWG NO. DWG-205591-ME-0010
REV B
SCALE: SHOWN
SHEET: 3 OF 13

NOTES:

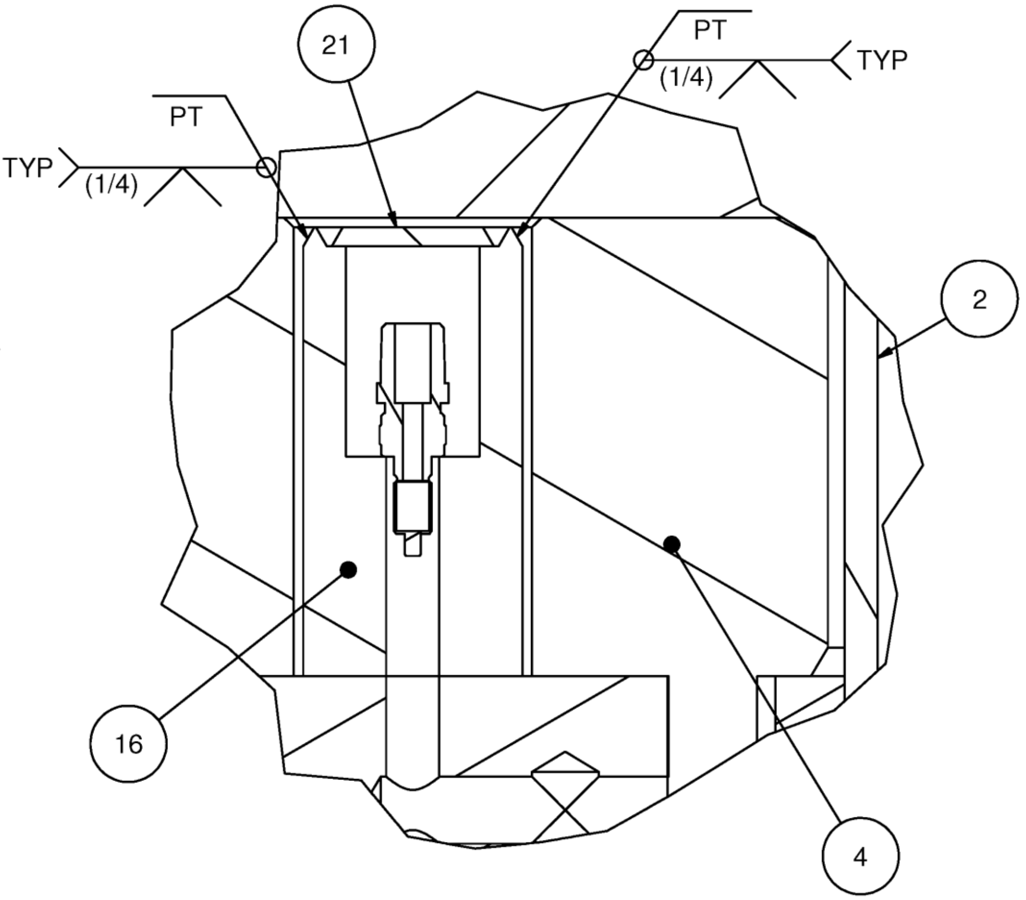
FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.



SECTION B-B
SCALE: 1/24
SHEET 2



DETAIL L
SCALE: 1 / 8



DETAIL W
SCALE: 1 / 2

PRELIMINARY

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

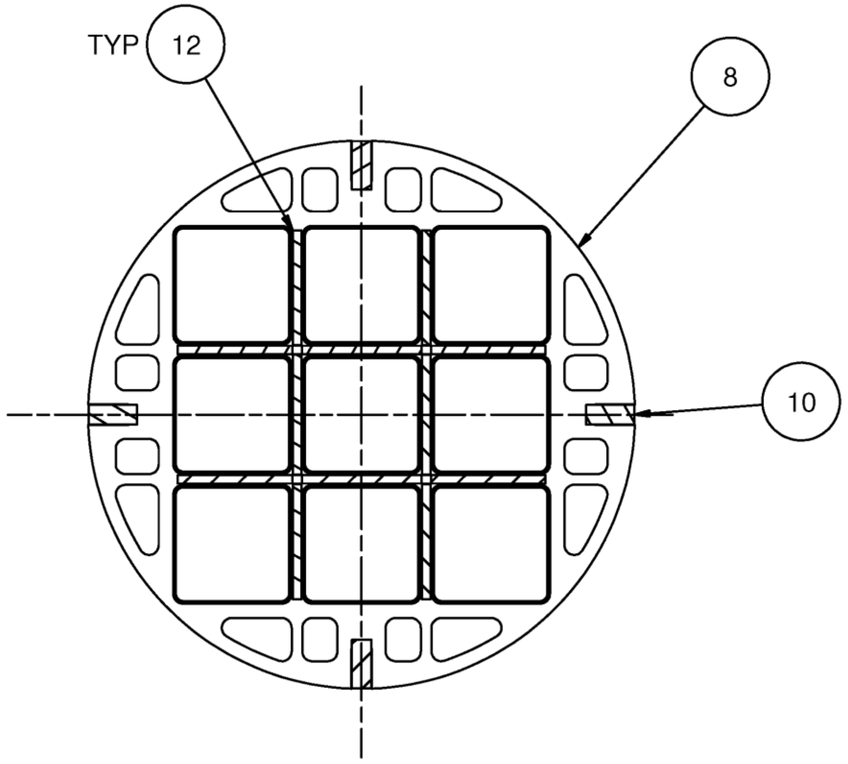
CONTRACT NO. DE-NE-0000293
PROJECT NO. 205591

TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
9B ASSEMBLY AND DETAILS

SIZE B
DWG NO. DWG-205591-ME-0010
REV B
SCALE: SHOWN
SHEET: 4 OF 13

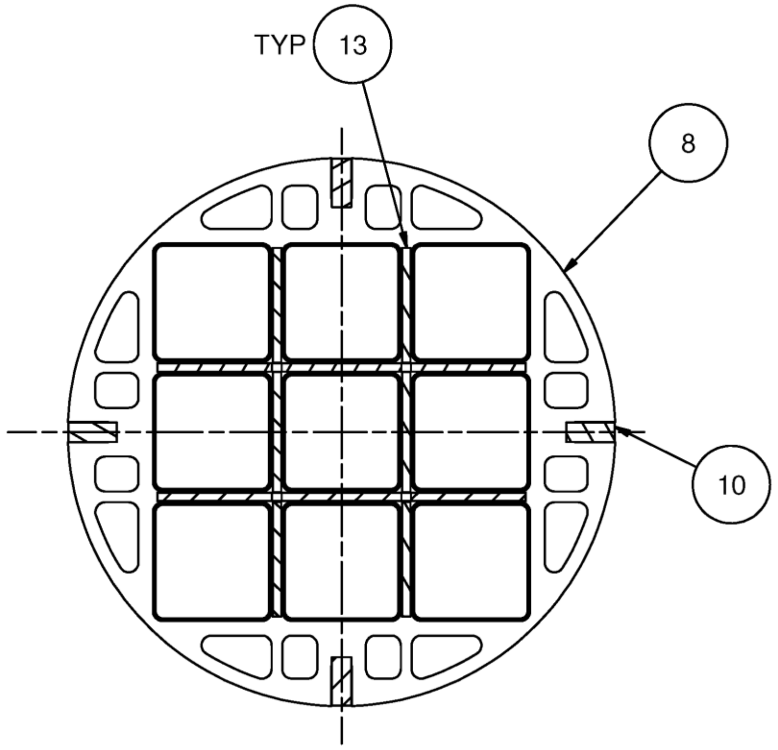
NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.



SECTION F-F

SCALE: 1/8
SHEET 3



SECTION E-E

SCALE: 1/8
SHEET 3

PRELIMINARY

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

TALISMAN
PETERSEN
Exelon Nuclear Partners
NAC INTERNATIONAL

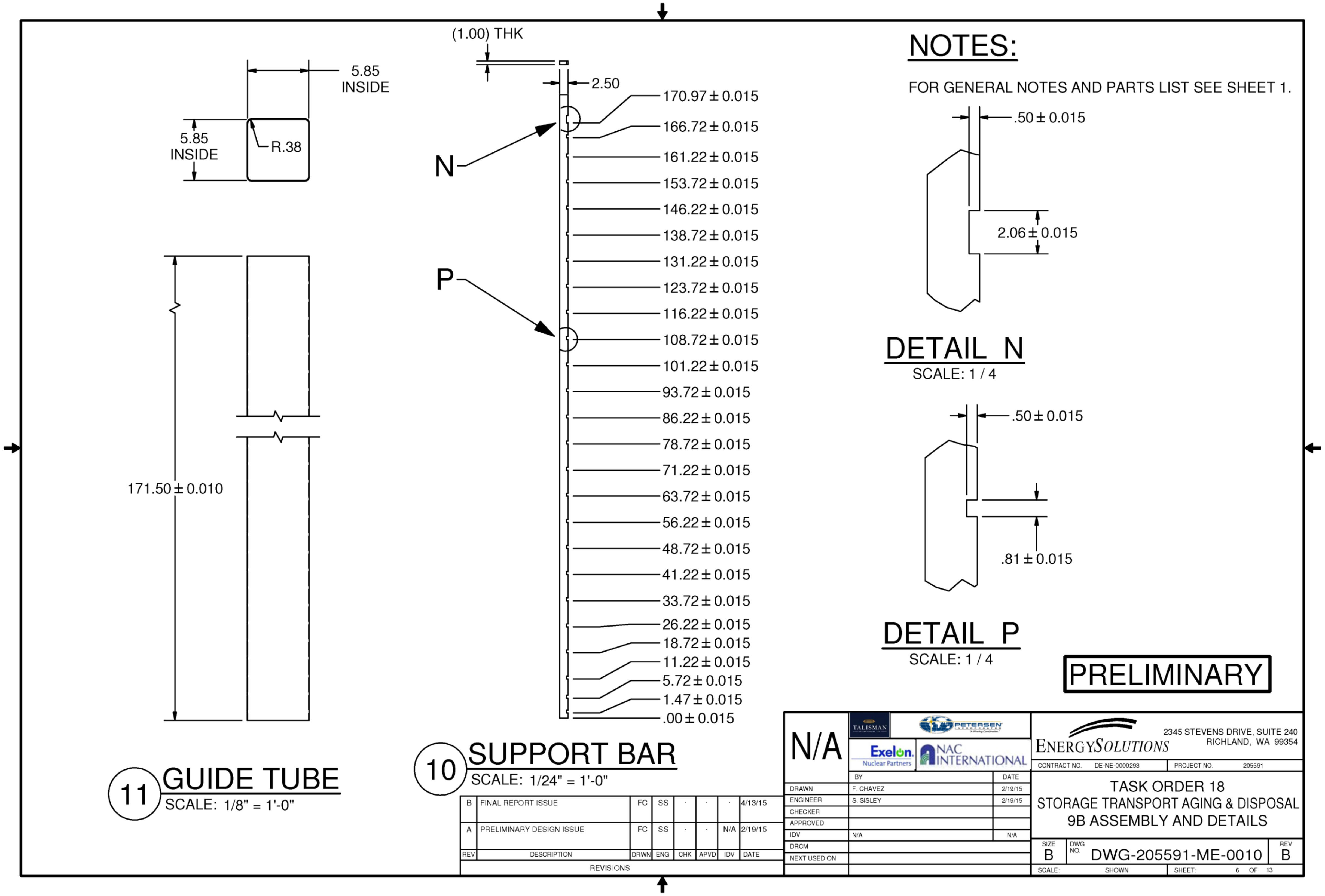
	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

CONTRACT NO. DE-NE-0000293
PROJECT NO. 205591

TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
9B ASSEMBLY AND DETAILS

SIZE B
DWG NO. DWG-205591-ME-0010
REV B
SCALE: SHOWN
SHEET: 5 OF 13



NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.

DETAIL N
SCALE: 1 / 4

DETAIL P
SCALE: 1 / 4

PRELIMINARY

10 SUPPORT BAR
SCALE: 1/24" = 1'-0"

11 GUIDE TUBE
SCALE: 1/8" = 1'-0"

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	-	-	-	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	-	-	N/A	2/19/15

REVISIONS

N/A

TALISMAN
PETERSEN
Exelon Nuclear Partners
NAC INTERNATIONAL

	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

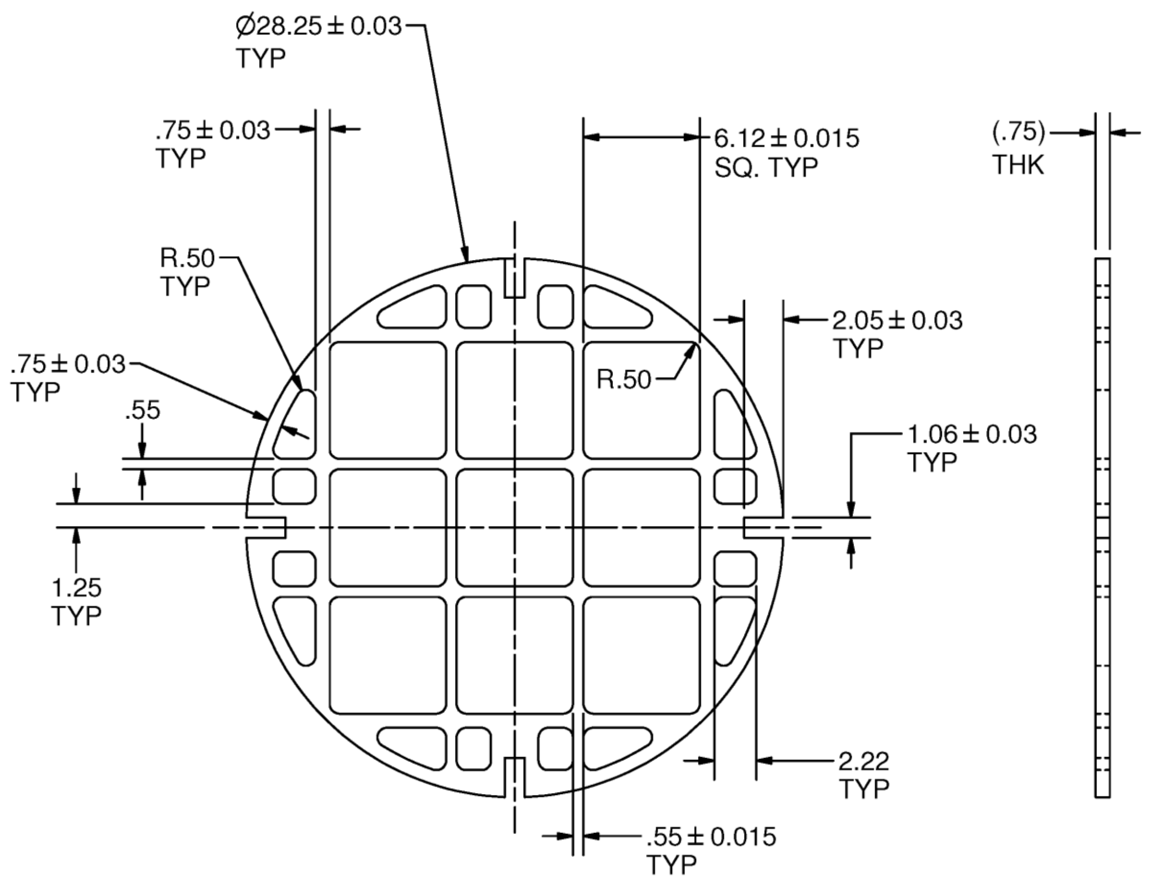
CONTRACT NO. DE-NE-0000293
PROJECT NO. 205591

TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
9B ASSEMBLY AND DETAILS

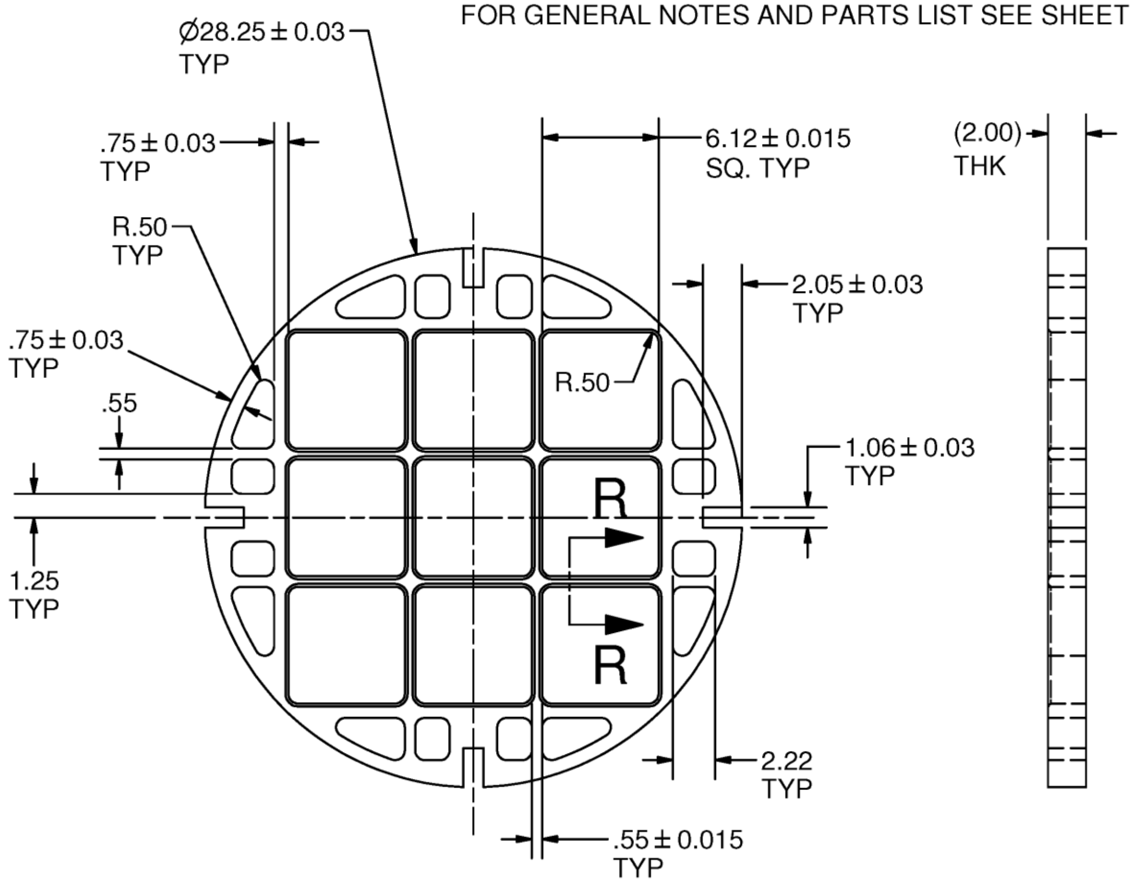
SIZE B
DWG NO. DWG-205591-ME-0010
REV B
SCALE: SHOWN
SHEET: 6 OF 13

NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.

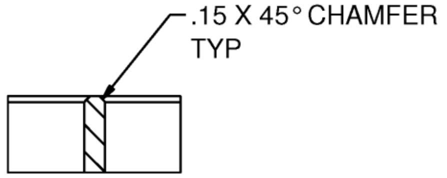


⑧ **SPACER PLATE**
SCALE: 1/8" = 1'-0"



⑨ **TOP SPACER PLATE**
SCALE: 1/8" = 1'-0"

PRELIMINARY



SECTION R-R
SCALE: 1/4

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

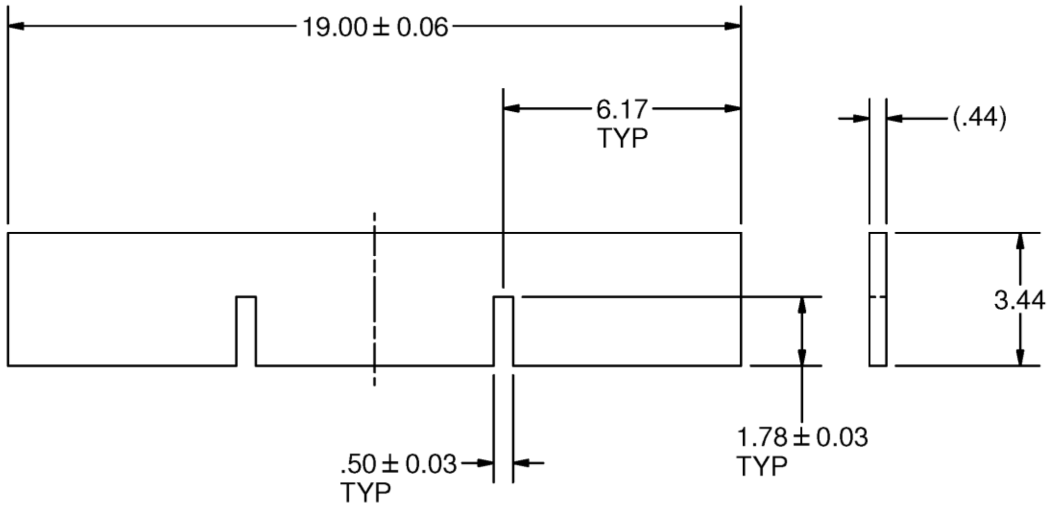
CONTRACT NO. DE-NE-0000293 PROJECT NO. 205591

TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
9B ASSEMBLY AND DETAILS

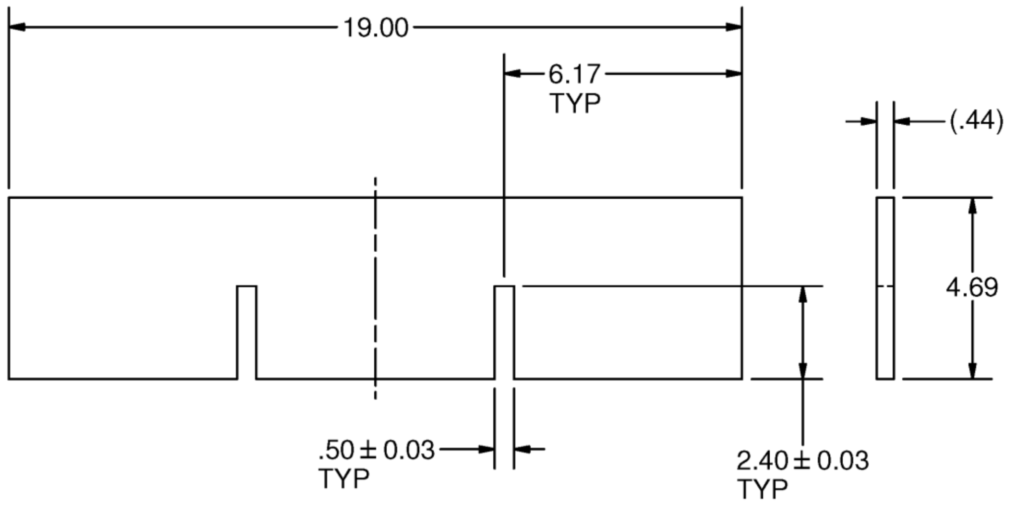
SIZE B DWG NO. DWG-205591-ME-0010 REV B
SCALE: SHOWN SHEET: 7 OF 13

NOTES:

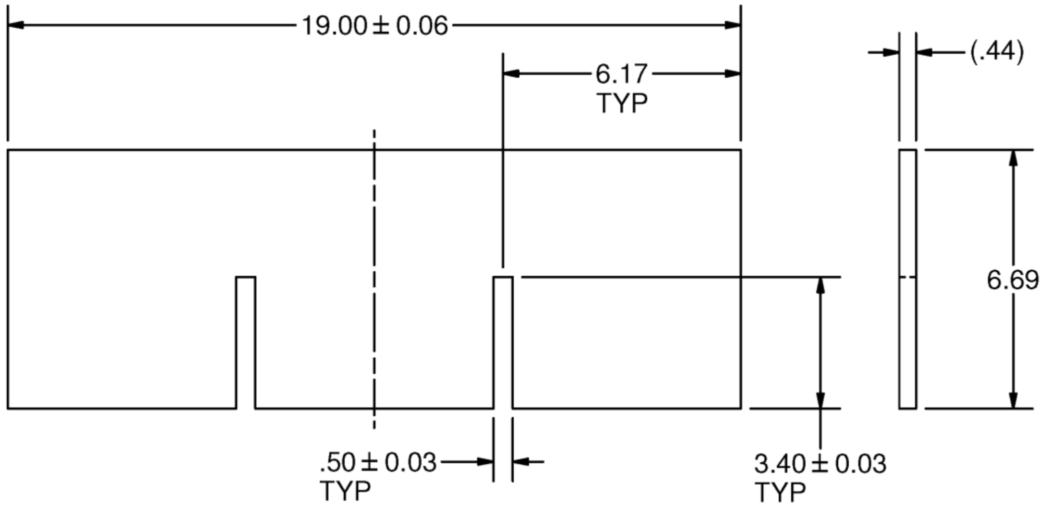
FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.



12 NEUTRON ABSORBER PLATE
SCALE: 1/4" = 1'-0"



13 NEUTRON ABSORBER PLATE
SCALE: 1/4" = 1'-0"



14 NEUTRON ABSORBER PLATE
SCALE: 1/4" = 1'-0"

PRELIMINARY

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

TALISMAN PETERSEN Exelon Nuclear Partners NAC INTERNATIONAL

	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

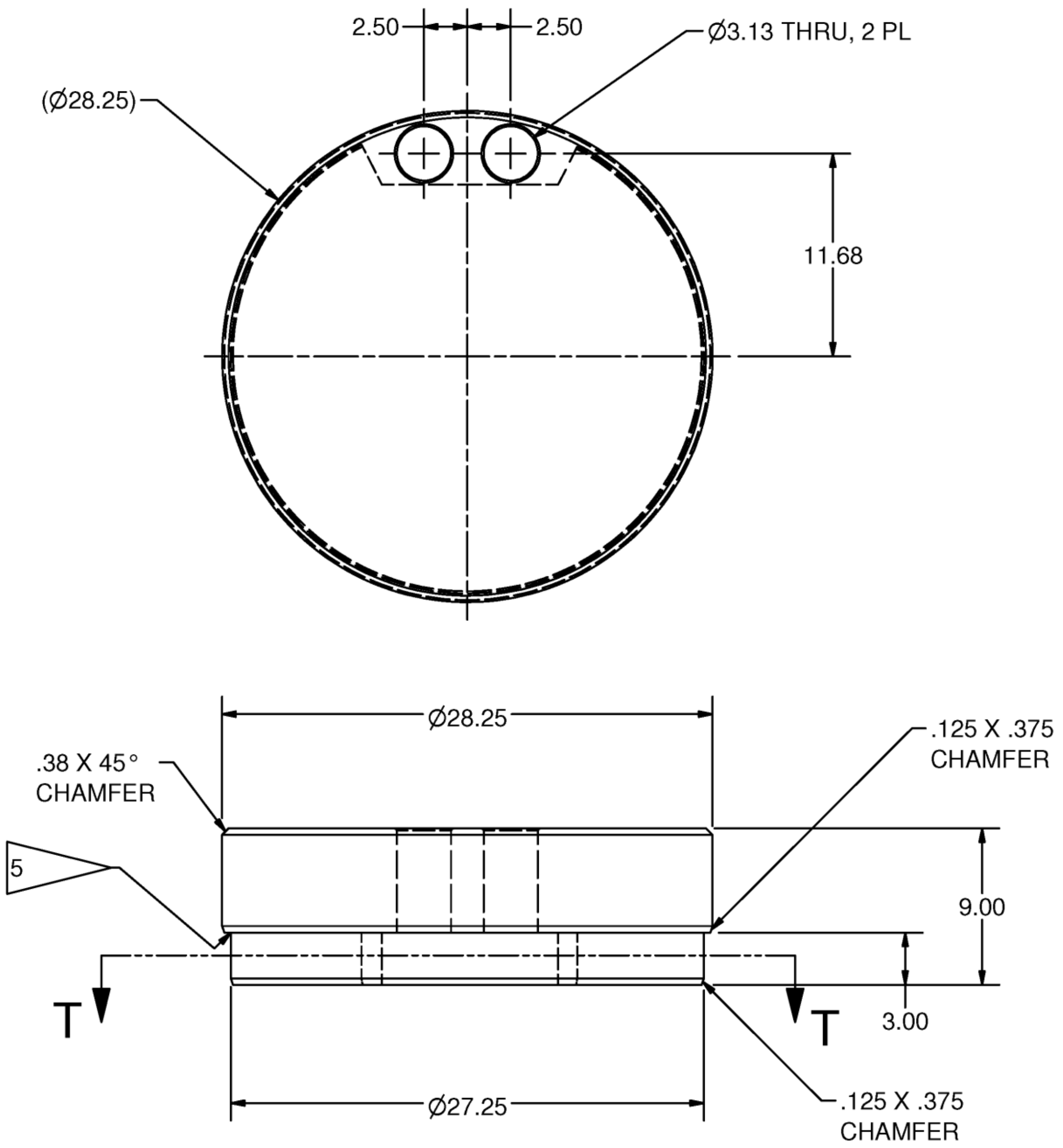
ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

CONTRACT NO. DE-NE-0000293 PROJECT NO. 205591

TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
9B ASSEMBLY AND DETAILS

SIZE B DWG NO. DWG-205591-ME-0010 REV B

SCALE: SHOWN SHEET: 8 OF 13

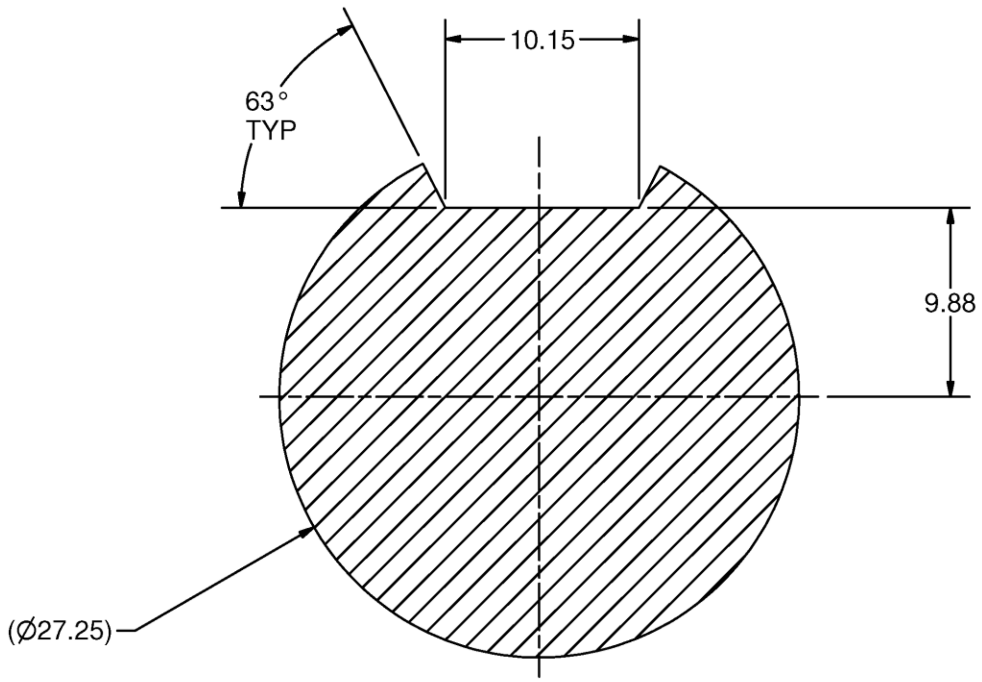


4 SHIELD PLUG

SCALE: 1/8" = 1'-0"

NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.



SECTION T-T

SCALE: 1 / 8

PRELIMINARY

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

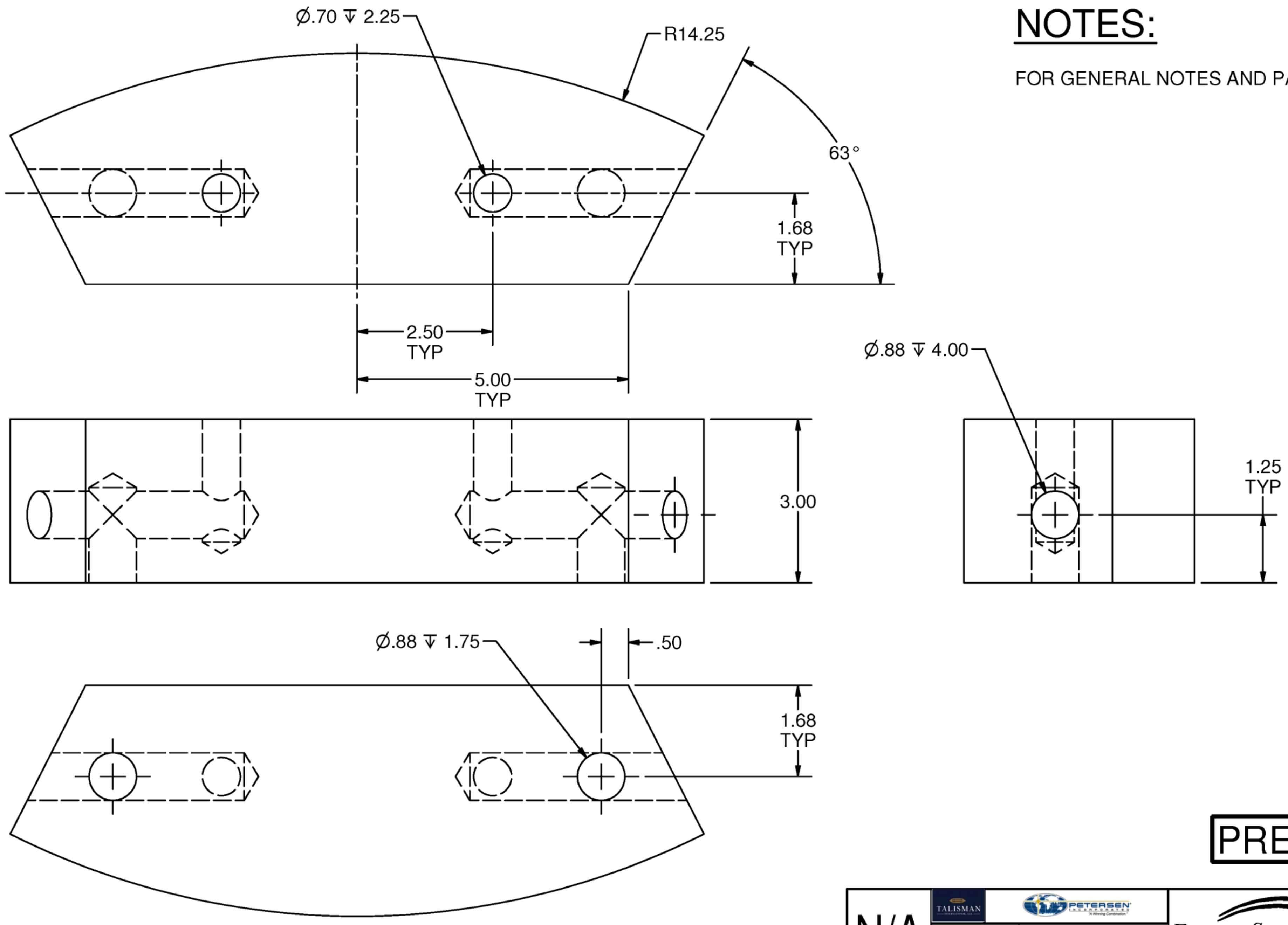
CONTRACT NO. DE-NE-0000293
PROJECT NO. 205591

TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
9B ASSEMBLY AND DETAILS

SIZE B
DWG NO. DWG-205591-ME-0010
REV B
SCALE: SHOWN
SHEET: 9 OF 13

NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.



15 DRAIN/VENT PORT BODY

SCALE: 1/2" = 1'-0"

PRELIMINARY

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

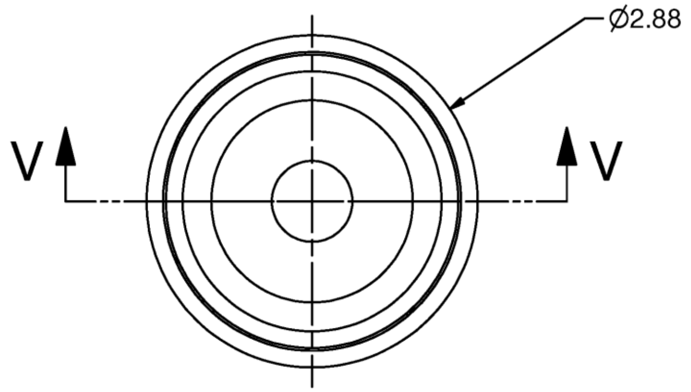
ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

CONTRACT NO. DE-NE-0000293
PROJECT NO. 205591

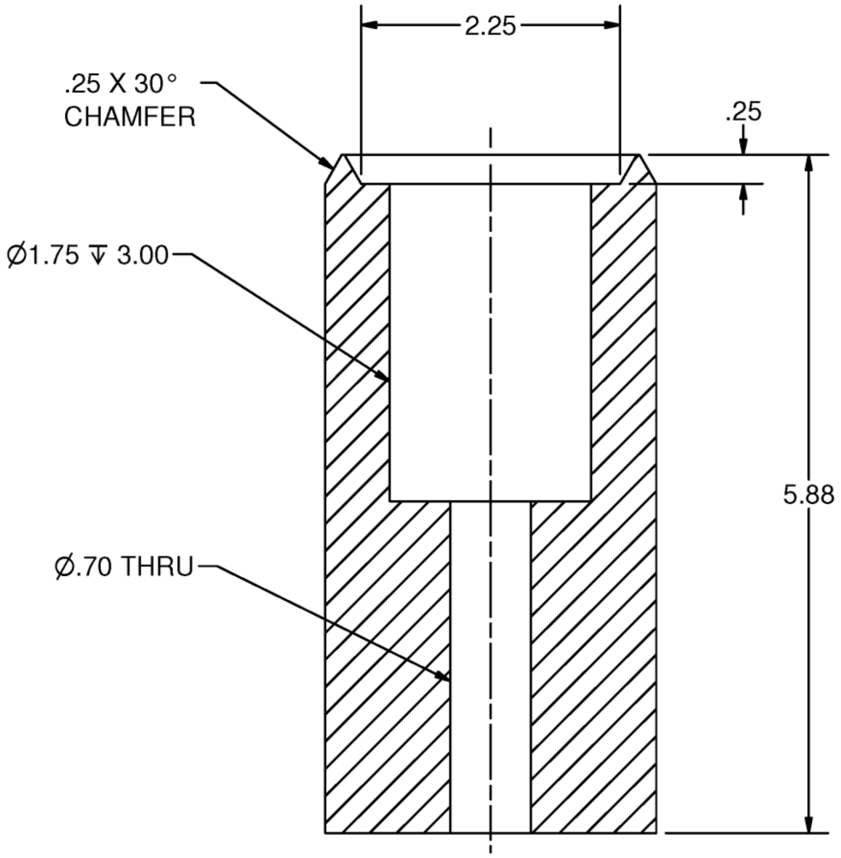
TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
9B ASSEMBLY AND DETAILS

SIZE B
DWG NO. DWG-205591-ME-0010
REV B

SCALE: SHOWN
SHEET: 10 OF 13



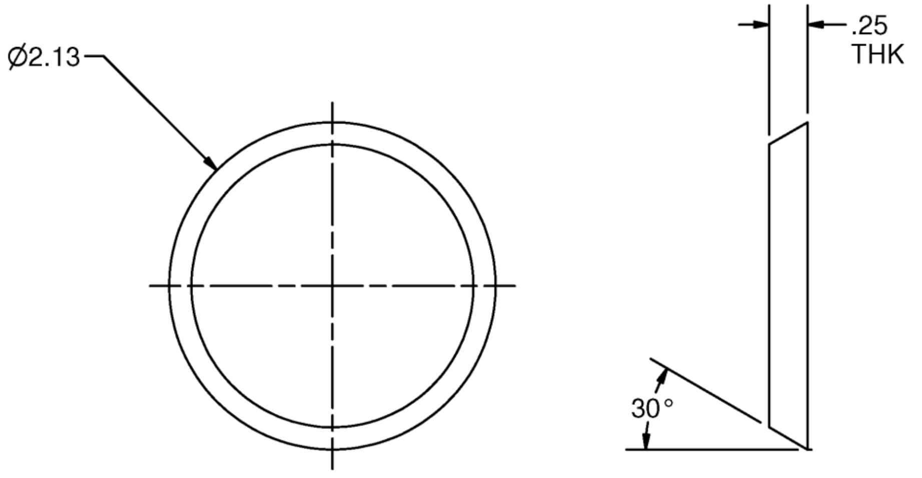
16 DRAIN/VENT PORT TOP
SCALE: 1/2" = 1'-0"



SECTION V-V
SCALE: 3/4

NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.



21 DRAIN/VENT PORT COVER
SCALE: 1" = 1'-0"

PRELIMINARY

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

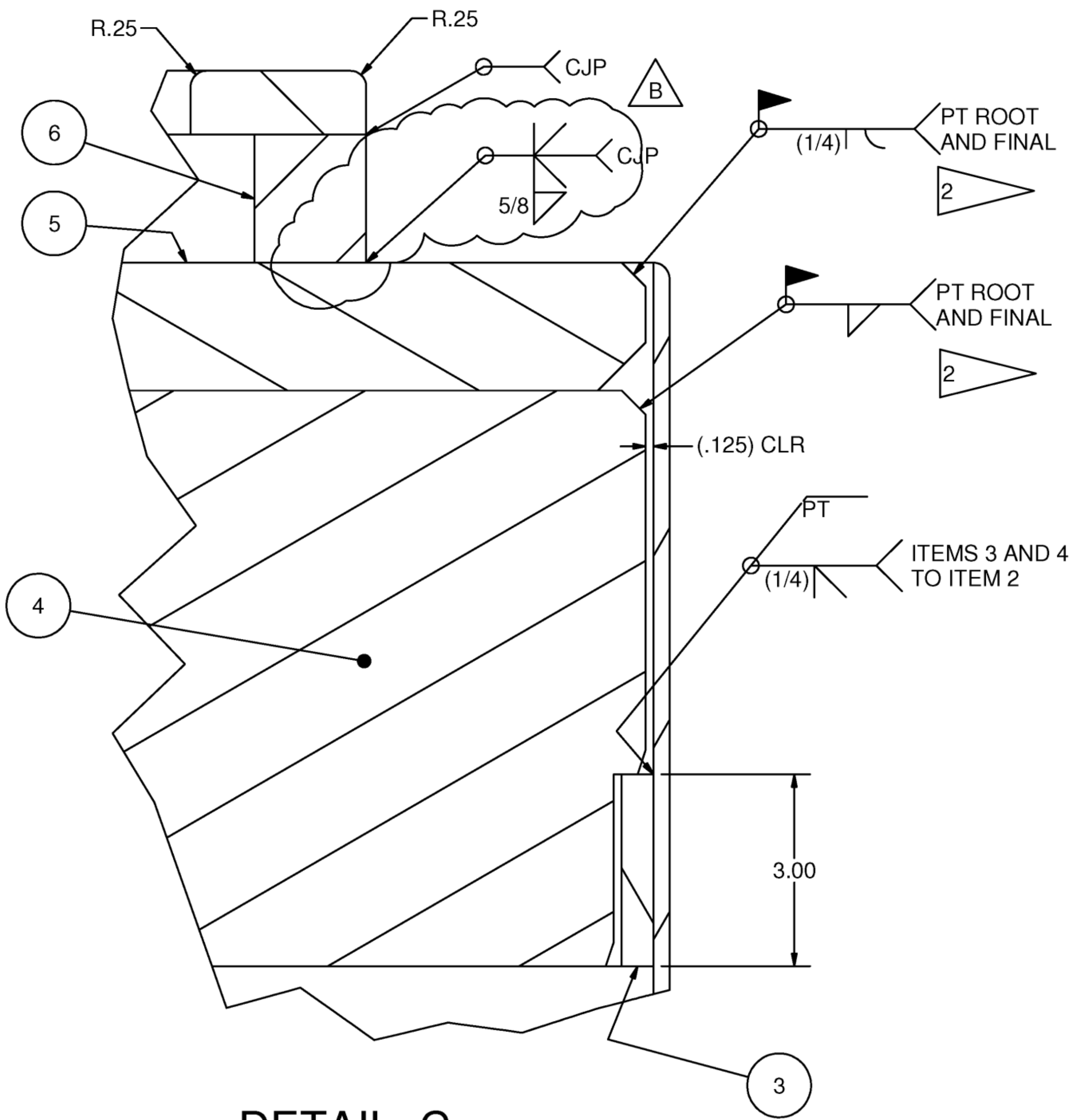
	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

CONTRACT NO. DE-NE-0000293
PROJECT NO. 205591

TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
9B ASSEMBLY AND DETAILS

SIZE B
DWG NO. DWG-205591-ME-0010
REV B
SCALE: SHOWN
SHEET: 11 OF 13

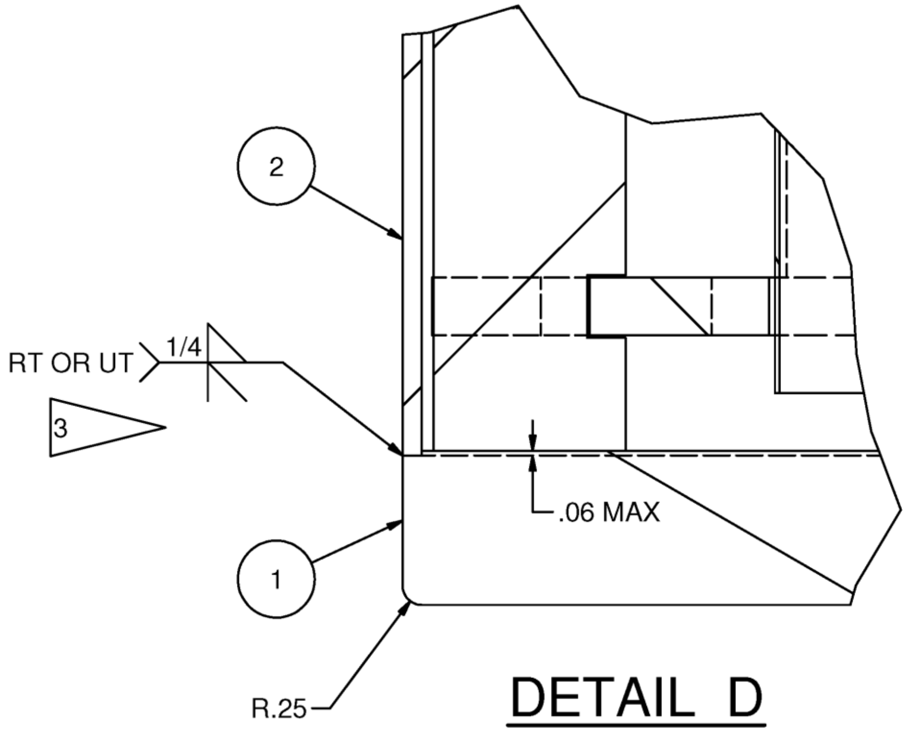


DETAIL C

SCALE: 1 / 2
SHEET 2

NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.



DETAIL D

SCALE: 1 / 2
SHEET 2

PRELIMINARY

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

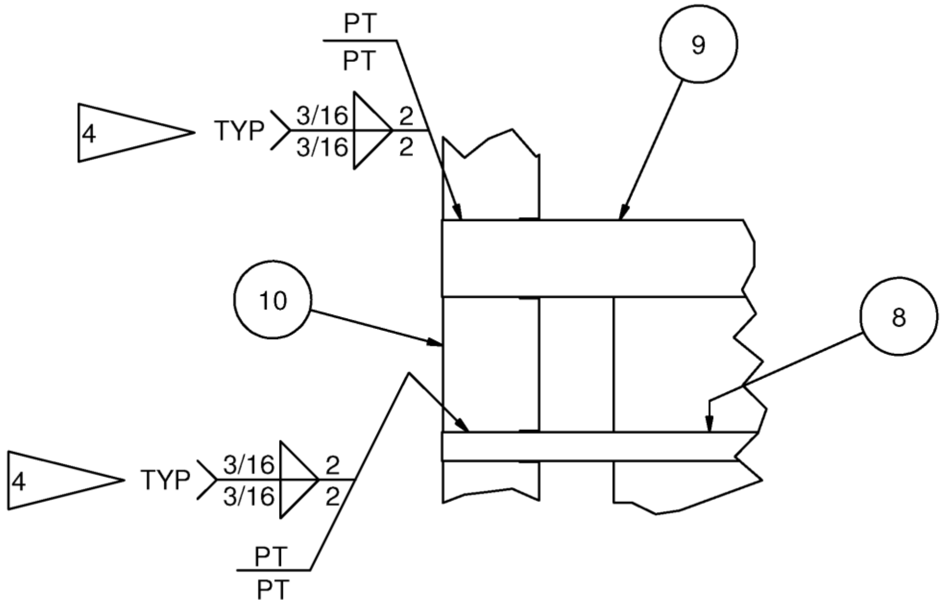
	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

CONTRACT NO. DE-NE-0000293
PROJECT NO. 205591

TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
9B ASSEMBLY AND DETAILS

SIZE B
DWG NO. DWG-205591-ME-0010
REV B
SCALE: SHOWN
SHEET: 12 OF 13

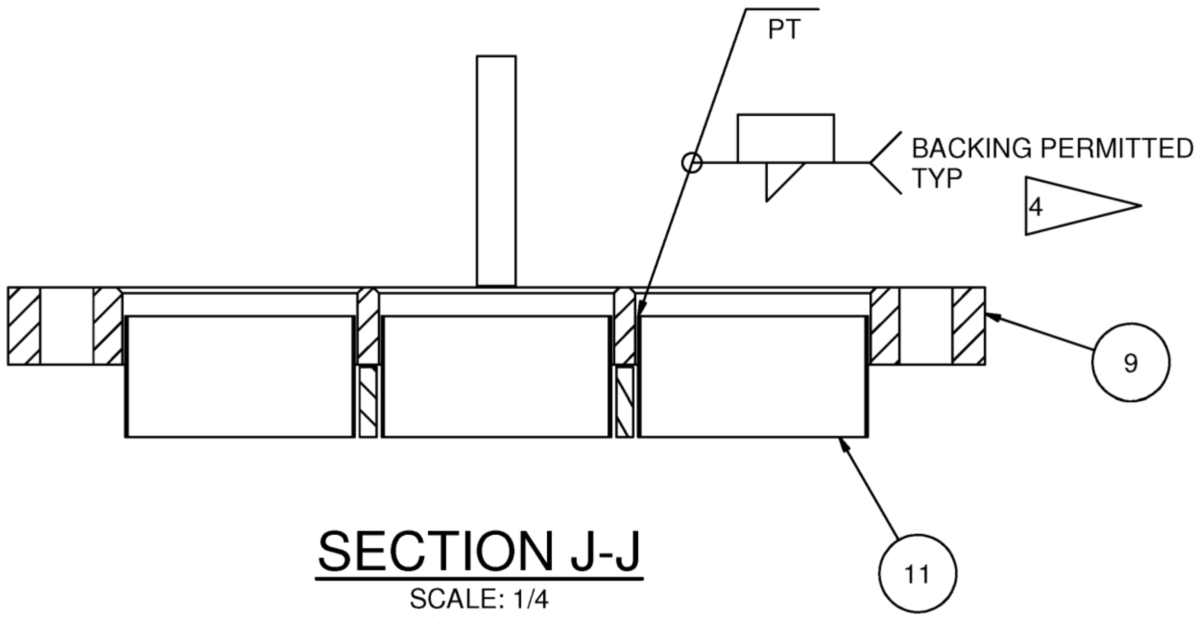


DETAIL K

SCALE: 1 / 4
SHEET 3

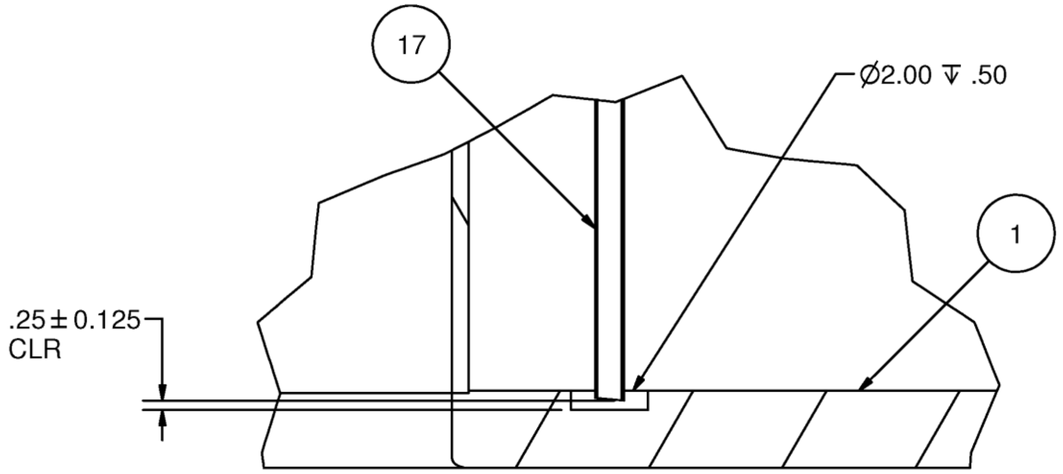
NOTES:

FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.



SECTION J-J

SCALE: 1/4
SHEET 3



DETAIL M

SCALE: 1 / 4
SHEET 4

PRELIMINARY

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
B	FINAL REPORT ISSUE	FC	SS	·	·	·	4/13/15
A	PRELIMINARY DESIGN ISSUE	FC	SS	·	·	N/A	2/19/15

REVISIONS

N/A

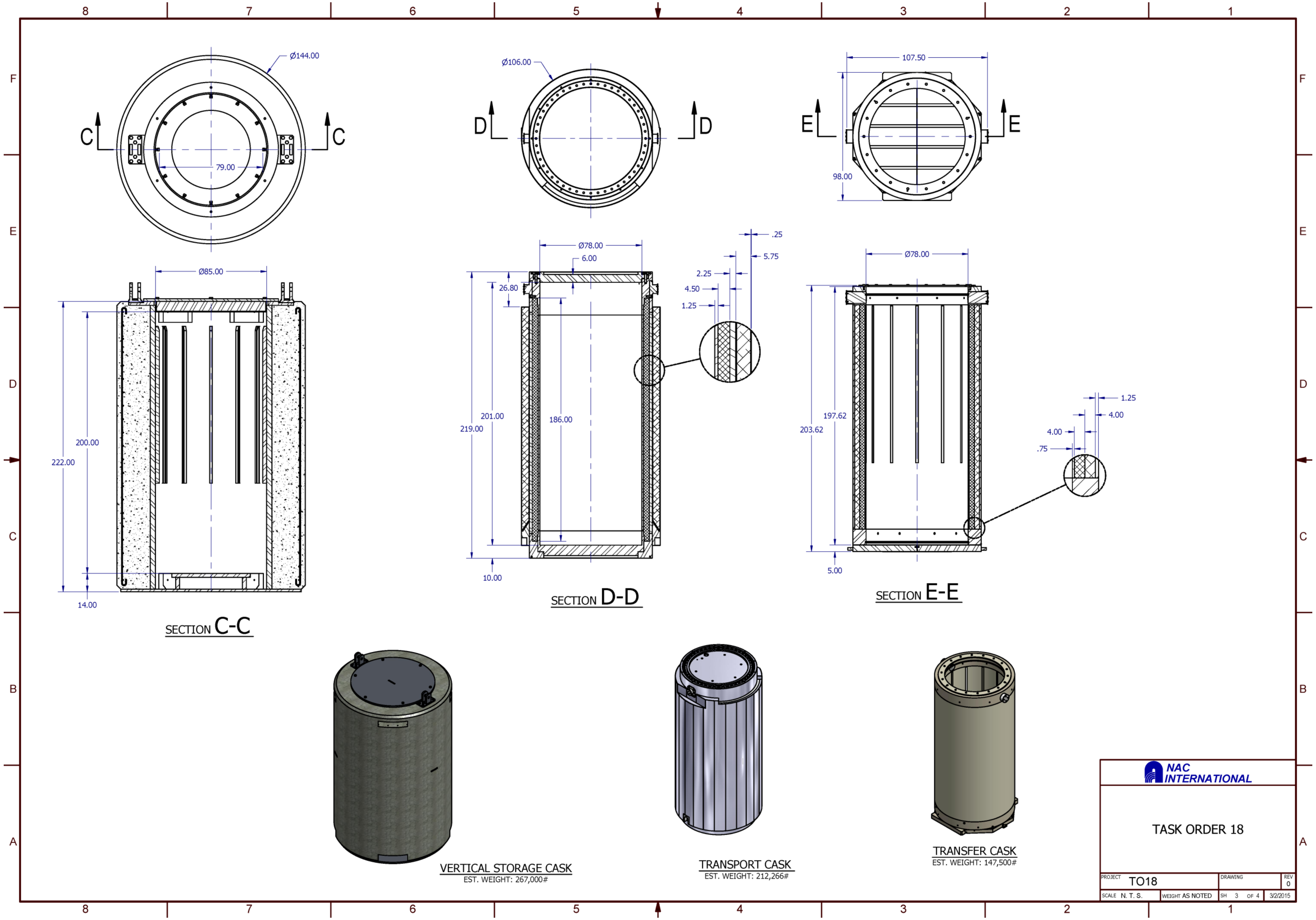
	BY	DATE
DRAWN	F. CHAVEZ	2/19/15
ENGINEER	S. SISLEY	2/19/15
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM		
NEXT USED ON		

ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

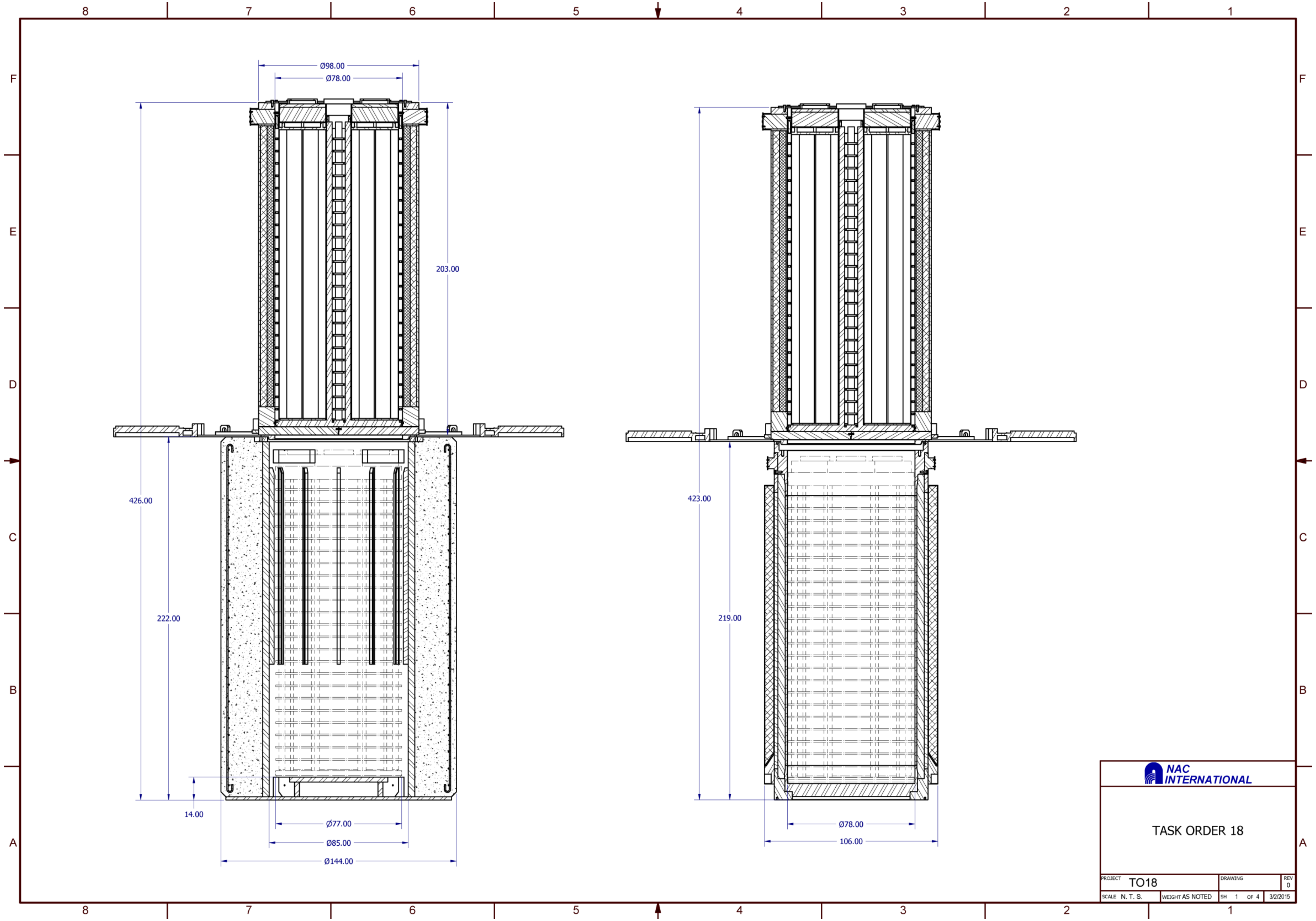
CONTRACT NO. DE-NE-0000293 PROJECT NO. 205591

TASK ORDER 18
STORAGE TRANSPORT AGING & DISPOSAL
9B ASSEMBLY AND DETAILS

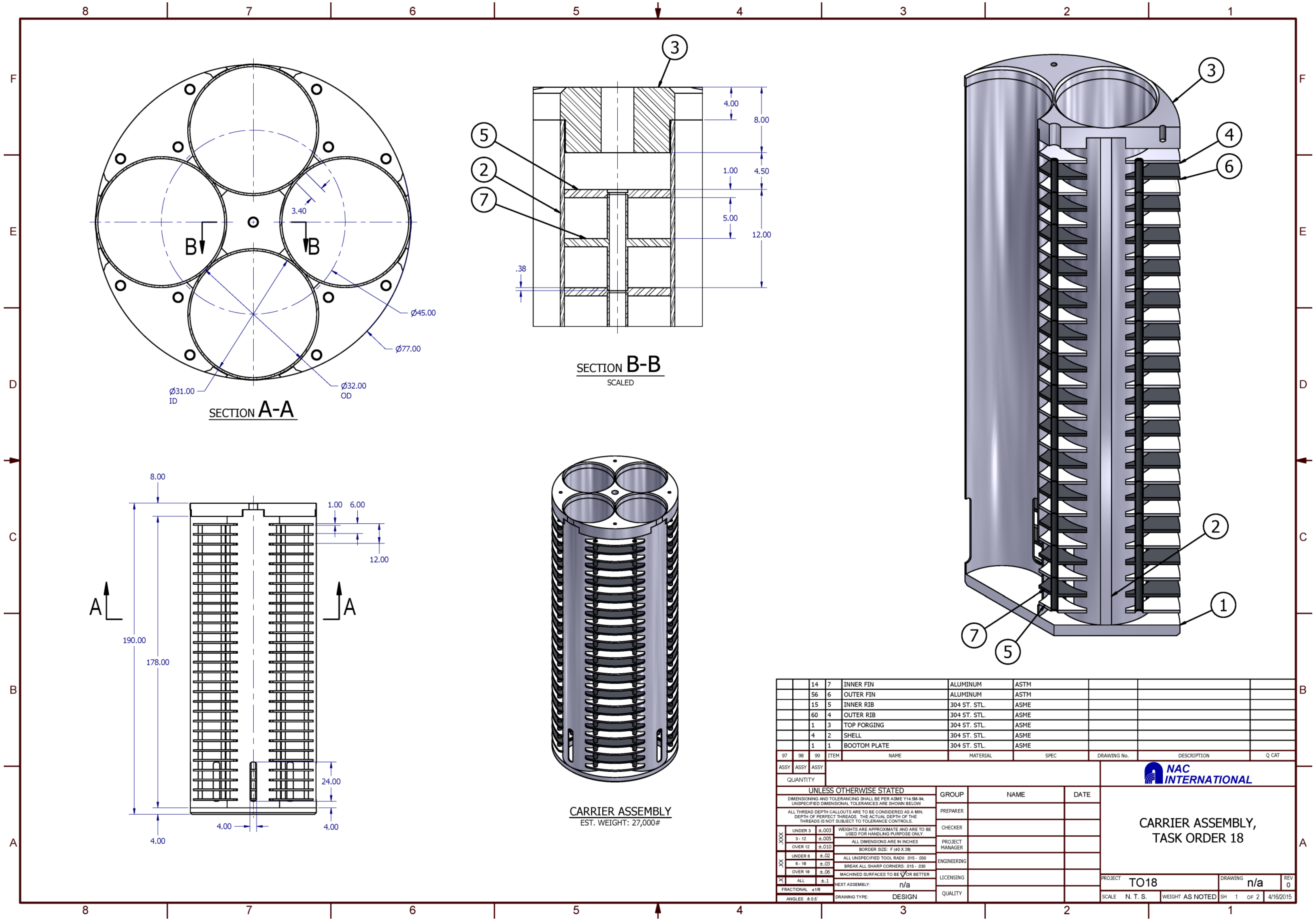
SIZE B DWG NO. DWG-205591-ME-0010 REV B
SCALE: SHOWN SHEET: 13 OF 13



Note. In the above drawing, the Transport Cask is shown without the impact limiters.



Note. On the left hand side of the drawing, the Transfer Cask is shown located above an aboveground Storage Overpack.
On the right hand side of the drawing, the Transfer Cask is shown located above a Transportation Cask.



		14	7	INNER FIN	ALUMINUM	ASTM			
		56	6	OUTER FIN	ALUMINUM	ASTM			
		15	5	INNER RIB	304 ST. STL.	ASME			
		60	4	OUTER RIB	304 ST. STL.	ASME			
		1	3	TOP FORGING	304 ST. STL.	ASME			
		4	2	SHELL	304 ST. STL.	ASME			
		1	1	BOOTOM PLATE	304 ST. STL.	ASME			
97	98	99	ITEM	NAME	MATERIAL	SPEC	DRAWING No.	DESCRIPTION	Q CAT
ASSY	ASSY	ASSY							
QUANTITY									

NAC INTERNATIONAL

UNLESS OTHERWISE STATED

DIMENSIONING AND TOLERANCING SHALL BE PER ASME Y14.5M-94, UNSPECIFIED DIMENSIONAL TOLERANCES ARE SHOWN BELOW

ALL THREAD DEPTH CALLOUTS ARE TO BE CONSIDERED AS A MIN. DEPTH OF PERFECT THREADS. THE ACTUAL DEPTH OF THE THREADS IS NOT SUBJECT TO TOLERANCE CONTROLS.

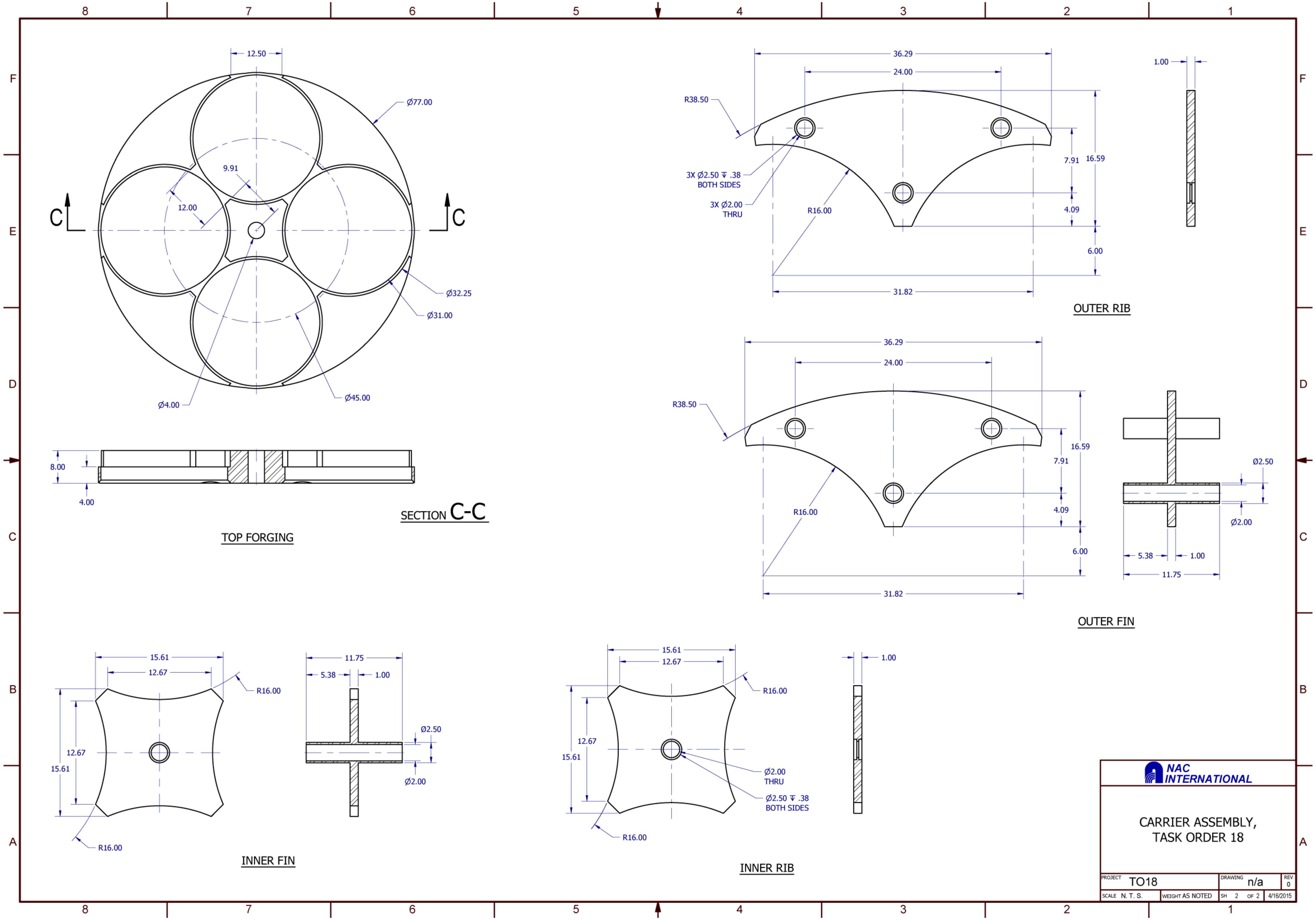
.XXX	UNDER 3	±.003	WEIGHTS ARE APPROXIMATE AND ARE TO BE USED FOR HANDLING PURPOSE ONLY.
	3 - 12	±.005	ALL DIMENSIONS ARE IN INCHES
	OVER 12	±.010	BORDER SIZE: F (40 X 28)
.XX	UNDER 6	±.02	ALL UNSPECIFIED TOOL RADII: .015 - .030
	6 - 18	±.03	BREAK ALL SHARP CORNERS: .015 - .030
	OVER 18	±.06	MACHINED SURFACES TO BE ∇ OR BETTER
.X	ALL	±.1	NEXT ASSEMBLY: n/a
FRACTIONAL ±1/8			DRAWING TYPE: DESIGN
ANGLES ± 0.5˚			

GROUP	NAME	DATE
PREPARER		
CHECKER		
PROJECT MANAGER		
ENGINEERING		
LICENSING		
QUALITY		

CARRIER ASSEMBLY,
TASK ORDER 18

PROJECT TO18
DRAWING n/a
REV 0
SCALE N. T. S.
WEIGHT AS NOTED
SH 1 OF 2
4/16/2015

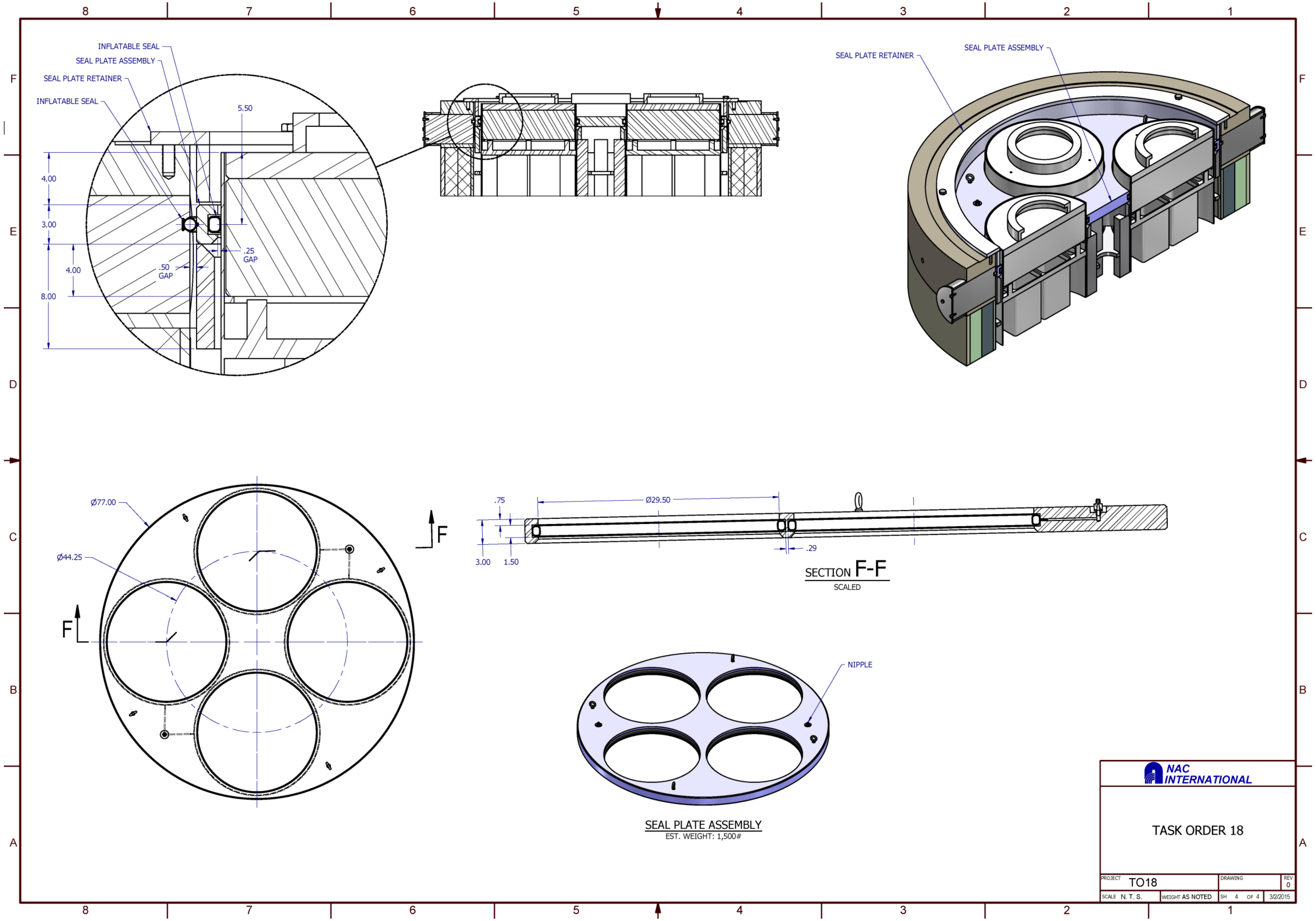
Note. The carrier length shown (190") is for use with a sealing plate assembly, which is to allow the seals to be located far enough below the top of the STAD canisters to avoid thermal damage during welding. If the sealing plate assembly is not used, then a carrier length of 197" is used. For this configuration, in addition to the pressurized deionized water supply system, wiper rings are used between each STAD canister and the carrier top plate.



NAC INTERNATIONAL

CARRIER ASSEMBLY,
TASK ORDER 18

PROJECT TO18
DRAWING n/a
REV 0
SCALE N. T. S.
WEIGHT AS NOTED
SH 2 OF 2
4/16/2015



Note. The above drawing shows the seal arrangement concept, which is used on top of the carrier whilst it is loaded in the Transfer Cask. The carrier length for this concept is 190” versus a length of 197” for the carrier when it is used with wiper rings between each STAD canister and the carrier top plate.

Appendix F - STAD Canister System Datasheets

Multi-canister carrier (MCC): A structure to hold more than one canister inside a storage/transfer/transportation overpack.		
Name	Task Order 18	
Fabricator	N/A	
Design/operation life	150 years	
Capacity	# canisters	# assemblies
- Zone 1	4	16 PWR or 36 BWR
- Zone 2 {if applicable}	N/A	N/A
Type of Canister (4P, 12P, 9B)		
- Zone 1	4P or 9B	
- Zone 2 {if applicable}	N/A	
Proposed Certificate of Compliance Limits		
Total Thermal Limit (kW)	32	
Thermal limit per zone {if applicable}		
- Zone 1 (kW)	N/A	
- Zone 2 (kW) {if applicable}	N/A	
Drying procedures (vacuum, FHD, other)	Vacuum	
Criticality methodology for storage (boron credit, none)	PWR-boron, BWR - none	
Boron loading requirement in ppm {if applicable}	2000	
Max. enrichment for storage due to criticality requirements	5.00%	
Min. enrichment for storage due to shielding requirements	Varies w/ burnup	
Min. cooling time for storage due to shielding & thermal requirements	5 years	
Max. burnup for storage due to shielding & thermal requirements	62.5 GWd/MTU	
Criticality methodology for transportation (burnup credit, none)	Moderator Exclusion	
Criticality loading curve {table or equation, if burnup credit}	-	
Max. enrichment for transportation due to criticality requirements {if no burnup credit}	5.00%	
Shielding loading curve {table or equation}	62.5 GWd/MTU, 5 year cooled	
Thermal loading curve {table or equation} {may be combined with shielding loading curve}	**< 2.0 kW/assembly - PWR Storage** **< 0.89 kW/assembly - BWR Storage** **< 1.5 kW/assembly - PWR Storage** **< 0.667 kW/assembly - BWR Transport**	
Physical Properties (STAD canister)		
Outer length (cm)	497.84 (incl handle)	
Cavity length (cm)	457.2	
Top shield thickness (cm)	22.86	
Bottom shield thickness (cm)	5.08	
Outer diameter (cm)	73.66	
Cavity diameter (cm)	72.39	
Empty weight (lb)	6,380 - 4-PWR 7,450 - 9-BWR	
Maximum loaded weight - flooded (lb)	15,900 - 4-PWR 16,335 - 9-BWR	
Maximum loaded weight - dry (lb)	13,280 - 4-PWR 13,804 - 9-BWR	
Basket material	ASME SA-240 Type 316L Stainless Steel	
Basket neutron poison material (type, none)	ASTM A887-89 Grade A Borated Stainless Steel	
Basket neutron poison B10 areal density {if any}	18 mg/cm2	

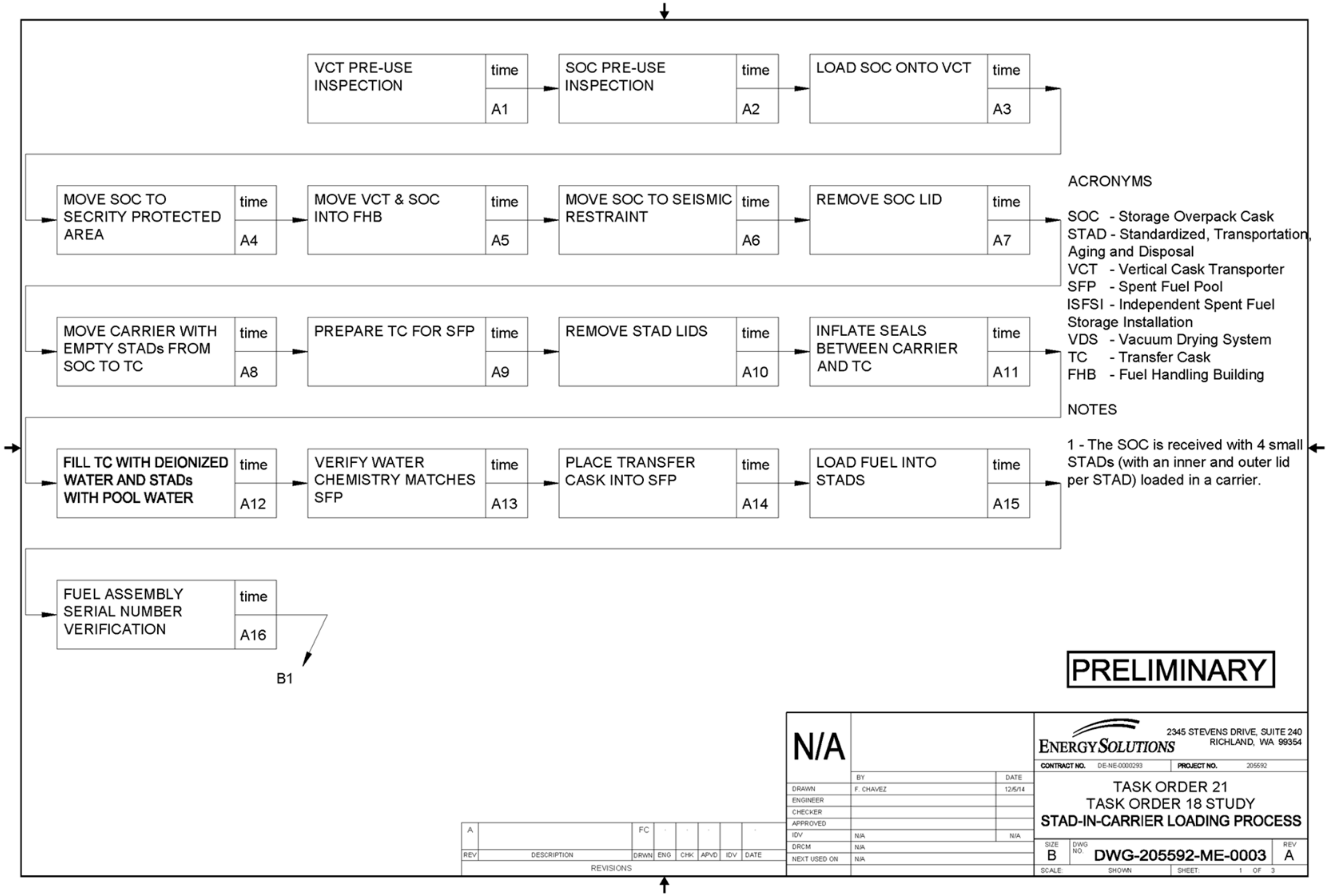
Multi-canister carrier (MCC): A structure to hold more than one canister inside a storage/transfer/transportation overpack.		
Name	Task Order 18	
Fabricator	N/A	
Design/operation life	150 years	
Capacity	# canisters	# assemblies
- Zone 1	4	16 PWR or 36 BWR
- Zone 2 {if applicable}	N/A	N/A
Physical Properties (Carrier)		
Empty weight (lb)	23,800	
Loaded with Four 4-PWR STAD Canisters - Dry (lb) (includes 1,220 lbs Yoke/Lifting Ring)	78,120	
Loaded with Four 9-BWR STAD Canisters - Dry (lb) (includes 1,220 lbs Yoke/Lifting Ring)	80,216	
Length (cm)	482.60	
Diameter (cm)	195.58	
Unit Processing Times and Corresponding Dose	Time (hr)	Dose (mrem)
MCC loading for storage or transportation	Refer to Task Order 21	Refer to Task Order 21
- Preparation	-	-
- Canister transfer to MCC	-	-
- Decontamination	-	-
- Drying	-	-
- Closing	-	-
MCC receipt and processing	Refer to Task Order 21	Refer to Task Order 21
- MCC opening	-	-
- Canister transfer from MCC	-	-
- Inspection	-	-
- Maintenance	-	-
Unit Costs (per MCC)		
MCC Purchase ($)	355,657(1)	
Ancillary equipment - loading ($)	N/A	
Loading operation ($)	Refer to Task Order 21	
Ancillary equipment - unloading ($)	N/A	
Unloading operation ($)	Refer to Task Order 21	
Inspection ($)	N/A	
Maintenance ($)	N/A	
Refurbishment ($)	N/A	
Note 1: Price is based on fabricating 150 per calendar year.		

Overpack: The closed structure/container used to host canister(s). It is used for transfer of canister(s).		
Name	Task Order 18	
Fabricator	N/A	
Design/operation life	30 years +	
Mode (storage, transportation, storage & transportation)	Transfer	
Proposed Certificate of Compliance Limits		
Max. external surface dose {if any}	N/A	
Max. 1 m dose {if any}	N/A	
Physical Properties		
Length w/o impact limiters (cm)	517.2	
Length w/ impact limiters (cm) {if applicable}	N/A	
Diameter w/o impact limiters (cm)	273.05 (max) 248.92 (min)	
Diameter w/ impact limiters (cm) {if applicable}	N/A	
Cavity length (cm)	501.96	
Cavity diameter (cm)	198.12	
Top lid thickness including neutron shield (cm)	N/A	
Top neutron shield thickness (cm)	N/A	
Bottom thickness including neutron shield (cm)	12.7	
Bottom neutron shield thickness(cm)	N/A	
Wall thickness including neutron shield (cm)	25.4	
Neutron shield side thickness (cm)	10.16	
Empty weight w/o impact limiters (lb.)	147,500	
Empty weight w/ impact limiters (lb.) {if applicable}	N/A	
Max. loaded weight w/o impact limiters - flooded canister and annulus (lb.)	251,593 (4-PWR(4) in Carrier) 253,333 (9-BWR(4) in Carrier)	
Max. loaded weight w/o impact limiters - dry (lb.)	240,400 (4-PWR(4) in Carrier) 242,140 (9-BWR(4) in Carrier)	
Max. loaded weight w/ impact limiters - dry (lb.)	N/A	
Neutron shield type (type, none)	NS-4-FR (Epoxy Resin)	
Overweight truck (yes, no)	NO	
Unit Processing Times and Corresponding Dose	Time (hr)	Dose (mrem)
Overpack loading	Refer to Task Order 21	Refer to Task Order 21
- Preparation		
- Decontamination		
- Closing		
- Stacking process {if applicable}		
- Loading onto vehicle {if applicable}		
- Preparation for transport {if applicable}		
Overpack receipt and processing	N/A	N/A
- Preparation		
- Overpack opening		
- Inspection		
- Maintenance		
Unit Costs (per overpack)		
Overpack purchase ($)	687,157	
Ancillary equipment - loading ($)	N/A	
Loading operation ($)	N/A	
Ancillary equipment - unloading ($)	N/A	
Unloading operation ($)	N/A	
Inspection ($)	N/A	
Maintenance ($)	N/A	
Refurbishment ($)	N/A	

Overpack: The closed structure/container used to host canister(s). It is used for storage of canister(s).		
Name	Task order 18	
Fabricator	N/A	
Design/operation life	30 years +	
Mode (storage, transportation, storage & transportation)	Storage	
Proposed Certificate of Compliance Limits		
Max. external surface dose {if any}	Peak side < 100 mR/hr Top surface average < 100 mR/hr	
Max. 1 m dose {if any}	N/A	
Physical Properties		
Length w/o impact limiters (cm)	563.88	
Length w/ impact limiters (cm) {if applicable}	N/A	
Diameter w/o impact limiters (cm)	365.76	
Diameter w/ impact limiters (cm) {if applicable}	N/A	
Cavity length (cm)	508	
Cavity diameter (cm)	215.9	
Top lid thickness including neutron shield (cm)	17.15	
Top neutron shield thickness (cm)	14.61	
Bottom thickness including neutron shield (cm)	2.54	
Bottom neutron shield thickness(cm)	N/A	
Wall thickness including neutron shield (cm)	74.93	
Neutron shield side thickness (cm)	67.31	
Empty weight w/o impact limiters (lb.)	267,000	
Empty weight w/ impact limiters (lb.) {if applicable}	N/A	
Max. loaded weight w/o impact limiters - flooded canister and annulus (lb.)	N/A	
Max. loaded weight w/o impact limiters - dry (lb.) - Loaded with 4-PWR (4) in carrier	343,920	
Max. loaded weight w/o impact limiters - dry (lb.) - Loaded with 9-BWR (4) in carrier	346,016	
Max. loaded weight w/ impact limiters - dry (lb.)	N/A	
Neutron shield type (type, none)	Concrete	
Overweight truck (yes, no)	N/A	
Unit Processing Times and Corresponding Dose	Time (hr)	Dose (mrem)
Overpack loading	N/A	N/A
- Preparation		
- Decontamination		
- Closing		
- Stacking process {if applicable}		
- Loading onto vehicle {if applicable}		
- Preparation for transport {if applicable}		
Overpack receipt and processing	N/A	N/A
- Preparation		
- Overpack opening		
- Inspection		
- Maintenance		
Unit Costs (per overpack)		
Overpack purchase ($)	300,000(1)	
Ancillary equipment - loading ($)	N/A	
Loading operation ($)	N/A	
Ancillary equipment - unloading ($)	N/A	
Unloading operation ($)	N/A	
Inspection ($)	N/A	
Maintenance ($)	N/A	
Refurbishment ($)	N/A	
Note 1: Price is comprised of $120,000 for the liner and supporting structure (based on fabricating 300 in a calendar year) and an estimate of $180,000 for the labor and materials to construct the concrete shielding.		

Overpack: The closed structure/container used to host canister(s). It is used for transport of canister(s).		
Name	Task Order 18	
Fabricator	N/A	
Design/operation life	30 years +	
Mode (storage, transportation, storage & transportation)	Transport	
Proposed Certificate of Compliance Limits		
Max. external surface dose {if any}	10 CFR 71 Limits Package Surface < 200 mR/hr 2-m Plane < 10 mR/hr	
Max. 1 m dose {if any}	None	
Physical Properties		
Length w/o impact limiters (cm)	556.26	
Length w/ impact limiters (cm) {if applicable}	701.04	
Diameter w/o impact limiters (cm)	269.24	
Diameter w/ impact limiters (cm) {if applicable}	325.12	
Cavity length (cm)	510.54	
Cavity diameter (cm)	198.12	
Top lid thickness including neutron shield (cm)	15.24	
Top neutron shield thickness (cm)	N/A	
Bottom thickness including neutron shield (cm)	22.86	
Bottom neutron shield thickness(cm)	N/A	
Wall thickness including neutron shield (cm)	35.56	
Neutron shield side thickness (cm)	15.24	
Empty weight w/o impact limiters (lb.)	212,266	
Empty weight w/ impact limiters (lb.) {if applicable}	231,266	
Max. loaded weight w/o impact limiters - flooded canister and annulus (lb.)	N/A	
Max. loaded weight w/o impact limiters - dry (lb.) - Loaded with 4-PWR (4) in Carrier	294,686	
Max. loaded weight w/ impact limiters - dry (lb.) - Loaded with 4-PWR (4) in Carrier	313,686	
Max. loaded weight w/o impact limiters - dry (lb.) - Loaded with 9-BWR (4) in Carrier	296,782	
Max. loaded weight w/ impact limiters - dry (lb.) - Loaded with 9-BWR (4) in Carrier	315,782	
Neutron shield type (type, none)	NS-4-FR (Epoxy Resin)	
Overweight truck (yes, no)	NO	
Unit Processing Times and Corresponding Dose	Time (hr)	Dose (mrem)
Overpack loading	N/A	N/A
- Preparation		
- Decontamination		
- Closing		
- Stacking process {if applicable}		
- Loading onto vehicle {if applicable}		
- Preparation for transport {if applicable}		
Overpack receipt and processing	N/A	N/A
- Preparation		
- Overpack opening		
- Inspection		
- Maintenance		
Unit Costs (per overpack)		
Overpack purchase ($)	2,517,513(1)	
Ancillary equipment - loading ($)	N/A	
Loading operation ($)	N/A	
Ancillary equipment - unloading ($)	N/A	
Unloading operation ($)	N/A	
Inspection ($)	N/A	
Maintenance ($)	N/A	
Refurbishment ($)	N/A	
Note 1. Excludes cost of impact limiters.		

Appendix G - STAD-in-Carrier Loading Process

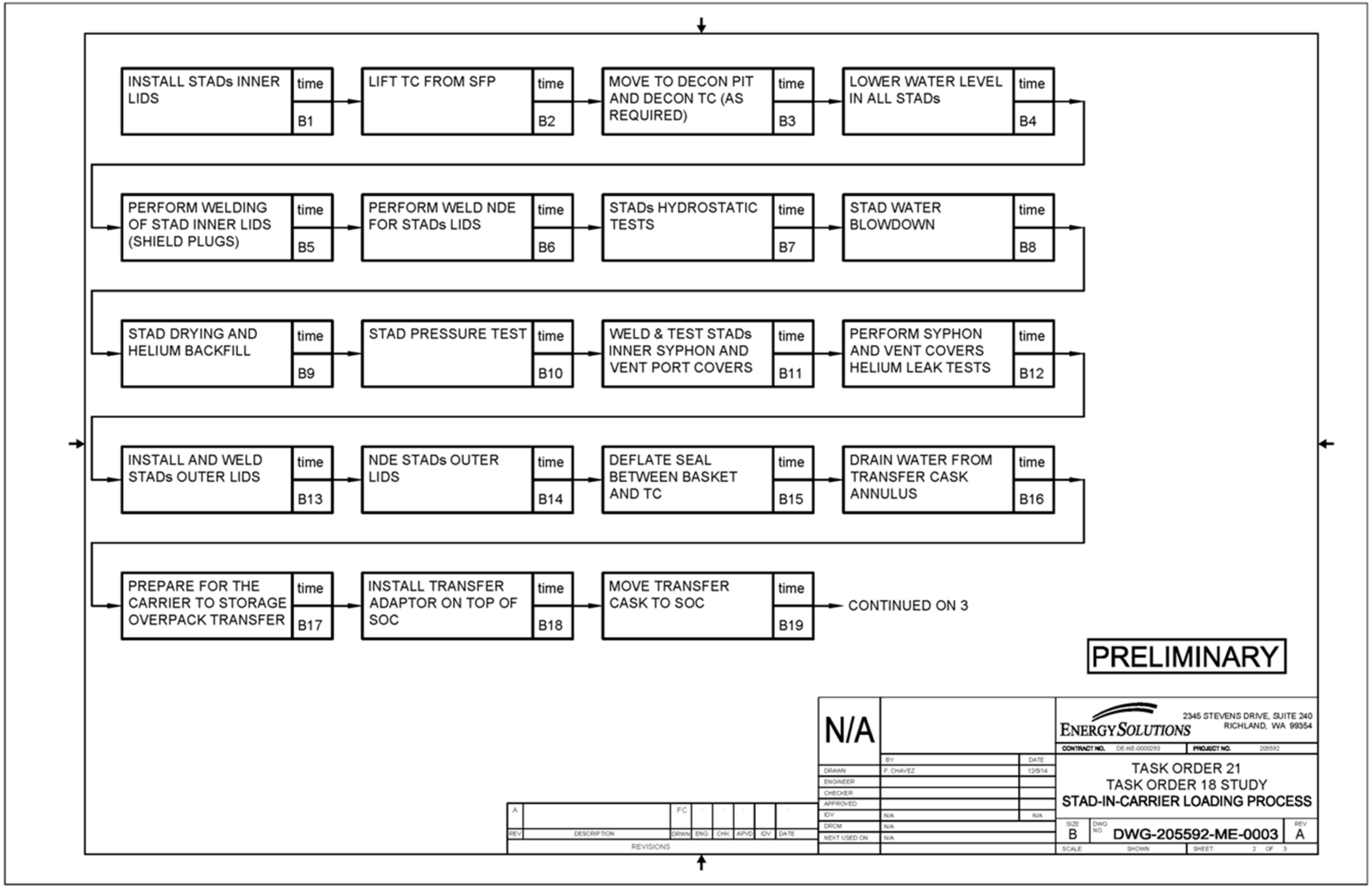


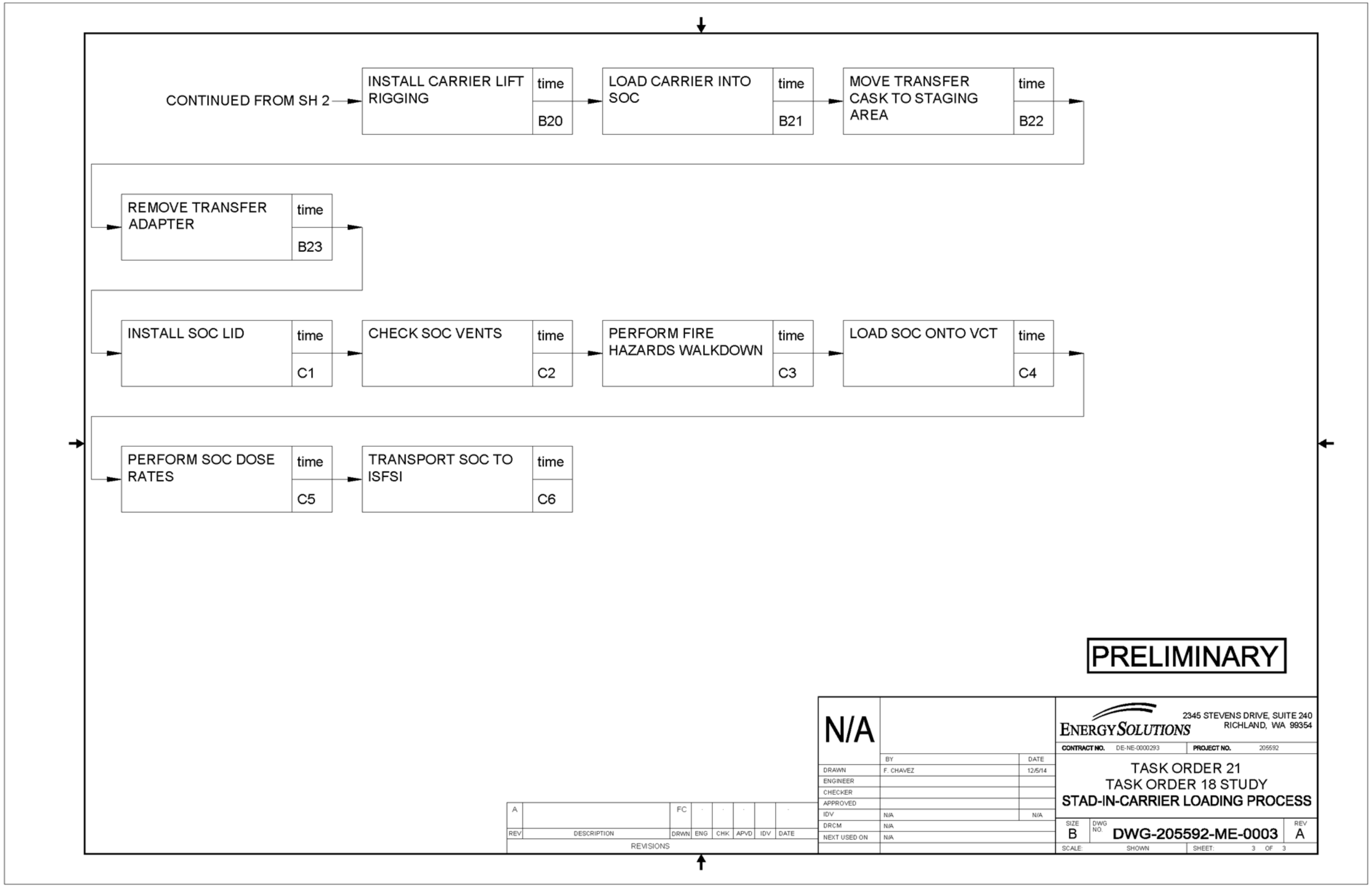
ACRONYMS

SOC - Storage Overpack Cask
STAD - Standardized, Transportation, Aging and Disposal
VCT - Vertical Cask Transporter
SFP - Spent Fuel Pool
ISFSI - Independent Spent Fuel Storage Installation
VDS - Vacuum Drying System
TC - Transfer Cask
FHB - Fuel Handling Building

NOTES

1 - The SOC is received with 4 small STADs (with an inner and outer lid per STAD) loaded in a carrier.


INSTALL STADs INNER LIDS
time
B1
LIFT TC FROM SFP
time
B2
MOVE TO DECON PIT AND DECON TC (AS REQUIRED)
time
B3
LOWER WATER LEVEL IN ALL STADs
time
B4
PERFORM WELDING OF STAD INNER LIDS (SHIELD PLUGS)
time
B5
PERFORM WELD NDE FOR STADs LIDS
time
B6
STADs HYDROSTATIC TESTS
time
B7
STAD WATER BLOWDOWN
time
B8
STAD DRYING AND HELIUM BACKFILL
time
B9
STAD PRESSURE TEST
time
B10
WELD & TEST STADs INNER SYPHON AND VENT PORT COVERS
time
B11
PERFORM SYPHON AND VENT COVERS HELIUM LEAK TESTS
time
B12
INSTALL AND WELD STADs OUTER LIDS
time
B13
NDE STADs OUTER LIDS
time
B14
DEFLATE SEAL BETWEEN BASKET AND TC
time
B15
DRAIN WATER FROM TRANSFER CASK ANNULUS
time
B16
PREPARE FOR THE CARRIER TO STORAGE OVERPACK TRANSFER
time
B17
INSTALL TRANSFER ADAPTOR ON TOP OF SOC
time
B18
MOVE TRANSFER CASK TO SOC
time
B19
CONTINUED ON 3
PRELIMINARY
N/A
ENERGYSOLUTIONS
2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354
CONTRACT NO. DE-NE-0000293
PROJECT NO. 205592
BY
DATE
DRAWN F. CHAVEZ 12/5/14
ENGINEER
CHECKER
APPROVED
IDV N/A N/A
DRCM N/A
NEXT USED ON N/A
TASK ORDER 21
TASK ORDER 18 STUDY
STAD-IN-CARRIER LOADING PROCESS
SIZE B
DWG NO. DWG-205592-ME-0003
REV A
SCALE SHOWN
SHEET 2 OF 3
A
FC
REV
DESCRIPTION
DRWN
ENG
CHK
APVD
IDV
DATE
REVISIONS



2345 STEVENS DRIVE, SUITE 240
RICHLAND, WA 99354

CONTRACT NO. DE-NE-0000293
PROJECT NO. 205592

TASK ORDER 21
TASK ORDER 18 STUDY
STAD-IN-CARRIER LOADING PROCESS

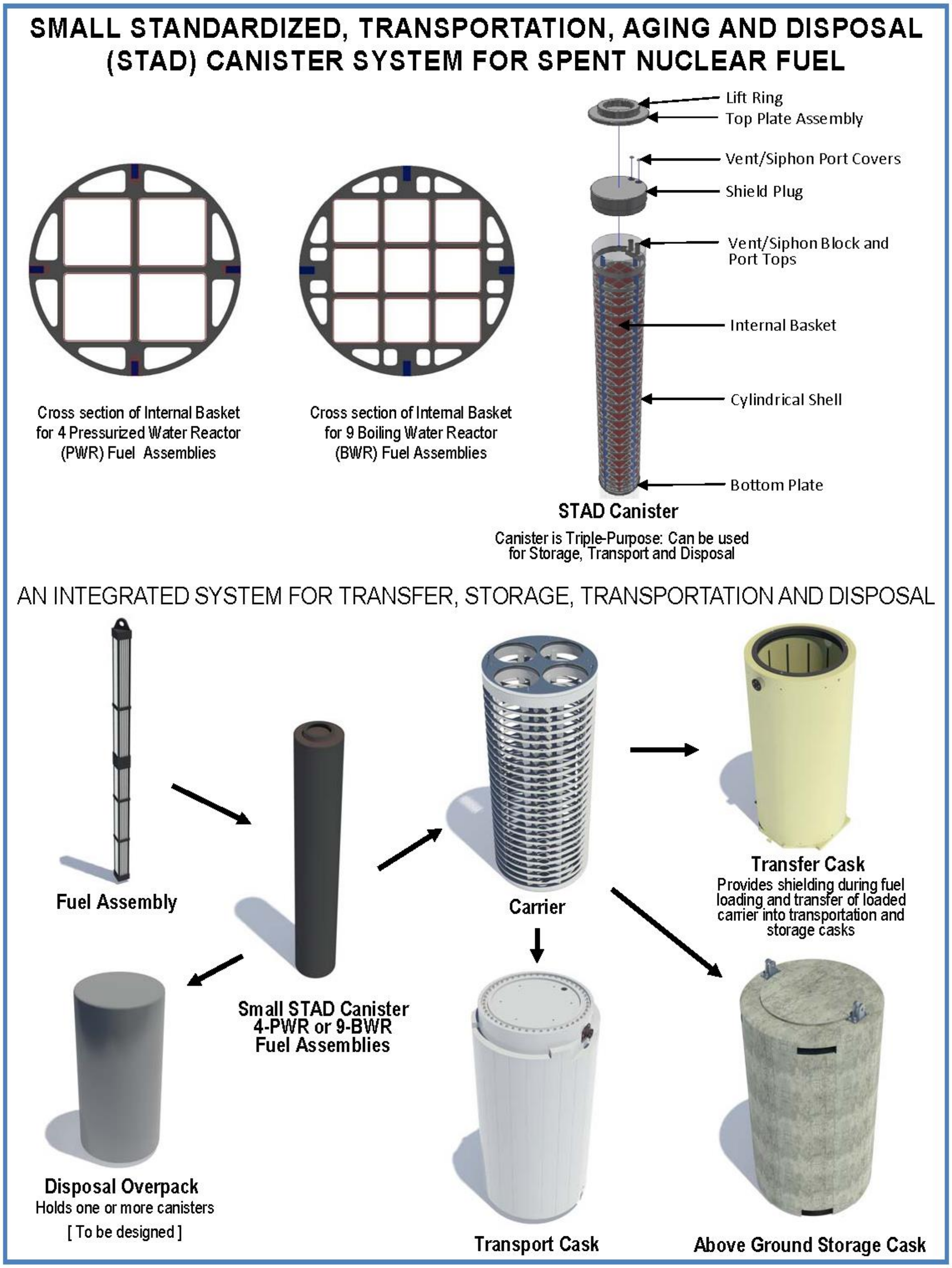
	BY	DATE
DRAWN	F. CHAVEZ	12/5/14
ENGINEER		
CHECKER		
APPROVED		
IDV	N/A	N/A
DRCM	N/A	
NEXT USED ON	N/A	

REV	DESCRIPTION	DRWN	ENG	CHK	APVD	IDV	DATE
A		FC	-	-	-		-

REVISIONS

SIZE B
DWG NO. DWG-205592-ME-0003
REV A
SCALE: SHOWN
SHEET: 3 OF 3

Appendix H – Fact Sheet



SMALL STANDARDIZED, TRANSPORTATION, AGING AND DISPOSAL (STAD) CANISTER SYSTEM FOR SPENT NUCLEAR FUEL

Cross section of Internal Basket for 4 Pressurized Water Reactor (PWR) Fuel Assemblies

Cross section of Internal Basket for 9 Boiling Water Reactor (BWR) Fuel Assemblies

STAD Canister

Canister is Triple-Purpose: Can be used for Storage, Transport and Disposal

AN INTEGRATED SYSTEM FOR TRANSFER, STORAGE, TRANSPORTATION AND DISPOSAL

Fuel Assembly

Small STAD Canister 4-PWR or 9-BWR Fuel Assemblies

Carrier

Transfer Cask
Provides shielding during fuel loading and transfer of loaded carrier into transportation and storage casks

Disposal Overpack
Holds one or more canisters
[To be designed]

Transport Cask

Above Ground Storage Cask

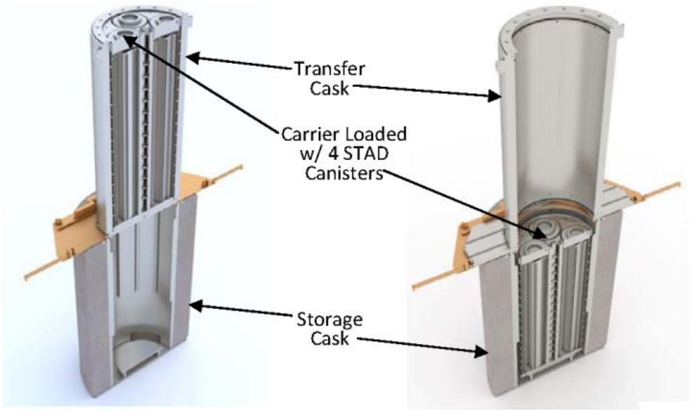
Produced by Energy*Solutions* and team partners: NAC International, Talisman International, Petersen Incorporated and Exelon Nuclear Partners for the U.S. Department of Energy's Nuclear Fuels Storage and Transportation Planning Project

STAD CANISTER SYSTEM FOR SPENT NUCLEAR FUEL MANAGEMENT

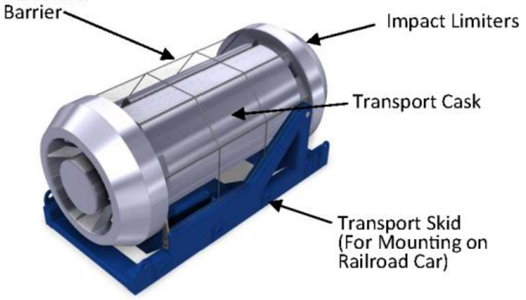
Key System Characteristics

Parameter	*Canister	Transfer Cask	Transport Cask	Storage Cask
Capacity (assemblies)	4 PWR/9 BWR	16 PWR/36 BWR	16 PWR/36 BWR	16 PWR/36 BWR
Thermal Capacity (kilowatts)	8	32	24	32
External Length (inches)	196	204	**219	222
External Diameter (inches)	29	108 (max)	106	144
Cavity Length (inches)	180	198	201	200
Cavity Diameter (inches)	29	78	78	85
Weight Loaded (lbs)	13,280 (4-PWR) 13,804 (9-BWR)	***251,593 (16-PWR) ***253,333 (36-BWR)	**294,686 (16-PWR) **313,686 (36-BWR)	343,920 (16-PWR) 346,016 (36-BWR)
Weight Empty (lbs)	6,380 (4-PWR) 7,450 (9-BWR)	***147,500	212,266	267,000

*Primary Material of Construction: Canister Shell - ASME SA-240, Type 316L Stainless Steel
**The weight load and length of the Transport Cask is w/o impacts limiters.
***Preliminary weights: Target maximum loaded weight for final design is 250,000 lbs



Transfer of Carrier to Storage Cask



Transport Cask
(Shown horizontal on skid)

Transport Cask & Carrier Loaded with 4 STAD Canisters
(Shown vertical w/o impact limiters)

Produced by Energy*Solutions* and team partners: NAC International, Talisman International, Petersen Incorporated and Exelon Nuclear Partners for the U.S. Department of Energy's Nuclear Fuels Storage and Transportation Planning Project

Appendix I - Task Order 18 Statement of Work

The Task Order 18 Statement of Work (SOW) provided by the DOE identified the following scope of work requirements:

> *The contractor shall develop a generic design of a small (4 PWR/9 BWR) STAD canister system. The STAD canister system consists of:*
>
> - *a canister shell;*
> - *lid(s);*
> - *internal components (e.g., basket for holding fuel assemblies, thermal shunts, and neutron absorbers, etc.);*
> - *a canister transfer system;*
> - *storage options, including a multi-canister storage overpack, and a vault storage configuration; and*
> - *transportation options, including a multi-canister transportation overpack, and associated impact limiters.*
>
> *The STAD canister may be loaded with commercial SNF and sealed at a reactor site, at an Interim Storage Facility (ISF), or at a repository. The loaded STAD canister may be stored in a storage overpack at a reactor site or transported (in a transportation overpack) and stored at an ISF and/or the repository. Eventually, loaded STADs will be disposed of in a waste package overpack, thus avoiding the need to open STADs once these have been sealed.*
>
> *Design requirements should be derived from the performance specifications:*
>
> - *Performance Specification for Small and Medium Standardized Transportation, Aging, and Disposal Canister Systems, FCRD–NFST–2014–000579*
>
> *The contractor should provide analyses that demonstrate that the STAD can be stored in the following storage configurations: 1) multi-canister storage overpack in horizontal or vertical mode and 2) vault. In this case, a vault is an above or below grade storage system designed as a hardened reinforced concrete structure with an above grade structure providing an operating area for canister placement, storage, and removal. The contractor should demonstrate that the STAD can be transported in a horizontal mode in a multi-canister transportation overpack. The contractor shall perform analyses on radiation dose, heat load, criticality, and structural integrity. The contractor shall also provide cost estimates for each piece of the STAD system.*

The design information to be developed by this procurement will support analyses and planning related to the waste management system. Therefore, the level of design detail required is limited to this intended usage, which requires reliable estimates of STAD canister system characteristics, such as capacity, dimensions, component masses and costs, operational characteristics and attributes, and any limitations or anticipated licensing considerations of relevance. Design and design analyses should be sufficient to provide reasonable assurance that each STAD canister system design is viable and has the capability to meet the fundamental licensing requirements for transportation and storage, thereby providing confidence in the reliability of the provided data. At this time SAR level design is not required.

The STAD canister systems must ultimately be NRC licensable, able to be fabricated within current facilities and capabilities, and usable by all or most nuclear utilities within their various physical and operational constraints, and able to be transported via rail. The STAD system design should have features that allow for uncomplicated manufacturing and operations.

As part of the Final Report and Briefing (Subtask 2.4 below), the contractor should develop information to communicate to decision makers and stakeholders (fact sheets, solid works representations, animation, etc.).

Appendix J – Fabrication Sequences for 4-PWR and 9-BWR STAD Canisters

Fabrication Sequence for 4-PWR STAD Canister, Drawing 205591-ME-0005 Rev. A

Item #1 (Bottom Plate) - 2" thick plasma cut OD. Machine to 29.00" OD machine the .06 step and weld prep for Item 2.

Item #2 (Canister Body) - The canister body will be purchased as a pipe 29.00" OD x 1/4" wall x 191" long. The body section will be fitted to the Bottom Plate and welded at this time.

Item #3 (Support Ring) - Ring will be plasma cut rolled and welded. The ring will be fit in the Canister and welded. The support ring will then be machined to the depth required for the shield plug.

Item #4 (Shield Plug) - Plug will be two piece construction to achieve overall height of 9.00" and will be welded per flag note 5. Plug will then be machined to the required dim and checked for fit.

Item #5, 6 & 7 (Top Plate Assy.) - Items 5, 6 & 7 will be fabricated and machined as an assembly to insure concentricity. Part will be checked for fit in cylinder.

Item #8 (Spacer Plate) - Spacer will be Water Jet cut from 3/4" SA240-Type 316L Stainless to the required dimensions and tolerance per the drawing detail.

Item #9 (Top End Spacer Plate) - Top Spacer will be Water Jet cut from 2-1/4" (Thickness to be adjusted for overall height) SA240-Type 316L Stainless to the required dimensions and tolerance per the drawing detail.

Item #10 (Support Bar) - Support bar to be water jet cut from 1" plate. Items 8, 9 & 10 will be fit using a shop aid to insure straightness and spacing.

Item #11 (Guide Tube) - Guide tubes will be fabricated from 2 pieces of 16 gauge SA240-Type 316L Stainless steel. The 16 GA plate will be water jet cut, formed and welded with the aid of tooling developed by Petersen Inc. The tubes will be tested for straightness and then inserted in to the Basket Assembly, where they will be welded to item 9 as required.

Items #12, 13 &14 (Neutron Absorber) - These plates will be purchased per drawing and installed by Petersen. Inc. The welding of these items will be done before the Guide Tubes are inserted.

Item #15 (Drain Vent Port) - Vent Port will be machined from Plate 3-1/4" thick to the print. Part will then be fit and welded into the cylinder.

Item #16 ((Drain Port Top) - Drain port will be made from round bar and machined to the print then fit and welded to the Vent Port.

Item #17 & 18 (Siphon Tube) - Saw cut tube to length and weld Item 18, Fit Tube Assembly into the basket Assembly.

Item #19 & 20 - Install Per manufacture requirements.

Item #21 (Drain Vent Cover) - Water jet cut and weld prep. per detail.

Flag note 6 - Hydro test in Petersen Inc. fixture.

Flag note 7 - Helium Leak Test will be subcontracted.

<u>Fabrication Sequence for 9-BWR STAD Canister, Drawing 205591-ME-0010 Rev. A</u>

Item #1 (Bottom Plate) - 2" thick plasma cut OD. Machine to 29.00" OD machine the .06 step and weld prep for Item 2.

Item #2 (Canister Body) - The canister body will be purchased as a pipe 29.00" OD x 1/4" wall x 191" long. The body section will be fitted to the Bottom Plate and welded at this time.

Item #3 (Support Ring) - Ring will be plasma cut rolled and welded. The ring will be fit in the Canister and welded. The support ring will then be machined to the depth required for the shield plug.

Item #4 (Shield Plug) - Plug will be two piece construction to achieve over all height of 9.00" will be welded per flag note 5. Plug will then be machined to the required dimension and checked for fit.

Item #5, 6 & 7 (Top Plate Assy.) - Items 5, 6 & 7 will be fabricated and machined as an assembly to insure concentricity. Part will be checked for fit in cylinder.

Item #8 (Spacer Plate) - Spacer will be Water Jet cut from 3/4" SA240-Type 316L Stainless to the required dimensions and tolerance per the drawing detail.

Item #9 (Top End Spacer Plate) - Top Spacer will be Water Jet cut from 2-1/4" (Thickness to be adjusted for overall height) SA240-Type 316L Stainless to the required dimensions and tolerance per the drawing detail.

Item #10 (Support Bar) - Support bar to be water jet cut from 1" plate. Items 8, 9 & 10 will be fit using a shop aid to insure straightness and spacing.

Item #11 (Guide Tube) - Guide tubes will be fabricated from 2 pieces of 16 gauge SA240-Type 316L Stainless steel. The 16 GA plate will be water jet cut, Formed and welded with the aid of tooling developed by Petersen Inc. The tubes will be tested for straightness and then inserted into the Basket Assembly, where they will be welded to item 9 as required.

Items #12, 13 &14 (Neutron Absorber) - These plates will be purchased per drawing and installed by Petersen. Inc. The welding of these items will be done before the Guide Tubes are inserted. (On this Assembly we will insert the center tube to assist in alignment of the basket)

Item #15 (Drain Vent Port) - Vent Port will be machined from Plate 3-1/4" thick to the print. Part will then be fit and welded into the cylinder.

Item #16 ((Drain Port Top) - Drain port will be made from round bar and machined to the print then fit and welded to the Vent Port.

Item #17 & 18 (Siphon Tube) - Saw cut tube to length and weld Item 18. Fit Tube Assembly into the basket Assembly.

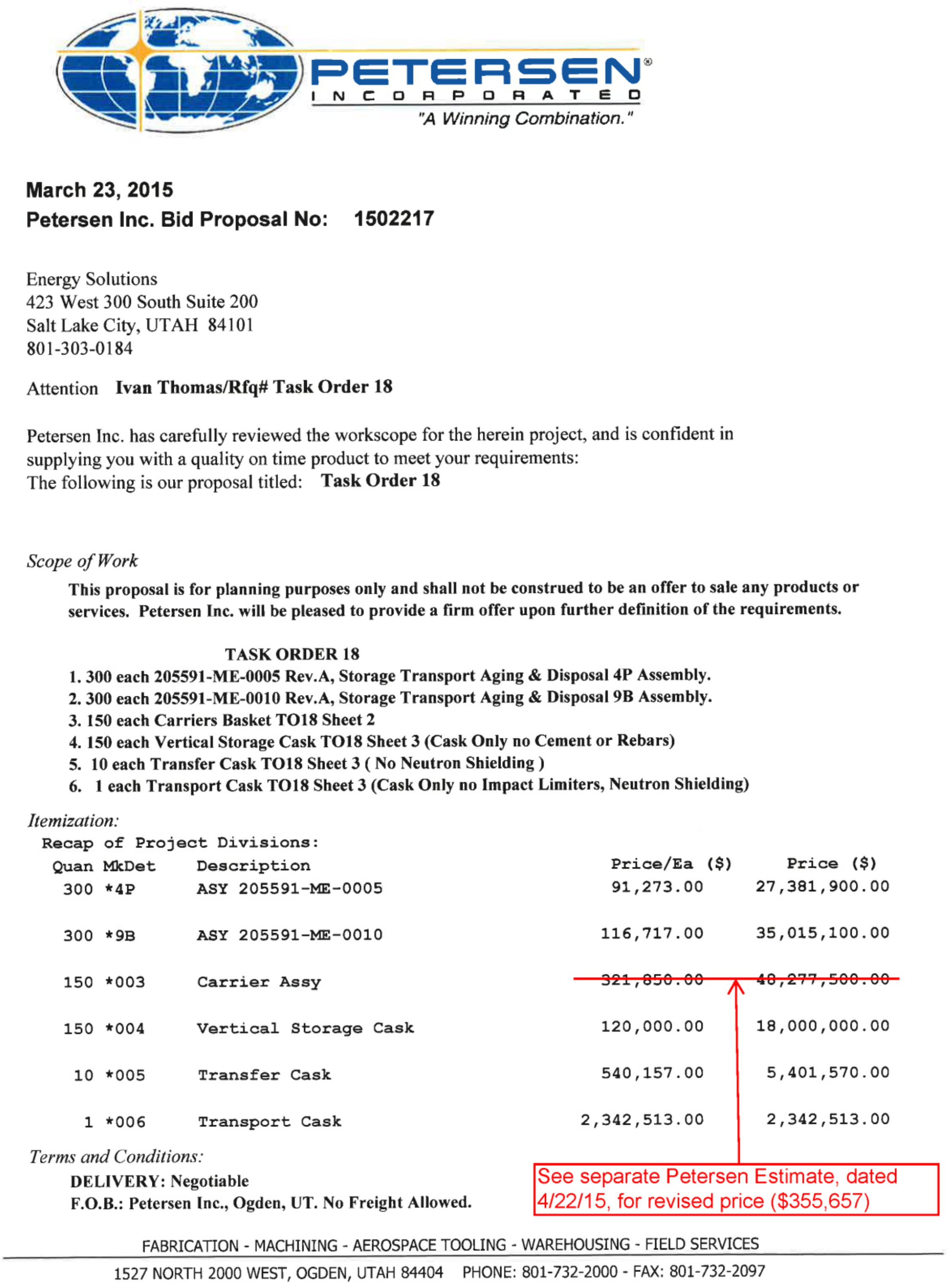
Item #19 & 20 - Install Per manufacture requirements.

Item #21 (Drain Vent Cover) - Water jet cut and weld prep per detail.

Flag note 6 - Hydro test in Petersen Inc. fixture.

Flag note 7 - Helium Leak Test will be subcontracted.

Appendix K – Supporting Information for Cost Estimates



PETERSEN®
INCORPORATED
"A Winning Combination."

March 23, 2015
Petersen Inc. Bid Proposal No: 1502217

Energy Solutions
423 West 300 South Suite 200
Salt Lake City, UTAH 84101
801-303-0184

Attention **Ivan Thomas/Rfq# Task Order 18**

Petersen Inc. has carefully reviewed the workscope for the herein project, and is confident in supplying you with a quality on time product to meet your requirements:
The following is our proposal titled: **Task Order 18**

Scope of Work

This proposal is for planning purposes only and shall not be construed to be an offer to sale any products or services. Petersen Inc. will be pleased to provide a firm offer upon further definition of the requirements.

TASK ORDER 18

1. **300 each 205591-ME-0005 Rev.A, Storage Transport Aging & Disposal 4P Assembly.**
2. **300 each 205591-ME-0010 Rev.A, Storage Transport Aging & Disposal 9B Assembly.**
3. **150 each Carriers Basket TO18 Sheet 2**
4. **150 each Vertical Storage Cask TO18 Sheet 3 (Cask Only no Cement or Rebars)**
5. **10 each Transfer Cask TO18 Sheet 3 (No Neutron Shielding)**
6. **1 each Transport Cask TO18 Sheet 3 (Cask Only no Impact Limiters, Neutron Shielding)**

Itemization:

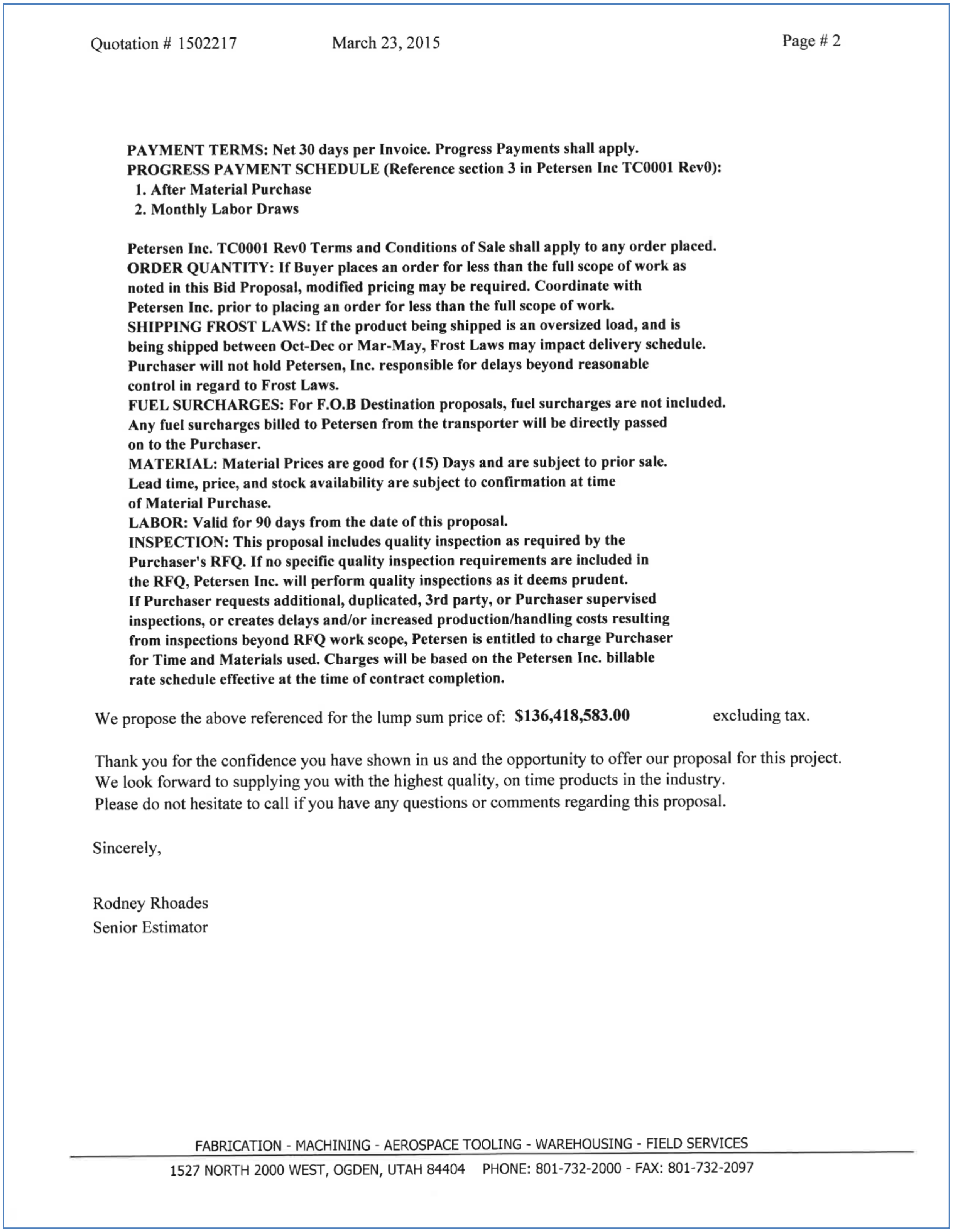
Recap of Project Divisions:

Quan	MkDet	Description	Price/Ea ($)	Price ($)
300	*4P	ASY 205591-ME-0005	91,273.00	27,381,900.00
300	*9B	ASY 205591-ME-0010	116,717.00	35,015,100.00
150	*003	Carrier Assy	~~321,850.00~~	~~48,277,500.00~~
150	*004	Vertical Storage Cask	120,000.00	18,000,000.00
10	*005	Transfer Cask	540,157.00	5,401,570.00
1	*006	Transport Cask	2,342,513.00	2,342,513.00

See separate Petersen Estimate, dated 4/22/15, for revised price ($355,657)

Terms and Conditions:

DELIVERY: Negotiable
F.O.B.: Petersen Inc., Ogden, UT. No Freight Allowed.



PAYMENT TERMS: Net 30 days per Invoice. Progress Payments shall apply.
PROGRESS PAYMENT SCHEDULE (Reference section 3 in Petersen Inc TC0001 Rev0):

1. **After Material Purchase**
2. **Monthly Labor Draws**

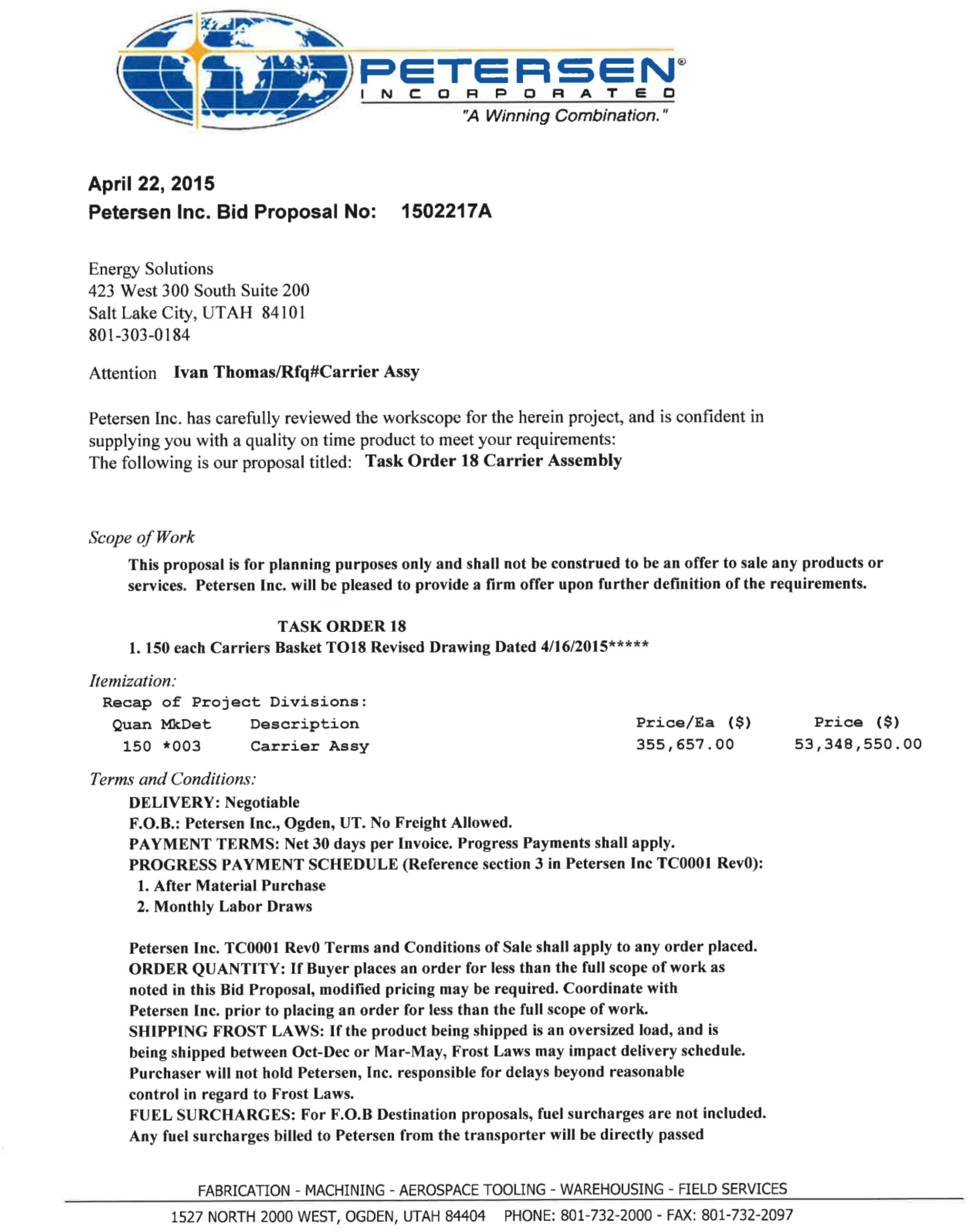
Petersen Inc. TC0001 Rev0 Terms and Conditions of Sale shall apply to any order placed.
ORDER QUANTITY: If Buyer places an order for less than the full scope of work as noted in this Bid Proposal, modified pricing may be required. Coordinate with Petersen Inc. prior to placing an order for less than the full scope of work.
SHIPPING FROST LAWS: If the product being shipped is an oversized load, and is being shipped between Oct-Dec or Mar-May, Frost Laws may impact delivery schedule. Purchaser will not hold Petersen, Inc. responsible for delays beyond reasonable control in regard to Frost Laws.
FUEL SURCHARGES: For F.O.B Destination proposals, fuel surcharges are not included. Any fuel surcharges billed to Petersen from the transporter will be directly passed on to the Purchaser.
MATERIAL: Material Prices are good for (15) Days and are subject to prior sale. Lead time, price, and stock availability are subject to confirmation at time of Material Purchase.
LABOR: Valid for 90 days from the date of this proposal.
INSPECTION: This proposal includes quality inspection as required by the Purchaser's RFQ. If no specific quality inspection requirements are included in the RFQ, Petersen Inc. will perform quality inspections as it deems prudent. If Purchaser requests additional, duplicated, 3rd party, or Purchaser supervised inspections, or creates delays and/or increased production/handling costs resulting from inspections beyond RFQ work scope, Petersen is entitled to charge Purchaser for Time and Materials used. Charges will be based on the Petersen Inc. billable rate schedule effective at the time of contract completion.

We propose the above referenced for the lump sum price of: **$136,418,583.00** excluding tax.

Thank you for the confidence you have shown in us and the opportunity to offer our proposal for this project. We look forward to supplying you with the highest quality, on time products in the industry. Please do not hesitate to call if you have any questions or comments regarding this proposal.

Sincerely,

Rodney Rhoades
Senior Estimator



PETERSEN®
INCORPORATED
"A Winning Combination."

April 22, 2015
Petersen Inc. Bid Proposal No: 1502217A

Energy Solutions
423 West 300 South Suite 200
Salt Lake City, UTAH 84101
801-303-0184

Attention **Ivan Thomas/Rfq#Carrier Assy**

Petersen Inc. has carefully reviewed the workscope for the herein project, and is confident in supplying you with a quality on time product to meet your requirements:
The following is our proposal titled: **Task Order 18 Carrier Assembly**

Scope of Work

This proposal is for planning purposes only and shall not be construed to be an offer to sale any products or services. Petersen Inc. will be pleased to provide a firm offer upon further definition of the requirements.

TASK ORDER 18

1. 150 each Carriers Basket TO18 Revised Drawing Dated 4/16/2015***

Itemization:

Recap of Project Divisions:

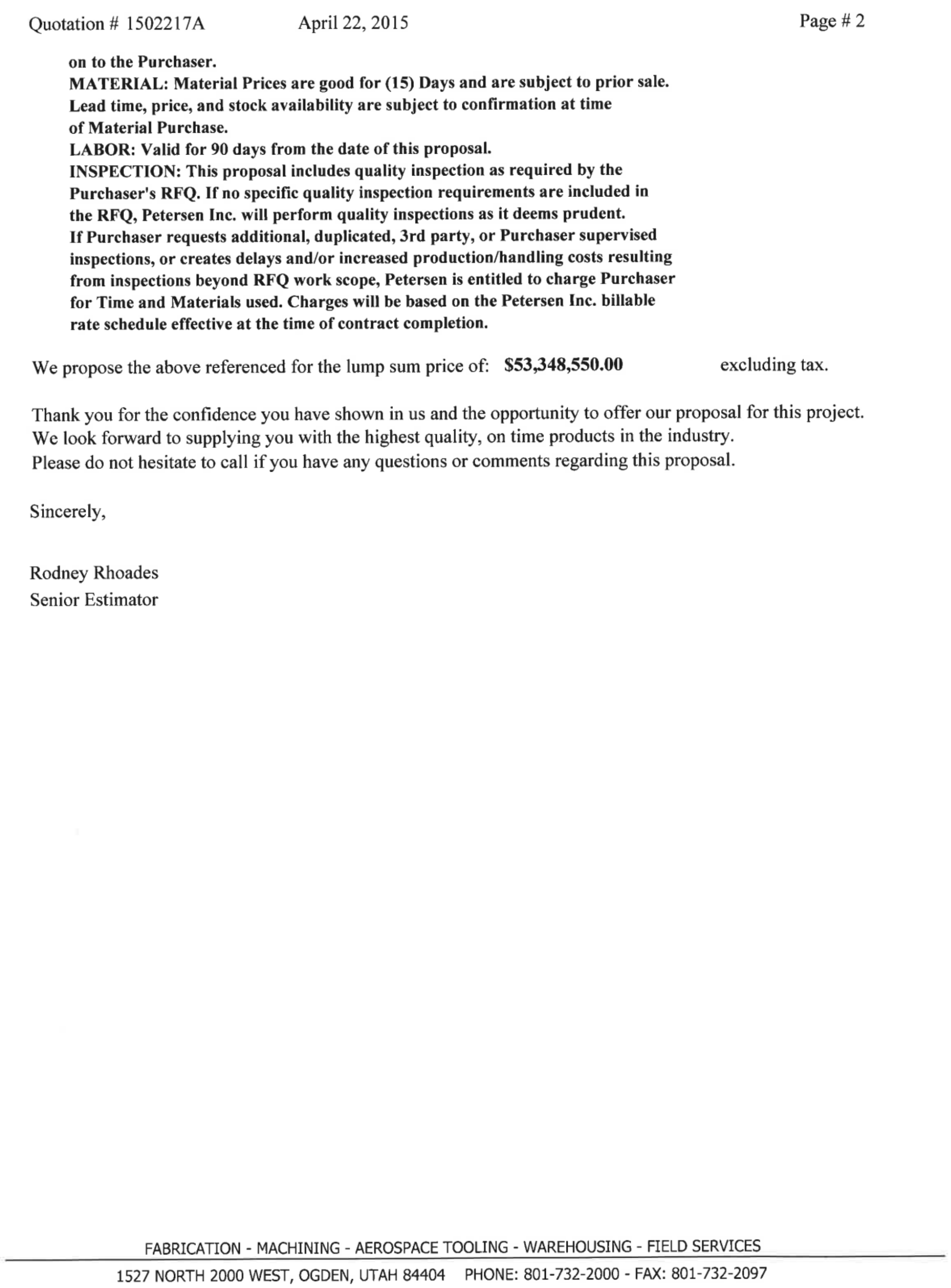
Quan	MkDet	Description	Price/Ea ($)	Price ($)
150	*003	Carrier Assy	355,657.00	53,348,550.00

Terms and Conditions:

DELIVERY: Negotiable
F.O.B.: Petersen Inc., Ogden, UT. No Freight Allowed.
PAYMENT TERMS: Net 30 days per Invoice. Progress Payments shall apply.
PROGRESS PAYMENT SCHEDULE (Reference section 3 in Petersen Inc TC0001 Rev0):
1. **After Material Purchase**
2. **Monthly Labor Draws**

Petersen Inc. TC0001 Rev0 Terms and Conditions of Sale shall apply to any order placed.
ORDER QUANTITY: If Buyer places an order for less than the full scope of work as noted in this Bid Proposal, modified pricing may be required. Coordinate with Petersen Inc. prior to placing an order for less than the full scope of work.
SHIPPING FROST LAWS: If the product being shipped is an oversized load, and is being shipped between Oct-Dec or Mar-May, Frost Laws may impact delivery schedule. Purchaser will not hold Petersen, Inc. responsible for delays beyond reasonable control in regard to Frost Laws.
FUEL SURCHARGES: For F.O.B Destination proposals, fuel surcharges are not included. Any fuel surcharges billed to Petersen from the transporter will be directly passed

FABRICATION - MACHINING - AEROSPACE TOOLING - WAREHOUSING - FIELD SERVICES
1527 NORTH 2000 WEST, OGDEN, UTAH 84404 PHONE: 801-732-2000 - FAX: 801-732-2097



on to the Purchaser.
MATERIAL: Material Prices are good for (15) Days and are subject to prior sale. Lead time, price, and stock availability are subject to confirmation at time of Material Purchase.
LABOR: Valid for 90 days from the date of this proposal.
INSPECTION: This proposal includes quality inspection as required by the Purchaser's RFQ. If no specific quality inspection requirements are included in the RFQ, Petersen Inc. will perform quality inspections as it deems prudent. If Purchaser requests additional, duplicated, 3rd party, or Purchaser supervised inspections, or creates delays and/or increased production/handling costs resulting from inspections beyond RFQ work scope, Petersen is entitled to charge Purchaser for Time and Materials used. Charges will be based on the Petersen Inc. billable rate schedule effective at the time of contract completion.

We propose the above referenced for the lump sum price of: **$53,348,550.00** excluding tax.

Thank you for the confidence you have shown in us and the opportunity to offer our proposal for this project. We look forward to supplying you with the highest quality, on time products in the industry. Please do not hesitate to call if you have any questions or comments regarding this proposal.

Sincerely,

Rodney Rhoades
Senior Estimator

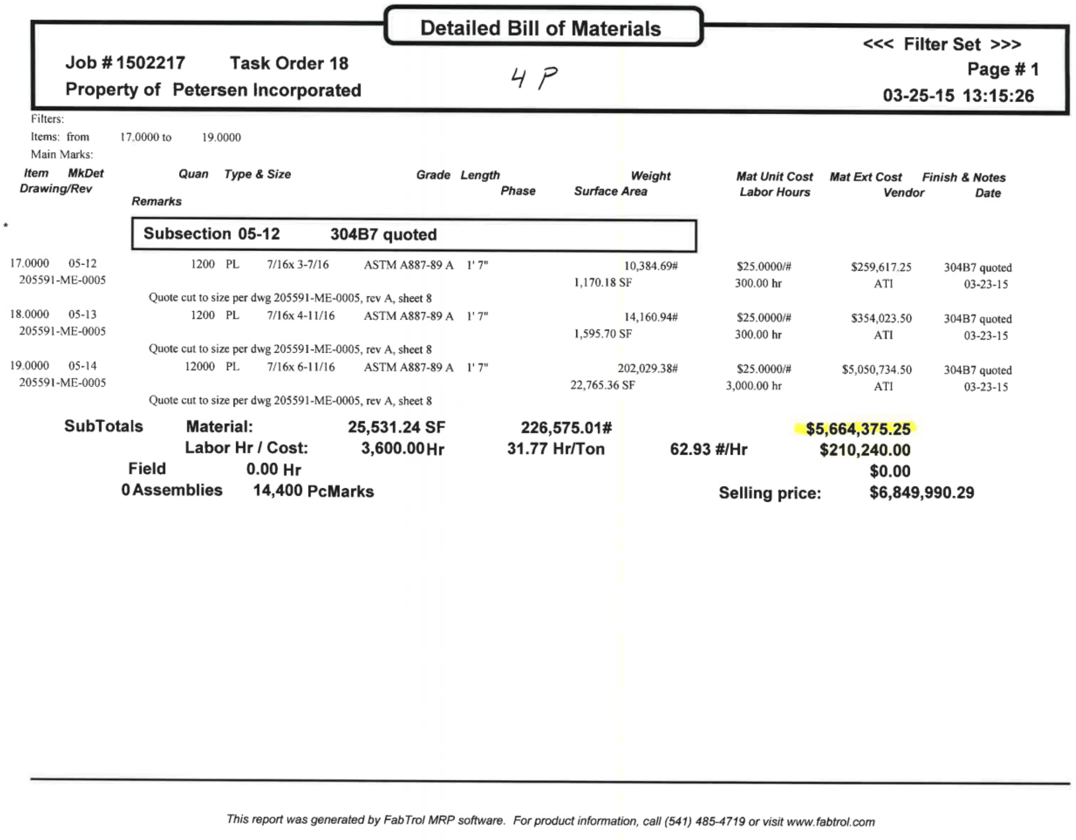
Borated Stainless Steel Materials for the 4-PWR and 9-BWR STAD canisters

The material sheets below (Figures K-1 and K-2), represent the total borated stainless steel (11mm plate) materials for 300 each of the 4-PWR and 9-BWR STAD canisters.

For 300 of the 4-PWR canisters there is $5,664,375.25 in total cost, 25,531.24 square feet of the 11mm plate, 226,575 pounds total weight and 14,400 individual plates. This would equate to 4-PWR unit figures of $18,881.25 in cost, 85.1 square feet, 755.25 pounds per canister, and 48 individual plates per canister.

For 300 of the 9-BWR canisters there is $11,328,750.25 in total cost, 51,062.50 square feet of the 11mm plate, 453,150 pounds total weight, and 28,800 individual plates. This would equate to 9-BWR unit figures of $37,762.50 in cost, 170.2 square feet, 1510.5 pounds per canister, and 96 individual plates per canister.

Please note that the above figures are for delivered plate cut to the drawing flat patterns ready for assembly.



Detailed Bill of Materials

Job # 1502217 **Task Order 18**
Property of Petersen Incorporated

4 P

<<< Filter Set >>>
Page # 1
03-25-15 13:15:26

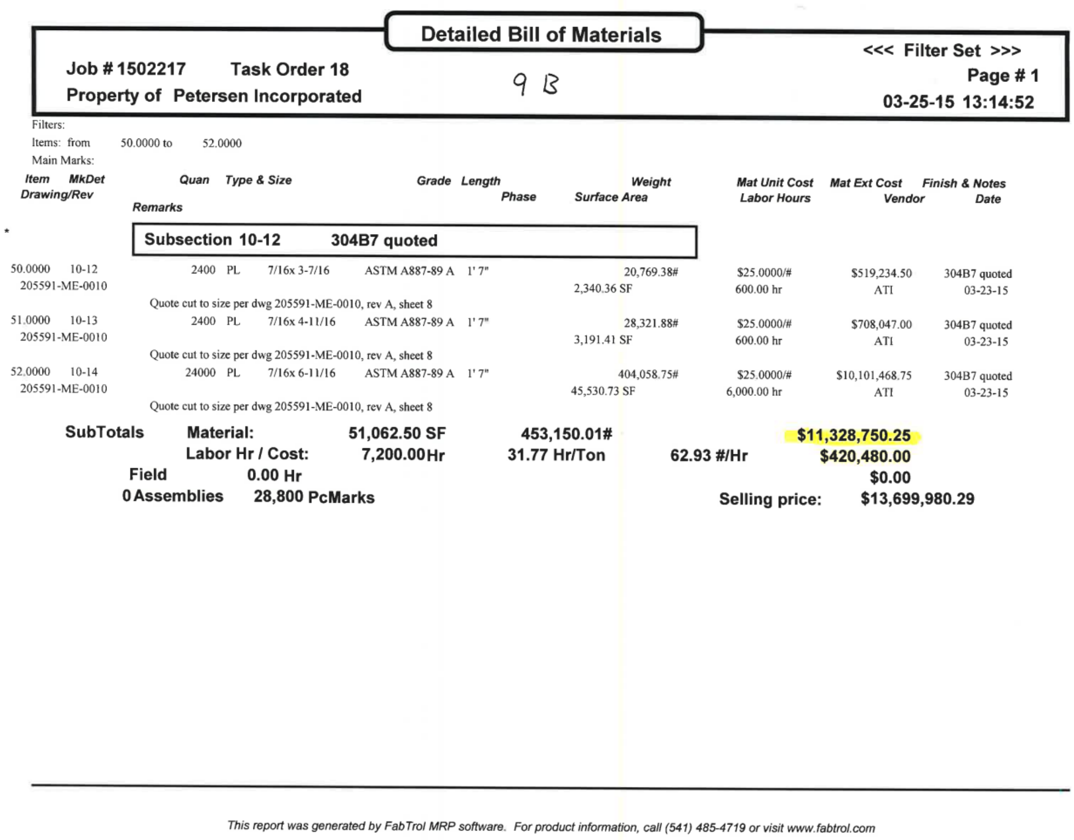
Filters:
Items: from 17.0000 to 19.0000
Main Marks:

Item Drawing/Rev	MkDet	Quan	Type & Size	Grade	Length	Phase	Weight Surface Area	Mat Unit Cost Labor Hours	Mat Ext Cost Vendor	Finish & Notes Date
*		Subsection 05-12	304B7 quoted							
17.0000 205591-ME-0005	05-12	1200	PL 7/16x 3-7/16	ASTM A887-89 A	1' 7"		10,384.69# 1,170.18 SF	$25.0000/# 300.00 hr	$259,617.25 ATI	304B7 quoted 03-23-15
		Quote cut to size per dwg 205591-ME-0005, rev A, sheet 8								
18.0000 205591-ME-0005	05-13	1200	PL 7/16x 4-11/16	ASTM A887-89 A	1' 7"		14,160.94# 1,595.70 SF	$25.0000/# 300.00 hr	$354,023.50 ATI	304B7 quoted 03-23-15
		Quote cut to size per dwg 205591-ME-0005, rev A, sheet 8								
19.0000 205591-ME-0005	05-14	12000	PL 7/16x 6-11/16	ASTM A887-89 A	1' 7"		202,029.38# 22,765.36 SF	$25.0000/# 3,000.00 hr	$5,050,734.50 ATI	304B7 quoted 03-23-15
		Quote cut to size per dwg 205591-ME-0005, rev A, sheet 8								

SubTotals	**Material:**	**25,531.24 SF**	**226,575.01#**		**$5,664,375.25**
	Labor Hr / Cost:	**3,600.00 Hr**	**31.77 Hr/Ton**	**62.93 #/Hr**	**$210,240.00**
Field	**0.00 Hr**				**$0.00**
0 Assemblies	**14,400 PcMarks**			**Selling price:**	**$6,849,990.29**

This report was generated by FabTrol MRP software. For product information, call (541) 485-4719 or visit www.fabtrol.com

Figure K-1. Borated Stainless Steel Material Sheet for 300 off 4-PWR STAD Canisters



Detailed Bill of Materials

Job # 1502217 Task Order 18
Property of Petersen Incorporated

9 B

<<< Filter Set >>>
Page # 1
03-25-15 13:14:52

Filters:
Items: from 50.0000 to 52.0000
Main Marks:

*

Subsection 10-12 304B7 quoted

Item Drawing/Rev	MkDet	Quan	Type & Size	Grade	Length Phase	Weight Surface Area	Mat Unit Cost Labor Hours	Mat Ext Cost Vendor	Finish & Notes Date	Remarks
50.0000 205591-ME-0010	10-12	2400	PL 7/16x 3-7/16	ASTM A887-89 A	1' 7"	20,769.38# 2,340.36 SF	$25.0000/# 600.00 hr	$519,234.50 ATI	304B7 quoted 03-23-15	Quote cut to size per dwg 205591-ME-0010, rev A, sheet 8
51.0000 205591-ME-0010	10-13	2400	PL 7/16x 4-11/16	ASTM A887-89 A	1' 7"	28,321.88# 3,191.41 SF	$25.0000/# 600.00 hr	$708,047.00 ATI	304B7 quoted 03-23-15	Quote cut to size per dwg 205591-ME-0010, rev A, sheet 8
52.0000 205591-ME-0010	10-14	24000	PL 7/16x 6-11/16	ASTM A887-89 A	1' 7"	404,058.75# 45,530.73 SF	$25.0000/# 6,000.00 hr	$10,101,468.75 ATI	304B7 quoted 03-23-15	Quote cut to size per dwg 205591-ME-0010, rev A, sheet 8

SubTotals Material: 51,062.50 SF 453,150.01# $11,328,750.25
Labor Hr / Cost: 7,200.00Hr 31.77 Hr/Ton 62.93 #/Hr $420,480.00
Field 0.00 Hr $0.00
0 Assemblies 28,800 PcMarks Selling price: $13,699,980.29

This report was generated by FabTrol MRP software. For product information, call (541) 485-4719 or visit www.fabtrol.com

Figure K-2. Borated Stainless Steel Material Sheet for 300 off 9-BWR STAD Canisters