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Canister Storage Building Trade Study Final Report

C.E. Swenson

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CANISTER STORAGE BUILDING TRADE STUDY Final Report

Prepared for
Westinghouse Hanford Company

Prepared By
Fluor Daniel, Inc.
Government Services Operating Company
May 1995

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CSB TRADE STUDY

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LIST OF ACRONYMS

B&O	Business and Occupation Tax
CEDE	Committed Effective Dose Equivalent
CFD	Computational Fluid Dynamic
CR	Change Request
CSB	Canister Storage Building
CTEDE	Cumulative Total Effective Dose Equivalent
DBA	Design Basis Accident
DBE	Design Basis Earthquake
DBW	Design Basis Wind
EHW	Extremely Hazardous Waste
EPA	Environmental Protection Agency
ESAAB	Energy System Acquisition Advisory Board
ES&H	Environmental, Safety and Health
F&Rs	Functions and Requirements
FHA	Fire Hazards Analysis
HP	Health Physics
HWVP	Hanford Waste Vitrification Plant
ICE	Independent Cost Estimate
ISFSIs	Independent Spent Fuel Storage Installations
K-D	Key Decision
LANL	Los Alamos National Laboratory
LATA	Los Alamos Tech Associates
MAR	Material At Risk
MCO	Multi-Canister Overpack
MIC	Microbiologically Influenced Corrosion
MOI	Maximum Offsite Individual
NFPA	National Fire Protection Association
NPH	Natural Phenomena Hazards
PC	Performance Category
PGA	Peak Ground Acceleration
PHA	Preliminary Hazards Analysis
PSAR	Preliminary Safety Analysis Report
PSE	Preliminary Safety Evaluation
RAZ	Radiation Access Zone
RCRA	Resource Conservation and Recovery Act
RF	Release Fraction
ROM	Rough Order of Magnitude
RR	Respiration Rate
RWP	Radiation Work Permit
SA	Specific Activity
SAR	Safety Analysis Report
SC	Safety Class
SCT	Shielded Canister Transporter
SNF	Spent Nuclear Fuel
SOP	Step-Off-Pads
SS	Stainless Steel

LIST OF ACRONYMS

SSCs	Structures, Systems and Components
SSF	Staging and Storage Facility
SWP	Special Work Permit
TSD	Treatment, Storage and Disposal
TSR	Technical Safety Requirements
TWRS	Tank Waste Remediation System
WAC	Washington Administrative Code
WBS	Work Breakdown Structure
WHC	Westinghouse Hanford Company

EXECUTIVE SUMMARY

01

EXECUTIVE SUMMARY

This study was performed to evaluate the impact of several technical issues related to the usage of the Canister Storage Building(CSB) of the Hanford Waste Vitrification Plant(HWVP) Project to safely stage and store N-Reactor spent fuel currently located at K-Basin 100KW and 100KE. Each technical issue formed the basis for an individual Trade Study that was used to develop Rough Order Magnitude(ROM) cost and schedule estimates. The study used Concept 2D from the Fluor Daniel prepared "Staging and Storage Facility (SSF) Feasibility Report", dated February 1995, as the basis for development of the individual trade studies.

Concept 2D was a variation of Concepts 2A and 2C presented in the feasibility study. Concept 2D had storage tubes installed in only two of the three vaults, resulting in a total of 440 storage tubes. The storage tubes were fabricated of Corten material. The vaults containing tubes were cooled with 35° F refrigerated air during the staging phase and convective cooling once all the fuel had been stabilized. The MCO characteristics included 880 MCOs with 8 fuel canisters stacked four high per MCO and a temperature of 100° F. Heat generation per MCO was 176 W(Nominal) and 328 W(Limit), based on an 80% Nominal, 5% Limit and 15% below Nominal distribution. The fuel centerline temperature after stabilization was limited to 400° F.

To perform the trade studies WHC requested further modification to Concept 2D, including revising MCO characteristics. Concept 2D was to be adjusted to accommodate 750 MCOs with 10 fuel canisters stacked five high per MCO with a maximum temperature of 100° F. Heat generation per MCO was increased to 221 W(Nominal) and 482 W(Limit), based on an 80% Nominal and 20% Limit distribution. Fluor Daniel was further instructed not to reconfigure the building for 750 MCOs, but to continue on a with 220 storage tube per vault arrangement. To ensure that worst case loads were used for our heat load calculations it was assumed that all 220 tubes per vault were filled with two MCOs each. The fuel centerline temperature remained at 400° F after stabilization.

A re-evaluation of Concept 2D with the modifications indicated is presented in Section 2.0. The results of the re-evaluation found that it is not feasible to adapt the current design of the CSB and comply with the functions and requirements of the SSF. The high heat load per MCO and 80/20 MCO distribution would require 35° F refrigerated air operating in excess of 500,000 CFM to achieve a 105° F MCO temperature, not 100° F as required.

The re-evaluation also highlighted several other technical challenges that would need to be overcome to meet operating and

safety concerns. By increasing the allowable MCO temperature requirement to 100° F, hydrogen gas production due to water in the MCOs will be increased requiring the tubes to be vented and purged more often. The volume of hydrogen gas would be high enough to warrant the purging of nearly 100 tubes per day or roughly 25% of all tubes would require purging daily during the staging phase prior to stabilization. The 100° F MCO temperature would further exacerbate Microbiological Influenced Corrosion (MIC) reducing the fuel storage time and life of the MCO. The radionuclide concentrations are also much higher for the revised MCO requiring significantly thicker shielding, especially for the facility (handling) cask within the CSB, to ensure worker safety. The heavier cask will also increase the crane capacities required to handle the material flow. During conceptual design an investigation into remote handling of the MCOs without a cask might be given consideration. The dose rates and exposure concerns would further complicate use of the empty vault in the future. To protect personnel in the future it may be required to isolate the empty vault with sufficient shielding at the air intake and exhaust plenum, as well as increase the common wall thickness.

The study also included an evaluation of the technical, cost and schedule impacts to Concept 2D due to eight independent Trade Studies. The estimate for Concept 2D was updated to reflect structural and mechanical changes. An allowance was left in the estimate for HVAC equipment with the understanding that a change may occur as a result of the technical feasibility evaluation. In addition, the cost of transport and facility casks and the railroad donkey engine were excluded from the Concept 2D estimate update to more accurately reflect only facility cost. A summary of the cost estimates for each of the Trade Studies in relation to Concept 2D is provided in Table 1. In terms of the construction schedule, it appears that only Task "H" of the Trade Studies, i.e. RCRA Functions: Prevention and Detection of MCO leaks, would have an impact on the proposed construction schedule end date indicated in Section 2.5. It is estimated that RCRA compliance would extend the facility completion date by a minimum of two months. Some intermediate activities may be enhanced by certain other Trade Studies.

1.0 INTRODUCTION

09-1

1.0 INTRODUCTION

1.1 Background

In January 1995 Westinghouse Hanford Company (WHC) commissioned Fluor Daniel to investigate the feasibility of adapting the design of the HWVP Canister Storage Building (CSB) to meet the needs of the WHC Spent Nuclear Fuel Project for a Staging and Storage Facility (SSF) and to develop Rough Order of Magnitude (ROM) cost and schedule estimates. The SSF is to store spent N-Reactor fuel in Multi-Canister Overpacks (MCOs) filled with water until a Stabilization Facility is available to stabilize the fuel. After stabilization of the fuel the MCOs will be returned to the SSF for storage until a geologic repository is available for final disposal. The study investigated two concepts for the SSF which were selected by WHC, 1) the use of water cooling prior to stabilization of the fuel followed by passive dry storage, and 2) the use of refrigerated air cooling prior to stabilization followed by passive dry storage.

The design criteria for the study stipulated that the water temperature in the MCO prior to stabilization is to be limited to 50° F maximum and the fuel centerline temperature after stabilization is to be limited to 400° F maximum.

The study report was completed in late February 1995 and was issued to WHC. The study found that it is feasible to adapt the design and partially completed construction of the CSB to meet the functions and requirements of the SSF using either of the specified concepts.

Under Concept 1, the MCOs are stored in racks in a single layer in an open pool of water with a recirculating water treatment system which returns the water to the pool at 44-45° F. This portion of the SSF utilizes approximately 1/3 of the completed CSB foundation. The balance of the facility, which utilizes the remaining 2/3 of the CSB foundation and the design of the CSB dry storage vaults, is constructed so that it is operational at the same time as the Stabilization Facility. After stabilization, the MCOs are returned to the newly constructed dry storage vaults of the SSF, where they remain in passive dry storage until a geologic repository is available for final disposal.

Two alternatives were evaluated under Concept 1. Alternative 1B provides 512 storage tube locations for dry storage in two vaults and does not require any addition to the CSB foundation footprint. Alternative 1C provides 660 storage tubes and requires the addition of space for another vault to the CSB footprint.

Under Concept 2, the MCOs are stored in two layers in water filled tubes extending into three, below grade, concrete enclosed, shielding vaults cooled by recirculating 35° F refrigerated air. This utilizes the entire foundation and design of the CSB. After stabilization, the storage tubes are drained of water and the MCOs reinstalled. When all the MCOs have been stabilized, the recirculating refrigerated air system is shut down and natural circulation passive air cooling established.

During review of the draft of this report, interest was expressed in other alternatives which were not constrained by the Design Basis. In particular, it was indicated that it was possible that the 50° F MCO temperature limit prior to stabilization could be relaxed. If this temperature were relaxed to about 100°F, it would be possible to store the MCOs in dry Corten storage tubes cooled by refrigerated air. Relaxing the MCO temperature limit prior to stabilization would not have any significant affect on the design or cost of the water cooled alternatives, i.e. Concept 1.

In order to permit evaluation of these other alternatives against those previously studied, ROM cost estimates were developed for the following additional alternatives:

Alternative 2C. This alternative is the same as Alternative 2A (660 storage tubes) except that the storage tubes are not filled with water, allowing Corten to be used, which results in an MCO temperature of about 100° F when cooled with 35° F refrigerated air.

Alternative 2D. This Alternative is the same as Alternative 2C except that storage tubes are installed in only two of the three vaults, resulting in a total of 440 storage tubes. The number of storage tubes in two vaults could be increased to 512 using the same configuration as for Alternative 1B, but the cost of this was not evaluated. The MCO temperature would be about the same as for Alternative 2C (about 100° F).

Alternative 2E. This alternative is the same as Alternative 2A except that storage tubes are installed in only two of the three vaults, resulting in a total of 440 storage tubes. As above, the number of storage tubes in two vaults could be increased to 512. The MCO temperature would be about the same as for Alternative 2A (about 50° F).

1.2 Study Objectives

The objectives of this study were to determine any new facility functions and evaluate the impacts to the cost estimate, risk and safety issues and design/construction

schedule for the Concept 2D, i.e. Alternate 2D for the SSF Feasibility Study. This study will be performed concurrently with the Spent Nuclear Fuels (SNF) CSB conceptual design effort and be used as basis for development of a conceptual design.

1.3 Scope of Work

Using Fluor Daniel Concept 2D (dry stage/dry store/100° F MCO/3 vaults one without tubes/Corten tubes) from the Fluor Daniel SSF Feasibility Study, dated February 1995, perform trade studies and prepare individual reports documenting the results of each investigation in accordance with Statement of Work, Revision 5, dated April 21, 1995, in Attachment 1 of WHC Work Order TVW-SVV-370252, Modification No. 90. Use the same criteria as the SSF Feasibility Study, unless directed otherwise. The trade studies are as follows:

Concept 2D. Adjust for 750 MCOs with 10 canisters stacked 5-high per MCO. Use MCO characteristics defined in Section 3.2.2.1.2.2 of WHC-SNF-FRD-014, "Draft Performance Specification for the Spent Nuclear Fuel Canister Storage Building", Rev. A, dated May 1995. Do not reconfigure the HWVP CSB storage vaults to support only 750 MCOs. Storage tube quantity should remain at 220 tubes per vault for a total tube count of 440 tubes (two vaults). Revise cost and schedule data from the SSF Feasibility Study as appropriate.

- Task A Further investigate the requirements for Safety Class 1 confinement of the operating spaces above the storage tubes. A negative air pressure relative to atmospheric pressure is required. Considerations include, but are not limited to, sealing the building, providing airlocks, and adequate capacity exhaust fans to maintain a negative relative air pressure. Refer to the draft Preliminary Safety Evaluation (PSE).
- Task B Remove the new MCO receipt and staging, i.e. cask/MCO unloading and storage, function and area.
- Task C Remove the cask decontamination, i.e. wash area, function and area.
- Task D Simplify rail service to one track with passing track outside facility.
- Task E Determine the technical feasibility of non-stainless steel water-filled tubes. Recommend material to resist wet corrosion for only 7 years versus 40 years.

- Task F Reduce from 4 to 2 shipments per day. Handling equipment demands should be reduced.
- Task G Evaluate handling and staging MCOs shipped drained, damp dried from K-Basin assuming 10 SNF canisters per MCO. Determine cooling requirements and investigate natural circulation cooling during staging.
- Task H Functions to comply with Resource Conservation and Recovery Act (RCRA) for prevention and detection of MCO and tube leaks.

1.4 Design Basis

The criteria for the trade studies is the same as the SSF Feasibility Study unless noted otherwise. MCO characteristics are defined in Section 3.2.2.1.2.2 of WHC-SNF-FRD-014, "Draft Performance Specification for the Spent Nuclear Fuel Canister Storage Building", Rev. A, dated May 1995. Design Basis requirements are defined in Section 2.8.

2.0 CONCEPT 2D TECHNICAL DESC.

2.0

2.0 CONCEPT 2D TECHNICAL DESCRIPTION

2.1 FACILITY DESCRIPTION

2.1.1 Plot Plans

Figure 2-1 shows the outline of the Concept 2D SSF and an assumed adjacent Stabilization Facility superimposed on a modified Master Site Plan for what was previously the HWVP site within the 200 East Area. The SSF is shown on the location of the existing CSB foundation. Other existing buildings, roads, rail lines and underground utilities in the area are shown in their current locations. New facilities which have been proposed for construction in the area as shown in the Master Site Plan prepared by Fluor Daniel for the Tank Waste Remediation System (TWRS) Site Integration Task Force have been rearranged to be compatible with the Concept 2D layout and location. The Figure shows that location of the SSF on the existing CSB foundation is feasible and provides good access to all required utilities, roads and rail lines. It also shows that location of the SSF in this area is compatible with plans for other facilities which have been proposed for construction in the area.

A more detailed plot plan for Alternative 2D is shown in Figure 2-2. The Stabilization Facility outline shown in Figure 2-2 shows one possible location for the Stabilization Facility relative to the SSF based on a 100'x 100' foot print and is not intended to portray an accurate representation of its size or geometry.

2.1.2 Rail Tunnel/Cask Unloading Area

2.1.2.1 General Description

The Rail Tunnel/Cask Unloading area is a new addition of approximately 10,000 square feet to the original CSB design. It is located in the north west corner of the CSB and interfaces with the MCO Storage Tube Area via a covered water canal as shown in Figure 2-3.

The main functions of this area are to safely receive, handle and prepare the incoming packaged MCO for placement in the storage tubes prior to stabilization. The packaged MCOs are delivered inside a transport cask, via rail car or truck, one at a time. Before being returned to the K-Basins, the transport casks are prepared for handling and loaded with an empty MCO.

In addition to the underwater transfer canal to transfer MCOs to a receiving station within the operating area of the storage facility where they can be retrieved by the bottom loading MCO shield cask for transfer to their storage tubes, the Rail Tunnel/Cask Unloading

SSF FEASIBILITY STUDY
 CONCEPT 2D
 PLOT PLAN

FIGURE 2-2

CADFILE: FIG2-2

CA 5-30-95

SSF FEASIBILITY STUDY
CONCEPT 2D
FLOOR PLAN
FIGURE 2-3

CADFILE: 2DDBASE

CA 5-30-95

Area contains the following:

- (2) rail cars outside the facility
- (2) rail cars in the facility
- (4) transport casks: (2) clean, ready for use, (1) contaminated, waiting for decontamination and (1) in the decontamination pit
- (28) empty new MCOs
- (1) empty new MCO overpack

The Rail Tunnel/Cask Unloading Area includes the Wash Area, the Cask Unloading and Storage Area, the Cask Preparation Pit, the Cask Unloading Pool, MCO Transfer Canal, MCO Transfer Canal Cart and the Cask Loading Pit.

A remotely operated hot cell type facility was considered as an alternative to the Cask Preparation Pit/Cask Unloading Pool/MCO Transfer Canal/Cask Loading Pit, but was expected to be more costly and was therefore not considered further.

2.1.2.2 Wash Area

The Wash Area is a air lock confinement area where the incoming railroad cars and delivery truck/trailer are washed prior entering the Cask Unloading and Storage Area. Two railroad cars, and the donkey engine, and a truck trailer parked in parallel can be accommodated inside. A permanent ceiling installed liquid spray arrangement allows wash/decon of the shipping cask upper section. Hand held wash/decon lances are available for the lower areas. Wash water can be pumped out of one or more sumps into a hold tank for monitoring, before being sent through the non-radioactive drain line to the 200 area.

2.1.2.3 Cask Unloading and Storage Area

The Cask Unloading and Storage Area is designed for unloading and loading transport casks and for handling and storage of empty MCOs. Two railroad cars, one truck trailer, twenty eight MCOs, one MCO overpack and two clean ready to use shipping casks can be accommodated in this area. A cask unloading overhead crane, with an auxiliary hoist, running in the west/east direction services this area. A fifteen foot tall wall partially isolates this area from the Cask Preparation Pit, the Cask Unloading Pool, MCO Transfer Canal and the Cask Loading Pit, but allows the passage of the overhead crane above it.

2.1.2.4 Cask Preparation Pit

The Cask Preparation Pit is dedicated to the preparation of shipping casks for unloading, which consists primarily of unbolting the cask cover. A sleeve, anchored to the bottom of the pit,

receives and restrains the cask. Access working platforms are affixed to the upper interior walls of the pit. The overhead crane is used to handle the cask. The Cask Preparation Pit could also be used for additional cask decontamination or other pre-unloading services if necessary.

2.1.2.5 Cask Unloading Pool/MCO Transfer Canal

The Cask Unloading Pool, adjacent to the Cask Preparation Pit west end, is dedicated to unloading MCOs from their casks, MCO servicing and placing defective MCOs in an overpack. Underwater fixtures are provided to support the cask cover and two MCOs during servicing. Required MCO servicing is performed underwater at this location, using specially designed tools as described in Section 2.1.3. An opening, i.e. MCO Transfer Canal, through the common wall separating the Unloading Pool with the MCO Storage Area Transfer Canal Pool allows underwater transfer of MCO's from one pool to the other. To minimize cross contamination to the MCO Storage Area Transfer Canal Pool, the pool water return flow is directed toward the Unloading Pool. In case contamination is detected in the Unloading Pool a portable gate can be placed in the wall opening to isolate the two pools. When retrieving an empty cask from the pool, the water in the cask is drained above the Unloading Pool using special tools. The overhead crane is used to handle the cask and the portable gate. The auxiliary hoist is used to handle the cask cover, MCO and overpack.

The underwater transfer of the MCO from the Unloading Pool to the Storage Area Transfer Canal Pool is accomplished using the MCO Transfer Canal Cart.

2.1.2.6 Cask Loading Pit

The Cask Loading Pit, similar in construction to the Cask Preparation Pit, is located west of the Cask Unloading Pool and is dedicated to cask preparation for return to the K-basins. With the cover removed, the cask is decontaminated, and an empty MCO is loaded inside the cask. The gap between cask cavity and MCO is filled with deionized water. Finally the cask cover is bolted on and decontaminated if necessary. The now ready to use cask is transferred to a storage position or to an empty railroad car located in the Cask Loading and Storage area.

2.1.3 MCO Servicing

2.1.3.1 Functional Description

After each MCO is received into the SSF for staging, the MCO will be purged with nitrogen, then deionized water will be added if needed to reach the desired level in the MCO. The servicing will be done with the MCO submerged in the Cask Unloading Pool. A pool

water treatment system will maintain pool temperature, clarity, and radioactive contamination at acceptable levels.

2.1.3.2 System Design Requirements

Once all MCOs have been received, only water-filled MCOs will need to be serviced. Based on the water reaction rate with uranium and the evaporation rate at 100 °F, the worst MCO must be serviced at least every 300 days. Since there is no means of determining the water level within an MCO, a conservative schedule must be established to ensure that the top canister in the most active MCO does not become dry. This requires servicing at least 3 MCOs per day, starting within 300 days after placement. For water-filled MCOs, it was assumed that the hydrogen inside each MCO does not constitute a hazard, assuming the MCOs are designed so they will not release gas in the event of a Design Basis Accident (if this assumption is incorrect, then more than 500 MCOs per day must be purged in order to keep hydrogen concentrations below the hazardous level of 6%. The pool water will provide sufficient shielding for operators above the pool to assist in making the necessary piping or hose connections to the MCO using specially designed tools. Water will flow into the servicing area from the MCO Storage Area Transfer Canal Pool, then back to the pool treatment system. The containment and confinement requirements for this area are as defined in ANSI/ANS Standard 57-7. Because of the greater chance for contamination of the pool when MCO valves are opened, the water turnover time in the service area is 36 hr, half that of the ANSI Standard requirement.

2.1.3.3 Design Assumptions

The MCO will be designed so that a grapple can be attached for transporting it underwater without the cask. The MCO will have at least three valved connections that can be remotely connected to piping or hoses, with each valve capable of remote operation (see Figure 2-4). One of the connections will have an interior dip tube which extends a known length below the desired water level (but above any sludge), and another connection will terminate at the top of the MCO, so that a differential pressure sensor in the service area can determine the MCO water level. One of the differential pressure legs will also be used for nitrogen purging, described below. The third valved connection will allow the MCO to be filled while the water level is monitored.

2.1.3.4 Mechanical Design and Operation

The servicing of 4 MCOs per day requires two service stations in the servicing area. Each station is equipped with a gas collection pot, filter, piping, and instruments that must be connected to the MCO for servicing. The station is attached by flexible hoses to fixed piping for nitrogen, water, and vent gas. The basic

components of a station are shown on Figure 2-4. The system equipment list (Table 2-1) indicates the major items needed for the two stations as well as auxiliary equipment that supports the function of the stations.

The cask unloading crane brings the shielding cask with MCO into the Cask Unloading Pool. The cask provides operator shielding until the cask is covered by at least 8 ft of water. After the crane removes the cask lid and places the MCO on an underwater stand for servicing, the operator manually positions the servicing piping assembly onto the MCO, remotely couples the piping to the MCO connections and prepares to operate the MCO valves. The vent gas pressure and contamination level are monitored before the gas is released through a HEPA filter to the operating area building stack. Upstream of the HEPA filter is a shielded gas collection pot which will serve as a radiation monitor source, catch any entrained liquid in the vent gas, and provide capability for gas sampling. After the pressure in the MCO is released, sufficient nitrogen is purged through the MCO to reduce the hydrogen concentration to 1% by volume or less. After purging, the nitrogen flow is reduced in order to measure the level of water in the MCO. Nitrogen is stored in cylinders delivered by truck to a rack outside the building. If needed, deionized water is added by a metering pump through the collection pot in order to flush any contamination back into the MCO. The valves on the MCO are closed after servicing, the service station is disconnected, and the MCO is transported underwater by the MCO Transfer Canal Cart into the MCO Storage Area Transfer Canal Pool.

2.1.4 Cask Unloading Pool Water Treatment System

2.1.4.1 Functional Description

After each MCO is received and passed through the Cask Preparation Pit, the MCO will be placed in the Cask Unloading Pool. The pool water provides shielding and cooling for the worst case. The pool water treatment system will maintain pool temperature, clarity, and radioactive contamination at acceptable levels. Although no leakage is expected from MCOs or system components, the pool and its water treatment system are designed to minimize radiation exposure in the event of leakage due to a credible accident.

2.1.4.2 System Design Requirements

The nominal value of heat generation per MCO is 221 W and the maximum value is 482 W. At 100 °F the maximum MCO produces near 40 L/day of hydrogen gas contaminated with 4.62 mCi/L of Kr-85. The nominal values apply to 80% of the MCOs, the upper limits apply to 20%. There are no particulates or condensible vapors generated during non-accident conditions. The total system cooling duty is based on the maximum MCO.

FIGURE 2-4
MCO SERVICE STATION
CONCEPT 2D

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WHC P.O. TVW-SVV-370252

Fluor Daniel, Inc.
Government Services
Contract 04436306

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TABLE 2-1

EQUIPMENT LIST
STAGING AND STORAGE FACILITY
SSF
(CONCEPT 2D)

EQUIPMENT DESCRIPTION	EQUIPMENT ID	CAPACITY/FLOW RATE	PHYSICAL SIZE (DIA X H)	MATERIAL	POWER	HEAT LOAD	COMMENT
<u>MCO SERVICING SYSTEM</u>							
NITROGEN CYLINDER RACK	R-1	40 SCF/DAY	FOUR 9" OD X 5' H CYLINDERS	STEEL			
DECON SOLUTION TANKS	V-1A/B/C/D	ATMOS. PRESS.	FOR 3' OD X 4' H	SS			
DECON PUMPS	P-1A/B	0.1 GPM, 150 PSIG	1' OD X 1'4"	SS	1.00	HP	
DECON SPRAY WATER HEATERS	H-1A/B	0.1 GPM	1' OD X 1'4"	STEEL	0.20	kW	
DIONIZED WATER TANK	V-2	ATMOS. PRESS.	3' OD X 8' H	SS			
MCO FILL PUMPS	P-2A/B	1 GPM, 10 PSIG	1' OD X 1'4"	SS	1.00	HP	
MCO PURGE COLLECTION POTS	V-3A/B	150 PSIG	12" OD X 1'4"	SS			
BETA/GAMMA PROCESS MONITORS	CAM-1A/B						
MCO VENT HEPA FILTERS	F-1A/B	10 CFM, 1M	3" OD X 3'4"	SS BODY			NUCLEAR GRADE CARTRIDGE FILTER

The pool is lined with stainless steel to ensure water purity, to prevent water migration through the concrete pool structure, and to allow decontamination at the end of the facility life. As recommended by DOE Order 6430.1A, Section 1320, the liner has a leak detection system with a collection sump in the concrete structure.

The water treatment system returns water which has been purified and cooled to 95 °F. This will maintain the MCO at 100 °F or less under normal conditions. The system has sufficient redundancy (or else contingency back-up capability within the available response time) so that a single failure of any active component (such as a pump, filter, or control) will not cause loss of system function. The following requirements of ANSI/ANS 57.7 and NRC Reg Guide 3.49 are met: Clarity will be sufficient to clearly see to the bottom of the pool. Contamination will be maintained at an annual average gross activity level of 5×10^{-4} mCi/L or less during normal operation. The recirculation rate is sufficient to turnover the pool volume in 36 hours and the deionization units will not be regenerated. The piping is designed so that water will not siphon out of the pool in the event of a piping leak. Because of the small size of the units, the resin beds are replaced when they become saturated.

The system will maintain a safe condition after loss of normal power, loss of cooling, and Design Basis Accidents such as earthquake; in these cases, credit will be taken for portable equipment that can be moved in during the period of time before temperatures, hydrogen concentration, or contamination levels exceed safe levels. The clean-up system will have the capacity for the worst-credible release of contamination into the pool.

2.1.4.3 Design Assumptions

The MCO will be designed so that a grapple can be attached for transporting it underwater without the cask. The laboratory required for periodic analysis of pool water samples is not part of this facility. Fresh make-up to the deionizer will come from the site sanitary water, containing 95.1 ppm dissolved solids, less than 10 ppm suspended solids, pH 7.80, and CaCO₃ hardness of 73.46 ppm.

2.1.4.4 Mechanical Design and Operation

Figure 2-3 shows the arrangement of the Cask Unloading Pool and associated areas. MCOs are transported to and from the cask unloading pool by the MCO Transfer Cart. The depth of water above the MCO Transfer Cart allows the MCO being transported to be covered by 8 ft of water at all times.

Refer to Figure 2-5, the block diagram for pool water treatment and cooling. The pool water treatment system consists of pool skimmers and flow distribution piping, recirculation pumps, high-efficiency filters, filter backwash equipment, deionization units, deionization unit replacement, waste slurry holding, waste water holding, water chillers, and water sterilizers.

Table 2-2 lists the major equipment for the pool water treatment system. The skimmers remove floating debris from the cask unloading pool. Inlet and outlet piping for the pool is designed to provide distribution of flow through the pool with minimum pressure loss. One operating pump and one spare provide a 36 hr turnover of the pool volume during normal operation. If contamination in the pool becomes abnormally high, both pumps can be operated to increase the recirculation rate. The filters are nuclear-grade filters with a particle capture size of one micron. Compressed air at 300 psig will be produced to improve backwashing and to supply the facility instrument air system. Stainless steel material was chosen for the compressed air to avoid getting pipe scale particles on the clean side of the filters during backwash. The deionization unit is a duplex package of two trains, so that one train can remain in operation while the other is out of service. Each train removes both anions and cations (positively and negatively charged ions) from the water in resin beds. If contamination in the pool becomes abnormally high, both trains can be temporarily operated in parallel to increase the recirculation rate. The design of the filters and deionizers for accident conditions is discussed in section 2.2.3.3. Normally, deionization resin replacement is required less than once per year.

Pool water treatment system drainage will go to the waste water hold tank to be neutralized and monitored before being picked up by a truck with a pump. Pool water filtrate slurry will go to the contaminated waste slurry hold tank to be monitored before being pressurized into a shielded container on a truck, using compressed air. Fresh resin can be exchanged into the deionization units from the shielded room containing the units. Separate curbed areas are provided for truck loading and unloading at the tanks for waste water and contaminated waste slurry.

Each chiller is sized for the maximum heat input from the MCO, heat gains from the surroundings, and the dissipated energy from the 10 hp recirculating pump. A 100% spare chiller and heat exchanger is provided, although interruptions in cooling can be tolerated. In the event of loss of cooling, the pool requires over 165 hours to warm up 10 °F. However, recovery from an overheated condition requires some spare cooling capacity. The pool water sterilizers, along with chemical addition, inhibit biological growth which would cloud the water. The glass in the ultraviolet sterilizers will require regular cleaning. The equipment used to detect excessive

FIGURE 2-5

PROCESS BLOCK FLOW DIAGRAM
CASK UNLOADING POOL
WATER TREATMENT

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TABLE 2-2

EQUIPMENT LIST
STAGING AND STORAGE FACILITY
SSF
(CONCEPT 2D)

EQUIPMENT DESCRIPTION	EQUIPMENT ID	CAPACITY/FLOW RATE	PHYSICAL SIZE (DIA X H)	MATERIAL	POWER	HEAT LOAD	COMMENT
<u>POOL WATER TREATMENT SYSTEM</u>							
RECIRCULATION PUMPS	P-3A/B	30 GPM, 300 PSIG	2" SUCTION	SS	10.00 HP		ONE SPARE
PRIMARY POOL FILTERS	F-2A/B	30 GPM, 50 PSIG		SS			
DEIONIZATION UNIT	R-1A/B	30 GPM, NET	FOUR TANKS 18' OD X 6' H	SS			
WASTE SLURRY HOLD TANK	V-4	25 PSIG	3' OD X 6' H	SS			
WASTE WATER HOLD TANK	V-5	15 PSIG	3' OD X 6' H	SS			
POOL WATER CHILLERS	CH-1A/B	2,200 BTU/HR (0.18 TONS) NET		STEEL	60.00 HP		ONE SPARE
POOL WATER EXCHANGERS	E-1A/B	600 BTU/HR		STEEL & SS			
POOL WATER STERILIZERS	UV-1A/B	30 GPM		GLASS & SS			
<u>INSTRUMENT AIR SYSTEM</u>							
AIR COMPRESSOR	C-1A/B	100 SCFM, 300 PSIG		STEEL			ONE SPARE
INSTRUMENT AIR DRYER	DY-1	100 SCFM, NET					DUPLEX
INSTRUMENT AIR RECEIVER	V-1	300 PSIG	8' OD X 8' H	STEEL			

contamination in the pool and locate a leaking MCO is discussed in Section 2.2.3.3.

2.1.5 MCO Cooling and HVAC

2.1.5.1 HVAC Systems for Normal Operation

Vault Refrigerated Air System. The block flow diagram for the HVAC system serving the SSF Vaults during staging is shown on Figure 2-6. The HVAC system is a recirculating refrigerated air system consisting of five 50,000 CFM Air Handling Units (4-operating and 1-standby) which supply chilled air at 35 °F to the vault. This supply air temperature to the vault will maintain the MCOs at 111 °F. The 111 °F does not comply with current MCO temperature (100 °F) requirements, but is used as the basis for the ROM cost estimate. Since the MCO's are stored in dry air filled Corten tubes which serve as a secondary confinement barrier, the air inside the vault will not be contaminated.

Vault Passive Ventilation System. The passive ventilation system for the vault during dry storage will be identical to the CSB design. This concept has two vaults, each with 220 tubes. There are provisions for 11 overpacks and the tube spacing for this concept will be identical to the CSB design. A third vault is provided as in the original CSB design, however, no tubes will be installed.

Operating Area HVAC System. The Operating Area HVAC System for the CSB design will be modified to accommodate the ventilation system for the MCO service area and the MCO/Cask unloading and storage area. The system is capable of diluting the hydrogen and krypton-85 to acceptable levels by introducing sufficient amounts of outside air. The block flow diagram for this system is depicted in Figure 2-7).

Pool Water Treatment Building. This building consists of clean areas and potentially contaminated areas. A single HVAC system will be used to serve these areas.

The block flow diagram for the HVAC system serving these areas is shown on Figure 2-8. Redundant 2,000 CFM Air Handling Units (AHU-1 and AHU-2) with evaporative cooler and heating coil supply air to these areas and the air is exhausted through redundant HEPA filter plenums (PF-1 and PF-2) and exhaust fans (EF-1 and EF-2).

2.1.5.2 HVAC Systems for Abnormal Operation

Vault Refrigerated Air System. It has been estimated that on failure of the vault refrigerated air system used during staging, the MCO temperature will increase by 30 °F in approximately 20 hours. Concept 2D is currently not a safety class system.

FIGURE 2-6

SSF FEASIBILITY STUDY
CONCEPT 2D
VAULT - HVAC SYSTEM

FIGURE: 2-7

SSF FEASIBILITY STUDY
CONCEPT 2D
OPERATING AREA
HVAC SYSTEM

FIGURE 2 - 8

SSF FEASIBILITY STUDY
CONCEPT 2D
POOL WATER TREATMENT BUILDING
HVAC SYSTEM

FIGURE 2 - 9

SSF FEASIBILITY STUDY
CONCEPT 2D
OPERATING AREA
HVAC EMERGENCY VENTILATION SYSTEM

Adequate time would mostly likely not be available in the event of a sustained loss of refrigerated air cooling to bring in mobile emergency cooling capability before MCO temperatures became excessive.

Vault Passive Ventilation System. The vault passive ventilation system used during dry storage is designed to operate following all DBA's. No other HVAC systems are required for operation of the vaults during abnormal operation.

Operating Area. The block flow diagram for the HVAC system for emergency ventilation of the Operating Area is shown on Figure 2-9). This system is designed to be activated following an accident (potential drop of an MCO and release of contamination to the operating area) and is interlocked to stop the normally operating HVAC system. The HVAC system consists of two trains with HEPA filter plenums (PF-1 and PF-2) and exhaust fans (EF-1 and EF-2).

2.1.6 Structural

The CSB below grade concrete vaults and the operating floor will essentially remain the same as originally designed. Vaults 1 and 2 will be used for the staging and storage of the MCOs containing SNF, and vault 3 will remain empty for future storage of undefined material. The existing 3 feet east-west wall between vaults 2 & 3 must be increased to 42" to provide adequate shielding protection to persons entering the vault 3 for activation at a later date. Preliminary HVAC calculations indicate that the concrete surface temperature inside the vaults during staging and support phases will not exceed 150°F. Therefore, the insulating concrete may be deleted from the original design. Also the 1 inch metallic traffic topping over the concrete operating floor will be replaced with a less expensive concrete sealer / hardener since the MCOs are to be handled by crane and not by shielded transporters. The structural consequence of dropping the facility cask containing MCO from a 3 foot height on the operating floor will require further evaluation including a crane with features to prevent a drop. The storage tubes will be of Corten material similar to those designed for the CSB.

The existing design of the steel shelter over the operating floor will be modified to include crane rails and girders for the overhead crane for the cask/MCO handling system. This building height will be increased by approximately 12 feet and the currently designed steel columns and portion of roof trusses members will be replaced with stronger sections. The north wall of the operating building may require relocation north by approximately 8'-0" to accommodate crane operation. The Cask/MCO Unloading and Storage Area Building is approximately 170 feet long, 61 feet wide, and 33 ft high. This building will have an overhead crane for unloading

and loading of casks and MCOs. Within this building is below grade cask unloading and MCO transfer pool. The concrete pit floor and walls will be lined with 1/4 inch and 3/16 inch stainless steel plate respectively, complete with leak detection system. The Wash Area Building is approximately 64 feet long, 50 feet wide and 27 feet high. These buildings will be constructed of structural steel framing enclosed by insulated metal siding and metal roof deck.

The Pool Water Treatment & Instrument Air Compressor Building is approximately 35 by 30 by 17 feet high steel structure. The Equipment /Office/Generator Area Building will be a steel frame building and similar in construction to the existing CSB equipment/office area building except, the size will be approximately 100 by 33 by 17 feet high. The Refrigerated Air Mechanical Area Building is approximately 120 by 40 by 20 feet high steel framed structure enclosed by insulated metal siding and metal roof deck.

An HVAC duct, approximately 10 ft by 5 ft in size will be added connecting the exhaust stack and the Refrigerated Air Mechanical Area. This duct will be supported by the operating shelter. Refrigerated air will be returned to the air inlet ducts via ducts from the Refrigerated Air Mechanical Area. Removable blinds in the air inlet ducts and exhaust stack will isolate the refrigerated air system from the environment. The inlet air temperature to the vault will be about 35°F during the staging phase.

The preliminary safety classification of the SSCs for the staging and storage phases is defined in Tables 2-9 and 2-10 respectively.

2.1.7 Material Flow

2.1.7.1 General Description

The Material Flow includes two distinct phases: the Staging Material Flow and the Storage Material Flow which takes place only after completion of the Stabilization Facility.

2.1.7.2 Staging Material Flow

The Staging Material Flow involves tasks and sequences necessary to place packaged MCOs, received from the K-Basins, into forced air cooled storage tubes in the Storage Tube Area, prior to stabilization.

The Staging Material Flow begins with a packaged MCO in a cask, on top of a rail road car or truck parked outside the Rail Tunnel/Cask Unloading Area. It terminates at the removal, from the facility, of a decontaminated cask loaded with an empty, ready to use, MCO.

Figures 2-10 through 2-13 depict the tasks, sequences, equipment and estimated time required to perform the tasks.

It is assumed that placement of the bottom impact absorbers inside the storage tubes is performed during the completion of construction. The upper impact absorbers are assumed to be installed in a campaign style manner during a down time period.

2.1.7.3 Storage Material Flow

The storage material flow involves tasks and sequences for storing stabilized MCOs inside dry, passively cooled storage tubes. These tubes being the same used for the prior staging phase. This phase will occur only after the Stabilization Facility has been made operative.

The Storage Material Flow begins with the removal of an MCO from a storage tube and its transfer to the Stabilization Facility. It terminates with closure of a dry storage tube after loading a stabilized MCO in it. If required, MCOs can be retrieved and sent to the Stabilization Facility for overpacking by reversing the sequences order. Figures 2-14 and 2-15 depict the tasks, sequences, equipment and estimated time required to perform the tasks.

It is assumed that removal and replacement of the upper impact absorbers inside the storage tubes is performed outside the MCO handling time frame. The bottom impact absorbers remain in place and do not require handling. The upper impact absorbers are assumed to be removed and reinstalled in a campaign style manner, during a down time period.

2.1.7.4 Overhead Crane Design and Operation

For loading MCOs into the storage tubes in the SSF dry staging/storage vaults an overhead crane with associated casks and fixtures will be used. The overhead crane system is similar to methods used in Europe and at the Fort St. Vrain Fuel Storage Facility. Other methods for loading the storage tubes are possible, i.e. a Shielded Canister Transporter (SCT) as was designed for HWVP/CSB, but were deemed less attractive for this application.

The size and weight of the MCO will have an affect on the handling equipment and overall capital and operating cost of the system adopted. Two different size MCOs were considered in this evaluation:

- 1) A 10 canister MCO, 181 inches long, weighing 11,600 lbs.
- 2) A 10 canister MCO, 181 inches long, weighing 13,100 lbs.

FIGURE 2-10
CONCEPT 2D

SHIPPING CASKS & MCOs

FIGURE 2-11
CONCEPT 2D
STAGING MATERIAL TIME STUDY
IN CASK UNLOADING & STORAGE AREA

CADFILE: FIG2-11

FIGURE 2-12
CONCEPT 2D

STAGING MATERIAL FLOW DIAGRAM, IN STORAGE

CADFILE: FIG2-13

FIGURE 2-14
CONCEPT 2D

STORING MATERIAL FLOW DIAGRAM: TO AND FROM FUTURE STABILIZATION FACILITY

The equipment required for the transfer systems associated with each of the above MCOs is described in Tables 2-3 and 2-4. Figure 2-16 describes the possible operation of this equipment. Cask weights were based on the requirements defined in Section 2.8, Design Basis, Section 3.2.2.1.2.2 of WHC-SNF-FWD-014, "Draft Performance Specification for the Spent Nuclear Fuel Canister Storage Building", Rev. A, dated May 1995. Crane capacities were estimated based on the heaviest loads to be lifted including the weight of the cask based on shielding requirements defined in Section 2.2.5.7, and the safety margins required for critical lifts at Hanford. The SSF crane capacity was based on a safety margin of 125% of the heaviest lift anticipated.

The MCO shield cask is a bottom loading cask that incorporates an MCO grapple and hoist assembly. It would be positioned above a shield gate located above a selected SSF storage tube. The storage tube shield plug is handled (removed and installed) using a handling flask. This system is similar to that employed at the Fort St. Vrain fuel storage facility and at several locations in Europe. The MCO Transfer Canal will be the point of entry for the MCO for the overhead crane/cask method. This station would require a floor plug shield gate.

The overhead cask/crane method will require a means to transport the MCO to the Stabilization Plant. If the Stabilization Plant is close coupled to the dry storage facility an unshielded transfer cart operating in a below grade tunnel can be used to make the transfer similar to in Figure 2-16. If the Stabilization Plant is at a distant location, a top-loading shipping cask can be used.

The overhead cask/crane will require four basic components to load the canisters into the SSF storage tubes.

- 1) The bottom loading MCO shield cask
- 2) The floor plug shield gate
- 3) The portable shielded floor plug handling flask
- 4) The 120T overhead bridge crane with 10T auxiliary hoist

The bottom loading MCO shield cask will contain an integral hoist and grapple system to handle the MCO. It will incorporate a shield gate at the bottom and a ventilation system to control the atmosphere within the storage tube during MCO transfer.

The floor plug shield gate is used to seal and shield the storage tube when the tube's shield plug is removed. The gate is located over the desired storage tube using the overhead bridge crane. The portable shielded floor plug handling flask is then mated with the top of the shield gate. A grapple within the flask is used to lift the plug thru the open shield gate. The gate is then closed and the flask containing the plug removed. The storage tube is now ready for installation of the MCO.

CSB Trade Study
 Westinghouse Hanford Company
 WHC P.O. TVW-SVV-370252

Fluor Daniel, Inc.
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 Contract 04436306

TABLE 2-3, 10 CANISTER MCO TRANSFER SYSTEMS
 MCO SIZE AND WEIGHT
 181 IN. LONG
 11,600#

	Stabilization Facility	Transfer to SSP Dry Storage Vaults	SSP Dry Storage
OVERHEAD CASK/CRANE SYSTEM SEE FIGURE 2-16	<ul style="list-style-type: none"> • Shielded MCO loading station • Powered transporter 	<ul style="list-style-type: none"> • Shielded transfer tunnel 	<ul style="list-style-type: none"> • Deck mounted shielded plug/valve access to transfer tunnel • Overhead crane (120T) • Floor plug shield gate • MCO/shield cask (bottom loading) (85T) • Floor plug handling flask • Deck mounted shielded plug access to storage tubes

TABLE 2-4, 10 CANISTER MCO TRANSFER SYSTEMS
MCO SIZE AND WEIGHT
181 IN. LONG
13,100#

	Stabilization Facility	Transfer to SSP Dry Storage Vaults	SSP Dry Storage
OVERHEAD CASK/CRANE SYSTEM SEE FIGURE 2-16	<ul style="list-style-type: none"> Shielded MCO loading station Powered transporter 	<ul style="list-style-type: none"> Shielded transfer tunnel 	<ul style="list-style-type: none"> Deck mounted shielded plug/ valve access to transfer tunnel Overhead crane (120T) Floor plug shield gate MCO/shield cask (bottom loading) (93T) Floor plug handling flask Deck mounted shielded plug access to storage tubes

FIGURE 2-16
OVERHEAD CASK/CRANE PICKUP AND DELIVERY

CADFILE: FIG2-16

The MCO contained within the MCO storage tube loading cask is next positioned on top of the shield gate using the overhead bridge crane. The floor gate and the MCO cask bottom gate are next opened and the MCO lowered into the storage tube. Upon reaching bottom, the MCO cask grapple is disengaged and raised back into the MCO cask. The gates are closed and the MCO cask removed from the storage tube. Finally, the storage tube floor plug is re-installed, and the floor gate removed and installed over the next storage tube to be loaded.

2.2 FEASIBILITY ISSUES

2.2.1 Structural

The SSF Feasibility Study final report dated February 1995 (Reference FDI transmittal No. FRT-2604) had enumerated on two structural issues: (a) seismic criteria change; (b) existing CSB configuration/design adaption. With respect to the seismic criteria WHC has confirmed that the basis for design will be Hanford Plant Standard SDC 4.1, Revision 12 as specified in the Draft Performance Specification document WHC-SNF-FRD-014. The design and evaluation of the SSCs will be based on UCRL 15910 as Hanford site has not implemented the replacement document DOE-STD-1020-94. The CSB had been designed to 0.35g PGA and there should be little impact to the concrete vault design for adaption to SNF SSF. The operating floor shelter will have to be redesigned for the 12 feet increase in height and addition of bridge crane lead.

Further, the document "Implementation Strategies for U.S. DOE Order 5480.28 Natural Phenomena Hazards Mitigation" by Tom Conrads of WHC, has correlated WHC safety class 1 (high hazard) as equal to performance category (PC) 3 of DOE Order 5480.28. For PC-3 the earthquake return period is 2000 years in DOE-STD-1020, whereas in UCRL 15910 the return period is 5000 years for high hazard (WHC SC-1) usage. From Figure 5-1b of Geomatrix Consultants report "Probabilistic Seismic Hazard Analysis" (Project No. 2169, May 1993), the PGA for 2000 year return is 0.19g and for 5000 year return is 0.28g. These values when multiplied by 1.25 scale factor, as given in DOE-STD-1020, will give design PGA of 0.24g for PC-3 and 0.35g for UCRL high hazard usage facility. Therefore, DOE-STD-1020 PC-3 level earthquake forces are much less than UCRL 15910 high hazard class provided the correlation of PC-3 with WHC SC-1as stated by Mr. Conrads is correct.

The MCO/Cask drop over the operating floor during crane handling will require further evaluation including a crane with features to prevent a drop. Also as-built drawings of the partially constructed CSB need to be developed prior to start of detailed design. Field inspection of the existing construction by an experienced structural engineer is recommended to evaluate any sign

of rebar corrosion that may have initiated since the stop of work in 1992. An optional Gantry crane handling of the MCO/Cask over the vault area should be investigated during conceptual design.

The performance specification WHC-SNF-FRD-014 requires the SC-1 structures design life as 200 years. This new requirement will require further investigation of the concrete degradation due to various factors such as temperature, wet-dry exposure, reactive chemicals in aggregates, sulfates in soil, etc.

2.2.2 Thermal/HVAC

This section documents the results of a series of thermal analyses that were performed to assess the feasibility of meeting the Multi-Canister Overpack (MCO) temperature requirements during wet and dry storage with the Concept 2D Staging and Storage Facility (SSF). These analyses were performed for forced refrigerated air and passive ventilation systems.

The thermal feasibility analyses is based on storage of MCO's in dry air filled tubes in vaults 1 and 2 with a forced refrigeration air cooling of the tubes during staging. MCO's are removed and returned to the tubes after stabilization. After all fuel is stabilized, the passive air ventilation system is made operational. Vault 3 will contain no storage tubes.

2.2.2.1 Design Basis Assumptions

The following design basis assumptions were used for the thermal analyses:

- The heat generation rate was based on a total 880 MCO's. Twenty(20) percent are assumed to be at the upper limit (maximum) (482 W) and the remaining 80% are assumed to be at the nominal (average) value (221 W). Due to the preliminary nature of the heat transfer calculations a ten percent safety factor was used for the heat generation rate. Additional heat loads were added for building heat gains and fan heat.
- The heat generation for the limiting case (482 W) per MCO was used for the calculating the MCO's temperature assuming that it is located at the end of the vault.
- The design basis required storage conditions are as follows:
Staging: The MCO temperature at 100 °F.
Storage: Maximum fuel centerline temperature at 400 °F.
- During the staging operation the MCO provides primary confinement and the dry air filled storage tubes provide the

secondary confinement. It is assumed that the interior of the storage tubes are isolated from the vault, which would prevent the vault from getting contaminated.

- The total flow is assumed to be evenly and uniformly distributed around each of the containment tubes. This is a critical assumption that must be assured by design and verified by additional analyses using Computational Fluid Dynamic (CFD) techniques.
- The heat transfer coefficients for air were calculated at the point of maximum vault air temperature.
- One dimensional (radial) heat transfer only. Two-dimensional (radial and axial) heat transfer was not modeled.
- Heat transfer by radiation between the tubes was not considered.

2.2.2.2 Summary of Results:

The results of the thermal analyses during staging are shown in Table 2-5 and involve various combinations of MCO's surrounded by air in tubes for different ventilation flow rates. The analyses were performed for 35 °F and 50 °F supply air.

The results indicate that it is not feasible to maintain the MCO temperature at 100 °F with a refrigerated forced air ventilation system. This system would require 200,000 to 500,000 CFM at a supply air temperature of 35 °F based on the above heat generation rate to maintain the MCO temperature between 105 °F and 111 °F. The temperature of 35 °F was selected to prevent freezing of MCO's having very low heat generation. The MCO temperature is calculated on the basis that the MCO is located at the end of the vault with the limiting heat load.

The results of the thermal analyses during storage operation with the existing CSB design concept, assuming the same intake structure, vault size and exhaust stack (height and diameter) indicate that an MCO fuel centerline temperature of 270 °F can be maintained by a passive ventilation system. This is based on an inlet air temperature of 115 °F (same design basis as CSB) and a ventilation flow rate of 53,000 CFM. The vault air temperature distribution and velocity profile for a fully loaded vault during passive ventilation are shown in Figures 2-17 and 2-18.

The above results demonstrate that it is not feasible to use the refrigerated air system to maintain the MCO temperature below 100 °F during the staging operation. However, the passive

TABLE - 2-5

CONCEPT 2D

THERMAL ANALYSIS - SUMMARY

MCO TEMPERATURE FOR		SUPPLY AIR QUANTITY (CFM)
Supply air = 35 F (F)	Supply air = 50 F (F)	
213	232	10,000
159	176	20,000
142	158	30,000
133	149	40,000
128	144	50,000
125	140	60,000
122	138	70,000
120	136	80,000
119	134	90,000
117	133	100,000
116	132	110,000
115	130	130,000
114	129	140,000
113	128	160,000
112	127	180,000
111	126	200,000
110	125	230,000
109	124	260,000
108	123	300,000
107	122	350,000
106	121	400,000
105	120	500,000

FIGURE 2-17

PASSIVE COOLING VAULT TEMPERATURE
PROFILE CONCEPT 2D

FIGURE 2-18
PASSIVE COOLING VELOCITY PROFILE,
CONCEPT 2D

ventilation systems can maintain the MCO temperature below the 400 °F limit during the storage operation.

It must be emphasized that these are rough conservative feasibility analyses using limited design information and do not cover all limiting or upset conditions. More detailed analyses are required using CFD techniques to cover all limiting and upset conditions and to verify some basic assumptions. Also no analysis was performed for MCO's stored in an overpack.

2.2.3 Contamination Control

2.2.3.1 Introduction

The potential hazards are from gas normally generated by the MCOs before stabilization and from the unlikely failure of an MCO to contain the spent fuel. The feasibility concern is whether the MCOs can be cooled and vented while maintaining acceptable confinement/containment.

The unstabilized MCOs normally generate decay heat and hydrogen gas. The gas is contaminated and the rate of gas generation roughly doubles for every 10°C (18 °F). The gas must be released from the MCOs without creating a fire or explosion hazard and without exceeding acceptable levels of contamination in occupied areas. The MCOs must be cooled to reduce the rate of gas generation and to prevent the MCOs from drying out. If the water contained in the unstabilized MCOs evaporates and uranium metal or uranium hydride from the fuel is exposed to air, there is a hazard of pyrophoric reaction. This intense reaction could melt the MCO shell, causing the release of fine particles of oxidized fuel containing radionuclides.

The remainder of this section discusses confinement and containment issues during normal MCO venting or accident conditions during staging and storage.

2.2.3.2 Normal Operation

MCO Servicing. The MCOs require servicing after receipt from the K-Basins prior to staging: After each MCO is received into the SSF, the MCO is purged with nitrogen and deionized water is added if needed to reach the desired level in the MCO. The services can be done with the MCO submerged in the Cask Unloading Pool. The pool temperature, clarity, and radioactive contamination must be maintained at acceptable levels; also, the level of contamination above the pool must be acceptable for controlled occupancy. The issues concerning gas and liquid releases from the MCO while submerged are discussed in Section 2.2.3.1. The design includes the normal building ventilation system for dilution of hydrogen and

krypton-85, and an MCO servicing system that vents MCO gas to a stack and prevents overfilling of MCOs.

Closed Tube Staging. During abnormal operation, i.e. when the floor plug is removed, gas vented from the MCOs rises through the storage tube to reach the operating area, which is normally ventilated with enough fresh air (over 10,000 cfm) to dilute the hydrogen and krypton-85 to acceptable levels. However, since the storage tube is normally an enclosed space in which hydrogen could accumulate, provisions must be made to ensure that explosive concentrations do not develop. The following paragraph describes one concept for achieving this objective.

Each storage tube has a sealed floor plug with an embedded vent line and two test lines. The test lines have normally-closed valves and the vent line contains a HEPA filter. The tubes as originally designed can contain a pressure of almost 5 psig before the plug lifts from its sealed seat; the tube wall and bellows were designed for higher pressures. It would be simple to add a relief device to each vent line so that the vent would only be used if the pressure in the tube were to rise to about 4 psig. With a local pressure indicator added to each tube plug, pressures could be monitored and a portable cart used to sample and purge each tube with nitrogen. The cart would consist of a nitrogen cylinder on wheels, a regulator, a vent HEPA filter (similar to the one in the tube plug), and half-inch hoses to connect to the test lines on the plug. As long as each tube is vented and purged with nitrogen before the pressure rises above 0.8 psig, the hydrogen concentration will not exceed 6% by volume. A 6% mixture of hydrogen in nitrogen is non-flammable when mixed with any proportion of air. At the nominal design hydrogen generation rate, a tube with one MCO takes 4.8 days to reach 0.8 psig after venting and purging. With 750 MCOs staged in 375 tubes, an average of 78 tubes per day would have to be vented and purged to maintain non-hazardous mixtures of hydrogen in the tubes.

Passive Air-Cooled Storage. After stabilization, the MCOs do not normally vent gas. There are no contamination issues during normal operation.

2.2.3.3 Abnormal Operation

MCO Servicing. The Cask Unloading Pool could become contaminated in the event of the failure of an MCO during unloading or servicing. Until the accident is quantified, it is assumed that the unmitigated consequences are severe enough to require safety class 1 or 2 systems, as defined in WHC document MRP 5.46 and DOE Order 6430.1A. To prevent this potential contamination from reaching the soil, the pit must be lined with stainless steel and monitored for leakage. Any place where pit water is contained, there must be a way to inspect or test for leaks; this includes any piping that penetrates through walls or the ground. The glycol

coolant in the chillers must have monitors or test connections to detect any leaks across the glycol/pit water heat exchangers.

The operating area above the pit could become contaminated in the event of a crane accident during cask or MCO handling. Should any abnormal contamination be detected above the pool, alarms warn the operators to leave the area and the Emergency Ventilation System is activated. This system ensures that there is no unfiltered release from the building and that the hydrogen concentration remains orders of magnitude below the flammable limit.

The dropping of an MCO in the pool is not the worst MCO accident (compared, for example, to an accident during MCO handling above the storage tube operating floor), but this accident is a basis for designing the pool water treatment system. The pool water filters and deionizers are sized to contain the upper limit corrosion products from an MCO. The soluble corrosion products (cesium hydroxide) do not pose a criticality threat in the deionizer. The critically-safe geometry for the filters has not been determined in this study, due to time limitations.

Closed Tube Staging. If there is a failure of an MCO during staging, the HEPA filter in the sealed tube plug will prevent airborne contamination from spreading out of the tube. The tube plugs have test fittings which allow for periodic water sampling to detect MCO failure. The contamination is localized, but there is no built-in design feature for clean-up.

Passive Air-Cooled Storage. If there is a failure of a stabilized MCO during storage in a tube, only one tube becomes contaminated. The floor plugs have HEPA filters and test fittings which allow for periodic gas sampling to detect MCO failure. The contamination is localized, but there is no built-in design feature for clean-up.

2.2.4 Criticality

2.2.4.1 Introduction

One of the issues identified at the start of the SSF Feasibility Study was the minimum allowable spacing between MCO's, from a criticality standpoint, and the identification of a feasible storage configuration based on criticality considerations. Some of the conclusions reached as part of other concepts within the SSF Feasibility Study are applicable to Concept 2D and are addressed herein. Since criticality safety was identified as a potential design driver, an analysis effort was undertaken to identify and quantify restrictions on N-Reactor fuel storage configurations based on criticality. Although the Design Basis contained in Section 2.8 indicates that there are no restrictions on MCO spacing

and stacking based on criticality, it was decided to continue the analysis to verify the Design Basis.

2.2.4.2 Summary of Results

Preliminary criticality calculations were performed with simplified geometries, taking no credit for structural material, such as canister and MCO walls, and all simplifying assumptions made were conservative. These calculations confirmed that the MCO's could be stacked, even when loaded with five layers of canisters, and can be placed side-by-side without additional space between MCO's. The worst-case k_{eff} calculated was less than 0.90, well within the 0.95 limit imposed by the Nuclear Criticality Safety Manual, Section 2.0, Paragraph 5.1.3, Allowed Maximum Calculated K-effective.

2.2.4.3 Criteria and Assumptions

The criteria and standards on which these criticality calculations are based, as well as the assumption used in formulating the computations, are given the following paragraphs.

Applicable Orders and Standards. The criticality calculations performed in support of this feasibility study conform with the following criteria and standards:

DOE Order 5480.24, "Nuclear Criticality Safety"

DOE-STD-3007-93, "Guidelines for Preparing Criticality Safety Evaluations at Department of Energy Non-reactor Nuclear Facilities"

WHC-CM-4-29, "Nuclear Criticality Safety Manual," issued September 15, 1988.

Choice of Computer Models. The principal tool selected for criticality calculations is the PC version of MCNP, Version 4A, developed and supported by the Los Alamos National Laboratory (LANL), Reference 2. This code was selected because of its great flexibility, high fidelity modeling (e.g., ENDF/B-V continuous cross sections), and the ability to perform both shielding and criticality calculations.

Another code available for criticality calculations is KENO, Version V.A (contained in the SCALE-PC, Version 4.1; Reference 3). This code was not used to perform criticality calculations directly for this study, but was used to compare results during the validation and verification process.

Code Verification & Validation. All codes used in shielding and criticality calculations at Fluor Daniel have been verified by running the test problems supplied with the code packages. The

test problem results are shown to be in agreement either with the published documentation supplied as part of the code package, or with the sample problem output, if supplied. This information is documented, dated, and retained on file at Fluor Daniel. Any changes, such as upgrades, corrections, modifications, etc., are incorporated into the documentation following rerunning of the verification problems.

MCNP, Version 4A is the latest version, Reference 2, of a widely used and well accepted radiation transport code employed for a wide variety of radiation analyses including neutron, photon and electron transport, and criticality. LANL has performed extensive calculations with MCNP, duplicating a wide range of experimental results, to validate the models contained in this code. The results of these benchmark cases are documented in References 4 and 5. The version of MCNP4A used at Fluor Daniel was tested by exercising the twenty-five sample problems supplied by LANL, and the results were found to be in agreement within reasonable statistical limits. These sample problems are designed to exercise a broad range of the code's computational capabilities, including criticality calculations, which is addressed by five of the twenty-five sample problems.

Material Properties. The densities and composition of materials used in the criticality calculations are given in Tables 2-6 and 2-7.

Preliminary Calculations. Preliminary criticality calculations were performed to define the worst case spacing of fuel elements inside a canister, and/or each layer of a CSB storage tube. To this end, a computational model of seven storage tubes was formulated; with 12 vertical layers, each layer consisting of 31 fuel elements in a triangular pitch array. The material composition of this array consisted of fuel elements only: concentric cylinders of 1.25% enriched uranium, with zirconium cladding. All voids and spaces within the fuel elements and storage tubes were filled with water, and water was medium surrounding these storage tubes on all sides. The k_{eff} of the configuration was calculated, varying the pitch of the triangular array. The results are shown in Figure 2-19. The important result of these calculations is that the worst case spacing between fuel elements is 3.2 inches.

The spacing between storage tubes, was 55 inches. These tubes were again arranged in a hexagonal pattern, in cross section, which approximated the storage tube configuration within the CSB vaults. Because of this spacing between tubes, and because the tubes were immersed in water, there was no appreciable interaction between the tubes, and the results show no sensitivity to variations in this spacing (except when the tubes were placed very close together, as discussed below).

TABLE 2-6
DENSITIES OF SOME MATERIALS

<u>Material</u>	<u>Density (g/cc)</u>	<u>Material</u>	<u>Density (g/cc)</u>
Air	0.00122	Uranium	18.7
Aluminum	2.70	Water	1.0
Iron (Steel)	7.83	Zirconium	6.4

The fractional densities for compound materials used in this study are listed in Table 2-7.

TABLE 2-7 COMPOSITION OF MATERIALS USED IN RADIATION SHIELDING CALCULATIONS (Given as Fractional Densities in g/cm ³)				
Atomic Number	Element	Air	Water	Stainless Steel 304L ASTM A240
1	H		0.11111	
5	B ¹⁰			
5	B ¹¹			
6	C	0.00000017		0.0023
7	N	0.00092132		
8	O	0.00028276	0.88889	
11	Na			
12	Mg			
13	Al			
14	Si			0.0587
15	P			0.0035
16	S			0.0023
18	Ar	0.00001575		
19	K			
20	Ca			
22	Ti			
24	Cr			1.5660
25	Mn			0.1566
26	Fe			5.1009
28	Ni			0.9396
Total		0.00122	1.00	7.8299

2.2.4.4 Results Of Calculations

A computational model was formulated which could address key factors with respect to criticality safety for Concept 2D. All uncertainties were compensated for with conservative assumptions. In the event these assumptions led to an unacceptable risk of a criticality event, it was planned to perform sensitivity studies to identify safe limits.

In this computational model, fuel elements were arranged in columns, each containing 280 fuel elements. Each column contained fuel arranged in patterns representative of two MCO's, stacked one on top of the other. Each MCO was modeled with five vertical layers of canisters, two canisters of 28 fuel elements, per layer. The 28 fuel elements in each layer were arranged in a pattern similar to that found in the canisters, Figure 2-20, but the center-to-center separation between fuel elements was taken to be 3.2 inches, the worst-case spacing from Figure 2-19.

In a nominal CSB vault, 220 such columns would have been arranged in a hexagonal pattern. This pattern was modeled as a triangular pitch array, with a 55 inch center-to-center separation between columns, Figure 2-21. (Since interaction between columns is negligible, this will be shown in what follows, changing the size of this array was not required.) The closest spacing between columns, which could be achieved in a flooded pool, was assumed to be 26 inches, center-to-center. This assumes a bare MCO, no tube, and a minimal amount of structural material for keeping the 24 inch OD MCO in place. For this calculation, no credit was taken for either the MCO or the canister walls. In fact, the only materials included in this model are the fuel, cladding, and the surrounding water. The results for this configuration gave a k_{eff} of 0.81289 with a standard deviation of 0.00091 (calculation ID: NF032). Replacing the water outside the MCO boundaries with air, gave a k_{eff} of 0.87063, +/- 0.00073 (NF033). This increase is probably due to the increased interaction between columns for this close a spacing.

To evaluate the impact of some of the structural material, assumed to be stainless steel (SS 304), the case with air outside the MCO was repeated, but this time the canister walls were included in the model. This calculation gave a k_{eff} of 0.77375, with a standard deviation of 0.00065 (NF034). Including the MCO wall material, further reduced the k_{eff} to 0.74524 +/- 0.00069 (NF035). (To accommodate the 3.2 inch spacing between fuel elements, the canister outside diameter was taken to be 9.2 inches and its thickness 0.25 inches, Figure 2-22. This should be compared to a standard schedule 20, 8 inch pipe which has an outside diameter of 8.625 inches and the same thickness.)

Increasing the spacing between columns to 55 inches and including the tube material, reduced the k_{eff} to 0.7234 +/- 0.00061 (NF036).

FIGURE 2-19
SENSITIVITY TO SPACING, 31 FUEL ELEMENTS
(IN A TRIANGULAR ARRAY) PER LAYER, 12 LAYERS, 7 COLUMNS

```
I 01/19/93 13:36:49
NP0307, N fuel, 28
elements/layer, 220 columns 47
inch spacing
prebid = I 01/19/93 19:11:34
basis:
( 1.000000, 0.000000, 0.000000)
( 0.000000, 1.000000, 0.000000)
origin:
( 0.00, 0.00, 142.60)
extent = ( 30.00, 30.00)

.pas=142.60
```

FIGURE 2-20
FUEL ELEMENTS IN A SINGLE LAYER OF AN MCO MODEL

```
I 08/13/74 13:50:37
MFO23, N Fuel, hex lattice, 3.2
in pitch, 31 elements per
layer, full inventory
prebid = I 08/13/74 13:49:16
basis:
( 1.000000, 0.000000, 0.000000)
( 0.000000, 1.000000, 0.000000)
origin:
( 0.00, 0.00, 0.00)
extent = ( 1700.00, 1700.00)
possible causes of dotted lines:
errors in the geometry.
cockle-butter cell in the source.
a problem plane coincident with
the plot plane.

.end
```

FIGURE 2-21
CSB VAULT MODEL SHOWING STORAGE TUBES IN A TRIANGULAR ARRAY

```
I 02/08/93 15:17:03
M0036, M fuel, MCO, can. Atake
walls, 250 columns 35 inch
spacing, air in vault
readid = I 02/08/93 15:09:47
basis:
( 1.000000, 0.000000, 0.000000)
( 0.000000, 1.000000, 0.000000)
origin:
( 0.00, 0.00, 142.00)
extent = ( 50.00, 50.00)
.end
```

FIGURE 2-22
CROSS SECTION OF STORAGE TUBE SHOWING MCO AND CANISTER WALLS

The relatively small decrease between this case and case NF035, indicates that the interaction between columns has already been significantly reduced by the addition of the MCO wall material.

Case NF036 is representative of Concept 2D storage of MCO's in air filled tubes with forced refrigerated air cooling of the tubes. Eliminating water from the calculation will result in an under-moderated situation with an effective decrease in k_{eff} . Filling the vault with water would have only a minor effect on the vault k_{eff} , since there is only negligible interaction between tubes at this spacing and when taking credit for tube and MCO wall thicknesses. (The case of a water filled vault is a credible accident scenario and would have to be considered in a criticality safety evaluation. Partial filling of the vault with water may actually be a worst case situation, as was illustrated by comparing results for cases NF032 and NF033.)

2.2.5 Shielding

Shielding calculations during the feasibility study evaluations were performed with MicroShield 4 which is adequate for the bulk shielding studies performed. The adequacy of this method was calculated using the MCNP, Version 4A, code. Penetrations, ducts, and cracks were not evaluated but are noted where additional work will be needed in the future. Some allowances were taken with the bulk shielding thicknesses in anticipation of the more complicated geometries.

Shielding issues associated with Concept 2D which were not addressed in either the Feasibility Study or the Trade Study, but which may contribute to design changes, include the following:

- Tube Closure Design, Tube Spacing

Tube spacing in the vault may depend, in part, on the design of the tube closure at the operating floor level. Exposure levels above tube closures will depend on operating floor thickness and radiation streaming through gaps around the closures. Any penetrations through these closures, for gas/liquid sampling, may also contribute to these exposure levels. The MCO's internal structure may favor propagation in the axial directions, enhancing the radiation environment at the top and bottom of the tubes. (This will be particularly significant after stabilization.)

- Unfinished Vault Capable of Future Outfitting

An unfinished vault presents several closure and shielding problems. Openings to both the intake and exhaust plenums will have to be closed off both to reduce radiation in this vault and to restrict refrigerated air flow through the unused vault.

Provisions must be made to remove these barriers, under a high radiation environment, when this vault is eventually activated.

- Temporary Refrigerated Air System

The means of delivering refrigerated air to the vaults may require additional ducting and wall penetrations. These ducts, and wall penetrations will have to be designed to preserve the required low radiation exposure levels outside the building. Any closures to existing air intakes and exhausts will have to be removed, under enhanced radiation conditions, when the switch is made to passive cooling for stabilized fuel.

2.2.5.1 Introduction

The shielding issues for Concept 2D involve health protection of the occupants of the SSF throughout its life. During the SSF Feasibility Study selection of an appropriate source term was examined by looking at the defined "limit" (maximum) source and another "shield" (average) source, as well as a combination of the two sources. There are several water conditions that must be met at all times to provide a maximum dose rate of 0.2 mrem/hr. These include the minimum pool water depth over the filled MCO racks and the minimum water level over an individual MCO. The interior and exterior wall thicknesses are important to provide health protection during possible construction activities. The operating floor thickness must protect workers during maintenance activities. The thickness of the transporter or shielded cask must provide adequate shielding during transport, insertion and removal of the shield plugs and MCO's.

2.2.5.2 Source Selection

Three possible sources were examined to determine the most appropriate for the shielding studies. The "maximum" source is that found in Section 2.8, Basis For Design, "Draft MCO Table" by R. G. Cowan, March 17, 1995. The "shield" source is that found in Table 3.6 - Safety Basis Radionuclides - referenced as the shield source in paragraph 3.6 - Shielding Design Basis of the "Draft Design Basis Feed Development", A. L. Pajunen, December 22, 1994. Direction from Westinghouse indicated that the "maximum" source identified with 10 canisters should be used. Previous experience and the increased number of radionuclides in the "shield" source prompted examination of the two sources. The "shield" source is based on the most radioactive fuel elements currently in the K-Basins. Apparently, there is only 0.6 metric tons of this material, which is considerably less than one filled MCO. However, three cases were examined: 1) filled MCO with the "maximum" source; 2) filled MCO with the "average" source; and 3) combined MCO with 0.6 metric tons of the "average" source and the balance of the fuel elements of the "maximum" source. A simple geometry of an

MCO immersed in water with a 2 foot concrete wall was used to evaluate the three sources. All other things being equal, except for the radionuclide composition, the resulting dose rates were: "maximum" - 0.0112 mrem/hr; "average" - 0.0122 mrem/hr; and "combined" - 0.0114 mrem/hr. The limit source was selected since all sources were very close to being equal.

The impact on shielding requirements, of changing the MCO configuration to include five layers of canisters, instead of four, and changing the isotope mix to that specified as the "Maximum" MCO (Appendix 1), was evaluated. This was done by generating a more representative model of the MCO geometry for use in MCNP Monte Carlo simulations. Sample calculations were performed with this model, using a gamma source based on the "Maximum" MCO isotope mix. The results of these calculations confirmed that the conservative approach used to define shielding requirements based on the MCO source model discussed above were adequate to accommodate the increased source of the new MCO model. The changes in shielding requirements, recommended as part of this Trade Study, are based on the lowered exposure level requirement for occupied areas (i.e., lowered from 0.5 mrem/h to 0.2 mrem/h).

2.2.5.3 Minimum Water Depth Over a Single MCO

The MCO is brought into the SSF in a shielded cask. The cask is immersed in water before withdrawing the MCO. Radiation shielding of the MCO is provided by the water surrounding the cask and the MCO. Whenever the MCO is not in the cask, it must be surrounded and covered by water. Personnel do not generally have access to the sides or bottom of the pool so only the top of the MCO must be shielded. This shielding is provided by establishing a minimum water depth above the MCO which must be maintained. This minimum water depth is 8 feet.

2.2.5.4 Minimum Concrete Thickness of Interior and Exterior Walls

There are several construction sequence possibilities for the SSF. The thickness of the interior walls is not important from a health protection standpoint if all construction is performed initially. However, if one vault is constructed first and filled and the other storage vaults are built at a later time, the construction workers will need to be shielded against radiation penetrating the interior wall between the filled vault and the adjacent vault. An additional need for personnel access to a vault could be for cleanup before conversion to natural convection cooling. If this cleanup is required, all MCO's in the vault to be cleaned will need to be removed. Radiation levels from adjacent filled vaults will need to be less than 0.2 mrem/hr to avoid partial emptying of the adjacent vaults. The minimum wall thickness required is 42 inches of full density standard concrete. Since the interior walls are currently 36 inches of full density concrete, the wall thickness is

less than adequate for maintenance activities near the wall. At one time, there was an additional layer of thermal concrete (low density) applied to the interior surfaces of the vaults. If this additional thermal layer is included in the SSF design, the shielding may be adequate. Also, since entry into the vault will only occur if cleanup is required, localized shielding might be a better solution than increasing the wall thickness.

An unfinished vault presents several shielding problems, in addition to the inside wall thickness requirements. Openings to both the intake and exhaust plenums will have to be closed off with shielding materials to reduce radiation exposure levels in this vault during any future reconfiguration. Provisions must be made to remove these shields, under a high radiation environment, when this vault is eventually activated.

The second construction sequence involves the construction of the Stabilization Facility adjacent to the exhaust plenum. Excavation could remove all of the soil surrounding the exterior wall. Again, the minimum wall thickness is 42 inches, so that the 54 inch exterior wall is more than adequate.

2.2.5.5 Minimum Thickness of Operating Floor

Radiation protection of personnel from stabilized MCO's in dry storage is provided by the concrete operating floor. This floor, along with the individual shield plugs which provide access into each storage tube, must provide shielding sufficient to maintain a target dose rate of 0.2 mrem/hr. The minimum floor thickness must be 48 inches. This floor thickness allows for a solid floor. When the floor is cast with plug holes and the holes are fitted with plugs which do not completely fill the space, radiation streaming is possible. Plugs and holes with steps solve this problem. It is estimated that the current design thickness of the floor is 60 inches which will provide adequate shielding. The geometry with the holes and plugs will need to be examined thoroughly at a later date.

2.2.5.6 Minimum Transporter/Cask Thickness of Steel and Tungsten

There are two options for transporting the MCO's filled with stabilized fuel tubes. The first would involve a stand alone transporter which would be driven around on the operating floor. The second would involve a special remote controlled cask which would be moved with an overhead crane. In either case, personnel health protection and shielding weight are important. The target contact dose rate is 0.2 mrem/hr. The thickness of iron to achieve this dose rate is 14 inches. The thickness of tungsten to achieve this dose rate is 4.7 inches. The tungsten shield is more expensive, but considerably lighter which reduces the cost of the transporter or overhead crane. These thicknesses provide gamma

shielding only. These shielding requirements will need to be reviewed for neutron shielding adequacy (Section 2.2.5.8)

2.2.5.7 Special Shielding Issues (Neutrons, Betas)

A neutron source was not provided and neutrons have been ignored during this study. However, in future design efforts, neutron dose rates will need to be evaluated. The areas of particular concern are the incoming and outgoing casks and the transporter/cask. These shielding structures are designed to provide adequate gamma shielding. Additional neutron shielding may be needed. The neutron source will result from some α, n reactions and spontaneous fission of the transuranics.

The beta source does not appear to be a significant shielding source in the MCO. The shielding concern is not to provide beta shielding which is provided by the shell of the MCO, but to provide adequate shielding of the Bremsstrahlung radiation resulting from the beta absorption in the gamma shield.

The secondary photon source, resulting from the "Maximum" MCO (Section 2.8) mix of beta emitting isotopes, was evaluated using MCNP. This source of photons was found to contribute less than 3% of the exposure rate contributed by the gammas.

2.2.6 Conversion

Conversion of Concept 2D from refrigerated air cooling of unstabilized fuel to passive dry storage will be accomplished after stabilization of all the MCOs is complete. As MCOs are removed for stabilization, MCOs containing dry stabilized fuel will be installed in dry storage tubes upon return from the Stabilization Facility. When all of the fuel has been stabilized and higher fuel and vault temperatures can be tolerated, blinds in the air intake plenums and stack would be removed, air refrigeration equipment would be shut down and isolated if necessary, allowing natural circulation cooling to be established.

There do not appear to be any additional feasibility issues associated with the conversion from refrigerated air cooling to passive dry storage for this concept other than shielding and radiation safety, already addressed.

2.2.7 Health Physics

2.2.7.1 Objective

Perform a Health Physics (HP) analytical review of the use of the Canister Storage Building (CSB) as a staging and storage facility (SSF) for the N-reactor fuel.

2.2.7.2 Summary

Whereas the facility as designed for the Hanford Waste Vittrification Plant (HWVP) project is ideally suited for the storage of spent fuel, there are some features of concept 2D that will need to be altered in order to meet the latest DOE requirements such as DOE/EH-0256T, *Radiological Control Manual*, Rev. 1, April 1994. For example, the facility will require change rooms, step-off-pads (SOP), and a personnel decontamination facility. In addition, the concept of allowing the third vault to remain empty will not work from an HP or an HVAC stand point without major changes to the building. The building modifications will more than likely off-set any potential savings attributable to deferring the third vault work at this time. Although data concerning the potential neutron source associated with the max A multi-canister overpack (MCO) shielding source is not available at this time, it is inevitable that there will be more neutrons associated with this source than there were with the HWVP source because this source contains far more fissile material. Further, since a neutron shield was required on the HWVP transporter, be advised that it will be required as an integral part of the shipping cask and as part of the floor plug shield valve. Finally, it is beyond the scope of this study and left to later design stages to verify that workers will be able to remain on the operating floor during insertion of the MCO into the storage tubes.

2.2.7.3 Facility Description And Evaluation

It should be noted that although the CSB was designed when the yearly exposure for radiation workers was 1,000 mrem cumulative total effective dose equivalent (CTEDE), the Westinghouse Hanford Corporation (WHC) and the Fluor Daniel Inc. (FDI), Health Physics departments mutually agreed that this dose should be divided into 400 mrem/yr, whole body dose, and 600 mrem/yr for internal dose exposure. The DOE regulation cited above, limits the yearly CTEDE to radiation workers to 500 mrem. This means that the CSB is designed in compliance with the latest contemporary DOE regulations. The design of the operating floor meets the latest WHC requirements for a radiation access zone (RAZ) 1 which permits 40 hours per week occupation.

The *Radiological Control Manual (Rad Con)* manual requires the HP facilities noted above in the summary. In addition, the SOPs must be contiguous with the radiological areas that require radiation work permit (RWP)/special work permit (SWP) such as the cask handling, storage, preparation and operating areas.

If the third vault remains empty, without any flow restrictions, then the preponderance of natural convection air, after stabilization, will flow through the empty vault and not through the MCO filled vaults. Flow restrictors will be difficult, if not impossible, to remove if WHC finds a use for the vault at a later

date because it is currently inconceivable that anyone can enter the area after the first and second vaults are filled with MCOs. Please be advised that even if the wall thickness between the second and third vault is increased, the scattering around the exhaust and inlet plenums will most likely produce a RAZ 5, which does not allow access.

The shipping cask and the floor plug shield valve will have to provide shielding against gammas, beta originated bremsstrahlung radiation (X-rays) and neutrons. The preliminary estimates without bremsstrahlung or neutrons, indicate that the maximum MCO will produce a dose rate of approximately 200 R/h at three feet from the midsection of the overpack. It should be noted that the shielding requirement to allow this source to become contact maintained in a RAZ 1 would be approximately 14 inches of steel. This shield may exceed the weight restrictions for the CSB floor and crane. This is one of the reasons why it may not be possible to allow workers to remain on the operating floor during insertion of the MCO into the storage tubes.

2.3.0 SAFETY ANALYSIS

2.3.1 APPLICABLE REQUIREMENTS

The environmental, safety and health (ES&H) requirements applicable to the SSF are very similar to the requirements applied to the HWVP CSB, especially for the storage phase. Other than updated requirements for protection against natural phenomena (recently issued DOE-STD-1020), all such requirements applicable to the CSB will apply to the SSF.

The CSB design (the starting point for the SSF design) was completed using these ES&H requirements as part of the design basis. This CSB design has been reviewed and approved by the DOE, WHC and the State of Washington as meeting all these requirements. This successful track record should ease the regulatory process for the SSF.

On the other hand, the fact that spent nuclear fuel (SNF) is being stored instead of glass, and the necessity for wet storage of unstabilized fuel in the staging phase, will make several new additional requirements applicable to the SSF. For example, in addition to meeting the requirements applicable to the CSB, WHC has indicated that the SSF will be required to meet the intent of Nuclear Regulatory Commission requirements for SNF storage facilities.

2.3.1.1 DOE Orders

The following safety related DOE Orders are applicable to the SSF. The technical descriptions provided in this report are intended to meet these regulations. They are the core of the safety design basis for the facility:

2.3.1.1.1 DOE Order 6430.1A, General Design Criteria

This is the primary design requirements document which the SSF must meet. Key safety related sections influencing the SSF design include:

1. Section 0200-1.3 Radiological Siting Guidelines
Section 1300-1.4 Guidelines on Limiting Exposure of the Public

Establish offsite exposure limits for normal operations, and the basic 25 rem offsite dose limit for Design Basis Accidents (DBAs).

2. Section 1300 Special Facilities (in general)
Section 1300-3 Safety Class Criteria (in particular)

Identify the requirements for DOE Safety Class (SC) structures, systems and components (SSCs), including the Single Failure Criterion.

3. Section 1320 Irradiated Fissile Material Storage Facilities

Identifies special design requirements applicable to dry-type spent nuclear fuel (SNF) storage facilities such as the SSF. It also requires the designer to consider the applicability of NRC SNF storage requirements, such as 10CFR72 and Regulatory Guide 3.60 to the design of DOE SNF facilities. It requires primary and secondary confinement systems.

2.3.1.1.2 DOE Order 5480.5, Safety of Nuclear Facilities

Identifies general safety requirements applicable to the SSF, including effluent release limits for normal operation.

2.3.1.1.3 DOE Order 5480.22, Technical Safety Requirements

This Order defines the requirements for the Technical Safety Requirements (TSR) document. The TSRs are an agreement between a facility's operating management and the DOE regarding the safe operation of the facility. They define the safe operating limits, surveillance requirements, and management controls under which the facility must operate to maintain its safety design basis. The TSRs are based on the facility Safety Analysis Report (SAR). They are closely related to the assumptions made in the Design Basis Accident (DBA) analyses regarding the initial condition of

the facility (e.g., operability of Safety Class systems) when each accident is initiated.

2.3.1.1.4 DOE Order 5480.23, Nuclear Safety Analysis Reports

This Order defines the requirements for the preparation, review, and approval of DOE Safety Analysis Reports (SARs). It also describes acceptable SAR format, content, and level of detail. WHC has applied for an exemption from this Order and has indicated that the SSF SAR will meet the intent of the format and content requirements in NRC Regulatory Guide 3.48.

2.3.1.1.5 DOE Order 5480.28, Natural Phenomena Hazards (NPH) Mitigation

This Order identifies the seismic and other NPH protection requirements applicable to the SSF. To a large degree, this Order and its implementing Standards define the design of SSF structures.

2.3.1.2 DOE Standards

The following safety related DOE Standards are applicable to the SSF. These standards generally provide guidance to the designer for meeting the intent of the above DOE Orders:

2.3.1.2.1 DOE Standard 1020, Natural Phenomena Hazards Design and Evaluation Criteria for DOE Facilities

This standard defines the detailed NPH design criteria applicable to each DOE site for structures to meet the intent of DOE Order 5480.28.

2.3.1.2.2 DOE Standard 1021, Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems and Components

This standard defines DOE structural Performance Categories applicable the safety related structures in a facility as a function of the facility's Hazard Category. It also defines the structural requirements for each Performance Category to meet the intent of DOE Order 5480.28.

2.3.1.2.3 DOE Standard 1027, Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23

This Standard provides standard techniques for determining the hazard level of a facility, and for performing a Preliminary Hazards Analysis.

2.3.1.3 NRC Regulations

2.3.1.3.1 10CFR72, Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste

Part 72 prescribes high level design and other licensing requirements for the independent storage of SNF. Its requirements in the design and safety analysis area are specified in more detail in Regulatory Guide 3.54.

2.3.1.3.2 Regulatory Guides

WHC has indicated that the SSF must meet the intent of the following NRC Regulatory Guides:

1. Regulatory Guide 1.25, Assumptions Used for Evaluating the Potential Radiological Consequences of a Fuel Handling Accident in the Fuel Handling and Storage Facility for Boiling Water and Pressurized Water Reactors

This Regulatory Guide identifies the assumptions required to be used in performing accident analysis for SNF storage facilities.

2. Regulatory Guide 3.48, Standard Format and Content for the Safety Analysis Report for an Independent Spent Fuel Storage Installation or Monitored Retrievable Storage Installation (Dry Storage)

WHC has indicated that the SSF SAR will meet the intent of the format and content requirements of these Regulatory Guides, rather than the requirements of DOE 5480.23, from which it has requested exemption.

3. Regulatory Guide 3.60, Design of an Independent Spent Fuel Storage Installation (Dry Type).

Generally, this Regulatory Guide merely finds acceptable the use of ANSI/ANS 57.9-1992 in the design of dry type Independent Spent Fuel Storage Installations (ISFSIs).

2.3.1.4 Other Federal Regulations

2.3.1.4.1 National Environmental Policy Act

NEPA will require the preparation, review and approval of an Environmental Impact Statement for the SSF design.

2.3.1.4.2 Resource Conservation and Recovery Act (RCRA)

Enforcement of RCRA requirements generally is delegated to the individual States. For the State of Washington, RCRA requirements are implemented primarily through WAC 173-303.

2.3.1.5 Washington State Regulations

Washington Administrative Code (WAC) 173-303

This (and several other statutes) implement the requirements of the Federal Resource Conservation and Recovery Act (RCRA) for the State of Washington. The primary objective of the 173-303 is to prevent the release of dangerous wastes into the ground water.

If the facility would contain dangerous wastes, it must apply to the Washington State Department of Ecology for a Dangerous Waste Permit. Key requirements of the RCRA that affect the design include a requirement for double containment of dangerous liquids and detection within 24 hours and collection of any leakage.

2.3.1.6 WHC Requirements

WHC-CM-4-46, Nonreactor Facility Safety Analysis

Provides requirements for the preparation, review and approval of safety analyses for facilities at the Hanford site. In particular, Section 9.0 (Draft Revision OB) of this manual defines a graded system for safety classification of systems, components, and structures (SSCs). It specifies design requirements applicable to the four WHC safety categories: Safety Class 1 (DOE Safety Class-offsite hazard), Safety Class 2 (onsite hazard only), Safety Class 3 (facility hazard only), and Non-Safety.

Section 9.0 (in Table 2 of Attachment 1) of WHC-CM-4-46 also specifies frequency-dependent Radiological Dose Limits for DBAs. These limits are discussed below in Section 6.2.

2.3.1.7 ANSI/ANS Standards

Standard 57.9, Design Criteria for an Independent Spent Fuel Storage Installation (Dry Type)

Provides detailed design criteria for dry type ISFSIs such as the SSF. This standard requires a minimum of two barriers between the SNF and the outside environment.

2.3.2 DESIGN BASIS ACCIDENTS/SAFETY CLASSIFICATIONS

This section documents the results of a first-cut Design Basis Accident (DBA) analysis for the SSF. It describes the

pre-conceptual safety design basis of SSF Feasibility Design Concept 2D, including the basis for determination of required Safety Class (SC) SSCs.

A spectrum of candidate accident scenarios is postulated. Included are scenarios required to be addressed by programmatic requirements and additional scenarios identified by the WHC Draft Preliminary Hazards Analysis (PHA). All postulated scenarios are addressed.

The radiological consequences for each DBA are calculated for SSF Feasibility Design Concept 2D. The SSF is located on the site of the HWVP CSB (20,000 meter site boundary distance).

These consequences are compared with the onsite and offsite radiological dose limits of WHC-CM-4-46, Section 9.0 (Revision OB). Where unmitigated consequences exceed the dose limits, mitigating SSCs are designated as SC-2 or SC-1 as appropriate. Credit is taken for the operability of these SSCs to mitigate the consequences of the DBA to within the dose limit.

These frequency-dependent dose limits include the following:

A. Offsite:

1. Accident frequency of $>1E-2$ to $\geq 1E-1$ /year: 0.5 rem
2. Accident frequency of $>1E-4$ to $\leq 1E-2$ /year: 5 rem
3. Accident frequency of $>1E-6$ to $\leq 1E-4$ /year: 25 rem

B. Onsite:

1. Accident frequency of $>1E-2$ to $\geq 1E-1$ /year: 5 rem
2. Accident frequency of $>1E-4$ to $\leq 1E-2$ /year: 25 rem
3. Accident frequency of $>1E-6$ to $\leq 1E-4$ /year: 100 rem

2.3.2.1 DBA Methodology

2.3.2.1.1 Event Consequences

The methodology described in DOE-STD-1027-92 is used for this analysis. The following equation, from page A-6 of DOE-STD-1027-92, describes the basic method used to calculate the offsite dose for each DBA:

$MOI \text{ Dose} = (MAR) (RF) (X/Q) (RR) (SA) (CEDE) (1)$

or: $(\text{Source Activity}) (CEDE) (RF) (X/Q) (RR) (1a)$

where:

MOI Dose - Maximum Offsite Individual Dose[rem]

MAR - Material at Risk [grams]; RF - Release Fraction [Unitless]

RR - Respiration Rate [m3/sec]; SA - Specific Activity [ci/g]

X/Q - Atmospheric dispersion factor for the [sec/m3]
site boundary distance

CEDE - Committed Effective Dose Equivalent [rem/ci]
per curie inhaled

Source Activity = (MAR) (SA) [ci]

2.3.2.1.2 Initiating Event Frequencies

Formal quantitative calculation of event frequencies is not included in this assessment. The estimated frequencies listed in Results Table A are based on the frequency categories shown in the WHC Draft PHA.

As stated in the assumptions below, the frequencies of several scenarios are assumed to be below the threshold of credibility, based on the assumed outcomes of future, more detailed safety analyses. These assumptions should be verified or changed in later phases of the design of the SSF, based on the results of these analyses.

2.3.2.1.3 Scenario Development/Screening

The first step in the DBA analysis process is a screening process to justify eliminating from consideration all scenarios that are not DBAs. Remaining as DBAs are those scenarios that meet both of the following criteria:

A. The scenario is "credible:" The frequency of occurrence of the initiating event is equal to or greater than 1E-6/year. Accidents with frequencies less than this threshold are considered to be "beyond the design basis," or "not credible." This credibility threshold is defined in Section 1300-1.4.2 (and the Glossary) of DOE Order 6430.1A. The basic credibility threshold of 1E-6/year is modified by DOE-STD-1021 for natural phenomena hazards (NPH) to 1E-5/year. Accidents beyond the design basis, or "residual risk," will be analyzed in later phases of the design as required by DOE Order 5480.23.

B. The scenario is the limiting, or highest consequence, accident in its type: For example, the (credible) spill with the most severe consequence is the "design basis spill." If the plant is

designed to mitigate the risk of the design basis spill to within the dose limits, then it also can mitigate adequately all spills of lesser consequence.

2.3.2.1.4 Material At Risk Estimates

All spent fuel received at the SSF will be contained in Safety Class Multi-Canister Overpacks (MCOs). For the purposes of this assessment, Material At Risk (MAR) is assumed to be the "maximum" inventory of radionuclides in each MCO, taken from the "MCO Description" contained in Section 2.8, times the number of MCOs at risk in each accident scenario. The one exception to this is the "uncontrolled gas discharge" DBA, where the MAR is assumed to be the Kr-85 inventory of one MCO.

Failure of a MCO containing the "maximum" radionuclide inventory would cause a release and a resultant dose that can be calculated. The theoretical inhalation dose that would result from uptake of the entire contents of a MCO (immersion dose for Kr-85) is calculated. This dose is the "peak inhalation Committed Effective Dose Equivalent (CEDE) at the source." The method of calculation of this dose source term is described below.

2.3.2.1.5 Source Terms

Equation (1a) shown in the Methodology section above can be restated as follows:

$$\text{MOI Dose} = [(\text{Source Activity [in curies]}) (\text{CEDE})] \quad [(\text{RF}) (\text{X/Q}) (\text{RR})]$$

$$\text{or} \quad = [\text{Inhalation CEDE at the source}] \quad [K]$$

where:

$$[\text{Inhalation CEDE at the Source}] = (\text{Source Activity}) (\text{CEDE}) (2)$$

$$\text{and } K = (\text{RF}) (\text{X/Q}) (\text{RR})$$

The "K" part the dose calculation is independent of the nuclear characteristics of the source MAR. Inhalation CEDE At the Source, on the other hand, is completely characteristic of the each nuclide making up the source term.

In fact, the RF (1E-3 for all isotopes except Kr-85) and RR (3.5E-4 m3/sec) and meteorology all are assumed to be fixed for the SSF by DOE-STD-1027-92. The CSB site boundary distance (20,000 meters) fixes X/Q for the SSF as well, as described below.

Equation 1 is intended to be used to calculate the dose caused by one source radionuclide at a time. The inventory of a MCO comprises several isotopes as listed given in the Appendix 1 "MCO Description".

The dose that would result from a failed MCO containing this mixture of isotopes actually would comprise the sum of the individual doses contributed by each isotope present in the mixture at the time of release:

$$(\text{Inhalation CEDE} = \sum (\text{Source Activity})_i (\text{CEDE})_i \text{ of the mixture})^1$$

The $(\text{Source Activity})_i$ values used in this analysis are taken from the Section 2.8 "MCO Proposed Description". The CEDE_i values are taken from DOE/EH--0070 and DOE/EH--0071.

2.3.2.1.6 Release Modeling

As stated above, the release model used for this analysis is taken from DOE-STD-1027-92. The Release Fraction (RF) used for each scenario is $1\text{E-}3$ (except for noble gases such as Kr-85, which have an RF of 1). Respiration rate (RR) of the receptor used for each scenario is $3.5\text{E-}4 \text{ m}^3/\text{sec}$. Both are bounding values taken from DOE-STD-1027-92, page A-7.

The offsite receptor distance for the HWVP CSB is 20,000 meters. The onsite receptor distance is 300 meters per DOE-STD-1027-92, page A-7.

Atmospheric dispersion factors (X/Q values) are derived for the offsite and onsite receptor distances using the meteorological assumptions recommended for Preliminary Hazard Analyses in Appendix A (p. A-7) of DOE-STD-1027-92:

D-stability weather classification

4.5 meters/second wind speed

These parameters are used with the appropriate distances as inputs to the GENII algorithm, documented in PNL-6584, to calculate the following X/Qs:

- A. Maximum Offsite Individual
(MOI) (20,000 meter Offsite Boundary): $3.206\text{E-}7$
- B. Onsite receptor (300 meters): $2.200\text{E-}4$

These values are significantly less conservative than the X/Qs used for the HWVP CSB accident analyses. At the high end of the range for X/Q is the conservative X/Q used for the HWVP CSB PSAR

Addendum, the "0-8 hour release" site boundary X/Q, $8.67E-6$. This is greater than the DOE-STD-1027 offsite X/Q by a factor of approximately twenty seven. This wide range of X/Qs that are potentially applicable to the SSF is used to calculate the "range" of doses reported in Results Table 2-8 below.

2.3.2.2 Assumptions

2.3.2.2.1 Initiating Event Frequency/Credibility

A. Except for the "MCO failure" DBA, fire anywhere within the SSF is not a credible initiating event. Similarly, fire as a dependent event (e.g., caused by a DBE) is not a credible event. The basis for these assumptions is qualitative at this early phase of the design. The Fire Hazards Analysis (FHA) has not been performed. For several reasons, however, there is a level of confidence that the FHA will result in a detailed facility configuration that positively will prevent the introduction of significant combustibles into the facility and support this assumption.

Historically, SNF storage facilities such as the SSF have posed a substantially lower fire risk than other types of facilities such as reactors and radiochemical processing plants. Normal combustible loadings are at insignificant levels throughout most of the SSF. Review of chemical usage in the facility generally shows minimal use of combustible chemicals.

Process engineering has reviewed the rates and amounts of hydrogen releases from MCOs during normal operation. At the rate of once-through ventilation planned for the operating deck, hydrogen concentrations will stay several orders of magnitude below flammable limits. Even after an extended loss of ventilation (not considered credible) it would take several days for concentrations to reach flammable levels. This could be prevented merely by opening exterior doors to the wind.

For Concept 2D, periodic purging of the tube annulus during normal operation will prevent the buildup of hydrogen to dangerous levels. Even if hydrogen levels did reach flammable levels in the annulus, there is no ignition source in the tube.

There are, however, a few issues identified to date that could bear on the validity of this assumption and should be addressed in detail by the FHA:

- i. The capability should be provided for an adequate, timely response to a possible fire resulting from the failure of a MCO, resulting from a handling drop or other leakage of water from a MCO and ignition of the uncovered fuel rods.

ii. If diesel generators and/or batteries are used for backup electrical power, then the fire risk associated with this equipment should be addressed.

iii. Although it is a relatively smaller risk, the fire risk associated with the use of ion exchange resins, filter media and regenerant chemicals should be addressed.

iv. The FHA should consider the fire risks associated with any use of liquid nitrogen inside the SSF, such as the condensation and reevaporation of oxygen from the surrounding atmosphere.

This assumption is key to this assessment. If it were invalid (if a substantial release due to a fire (not related to a MCO failure) were credible inside the SSF, then SC mitigation may be required to meet the dose limits. Substantial additional SC SSCs could be required. This change could affect the estimated capital cost of the facility significantly.

B. Explosion anywhere within the vicinity of the SSF structure (including the stacks) is not a credible initiating event. Similarly, explosion as a dependent event (e.g., caused by a DBE) is not a credible event. The basis for these assumptions also is qualitative at this early phase of the design, because the Fire Hazards Analysis (FHA) has not been performed. For reasons similar to those listed above for fire, however, there is a level of confidence that the FHA will result in a detailed plant configuration that positively will prevent the creation of a credible explosive hazard in the vicinity of the SSF and support this assumption.

There are, however, a few issues identified to date that could bear on the validity of this assumption and should be addressed in detail by the FHA:

i. If hydrogen gas or other explosive gases or liquids would be used in the facility, the source containers preferably should be located outside the SSF, far enough away so that leakage and explosion involving all the stored gas would not be a credible threat to the SSF structures.

ii. If any such gases are brought into the facility via permanently installed tubing, then the tubing from the storage bottle should be provided with Safety Class isolation valves. These valves must close automatically on high seismic acceleration.

iii. If a bottles of such gases are transported into (the vicinity of) SSF structures, then the frequency and consequences of the resultant hazard should be limited:

- a) The capacity of the bottles should be minimized, and
- b) The amount of time the bottle is in the facility should be minimized.

The FHA should show that an explosion capable of failing Safety Class SSF structures is not a credible event.

This assumption also is key to this assessment. If it were invalid (if an explosion capable of threatening failure of SSF structures were credible), then SC mitigation and/or structural upgrades could be required to meet the dose limits. Substantial additional or upgraded SC SSCs could be required. This change could also affect the estimated capital cost significantly.

C. Analysis of aircraft crash, both credibility (frequency) and consequences, is not included in this assessment (i.e., for purposes of this assessment, aircraft crash is assumed not credible). The extensive analysis already done for the HWVP PSAR proves that this is the case.

D. This analysis assumes that a MCO will fail (release its radioactive contents) if dropped from a significant height, both in and out of water, whether or not it is inside a MCO handling cask. In contrast, it is assumed that the transport cask (and the MCO inside it) will not fail if dropped from any height attainable in the facility, unless the lid is unbolted. If the lid is unbolted when the cask is dropped, then it is assumed that the impact ejects the MCO from the transport cask and causes the MCO to fail.

Similarly, it is assumed that an uncontrolled discharge of gas from an MCO (due to a relief valve sticking open or a hydrogen burn inside the MCO) results in the release of the entire maximum inventory of Kr-85 from the MCO. This is considered to be a very conservative assumption that is a candidate for relaxation if necessary, by more detailed analysis in later phases of the design.

2.3.2.2.2 Event Consequences

A. Loss of ventilation due to equipment failure or power failure is not considered to be a DBA initiating event because it causes no release by itself, and requires no mitigation by permanently installed SSCs. In later stages of the design, the effects of these and other equipment failures will be considered in the design of SC SSCs, when taken as single failures in addition to DBA initiating events, as required to meet the single failure criterion of DOE Order 6430.1A, WHC-CM-4-46(MRP 5.46) and IEEE 379.

B. It is assumed that SSF SC SSCs will be designed to withstand the effects of the site-specific Design Basis Earthquake (DBE), Design Basis Wind (DBW), and Design Basis Ashfall and other natural

phenomena hazards without causing an offsite dose exceeding the limit, as required by DOE-STD-1021-92, Reference L. This assumption is reflected in the capital cost estimates herein.

C. It is assumed that only one MCO or cask will be moved at a time during any loading, unloading, servicing or inspection activity.

D. HVAC calculations show that approximately 20 hours after forced air cooling is lost, the temperature in the tubes has risen only 30 °F. Concept 2D is currently not a safety class system. Adequate time would most likely not be available after a loss of cooling or loss of power event to bring in mobile emergency cooling capability well before temperatures reach unacceptable levels. Based on this assumption, no permanently installed emergency cooling or makeup system is included in the SSF Feasibility Design, in accordance with Section 1320-4 of DOE Order 6430.1A.

2.3.2.3 Results

2.3.2.3.1 Scenario Screening Results

Table 2-8 shows the results of the scenario screening process used to determine which scenarios are considered DBAs applicable to each phase of SSF Concept 2D.

2.3.2.3.2 Material At Risk/Source Terms

Table 2-8 also shows the MAR quantities/source terms for each DBA.

2.3.2.3.3 Unmitigated Doses/Facility Hazard Category

Table 2-8 also shows the unmitigated offsite and onsite dose consequences for each DBA. Dose consequences are compared with the onsite and offsite dose limits of Section 2.3.2 above.

As Table 2-8 clearly shows, the total quantity of MAR present in the SSF makes the facility a candidate for DOE Hazard Category 1 (High Hazard), the same category as the K-Basins (and the HWVP CSB).

2.3.2.3.4 Safety Classifications

Where unmitigated offsite consequences exceed the applicable dose limit, credit must be taken for the operability of DOE Safety Class (WHC SC-1) SSCs to prevent or mitigate the consequences of the DBA to within the limit. When credit is taken for the SC-1 SCCs shown in Table 2-8, offsite consequences are less than the dose limits for all eight DBAs analyzed, given the Assumptions on which the analysis is based.

Similarly, onsite consequences are less than the onsite limits for

most DBAs analyzed, again given the assumptions on which the analysis is based. The exceptions are DBA Nos. 2, 3 and 4, MCO failure scenarios. For these accidents, the particulate releases can be filtered by the emergency ventilation exhaust system to a small fraction of the threshold. Along with the particulate, however, the maximum MCO inventory of Kr-85, an unfilterable noble gas, is released.

Calculations show that release of the Kr-85 inventory only from a single MCO may exceed the onsite limits, depending on the X/Q used. If the X/Qs used for the HWVP PSAR are used (resulting in up to 720 rem), the limit would be exceeded. This issue probably can be resolved by more detailed analysis in later phases of the design.

Tables 2-8, 2-9 and 2-10 show the SC-2 and SC-1 SSCs required for the SSF design to meet the onsite and offsite dose limits.

Structures/Performance Categories. Because the SSF is a candidate for DOE Hazard Category 1, and because some of the structures listed in Table 2-9 and 2-10 provide DOE Safety Class (WHC SC-1) protection against natural phenomena hazards, these structures are candidates for designation as Performance Category 3 as defined in DOE Order 5480.28, and DOE-STD-1021.

Other structures listed in Tables 2-9 and 2-10 provide WHC SC-2 protection against natural phenomena hazards. These structures are Performance Category 2 as defined in DOE Order 5480.28, and DOE-STD-1021.

Systems. As Tables 2-9 and 2-10 show, there are no non-structure-related DOE Safety Class (WHC SC-1) systems required for the SSF (except the MCO pressure boundary itself, which is not part of the SSF scope). These tables also show the WHC SC-2 systems required for each SSF phase.

2.4 COST ESTIMATES

2.4.1 ESTIMATE BASIS

The capital cost estimates of the Concept 2D SSF configuration was prepared as a Rough Order of Magnitude (ROM) estimate, utilizing a combination of estimating methodologies. The excavation estimate for the vault/plenum area is shown at zero cost. The excavation was performed by the C200-01 construction package contractor, HWVP Project. The estimate for the existing slab constructed by David Mowat Company, (C350-01 construction package contractor), is shown at zero cost. Unit rates for the construction of the below grade portion of the SSF Facility, including the fabrication and installation of the storage tubes, were obtained from the HWVP CSB C350-01 package fair cost estimate. Unit rates for the above grade

TABLE 2-8
SAFETY ANALYSIS RESULTS SUMMARY

Applicable to Phases	DBA No.	Initiating Event Scenario	Source Term	Unmitigated Offsite Dose/ Limit [rem]	Unmitigated Onsite Dose/ Limit [rem]	Estim. Freq. [Yr ⁻¹]	S.C. SSCs Required*
Staging Only	1	Uncontrolled gaseous discharge from one MCO (relief sticks open, H ₂ burn inside MCO) [staging phase only]	1 MCO Kr-85 Inventory	.039 - 1.07 0.5 - 5	27 - 1,024 5 - 25	1E-1 to 1E-3	MCO pressure boundary, Cask
Staging & Storage	2	One MCO fails (Drop, damage, loss of MCO water inventory)	1 MCO Inventory	.21 - 5.5 5	141 - 5,324 25	1E-3	Emergency Ventilation Exhaust Filtration System (Minimum Filtration Efficiency of Approx. 99.9 percent), Tube Vent Capability
Staging Only	3	2 MCOs fail (Drop)	2 MCOs Inventory	.41 - 11.1 5	282 - 10,648 25	1E-3	
Staging & Storage	4	3 MCOs fail (Stacking too many MCOs in tube)	3 MCOs Inventory	.62 - 16.6 25	423 - 15,972 100	1E-4	
Staging Only	5	Excessive cooling: Freezing & failure of multiple MCOs [staging phase only]	750 MCOs	154 - 4,156 25	1.1E5 - 4.0E6 100	1E-4	HVAC temperature controls, alarms
Staging & Storage	6	Design Basis Earthquake	750 MCOs	154 - 4,156 25	1.1E5 - 4.0E6 100	1E-5	Structures only
Staging & Storage	7	Design Basis Wind	750 MCOs	154 - 4,156 25	1.1E5 - 4.0E6 100	1E-5	Structures only
Staging & Storage	8	Design Basis Ashfall	750 MCOs	154 - 4,156 25	1.1E5 - 4.0E6 100	1E-5	Structures, ash handling equipment on air intakes

*WHC Safety Class 2 if the Onsite Limit applicable to the event frequency is exceeded, WHC Safety Class 1 (DOB Safety Class) if the Offsite Limit applicable to the event frequency is exceeded.

TABLE 2-9
DOE/WHC SAFETY CLASS STRUCTURES, SYSTEMS,
AND COMPONENTS ("STAGING PHASE")

SSC Type	Description ¹	Mitigates These DBAs	DOE S.C.? (WHC S.C.) ² Perf. Cat. ^{1,2}	S.F. Proof Design Req'd?	Q.L.	Operability Requirement
Structure	Vault, including operating deck floor & tubes, if present	Natural phenomena hazards, including Design Basis: Earthquake/Wind/Ashfall + Cask & MCO Drops	Yes (1)/PC-3	No	1	Whenever MCOs are present
	Cask handling crane (structure only) & supports		Yes (1)/PC-3			
	MCO handling crane (structure only), overhead or deck-mounted, & supports					
	Above grade walls and roof					
	Structures subject to compromise by "runaway rail transport"	Runaway rail transport				
	HVAC rooms	Cask & MCO Drops	No (2)/PC-2	No		Whenever MCOs/Casks are moved
System	Emergency generator & switchgear rooms	Cask & MCO Drops	No (2)/PC-2	No		
	Emergency HVAC Exhaust (Fans, filters, ducting, sensing & actuation) + supports + electrical power (AC/DC)	Cask & MCO Drops	No (2)/PC-2	Yes	1	During cask & MCO handling
	MCO (incl. relief valve, fittings and other pressure boundary components) [NOT PART OF THE SSP SCOPE]	DBE, Uncontrolled gaseous discharge from MCO	Yes (1)/PC-3	Yes ³	1	Fuel present
	Transport cask [NOT PART OF THE SSP SCOPE]	Cask drops, collisions	No (2)/PC-2	No	1	MCO Present

1. The SSP is designated DOE Hazard Category 2 per DOE-STD-1027. All DOE Safety Class (WHC SC-1, SC-1*) structures are Performance Category 3 and must withstand Natural Phenomena Hazards per DOE Order 5480.28 and DOE-STD-1021.

2. All DOE "Safety Significant" (WHC SC-2) structures are Performance Category 2 and must withstand Natural Phenomena Hazards per DOE Order 5480.28 and DOE-STD-1021.

CSB Trade Study
Westinghouse Hanford Company
WHC P.O. TVW-SVV-370252

Fluor Daniel, Inc.
Government Services
Contract 04436306

TABLE 2-10
DOE/WHC SAFETY CLASS STRUCTURES, SYSTEMS,
AND COMPONENTS "STORAGE PHASE"

SSC Type	Description	Mitigates These DBAs	DOE S.C. ? (WHC S.C.)/ Perf. Cat. ^{1,2}	S.F. Proof Design Req'd?	Q.L.	Operability Requirement
Structure	Vault, including tubes, operating deck floor, and passive natural circulation plenums and stacks	Natural phenomena hazards, including Design Basis: Earthquake/Wind/Ashfall	Yes (1)/PC-3	No	1	At all times
	Cask handling crane (structure only) & supports (Applicable to SSP only, not present in HWVP CSB)		Yes (1*)/PC-3			
	MCO handling crane (structure only), & supports (Applicable to SSP only, not present in HWVP CSB)					
	Above-grade walls and roof					
System	Canister Transporter (Applicable for CSB, not present in SSP)	Canister drop or shear	No (2)/PC-2	Yes	1	Canister present
	MCO (incl. relief valve, fittings and other pressure boundary components) [NOT PART OF THE SSP SCOPE]	DBE, Uncontrolled gas discharge from MCO	Yes (1)/PC-3	Yes	1	Fuel present
	Transport cask [NOT PART OF THE SSP SCOPE]	Cask drops, collisions	No (2)/PC-2	No	1	MCO Present

1 The SSP "storage phase" vaults are designated for DOE Hazard Category 2 per DOE-STD-1027. All DOE Safety Class (WHC SC-1, SC-1*) structures are Performance Category 3 and must withstand Natural Phenomena Hazards per DOE Order 5480.28 and DOE-STD-1021.

2 All DOE "Safety Significant" (WHC SC-2) structures are Performance Category 2 and must withstand Natural Phenomena Hazards per DOE Order 5480.28 and DOE-STD-1021.

portion of the facility were obtained from the Independent Cost Estimate (ICE) prepared by the architect engineer in October, 1992, as part of the HWVP review of Key Decision (K-D) 3B. Quantities of structural steel were developed by Engineering. The Mechanical and Process equipment requirements were obtained from the Equipment List. Equipment installation and associated bulk material costs were factored from the equipment, which was priced in-house.

Miscellaneous site support costs were derived from quantity take-off estimates. Estimates for engineering construction, and project management, are expressed as percentages of direct construction and GFE procurement costs.

2.4.1.1 Assumptions

- All direct costs are expressed in present day (1995) dollars.
- The estimate was based on a standard 40 hour work week.
- Sufficient skilled labor is available on site during the period of construction.
- No project mission changes or major rework will occur during the engineering and construction of the facility.
- No radioactive or otherwise contaminated soil, or underground obstructions, will be encountered during excavation for the facility.
- An estimated average craft wage rate of \$31.50/hour was applied to the estimated direct construction manhours. The average rate is based on the current Hanford Site stabilization agreement, and current Hanford Site prevailing wages. The estimated rate covers the craft's base wage, plus benefits and state legislated burdens.
- Engineering Costs:

25% of the direct construction cost estimates of the MCO Loading/Storage, Pool Water Treatment and Infrastructure Areas, including the Refrigeration HVAC Bldg. was added to 12.5% of the Direct Construction Cost Estimate of the vaults and office areas to provide an estimate of the Conceptual / Advanced Conceptual and Detail Design costs. Conceptual / Advanced Conceptual Design was assumed to be 20% of the engineering cost estimate, and detail design was assumed to be 80%.
- The Title III engineering estimate was calculated at 4.0% of the direct construction cost estimate.

- The Title III inspection estimate was calculated at 4.0% of the Direct Construction Cost Estimate.
- Construction management costs were calculated at 8.0% of direct construction costs.
- Project management costs were calculated at 8.0% of direct construction costs.
- Field construction is fixed price. An allowance of 53% was applied to direct field labor dollars to provide for associated indirect field labor, temporary facilities, personnel protection, weather protection, area maintenance, small tools and consumables, field and home office staff, QA/AC staff, construction equipment usage, bond and insurance, and the Washington state business and occupation (B&O) tax.
- 5% was applied to direct field materials and equipment to provide for overhead and profit.
- 10% was applied to direct subcontract costs to provide for overhead and profit.
- Construction acceptance testing was calculated at 3% of direct field manhours.
- Mobilization and demobilization costs were calculated at 5% of direct field manhours.

2.4.1.2 Estimate Inclusions

The capital cost estimate includes all conceptual, detailed, field engineering and inspection costs, direct and indirect field construction labor, material, equipment, and subcontract costs, construction management, and project management costs, expended in the execution of the SSF project. The estimate was prepared in present day (1995) dollars and is escalated to the appropriate activity centroid dates dictated by the schedule (Section 2.5).

2.4.1.3 Estimate Exclusions

The following costs were excluded from the scope of the capital cost estimate:

- All capital, start-up and operating spare parts.
- Canister tube impact limiters.
- Cask transportation equipment (includes casks (transport & facility) & donkey engine).
- Expense funded costs

- Operating costs
- Special work procedure (SWP) construction
- Transfer tunnels and carts to and from the Stabilization Facility

2.4.1.4 Work Breakdown Structure (WBS)

The estimate was accrued to the following WBS:

WBS	ESTIMATE CODE ⁽¹⁾	DESCRIPTION	REMARKS
100	210/310	Rail Tunnel/Cask Unloading/Area	All Alts
200	220/320	Staging Pool	N/A
300	230/330	Vaults & Inlet Exhaust Plenums	All Alts
400	240/340	Pool Water Treatment/Inst Air Compressor	All Alts
500	250/350	HVAC/Office/ Generator Equipment	All Alts
600	260/360	Refrigerated Air Mechanical Area	Alt 2D Only
700	370	Site Support	All Alts
	100	Engineering	All Alts
	400	Construction Management	All Alts
	500	Project Management	All Alts

⁽¹⁾ Note the prefix code 2 indicates Procurement Costs, the prefix code 3, Construction Costs. WBS areas are reflected in Figure 2-23. In addition, the estimate was encoded by DOE code as described in, and required by DOE Order RL5700.3.

The estimate was further accrued by CSI Code of Accounts.

PREFIX 2 = PROCUREMENT
PREFIX 3 = CONSTRUCTION

CANISTER STORAGE BUILDING
PLOT PLAN
CONCEPT 2D WBS AREAS

FIGURE 2-23

CADFILE: FIG2-2

CA 5-23-95

2.4.1.5 Quantities

The following quantity abbreviations were used throughout the estimate for all capital cost estimate line items:

<u>Description</u>	<u>Unit Abbreviations</u>
Excavation and Backfill	Yd ³ = Cubic yards
Concrete	Yd ³
Structural Steel	Tons
Liner Plate, Finishes/Coatings	Sq Ft = Square Feet
Machinery & Equipment	EA = Each
Misc. Individual Items	EA
Allowances and Composites	Lot
Manhours	MH

2.4.1.6 References

The following documents were used as reference documents in the preparation of the capital cost estimate.

- Hanford Waste Vittrification Plant (HWVP) Baselined Preliminary Design Estimate, Rev. "F", dated July 1991.
- K-D 3B ICE estimate of Package 350 [(HWVP) Canister Storage Building (CSB)] dated October, 1992.
- Fair cost estimate of Package 350-01 (below grade portion of the HWVP CSB) dated February, 1993.
- Drawings and Equipments Lists prepared in support of the SSF Report.

2.4.1.7 Escalation

The direct costs are expressed in current (1995 dollars). The estimate was evaluated in terms of the study schedule. The following direct costs were escalated to the centroid dates of their respective activities:

- Conceptual and Detailed Engineering - Design through initial construction
- Title III - Engineering and Inspection
- Procurement
- Construction
- Construction Management

- Project Management

The escalation table used in the estimate preparation was provided by WHC through ICF Kaiser Hanford, Richland, WA.

2.4.1.8 Contingency

The estimated contingency was developed from an evaluation of the completeness of design information available to estimating, and the reliability of unit cost data obtained from prior estimates. The following contingencies were applied to the direct procurement, construction, and indirect cost centers of the estimate:

● Load In/Load Out & Pool Water Treatment -	30%
● Infrastructure -	15%
● Vaults -	15%
● Engineering -	15%
● Construction Management -	15%
● Project Management -	15%

The resulting composite contingency is 17%.

2.4.2 CONCEPT 2D CAPITAL COST

The following capital cost alternative is included in support of Concept 2D, 3 vaults, one empty, processed material stored in 440 (2 vaults) dry Corten tubes.

2.4.2.1 Concept 2D Cost Estimate

Tables 2-11 and 2-12 contain the estimated capital cost and cash flow requirements for Alternative 2D, respectively. Supporting detail is contained in Tables 2-13 and 2-14.

2.4.3 SIGNIFICANT OPERATING COST DIFFERENCES

Review of the operating costs indicated that Concept 2D may have higher operating costs than other concepts i.e. a staging pool. The following operating cost factors were considered in reaching this conclusion:

2.4.3.1 Operating Labor During Staging

The loading of MCOs into tubes is more labor-intensive than other loading methods such as a pool rack. The distances that a pool crane would have to travel are shorter than for tube storage. Placing MCOs in tubes requires many more operating steps, because the floor plug, floor plug handling flask, bottom-loading cask, and impact absorbers have to be handled in addition to the MCO. A task analysis of tube loading shows that 4 operators would be required during the loading, while 2 operators would be required for loading

pool racks. At the design rate of 4 MCOs per day, the loading will require 300 days. Unloading at the end of staging will require another 300 days. At the current estimated wage plus burdens and overheads rate of \$34.50 per hour, plus 15% average shift differential, the Concept 2D labor cost is estimated at \$1,140,000 more (in present dollars) for loading and unloading.

In Concept 2D during staging, the tubes must be vented and purged at the rate of at least 78 per day to prevent hydrogen from building up in the tubes. If 375 tubes were filled and if 440 tubes were used, 92 tubes per day would require purging (see Section 2.2.3.2); if one were to use Los Alamos Tech Associates (LATA) data, 130 per day would require purging for 375 tubes and 150 per day for 440 tubes; pool concepts would not require this activity. From an estimate of 2 operators working regular days, the Concept 2D labor cost is \$144,000 more per year of staging. Based on 7 years of staging, the Concept 2D labor cost is \$1,000,000 more (in present dollars) for venting and purging, with the cost increasing for each year of staging.

Combining the above labor costs without escalation, the Concept 2D labor cost differential (above a pool concept) will be \$2,150,000 plus \$144,000 per year for each year that staging extends beyond the assumed staging period of 7 years.

2.4.3.2 Fuel Cooling During Staging

Regardless of the concept used, heat load from the MCOs is the same. However, a pool cooling concept would be more efficient than air cooling, and the heat gain from surroundings would be less for the pool. As a result, the horsepower ratings for the chillers and pool recirculation pumps in a pool concept would be about 500 kW less than for the chillers and air handling fans in Concept 2D. At the Bonneville Power wholesale rate of 30 mills per kW-hr, Concept 2D costs about \$13,000 per year more for power.

2.4.3.3 Heating, Ventilation, and Lighting

Because the buildings have about the same size and requirements regardless of concept, there is no significant difference.

2.4.3.4 Crane Usage

In a pool concept the crane would be smaller than the storage crane in Concept 2D. In addition, the storage crane has to travel farther with each MCO and perform more operations. The difference in power consumption averages about 50 kW, and is balanced by the difference below due to water sterilization. This difference is not significant.

CSB Trade Study
Westinghouse Hanford Company
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Fluor Daniel, Inc.
Government Services
Contract 04436306

TABLE 2-11

FLUOR DANIEL INC.
WESTINGHOUSE HANFORD COMPANY
JOB NO. 436306

** TEST - INTERACTIVE ESTIMATING **
STAGING AND STORAGE FACILITY
CONCEPT 2D, REVISED
DOE_R01 - PROJECT COST SUMMARY

PAGE 01 OF 01
DATE 05/31/95 12:00:01
BY AAF/JFD

COST CODE	DESCRIPTION	1995 \$ DIRECT COST	ESCALATED TOTAL COST	CONTINGENCY %	TOTAL	ESTIMATED TOTAL COST
000	ENGINEERING	10,600,000	11,030,000	15	1,650,000	12,680,000
460	IMPROVEMENTS TO LAND	1,160,000	1,230,000	15	180,000	1,410,000
501	BUILDINGS	31,630,000	33,650,000	17	5,620,000	39,270,000
600	UTILITIES	860,000	910,000	15	140,000	1,050,000
700	SPECIAL EQUIP/PROCESS SYSTEMS	12,230,000	13,030,000	20	2,580,000	15,610,000
XXX	CONSTRUCTION MANAGEMENT	3,700,000	3,930,000	15	590,000	4,520,000
YYY	PROJECT MANAGEMENT	3,700,000	3,890,000	15	580,000	4,470,000
	(ADJUSTED TO MEET DOE \$100.4)					

PROJECT TOTAL

63,880,000	67,670,000	17	11,340,000	79,010,000
------------	------------	----	------------	------------

TYPE OF
ESTIMATE ROUGH ORDER OF MAGNITUDE (R O M)

ARCHITECT

ENGINEER FLUOR DANIEL

OPERATING

CONTRACTOR WESTINGHOUSE HANFORD COMPANY

REMARKS:

CONCEPT 2D (REVISED):

INITIAL CONSTRUCTION OF THREE STORAGE VAULTS, MCO STORAGE
IN 440 STANDARD, AND 12 OVERPACK CORTEN STORAGE TUBES, NO
DEFERRED CONSTRUCTION.

THIS ESTIMATE REVISION REFLECTS THE DELETION OF THE SSF
CASK LOADER, STORAGE GATE/PLUG FLASK UNIT AND THE DONKEY
ENGINE FROM THE CAPITAL COST ESTIMATE. THE ESTIMATE FURTHER
REFLECTS MECHANICAL CHANGES TO ACCOMMODATE HEAVIER CASKS.

(ROUNDED/ADJUSTED TO THE NEAREST " 10,000 / 100,000 " - PERCENTAGES NOT RECALCULATED TO REFLECT ROUNDING)

CSB Trade Study
Westinghouse Hanford Company
WHC P.O. TVW-SVV-370252

Fluor Daniel, Inc.
Government Services
Contract 04436306

Table 2-12 STAGING & STORAGE FACILITY CONCEPT 2 D \$ EXPENDITURE - FY ESCALATED (\$ X 1000)										
										31-May-95
DESCRIPTION	TOTAL	FY 1995	FY 1996	FY 1997	FY 1998	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003
ENGINEERING/DESIGN	10,485	1,925	7,045	1,515						
TITLE 3 INSP SERVICES	2,199		764	1,435						
PROCUREMENT PROCUREMENT	24,688		1,865	22,823						
CONSTRUCTION CONSTRUCTION	32,654		6,245	26,409						
CONSTRUCTION MGMT CM	4,521		1,799	2,360	362					
PROJECT MGMT PM	4,469	672	1,703	1,703	391					
TOTAL	79,016	2,597	19,421	56,245	753					

CSB TRADE STUDY
WESTINGHOUSE HANFORD COMPANY
WHC P.O. TVW-SVV-370252

TABLE 2-13
** TEST - INTERACTIVE ESTIMATING **
STAGING AND STORAGE FACILITY
CONCEPT 2D, REVISED
DOE_R02 - WORK BREAKDOWN STRUCTURE SUMMARY

FLUOR DANIEL, INC.
GOVERNMENT SERVICES
CONTRACT 04436306
DATE 05/31/95 12:00:01
BY AAF/JFD

WBS	DESCRIPTION	ESTIMATE SUBTOTAL	ONSITE INDIRECTS	SUB TOTAL	ESCALATION % TOTAL	SUB TOTAL	CONTINGENCY % TOTAL	TOTAL DOLLARS
=====	=====	=====	=====	=====	=====	=====	=====	=====
110	CONCEPTUAL/ADVANCED CONCEPTUAL DESM	1700000	0	1700000	1.59	27030	15	1986085
120	DETAILED DESIGN	5200000	0	5200000	3.29	171080	15	6176742
130	TITLE III ENGINEERING	1900000	0	1900000	6.25	118750	15	2321563
132	TITLE III INSPECTION	1800000	0	1800000	6.25	112500	15	2199375
SUBTOTAL 1 ENGINEERING		10600000	0	10600000	4.05	429360	15	12683765
210	RAIL TUNNEL/CASK UNLOAD/MCO SERVICE	2810508	0	2810508	6.67	187461	30	3897359
230	VAULTS AND INLET/EXHAUST PLENUMS	13071181	0	13071181	6.67	871847	15	16034483
240	POOL WTR COOLING & INST AIR COMP	91911	0	91911	6.67	6131	30	127454
250	HVAC/OFFICE/GENERATOR//EQUIP BLDG	3600574	0	3600574	6.67	240159	15	4416842
260	HVAC MECHANICAL ROOM	152807	0	152807	6.67	10192	30	211899
SUBTOTAL 2 PROCUREMENT		19726981	0	19726981	6.67	1315790	17	24688037
310	RAIL TUNNEL/CASK UNLOAD/MCO SERVICE	2429238	0	2429238	6.25	151828	30	3355383
330	VAULTS AND INLET/EXHAUST PLENUMS	18893671	0	18893671	6.25	1180853	15	23085704
340	POOL WTR COOLING & INST AIR COMP	684567	0	684567	6.25	42785	30	945557
350	HVAC/OFFICE/GENERATOR//EQUIP BLDG	1421807	0	1421807	6.25	88864	15	1737271
360	HVAC MECHANICAL ROOM	1302607	0	1302607	6.25	81413	30	1799228
370	SITE SUPPORT	1416945	0	1416945	6.25	88560	15	1731329
SUBTOTAL 3 CONSTRUCTION		26148835	0	26148835	6.25	1634303	18	32654472
411	CONSTRUCTION MANAGEMENT	3700000	0	3700000	6.25	231250	15	4520938
SUBTOTAL 4 CONSTRUCTION MANAGEMENT		3700000	0	3700000	6.25	231250	15	4520938
511	PROJECT MANAGEMENT	3700000	0	3700000	5.02	185740	15	4468601
SUBTOTAL 5 PROJECT MANAGEMENT		3700000	0	3700000	5.02	185740	15	4468601
PROJECT TOTAL		63,875,816	0	63,875,816	5.94	3,796,443	17	79,015,813

CS8 TRADE STUDY
WESTINGHOUSE HANFORD COMPANY
WMC P.O. TVH-SVV-370252

TABLE 2-14

** TEST - INTERACTIVE ESTIMATING **
STAGING AND STORAGE FACILITY
CONCEPT 2D, REVISED
S1 - ESTIMATE SUMMARY BY WBS

FLUOR DANIEL INC.
GOVERNMENT SERVICES
CONTRACT 04436306
DATE 05/31/95 12:00:01
BY AAF/JFD

WBS	DESCRIPTION	MANHOURS	LABOR	EQUIP USAGE	MATERIAL	SUB- CONTRACT	EQUIPMENT	OVERHEAD & PROFIT	TOTAL DOLLARS
110	CONCEPTUAL/ADVANCED CONCEPTUAL DESM	0	0	0	0	0	0	0	17000000
120	DETAILED DESIGN	0	0	0	0	0	0	0	5200000
130	TITLE III ENGINEERING	0	0	0	0	0	0	0	1900000
132	TITLE III INSPECTION	0	0	0	0	0	0	0	1800000
SUBTOTAL 1	ENGINEERING	0	0	0	0	0	0	0	10600000
210	RAIL TUNNEL/CASK UNLOAD/MCO SERVICE	0	0	0	0	0	2676674	133834	2810508
230	VAULTS AND INLET/EXHAUST PLENUMS	0	0	0	0	0	12448744	622437	13071181
240	POOL WTR COOLING & INST AIR COMP	0	0	0	0	0	87534	4377	91911
250	HVAC/OFFICE/GENERATOR//EQUIP BLDG	0	0	0	0	0	3429118	171456	3600574
260	HVAC MECHANICAL ROOM	0	0	0	0	0	145530	7277	152807
SUBTOTAL 2	PROCUREMENT	0	0	0	0	0	18787600	939381	19726981
310	RAIL TUNNEL/CASK UNLOAD/MCO SERVICE	33330	1049895	0	734118	47340	0	597885	2429238
330	VAULTS AND INLET/EXHAUST PLENUMS	278450	8771176	0	5213112	0	0	4909383	18893671
340	POOL WTR COOLING & INST AIR COMP	10700	337050	0	160838	0	0	186679	684567
350	HVAC/OFFICE/GENERATOR//EQUIP BLDG	20600	648900	0	408562	0	0	364345	1421807
360	HVAC MECHANICAL ROOM	17610	554715	0	432278	0	0	315614	1302607
370	SITE SUPPORT	5615	176874	0	166399	883280	0	190392	1416945
SUBTOTAL 3	CONSTRUCTION	366305	11538610	0	7115307	930620	0	6564298	26148835
411	CONSTRUCTION MANAGEMENT	0	0	0	0	3700000	0	0	3700000
SUBTOTAL 4	CONSTRUCTION MANAGEMENT	0	0	0	0	3700000	0	0	3700000
511	PROJECT MANAGEMENT	0	0	0	0	3700000	0	0	3700000
SUBTOTAL 5	PROJECT MANAGEMENT	0	0	0	0	3700000	0	0	3700000
PROJECT TOTAL		366,305	11,538,610	0	7,115,307	18,930,620	18,787,600	7,503,679	63,875,816

2.4.3.5 Pool Water Sterilization

In a pool concept, the ultraviolet lamps for the sterilizers will consume less than 50 kW of power, which is not significant, and is balanced by the difference above due to cranes.

2.4.3.6 Chemical Consumption

The nitrogen consumption for MCO servicing and the decontamination chemical consumption are the same regardless of concept. Because pool water deionizers would not require regeneration as water treatment chemical usage is not significant.

2.5 SCHEDULES

2.5.1 SCHEDULE ASSUMPTIONS

2.5.1.1 General

These schedules are based on the use of the Canister Storage Building (CSB) design and partially completed construction from the Hanford Waste Vitrification Plant (HWVP) Project. Utility tie-ins are available from the completed construction of the HWVP project.

WHC provided the date for start of the engineering studies, the Key Decision 0 date of 10 March 1995, and the date of May 9, 1995 for approval by DOE of the Functions and Requirements (F&Rs) for the project. April 24, 1995 is assumed to be the start of Conceptual Design and Capital funds are assumed to be available in October 1995. The Stabilization Facility is assumed to be operational in December 2002.

This schedule assumes that there will be no annual funding constraints for the duration of the project.

The cost estimates prepared for each alternative provide a basis for each schedule.

An important objective of these schedules was to have the SSF operational and ready to receive MCO's from the K-Basins as rapidly as possible. Aggressive, but achievable schedules were therefore developed.

2.5.1.1.1 Engineering and Design

Maximum use of the existing engineering and design of the CSB and the results of this feasibility study allows the approximately three month duration for conceptual design. New requirements and additional facilities will have minimal impact to the existing facility design and drawings.

Client review changes will have no impact at the end of conceptual engineering and definitive design. Continuous reviews and alignments are required to minimize change.

2.5.1.1.2 Procurement and Construction:

The October 1992 statused Mowat schedule for the CSB was used as a basis for deriving activity durations for completion of the walls, the operating floor and storage tube installation.

The construction of the facility will be performed with specialty subcontractors.

There is no shortage of local craft labor or specialty contractors in the area.

Construction is based on a standard forty hour work week. Scheduled overtime is excluded from this schedule.

The concrete slab and walls that are currently in place will be used with minimal changes required to complete the concrete vault walls and operating floor.

The walls for all vaults will be formed and poured simultaneously.

Rebar for the walls and for the operating floors will be pre-assembled and set in place with cranes.

Structural steel buildings will be prefabricated in shops, and assembled in the field.

There is no shortage of material locally, including concrete batch plant requirements.

Long lead equipment items will be identified very early so as to not delay construction.

There are no shortages of construction equipment in the area.

Reviews by WHC will be concurrent with the design during all phases with a twenty day review continuing after the end of conceptual design.

DOE reviews will be for twenty days after the WHC review period.

Independent cost verifications will be for twenty days after the WHC review and concurrent with the DOE reviews.

ESAAB reviews will take place for twenty-five days subsequent to the DOE reviews and prior to Key decisions one through four.

Safety analysis reports will be generated on a one step SAR basis. Final review and approval extends for a nine month period and approval is required prior to start-up. Construction will be allowed to commence based on approval of a preliminary safety evaluation.

2.5.1.4 Concept 2D

Construction of the operating decks will be concurrent in all three vaults.

Storage tube installation will be concurrent in two vaults.

2.5.2 CONCEPT 2D SCHEDULE

Figure 2-24 contains the schedule for Concept 2D. It shows that, subject to the above assumptions, it is possible to achieve operation of the SSF in December 1997. The entire facility is constructed initially under this concept so there is no second phase of procurement and construction.

2.6 CONCLUSIONS AND RECOMMENDATIONS

2.6.1 FEASIBILITY OF CSB ADAPTATION

The results of this study demonstrate that it is currently not feasible to adapt the design of the CSB to meet the F&Rs of the SSF due to the 100 °F MCO temperature requirement. If a relaxation of the temperature requirement was to occur then construction of the SSF on the CSB site will enable the already completed CSB site clearing and grubbing, site preparation, excavation, base mat and walls to be utilized for the SSF, saving both time and money. Use of the CSB site for the SSF is also consistent with master plans currently being developed for the Hanford Site and the objective of moving the N-Reactor fuel away from the Columbia River.

2.6.2 OTHER TECHNICAL CONCERNS

Relaxation of the 100 °F maximum MCO temperature requirement prior to stabilization would allow further cost reduction alternatives to be considered.

In addition to a relaxation of the MCO Temperature requirement several other technical issues would require further investigation to ensure cost, schedule and safety requirements are achieved including:

- Shielding requirements regarding the empty vault and its future use.

CSB Trade Study
Westinghouse Hanford Company
WHC P.O. TVM-SVV-370252

Fluor Daniel, Inc.
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FIGURE 2-24 (Sheet 1 of 2)
STAGING & STORAGE FACILITY
CONCEPT 2 D - CSB ADAPTATION

Fluor Daniel, Inc.
Government Services
Contract 04436306

- Contact maintenance and servicing of the transport and facility casks due to the high source dose rates.
- RCRA requirements to detect liquid in the annular space between the MCO and staging tubes.
- Microbiological Influenced Corrosion (MIC) affects on the Stainless Steel (SS) MCO due to high MCO temperatures.
- Venting and purging of staging tubes due to hydrogen build-up in the MCOs due to high MCO temperature.
- MCO/Cask drop evaluation over the operating floor.
- Emergency response capability in the event of a sustained loss of cooling, e.g. due to DBE or loss of power, to prevent unacceptable high MCO temperatures.

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2.8 DESIGN BASIS

The following functions and requirements data was furnished by WHC for use as a design basis for this study:

TRANSPORTATION INTERFACES RAIL CAR AND CASK

- SIZE AND WEIGHT OF RAIL CAR: Standard flat-bed rail car
- CASK DIMENSIONS, WEIGHTS, LIFTING POINTS (CASK AND LID):
MCO facility cask: 86.5 tons, lifting trunions on side above center of gravity
- EXPECTED SURFACE CONT. LEVEL: Outside: DOT limits worst case; Inside: K-East Basin water; assume decon from top with cask upright. No tip/flip capability required.
- TIE DOWN POINTS: TBD
- MATERIALS/FINISHES (CASK): 304 SS
- CASK C-G's: Geometric center
- RAIL CAR TRANSPORTATION SAFE GUARD: Standard DOE requirements for SNF
- RAIL CAR POSITIONING TECHNIQUE IN SSF: Designer's choice
- RAIL CAR ATTACHMENT POINTS: TBD for loads; standard couplings front and back.
- STORAGE FACILITY/CASK HANDLING
 - STANDARD RIGGING: Pick cask with rigging fixture
 - SPECIAL TOOLS attached to the crane hook and
 - PICK HEIGHT lifting trunions. Maximum pick height at 2.5x height of cask from floor to bottom of cask.
- MONITORING REQUIREMENTS: Time from MCO closure and cask seal at K-Basins. Visual gauge monitoring of MCO - to - cask seal pressure and internal cask temperature.

- SERVICE REQUIREMENTS
 - AIR
 - WATER TBD, no special requirements
 - POWERS identified
 - IMPACT RECORDING
- NUMBER OF RAIL CARS: 2 cars in the facility at once for cask unload/load cycle and MCO load/unload cycle
- LAG STORAGE REQUIREMENTS
 - RAIL CARS: 2 cars on rail siding outside
 - CASKS: 4 casks; 2 clean, ready for use; 1 contaminated, waiting for decontamination; 1 in the decontamination station.
 - MCO's: 1 week supply at facility: 4/day consumed.
 - RAIL CAR WEIGHT - FULL CASK LOAD: Standard flatbed rail car plus 86.5 tons cask
 - IDENTIFICATION OF ANY OTHER TRANSPORTER CONCEPTS: TBD, assume rail
 - SECURITY NEEDS (LIMITS, ETC.): DOE standards for SNF
 - TRANSPORTER CONVEYANCE
 - LOCOMOTIVES Designer choice inside facility.
 - TRACKMASTER: Locomotive delivery to facility and pick-up from facility.
 - TUGGERS
 - RAIL CAR MATERIALS AND SURFACE FINISH: Assume easily decontamination design to facilitate standard wash-down technologies.
 - CAR IDENTIFICATION AND TRACKING: Visual
 - BRAKE STATUS: Visual indication

MCO INTERFACES

- SIZE: See attached table
- SHAPE: See attached table
- WEIGHT/CG'S: EMPTY/LOADED: See attached table

- MATERIAL AND FINISH CONDITION: 304 SS
- LIFTING POINTS/GEOMETRY: Top of MCO; specifics TBD.
Lifting fixtures compatible with normal crane hook.
- ATTACHMENTS FOR MONITORING: MCO lid
- ATTACHMENTS FOR SERVICES: MCO lid
- DEFINITIONS OF SERVICE REQUIREMENTS:
 - Vent and inert-gas purge MCO upon receipt;
 - Cycle for water addition at 2 MCOs/week after completion of MCO delivery to the SSF
- MONITORING REQUIREMENTS: Temperature of cooling media (must limit MCO temperatures as listed below)
- REQUIRED STORAGE Staging: MCO at 100° F.

CONDITIONS: Storage: Fuel centerline temperature at 400 C.
- IDENTIFICATION Visual identification of MCO, or
REQUIREMENTS: per
DOE standard material
accountability requirements for SNF
- TRACKING REQUIREMENTS: DOE standard material
accountability requirements for SNF
- MINIMUM, MAXIMUM, AVERAGE RADIATION LEVELS: TBD, being calculated
- EXPECTED SURFACE Nominal conditions: clean
CONDITIONS: Upset conditions: K-Basin water contamination
- CRITICALLY CONTROL MCO stacking acceptable, MCO
SPACING: placement side-by-side with no gap acceptable.
- INSPECTION REQUIREMENTS: Receipt inspection: MCO - to -
cask seal verification - visual
gauge observation. MCO seal
verification - visual gauge
observation. Surface contamination
of MCO and cask. MCO weight. MCO
H₂ levels during venting.

- ORIENTATION REQUIREMENTS: VERTICAL +- 10 degrees
- SEALING SURFACES LOCATION/CONFIGURATION/MATERIALS/ etc.:
Top of MCO lid
- ACCELERATION LIMITS: Normal crane operating limits; or
2-g vertical lift, 1-g vertical
lowering, 1-g horizontal, impact
limiters for long vertical
placements.
- SOURCE TERMS
 - RADIOLOGICAL See attached Cowan list.
 - CHEMICAL List must be updated to describe
 - HAZARDOUS minimum MCO source term, % of MCOs
 - LIQUID at minimum levels, sludge source
 - GAS term and # of sludge MCOs. Assume
 - THERMAL sludge MCOs contain RCRAwaste. Assume 100 m³ of sludge.
SSF must meet RCRA waste storage
requirements for sludge MCOs.
- STANDARD RIGGING Deployed from crane hook.
HARDWARE: Designer's choice.
- SPECIAL TOOLS: Deployed from crane hook. Designer's
choice.
- MAXIMUM ALLOWABLE OPERATION PRESSURE: 125 psig prior to
venting. Gas volume 50 liters. Gas venting through
breather filter (air cooling) or water trap (water pool
cooling).
- RESPONSIBILITY FOR MCO OVERPACK DESIGN: SSF designer
- ALLOWABLE PICK ELEVATIONS: 2.5 x MCO height from floor to
bottom of MCO.

MCO Proposed Description
Draft Rev. A R.G. Cowan May 17, 1995
MCO Radio nuclide Inventory

Radio nuclide	Unit	Average	Maximum
U	kg	2,800	3,287
Zr	kg	197	230
Pu	kg	5	100
Sn	kg	3	3
Al	kg	2	3
C	kg	2	2
All Other	kg	4	5
Total Mass For One MCO	kg	3,013	3,630
Co-60	Ci	197	786
Kr-85	Ci	937	2,440
Sr-90	Ci	14,000	27,941
Y-90	Ci	14,000	27,941
Cs-137	Ci	18,000	37,929
Ba-137m	Ci	17,067	35,906
Pm-147	Ci	1,440	8,180
Sm-151	Ci	229	344
Eu-154	Ci	171	804
Pu-238	Ci	167	496
Pu-239	Ci	300	499
Pu-240	Ci	173	378
Pu-241	Ci	7,840	35,021
Am-241	Ci	420	742
All Other	Ci	379	3,283
Total Activity For One MCO	Ci	77,320	182,692

MCO General Attributes

Parameter	Unit	Average	Maximum
Heat ⁽¹⁾	Watt	221	482
Water Weight	kg	963	984
Stainless/Al	kg	1,274	1,314
Total MCO Weight	kg	3,251	3,927
Fuel Volume	L	202	243
MCO Volume	L	1,203	1,265
MCO Fuel Fraction	%	17	19
MCO Length	cm	460	460
MCO Diameter	cm	61.00	62.50
MCO Wall Thickness	cm	1.00	1.00
MCO Top Shield	cm	20	20
Canisters/MCO		10	10
Cask (20 cm iron) Weight ⁽²⁾	kg	20,375	20,763
Loaded Cask & MCO	kg	25,626	26,690
Cask & MCO	tons	28.25	29.42
Fuel Surface	sq. m	37.77	44.34
MCO & Canisters	sq. m	29.17	29.40
Total Inside Surface	sq. m	66.94	73.74

Notes: See Page 2-99

MCO Heat Capacity

Parameter	Unit	Average	Maximum
Uranium	kw-hr/°C	0.10	0.11
Zirconium	kw-hr/°C	0.02	0.03
Stainless steel	kw-hr/°C	0.11	0.18
Water	kw-hr/°C	1.11	1.14
Cask	kw-hr/°C	2.53	2.58
Total	kw-hr/°C	3.95	4.05
@ 10 °C			
Uranium Corrosion	g/d	1.74	20.44
Gas Generation	L/d	0.33	3.85
Reaction Heat	Watt	0.05	0.55
Heat Loss	Watt	36.86	36.86
Temperature Rise	°C/hr	0.05	0.11
@ 25 °C			
Uranium Corrosion	g/d	6.12	71.80
Gas generation	L/d	1.15	13.52
Reaction Heat	Watt	0.17	1.95
Heat Loss	Watt	136.31	136.31
Temperature Rise	°C/hr	0.02	0.09
@ 50 °C			
Uranium Corrosion	g/d	49.63	582.60
Gas generation	L/d	9.34	109.67
Reaction Heat	Watt	1.35	15.80
Heat Loss	Watt	302.06	302.06
Temperature Rise	°C/hr	-0.02	0.05
@ 75 °C			
Uranium Corrosion	g/d	402.68	4,727.41
Gas generation	L/d	79.8	889.87
Reaction Heat	Watt	10.92	128.20
Heat Loss	Watt	467.81	467.81
Temperature Rise	°C/hr	-0.06	0.04
@ 85 °C			
Uranium Corrosion	g/d	930.37	10,922.54
Gas generation	L/d	175.13	2,056.01
Reaction Heat	Watt	25.23	296.20
Heat Loss	Watt	534.11	534.11
Temperature Rise	°C/hr	-0.07	0.06
@ 95 °C			
Uranium Corrosion	g/d	2,149.59	25,236.18
Gas generation	L/d	404.63	4,750.34
Reaction Heat	Watt	58.29	684.35
Heat Loss	Watt	600.41	600.41
Temperature Rise	°C/hr	-0.08	0.14

- (1) Heat generation design feed basis is calculated at 80% of the attributes shown under "Average" and 20% of those shown under "Maximum"
- (2) Cask weight not consistent with requirements to meet shielding.

3.0 TRADE STUDY REPORTS

3.0 TRADE STUDY REPORTS

3.1 TABLE OF CONTENTS

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E	Storage Tube Material Investigation	E
F	MCO Shipment Reduction	F
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3.2 INTRODUCTION

In accordance with the Statement of Work, Revision 5, dated April 21, 1995 in Work Order TVW-SVV-37052, Modification No. 90, individual Trade Study Reports have been prepared and are included in this section. Each report is independent of the others; however, each study is based on requirements defined in the Base Case Concept 2D description, Section 2.0. A cost summary is presented in Table 3-1. The cost and schedule basis for the Trade Studies is identical to that defined in Sections 2-4 and 2-5, of the Base Case Concept 2D.

In terms of the Construction schedule, it appears only Task "H", RCRA Functions: Prevention and Detection of MCO leaks, would have an impact on the proposed construction schedule and date. It is estimated that RCRA compliance would extend the facility completion date by a minimum of two months.

No cost data has been provided for Task "G", Damp-Dried MCO, as the analysis demonstrated that it was not feasible to adapt the CSB to comply with the functions and requirements for the SNF CSB.

CSB Trade Study
Westinghouse Hanford Company
WHC P.O. TVW-SVV-370252

TABLE 3-1
CSB TRADE STUDIES
COST IMPACT BY TASK
(\$ 1995)

Fluor Daniel, Inc.
Government Services
Contract 04436306

	Concept 2D 100' Refig Air 3 Vaults 1 Empty 440 Corten Sig Tubes	Concept 2D Revised (1) 100' Refig Air 3 Vaults 1 Empty 440 Corten Sig Tubes	TASK "A" Facility Confinement Investigation	TASK "B" MCO Receipt and Staging Function and Area Removal	TASK "C" Cask Decon Function and Area Removal	TASK "D" One Track Rail Service	TASK "E" Storage Tube Material Investigation Carbon Steel ⁽²⁾	TASK "F" MCO Shipment Reduction	TASK "G" Damp-Dried MCO	TASK "H" RCRA Functions: Prevention and Detection of MCO Leaks
Load In / Load Out	6,604	6,474	<40>	<2,138>	<778>	0	0	<86>		0
Infrastructure	1,417	1,417	0	0	0	<98>	0	<98>		0
Vault	41,246	37,885	1,751	0	0	0	<2,494>	0		0
Total Direct Cost \$ (1995)	49,267	45,876	1,711	<2,138>	<778>	<98>	<2,494>	<184>		3,000
Engineering	10,400	8,800	496	<621>	<226>	<29>	<412>	<53>		3,000
Title III Inspection	2,200	1,800	68	<86>	<31>	<4>	<100>	<7>		870
Construction Management	4,000	3,700	137	<171>	<62>	<8>	<200>	<15>		120
Project Management	4,000	3,700	137	<171>	<62>	<8>	<200>	<15>		240
Total, 1995 \$	69,867	63,876	2,549	<3,187>	<1,159>	<147>	<3,406>	<274>		240
Erection	4,145	3,796	By WHC	By WHC	By WHC	By WHC	By WHC	By WHC		4,470
Contingency	12,388	11,344	By WHC	By WHC	By WHC	By WHC	By WHC	By WHC		By WHC
Total Estimated Cost (TEC)	86,400	79,016	By WHC	By WHC	By WHC	By WHC	By WHC	By WHC	N/A ⁽³⁾	By WHC

(1) Revised Concept 2D reflects the deletion of the SSF Cask Loader, Storage Gate/Plug Flask Unit and the Donkey Engine from the capital cost estimate. The estimate further reflects mechanical changes to accommodate heavier casks.
(2) Subject to test validation.
(3) Not feasible.

TASK "A" FACILITY CONFINEMENT

FA

CANISTER STORAGE BUILDING
TRADE STUDY REPORT
TASK "A"

FACILITY CONFINEMENT INVESTIGATION

PREPARED FOR WESTINGHOUSE HANFORD COMPANY
RICHLAND, WASHINGTON

PREPARED BY FLUOR DANIEL, INC.

MAY 31, 1995

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1.0 OBJECTIVE

The objective of Trade Study Task "A" is to investigate the requirements for a Safety Class 1 (SC-1) confinement of the operating area above the storage vault.

2.0 SUMMARY

A SC-1 HVAC system is provided for the Operating Area which is capable of maintaining negative pressure during normal and Design Basis Accident (DBA) conditions. The Operating Area structure will be upgraded for SC-1. Emergency power is provided to the HVAC system and the associated equipment by a class 1E emergency generator system. A minimum of two trains are required to meet the single point failure criterion associated with safety class systems. It is estimated that \$1.7 million in direct cost and \$840,000 in Engr/PM/CM cost will be added to the construction cost to provide SC-1 operating requirements. Should the safety analyses determine the site helicopter crash and design basis fire are credibly, then the cost of the SC-1 structures would increase.

3.0 FACILITY DESCRIPTION AND EVALUATION

3.1 Structural

The facility structural system and materials of construction for Task A requirements will be essentially the same as that of Concept 2D. The SC-1 confinement of the operating floor area above the storage vaults requires the structure to be classified as SC-1 also. The existing shelter is classified as SC-3 structure but designed for SC-1 Design Basis Earthquake (DBE) anchored at 0.35g Peak Ground Acceleration (PGA) to prevent collapse over the concrete vault. In addition to DBE, the building will have to be evaluated for other DBAs such as design basis wind, ashfall, fire, and wind generated missile. The operating shelter building structural steel, siding and roof deck cost would increase by approximately 10 percent. Current safety analysis has assumed fire as being not credible within the operating area. Should future fire hazard analysis be shown as credible, the building steel framing system will have to be fireproofed to provide 2 hour resistance rating.

The existing wall system, consisting of corrugated 22 gage steel exterior panel and 22 gage flat liner interior panel with insulation between them, would be specified to provide an adequately sealed enclosure for maintaining negative air pressure within the building. If for SC-1 the site security helicopter crash is considered credible, as it was for the

HWVP project, the steel building will not meet this requirement. A concrete structure of 24 to 36 inch thick walls and roof would be required for helicopter crash. If the helicopter crash becomes a requirement it would add a significantly to the facility cost, and add 2 to 3 months to the design/construction schedule.

Section 1320-5.4 of DOE 6430.1A states that irradiated fissile material storage facilities need not be protected from missiles, but shall be designed from massive collapse of the building structure or the dropping of heavy objects on to the stored SNF as a result of building structural failures. This requirement could be met by designing to SC-1 DBAs.

The mechanical room containing the SC-1 HVAC equipment and the emergency generator room will be designed to withstand the NPH forces appropriate for SC-1 requirements.

3.1.1 Structural Issues

The structural issues described for concept 2D, Section 2.2.1, are also applicable to this task. In addition the two DBA's, fire and helicopter crash, if determined credible would impact significantly the building cost since a concrete structure would be necessary for conforming to these DBAs. The requirements for other DBAs can be met with some modification to the existing operating steel shelter.

3.2 HVAC System

The block flow diagram for the HVAC System for the Operating Area is shown on Figure 3-1. This HVAC system is designed to provide confinement in the operating areas during normal and DBA conditions. The HVAC supply system consists of two 18,000 CFM air handling units (AHU-1 and 2) and the exhaust system consists of exhaust fans (EF-1 and 2) and two stage HEPA filter plenums (PF-1,2,3 and 4). The capacity of each filter plenum is 9,000 CFM. The system is capable of diluting the hydrogen and Kr-85 to acceptable levels by introducing sufficient amounts of outside air. The air from the Operating Area is exhausted to the atmosphere through a SC-1 exhaust stack. Following a DBA only one train of the exhaust system which is SC-1 is required to operate. The building layout shown on Figure 3-2 has been modified to accommodate the additional space required to handle the SC-1 HVAC system.

3.3 Electrical System

Based on the requirements of the SC-1 HVAC system and the associated equipment required to maintain confinement following a DBA, the size of the emergency SC-1 generators is

estimated at 80 KW. This is based on the assumption that no heating is required after a DBA event. The additional space required to accommodate the generators and associated electrical and control equipment is indicated on Figure 3-2.

3.4 Plot Plans

A plot plan for the Concept 2D is shown on Figure 3-2. This overall plan includes the additional requirements for a SC-1 HVAC confinement system, emergency generators and the associated equipment.

4.0 SCHEDULE

Provided a site helicopter crash is determined not to be a credible accident, no impact is anticipated to the facility completion date indicated in the Concept 2D base case.

5.0 COST ESTIMATE

The structural steel costs for the operating shelter will increase by approximately 10 percent, for the Operating HVAC Mechanical Area by 20 percent, and for the Emergency Generator Area by 20 percent due to SC-1 design requirements. No allowance for fireproofing and helicopter crash is included at this time.

The assumptions, exclusions, and basis for the estimate remain the same as for the Concept 2D Feasibility Study. The difference in the direct cost from the baseline Concept 2D estimate is:

Structures,	add	\$ 131,000
HVAC,	add	\$ 517,000
Elect,	add	\$ 101,000
I&C,	add	\$ 962,000
	Subtotal	\$ 1,711,000
Engr/PM/CM,	add	\$ 838,000
Total direct cost addition		\$ 2,549,000

6.0 REFERENCES

"Staging and Storage Facility Feasibility Study Final Report", Fluor Daniel, Inc., February 1995.

Statement of Work, "Trade Studies for the Evaluation of HWVP Canister Storage Building for Spent Nuclear Fuels", Rev. 5, April 21, 1995.

WHC-SNF-FRD-014, May 1995, Section 3.2.2.1.2.2, Rev. A, "Draft Performance Specification for the Spent Nuclear Fuel Canister Storage Building" (Contains tabular data from R. G. Cowan of WHC on proposed MCO description).

FIGURE 3-1
CANISTER STORAGE BUILDING
TASK "A"
OPERATING AREA
HVAC SYSTEM - POTENTIALLY CONTAMINATED AREA (SC-1)

CA 5-30-95

CADFILE 2DITASKA

TASK "B" MCO STAGING AREA REMOVAL

CANISTER STORAGE BUILDING
TRADE STUDY REPORT
TASK "B"

MCO RECEIPT AND STAGING FUNCTION AND AREA REMOVAL

PREPARED FOR WESTINGHOUSE HANFORD COMPANY
RICHLAND, WASHINGTON

PREPARED BY FLUOR DANIEL, INC.

MAY 31, 1995

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Figure 3-1	CSB Trade Study, Task "B", Floor Plan B-4

TB- ii

1.0 OBJECTIVE

The objective of Trade Study Task "B" is to determine the effects of changing the Base Case Concept 2D by removing the MCO Receipt and Staging Function and Area.

2.0 SUMMARY

The results of this study show that the receipt and staging function and area can be removed from the SSF provided the MCO is shipped in a bottom loading cask and that the MCO is serviced (purged and water level checked) before shipping. The size of the receipt and staging area would be smaller. It is estimated that approximately \$3.2 million may be saved by not constructing this area; however, no reduction in the completion schedule is anticipated.

3.0 FACILITY DESCRIPTION AND EVALUATION

3.1 Plot Plans

Figure 3-1 shows the floor plan of Concept 2D SSF with Trade Study Task B. This is the same as the original feasibility study base case Concept 2D except for the Rail Tunnel/Cask Unloading Area.

3.2 Rail Tunnel/Cask Unloading Area

3.2.1 General Description

The Rail Tunnel/Cask Unloading Area is a facility of about 4,000 square feet attached to the CSB at the northwest corner. This facility interfaces with the MCO Storage Tube Area via a transfer cart. The main functions of this area are to safely receive and handle incoming MCOs for placement in the storage tubes prior to stabilization. The packaged MCOs are delivered inside a bottom loading transport/facility cask via rail car or truck one at a time.

The bottom loading transport/facility cask will be similar to the bottom loading MCO shield cask as described in the base case except that it must also be designed as a shipping cask.

The Rail Tunnel/Cask Unloading Area will be used as a wash area cask unloading/loading for rail cars and loading on to the transfer cart.

Two railroad cars and a truck trailer parked in parallel can be accommodated inside. A permanent ceiling installed liquid spray arrangement allows wash/decon of the shipping cask upper

section. Hand held wash/decon lances are available for the lower areas.

The casks will be unloaded from the railroad cars or truck and loaded on to a transfer cart. A 120 ton overhead crane, with a 10 ton auxiliary hoist running in the east/west direction services this area. The transfer cart runs on rails at floor level and transfers the bottom loading transport/facility cask between the rail tunnel/cask unloading area and the canister storage operating area.

3.3 Findings

3.3.1 Impacts

The size of the Rail Tunnel/Cask Unloading Area is reduced from the base case Concept 2D of approximately 10,000 to 4,000 square feet for Task B.

The bridge crane in the Rail Tunnel/Cask Unloading Area must have a larger capacity to handle the heavier cask. For Task B the crane would have a capacity of 120 tons vs 110 for the base case.

For the base case only one bottom loading handling cask is required but for Task B approximately 6 are required.

3.3.2 Advantages/Disadvantages

The advantages of removing the MCO receipt and staging function and area are:

- Smaller and less costly building.
- No water pools and associated water treatment system.
- No below grade pits in the Rail Tunnel/Cask Unloading Area.
- No MCO servicing area.

The disadvantages of removing the MCO receipt and staging function and area are:

- Capacity of the bridge crane increases.
- The design of the bottom loading transport cask will be more complicated than a bottom loading facility cask.
- Increase the number of casks.

3.3.3 Concerns/Uncertainties

The concern of removing the MCO receipt and staging area is:

- With no MCO servicing stations the MCO cannot be purged or water level checked and adjusted at the SSF.

There are no uncertainties with removing the MCO receipt and staging area at this time.

4.0 SCHEDULE

With the size and complexity reduction of the Rail Tunnel/Cask Unloading and with the removal of the MCO Receipt and Staging Area no impact is anticipated to the facility completion date as indicated in the Concept 2D base case.

5.0 COST ESTIMATE

Assumptions, exclusions, and basis for the estimate remain the same as for the Concept 2D Feasibility Study. The difference in the direct cost from the baseline Concept 2D estimate is:

Structures, deduct	<\$ 570,000>
Mechanical, deduct	<\$ 1,568,000>
Engr/PM/CM, deduct	<\$ 1,049,000>
Total direct cost reduction	<\$ 3,187,000>

6.0 REFERENCES

"Staging and Storage Facility Feasibility Study Final Report", Fluor Daniel, Inc., February 1995.

Statement of Work, "Trade Studies for the Evaluation of HWVP Canister Storage Building for Spent Nuclear Fuels", Rev. 5, April 21, 1995.

WHC-SNF-FRD-014, May 1995, Section 3.2.2.1.2.2, Rev. A, "Draft Performance Specification for the Spent Nuclear Fuel Canister Storage Building" (Contains tabular data from R. G. Cowan of WHC on proposed MCO description).

CSB TRADE STUDY
 TASK "B"
 FLOOR PLAN
 FIGURE 3-1

CADFILE: 2DTASKB

CA 5-30-95

TASK "C" DECON AREA REMOVAL

Co

CANISTER STORAGE BUILDING
TRADE STUDY REPORT
TASK "C"

CASK DECONTAMINATION FUNCTION AND AREA REMOVAL

PREPARED FOR WESTINGHOUSE HANFORD COMPANY
RICHLAND, WASHINGTON

PREPARED BY FLUOR DANIEL, INC.

MAY 31, 1995

COO

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1.0 OBJECTIVE

The objective of Trade Study Task "C" is to determine the effects of changing the original feasibility study Base Case Concept 2D by removing the cask decontamination function and area (wash area).

2.0 SUMMARY

The results of removing the cask decontamination function and area will reduce the size of the receipt area and amount of equipment. It is estimated that approximately \$1.2 million may be saved by not constructing this area; however, no reduction in the completion schedule is anticipated.

3.0 FACILITY DESCRIPTION AND EVALUATION

3.1 Plot Plans

Figure 3-1 shows the floor plan of the Concept 2D SSF with Trade Study Task "C". This is the same as base case Concept 2D except for the removal of the wash area from the Rail Tunnel/Cask Unloading Area.

3.2 Rail Tunnel/Cask Unloading Area

3.2.1 General Description

The Rail Tunnel/Cask Unloading Area is a facility of about 6,600 square feet attached to the CSB at the northwest corner. This facility interfaces with the MCO Storage Tube Area via a covered water canal as shown in Figure 3-1. This task is the same as the base case except for the following changes:

- Removal of the wash area and its associated pumps, tanks, and holding tanks.

3.3 Findings

3.3.1 Impacts

The size of the Rail Tunnel/Cask Unloading Area is reduced from the base case of approximately 10,000 to 6,600 square feet.

The cycle time for the MCO/Transport Cask within the Rail Tunnel/Cask Unloading Area would be reduced by about 2 hours by removing the wash area.

3.3.2 Advantages/Disadvantages

The advantages of removing the wash area are:

- Smaller building.
- Less equipment required to service incoming shipments.

No disadvantages have been determined at this time.

3.3.3 Concerns/Uncertainties

There are no concerns or uncertainties at this time.

4.0 SCHEDULE

With the size and complexity reduction of the Rail Tunnel/Cask Unloading Area and with the removal of the decontamination area no impact is anticipated to the facility completion date as indicated in the Concept 2D base case.

5.0 COST ESTIMATE

Assumptions, exclusions, and basis for the estimate remain the same as for the Concept 2D Feasibility Study. The difference in the direct cost from the baseline Concept 2D estimate is:

Structures, deduct	<\$ 635,000>
Mechanical, deduct	<\$ 143,000>
Engr/PM/CM, deduct	<\$ 381,000>
Total direct cost reduction	<\$ 1,159,000>

6.0 REFERENCES

"Staging and Storage Facility Feasibility Study Final Report", Fluor Daniel, Inc., February 1995.

Statement of Work, "Trade Studies for the Evaluation of HWVP Canister Storage Building for Spent Nuclear Fuels", Rev. 5, April 21, 1995.

WHC-SNF-FRD-014, May 1995, Section 3.2.2.1.2.2, Rev. A, "Draft Performance Specification for the Spent Nuclear Fuel Canister Storage Building" (Contains tabular data from R. G. Cowan of WHC on proposed MCO description).

CSB TRADE STUDY
TASK "C"
FLOOR PLAN
FIGURE 3-1

CADFILE: 2DTASKC

CA 5-30-95

TASK "D" ONE TRACK RAIL SERVICE

①

CANISTER STORAGE BUILDING
TRADE STUDY REPORT
TASK "D"

ONE TRACK RAIL SERVICE

PREPARED FOR WESTINGHOUSE HANFORD COMPANY
RICHLAND, WASHINGTON

PREPARED BY FLUOR DANIEL, INC.

MAY 31, 1995

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1.0 OBJECTIVE

The purpose of Trade Study Task "D" was to determine changes to facility functions, technical requirements, identify risk and safety issues, and evaluate the impacts to the cost estimate, and design/construction schedule due to simplification of the rail service to one track with a passing track outside the facility, versus two tracks used in the original feasibility base case Concept 2D.

The work was performed under Task "D" of the Statement of Work, Revision 5, dated April 21, 1995 in Attachment 1 to WHC Work Order TVW-SVV-370252, Modification 090.

2.0 SUMMARY

Except for the smaller size of the railcar Wash Area and the Cask/MCO Unloading and Storage Area due to the elimination of one track within the facility, there are no significant changes to facility functions and technical requirements. The risks, technical and safety issues as enumerated in the Concept 2D Feasibility Study Report remain unchanged. There is no impact to the design and construction schedule as given for the base case.

The Cask/MCO transportation on one track into the facility will be able to handle 3.4 shipments per day as opposed to 4 in Concept 2D. The reduction in the estimated direct cost of the facility from the Concept 2D case will be approximately \$98,000.00 and the cost of Engr/PM/CM is approximately \$49,000.

3.0 FACILITY DESCRIPTION AND EVALUATION

3.1 Plot Plan

Figure 3-1 shows the master site plan for Task "D" for the one rail spur entering the CSB. The overall plot showing various buildings floor plans is shown in Figure 3-2 with the reduced footprint of the Wash Area and the Cask/MCO Unloading Area Buildings. A Change Room area has been added.

3.2 System Descriptions

The facility system descriptions are similar to those given in the Concept 2D Feasibility Study Report. The elimination of one rail track will reduce the track length by about 250 feet; reduce the Cask Wash Area by approximately 1040 square feet; and reduce the Cask/MCO Unloading and Storage Area by about 640 square feet. A 1550 square foot area has been added for

the Change Rooms between the Cask/MCO Unloading and the Equipment/Office Buildings.

There will be some change in the material flow in the Cask Wash and Unloading Areas when using one rail track. It is possible to receive and handle 1 Cask/MCO every 7 hours (3.4 per 24 hour workday). Figures 3-4 and 3-5 depict the tasks, sequences, equipment, and estimated time required to perform the tasks.

3.3 Facility Issues

The facility issues and concerns described for the Concept 2D Feasibility Study are also applicable to this Task "D" study. A single rail system in the facility is able to handle 3.4 Casks/MCOs per 24 hour workday.

4.0 SCHEDULE

The design/ construction schedule for the Concept 2D Feasibility Study is also applicable to this Task study and no new impacts are identified.

5.0 COST ESTIMATES

Assumptions, exclusions, and basis for the estimate remain the same as for the Concept 2D Feasibility Study. The difference in the direct cost from the baseline Concept 2D estimate is:

Structures, add	\$ 4,000
Railroad, deduct	<\$ 102,000>
Engr/PM/CM, deduct	<\$ 49,000>
Total direct cost reduction	<\$ 147,000>

6.0 REFERENCES

"Staging and Storage Facility Feasibility Study Final Report",
Fluor Daniel, Inc., February 1995.

CSB TRADE STUDY
TASK "D"
MASTER SITE PLAN
FIGURE 3-1

CORRECTION 1 CA 3-30-95

HANFORD PLANT GRID
 200 EAST AREA DATUM

CSB TRADE STUDY
 TASK "D"
 FLOOR PLAN
 FIGURE 3-2

CADFILE: 2DTASKD

CA 5-30-95

STAGING MATERIAL FLOW DIAGRAM, IN RAIL TUNNEL/CASK UNLOADING AREA

FIGURE 3-3
TASK "D"

GRAPHIC 3001-1

CSB Trade Study
Westinghouse Hanford Company
WHC P.O. TW-5V-370252

Fluor Daniel, Inc.
Government Services
Contract 04436306

SHIPPING CASKS & MCOS

▨ DONKEY ENGINE

▩ 110T/10T CRANE

▤ UNLOADING POOL JIB CRANE

▥ LOADING PIT JIB CRANE

○ SEQUENCE #s FROM STAGING MATERIAL FLOW DIAGRAM, FIG. 3-3

TIME PERIOD (HOURS)

FIGURE 3-4

TASK "D"

STAGING MATERIAL TIME STUDY
IN CASK UNLOADING & STORAGE AREA

TASK "E" STORAGE TUBE MATERIAL

E

CANISTER STORAGE BUILDING
TRADE STUDY REPORT
TASK "E"

STORAGE TUBE MATERIAL INVESTIGATION

PREPARED FOR WESTINGHOUSE HANFORD COMPANY
RICHLAND, WASHINGTON

PREPARED BY FLUOR DANIEL, INC.

MAY 31, 1995

EO

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1.0 OBJECTIVE

1.1 Background

The Canister Storage Building as originally designed in 1992 for the Hanford Waste Vitrification Project contained storage tubes made of ASTM A242 weathering steel (e.g., Corten brand by U.S. Steel). During the Staging and Storage Facility Feasibility Study, stainless steel tube material was proposed for the options involving water-filled tubes. Stainless steel was chosen based on 50 °F deionized water in the tubes and a 40-year design life. The Feasibility Study Final Report noted the unresolved technical issue of corrosion of the stainless steel in stagnant (oxygen-depleted) water.

The objective of the trade studies is to resolve technical issues related to the usage of the Canister Storage Building to safely stage and store N-Reactor spent fuel now located at K-Basin 100KW and 100KE. The Trade Study Task "E" Statement of Work is to determine the technical feasibility of non-stainless steel water-filled storage tubes and recommend material to resist wet corrosion for only 7 years versus 40 years.

1.2 Purpose and Need

Although the building will be used for 40 years (or more), the staging phase when the tubes could be filled with water will not exceed 7 years. Each of the three vaults in the original design contains 220 tubes. The present fabricated cost of each stainless steel tube was estimated to be \$43,300, compared to \$17,100 for weathering steel. Carbon steel would cost 30% less than weathering steel. The installed cost of stainless tubes would be a major portion of the total building cost. As noted in the Feasibility Study Final Report, corrosion of stainless steel is possible in stagnant water.

2.0 SUMMARY

A review of literature on corrosion due to stagnant water revealed a threat to not only the storage tubes, but also the inside and outside of the MCOs. Pitting corrosion of stainless steel in oxygen-depleted water is well-known, as is the fact that this form of corrosion is accelerated by bacterial action. The iron-oxidizing bacteria which accelerate the corrosion are found in spent fuel storage pools. The rate of local corrosion is unpredictable, ranging from slight pitting to complete penetration within a few years.

Although the options for tube design are discussed below, none of these options solves the more important problem of corrosion of the MCO from the inside by stagnant water.

Any option with water-filled tubes requires the addition of a system for detecting that a tube leak has occurred and finding the leaky tube. Even a single undetected tube failure might have severe consequences if this could also cause MCO failure due to high temperature, which might result in contamination of the concrete vault around the tubes. The tube-leak detection system is yet to be defined, subject to many safety and feasibility issues. The building must contain features necessary for recovery and clean-up in the event of leakage.

If the water in each of the tubes is treated and regularly monitored to maintain the pH above 10.5 with an acceptable concentration of biocide, then it is likely that there will be no unacceptable corrosion due to stagnant water when the tubes are constructed of bare carbon steel or weathering steel. Weathering steel (such as Corten) probably would be suitable for staging and storage. Weathering steel was determined to be preferable to carbon steel for HWVP storage. The impact absorbers in the tubes would have to be redesigned so that when water treatment chemicals are added, the chemicals will mix evenly between the top and bottom of the tube. Because of the uncertainty intrinsic to corrosion prediction in these circumstances, and the severe consequences associated with tube failures, further investigation is recommended. Corrosion literature should be searched for reports of corrosion of stainless steel and weathering steel (or carbon steel) in stagnant treated water. Testing is recommended to verify the material choice and to determine the required interval for monitoring and replenishing the treated water.

If further investigation shows that it is not practical to treat and monitor the water in the individual tubes, then the only design using well-developed technology (known to Fluor Daniel) which assures the integrity of all tubes and MCOs over a period of 7 years requires an interconnecting water circulation system and stainless steel tubes. Other possible designs are more expensive, require development/testing and/or involve a significant chance of at least one tube failure caused by undetected damage during MCO insertion. Epoxy coating is an option which appears acceptable, subject to verification that there is no problem with dry MCO damage during MCO placement.

Although it may be feasible to connect the tubes and circulate treated water through them, this design is more expensive than the base case, and therefore is a step in the wrong direction. A system of connected tubes is functionally similar to an

expensive version of the open pool Alternative 1 of the Feasibility Study. Rather than estimate the cost of an undesirable option, it should suffice to say that the cost would exceed that of Alternative 2A in the Feasibility Study.

3.0 FACILITY DESCRIPTION AND EVALUATION

3.1 System Description

The N-Reactor fuel consisted of uranium metal with zirconium cladding. The spent fuel has been stored underwater in the east and west K-Basin pools in order to cool the fuel and prevent contact with air. Uranium metal can react with air in an uncontrolled, highly-exothermic (pyrophoric) manner. This pyrophoric reaction could destroy the fuel containers and release the spent fuel in the form of smoke. During the staging phase of operation, metallic fuel contained in stainless steel Multi-Canister Overpacks (MCOs) will be maintained at 100 °F or less in the tubes using refrigerated forced-air cooling on the outside of the tubes. Although it is not essential to have water in the tubes, water is by far the cheapest and most effective heat transfer fluid. The use of other fluids in the tubes (such as air, nitrogen, helium, or fluorocarbons) will result in greater cooling flow requirements or higher MCO temperatures. Later, the fuel will be removed and stabilized in an adjacent facility. In the stabilization process, fuel surfaces are oxidized to prevent further reaction and to allow higher-temperature storage. Then, in the storage phase, the returned stabilized fuel in MCOs will be stored in dry tubes and maintained at 400 °F or less by natural convection of outside air.

An MCO is inserted into a tube by an overhead crane equipped with a grapple which grips the top of the MCO. The MCO dimensions are 24" OD and 15'-1" long. The maximum MCO weight is 13,100 lb. The maximum heat generation rate is 482 W per MCO.

Figure 3-1 shows a typical tube with two MCOs. The top of the tube is covered with a concrete shielding plug. The plug is moved aside when an MCO is inserted. The plug seals the tube, but contains two valved tubing connections. One connection could allow the gas space above the MCOs to be monitored and purged during operation. The other connection has a HEPA filter and would be attached to a relief valve to vent the tube before gas pressure could lift the plug. Below the plug is an embedded funnel which aligns the MCO into the tube during insertion.

Two MCOs will fit in each storage tube, which is 34'-3" from the base to the funnel. The bottom 23'-4" of the tube is 27"

FIGURE 3-1
TASK "E"
STORAGE TUBE CONTAINING MCOs

E - 4

CADFILE: P1023-1

ID and 28" OD. The top of the tube is 29" ID and 30" OD. Stainless steel impact absorbers about 18" high are installed under each MCO in case an MCO is dropped. Stagnant, deionized water at approximately 100 °F would cover the MCOs. With two MCOs in place, the water volume is 24.8 cubic feet or 185 gallons.

3.2 Evaluation

Concern for the design of water-filled tubes is not the general corrosion of the carbon steel tubes but the Microbiologically Influenced Corrosion (MIC) of the carbon steel or weathering steel tubes and the stainless steel MCOs due to stagnant water.

MIC is a well-known corrosion phenomenon and is recognized as a serious problem affecting industrial facilities, including nuclear sites. MIC was a major concern of Westinghouse Hanford Company on the HWVP project, based on experience reported by the Tennessee Valley Authority with stainless steel piping (Guthrie and Kuzniak). With the wet design, the carbon steel tubes and the stainless steel canisters (inside and outside) are at risk of MIC. The corrosion could range from minor pitting to complete through-wall penetrations.

Methods of preventing MIC are having constant flow above 5 ft/sec to prevent microbes and nutrients from accumulating on the materials surface, treating the water with a biocide to control microbial population, raising the pH to 10.5 or greater, or applying cathodic protection. An effective monitoring program is essential in controlling microbial population.

Provided MIC is prevented, one option for the material of construction for stagnant water-filled storage tubes is carbon steel. Weathering steel, ASTM grade A242, is also acceptable but more expensive. General corrosion of carbon steel tubes is not a major concern due to the fact that the extent of corrosion is dependent on the amount of water and surface area exposed to the water. Carbon steel will only corrode until the dissolved oxygen is consumed. The extent of penetration of corrosion is 0.0006 inch per sq. in. of surface per gallon of water. With the large amount of surface area and the rather small amount of water (approximately 185 gallons) the carbon steel would perform satisfactorily in this application. If MIC is prevented and the corrosion products derived from general corrosion are not a problem, then carbon steel is an acceptable material for the tubes.

Alternative material to eliminate or reduce the corrosion products and possibly avoid MIC of the tubes could be epoxy-

coated carbon steel or bare carbon steel with cathodic protection. If epoxy-coated carbon steel is considered the design must incorporate the standard preparation techniques such as rounded corners, contoured welds and clean base metal surface. Any pinhole flaw in the coating would result in rapid corrosion of the steel behind the flaw. Coating flaws during fabrication can be detected by holiday testing (electric discharge testing). Damaging of the coating during canister placement seems likely with the current placement mechanism shown in the feasibility study. However, a soft protective bumper around the bottom edge of the MCO could be added to protect the coating during placement. The feasibility of cathodic protection for this application requires further consideration of maintainability. Most importantly, protection of the tubes does not solve the more serious problem of corrosion of the MCO.

From a corrosion viewpoint, it would be best to eliminate water as a cooling media for the MCO. If a change is not possible because of heat transfer limitations, methods of preventing MIC should be implemented. Prevention of MIC would require a method of circulating biocide-treated water between tubes or monitoring the water quality in each tube. Treating or monitoring the water inside the MCO would be required, which might be a difficult or costly task. If MIC cannot be prevented, materials with an assured resistance to MIC must be investigated and tested. The referenced report by Guthrie and Kuzniak suggests that titanium may be a suitable material.

4.0 SCHEDULE

The choice of storage tube material does not affect the design or construction schedule of the revised Canister Storage Building.

5.0 COST ESTIMATES

If unacceptable corrosion of the MCO and tube cannot be prevented by treatment and monitoring the water in each tube, the cost of circulating treated water through the tubes to avoid stagnant conditions will exceed that of Alternative 2A in the Feasibility Study. Although this water-circulation option will prevent unacceptable corrosion of the storage tubes, it does not address internal corrosion of the MCO by stagnant water.

If the water in the tubes can be treated and monitored to prevent unacceptable corrosion by stagnant water, then weathering steel (such as Corten) is suitable for the tubes. This design has been estimated as Concept 2D.

The assumptions, exclusions, and basis for the estimate remain the same as for the Concept 2D Feasibility Study. The difference in the direct cost from the baseline Concept 2D estimate is:

<u>OPTION</u>	<u>DIRECT COST</u>	<u>ENGR/PM/CM</u>	<u>TOTAL DIRECT COST</u>
Titanium	\$ 40,736,000	\$ 15,797,000	\$ 56,533,000
Epoxy Coating	\$ 1,400,000	\$ 543,000	\$ 1,943,000
Carbon Steel	<\$ 2,494,000>	<\$ 912,000>	<\$ 3,406,000>

6.0 REFERENCES

P.V. Guthrie and W.C. Kuzniak, "Are Our Pipes Safe From Microbiologically Influenced Corrosion?"

Hanford Waste Vitrification Project, memo from Kishor Shah to N.H. Williams, "Project Wide Concern, MIC Impact," 7/8/92.

Hanford Waste Vitrification Project, mechanical drawings for the Canister Storage Building: H-2-120142, -120394, -120395, and -120397, Rev. 0 (Approved for Construction), 8/28/92.

"Staging and Storage Facility Feasibility Study Final Report", Fluor Daniel, Inc., Feb. 1995.

Statement of Work, "Trade Studies for the Evaluation of the HWVP Canister Storage Building for Spent Nuclear Fuels," Rev. 5, 4/21/95.

WHC-SNF-FRD-014, May 1995, Section 3.2.2.1.2.2, Rev. A, "Draft Performance Specification for the Spent Nuclear Fuel Canister Storage Building" (Contains tabular data from R. G. Cowan of WHC on proposed MCO description).

TASK "F" MCO SHIPMENT REDUCTION

F

CANISTER STORAGE BUILDING
TRADE STUDY REPORT
TASK "F"

MCO SHIPMENT REDUCTION

PREPARED FOR WESTINGHOUSE HANFORD COMPANY
RICHLAND, WASHINGTON

PREPARED BY FLUOR DANIEL, INC.

MAY 31, 1995

F₀

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1.0 OBJECTIVE

The objective of Trade Study Task "F" is to determine the effects of changing the original Feasibility Study Base Case Concept 2D by reducing MCO shipments from 4 to 2 per day.

2.0 SUMMARY

The results of reducing the MCO shipments from 4 to 2 reduces the size of the receipt area by removing one of the two railroad tracks coming into the building and reduces the quantity handling equipment. It is estimated that approximately \$274,000 may be saved by not constructing this area; however, no reduction in the completion schedule is anticipated.

3.0 FACILITY DESCRIPTION AND EVALUATION

3.1 Plot Plans

Figure 3-1 shows the outline of Concept 2D SSF with Trade Study Task "F". This is similar to the base case Concept 2D except for the Rail Car Wash Area and Rail Tunnel/Cask Unloading Area.

3.2 Rail Tunnel/Cask Unloading Area

3.2.1 General Description

The Rail Tunnel/Cask Unloading Area is a facility of about 8,000 square feet attached to the CSB at the northwest corner. This facility interfaces with the MCO Storage Tube Area via a covered water canal as shown in Figure 3-1.

This task is the same as the base case except for the following changes:

- Only one MCO servicing station is required.
- The size of the clean MCO/MCO Overpack/Cask Storage Rack can be reduced to 1/2 of the base case rack.
- The Unloading Pool Jib Crane and the Cask Loading Pit Jib Crane are not required. The operations performed by the jib cranes can be done by the 10 ton hoist on the bridge crane because of the reduced use of this crane.
- Only one rail track is required to service the 2 shipments per day.

The operations for Task "F" within the Rail Tunnel/Cask Unloading Area will be the same as the base case.

3.3 Findings

3.3.1 Impacts

The size of the Rail Tunnel/Cask Unloading Area including the wash area, is reduced from the base case Concept 2D of approximately 10,000 to 8,100 square feet.

Only one rail track is required.

3.3.2 Advantages/Disadvantages

The advantages of two MCO shipments per day are:

- Smaller building.
- Less handling and servicing equipment for the MCOs.

The disadvantage of two MCO shipments per day is:

- It will take longer to remove the spent nuclear fuel from K-Basins.

3.3.3 Concerns/Uncertainties

There are no additional concerns or uncertainties from the base case.

4.0 SCHEDULE

With the reduction in the size and complexity of the Rail Tunnel/Cask Unloading Area no impact on the schedule is anticipated from Concept 2D.

5.0 COST ESTIMATE

Assumptions, exclusions, and basis for the estimate remain the same as for the Concept 2D Feasibility Study. The difference in the direct cost from the baseline Concept 2D estimate is:

Structures, deduct	<\$ 98,000>
Mechanical, deduct	<\$ 86,000>
Engr/PM/CM, deduct	<\$ 90,000>
Total direct cost reduction	<\$ 274,000>

6.0 REFERENCES

"Staging and Storage Facility Feasibility Study Final Report",
Fluor Daniel, Inc., February 1995.

Statement of Work, "Trade Studies for the Evaluation of HWVP
Canister Storage Building for Spent Nuclear Fuels", Rev. 5,
April 21, 1995.

WHC-SNF-FRD-014, May 1995, Section 3.2.2.1.2.2, Rev. A, "Draft
Performance Specification for the Spent Nuclear Fuel Canister
Storage Building" (Contains tabular data from R. G. Cowan of
WHC on proposed MCO description).

CSB TRADE STUDY
TASK "F"
FLOOR PLAN

FIGURE 3-1

CAD FILE: 2DTASKF

CA 5-30-95

TASK "G" Damp Dried MCD

G

CANISTER STORAGE BUILDING
TRADE STUDY REPORT
TASK "G"

DAMP-DRIED MCO

PREPARED FOR WESTINGHOUSE HANFORD COMPANY
RICHLAND, WASHINGTON

PREPARED BY FLUOR DANIEL, INC.

MAY 31, 1995

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1.0 OBJECTIVE

The objective of Trade Study Task "G" is to evaluate handling and staging requirements for MCOs shipped drained, damp-dried from K-Basin. Determine cooling requirements for a refrigerated air system during staging operations and investigate natural circulation cooling system during storage operations.

2.0 SUMMARY

The results of the thermal analyses for MCOs shipped drained, damp-dried from K-Basin for staging in 2-vaults indicates that it is not feasible to maintain MCO temperatures at 100 °F with a refrigerated forced air system. However, during the storage operation the MCO temperature can be maintained at 270 °F by a passive ventilation system, this is below the limiting criteria of 400 °F for storage operations.

3.0 EVALUATION OF MCO HANDLING/STAGING AND COOLING REQUIREMENTS

3.1 Evaluation of MCO Handling and Staging

There will be no significant impact in the conceptualized parameters for handling and staging of MCO's in the Concept 2D.

The immediate affect on handling a dry MCO will be an approximate 1 ton reduction in weight of a loaded transportation cask due to the weight of water. This reduction is not considered large enough to re-size the cask handling cranes for this trade study.

3.2 Evaluation of MCO Cooling Requirements

This section documents the results of a series of thermal analyses that were performed to assess the feasibility of meeting the Multi-Canister Overpack (MCO) temperature requirements during dry staging with the Concept 2D Staging and Storage Facility (SSF). These analyses were performed for forced refrigerated air and passive ventilation systems.

The thermal feasibility analysis is based on staging of drained, damp-dried MCOs in air filled tubes in vaults 1 and 2 (third vault contains no tubes) with a forced refrigeration air cooling of the tubes during staging. MCOs are removed and returned to the tubes after stabilization. After all fuel is stabilized, the passive air ventilation system is made operational.

3.2.1 Design Basis Assumptions

The following design basis assumptions were used for the thermal analyses:

- The heat generation rate was based on a total 880 MCOs. Twenty percent are assumed to be at the upper limit ("maximum") (482 W) and the remaining eighty percent are assumed to be at the nominal value ("average") (221 W). Due to the preliminary nature of the heat transfer calculations a ten percent safety factor was used for the heat generation rate. Additional heat loads were added for building heat gains.
- The heat generation for the "maximum" case (482 W) per MCO was used for calculating the MCO temperature assuming that it is located at the end of the vault. Each MCO consists of five canisters, each storage tube contains two MCOs, and each vault contains 220 tubes.
- The design basis required staging/storage conditions are as follows:

Staging: Maximum MCO temperature at 100 °F.
Storage: Maximum fuel centerline temperature at 400 °F.
- During the staging operation the MCO provides primary confinement and the air filled storage tubes provide the secondary confinement. It is assumed that the interior of the storage tubes are isolated from the vault, which would prevent the vault from getting contaminated.
- The total flow is assumed to be evenly and uniformly distributed around each of the containment tubes. This is a critical assumption that must be assured by design and verified by additional analyses using Computational Fluid Dynamic (CFD) techniques.
- The heat transfer coefficients for air were calculated at the point of maximum vault air temperature.
- One dimensional (radial) heat transfer only. Two-dimensional (radial and axial) heat transfer was not modeled.
- Heat transfer by radiation between the tubes was not considered.

3.2.2 Summary of Results

The results of the thermal analyses during staging are shown in Table 3-1 and involve various combinations of drained, damp-dried MCOs surrounded by air in tubes for different ventilation flow rates.

The results indicate that it is not feasible to maintain the MCO temperature at 100 °F with a refrigerated forced air ventilation system with a supply air temperature of 35°F. With 200,000 CFM system and a supply air temperature of 35 °F (Concept 2A of the SSF Feasibility Study) the MCO temperature can only be maintained at 173 °F based on the above heat generation rate. The temperature of 35 °F was selected to maintain the same basis as the previous feasibility study alternatives. The MCO temperature is calculated on the basis that the MCO is located at the end of the vault with the limiting heat load. (The MCO temperature could be maintained at 100 °F with 200,000 CFM supply air at minus 37 °F, this is not feasible).

The results of the thermal analyses during storage operation with the existing CSB design concept, assuming the same intake structure, vault size (2-vaults) and exhaust stack (height and diameter) indicates that an MCO temperature of 270 °F can be maintained by a passive ventilation system. This is based on an inlet air temperature of 115 °F (same design basis as CSB) and a ventilation flow rate of 53,000 CFM.

The above results indicate that it is not feasible to use the refrigerated air system to maintain the MCO temperature below 100 °F during the staging operation. However; the passive ventilation system can maintain the MCO temperature below the 400 °F limit during the storage operation.

It must be emphasized that these are rough conservative feasibility analyses using limited design information and do not cover all limiting or upset conditions. More detailed analyses are required using CFD techniques to cover all limiting and upset conditions and to verify some basic assumptions. Also no analysis was performed for MCOs stored in an overpack.

4.0 SCHEDULE

As the Trade Study requirements were determined not feasible the current construction schedule is not impacted.

TABLE - 3-1

THERMAL ANALYSIS - SUMMARY
(Drained, Damp-Dried MCOs)

MCO TEMPERATURE (°F)	SUPPLY AIR QUANTITY (CFM)	SUPPLY AIR TEMPERATURE TO VAULT (°F)
180	100,000	35
176	150,000	35
173	200,000	35
170	300,000	35
168	400,000	35
167	500,000	35

5.0 COST ESTIMATE

As the Trade Study requirements were determined not feasible the current estimate for Concept 2D is not impacted.

6.0 REFERENCES

"Staging and Storage Facility Feasibility Study Final Report",
Fluor Daniel, Inc., February 1995.

Statement of Work, "Trade Studies for the Evaluation of HWVP
Canister Storage Building for Spent Nuclear Fuels", Rev. 5,
April 21, 1995.

WHC-SNF-FRD-014, May 1995, Section 3.2.2.1.2.2, Rev. A, "Draft
Performance Specification for the Spent Nuclear Fuel Canister
Storage Building" (Contains tabular data from R. G. Cowan of
WHC on proposed MCO description).

Appendix 1

Calculations specific to TASK "G"

Determine tolerable amount of water in MCOs - Closed Canisters

IF the MCOs are staged at 100°F (or above), the rate of U metal corrosion and resultant H₂ generation will increase, as shown in the Independent Technical Assessment Team on Dry Storage of N-Reactor Fuel report. According to that report, the corrosion rates at 50°F and 75°F (10°C and 24°C) are 8×10^{-5} and 4×10^{-4} mg U/cm²-hr respectively, for a ratio of 5.0. Extrapolating to 100°F, the corrosion rate would be 10 times greater than at 50°F, per canister.

For an 8-canister MCO, WNC had us design for 14 L/day H₂ generation (1% /year U oxidation by water) when the MCO was to be maintained at 50°F - R.F. RFK-329 & RFK-331.

This value was checked in the process calc dated 1-17-95

In the previous studies with 8-canister MCOs at 50°F, the servicing required more than twice the crane work than bringing in and placing new MCOs. Increasing this work by a factor of 10 makes the design infeasible, because we cannot put in 10 times as many bridge cranes. One option is to limit the moisture in the MCO so that the hydrogen concentration remains safe.

A calculation (1/19/95) showed that 6% H₂-94% N₂ by volume is non-combustible when mixed with any proportion of air.

MCO and canister dimensions are shown in the following pages. The gas volume equals 15.3 Ft³. Limiting H₂ to 6% means no more than 0.92 Ft³ of H₂. If the MCO was filled with 15.3 Ft³ of N₂ at 100° and 0.92 Ft³ of H₂ are added, the pressure increases to $(14.7 \text{ psia})(16.22 \text{ Ft}^3)/(15.3 \text{ Ft}^3) = 15.6 \text{ psia} = 0.9 \text{ psig}$.

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tolerable amount of water in MCOs

at 100°F (560°R) and 15.6 psia, the ideal gas law applies

$$PV = nRT$$

$$n = \frac{PV}{RT} = \frac{(15.6 \text{ psia})(0.92 \text{ Ft}^3)}{(10.731)(560^\circ\text{R})} = 0.0024 \text{ lb-moles}$$

from the corrosion reaction, each mole of H_2O produces one mole of H_2 . MW of $\text{H}_2\text{O} = 18.016$

$$\text{tolerable water} = (18.016)(0.0024) = 0.043 \text{ lb of water}$$

say 0.04 lb

at 100°F, the specific volume of water is 0.0161 Ft^3/lb which is equivalent to 27.8 in^3/lb .

0.04 lb of water is 1.1 in^3 of water

CONCLUSION: In order to ensure a safe mixture of hydrogen after uranium metal corrosion in an unvented 10-canister MCO, the amount of water has to be limited to less than 1 cubic inch after draining.

TIMING: At 50°F for 8 canisters in an MCO, the nominal H_2 rate was 1.2 L/day. For 10 canisters at 100°F, the nominal rate would be $(10/8)(10)(1.2 \text{ L/day}) / (28.3 \text{ L/Ft}^3) = 0.53 \text{ Ft}^3/\text{day}$. Time required for H_2 concentration to reach 6% = $(0.92 \text{ Ft}^3) / (0.53 \text{ Ft}^3/\text{day}) = 1.7 \text{ days}$

For a building containing 750 MCOs, 440 MCOs per day would have to be serviced $(750)/(1.7) = 440$. If there are 880 MCOs, servicing rate is 520 per day. [If 6% H_2 in an MCO constitutes a hazard that must be corrected by servicing (monitoring & purging)].

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Amount of water in MCOs

Mark II canister length = 27.05" not counting vent tubing
OD = 9.5"

$$\begin{aligned} \text{Canister volume is a little over } 2\pi (d/2)^2 h \\ = \frac{1}{2}\pi d^2 h = \frac{1}{2}\pi (9.5\text{ in})^2 (27.05\text{ in}) = 3,835\text{ in}^3 \\ = 2.22\text{ ft}^3 \end{aligned}$$

$$\text{Volume occupied by 10 canisters} = 22.2\text{ ft}^3$$

MCO inside dimensions = 156.75" length, 23.25" ID.

Internal gratings occupy 4" of length, leaving 152.75".

$$\begin{aligned} V = \pi (d/2)^2 h = \frac{1}{4}\pi (23.25)^2 (152.75) = 64,851\text{ in}^3 \\ = 37.5\text{ ft}^3 \end{aligned}$$

$$\text{gas volume inside 10-canister MCO} = 37.5 - 22.2 = 15.3\text{ ft}^3$$

SSF FEASIBILITY

TASK 2

VENTING OF SEALED TUBES.

WITH INERT GAS BLANKET

To prevent an explosive mixture from forming, an inert gas must be used to blanket the tube. CO_2 is a possible choice because it inhibits combustion better than nitrogen or argon, and because it can be stored as a liquid at low pressures, which requires less space. The disadvantage is that CO_2 liquid is cold enough (about -40°) to create a hazard to people and structures. A safer choice is nitrogen, stored as a high-pressure gas.

From the flammability diagram, we can see that a mixture with 6% or less hydrogen by volume with 94% N_2 is non-flammable in any combination with air.

Starting with a tube with two MCO's, and the tube contains 1% H_2 - 99% N_2 at 14.7 psia pressure, and adding H_2 until the H_2 concentration reaches 6%:

$$(0.06)(V + 54.48) = (0.01)(54.48) + V$$

$$(0.94)V = (0.05)(54.48)$$

$$V = 2.90 \text{ ft}^3$$

[Free vol. in tube = 54.48 ft^3

See process calc. of 1/18/95]

$$P = (14.7)(54.48 + 2.90) / (54.48) = 15.5 \text{ psia} = 0.8 \text{ psig}$$

So, starting with 99% N_2 , the tube must be purged when the pressure reaches 0.8 psig, to maintain an absolutely safe mixture. This is feasible, since a 40 tube-per-day venting schedule will vent the tubes at 0.4 psig. [Ref. process calc. dated 1/18/95].

After venting the tube, the tube has to be purged to reduce the H_2 concentration back to 1%.

The vent gas volume will equal $(1200)(0.494 \text{ ft}^3/\text{D}) = 593 \text{ ft}^3/\text{D}$

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SSF FEASIBILITY

TASK 2

VENTING OF SEALED TUBES

(because N_2 is heavier)

The worst case for purge volume is a tube with one MCO. When N_2 is introduced to the tube, the gas flow will somewhere between bottom-up plug flow and continuously well-mixed. If the flow were plug-type, the purge volume would be less than 101.34 ft³. For well-mixed flow, the purge is greater:

$$C_f = (1.00) - C_0 e^{-V/V_0}$$

$$C_f = 0.99$$

$$C_0 = 0.94$$

$$V_0 = 101.34$$

Ref Levenspiel
"Chemical Reaction
Engineering" 2nd Ed.
p. 260

$$(0.99) = (1.00) - (0.94) e^{-x}$$

$$(0.94) e^{-x} = (0.01)$$

$$e^{-x} = 0.0106$$

$$x = 4.543$$

$$V_f = (4.543)(101.34) = 460 \text{ ft}^3 \text{ per purge}$$

$$\text{at 40 purges per day, purge} = (40)(460) = 18,400 \text{ ft}^3/\text{D}$$

$$\text{the total release of vent + purge} = 18,400 + 600 = 19,000 \text{ ft}^3/\text{D}$$

$$= 13 \text{ ft}^3/\text{min of 94 to 99\% } N_2$$

which will have a negligible effect on building ventilation.

If the N_2 is provided by cylinders, each industrial size cylinder (9" OD x 5 ft) contains 200-230 ft³.*
Each purge would use about two cylinders of compressed nitrogen for a tube with one MCO. A tube with two MCO's would only require about one cylinder.

*Ref Imperial Welding Supply.

Hydrogen Safety Handbook

by Paul M. Ordan
for NASA

Figure A5. — Effect of nitrogen, helium, carbon dioxide, and water vapor on flammability of hydrogen in air. Example: at point A, in flammable range, concentrations are hydrogen, 35 vol %; air, 45 vol %; and inert, 20 vol %.

A 6% H_2 - 94% N_2 mixture is non-flammable when combined with any proportion of air.

MCO VENT GAS CONTAMINATION

Design basis shows ^{85}Kr present, but no I or tritium. Cesium when wet will remain with the fuel as CsOH , which is not volatile. The gas released from an 8-canister MCO is 2.56 mCi/L nominal, or 4.62 mCi/L upper limit. Gas released is 1.2 L/day nominal, or 14 L/day upper limit. (Ref. FAX from M. Henderson 1/20/95).

$$\text{Average release} = (2.56 \text{ mCi/L})(1.2 \text{ L/day}) = 3.07 \text{ mCi/day}$$

$$3,070 \text{ } \mu\text{Ci/day} = 128 \text{ } \mu\text{Ci/hr} = 2.13 \text{ } \mu\text{Ci/min. per MCO}$$

The acceptable contamination in a Controlled-Access area is $1 \times 10^{-5} \text{ } \mu\text{Ci/cc}$ (from D. Padula, based on 10 CFR 20, including the 10^{-1} factor specified for ^{85}Kr in the DOE Radiological Control Manual, DOE/EH-02561, Rev. 1, Apr. 1994).

$$1 \text{ ft}^3 = 2.8317 \times 10^4 \text{ cc}$$

$$1 \times 10^{-5} \text{ } \mu\text{Ci/cc} = 0.283 \text{ } \mu\text{Ci/ft}^3$$

to maintain an acceptable ^{85}Kr level in the occupied area above the MCO's, the air purge/make-up rate must exceed:

$$V = (2.13 \text{ } \mu\text{Ci/min}) / (0.28317 \text{ } \mu\text{Ci/ft}^3) \\ = 7.5 \text{ ft}^3/\text{min per MCO}$$

during normal operation (50°F)

$$(1200)(7.5) = 9,000 \text{ ft}^3/\text{min minimum purge air for CSE.}$$

This is much more than the purge air req'd to dilute H_2 below the flammable limit at 50°F.

The purge/makeup air requirement for Kr is independent of temperature.

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TASK 1 & TASK 2

LOSS OF BUILDING VENTILATION

H₂ BUILD-UP

As hydrogen is generated in MCDs at 35°-50°F, the density is still much less than air at the max historical outdoor temperature of 115°F.

$$\rho = \frac{PM}{RT} \quad \text{Ideal gas law} \quad R = 10.73 \quad P = 14.7 \text{ psia}$$

for H₂ @ 35°, MW = 2.016 T = 495°R

$$\rho = (14.7)(2.016)/(10.73)/(495) = 0.0056 \text{ lb/ft}^3$$

for air @ 115°, MW = 28.97, T = 575°R

$$\rho = (14.7)(28.97)/(10.73)/(575) = 0.690 \text{ lb/ft}^3$$

The hydrogen will tend to rise until it mixes with air. By the time any hydrogen molecules rise the 35 ft distance from the pool surface or tube plugs to the ceiling, we can assume the hydrogen will be well-mixed with air.

(Ref. H-2-119293 Rev. 1) Building is 136 ft x 183 ft across

(Ref. H-2-119290 Rev. 1). The building volume = (35)(136)(183) = 871,000 ft³

At 50°F only 3.5 ft³/min will reduce H₂ concentration to 1%. (Ref. process calc. 1/23/95). At the normal flow, which exceeds 1,000 ft³/min, concentration < (1%)(3.5)/(1000) = 0.0004%.

The H₂ concentration has to reach 4% vol before it is flammable in air. (0.04)(871,000) = 34,800 ft³ of H₂ are required if the air and H₂ are well-mixed.

The building H₂ generation rate is 50.9 ft³/day (process calc 1/23/95) so around 685 days are required before hydrogen poses a fire hazard, with the assumption of well-mixed gas. This assumption over-estimates the time, but is probably close to the truth.

TASK "H" RCRA LEAK INVESTIGATION

H

CANISTER STORAGE BUILDING
TRADE STUDY REPORT
TASK "H"

RCRA FUNCTIONS:
PREVENTION AND DETECTION OF MCO LEAKS

PREPARED FOR WESTINGHOUSE HANFORD COMPANY
RICHLAND, WASHINGTON

PREPARED BY FLUOR DANIEL, INC.

MAY 31, 1995

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1.0 OBJECTIVE

Part of the mission of the SNF CSB is to provide environmentally sound staging and storage of K Basin SNF. This mission may require compliance with the Federal Resource Conservation and Recovery Act (RCRA). The purpose of Trade Study "H" is to identify the impacts on the SNF CSB Project assuming compliance with RCRA, and specifically to identify the design functions required to prevent and detect MCO leaks.

2.0 SUMMARY

Several SNF CSB functions would be required to comply with RCRA. Some already are a requirement in the base case (e.g., MCO retrievability) and would not cause a cost/schedule impact for the purpose of this trade study. Others are not in Base Case 2D and would be required only to comply with RCRA (e.g., thirty inch minimum separation between rows of MCOs, a requirement which probably would be waived because direct visual inspection of the MCOs would not be feasible).

Only one RCRA-required function would cause significant cost/schedule impact, detection of MCO leakage within twenty-four hours. To achieve this function would appear difficult and expensive, regardless of the approach considered, and would pose significant feasibility issues. Continuously operating MCO leak detection would add approximately \$4.5 million to the facility cost and extend the scheduled facility completion date by a minimum of two months. Given the Base Case 2D design, featuring an MCO filled with water (the primary heat sink) in a dry tube, potential safety and licensing risk could be incurred by not including this function, even if RCRA compliance is not a project requirement.

3.0 FACILITY DESCRIPTION AND EVALUATION

3.1 Applicability

The Federal Resource Conservation and Recovery Act (RCRA) gave guidance to the Environmental Protection Agency (EPA) for the "cradle to grave" regulation of hazardous wastes. In general, RCRA regulates the generation, transportation, treatment, storage and disposal of hazardous wastes, and these regulations are found in 40 CFR 260 to 270.

The State of Washington has obtained authorization from the EPA to administer the basic RCRA program. The Washington Hazardous Waste Management Act (the Washington Act) parallels the federal RCRA requirements, and gives authorization to the Department of Ecology (Ecology) to regulate permitting for the

generation, transportation, treatment, storage and disposal of hazardous wastes. The Washington regulations are contained in WAC (Washington Administration Code) 173-303, Dangerous Waste Regulations.

The applicability of WAC 173-303 to the SNF CSB is contained in 173-303-020, Applicability, which reads in part, "This chapter 173-303 WAC shall apply to all persons who handle dangerous wastes including, but not limited to owners and operators of dangerous waste recycling, transfer, storage, treatment, and disposal facilities."

Since spent fuel elements potentially meet the requirements as a Washington State extremely hazardous waste (EHW), see sections 173-303-070 to 173-303-103, the SNF-CSB could require a RCRA type permit from the Department of Ecology, see sections 173-303-800 to 173-303-840. This permit would be for a TSD (Treatment, Storage and Disposal) facility for the storage of dangerous wastes.

3.2 The Regulation of MCOs (as either containers or tanks)

The regulatory requirements in WAC 173-303 are different for storage of dangerous wastes in containers versus storage in tanks. Section 173-303-040 defines a container as, "Container means any portable device in which a material is stored, transported, treated, disposed of, or otherwise handled," and a tank as, "Tank means a stationary device designed to contain an accumulation of dangerous waste, and which is constructed primarily of nonearthen materials to provide structural support."

The main difference of the two definitions appears to be between a portable device and a stationary device. Since an MCO is a portable device, it appears to meet the definition of a container. However, the storage of an MCO in a tube is essentially stationary, and as a result, the regulators (Ecology) may classify the MCOs as a tank.

Since the classification of the MCOs may be that of either a container or a tank, the regulatory requirements for both classifications are presented in this analysis.

3.3 Containers

WAC 173-303-630 regulates the use and management of containers used to store dangerous wastes.

3.3.1 173-303-630(2) Condition of Containers

3.3.1.1 Regulatory Requirements

If a container holding dangerous waste is not in good condition (e.g., severe rusting, apparent structural defects) or if it begins to leak, the owner or operator must transfer the dangerous waste from the container to a container that is in good condition or manage the waste in some other way that complies with the requirements of 173-303, including that for leaks and spills.

3.3.1.2 Regulatory Impact

The above requirement can be met with retrievable MCOs, some type of inspection system (as discussed in 3.3.3 below), and an overpack capability for leaking MCOs. Retrievability and overpack capability are provided in the base case design.

3.3.2 173-303-630(5) Management of Containers

3.3.2.1 Regulatory Requirement

Subsection (c) requires a minimum thirty-inch separation between isles of containers holding dangerous waste(s), and a row of drums must be no more than two drums wide.

3.3.2.2 Regulatory Impact

These requirements appear to be for containers such as 55-gallon drums and it is not clear how a regulator would apply the requirements to MCOs. A strict application might require a minimum thirty-inch separation between the storage tubes. This is a factor that would need interpretation by the regulators.

Since lethal radiation dose rates preclude direct visual inspection of MCOs, however, these requirements would have no purpose for the SNF CSB. Waiver of this requirement (no change from the base case design) would meet the intent of the regulation.

3.3.3 173-303-630(6) Inspections

3.3.3.1 Regulatory Requirement

At least weekly, the owner or operator must inspect areas where containers are stored, looking for leaking containers and for deterioration of containers and the containment system caused by corrosion, deterioration, or other factors.

3.3.3.2 Regulatory Impact

This is another requirement that is directed at conventional containers, such as 55-gallon drums. For MCOs in a storage tube, the regulators may agree to some type of acceptable

weekly leak inspection system. This is another factor that needs interpretation by the regulators.

Compliance with the letter of this requirement clearly is not feasible because of the extremely high MCO dose rate. Weekly direct observation of each MCO, even by remote means such as a fiber optics, clearly is not feasible. CCTV would not fit into a tube. A continuously operating leak detector in each tube should, however, meet the intent of this requirement.

3.3.4 173-303-630(7) Containment

3.3.4.1 Regulatory Requirements

Container storage areas must have a containment system that is capable of collecting, holding and removing spills and leaks. Spilled or leaked waste must be removed from the containment system in an timely manner as is necessary to prevent overflow.

3.3.4.2 Regulatory Impact

The storage tubes will meet the containment system requirement to collect and hold spills and leaks, if the tubes are designed to be watertight. (Note: The HWVP CSB design does not require the tube to be watertight [leaktight]. Grouted anchor bolts penetrate the bottom plate of each tube.)

Tube/facility design also would have to provide for some manner of removing liquid that has leaked from an MCO. Because of the radiation field, removal of liquid would have to be accomplished remotely, after both MCOs have been removed and the leaking MCO has been placed in a MCO overpack.

3.3.5 173-303-630(8) Special Requirements for Ignitable Waste

3.3.5.1 Regulatory Requirement

The owner or operator shall design, operate and maintain ignitable waste container storage in a manner equivalent with the Uniform Fire Code.

3.3.5.2 Regulatory Impact

Section 173-303-630(8) is applicable if the generation of hydrogen in the MCOs is considered possible. However, as long as a sufficient amount of HVAC air exists to dilute hydrogen to levels below the lower explosive limit, which is expected, the requirements of 173-303-630(8) might be waived. If not, the spacial requirements required by the Uniform Fire Code may

be necessary (this is another area where the regulators would need to be consulted).

3.3.6 Summary of Regulatory Impacts

A summary of the regulatory impacts for Base Case Concept 2D and the classification of the MCOs as containers follows:

- The MCOs would have to be retrievable (already an intrinsic characteristic of the MCO conceptual design)
- Some type of continuously operating leak detection system would have to be provided in lieu of inspection, which probably is not feasible
- An MCO overpack capability would have to be provided (already provided in the Base Case)
- Depending upon interpretation, a minimum thirty-inch separation (or other spacing arrangement) between storage tubes may be required, but would have no known purpose
- The design would have to include watertight storage tubes and provide for prompt (and probably remote) removal of material that has leaked from an MCO
- Since the entire SNF CSB facility has the potential to be radiologically contaminated, all drainage sumps also should be provided with continuously operating leak detection systems and provisions for removal of accumulated liquids

3.4 Tank Systems

WAC 173-303-640, Tank Systems, applies to owners and operators of facilities that use tank systems to treat or store dangerous wastes. Under the WAC regulations, the MCOs in Concept 2D would be considered the primary containment vessel (or tank) and the storage tubes would be considered the secondary containment vessel.

3.4.1 173-303-640(4) Containment and Detection of Releases:

3.4.1.1 Regulatory Requirements

In order to prevent the release of dangerous waste or dangerous constituents to the environment, secondary containment must be provided that meets the following requirements: secondary confinement systems must be designed (and installed and operated) to prevent any migration of wastes or accumulated liquid out of the system to the soil,

ground water or surface water at any time during the use of the tank system, and the secondary confinement system must be capable of detecting and collecting releases and accumulated liquids until the collected material is removed.

To meet these requirements, the secondary confinement systems must be provided with a leak detection system that is designed (and operated) so that it will detect the failure of the primary or secondary containment structure or the presence of any release of dangerous waste or accumulated liquid in the secondary containment system within twenty-four hours. Spilled or leaked waste and accumulated precipitation must be removed from the secondary containment system within twenty-four hours.

Secondary containment for tanks must include one or more of the following devices: a liner, a vault, a double-lined tank, or an equivalent device. External liner systems serving as secondary confinement must be designed (or operated) to contain one hundred percent of the capacity of the largest tank within its boundary, and must be designed (and installed) to surround the primary tank completely.

The secondary containment requirement applies to ancillary equipment (e.g., tubing and other penetrations of the containment pressure boundary) as well. (Some exemptions exist).

3.4.1.2 Regulatory Impact

In Base Case Concept 2D, the MCOs would be considered the primary containment vessel and the storage tubes containing the MCOs would serve as secondary containment. Thus, the design would have to provide for detection of leaks of the MCOs within twenty-four hours and removal of any material that has leaked into a storage tube within twenty-four hours of detection. Considering the geometry of the storage tubes, the requirement on the secondary containment system for containing one hundred percent of the capacity of the primary vessels is readily met, if the tubes are designed to be watertight.

3.4.2 173-303-640(7) Response to Leaks or Spills and Disposition of Leaking or Unfit-for-use Tank Systems

3.4.2.1 Regulatory Requirements

A tank system or secondary containment system from which there has been a leak or spill, or which is unfit for use, must be removed from service immediately, and the owner or operator must satisfy the following requirements:

- Cessation of use; prevent flow or addition of wastes. The owner must immediately stop the flow of dangerous waste into the tank system or secondary confinement system and inspect the system to determine the cause of the release.
- If the release was from the tank system, the owner/operator must, within twenty-four hours after detection of the leak or, if the owner/operator demonstrates that it is not possible, at the earliest practicable time, remove as much of the waste as is necessary to prevent further release of dangerous waste to the environment and allow inspection and repair of the tank system to be performed.

If the leak was to the secondary confinement system, all released materials must be removed within twenty-four hours or in a timely manner as is possible to prevent harm to human health and the environment.

- The owner/operator must immediately conduct a visual inspection of the release and prevent any further migration of the leak or spill.

3.4.2.2 Regulatory Impact

These requirements are satisfied by having retrievable MCOs, watertight tubes, and the ability to detect and remove (probably remotely) any MCO leakage from inside the storage tubes. A leaking MCO probably could be retrieved and placed in an MCO overpack within twenty four hours. It probably could be shown, however, that (remote) removal of MCO leakage from a storage tube within twenty four hours of detection is not practicable.

3.4.3 173-303-640(9) Special Requirements for Ignitable (or Reactive) Wastes

3.4.3.1 Regulatory Requirement

Ignitable wastes must not be placed in tank systems unless:

- the waste is treated, rendered or mixed before or immediately after placement in the tank system so that the resulting waste, mixture, or dissolution of material no longer meets the definition of ignitable waste and (a) the storage does not generate extreme heat or pressure, fire or explosion or violent reaction (b) produce uncontrolled toxic gases in sufficient quantities to threaten human health, (c) produce uncontrolled flammable fumes or gases in sufficient quantities to pose a risk of

fire or explosions, (d) damage the structural integrity of the facility or device containing the waste, and (e) through other means, threaten human health or the environment, or

- the waste is stored or treated in such a way that it is protected from any material or conditions which may cause the waste to ignite or react.

The owner or operator of a facility which treats or stores ignitable waste in covered tanks must locate the tanks in a manner equivalent to the National Fire Protection Association's (NFPA) buffer zone requirements for tanks.

Along with 173-303-640(9), WAC 173-303-395(1) regulates precautions to be taken with ignitable wastes.

3.4.3.2 Regulatory Impact

As noted earlier, section 173-303-640(9) would be applicable if the generation of hydrogen in the MCOs is considered possible. However, as long as a sufficient amount of HVAC air exists to dilute hydrogen to levels below the lower explosive limit, which is expected, the requirements of 173-303-640(9) would be satisfied using the provision in part (2) above, i.e. Section 3.3-1.

If section 173-303-640(9) is applicable, a NFPA buffer zone requirement might exist.

3.4.4 Summary of Regulatory Impacts

A summary of the regulatory impacts for the designs associated with Base Case Concept 2D and with the classification of the MCOs as tanks follows:

- Some type of system for detecting leaks in the MCOs within twenty-four would have to be provided
- The design would have to provide for the removal of any leaked material (from the MCOs) into the storage tubes within twenty-four hours after detection
- The MCOs would have to be retrievable (already a characteristic of the Base Case MCO)
- Some type of system would have to be provided for inspecting storage tubes (after a leak from an MCO)

- The spent fuel would have to be stored in such a way that it is protected from any material or conditions which may cause the (hydrogen produced by the) waste to ignite

3.5 Other Requirements

There are other regulations in WAC 173-303 that apply to the design of the SNF CSB facility, but these are very generic in nature (e.g., siting criteria) and have not been included here.

3.6 Summary of Functions To Comply with RCRA Requirements

Several SNF CSB functions would be required to comply with RCRA, if the stored SNF were classified as "dangerous waste." These functions can be categorized as:

- Already a requirement in the original Feasibility Study Base Case Concept 2D,
- Currently not a requirement in the Base Case, but should be a requirement, whether or not RCRA compliance would be required, and
- Currently not a requirement in the Base Case, but would be required only for compliance with RCRA

Only the last category of functions, listed in Section 3.8 below, would have cost/schedule impacts for the purpose of this trade study.

3.6.1 Functions already a requirement in the Base Case:

- MCOs would have to be retrievable.
- MCO overpack capability would have to be provided.
- SNF would have to be stored in such a way that it is protected from any material or conditions which may cause it (or the hydrogen produced by it) to ignite. Protective functions would include:
 - Adequate MCO cooling
 - Storage tube ventilating/purging/inerting capability
 - "Explosion-proof" components (e.g., hoist/motor, limit switches) inside the handling cask/floor shield gates, and storage tube, and
 - An operating deck HVAC system capable of removing vented hydrogen before it reaches explosive concentrations.

3.6.2 Functions currently not a requirement in the Base Case, but should be a requirement, whether or not RCRA compliance would be required:

- The design would have to include watertight storage tubes [HWVP CSB design does not require the tube to be watertight].
- The design would have to provide for prompt (and probably remote) removal of material that has leaked from an MCO.
- Because the entire operating area of the facility has the potential to be radiologically contaminated, all drainage sumps should be provided with continuously operating leak detectors and provisions for removal of accumulated liquids.

3.6.3 Functions currently not a requirement in the Base Case, that would be required only for compliance with RCRA:

- Continuously operating MCO leak detection (capable of detecting leakage within twenty four hours) would have to be provided in lieu of inspection, which probably is not feasible.
- Capability to inspect storage tubes, probably remotely, after a MCO leak.
- Depending upon interpretation by the regulator, a minimum thirty-inch separation (or other spacing arrangement) between storage tubes may be required. This would have no known purpose, however, given that inspection by direct observation is not feasible. A waiver of this requirement would be anticipated.

3.7 Detailed Schedule Impacts

- MCO leak detection:

If installation of detectors requires modification of each tube (e.g., watertight penetrations), then the duration of both tube procurement and tube installation could be extended. If installation of detectors requires modification of the operating deck floor (e.g., embedded cable conduits), then the construction duration for the operating deck floor could be extended.

Because of the lead time required, procurement of the MCO leak detection system and other RCRA leak detection

systems should be initiated as soon as possible after a decision is made to provide these functions.

- Post-leakage inspection of storage tubes:

No anticipated effects on schedule.

- Minimum thirty inch separation between tubes

No anticipated effects on schedule, if waived.

3.8 Equipment Required to Implement RCRA Functions

The design functions to comply with RCRA would require the following equipment:

- MCO leak detection (per tube, plus one central display panel):
 - In-tube sensor
 - Signal path from sensor to display, via water-tight penetration through tube or conduit to and through operating deck, plus cabling to display panel location

The direct cost is estimated to be \$3.0 million and the cost of Engr/PM/CM approximately \$1.6 million

- Post-leakage inspection of storage tubes:

No additional equipment would be anticipated above the inspection capability that would have to be built in to provide the leakage removal capability referred to in Section 3.7 above.

- Minimum thirty inch separation between tubes

No additional equipment would be anticipated, if waived.

4.0 SCHEDULE

The procurement and installation of an MCO leak detection system extend the facility completion date a minimum of two months.

5.0 COST ESTIMATES

The assumptions, exclusions, and basis for the estimate remain the same as for the Concept 2D Feasibility Study. The difference in the direct cost from the baseline Concept 2D estimate is:

Direct cost,	add	\$ 3,000,000
Mech/I&C/Elec		
Engr/PM/CM,	add	<u>\$ 1,470,000</u>
Subtotal		\$ 4,470,000

6.0 REFERENCES

"Staging and Storage Facility Feasibility Study Final Report", Fluor Daniel, Inc., February 1995.

WHC-SNF-FRD-014, May 1995, Section 3.2.2.1.2.2, Rev. A, "Draft Performance Specification for the Spent Nuclear Fuel Canister Storage Building" (Contains tabular data from R. G. Cowan of WHC on proposed MCO description).

APPENDIX - CALCULATIONS

Ca

PROCESS CALCULATIONS

CONCEPT 2D

Ca-i

Hydrogen generation at 100°F
Concentration of H₂ in Tubes
based on LATA tests

For an 8-canister MCO at 50°F, the nominal H₂ generation rate was 1.2 L/day and the max rate was 14 L/day.

At 100°F, the H₂ generation per canister will be 10x greater, based on LATA info (RFK-339). The H₂ generation per MCO will be greater by $(10/8)(10) = 12.5$.

The nominal H₂ generation rate at 100°F is
 $(12.5)(1.2 \text{ L/d}) / (28.3 \text{ L/ft}^3) = 0.53 \text{ ft}^3/\text{d}$ per MCO

The tube volume is 148.2 ft³ and each MCO is 45.4 ft³
(Ref. calc. of 1/18/95) Free Volume = 57.4 ft³

The H₂ volume at 6% concentration is 3.06 ft³
(at this point, the tube pressure is 0.8 psig.)

The time for the nominal MCOs to form 6% H₂ in tubes:
 $(3.06) / (0.53) / 2 = 2.9$ days

On average, the number of tubes to be purged
per day is $(750 \text{ mco}) / (2.9 \text{ d}) / (2 \text{ mco}) = 130$ per day

I all 440 tubes are filled, $440 / 2.9 = 152$ per day,
say 150

Total H₂ generation = $(750)(0.53 \text{ ft}^3/\text{d}) = 400 \text{ ft}^3/\text{d} = 0.3 \text{ ft}^3/\text{min}$
to maintain H₂ at 2% ($\frac{1}{2}$ LEL),
required air flow is 14 ft³/min

However, Kr concentration will require much more flow

BASE CASE

H₂ Generation at 100°F.
Time to reach 6% in tubes, based on 5/8/95 FAX

At 100°F the nominal Case A. H₂ generation rate is about 3.5 L/d (see page 2) and the max Case A H₂ rate is about 40 L/d (see page 3). With 80% of the canisters nominal (on average) and 20% max, the average H₂ rate is $(0.80)(3.5) + (0.20)(40) = 10.8 \text{ L/d}$

As shown in the calculation of 5/8/95, the free volume in a tube with two MCOs is 57.4 ft³.
 $(57.4 \text{ ft}^3)(28.3 \text{ L/ft}^3) = 1620 \text{ L}$

The H₂ concentration will reach 6% when the volume of H₂ generated reaches $(6\%/94\%)(1620 \text{ L}) = 103 \text{ L}$

The average time required for two MCO's to bring the H₂ up to 6% by vol:
 $(103 \text{ L}) / (10.8 \text{ L/MCO-d}) / (2 \text{ MCO}) = 4.77 \text{ d}$
say 4.8 days

If there are 750 MCOs in 375 tubes, the purge has to be performed $(375) / (4.8) = 78 \text{ per day}$
if all 440 tubes are filled $(440) / (4.8) = 92 \text{ per day}$

Total H₂ generation = $(750)(10.8 \text{ L/d}) = 8100 \text{ L/d} = 5.6 \text{ L/min} = 0.2 \text{ FPM}$
at 880 MCOs, 0.23 ft³/min.

to maintain 2% or less H₂, flow req'd is 12 ft³/min.

However, Kr concentration will require much more flow.

WHC H₂ generation data
from FAX dated MAY 8, 1995

CURVE FITTED TO WHC DATA
FOR NOMINAL CONCEPT A

- 8.4d

- 6.4d

- 4.4d

- 2.4d

- 1.4d

FORM E50 (Rev. 8-91)

25°C

3A

100°F

50°C

WHC H₂ gas generation data

FROM FAX DATED MAY 8 '95

CURVE FITTED TO WHC DATA
FOR MAX. CONCEPT A.

SSF FEASIBILITY

04436305

RLD 1/18/95

p.1 of 2

TASK 2 MCO gas release calculation

Option where storage tubes are sealed, except for a vent line which is opened regularly

Worst case leak rate per 8 canister MCO is 14 4/D
(Ref. Fax from Craig Swenson dated 1/16/94)

$$(14 \text{ 4/D}) / (28.32 \text{ 4/Ft}^3) = 0.494 \text{ Ft}^3/\text{D}$$

MCO outer dimensions are 14'-5.5" x 2'-0" OD. (Design Basis)

$$\text{MCO Volume} = \pi (1.0)^2 (14.46) = 45.4 \text{ Ft}^3 \text{ displacement.}$$

existing storage tube length is 709'-0" - 667'-3/4" - 5'-10"
for standard tube (Ref H-2-120397 Rev.1) not counting
Impact absorbers. The bottom 23'-4" of tube is 28" OD,
the top 12'-1" is 30" OD. Overall height = 35'-5"
(Ref H-2-120395 Rev.1). The top tube is 29" ID (1/2" wall).
Impact absorbers only have about 4 1/2" thickness of solid
metal with an OD of 28.5" or 26.5"
combined (all 3)

$$\begin{array}{r} 35'-5" \\ - 28'-11" \\ - 0'-9" \\ \hline 5'-9" \end{array}$$

$$\begin{aligned} \text{Tube internal volume} &= \frac{1}{4} \pi (27/12)^2 (23.33) + \frac{1}{4} \pi (29/12)^2 (12.0833) \\ &= 92.77 \text{ Ft}^3 + 55.43 \text{ Ft}^3 \\ &= 148.2 \text{ Ft}^3 \end{aligned}$$

$$\text{Impact absorber} = \frac{1}{4} \pi (26.5/12)^2 (4.5/12) = 6.4 \text{ Ft}^3$$

$$\text{Free volume in tube with single MCO + absorber} = 101.3 \text{ Ft}^3$$

by difference

Just below 5 psig,

the plug
will lift up.
we must
say below
say 4 psig

pressure rise in the tube will be limited by the
bellows joint at the top. The vendor calculated 8 psig
maximum pressure before the bellows can no longer
perform its function (according to design spec, test pressure
is 12 psig) [Hill E 350-13088 p.5,7]

SA:

TASK 2

MCO gas release

sealed tubes option

SINGLE MCO

DESIGN LIMIT CASES:

When there is one 8-canister MCO present, the number of atmospheric ft^3 can increase to $(101.34)(18.7)/(14.7) = 128.92$. In the tube before the pressure approaches 4 psig (18.7 psia). The time required to reach 4 psig is $(128.92 - 101.34 \text{ ft}^3)/(0.494 \text{ ft}^3/\text{D}) = 56$ days with one 8-canister MCO.

If there are two 10 canister MCO's in a tube, the pressure increases much faster:

$$\text{gas release} = 2(10/8)(0.494 \text{ ft}^3/\text{D}) = 1.235 \text{ ft}^3/\text{D into tube}$$

$$\begin{aligned} \text{Free volume in tube} &= (148.20 \text{ ft}^3) - 2(45.42 \text{ ft}^3) - 2(1.44 \text{ ft}^3) \\ &= 54.48 \text{ ft}^3 \end{aligned}$$

$$(54.48)(18.7)/(14.7) = 69.30 \quad 69.30 - 54.48 = 14.82$$

$$\text{The time to reach 4 psig} = (14.82 \text{ ft}^3)/(1.235 \text{ ft}^3/\text{D}) = 12 \text{ days}$$

for a tube with two 10-canister MCO's at max gas rate; at the average gas rate, the time would be $(12)(14/1.2) = 140$ days

MULTIPLE MCO
MAXIMUM:

If we had all 10-canister MCO's the number would be about 960 MCO's. If the MCO's were placed two per tube, there would be 480 tubes to be vented. 44 days is a conservative value for the time between venting because it is based on the worst-case gas release; the nominal gas release is less than 10% of that. Therefore, a conservative estimate of the number of tubes that have to be vented is $(480 / 12) = 40$ tubes per day. For the nominal tube his venting schedule means that we usually vent the tube before the pressure reaches 4 psig.

CONCLUSION:

The off-gas from MCO's does not cause a feasibility problem for as pressure or venting schedule, but explosion hazard has to be addressed.

NOTE

The next calc (1/19/95) shows 6A

flammability is a tighter limit.

BASE CASE

MCO SERVICING

BASED ON LATA TESTS

The nominal rate of H_2 generation is 0.53 SCF/day at 100°F. (see calculation of 5/8/95)

$$379.45 \text{ SCF} = 1 \text{ lb-mole} \quad 0.53 \text{ SCF} = 0.0014 \text{ lb-mole}$$

0.0014 lb-mole of water reacts per day at the nominal rate.

$$(0.0014 \text{ lb-mole})(18 \text{ lb/lb-mole}) = 0.025 \text{ lb}$$

at 100°F the density of water is 62 lb/ft³

$$0.025 \text{ lb} = 0.00040 \text{ ft}^3 \text{ of water reacted per day per MCO}$$

Assuming the MCO vents at 100psig and 100°F,

the moisture content of the vent gas is 8,700 ppm (wt) (psychrometric chart)

$$(0.53 \text{ SCF } H_2)(0.0087) = 0.0046 \text{ SCF water vapor}$$

$$(0.0046 \text{ SCF}) / (379.45 \text{ SCF/mole}) = 0.000012 \text{ lb-mole moisture} \\ = 0.00024 \text{ lb}$$

evaporated moisture is negligible compared to reacted water.

According to Feasibility Study MCO sketch, there is only 6" freeboard above the top anister. Before 6" of water evaporates, the MCO is to be serviced.

$$\text{Water Volume} = \pi (1 \text{ ft})^2 (1/2 \text{ ft}) = 1.6 \text{ ft}^3$$

$$(1.6 \text{ ft}^3) / (0.00040 \text{ ft}^3/\text{D}) = 4,000 \text{ days between service (at nominal 11 years)}$$

$$880 \text{ MCOs} / 4,000 = 0.22 \text{ MCO} = 1 \text{ day for nominal}$$

max H_2 rate was 12X greater or 7A

$$\text{per day } 4,000/12 = 333 \text{ days}$$

THERMAL ANALYSIS
CONCEPT 2D AND TASK "G"

TA- ii

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TA 1

C:\SID\REPORT.4

THERMAL ANALYSIS FOR STORING K-BASIN FUEL IN THE HWVP CANISTER STORAGE BUILDING

Following is the rough calculation of heat transfer in the storage vaults. The assumptions as well as calculation results can be used only as a first guess. Detailed calculation using the Computational Fluid Dynamics (CFD) technique is proposed on the next stage of this project.

K-Basin fuel elements are stored in 2 vaults of the canister storage.

Unit	Vault	Sleeve	MCO	Assembly	Canister	Cylinder	Element
Storage	2 loaded	440	880	4400	8800	17600	104846 ¹
Vault		220	440	2200	4400	8800	52423 ²
Sleeve			2	10	20	40	280
MCO				5	10	20	140
Assembly					2	4	28
Canister						2	14
Cylinder							7

Table 1. Number of Units in the Storage

There is a mixed heat transfer media: air or water inside the MCOs, air between MCOs and sleeves, and air as a cooling media in the vault.

There is 20% of the maximum heat decay fuel elements and 80% of the nominal heat decay fuel elements. A single maximum heat decay element is releasing 3.44 W of heat. A single nominal heat decay element is releasing 1.56 W of heat.

It is assumed for conservative reason that 280 elements of maximum heat decay (3.44 W) can be loaded into a sleeve and located in the last row of the vault. This elements will be expressed to the highest vault air temperature. For comparison a number of calculations are made for the high loaded sleeve located at the beginning of the vault in the first row and expressed to the inlet airflow.

At the first stage, cooling air is supplied by the forced ventilation system with 100% of

¹Based on 750 MCOs

²Base on 375 MCOs

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return air. Proposed air inlet temperature is 35°F. For comparison, inlet temperature of 50°F is analysed as well. Maximum allowable temperature of the surface of a fuel element is 100°F. Calculation is made for the maximum vault load of 320 kW at for forced ventilation system and maximum vault load of 270 kW for natural convection. The difference of these loads is due to additional heat load from structures at low supply air temperature.

The purpose of this calculation is to find the maximum temperature of the surface of a fuel element.

The highest temperature is expected at the fuel elements closed to the center of the MCO. Each fuel element is assumed as a solid uranium cylinders surrounded by water or air (Figure 2).

The diameter of the hollow outer element ring is assumed the same as the diameter of the outer zirconium cladding (identified as #17).

$$D_{17} = 6.1 \text{ cm} = 2.4 \text{ in}$$

The diameter of the inner cylinder of the outer element (identified as # 14) is

$$D_{14} = 4.4 \text{ cm} = 1.7 \text{ in}$$

Relative diameters for the inner hollow cylinder (Identified as #13 and #10) are:

$$\begin{aligned} D_{13} &= 3.2 \text{ cm} = 1.25 \text{ in} \\ D_{10} &= 1.15 \text{ cm} = 0.45 \text{ in} \end{aligned}$$

Relatively the thicknesses of uranium are

$$\begin{aligned} \Delta_{\text{outer}} &= 2.4 - 1.7 = 0.7 \text{ in} \\ \Delta_{\text{inner}} &= 1.25 - 0.45 = 0.8 \text{ in} \end{aligned}$$

The uranium cross-section is

$$S = \pi / 4 ((D_{17}^2 - D_{14}^2) + (D_{13}^2 - D_{10}^2)) = \pi / 4 ((2.4_{17}^2 - 1.7_{14}^2) + (1.25_{13}^2 - 0.45_{10}^2)) = 3.32 \text{ sq.in}$$

The diameter of the equivalent by cross-section solid uranium cylinder is

$$D = (4 S / \pi)^{0.5} = (4 * 3.32 / \pi)^{0.5} = 2.06 \text{ in}$$

The volume of a single element is

$$V = \pi / 4 D^2 L = \pi / 4 (2.06/12)^2 * 2 = 0.0463 \text{ ft}^3$$

Since the maximum heat decay is 44 W which is 11.74 Btu/h, the rate of heat flow is

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$$q_x = Q / V = 11.74 / 0.0463 = 253.6 \text{ btu/h-ft}^3$$

The heat networking model is assumed with a number of zones of heat transfer. Considering a symmetrical heat transfer network the one-dimensional scheme is utilized in the following Figure 1.

Figure 1. Heat Transfer Network.

- Gap x: between the inner and the outer rings of a fuel element
- Gap x-1: between the center element and six peripheral fuel elements
- Gap 1-C: between the peripheral fuel elements and the canister,
- Gap C-M: between the canister and the MCO,
- Gap M-S: between the MCO and the sleeve,
- Gap S-AIR: resistance between the sleeve and surrounding air.

Networking resistance factors:

- Zone x; 1 element : $f_x = 1$
- Zone x-1; 6 elements: $f_1 = 1 + 1/6 = 1.17$
- Other zones in series: $f = 1$

Heat transfer between two adjacent zones i and i+1. Zones are assumed as flat

$$q_i = q_{i-1} + k (1/ f_i) A_i (T_i - T_{i+1}) n_i$$

where,

- q_{i-1} = heat transfer from previous zone, Btu/h
- k = thermal conductivity coefficient between two zones, btu/h-ft-F
- f_i = networking resistance factor, dimensionless
- A_i = heat conduction area for i-zone, sq.ft
- T_i = (i)-surface temperature, F
- T_{i+1} = (i+1)-surface temperature, F
- n_i = number of elements in (i)-zone

It is assumed for simplification reasons that the thermal conductivity coefficients are not changing with temperatures.

Following calculations, made for heat transfer areas, considering 80% of actual height of fuel element.

For zone x the heat transfer area is calculated for a single fuel element:

$$A_x = \pi (D_{17}) \circ L \circ 80\% = \pi (2.4) \circ 12 \circ .8 = 169 \text{ sq.in} = 1.17 \text{ sq.ft}$$

TA 4

For zone x-1 the heat transfer area is calculated for 7 elements:

$$A_{01} = \pi (D_{17} \cdot 7) \cdot (L) \cdot 80\% = \pi (2.4 \cdot 7) \cdot (28) \cdot 0.8 = 1182 \text{ sq.in} = 7.04 \text{ sq.ft}$$

For zone 1-C the heat transfer area is assumed as an average between 7 elements and cylinder tube surfaces:

$$A_{1C} = (A_{x1} + A_C) / 2 \cdot 80\% = \pi L (6 \cdot D_{x1} + D_C) / 2 \cdot 80\% = \pi (28) (6 \cdot (2.4) + (9) / 2) \cdot 0.8 = 823 \text{ sq.in} = 5.72 \text{ sq.ft}$$

For zone C-M the heat transfer area is assumed as an average between 2 assemblies (2 canisters, 28 elements) and MCO surfaces:

$$A_{CM} = (4 A_C + A_M) / 2 = \pi L (4 \cdot D_C + D_M) / 2 = \pi (28) (4 \cdot 9 + 24) / 2 = 2638 \text{ sq.in} = 18.33 \text{ sq.ft}$$

For zone M-S the heat transfer area is assumed as an average between the MCO and the sleeve surfaces (total height is 98" * 3):

$$A_{MS} = (A_M + A_S) / 2 = \pi L_{Tot} (D_M + D_S) / 2 = \pi (98 \cdot 3) (24 + 29) / 2 = 24476 \text{ sq.in} = 170 \text{ sq.ft}$$

Heat transfer surface from a sleeve to the cooling airflow is:

$$A_s = \pi L D_s = \pi (164 \cdot 2/12) (29/12) = 208 \text{ sq.ft}$$

Maximum center line temperature at the center zone 0 element (Kreith and Bohn, Principles of Heat Transfer, 5 ed., p.96, Eq.2.51. Ref. 1b)

$$T_{cl} = T_x + q_x (D/2)^2 / (4 \lambda_{\text{uranium}})$$

where:

q_x = rate of heat flow, Btu/h-ft²

λ_{uranium} = thermal conductivity coefficient for uranium, 17.3 Btu/h-ft-°F (Kreith and Bohn, Principles of heat Transfer, Ed.5, p.A13, Ref. 1d).

Heat transfer coefficient, k, depends on the media.

The total normal emittance for zirconium is assumed as for dark paints as 0.85 (ASHRAE 1989, p.3.8, Table 3. Ref. 2b). For horizontal direction of heat flow and 90°F mean temperature the approximate thermal resistance of plane airspace for each air gap is 0.77°F-ft²-h/Btu (ASHRAE 1989, p.22.3, Table 2. Ref. 2c).

Thermal conductivity coefficient for uranium is approximately 17.3 Btu/h-ft-°F (Kreith and Bohn, Principles of heat Transfer, Ed.5, p.A13. Ref. 1d)

Total heat transfer coefficient for an element with two air gaps and uranium slab

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(zirconium claddings are ignored due to their low thickness) is

$$k = 1 / (R_{gap1} + \Delta_1 / \lambda_{uranium} + \Delta_2 / \lambda_{uranium} + R_{gap2}) c$$

$$= 1 / (0.77 + (0.7/12) / 17.3 + (0.8/12) / 17.3 + 0.77) * 1.1 = 0.715 \text{ Btu/h-ft}^2\text{-}^\circ\text{F}$$

where

R_{gap} = Air gap resistance, F-ft²-h/Btu
 $\Delta_{uranium}$ = Thickness of uranium, in
 c = adjustment coefficient for conductance between elements by touching (assumed 1.1)

Following data are taken from HWVP project (FDI calculation No. E350-HV-1802, Book II):

Heat transfer coefficient between overpack and sleeve $h_{os} = 0.329 \text{ Btu/h-}^\circ\text{F-ft}^2$

Heat transfer coefficient between sleeve and airflow is calculated using ASHRAE 1989 Fundamentals, Chapter 3, p.3.15, Ref.2e) as a function of air velocity (vertical plane surfaces, $V < 16 \text{ fps}$)

$$h = 0.99 + 0.21 V$$

If water is used as a media between surfaces the free convection film coefficient is recalculated as:

$$h = Nu * (k / L) = C (Gr Pr)^n (k / L)$$

where,

Grashoff factor is

$$Gr = L^3 \rho^2 \beta \Delta T g / \mu^2$$

L = effective length, ft [1.87 ft]
 ρ = density, lbm/ft³, [61.2]
 β = thermal expansion, 1/F, [3.1E-4]
 ΔT = temperature difference, F
 g = gravitation constant, ft-lbm/lbf-s², [32.2]
 μ = absolute fluid viscosity, lb/ft-s, [0.29E-3]
 k = thermal conductivity of water, BTU/h-ft-F, [0.384]
 Nu = Nusselt factor
 Pr = Prandtl factor (2.74)

For forced air cooling system airflow is given. If passive cooling is applied, airflow is calculated as a function of stack height, air densities, and system resistance.

System conductance (K1) is based on system hydraulic characteristics calculated in HWVP Project (FDI calculation No. E350-HV-1802, Book II) for airflow at Q = 90000 cfm and $\Delta P = 0.19 \text{ in.WG}$ which is $K1 = 0.19/90000^2 = 2.34 * 10^{-11} \text{ in.WG/ft}^2$ for three vaults. For two vaults this coefficient is different due to higher resistance in the vaults.

Following system of simultaneous algebraic equations describes the heat transfer process

- 1) Maximum temperature in the center line of the centered fuel element, T_{cl} , as a function of surface temperature, T_x

$$T_{cl} = T_x + q (D/2)^2 / (4 k_{\text{uranium}})$$

- 2) Heat transfer between surface of a centered fuel element and six surrounding elements (zone 0-1)

$$6 q = k (1/f_1) A_{x1} (T_x - T_1)$$

- 3) Heat transfer between surface of six elements and a single canister cylinder (zone 1-C)

$$7 q = k (1/f) A_{1c} (T_1 - T_c)$$

- 4) Heat transfer between surface of assembly and MCO (zone C-M):

$$28 q = k (1/f) A_{cm} (T_c - T_m)$$

- 5) Heat transfer between surface of MCO and sleeve (zone M-S):

$$280 q = k A_{ms} (T_m - T_s)$$

- 6) Heat transfer between surface of sleeve and airflow (zone S-Air):

$$280 q = h A_s (T_s - T_{out})$$

- 7) Heat absorption by airflow

$$Q = c_{air} 60 (\rho_{in} + \rho_{out})/2 (CFM) (T_{out} - T_{in})$$

Following two equations are used for passive ventilation only in order to find airflow. For a forced cooling system airflow is given.

- 8) Hydraulic resistance of the natural convection system (T-DUCT calculation)

$$\Delta P = k1 (CFM)^2$$

- 9) Stack effect

$$P_{stack} = 0.192 (\rho_{out} - \rho_{in}) H$$

Let us rearrange those equations and present them in a calculation order:

- 0) CFM = initial guess

- 1) $T = T + Q / (c 60 (\rho + \rho) / 2 (CFM))$

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$$2) \quad \Delta P = k_1 (\text{CFM})^2$$

$$3) \quad \begin{aligned} p_{out} &= 1.75\text{E-}7 T_{out}^2 - 0.000166 T_{out} + 0.086 \\ p_{in} &= 1.75\text{E-}7 T_{in}^2 - 0.000166 T_{in} + 0.086 \end{aligned}$$

$$4) \quad P_{stack} = 0.192 (p_{out} - p_{in}) H$$

If $\Delta P = P_{stack}$, follow to the next calculation. Other vice change the initial guess and repeat iterations

$$5) \quad T_s = T_{out} + n_4 q / (h_{SA} A_s)$$

$$6) \quad T_o = T_s + n_3 q / (h_{CS} A_{OS})$$

$$7) \quad T_c = T_o + n_2 q / (k (1/f) A_{CO})$$

$$8) \quad T_1 = T_c + n_1 q / (k (1/f) A_{IC})$$

$$9) \quad T_x = T_1 + n_x q / (k (1/f_1) A_1)$$

$$10) \quad T_{cl} = T_x + q_x (D/2)^2 / (4 k_{uranium})$$

Transient Analysis

Description

The following study determines the heat transfer conditions after the loss of cooling air. The time duration will characterize the level of safety associated with the use of cooling air system.

The calculation is based on identification of changes in enthalpy between time periods. The difference between the sum of enthalpies for each material divided by the heat load will identify the time for reaching the particular temperature conditions.

Initial temperatures are assumed at airflow of 200,000 cfm flowing through 2 vaults fully loaded with radioactive material. The total heat load is 320 kW.

Assumptions

- 1) The heat from nuclear decay during the loss of cooling airflow is considered to be absorbed by fuel elements, cylinders, and assemblies filled with water, sleeves, and internal air.
- 2) It is assumed that the total mass of each heat absorption material has the same average temperature.
- 3) It is assumed for conservative reasons that the sleeves loaded with 3.44 kW elements located at the end of the vault where the air temperatures are the highest.
- 4) It is assumed that the difference between temperatures of heat absorbing materials is proportional regardless the fact of the loosing cooling air.

Calculation

Following heat transfer calculations are obtained for the steady state conditions. Initial data are presented at the time of accident occurrence.

Initial:

Average air temperature in the vault	= 37.35°F
Sleeve temperature	= 51.4°F
MCO temperature	= 110°F
Canister temperature	= 110.8°F
Water temperature	= 111.85°F

Following data are the results of calculations made for the different canister temperatures with an approximate interval of 10°F in order to identify the change in temperature for each heat absorption material.

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Period 1:

Average air temperature in the vault	= 41.75°F
Sleeve temperature	= 62.6°F
MCO temperature	= 121.2°F
Canister temperature	= 122.0°F
Water temperature	= 123°F

Period 2:

Average air temperature in the vault	= 46.35°F
Sleeve temperature	= 72.6°F
MCO temperature	= 131.2°F
Canister temperature	= 132.0°F
Water temperature	= 133°F

Period 3:

Average air temperature in the vault	= 51.2°F
Sleeve temperature	= 82.6°F
MCO temperature	= 141.2°F
Canister temperature	= 142.0°F
Water temperature	= 143°F

Period 4:

Average air temperature in the vault	= 56.1°F
Sleeve temperature	= 92.6°F
MCO temperature	= 151.2°F
Canister temperature	= 152.0°F
water temperature	= 153°F

Period 5:

Average air temperature in the vault	= 61.6°F
Sleeve temperature	= 102.7°F
MCO temperature	= 161.3°F
Canister temperature	= 162.1°F
Water temperature	= 163°F

Period 6:

Average air temperature in the vault	= 66.1°F
Sleeve temperature	= 112.6°F
MCO temperature	= 171.2°F
Canister temperature	= 172.0°F
water temperature	= 173°F

Heat load due to nuclear decay from the entire fuel elements is calculated as:

$$Q = 320 \times 3413 = 1,092,160 \text{ Btu/h}$$

The difference between enthalpies is calculated as:

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Elements: $\Delta E_e = m_e c_e n_e (T_{e2} - T_{e1})$

Cylinders: $\Delta E_c = m_c c_c n_c (T_{c2} - T_{c1})$

Assemblies: $\Delta E_m = m_m c_m n_m (T_{m2} - T_{m1})$

Sleeves: $\Delta E_s = m_s c_s n_s (T_{s2} - T_{s1})$

Water in MCO: $\Delta E_w = m_w c_w n_w (T_{w2} - T_{w1})$

Air in the vaults: $\Delta E_a = m_a c_a n_a (T_{a2} - T_{a1})$

where:

m = material mass, lb
 c = specific heat, Btu/lb-°F
 n = number of elements
 T₁, T₂ = temperatures at different periods, °F

Following masses are calculated for a single sleeve:

Elements: $m_e = 51.18 \times 280 = 14330 \text{ lb}$

Cylinders: $m_c = (\pi D_c L_c + 2 \pi D_c^2 / 4) \sigma_c \rho_c n_c$
 $= \pi (0.68 \times 2.2 + 2 \times 0.68^2 / 4) 0.021 \times 490 \times 40 = 2233 \text{ lb}$

Assemblies: $m_m = (\pi D_m L_m + 4 \pi D_m^2 / 4) \sigma_m \rho_m n_m$
 $= \pi (2 \times 2.33 + 2 \times 2^2 / 4) 0.031 \times 490 \times 10 = 3178 \text{ lb}$

Sleeves: $m_s = \pi D_s L_s \sigma_s \rho_s = \pi 2.42 \times 36 \times 0.041 \times 490 = 5498 \text{ lb}$

Water: $m_w = \pi D_m^2 L_m \sigma_w \rho_w - \Sigma (m/\rho)$
 $= ((\pi 2.38^2 / 4 \times 36) - 14330/1190 - 2233/490 - 5498/490) 62.4 = 7843 \text{ lb}$

Following mass is calculated for the entire storage:

Air: $m_a = ((603/12 \times 2/3) \times 447/12 \times 133) \rho_a = 11618 \text{ lb}$

Specific heat is calculated as:

Uranium elements: $c_e = 0.027 \text{ Btu/lb-°F}$

Stainless steel, Cor-ten: $c_c = c_e = c_m = c_s = 0.11 \text{ Btu/lb-°F}$

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Water: $c_w = 1.0 \text{ Btu/lb-}^\circ\text{F}$

Air: $c_a = 0.24 \text{ Btu/lb-}^\circ\text{F}$

Total enthalpy:

$$\Sigma \Delta E = \Delta E_s + \Delta E_o + \Delta E_m + \Delta E_s + \Delta E_w + \Delta E_s$$

Approximate time difference for temperatures at time index 1 to reach temperatures at time index 2 is calculated as:

$$t = \Sigma \Delta E / Q$$

CFD MODELING

The PHOENICS (Parabolic, Hyperbolic or Elliptic Numerical Integration Code Series) is a computer program that simulates fluid flow, heat transfer, and other related phenomena. This simulation is based on mathematical derivation from established physical principles. The basic capabilities provided by PHOENICS include:

- menu driven interface
- one-, two-, or three-dimensional in Cartesian, cylindrical-polar or body fitted coordinats
- steady-state or transient analysis
- single phase or two-phase media analysis
- compressible or incompressible flow
- subsonic, supersonic or transonic flow

The PHOENICS solves the equations for flows, turbulence, mass and heat transfer by a control volume method based on finite element approach. In the present problem, the flow is mostly turbulent and also under buoyancy effect of natural convection. This problem is governed by the Navier-Stokes equations representing the conservation of mass, momentum and energy.

PHOENICS has many limitations and restrictions. First, the realism of its simulations cannot exceed that of the assumptions on which its use is based. Secondly, a simulation produced by PHOENICS has an accuracy that depends upon the amount of computer time that its user has been willing or able to spend. Finally, fluid dynamic phenomena being what they are, it cannot be guaranteed that PHOENICS will provide a converged solution to every problem without user's making special settings of solution-control switches.

CHAM company, the author of PHOENICS, stated that the code "is very well validated and developed from over 10 years of commercial use (EasyFlow, release 2.01, page 1)."

There are a number of different simulations performed for this project using PHOENICS, including vault airflow and temperature distribution (CFD/Model), analyses of airflow around the building (Site Model), and study of entry device effect (T-Entry Inlet Model).

The details of PHOENICS simulation technique will be described using the CFD/Model.

Assumptions and Limitations

Finite volume method requires that the space be divided into discrete elements. The high-frequency and spatially very small fluctuations of turbulent flow variables cannot be quantified directly. Assumptions must be made for these unknown turbulence correlations. The best compromise between acceptable computer time and accuracy of the simulation of turbulent flow phenomena is the k- ϵ turbulent model, that consists of two additional differential equations for the turbulent kinetic energy (k) and the dissipation rate.

For all analyzed models flow in the vault under designed conditions are turbulent ($Re > 3000$).

Main Equations and Numerical Solution

Steady state turbulent flow in the vault can be described by conservation equations. The governing equations can be written in terms of cartesian tensors.

Continuity equation:

$$\frac{\partial}{\partial x_j} (u_i) = 0$$

where,

u = component of mean velocity, m/s
 x = coordinates, m
 i, j = directions

Momentum equation:

$$\frac{\partial}{\partial x_j} (u_i u_j) = - \frac{1}{\rho} \frac{\partial p}{\partial x_j} + \frac{\partial}{\partial x_j} (v_{eff} (\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i})) + g_i$$

where,

ρ = density, kg/m³
 p = pressure, Pa
 g = gravity acceleration, m/s²

$$v_{eff} = v_t + v_l$$

v_{eff}, v_t, v_l = effective, turbulent, and laminar kinematic viscosity, m²/s

The turbulent kinematic viscosity is

$$v_t = C_\mu k^{1/2} * l_m$$

where,

l_m = mixing length, meters

$$l_m = C_\mu k^{3/2} / \epsilon$$

Turbulent kinetic energy equation is:

$$\frac{\partial}{\partial x_j} (k u_j) = \frac{\partial}{\partial x_j} (\frac{v_{eff}}{\sigma_k}) \frac{\partial k}{\partial x_j} + G - \epsilon$$

where,

k = kinetic energy of turbulence, m²/s²
 G = generation rate of turbulence energy, m²/s²
 ϵ = dissipation rate of turbulent kinetic energy, m³/s³
 σ_k = effective Prandtl numbers in turbulent model

$$G = \nu_t \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \frac{\partial u_i}{\partial x_j}$$

Turbulent dissipation rate equation is:

$$\frac{\partial}{\partial x_j} (\epsilon u_j) = \frac{\partial}{\partial x_j} \left(\frac{\nu_{eff}}{\sigma_\epsilon} \right) \frac{\partial \epsilon}{\partial x_j} + (C_1 G - C_2 \epsilon) \frac{\epsilon}{k}$$

where,

C_μ, C_1, C_2 = empirical constants,
 σ_ϵ = effective Prandtl numbers in turbulent model

For the inlet boundary conditions, the air velocity distribution component is in z-direction.

The finite-domain technique, used by PHOENICS, combines the features of the method of Patankar S.V. and Spalding D.B. (1972, "A Calculation Procedure for Heat, Mass and Momentum Transfer in Parabolic Flows," Int.J. Heat and Mass Transfer, 21, London, England, 1565-1579). The calculated space area is discretized into finite intervals and the variables are computed only at a finite number of locations called "grid-points." The variables are connected with each other by algebraic equations.

Internally, PHOENICS solves sets of algebraic equations that represent the consequences of:

- ✖ integrating the differential equations over the finite volume of a computational cell over a finite time
- ✖ approximating the resulting volume, area and time averages by way of interpolation assumptions

It is assumed that, in convection terms, all fluid properties are uniform over cell faces; the timely new values are supposed to prevail throughout the time interval.

For each dependent variable there are as many algebraic equations as there are cells in the integration domain. Thus, there are a set of (NX x NY x NZ) algebraic equations for each dependent variable. PHOENICS solves them in an iterative manner, the object of which is to reduce the imbalance between the left and right sides of every equation to a magnitude that is small enough to be neglected. Iterations are needed because the equations, though linear in appearance, are non-linear in general. In each iteration cycle, the coefficients and sources are assumed as constants. On the next iteration, the coefficients and sources are updated from the latest values of the auxiliary and dependent variables, and the linear equations reassembled and solved. Buoyancy sources are included in the appropriate momentum equation.

Model Setup

Simulating a real problem requires to setup the model. This is one of the most important steps for obtaining a right solution. Necessary dimension of the problem has to be selected. It must be considered, that 3-dimensional model with many regions often makes the solution of a problem very difficult because of increased running time and convergency problems. Therefore, if requirement to the accuracy is moderate, 2-dimensional model should be selected. Symmetry in a model can be efficiently utilized by reducing model size on symmetrical line. However, in many cases of fluid flow, nonsymmetrical airflow pattern must be selected even in a field that has geometrical symmetry. For example, airflow in a narrow cave with vertical

symmetry is nonsymmetric.

PHOENICS allows to choose between 3 different coordinate options: cartesian, cylindrical-polar, and body-fitted.

Mesh Generation

PHOENICS allows to generate a mesh automatically by specifying the grid for each coordinate. Input of extents (sizes) and number of cells allows to visualize the geometry and make necessary correction prior to a run. Sensitive areas, where more accurate results are desired, need more cells. Also, distance between cells can be set as exponential function. This is often used to get "closer look" to the areas where more accurate solution is necessary.

Analysis Type, Properties, and Boundary Conditions

PHOENICS requires to specify the analysis type including hydraulic regime, heat transfer, flow regime (parabolic or elliptic), number of flow phases (one or two), steady-state or transient analysis.

PHOENICS has a number of physical properties that must be selected including density, laminar and turbulent viscosity, mixing-length, specific heat, and thermal conductivity.

Boundary conditions are the most important and complicated part of input data. They include inlets, outlets, walls, internal plates, obstructions, gravity, and heat sources. There is an opportunity to identify external relative pressure at outlet. Heat flux or temperature can be defined for walls as well as for obstructions. Walls allow to calculate airflow resistance as well. One useful option is obstruction porosity between 0 (solid) and 1 (fully open). Gravity force can be defined for buoyancy calculations, where the strength of buoyancy exists by using Boussinesq approximation associated with reference temperature and expansion coefficient. Volumetric heat sources can be defined in several ways: from separate screen, as a part of obstructions entry, or as a part of walls entry. There is an indication received from CHAM of North America (PHOENICS's author, letter of September 3, 1991), that volumetric heat source used as input must be divided by specific heat.

Solution Monitoring and Printout Control

PHOENICS has very extensive interactive capability for solution control. This control includes the initial value of dependent variables, termination of the calculations, relaxation of individual dependent variables, solution option for each dependent variable and the terms included in the equations. The program provides three different ways of under-relaxation: linear, automatic and false time-step. There is an opportunity to limit residuals by terminating the iterations for each dependent variable when residual value is reached.

During the calculation, converging process is monitored interactively (see Fig.A.51). Calculation can be interrupted any time and parameter type and/or the value can be changed. A graph and a table of current values are shown for both the hot area value and for the total residual for each variable. Good converging process is the one which shows that the upper plot stabilizes oscillations and the lower plot shows continuous decrease of residuals.

Color graphic results can be displayed by a post-processor using module PHOTON. This program has its own language that allows to display any cross-sections, variables, vectors in form of color fields and color vectors.

Program Verification and Validation

Verification and Validation procedure has been performed in accordance with Design Control Procedures Manual, section 4 "Calculations", and section 9 "Computer Code Validation and Verification"). Following steps are conducted:

- Available CFD commercial programs were studied and the most efficient, that is PHOENICS, has been selected. The cover page of the program has been signed by the Project Engineer and preapproved by WHC
- The PHOENICS introductory course, given by CHAM of North America, was completed by the originator
- Computer Code Summary has been filled. Project Classification is assigned to Class IIIB "Off-the Shelf Design Aid-third party supported." Program validation includes: history of acceptance/ use and analysis of data in literature. As follow from the list of publications (see A.7.5.1) PHOENICS has been intensively checked and verified by many independent reviewers
- Many sample test problems were run by the originator prior of using the program
- A complete description of model is included into this report
- The checked and the independent reviewer have verified that the model is a reasonable representation of the process or physical phenomenon of interest and outputs are reasonable.

Numerical evaluation including manual calculation has already been used and explained for the AF/Model (see FDI calculation E350-HV-1802). Similar evaluation for the CFD/Model is impossible due to a huge number of calculation and program complication. Logical way of verification includes data analyzing and referencing to respectable publications. Comparing to a similar program and/or to the test data are other ways for verification. However, we do not believe that similar data exist due to the unique configuration and conditions of canister storage building. There are a number of similar programs, such as FLUENT, FIDAP, FLOTRAN. However, if the results of programs are different, there is no answer which program is correct, since there is no test data. Therefore, the most valuable sources to evaluate such a large system as PHOENICS are respectable publications for similar problems and engineering judgment from a highly qualified and experienced engineer.

As stated by CHAM of North America, PHOENICS is the industrie's first full-capability computational fluid dynamics software package for PC. There are over 350 installation of PHOENICS throughout the world. PHOENICS references includes a list of publications that shows large number of applications where PHOENICS has been successfully used for solving many fluid mechanics and heat transfer problems.

Geometry

Figure A16a presents the 2-dimensional simulation model. A cross-section through the vertical symmetry axis in the center of vault is modeled.

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Figure A16a

Inlet air opening is located at the upper-left part of the model. Outlet opening is located at the upper-right part of the model. The middle part of the vault is occupied by sleeves. Airflow pressure loss in this part of the vault is simulated by using porosity factor. PHOENICS is not capable of simulating anisotropic porosity that would have some advantages for the specific air flow pattern of space occupied by sleeves. Airflow regime is turbulent since, for maximum loads, Reynolds number is above 3000. Wall surfaces are assumed adiabatic (conservative approach), however hydraulic resistances of walls are taken into consideration. Because of assumptions such as 2-dimensional simulation and porosity, temperatures in this simulation will be used as relative values only. The results of simulation will allow to calculate flow pattern in the vault and discover hot areas where temperatures are higher due to the buoyancy effect. The reference air temperatures are at inlet and/or outlet. All dimensions used in PHOENICS are in SI units.

For the model under consideration cartesian grid is selected. This grid consists of cells formed by intersection of planes of constant z and planes of constant y . A rectangular grid was constructed using interactive preprocessor EasyFlow. Y -direction is divided into 6 regions with physical dimensions shown on Figure 7. Each region has been divided into different number of cells. Z -direction is divided into 3 regions with equal spacing between cells.

Properties

Air density and laminar viscosity are assumed to be 1.01 kg/m^3 and $2.1\text{E-}5 \text{ m}^2/\text{s}$ respectively. Turbulent viscosity is calculated by the program itself as well as the mixing length. Air specific heat is $1004 \text{ J/kg-}^\circ\text{C}$ and air thermal conductivity is $0.0263 \text{ W/m-}^\circ\text{C}$. There is no need of using variable properties since the buoyancy effect is calculated by Bussinesq approximation with air expansion coefficient.

Boundary Conditions

Boundary conditions include: one inlet, one outlet, walls, obstructions, gravity, and heat sources.

Inlet is located in the HIGH face Z -region #3, Y -region #1. Using airflow of 53,000 cfm, inlet velocity is calculated for 2 vaults as

$$V = \frac{53000}{(6 \times (8 \times 21.5)) (2/3)} = 77.0 \text{ fpm} = 0.393 \text{ m/s}$$

where:

$6 \times (8 \times 21.5)$ is the total air entry area for 3 vaults, ft^2

The direction of air at inlet opening is -Z (see Fig.7). Turbulent intensity is recommended by PHOENICS (see EasyFlow manual, p.6-84) as 2% or 0.02. Inlet air temperature assumed is $115^\circ\text{F} = 46.06^\circ\text{C}$. Outlet and wall boundaries and obstructions are as shown in Fig.7. Since we are using constant density and considering buoyancy effect, Boussinesq approximation has been input. For reference temperature of 25°C the air volume expansion coefficient is $\beta = 0.00336^\circ\text{C}^{-1}$. This coefficient is the reciprocal of the absolute temperature for an ideal gas or $1/(273+25) = 0.00336^\circ\text{C}^{-1}$ (see PHOENICS EasyFlow Manual, p.6-96). Gravity acceleration is taken for negative Z-direction as -9.81 m/s^2 .

Effective vault volume is calculated as

$$\text{Vol.} = 96 \times 36 \times (3 \times 50) = 518,400 \text{ ft}^3 = 14,679 \text{ m}^3.$$

Vault volume occupied by sleeves (3 vaults) is

$$\text{Vol.} = 22 \text{ rows} \times 10 \text{ columns} \times 3 \text{ vaults} \times \pi/4 \times 3^2 \times 36 = 167,949 \text{ ft}^3 = 4755 \text{ m}^3$$

Volumetric heat flux is calculated as energy divided by volume and by specific heat considering only 2 vaults:

$$W_v = \frac{W}{(\text{Vol.}) c_p} = \frac{270 \times 1000}{14679 \times 2/3 \times 1004} = 0.275 \text{ W/m}^3$$

where:

270 is total decay energy dissipated from canisters in Kw, and
1004 is air specific heat in $\text{J/kg}^\circ\text{C}$.

Airflow resistance of the vault is simulated as porosity. Porosity coefficient is calculated as following expression (the same for 2 vaults with 440 sleeves as for 3 vaults with 660 sleeves)

$$1 - \text{Vol.}/\text{Vol.} = 1 - 167,949/518,400 = 0.67$$

Interpretation of Results

The results of PHOENICS modeling are presented in Figures 8 through 13.

Mostly convergency residuals are decreasing. Temperature in Hot Area value plot is increasing by 0.007% only.

On the right side of the screen the scale of temperatures is displayed. It is easy to find temperature in a region starting from the white cell (see 53 degree). Temperature fields show that higher air temperatures are in a wide area below the ceiling. Velocity vectors and thermal regions are shown on Fig.14.

There are four major flow regions:

Region 1. The beginning of the stream where entered air is moving down creating first entry vertex

Region 2. Lower stream moving in the direction from inlet to outlet.
This stream contains relatively low air temperatures. It cools external walls and floor

Region 3. Higher stream that consists two substreams. These substreams start about 1/4 to the end of the vault but one of them moves to inlet and the second one moves to the outlet. Air in this region is the hottest in the vault.

Region 4. Second vertex located below the vault outlet opening.

Air buoyancy and slower air movement in the third flow region create higher temperatures at the top of the vault called "Hot Pillow" or "Hot Area." To know actual air temperature in "Hot Area" is important for calculating surface temperature of the ceiling. The 2-dimensional simulation shows internal air temperatures at each cell including temperatures of inlet and outlet air. There is a difference between the outlet and the "Hot Area" air temperatures due to the buoyancy. The calculation of the hottest air temperature in the vault is evaluated by adding this temperature difference to the outlet temperature, calculated by the AF/Model. The new air temperature is called "Hot Area air temperature in the vault."

Calculations show maximum "Hot Area" temperature differences between outlet area of 9°F(5°C). The maximum air temperature is 57°F(135°C).

Figure 14.

Calculation Tables and Figures

1. Forced ventilation, water in MCOs, air between MCOs and sleeve, sleeve is located at the end of the vault, inlet temperature is 35°F, total load is 320 kW. Calculation is conducted for different cooling airflows in the range between 10,000 and 500,000 cfm. The calculations are presented in Tables 2 through 28. The results are presented in Figure 2 and Table 1.

The results show that after 200,000 cfm the increase of airflow moderately effecting the canister temperature.

2. Similar calculation for inlet air temperature of 50°F presented in Tables 29 through 55 and in Figure 4.
3. Forced ventilation, air in MCOs, air between MCOs and sleeve, Sleeve is located at the end of the vault, inlet temperature is 35°F, total load is 320 kW. Calculation is conducted for different cooling airflows in the range between 50,000 and 500,000 cfm. The calculations are presented in Tables 56 through 65. The results are presented in Figure 5.

The results show that after 200,000 cfm the increase of airflow moderately effecting the canister temperature. The substitution of water between MCOs and sleeve by air increasing the canister temperature approximately by 60°F.

4. Table 66 shows the inlet (supply) air temperature that makes the temperature of nuclear material equal 100°F. As show it is -37.3°F. This temperature is absolutely impractical.
5. Natural convection, air in MCOs, air between MCOs and sleeve, sleeve is located at the end of the vault, inlet temperature is 115°F, total load is 270 kW (decreased due to no heat load from constructions). Calculation is conducted to identify the temperature of nuclear material. The results in Table 67 show the temperature between 254 and 269°F.
6. The calculation of transient heat transfer is shown in Tables 68. The calculations in Tables 69 through 75 are made in order to identify the differences between temperatures when Tcanister has 10°F of increment.

The results of calculation are shown in Figure 6.

7. The results of CFD modeling are presented in Figures 8 through 14.

FIGURE 2. FUEL ELEMENT

Figure 3

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ALTERNATIVE 2D

THERMAL ANALYSIS - SUMMARY

MCO WATER TEMPERATURE FOR		SUPPLY AIR QUANTITY (CFM)	REMARKS
Supply air = 35 F (F)	Supply air = 50 F (F)		
213	232	10,000	
159	176	20,000	
142	158	30,000	
133	149	40,000	
128	144	50,000	
125	140	60,000	
122	138	70,000	
120	136	80,000	
119	134	90,000	
117	133	100,000	
116	132	110,000	
115	131	120,000	
115	130	130,000	
114	129	140,000	
113	128	150,000	
113	128	160,000	
112	127	180,000	
111	126	200,000	
110	125	230,000	
109	124	260,000	
108	123	300,000	
107	122	350,000	
106	121	400,000	
106	120	450,000	
105	120	500,000	

TABLE I.

7A 24

SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104848	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.08 in		
qx =	253.58 Btu/h-ft ²	A(2 vaults) =	1920.00 ft ²	hms =	0.33 Btu/h-ft ² -F
		Vair =	0.09 fps	hss =	1.01 Btu/h-ft ² -F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Gx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft ³	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s ²	Beta = 3.1E-04 1/F
	Gx =	1.5E+09	2.2E+09		2.3E+09
	Prc =	2.74	Pri =	2.74	Pro = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft ² -F
=>Temporary 2(Formulas)	Gx ==>	0	0		-43554.8
Coefficients:					
	ro =	1	rx =	1.00	AO = 1.17 ft ²
	fi =	1.17	n1 =	7.00	A1 = 7.04 ft ²
	f =	1.00	n2 =	28.00	A1c = 5.72 ft ²
			n3 =	280.00	Acm = 18.33 ft ²
			n4 =	280.00	Ams = 170 ft ²
					As = 208 ft ²
<hr/>					
Initial guess:	CFM =	10000	cfm		
Tout =	136.3 F	Tsleeve =	154.0 F	=	67.7 C air
		Tmco =	212.7 F	=	100.3 C air
		Tcanister =	213.4 F	=	100.7 C water
		Tinner =	214.2 F	=	101.1 C water
		" "	214.7 F	=	101.4 C water
ROout =	0.0664 lb/ft ³				
ROin =	0.0804 lb/ft ³				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

TABLE 2

TA- 25

c:\Sidd12D_4

SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104846	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.06 in		
qx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	0.17 fps	hsa =	1.03 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	81.2 lbm/ft3	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta = 3.1E-04 1/F
	Grx =	1.5E+09	2.2E+09		2.3E+09
	Prc =	2.74	Pr1 =	2.74	Prc = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==>	0	0		-32548.7
Coefficients:					
	f0 =	1	nx =	1.00	A0 = 1.17 ft2
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft2
	f =	1.00	n2 =	28.00	A1c = 5.72 ft2
			n3 =	280.00	Acm = 18.33 ft2
			n4 =	280.00	Ams = 170 ft2
					As = 208 ft2
<hr/>					
Initial guess:	CFM =	20000	cfm		
Tout =	84.4 F	Tsleeve =	99.8 F	=	37.6 C air
		Tmco =	158.4 F	=	70.2 C air
		Tcanister =	159.2 F	=	70.6 C water
		Tinner =	159.9 F	=	71.0 C water
ROout =	0.0732 lb/ft3	" "	160.4 F	=	71.3 C water
ROin =	0.0804 lb/ft3				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

TABLE 3

TA-26

c:\Sidd\2D_4

SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W					
No. of elements =	104846	Qtotal =	320 kW	=	1092180 Btu/h	
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1	
Tin =	35 F	D =	2.06 in			
qx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F	
		Vair =	0.26 fps	hse =	1.04 Btu/h-ft2-F	
				Lamda(ur) =	17.3 Btu/h-ft-F	
=>Temporary 1(Const)	Grx ==>	9E+09	1.00E+09		1.4E+09	
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft3	k =	0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta =	3.1E-04 1/F
	Grx =	1.5E+09	2.16E+09		2.3E+09	
	Pix =	2.74	Pri =	2.74	Proc =	2.74
	hx =	19.74	ht =	22.44	hc =	22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==>	0	0		-29054.8	
Coefficients:						
	r0 =	1	rx =	1.00	A0 =	1.17 ft2
	f1 =	1.17	n1 =	7.00	A1 =	7.04 ft2
	f2 =	1.00	n2 =	28.00	A1c =	5.72 ft2
			n3 =	280.00	Acm =	18.33 ft2
			n4 =	280.00	Ams =	170 ft2
					As =	208 ft2
<hr/>						
Initial guess:		CFM =	30000 cfm			
<hr/>						
Tout =	67.4 F	Tsleeve =	82.6 F	=	28.1 C	air
		Tmco =	141.2 F	=	60.6 C	air
		Tcanister =	142.0 F	=	61.0 C	water
		Tinner =	142.7 F	=	61.4 C	water
		" "	143.2 F	=	61.7 C	water
ROout =	0.0756 lb/ft3					
ROin =	0.0804 lb/ft3					

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

TABLE 4

SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104848	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.06 in		
qx =	253.58 Btu/h-ft ³	A(2 vaults) =	1920.00 ft ²	hms =	0.33 Btu/h-ft ² -F
		Vair =	0.35 fps	hss =	1.06 Btu/h-ft ² -F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	81.2 lbm/ft ³	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s ²	Beta = 3.1E-04 1/F
	Gnx =	1.5E+09	2.16E+09		2.3E+09
	Pnx =	2.74	Pri =	2.74	Prc = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft ² -F
=>Temporary 2(Formulas)	Grx ==>	0	0		-27321.1
Coefficients:					
	f0 =	1	rx =	1.00	A0 = 1.17 ft ²
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft ²
	f =	1.00	n2 =	28.00	A1c = 5.72 ft ²
			n3 =	280.00	Acm = 18.33 ft ²
			n4 =	280.00	Ams = 170 ft ²
					As = 208 ft ²
<hr/>					
	Initial guess:	CFM =	40000 cfm		
Tout =	59.1 F	Tsleeve =	74.0 F	=	23.3 C air
		Tmco =	132.6 F	=	55.9 C air
		Tcanister =	133.4 F	=	56.3 C water
		Tinner =	134.2 F	=	56.7 C water
		" "	134.7 F	=	57.0 C water
ROut =	0.0768 lb/ft ³				
ROin =	0.0804 lb/ft ³				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

TABLE 5

SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load = 3.44 W			
'No. of elements = 104848			
q = 11.74 Btu/h	Qtotal = 320 kW	=	1092160 Btu/h
Tin = 35 F	D17 = 2.4 in	c =	1.1
qx = 253.58 Btu/h-ft ³	D = 2.06 in		
A(2 vaults) =	f2 = 1920.00 ft ²	hms = 0.33	Btu/h-ft ² -F
Vair =	fss = 0.43 fpm	hsa =	1.08 Btu/h-ft ² -F
		Lambda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==> 9E+09	1.00E+09	1.4E+09
Water data:	L = 1.87 ft	Ro = 81.2 lbm/ft ³	k = 0.384 BTU/h-ft-F
	mu = 2.90E-04 lbm/ft-s	g = 32.2 ft/s ²	Beta = 3.1E-04 1/F
	Grc = 1.5E+09	2.16E+09	2.3E+09
	Prc = 2.74	Pri = 2.74	Prc = 2.74
	hx = 19.74	hi = 22.44	hc = 22.82 BTU/h-ft ² -F
=>Temporary 2(Formulas)	Grx ==> 0	0	-26273.4
<hr/>			
Coefficients:	f0 = 1	n0 = 1.00	A0 = 1.17 ft ²
	f1 = 1.17	n1 = 7.00	A1 = 7.04 ft ²
	f = 1.00	n2 = 28.00	A1c = 5.72 ft ²
		n3 = 280.00	Acm = 18.33 ft ²
		n4 = 280.00	Ams = 170 ft ²
			As = 208 ft ²
<hr/>			
Initial guess:		CFM =	50000 cfm
Tout = 54.2 F	Tsleeve = 88.9 F	=	20.5 C air
	Tmco = 127.5 F	=	53.0 C air
	Tcanister = 128.3 F	=	53.4 C water
	Tinner = 129.0 F	=	53.8 C water
	" " = 129.5 F	=	54.1 C water
ROout = 0.0775 lb/ft ³			
ROin = 0.0804 lb/ft ³			

Notice: 1) Tsleeve is calculated at the end of the vault.
2) Free area for airflow is calculated for 2 vaults.
3) Water inside the MCO and air between MCO and sleeve

TABLE 6

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SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104848	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.06 in		
qpr =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	0.52 fps	hsa =	1.10 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ros =	61.2 lbm/ft3	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta = 3.1E-04 1/F
	Grx =	1.5E+09	2.18E+09		2.3E+09
	Prx =	2.74	Pr1 =	2.74	Prp = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==>	0	0		-25564.4
Coefficients:	fo =	1	rx =	1.00	AO = 1.17 ft2
	fi =	1.17	n1 =	7.00	A1 = 7.04 ft2
	fe =	1.00	n2 =	28.00	A1c = 5.72 ft2
			n3 =	280.00	Acn = 18.33 ft2
			n4 =	280.00	Ams = 170 ft2
					As = 208 ft2
Initial guess:	CFM =	60000 cfm			
Tout =	51.0 F	Tsleeve =	85.4 F	=	18.5 C air
		Tmco =	124.0 F	=	51.0 C air
		Tcanister =	124.8 F	=	51.5 C water
		Tinner =	125.5 F	=	51.9 C water
		" "	126.0 F	=	52.2 C water
ROut =	0.0780 lb/ft3				
ROin =	0.0804 lb/ft3				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

TABLE 7

TA-30

SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104848	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.06 in		
qx =	253.56 Btu/h-ft ²	A(2 vaults) =	1920.00 ft ²	hms =	0.33 Btu/h-ft ² -F
		Vair =	0.61 fps	hsa =	1.12 Btu/h-ft ² -F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	81.2 lbm/ft ³	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s ²	Beta = 3.1E-04 1/F
	Gnx =	1.5E+09	2.16E+09		2.3E+09
	Pnx =	2.74	Pr1 =	2.74	Pr = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft ² -F
=>Temporary 2(Formulas)	Grx ==>	0	0		-25048.2
Coefficients:					
	f0 =	1	nx =	1.00	A0 = 1.17 ft ²
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft ²
	f =	1.00	n2 =	28.00	A1c = 5.72 ft ²
			n3 =	280.00	Acm = 18.33 ft ²
			n4 =	280.00	Ams = 170 ft ²
					As = 208 ft ²
<hr/>					
Initial guess:	CFM =	70000	cfm		
Tout =	48.7 F	Tsleeve =	62.8 F	=	17.1 C air
		Tmco =	121.4 F	=	49.6 C air
		Tcanister =	122.2 F	=	50.1 C water
		Tinner =	123.0 F	=	50.5 C water
		" "	123.5 F	=	50.8 C water
ROout =	0.0783 lb/ft ³				
ROin =	0.0804 lb/ft ³				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

TABLE 8

TA-31

c:\Sidd\2D_4

SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load	3.44	W	Qtotal=	320	kW	=	1092160	Btu/h	
No. of elements=	104846		D17=	2.4	in	c =	1.1		
q=	11.74	Btu/h	D=	2.06	in				
Tin=	35	F	A(2 vaults)=	1920.00	ft2	hms=	0.33	Btu/h-ft2-F	
qpc=	253.58	Btu/h-ft3	Vair=	0.69	fps	hsc=	1.14	Btu/h-ft2-F	
						Lamda(ur)=	17.3	Btu/h-ft-F	
=>Temporary 1(Const.)	Grx ==>	9E+09		1.00E+09			1.4E+09		
Water data:	L=	1.87	ft	Ro=	61.2	lbm/ft3	k=	0.364	BTU/h-ft-F
	mu=	2.90E-04	lbm/ft-s	g=	32.2	ft/s2	Beta=	3.1E-04	1/F
	Grx=	1.5E+09		2.16E+09				2.3E+09	
	Prc=	2.74		Prc=	2.74			2.74	
	hx=	19.74		h1=	22.44		hc=	22.82	BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==>	0		0				-24652	
Coefficients:	fo=	1	nx=	1.00		A0=	1.17	ft2	
	fi=	1.17	n1=	7.00		A1=	7.04	ft2	
	f=	1.00	n2=	28.00		A1c=	5.72	ft2	
			n3=	280.00		Acms=	18.33	ft2	
			n4=	280.00		Ams=	170	ft2	
						As=	208	ft2	
Initial guess:	CFM=	80000	cfm						
Tout=	48.9	F	Tsleeve=	60.9	F	=	16.0	C	air
			Tmco=	119.5	F	=	48.6	C	air
			Tcanister=	120.3	F	=	49.0	C	water
			Tinner =	121.0	F	=	49.4	C	water
			" "	121.5	F	=	49.7	C	water
ROout=	0.0786	lb/ft3							
ROin =	0.0804	lb/ft3							

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

TABLE 9

7A-32

SSF FUEL STUDY

c:\Sidd2D_4

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load = 3.44 W		Qtotal= 320 KW = 1092160 Btu/h	
No. of elements= 104848		D17= 2.4 in c= 1.1	
q= 11.74 Btu/h		D= 2.08 in	
Tint= 35 F		1920.00 ft2 hms= 0.33 Btu/h-ft2-F	
qx= 253.58 Btu/h-ft3		0.78 fps hsa= 1.15 Btu/h-ft2-F	
A(2 vaults)=		Lamda(ur)= 17.3 Btu/h-ft-F	
Vair=		1.4E+09	
=>Temporary 1(Const.)		1.00E+09	
Water data:		61.2 lbm/ft3 k= 0.384 BTU/h-ft-F	
Grx ==> 9E+09		32.2 ft/s2 Beta= 3.1E-04 1/F	
L= 1.87 ft		2.3E+09	
mu= 2.90E-04 lbm/ft-s		2.74	
Grc= 1.5E+09		Pr1= 2.74	
Prce= 2.74		Prce= 2.74	
hxc= 19.74		h1= 22.44	
=>Temporary 2(Formulas)		hc= 22.82 BTU/h-ft2-F	
Grx ==> 0		-24333.9	
Coefficients:		AD= 1.17 ft2	
f0= 1		A1= 7.04 ft2	
f1= 1.17		A1c= 5.72 ft2	
f= 1.00		Acm= 18.33 ft2	
		Ams= 170 ft2	
		As= 208 ft2	
Initial guess:		CFM= 90000 cfm	
Tout= 45.6 F		Tsleeve= 59.3 F = 15.2 C air	
		Tmco= 117.9 F = 47.7 C air	
		Tcanister= 118.7 F = 48.1 C water	
		Tinner = 119.5 F = 48.5 C water	
		" " = 120.0 F = 48.8 C water	
ROout= 0.0788 lb/ft3			
ROin = 0.0804 lb/ft3			

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

TABLE 10

7A-35

c:\Sidd\2D_4

SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W					
No. of elements =	104848	Qtotal =	320 kW	=	1092160 Btu/h	
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1	
Tin =	35 F	D =	2.06 in			
qx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F	
		Vair =	0.87 fps	hsa =	1.17 Btu/h-ft2-F	
				Lamda(ur) =	17.3 Btu/h-ft-F	
=>Temporary 1(Const.)	Grx ==>	9E+09	1.00E+09		1.4E+09	
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft3	k = 0.384 BTU/h-ft-F	
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta = 3.1E-04 1/F	
	Grx =	1.5E+09		2.16E+09		
	Prc =	2.74	Pr1 =	2.74	Prc = 2.74	
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft2-F	
=>Temporary 2(Formulas)	Grx ==>	0	0		-24074.2	
Coefficients:	r0 =	1	rx =	1.00	A0 = 1.17 ft2	
	r1 =	1.17	n1 =	7.00	A1 = 7.04 ft2	
	r =	1.00	n2 =	28.00	A1c = 5.72 ft2	
			n3 =	280.00	Acm = 18.33 ft2	
			n4 =	280.00	Ams = 170 ft2	
					As = 208 ft2	
Initial guess:	CFM =	100000	cfm			
Tout =	44.5 F	Tsleeve =	58.0 F	=	14.4 C	air
		Tmco =	116.6 F	=	47.0 C	air
		Tcanister =	117.4 F	=	47.4 C	water
		Tinner =	118.2 F	=	47.8 C	water
		" "	118.7 F	=	48.1 C	water
ROout =	0.0790 lb/ft3					
ROin =	0.0804 lb/ft3					

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

TABLE II.

SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load	3.44 W			
No. of elements	104848	Ototal=	320 kW	= 1092160 Btu/h
q=	11.74 Btu/h	D17=	2.4 in	c = 1.1
Tin=	35 F	D=	2.06 in	
qx=	253.58 Btu/h-ft3	A(2 vaults)=	1920.00 ft2	hms= 0.33 Btu/h-ft2-F
		Vair=	0.95 fps	hss= 1.19 Btu/h-ft2-F
				Lamda(ur)= 17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==> 9E+09		1.00E+09	1.4E+09
Water data:	L= 1.87 ft	Ro=	61.2 lbm/ft3	k= 0.384 BTU/h-ft-F
	mu= 2.90E-04 lbm/ft-s	g=	32.2 ft/s2	Beta= 3.1E-04 1/F
	Grx= 1.5E+09		2.16E+09	2.3E+09
	Prx= 2.74	Pr1=	2.74	Pr= 2.74
	hx= 19.74	h1=	22.44	hc= 22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==> 0		0	-23857.1
Coefficients:	f0= 1	rx= 1.00	AD= 1.17 ft2	
	f1= 1.17	n1= 7.00	A1= 7.04 ft2	
	f= 1.00	n2= 28.00	A1c= 5.72 ft2	
		n3= 280.00	Acm= 18.33 ft2	
		n4= 280.00	Ams= 170 ft2	
			As= 208 ft2	
Initial guess:	CFM=	110000	cfm	
Tout= 43.8 F	Tsleeve= 57.0 F	=	13.8 C	air
	Tmco= 115.8 F	=	46.4 C	air
	Tcanister= 116.3 F	=	46.8 C	water
	Tinner = 117.1 F	=	47.2 C	water
	" " = 117.8 F	=	47.5 C	water
ROut= 0.0791 lb/ft3				
ROin = 0.0804 lb/ft3				

Notice: 1) Tsleeve is calculated at the end of the vault.
2) Free area for airflow is calculated for 2 vaults.
3) Water inside the MCO and air between MCO and sleeve

TABLE 12

TA-35

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SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104848	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.06 in		
qx =	253.58 Btu/h-ft ³	A(2 vaults) =	1920.00 ft ²	hms =	0.33 Btu/h-ft ² -F
		Vair =	1.04 fps	hss =	1.21 Btu/h-ft ² -F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Re =	61.2 lbm/ft ³	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s ²	Beta = 3.1E-04 1/F
	Grx =	1.5E+09		2.16E+09	2.3E+09
	Prx =	2.74	Pr1 =	2.74	Pr = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft ² -F
=>Temporary 2(Formulas	Grx ==>	0		0	-23669.1
Coefficients:					
	f0 =	1	nx =	1.00	A0 = 1.17 ft ²
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft ²
	f =	1.00	n2 =	28.00	A1c = 5.72 ft ²
			n3 =	280.00	Acn = 18.33 ft ²
			n4 =	280.00	Ans = 170 ft ²
					As = 208 ft ²
<hr/>					
	Initial guess:	CFM =	120000	cfm	
Tout =	42.9 F	Tsleeve =	56.0 F	=	13.3 C air
		Tmco =	114.6 F	=	45.9 C air
		Tcanister =	115.4 F	=	46.3 C water
		Tinner =	116.2 F	=	46.7 C water
		" "	116.7 F	=	47.0 C water
ROout =	0.0792 lb/ft ³				
ROin =	0.0804 lb/ft ³				

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

TABLE 13

SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104846	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.06 in		
qx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	1.13 fps	hss =	1.23 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft3	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta = 3.1E-04 1/F
	Grx =	1.5E+09		2.16E+09	2.3E+09
	Prx =	2.74	Pr1 =	2.74	Pr = 2.74
	hx =	19.74	h1 =	22.44	h = 22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==>	0	0		-23505.2
Coefficients:					
	fo =	1	nx =	1.00	AO = 1.17 ft2
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft2
	f =	1.00	n2 =	28.00	A1c = 5.72 ft2
			n3 =	280.00	Ac = 18.33 ft2
			n4 =	280.00	Ams = 170 ft2
					As = 208 ft2
<hr/>					
Initial guess:	CFM =	130000	cfm		
Tout =	42.3 F	Tsleeve =	55.2 F	=	12.9 C air
		Tmco =	113.8 F	=	45.4 C air
		Tcanister =	114.6 F	=	45.8 C water
		Tinner =	115.4 F	=	46.3 C water
		" " =	115.9 F	=	46.5 C water
ROut =	0.0793 lb/ft3				
ROin =	0.0804 lb/ft3				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

TABLE 19

SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104848	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.06 in		
qx =	253.56 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	1.22 fps	hss =	1.25 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft3	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta = 3.1E-04 1/F
	Grx =	1.5E+09		2.16E+09	2.3E+09
	Ppx =	2.74	Pr1 =	2.74	Prc = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.62 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==>	0		0	-23360.3
Coefficients:	f0 =	1	nx =	1.00	A0 = 1.17 ft2
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft2
	f =	1.00	n2 =	28.00	A1c = 5.72 ft2
			n3 =	280.00	Ac = 18.33 ft2
			n4 =	280.00	Ams = 170 ft2
					As = 208 ft2
<hr/>					
Initial guess:		CFM =	140000 cfm		
Tout =	41.8 F	Tsleeve =	54.5 F	=	12.5 C air
		Tmco =	113.1 F	=	45.0 C air
		Tcanister =	113.9 F	=	45.5 C water
		Tinner =	114.6 F	=	45.9 C water
		" "	115.2 F	=	46.1 C water
ROout =	0.0794 lb/ft3				
ROin =	0.0804 lb/ft3				

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

TABLE 15

TA-38

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SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104848	Qtotal =	320 kW	=	1092180 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.06 in		
qx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	1.30 fps	hss =	1.26 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft3	k = 0.354 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta = 3.1E-04 1/F
	Grx =	1.5E+09		2.18E+09	2.3E+09
	Prx =	2.74	Pr1 =	2.74	Pr = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==>	0	0		-23230.8
Coefficients:					
	r0 =	1	nx =	1.00	A0 = 1.17 ft2
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft2
	f =	1.00	n2 =	28.00	A1c = 5.72 ft2
			n3 =	280.00	Acm = 18.33 ft2
			n4 =	280.00	Ams = 170 ft2
					As = 208 ft2
<hr/>					
Initial guess:	CFM =	150000	cfm		
Tout =	41.3 F	Tsleeve =	53.9 F	=	12.1 C air
		Tmco =	112.5 F	=	44.7 C air
		Tcanister =	113.3 F	=	45.1 C water
		Tinner =	114.0 F	=	45.5 C water
		" "	114.5 F	=	45.8 C water
ROout =	0.0794 lb/ft3				
ROin =	0.0804 lb/ft3				

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

TABLE 16

TA-34

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SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104846	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.06 in		
qpr =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	1.39 fps	hse =	1.28 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==> 9E+09	1.00E+09	1.4E+09		
Water data:	L = 1.87 ft	Ro = 61.2 lbm/ft3	k = 0.384 BTU/h-ft-F		
	mu = 2.90E-04 lbm/ft-s	g = 32.2 ft/s2	Beta = 3.1E-04 1/F		
	Grx = 1.5E+09	2.16E+09	2.3E+09		
	Prx = 2.74	Pr1 = 2.74	Prx = 2.74		
	hx = 19.74	h1 = 22.44	hc = 22.82 BTU/h-ft2-F		
=>Temporary 2(Formulas)	Grx ==> 0	0	-23113.9		
Coefficients:					
	f0 = 1	nx = 1.00	A0 = 1.17 ft2		
	f1 = 1.17	n1 = 7.00	A1 = 7.04 ft2		
	f2 = 1.00	n2 = 28.00	A1c = 5.72 ft2		
		n3 = 280.00	Acn = 18.33 ft2		
		n4 = 280.00	Ams = 170 ft2		
			As = 208 ft2		
Initial guess:	CFM =	180000 cfm			
Tout = 40.9 F	Tsleeve = 53.3 F	=	11.8 C	air	
	Tmco = 111.9 F	=	44.3 C	air	
	Tcanister = 112.7 F	=	44.8 C	water	
	Tinner = 113.4 F	=	45.2 C	water	
	" " = 113.9 F	=	45.5 C	water	
ROout = 0.0795 lb/ft3					
ROin = 0.0804 lb/ft3					

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

TABLE 17

SSF FUEL STUDY

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7A-40

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load = 3.44 W		No. of elements = 104846	q = 11.74 Btu/h	Tm = 35 F	q = 253.58 Btu/h-R3	A(2 vaults) = 1920.00 R2	hms = 0.33 Btu/h-R2-F	1.30 Btu/h-R2-F	Lambda(ur) = 17.3 Btu/h-R-F	1.4E+09	0.384 BTU/h-R-F	3.1E-04 1/F	2.3E+09	2.74	22.62 BTU/h-R2-F	-23007.6		
Octal = 320 kW		c = 1092160 Btu/h	D = 2.4 in	D17 = 2.06 in	hms = 1.48 fps	1920.00 R2	0.33 Btu/h-R2-F	1.30 Btu/h-R2-F	Lambda(ur) = 17.3 Btu/h-R-F	1.4E+09	0.384 BTU/h-R-F	3.1E-04 1/F	2.3E+09	2.74	22.62 BTU/h-R2-F	-23007.6		
Rout = 0.0796 lbm3		Tinner = 112.9 F	Tmco = 111.4 F	Tsleeve = 52.8 F	1.00E+09	61.2 lbm3	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42
Roin = 0.0804 lbm3		Tinner = 112.9 F	Tmco = 111.4 F	Tsleeve = 52.8 F	1.00E+09	61.2 lbm3	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42
Toute = 40.6 F		Tinner = 112.9 F	Tmco = 111.4 F	Tsleeve = 52.8 F	1.00E+09	61.2 lbm3	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42
Initial guess:		CFM = 170000 cfm																
Coefficients:		n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17
=>Temporary 1 (Const)		Grx = 9E+09	L = 1.87 R	Ro = 1.87 R	1.00E+09	61.2 lbm3	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42
=>Temporary 2 (Formulas)		Grx = 9E+09	L = 1.87 R	Ro = 1.87 R	1.00E+09	61.2 lbm3	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42
Water data:		Grx = 9E+09	L = 1.87 R	Ro = 1.87 R	1.00E+09	61.2 lbm3	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42	32.2 R42
Coefficients:		n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17	n = 1.17

Notice: 1) Sleeve is calculated at the end of the vault.
2) Free area for airflow is calculated for 2 vaults.
3) Water inside the MCO and air between MCO and sleeve

17825 18

SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104848	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.06 in		
qx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	1.56 fps	hss =	1.32 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft3	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta = 3.1E-04 1/F
	Grx =	1.5E+09	2.16E+09		2.3E+09
	Prc =	2.74	Pr1 =	2.74	Prc = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==>	0	0		-22910.3
Coefficients:	f0 =	1	rx =	1.00	A0 = 1.17 ft2
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft2
	f =	1.00	n2 =	28.00	A1c = 5.72 ft2
			n3 =	280.00	Acm = 18.33 ft2
			n4 =	280.00	Ams = 170 ft2
					As = 208 ft2
Initial guess:	CFM =	180000	cfm		
Tout =	40.3 F	Tsleeve =	52.3 F	=	11.3 C
		Tmco =	110.9 F	=	43.8 C
		Tcanister =	111.7 F	=	44.2 C
		Tinner =	112.4 F	=	44.6 C
		" "	112.9 F	=	44.9 C
ROout =	0.0798 lb/ft3				
ROin =	0.0804 lb/ft3				

- Notice:**
- 1) Tsleeve is calculated at the end of the vault.
 - 2) Free area for airflow is calculated for 2 vaults.
 - 3) Water inside the MCO and air between MCO and sleeve

TABLE 19

SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104846	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.06 in		
qx =	253.58 Btu/h-ft ³	A(2 vaults) =	1920.00 ft ²	hms =	0.33 Btu/h-ft-F
		Vair =	1.65 fps	hss =	1.34 Btu/h-ft-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	81.2 lbm/ft ³	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s ²	Beta = 3.1E-04 1/F
	Grx =	1.5E+09	2.16E+09		2.3E+09
	Prx =	2.74	Pr1 =	2.74	Pro = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft-F
=>Temporary 2(Formulas)	Grx ==>	0	0		-22820.5
Coefficients:	f0 =	1	rx =	1.00	A0 = 1.17 ft ²
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft ²
	f =	1.00	n2 =	28.00	A1c = 5.72 ft ²
			n3 =	280.00	Actm = 18.33 ft ²
			n4 =	280.00	Amc = 170 ft ²
					As = 208 ft ²
Initial guess:	CFM =	190000 cfm			
Tout =	40.0 F	Tsleeve =	51.8 F	=	11.0 C air
		Tmco =	110.5 F	=	43.5 C air
		Tcanister =	111.2 F	=	44.0 C water
		Tinner =	112.0 F	=	44.4 C water
		" "	112.5 F	=	44.7 C water
ROout =	0.0796 lb/ft ³				
ROin =	0.0804 lb/ft ³				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

TABLE 20

TA-43

c:\Sidd\2D_4

SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load = 3.44 W		Qtotal= 320 kW = 1092160 Btu/h	
No. of elements= 104848		D17= 2.4 in c = 1.1	
q= 11.74 Btu/h		D= 2.06 in	
Tin= 35 F		hms= 0.33 Btu/h-ft-F	
qrc= 253.58 Btu/h-ft3		hsa= 1.35 Btu/h-ft-F	
A(2 vaults)=		Lambda(ur)= 17.3 Btu/h-ft-F	
Vair= 1.74 fps		1.4E+09	
=>Temporary 1(Const)		k= 0.384 BTU/h-ft-F	
Water data:		Beta= 3.1E-04 1/F	
Grx==> 9E+09		2.3E+09	
L= 1.87 ft		2.74	
mu= 2.90E-04 lbm/ft-s		22.44	
Grx= 1.5E+09		0	
Prx= 2.74		-22737.3	
hx= 19.74			
=>Temporary 2(Formulas)			
Grx==> 0			
Coefficients:			
f0= 1		AO= 1.17 ft2	
f1= 1.17		A1= 7.04 ft2	
f= 1.00		A1c= 5.72 ft2	
		Acm= 18.33 ft2	
		Ams= 170 ft2	
		As= 208 ft2	
Initial guess:		CFM= 200000 cfm	
Tout= 39.7 F		Tsleeve= 51.4 F = 10.8 C air	
		Tmco= 110.0 F = 43.3 C air	
		Tcanister= 110.8 F = 43.7 C water	
		Tinner= 111.6 F = 44.2 C water	
		" " = 112.1 F = 44.4 C water	
ROout= 0.0797 lb/ft3			
ROin = 0.0804 lb/ft3			

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

TABLE 21

7A-49

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104846	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	50 F	D =	2.08 in		
qx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	2.00 fps	hss =	1.41 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft3	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta = 3.1E-04 1/F
	Grx =	1.5E+09	2.16E+09		2.3E+09
	Prx =	2.74	Pr1 =	2.74	Pr = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft2-F
=>Temporary 2(Formulas	Grx ==>	0	0		-25586.7
Coefficients:					
	f0 =	1	nx =	1.00	A0 = 1.17 ft2
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft2
	f =	1.00	n2 =	28.00	A1c = 5.72 ft2
			n3 =	280.00	Acm = 18.33 ft2
			n4 =	280.00	Ams = 170 ft2
					As = 208 ft2
Initial guess:	CFM =	230000	cfm		
Tout =	54.2 F	Tsleeve =	85.5 F	=	18.6 C air
		Tmco =	124.1 F	=	51.1 C air
		Tcanister =	124.9 F	=	51.5 C water
		Tinner =	125.6 F	=	52.0 C water
ROout =	0.0775 lb/ft3			=	52.2 C water
ROin =	0.0781 lb/ft3				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 22

TA- 45

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104848	Qtotal =	320 kW	=	1092180 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	50 F	D =	2.06 in		
qx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	2.26 fps	hss =	1.46 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft3	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta = 3.1E-04 1/F
	Grx =	1.5E+09		2.16E+09	2.3E+09
	Prx =	2.74	Pr1 =	2.74	Pr = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==>	0		0	-25401.7
Coefficients:					
	f0 =	1	rx =	1.00	A0 = 1.17 ft2
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft2
	f =	1.00	n2 =	28.00	A1c = 5.72 ft2
			n3 =	280.00	Acms = 18.33 ft2
			n4 =	280.00	Ams = 170 ft2
					As = 208 ft2
Initial guess:					
		CFM =	260000	cfm	
Tout =	53.7 F	Tsleeve =	64.8 F	=	18.1 C air
		Tmco =	123.2 F	=	50.6 C air
		Tcanister =	124.0 F	=	51.0 C water
		Tinner =	124.7 F	=	51.5 C water
ROout =	0.0776 lbm/ft3	" " =	125.2 F	=	51.7 C water
ROin =	0.0761 lbm/ft3				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 2 3

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104848	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	50 F	D =	2.08 in		
qx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	2.60 fps	hsa =	1.54 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft3	k = 0.364 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta = 3.1E-04 1/F
	Grx =	1.5E+09		2.16E+09	2.3E+09
	Pnx =	2.74	Pr1 =	2.74	Pr = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==>	0		0	-25197.1
Coefficients:					
	f0 =	1	rx =	1.00	A0 = 1.17 ft2
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft2
	f =	1.00	n2 =	28.00	A1c = 5.72 ft2
			n3 =	280.00	Ac = 18.33 ft2
			n4 =	280.00	Ams = 170 ft2
					As = 208 ft2
<hr/>					
Initial guess:	CFM =	300000	cfm		
Tout =	53.2 F	Tsleeve =	63.6 F	=	17.5 C air
		Tmco =	122.2 F	=	50.0 C air
		Tcanister =	122.9 F	=	50.5 C water
		Tinner =	123.7 F	=	50.9 C water
ROout =	0.0777 lb/ft3	" "	124.2 F	=	51.2 C water
ROin =	0.0781 lb/ft3				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 29

TA-48

c:\Sidd12D_4

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104848	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	50 F	D =	2.06 in		
qx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	3.47 fps	hsa =	1.72 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.67 ft	Ro =	61.2 lbm/ft3	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta = 3.1E-04 1/F
	Grx =	1.5E+09		2.16E+09	2.3E+09
	Prx =	2.74	Pr1 =	2.74	Pr = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft2-F
=>Temporary 2(Formulas	Grx ==>	0	0		-24806.8
Coefficients:					
	f0 =	1	nx =	1.00	A0 = 1.17 ft2
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft2
	f =	1.00	n2 =	28.00	A1c = 5.72 ft2
			n3 =	280.00	Acm = 18.33 ft2
			n4 =	280.00	Ams = 170 ft2
					As = 208 ft2
<hr/>					
	Initial guess:	CFM =	400000 cfm		
Tout =	52.4 F	Tsleeve =	61.6 F	=	16.5 C air
		Tmco =	120.3 F	=	49.0 C air
		Tcanister =	121.0 F	=	49.4 C water
		Tinner =	121.8 F	=	49.8 C water
		* * =	122.3 F	=	50.1 C water
ROout =	0.0778 lb/ft3				
ROin =	0.0761 lb/ft3				

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 26

TA-99

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W					
No. of elements =	104848	Qtotal =	320 kW	=	1092160 Btu/h	
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1	
Tin =	50 F	D =	2.06 in			
qx =	253.58 Btu/h-ft ³	A(2 vaults) =	1920.00 ft ²	hms =	0.33 Btu/h-ft ² -F	
		Vair =	3.91 fps	hss =	1.81 Btu/h-ft ² -F	
				Lamda(ur) =	17.3 Btu/h-ft-F	
=>Temporary 1(Const)	Gx ==>	9E+09	1.00E+09		1.4E+09	
Water data:	L =	1.87 ft	Rc =	61.2 lbm/ft ³	k =	0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s ²	Beta =	3.1E-04 1/F
	Gx =	1.5E+09		2.16E+09		2.3E+09
	Px =	2.74	Pr1 =	2.74	Prc =	2.74
	hx =	19.74	h1 =	22.44	hc =	22.82 BTU/h-ft ² -F
=>Temporary 2(Formulas	Gx ==>	0	0			-24861.2
Coefficients:						
	r0 =	1	nx =	1.00	A0 =	1.17 ft ²
	f1 =	1.17	n1 =	7.00	A1 =	7.04 ft ²
	f =	1.00	n2 =	28.00	A1c =	5.72 ft ²
			n3 =	280.00	Acn =	18.33 ft ²
			n4 =	280.00	Ams =	170 ft ²
					As =	208 ft ²
<hr/>						
Initial guess:	CFM =	450000	cfm			
Tout =	52.2 F	Tsleeve =	60.9 F	=	16.0 C	air
		Tmco =	119.5 F	=	48.6 C	air
		Tcanister =	120.3 F	=	49.0 C	water
		Tinner =	121.1 F	=	49.4 C	water
		" " =	121.6 F	=	49.7 C	water
ROut =	0.0778 lb/ft ³					
ROin =	0.0781 lb/ft ³					

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 27

TA- 50 SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W	Qtotal =	320 KW	=	1092180 Btu/h	
No. of elements =	104848	D17 =	2.4 in	c =	1.1	
q =	11.74 Btu/h	D =	2.06 in			
Tin =	50 F	A(2 vaults) =	1920.00 ft ²	hms =	0.33 Btu/h-ft ² -F	
qx =	253.58 Btu/h-ft ³	Vair =	4.34 fps	hsa =	1.90 Btu/h-ft ² -F	
				Lamda(ur) =	17.3 Btu/h-ft-F	
=> Temporary 1 (Const)						
Water data:	Grx ==>	9E+09	Ro =	1.00E+09	1.4E+09	
	L =	1.87 ft	g =	61.2 lbm/ft ³	k =	0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s		32.2 ft/s ²	Beta =	3.1E-04 1/F
	Grx =	1.5E+09	Pr1 =	2.16E+09		2.3E+09
	Prx =	2.74		2.74	Prc =	2.74
	hx =	19.74	h1 =	22.44	hc =	22.82 BTU/h-ft ² -F
		0		0		-24529.3
=> Temporary 2 (Formulas)						
Coefficients:	Grx ==>	0	nx =	1.00	A0 =	1.17 ft ²
	ro =	1	n1 =	7.00	A1 =	7.04 ft ²
	ft =	1.17	n2 =	28.00	A1c =	5.72 ft ²
	f =	1.00	n3 =	280.00	Acm =	18.33 ft ²
			n4 =	280.00	Ams =	170 ft ²
					As =	208 ft ²
Initial guess:						
			CFM =	500000	cfm	
Tout =	51.9 F	Tsleeve =	60.3 F	=	15.7 C	air
		Tmco =	118.9 F	=	48.2 C	air
		Tcanister =	119.7 F	=	48.7 C	water
		Tinner =	120.4 F	=	49.1 C	water
		" "	120.9 F	=	49.4 C	water
ROout =	0.0778 lb/ft ³					
ROin =	0.0781 lb/ft ³					

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 28

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SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W	Qtotal =	320 kW	=	1092160 Btu/h
No. of elements =	104846	D17 =	2.4 in	c =	1.1
q =	11.74 Btu/h	D =	2.06 in		
Tin =	50 F	A(2 vaults) =	1920.00 ft ²	hms =	0.33 Btu/h-ft ² -F
qx =	253.58 Btu/h-ft ³	Vair =	0.09 f/s	hss =	1.01 Btu/h-ft ² -F
				Lambda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==> 9E+09	1.00E+09	1.4E+09		
Water data:	L = 1.87 ft	Ro = 61.2 lbm/ft ³	k = 0.384 BTU/h-ft-F		
	mu = 2.90E-04 lbm/ft-s	g = 32.2 ft/s ²	Beta = 3.1E-04 1/F		
	Grx = 1.5E+09	2.16E+09	2.3E+09		
	Prx = 2.74	Pr1 = 2.74	Pr = 2.74		
	hx = 19.74	h1 = 22.44	hc = 22.82 BTU/h-ft ² -F		
=>Temporary 2(Formulas)	Grx ==> 0	0	-47237		
Coefficients:	f0 = 1	nx = 1.00	A0 = 1.17 ft ²		
	f1 = 1.17	n1 = 7.00	A1 = 7.04 ft ²		
	f = 1.00	n2 = 28.00	A1c = 5.72 ft ²		
		n3 = 280.00	Acm = 18.33 ft ²		
		n4 = 280.00	Ams = 170 ft ²		
			As = 208 ft ²		

Initial guess:	CFM =	10000 cfm		
Tout =	156.5 F	Tsleeve =	172.2 F	= 77.8 C air
		Tmco =	230.8 F	= 110.3 C air
		Tcanister =	231.6 F	= 110.8 C water
		Tinner =	232.3 F	= 111.2 C water
		" " =	232.8 F	= 111.5 C water
ROout =	0.0643 lb/ft ³			
ROin =	0.0781 lb/ft ³			

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 29

T canister as a function of CFM

Water in MCO, Air in Sleeve

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W					
No. of elements =	104848	Qtotals =	320 kW	=	1092160 Btu/h	
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1	
Tin =	50 F	D =	2.06 in			
qx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F	
		Vair =	0.17 fps	hsa =	1.03 Btu/h-ft2-F	
				Lamda(ur) =	17.3 Btu/h-ft-F	
=>Temporary 1(Const)	Grx ==>	9E+09	1.00E+09		1.4E+09	
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft3	k =	0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta =	3.1E-04 1/F
	Grx =	1.5E+09		2.16E+09		2.3E+09
	Prx =	2.74	Pr1 =	2.74	Pro =	2.74
	hx =	19.74	h1 =	22.44	hco =	22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==>	0	0			-35891.6
Coefficients:						
	f0 =	1	nx =	1.00	A0 =	1.17 ft2
	f1 =	1.17	n1 =	7.00	A1 =	7.04 ft2
	f =	1.00	n2 =	28.00	A1c =	5.72 ft2
			n3 =	280.00	Acn =	18.33 ft2
			n4 =	280.00	Amn =	170 ft2
					As =	208 ft2
Initial guess:						
		CFM =	20000	cfm		
Tout =	100.8 F	Tsleeve =	116.3 F	=	46.8 C	air
		Tmco =	174.9 F	=	79.3 C	air
		Tcanister =	175.7 F	=	79.7 C	water
		Tinner =	176.4 F	=	80.2 C	water
		" "	176.9 F	=	80.4 C	water
ROout =	0.0710 lb/ft3					
ROin =	0.0781 lb/ft3					

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 30

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
'No. of elements =	104846	Qtotl =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	50 F	D =	2.06 in		
qx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	0.26 fps	hsa =	1.04 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==> 9E+09		1.00E+09		1.4E+09
Water data:	L = 1.87 ft	Ro =	61.2 lbm/ft3	k =	0.384 BTU/h-ft-F
	mu = 2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta =	3.1E-04 1/F
	Grx = 1.5E+09		2.16E+09		2.3E+09
	Ppx = 2.74	Pri =	2.74	Pro =	2.74
	hx = 19.74	hi =	22.44	ho =	22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==> 0		0		-32292.9
Coefficients:					
	f0 = 1	rx =	1.00	A0 =	1.17 ft2
	f1 = 1.17	n1 =	7.00	A1 =	7.04 ft2
	f = 1.00	n2 =	28.00	A1c =	5.72 ft2
		n3 =	280.00	Acm =	18.33 ft2
		n4 =	280.00	Ams =	170 ft2
				As =	208 ft2
Initial guess:		CFM =	30000	cfm	
Tout =	83.4 F	Tsleeve =	98.5 F	=	36.9 C
		Tmco =	157.1 F	=	69.5 C
		Tcanister =	157.9 F	=	69.9 C
		Tinner =	158.7 F	=	70.3 C
		" " =	159.2 F	=	70.6 C
ROout =	0.0734 lb/ft3				
ROin =	0.0781 lb/ft3				

Notice: 1) Tsleeve is calculated at the end of the vault.
2) Free area for airflow is calculated for 2 vaults.
3) Water inside the MCO and air between MCO and sleeve

Table 3/

TA- 59

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SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104846	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	50 F	D =	2.06 in		
qx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	0.35 fps	hss =	1.06 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	R =	81.2 lbm/ft3	kw = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta = 3.1E-04 1/F
	Grx =	1.5E+09		2.18E+09	2.3E+09
	Pnx =	2.74	Pr1 =	2.74	Pr = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==>	0	0		-30508.4
Coefficients:					
	f0 =	1	nx =	1.00	A0 = 1.17 ft2
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft2
	f =	1.00	n2 =	28.00	A1c = 5.72 ft2
			n3 =	280.00	Acm = 18.33 ft2
			n4 =	280.00	Ams = 170 ft2
					As = 208 ft2
<hr/>					
Initial guess:	CFM =	40000	cfm		
Tout =	74.8 F	Tsleeve =	89.7 F	=	32.0 C air
		Tmco =	148.3 F	=	64.6 C air
		Tcanister =	149.1 F	=	65.0 C water
		Tinner =	149.9 F	=	65.4 C water
		" "	150.4 F	=	65.7 C water
ROut =	0.0746 lb/ft3				
ROin =	0.0781 lb/ft3				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 3 2

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load	3.44 W					
'No. of elements	104848	Ototal	320 kW	=	1092160 Btu/h	
q	11.74 Btu/h	D17	2.4 in	c	1.1	
Tin	50 F	D	2.06 in			
qx	253.58 Btu/h-ft3	A(2 vaults)	1920.00 ft2	hms	0.33 Btu/h-ft2-F	
		Vair	0.43 fps	hss	1.08 Btu/h-ft2-F	
				Lamda(ur)	17.3 Btu/h-ft-F	
=>Temporary 1(Const)	Grx	9E+09	1.00E+09		1.4E+09	
Water data:	L	1.87 ft	Ro	61.2 lbm/ft3	kw	0.384 BTU/h-ft-F
	mu	2.90E-04 lbm/ft-s	g	32.2 ft/s2	Beta	3.1E-04 1/F
	Grx	1.5E+09	2.16E+09		2.3E+09	
	Prc	2.74	Pr1	2.74	Prc	2.74
	hx	19.74	n1	22.44	hc	22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx	0	0		-29431.1	
Coefficients:	f0	1	rx	1.00	AO	1.17 ft2
	f1	1.17	n1	7.00	A1	7.04 ft2
	f	1.00	n2	28.00	A1c	5.72 ft2
			n3	280.00	Acm	18.33 ft2
			n4	280.00	Ams	170 ft2
					As	208 ft2
Initial guess:	CFM	50000	cfm			
Tout	69.8 F	Tsleeve	84.4 F	=	29.1 C	air
		Tmco	143.0 F	=	61.6 C	air
		Tcanister	143.8 F	=	62.1 C	water
		Tinner	144.6 F	=	62.5 C	water
		*	145.1 F	=	62.8 C	water
ROout	0.0753 lb/ft3					
ROin	0.0781 lb/ft3					

- Notice: 1) Sleeve is calculated at the end of the vault.
2) Free area for airflow is calculated for 2 vaults.
3) Water inside the MCO and air between MCO and sleeve

Table 33

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104848	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	50 F	D =	2.06 in		
qx =	253.58 Btu/h-ft	A(2 vaults) =	1920.00 ft ²	hms =	0.33 Btu/h-ft-F
		Vair =	0.52 fps	hss =	1.10 Btu/h-ft-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft ³	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s ²	Beta = 3.1E-04 1/F
	Grx =	1.5E+09		2.16E+09	2.3E+09
	Pnx =	2.74	Pr1 =	2.74	Prc = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft-F
=>Temporary 2(Formulas)	Grx ==>	0		0	-28702.8
Coefficients:	f0 =	1	nx =	1.00	A0 = 1.17 ft ²
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft ²
	f =	1.00	n2 =	28.00	A1c = 5.72 ft ²
			n3 =	280.00	Acm = 18.33 ft ²
			n4 =	280.00	Ams = 170 ft ²
					As = 208 ft ²
<hr/>					
Initial guess:	CFM =	60000 cfm			
Tout =	66.4 F	Tsleeve =	80.8 F	=	27.1 C air
		Tmco =	139.4 F	=	59.6 C air
		Tcanister =	140.2 F	=	60.1 C water
		Tinner =	141.0 F	=	60.5 C water
		" "	141.5 F	=	60.8 C water
ROout =	0.0757 lb/ft ³				
ROin =	0.0781 lb/ft ³				

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 34

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104848	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	50 F	D =	2.06 in		
qx =	253.58 Btu/h-ft ²	A(2 vaults) =	1920.00 ft ²	hms =	0.33 Btu/h-ft ² -F
		Vair =	0.61 fps	hsa =	1.12 Btu/h-ft ² -F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft ³	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s ²	Beta = 3.1E-04 1/F
	Grx =	1.5E+09		2.16E+09	2.3E+09
	Prc =	2.74	Prt =	2.74	Prc = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft ² -F
=>Temporary 2(Formulas)	Grx ==>	0	0		-26172.7
Coefficients:					
	f0 =	1	rx =	1.00	A0 = 1.17 ft ²
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft ²
	f =	1.00	n2 =	28.00	A1c = 5.72 ft ²
			n3 =	280.00	Acm = 18.33 ft ²
			n4 =	280.00	Ams = 170 ft ²
					As = 208 ft ²
Initial guess:	CFM =	70000	cfm		
Tout =	84.1 F	Tsleeve =	78.2 F	=	25.7 C air
		Tmco =	136.8 F	=	58.2 C air
		Tcanister =	137.6 F	=	58.6 C water
		Tinner =	138.4 F	=	59.0 C water
		" "	138.9 F	=	59.3 C water
ROut =	0.0781 lb/ft ³				
ROin =	0.0781 lb/ft ³				

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 35

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44	W	Qtotal=	320 kW	=	1092160 Btu/h
No. of elements=	104846		D17=	2.4 in	c =	1.1
q=	11.74	Btu/h	D=	2.06 in		
Tin=	50	F	A(2 vaults)=	1920.00 ft ²	hms=	0.33 Btu/h-ft-F
qx=	253.58	Btu/h-ft ³	Vair=	0.69 fps	hsa=	1.14 Btu/h-ft-F
					Lamda(ur)=	17.3 Btu/h-ft-F
=>Temporary 1(Const)	Gx ==>	9E+09		1.00E+09		1.4E+09
Water data:	L=	1.87 ft	Ro=	61.2 lbm/ft ³	k=	0.384 BTU/h-ft-F
	mu=	2.90E-04 lbm/ft-s	g=	32.2 ft/s ²	Beta=	3.1E-04 1/F
	Gnx=	1.5E+09		2.16E+09		2.3E+09
	Pnx=	2.74	Pr1=	2.74	Proc=	2.74
	hx=	19.74	h1=	22.44	hc=	22.82 BTU/h-ft-F
=>Temporary 2(Formulas	Gx ==>	0		0		-27766.1
Coefficients:	f0=	1	rx=	1.00	A0=	1.17 ft ²
	f1=	1.17	n1=	7.00	A1=	7.04 ft ²
	f=	1.00	n2=	28.00	A1c=	5.72 ft ²
			n3=	280.00	Acm=	18.33 ft ²
			n4=	280.00	Ams=	170 ft ²
					As=	206 ft ²
<hr/>						
Initial guess:	CFM=	80000	cfm			
Tout=	62.3 F	Tsleeve=	76.2 F	=	24.5 C	air
		Tmco=	134.8 F	=	57.1 C	air
		Tcanister=	135.6 F	=	57.5 C	water
		Tinner =	136.4 F	=	57.9 C	water
		" "	136.9 F	=	58.2 C	water
ROout=	0.0763 lb/ft ³					
ROin =	0.0781 lb/ft ³					

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 36

7A-59

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104846	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	50 F	D =	2.06 in		
qx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	0.78 fps	hsa =	1.15 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==> 9E+09	1.00E+09			1.4E+09
Water data:	L = 1.87 ft	Ro =	61.2 lbm/ft3	k =	0.384 BTU/h-ft-F
	mu = 2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta =	3.1E-04 1/F
	Grx = 1.5E+09		2.16E+09		2.3E+09
	Prx = 2.74	Pr1 =	2.74	Pro =	2.74
	hx = 19.74	h1 =	22.44	hc =	22.62 BTU/h-ft2-F
=>Temporary 2(Formulas	Grx ==> 0		0		-27441.9
Coefficients:					
	f0 = 1	n0 =	1.00	A0 =	1.17 ft2
	f1 = 1.17	n1 =	7.00	A1 =	7.04 ft2
	f2 = 1.00	n2 =	28.00	A1c =	5.72 ft2
		n3 =	280.00	Acm =	18.33 ft2
		n4 =	280.00	Ams =	170 ft2
				As =	206 ft2
Initial guess:	CFM =	90000 cfm			
Tout =	80.9 F	Tsleeve =	74.6 F	=	23.7 C air
		Tmco =	133.2 F	=	56.2 C air
		Tcanister =	134.0 F	=	56.6 C water
		Tinner =	134.8 F	=	57.0 C water
		" "	135.3 F	=	57.3 C water
ROout =	0.0765 lb/ft3				
ROin =	0.0781 lb/ft3				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 37

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SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load = 3.44 W					
'No. of elements = 104846		Qtotal = 320 kW		= 1092160 Btu/h	
q = 11.74 Btu/h		D17 = 2.4 in		c = 1.1	
Tin = 50 F		D = 2.06 in			
qx = 253.56 Btu/h-ft3		A(2 vaults) = 1920.00 ft2		hms = 0.33 Btu/h-ft2-F	
		Vair = 0.87 fps		hse = 1.17 Btu/h-ft2-F	
				Lambda(ur) = 17.3 Btu/h-ft-F	
=> Temporary 1 (Const)		Grx ==> 9E+09		1.00E+09	
Water data:		L = 1.87 ft		k = 0.384 BTU/h-ft-F	
		mu = 2.90E-04 lbm/ft-s		g = 32.2 ft/s2	
		Grx = 1.5E+09		2.16E+09	
		Prx = 2.74		Pr = 2.74	
		hx = 19.74		h1 = 22.44	
=> Temporary 2 (Formulas)		Grx ==> 0		0	
				-27175.5	
<hr/>					
Coefficients:		f0 = 1		AD = 1.17 ft2	
		f1 = 1.17		A1 = 7.04 ft2	
		f = 1.00		A1c = 5.72 ft2	
		n1 = 7.00		Acm = 18.33 ft2	
		n2 = 26.00		Ams = 170 ft2	
		n3 = 280.00		As = 208 ft2	
		n4 = 280.00			
<hr/>					
Initial guess:		CFM = 100000 cfm			
Tout = 59.8 F		Tsleeve = 73.3 F		= 22.9 C	
		Tmco = 131.9 F		= 55.5 C	
		Tcanister = 132.7 F		= 55.9 C	
		Tinner = 133.5 F		= 56.3 C	
		" " = 134.0 F		= 56.6 C	
ROout = 0.0767 lb/ft3					
ROin = 0.0781 lb/ft3					

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 38

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load	3.44	W							
No. of elements	104848		Qtotal=	320	kW	=	1092160	Btu/h	
q=	11.74	Btu/h	D17=	2.4	in	c =	1.1		
Tin=	50	F	D=	2.06	in				
qx=	253.58	Btu/h-ft3	A(2 vaults)=	1920.00	ft2	hms=	0.33	Btu/h-ft2-F	
			Vair=	0.95	fps	hsa=	1.19	Btu/h-ft2-F	
						Lamda(ur)=	17.3	Btu/h-ft-F	
=>Temporary 1(Const.)	Grx ==>	9E+09		1.00E+09			1.4E+09		
Water data:	L=	1.87	ft	Ro=	61.2	lbm/ft3	lc=	0.384	BTU/h-ft-F
	mu=	2.90E-04	lbm/ft-s	g=	32.2	ft/s2	Beta=	3.1E-04	1/F
	Grx=	1.5E+09		2.16E+09			2.3E+09		
	Pnx=	2.74		Pri=	2.74		Prc=	2.74	
	hx=	19.74		hi=	22.44		hc=	22.82	BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==>	0		0			-26951.3		
<hr/>									
Coefficients:									
	fo=	1	nx=	1.00		A0=	1.17	ft2	
	fi=	1.17	n1=	7.00		A1=	7.04	ft2	
	fe=	1.00	n2=	28.00		A1c=	5.72	ft2	
			n3=	280.00		Acm=	18.33	ft2	
			n4=	280.00		Ams=	170	ft2	
						As=	208	ft2	
<hr/>									
	Initial guess:		CFM=	110000	cfm				
Tout=	58.9	F	Tsleeve=	72.2	F	=	22.3	C	air
			Tmco=	130.8	F	=	54.8	C	air
			Tcanister=	131.8	F	=	55.3	C	water
			Tinner=	132.3	F	=	55.7	C	water
			" "	132.9	F	=	56.0	C	water
ROout=	0.0768	lb/ft3							
ROin=	0.0781	lb/ft3							

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 39

Notice: 1) Tsleeve is calculated at the end of the vault.
2) Free area for airflow is calculated for 2 vaults.
3) Water inside the MCO and air between MCO and sleeve

Table 40

SSF FUEL STUDY

Element Load =	3.44	W						
No. of elements =	104848		Qtotals=	320	kW	=	1092160	Btu/h
q=	11.74	Btu/h	D17=	2.4	in	c =	1.1	
Tin=	50	F	D=	2.06	in			
qx=	253.58	Btu/h-ft2	A(2 vaults)=	1920.00	ft2	hms=	0.33	Btu/h-ft2-F
			Vair=	1.13	fps	hss=	1.23	Btu/h-ft2-F
						Lamda(ur)=	17.3	Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==>	9E+09		1.00E+09			1.4E+09	
Water data:	L=	1.87	ft	Ro=	61.2	lbm/ft3	k=	0.384
	mu=	2.90E-04	lbm/ft-s	g=	32.2	ft/s2	Beta=	3.1E-04
	Grx=	1.5E+09		2.16E+09			2.3E+09	1/F
	Pnx=	2.74		Pr1=	2.74		Pro=	2.74
	hx=	19.74		h1=	22.44		hss=	22.82
=>Temporary 2(Formulas)	Grx ==>	0		0				-26S91.4
Coefficients:								
	f0=	1	rx=	1.00		AO=	1.17	ft2
	f1=	1.17	n1=	7.00		A1=	7.04	ft2
	f=	1.00	n2=	28.00		A1c=	5.72	ft2
			n3=	280.00		Acm=	18.33	ft2
			n4=	280.00		Ams=	170	ft2
						As=	208	ft2

130000 cfm

=	21.3 C	air
=	53.9 C	air
=	54.3 C	water
=	54.7 C	water
=	55.0 C	water

Tinner =	130.6 F
" "	131.1 F

Notice: 1) Tsleeve is calculated at the end of the vault.
2) Free area for airflow is calculated for 2 vaults.
3) Water inside the MCO and air between MCO and sleeve

Table 41

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W					
No. of elements =	104848	Qtotal =	320 kW	=	1092160 Btu/h	
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1	
Tin =	50 F	D =	2.06 in			
qx =	253.58 Btu/h-ft ²	A(2 vaults) =	1920.00 ft ²	hms =	0.33 Btu/h-ft ² -F	
		Vair =	1.22 fps	hsa =	1.25 Btu/h-ft ² -F	
				Lamda(ur) =	17.3 Btu/h-ft-F	
=>Temporary 1(Const.)	Gxx ==>	9E+09	1.00E+09		1.4E+09	
Water data:	L =	1.87 ft	Ro =	81.2 lbm/ft ³	k =	0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s ²	Beta =	3.1E-04 1/F
	Gxx =	1.5E+09	2.16E+09		2.3E+09	
	Pxx =	2.74	Pri =	2.74	Pro =	2.74
	hx =	19.74	h1 =	22.44	hc =	22.52 BTU/h-ft ² -F
=>Temporary 2(Formulas)	Gxx ==>	0	0		-26443.4	
Coefficients:	f0 =	1	rx =	1.00	A0 =	1.17 ft ²
	f1 =	1.17	n1 =	7.00	A1 =	7.04 ft ²
	f2 =	1.00	n2 =	28.00	A1c =	5.72 ft ²
			n3 =	280.00	Acms =	18.33 ft ²
			n4 =	280.00	Ams =	170 ft ²
					As =	208 ft ²
Initial guess:	CFM =	140000	cfm			
Tout =	57.0 F	Tsleeve =	89.7 F	=	20.9 C	air
		Tmco =	128.3 F	=	53.5 C	air
		Tcanister =	129.1 F	=	53.9 C	water
		Tinner =	129.8 F	=	54.3 C	water
		" "	130.3 F	=	54.6 C	water
ROout =	0.0771 lb/ft ³					
ROin =	0.0781 lb/ft ³					

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 42

TA 65

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
'No. of elements =	104848	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	50 F	D =	2.08 in		
qx =	253.58 Btu/h-ft ²	A(2 vaults) =	1920.00 ft ²	hms =	0.33 Btu/h-ft ² -F
		Vair =	1.30 fps	hse =	1.26 Btu/h-ft ² -F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft ³	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s ²	Beta = 3.1E-04 1/F
	Grx =	1.5E+09	2.16E+09		2.3E+09
	Prc =	2.74	Pr1 =	2.74	Prc = 2.74
	hse =	19.74	h1 =	22.44	hse = 22.82 BTU/h-ft ² -F
=>Temporary 2(Formulas)	Grx ==>	0	0		-26311.2
Coefficients:					
	f0 =	1	rx =	1.00	A0 = 1.17 ft ²
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft ²
	f2 =	1.00	n2 =	28.00	A1c = 5.72 ft ²
			n3 =	280.00	Acm = 18.33 ft ²
			n4 =	280.00	Ams = 170 ft ²
					As = 208 ft ²
<hr/>					
Initial guess:	CFM =	150000	cfm		
Tout =	56.5 F	Tsleeve =	69.0 F	=	20.6 C air
		Tmco =	127.7 F	=	53.1 C air
		Tcanister =	128.4 F	=	53.5 C water
		Tinner =	129.2 F	=	53.9 C water
		" "	129.7 F	=	54.2 C water
ROout =	0.0772 lb/ft ³				
ROin =	0.0781 lb/ft ³				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 43

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104846	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	50 F	D =	2.06 in		
qx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	1.39 fps	hsa =	1.28 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft3	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta = 3.1E-04 1/F
	Gpx =	1.5E+09	2.16E+09		2.3E+09
	Ppx =	2.74	Pr1 =	2.74	Prc = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==>	0	0		-26192
Coefficients:	f0 =	1	rx =	1.00	A0 = 1.17 ft2
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft2
	f2 =	1.00	n2 =	28.00	A1c = 5.72 ft2
			n3 =	280.00	Acn = 18.33 ft2
			n4 =	280.00	Ans = 170 ft2
					As = 206 ft2
Initial guess:	CFM =	160000	cfm		
Tout =	56.1 F	Tsleeve =	88.5 F	=	20.2 C air
		Tmco =	127.1 F	=	52.8 C air
		Tcanister =	127.9 F	=	53.2 C water
		Tinner =	128.6 F	=	53.6 C water
		" "	129.1 F	=	53.9 C water
ROout =	0.0772 lb/ft3				
ROin =	0.0781 lb/ft3				

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 44

TA 67

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SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104848	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	50 F	D =	2.06 in		
qx =	253.58 Btu/h-ft ²	A(2 vaults) =	1920.00 ft ²	hms =	0.33 Btu/h-ft ² -F
		Vair =	1.48 fps	hsa =	1.30 Btu/h-ft ² -F
				Lamda(ur) =	17.3 Btu/h-ft ² -F
=>Temporary 1(Const.)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft ³	k = 0.364 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s ²	Beta = 3.1E-04 1/F
	Grx =	1.5E+09	2.18E+09		2.3E+09
	Pnx =	2.74	Pri =	2.74	Prc = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.62 BTU/h-ft ² -F
=>Temporary 2(Formulas)	Grx ==>	0	0		-26063.6
Coefficients:	f0 =	1	rx =	1.00	A0 = 1.17 ft ²
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft ²
	f2 =	1.00	n2 =	28.00	A1c = 5.72 ft ²
			n3 =	280.00	Acn = 18.33 ft ²
			n4 =	280.00	Ans = 170 ft ²
					As = 208 ft ²
<hr/>					
	Initial guess:	CFM =	170000 cfm		
Tout =	55.7 F	Tsleeve =	87.9 F	=	19.9 C air
		Tmco =	128.5 F	=	52.5 C air
		Tcanister =	127.3 F	=	52.9 C water
		Tinner =	128.1 F	=	53.3 C water
		" " =	128.6 F	=	53.6 C water
ROut =	0.0773 lb/ft ³				
ROin =	0.0781 lb/ft ³				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 45

TA-68

c:\Sidd\2D_4

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104846	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	50 F	D =	2.06 in		
qx =	253.58 Btu/h-ft ³	A(2 vaults) =	1920.00 ft ²	hms =	0.33 Btu/h-ft ² -F
		Vair =	1.56 fps	hsa =	1.32 Btu/h-ft ² -F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const)	Gx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft ³	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s ²	Beta = 3.1E-04 1/F
	Grx =	1.5E+09		2.16E+09	2.3E+09
	Prx =	2.74	Pr1 =	2.74	Pr = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft ² -F
=>Temporary 2(Formulas	Gx ==>	0			-25984.4
Coefficients:	fo =	1	rox =	1.00	A0 = 1.17 ft ²
	fi =	1.17	n1 =	7.00	A1 = 7.04 ft ²
	f =	1.00	n2 =	28.00	A1c = 5.72 ft ²
			n3 =	280.00	Acm = 18.33 ft ²
			n4 =	280.00	Ams = 170 ft ²
					As = 206 ft ²
<hr/>					
	Initial guess:	CFM =	180000	cfm	
Tout =	55.4 F	Tsleeve =	67.4 F	=	19.7 C air
		Tmco =	126.0 F	=	52.2 C air
		Tcanister =	126.8 F	=	52.6 C water
		Tinner =	127.6 F	=	53.0 C water
		" "	128.1 F	=	53.3 C water
ROout =	0.0773 lb/ft ³				
ROin =	0.0781 lb/ft ³				

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 46

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load					
No. of elements=	104846	Qtotal=	320 kW =	1092160 Btu/h	
q=	11.74 Btu/h	D17=	2.4 in c =	1.1	
Tin=	50 F	D=	2.06 in		
qx=	253.58 Btu/h-ft ²	A(2 vaults)=	1920.00 ft ² hms=	0.33 Btu/h-ft ² -F	
		Vair=	1.85 fpm hsa=	1.34 Btu/h-ft ² -F	
=>Temporary 1(Const.)	Gx ==>	9E+09	1.00E+09	Lamda(ur)=	17.3 Btu/h-ft-F
Water data:	L=	1.87 ft R=	61.2 lbm/ft ³ k=	0.384 BTU/h-ft-F	
	m=	2.90E-04 lbm/ft-s g=	32.2 ft/s ² Beta=	3.1E-04 1/F	
	Grx=	1.5E+09	2.16E+09	Beta=	2.3E+09
	Ppx=	2.74	Ppr=	2.74	
	hx=	19.74	h1=	22.44 hc=	22.82 BTU/h-ft ² -F
=>Temporary 2(Formulas)	Gx ==>	0	0		-25893
Coefficients:					
	f0=	1	nv=	1.00	A0= 1.17 ft ²
	f1=	1.17	n1=	7.00	A1= 7.04 ft ²
	f=	1.00	n2=	28.00	A1c= 5.72 ft ²
			n3=	280.00	Acm= 18.33 ft ²
			n4=	280.00	Ams= 170 ft ²
					As= 208 ft ²
<hr/>					
Initial guess:		CFM=	190000	cfm	
<hr/>					
Tout=	55.1 F	Tsleeve=	67.0 F	=	19.4 C air
		Tmc=	125.6 F	=	51.9 C air
		Tcanister=	126.4 F	=	52.4 C water
		Tinner =	127.1 F	=	52.8 C water
		" " =	127.6 F	=	53.1 C water
ROut=	0.0774 lb/ft ³				
ROIn =	0.0781 lb/ft ³				

- Notice:**
- 1) Tsleeve is calculated at the end of the vault.
 - 2) Free area for airflow is calculated for 2 vaults.
 - 3) Water inside the MCO and air between MCO and sleeve

Table 47

TA 70

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SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104846	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	50 F	D =	2.06 in		
qx =	253.58 Btu/h-ft ³	A(2 vaults) =	1920.00 ft ²	hms =	0.33 Btu/h-ft ² -F
		Vair =	1.74 fpm	hss =	1.35 Btu/h-ft ² -F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==> 9E+09		1.00E+09		1.4E+09
Water data:	L = 1.87 ft	Rox =	61.2 lbm/ft ³	k =	0.384 BTU/h-ft-F
	mu = 2.90E-04 lbm/ft-s	g =	32.2 ft/s ²	Beta =	3.1E-04 1/F
	Grx = 1.5E+09		2.16E+09		2.3E+09
	Pnx = 2.74	Pr1 =	2.74	Prx =	2.74
	hx = 19.74	h1 =	22.44	hc =	22.82 BTU/h-ft ² -F
=>Temporary 2(Formulas	Grx ==> 0		0		-25808.3
Coefficients:					
	f0 = 1	nx =	1.00	A0 =	1.17 ft ²
	f1 = 1.17	n1 =	7.00	A1 =	7.04 ft ²
	f2 = 1.00	n2 =	28.00	A1c =	5.72 ft ²
		n3 =	280.00	Acm =	18.33 ft ²
		n4 =	280.00	Ams =	170 ft ²
				As =	208 ft ²
Initial guess:		CFM =	200000 cfm		
Tout =	54.9 F	Tsleeve =	66.8 F	=	19.2 C air
		Tmco =	125.2 F	=	51.7 C air
		Tcanister =	126.0 F	=	52.2 C water
		Tinner =	126.7 F	=	52.6 C water
		" "	127.2 F	=	52.8 C water
ROut =	0.0774 lb/ft ³				
ROin =	0.0781 lb/ft ³				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 48

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104848	Qtotal =	320 kW	=	1092180 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.06 in		
qx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	2.00 fpe	hss =	1.41 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft3	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta = 3.1E-04 1/F
	Grx =	1.5E+09	2.16E+09		2.3E+09
	Prx =	2.74	Pr1 =	2.74	Pro = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==>	0	0		-22519.4
Coefficients:	f0 =	1	rx =	1.00	A0 = 1.17 ft2
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft2
	f =	1.00	n2 =	28.00	A1c = 5.72 ft2
			n3 =	280.00	Acms = 18.33 ft2
			n4 =	280.00	Ams = 170 ft2
					As = 208 ft2
Initial guess:	CFM =	230000	cfm		
Tout =	39.1 F	Tsleeve =	50.4 F	=	10.2 C air
		Tmco =	109.0 F	=	42.7 C air
		Tcanister =	109.8 F	=	43.2 C water
		Tinner =	110.5 F	=	43.6 C water
		" "	111.0 F	=	43.8 C water
ROout =	0.0798 lb/ft3				
ROin =	0.0804 lb/ft3				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 49

TA 72

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104848	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.06 in		
qr =	253.58 Btu/h-ft2	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	2.26 fpm	hsa =	1.46 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx = 9E+09		1.00E+09		1.4E+09
Water data:	L = 1.87 ft	Ro =	61.2 lbm/ft3	k =	0.384 BTU/h-ft-F
	mu = 2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta =	3.1E-04 1/F
	Grx = 1.5E+09		2.16E+09		2.3E+09
	Prx = 2.74	Pr1 =	2.74	Pr =	2.74
	hx = 19.74	h1 =	22.44	hc =	22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx = 0		0		-22337.5
Coefficients:					
	f0 = 1	rx =	1.00	A0 =	1.17 ft2
	f1 = 1.17	n1 =	7.00	A1 =	7.04 ft2
	f = 1.00	n2 =	28.00	A1c =	5.72 ft2
		n3 =	280.00	Acn =	18.33 ft2
		n4 =	280.00	Ams =	170 ft2
				As =	208 ft2
Initial guess:		CFM =	260000 cfm		
Tout =	36.6 F	Tsleeve =	49.5 F	=	9.7 C air
		Tmco =	108.1 F	=	42.2 C air
		Tcanister =	108.9 F	=	42.7 C water
		Tinner =	109.8 F	=	43.1 C water
		" " =	110.1 F	=	43.4 C water
ROout =	0.0798 lb/ft3				
ROin =	0.0804 lb/ft3				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 50

TA-73

c:\Sidd\2D_4

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104846	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.08 in		
qx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	2.60 fps	hss =	1.54 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Re =	61.2 lbm/ft3	ke = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta = 3.1E-04 1/F
	Grx =	1.5E+09	2.18E+09		2.3E+09
	Prx =	2.74	Pr1 =	2.74	Pr = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==>	0	0		-22134.8
Coefficients:	f0 =	1	rx =	1.00	A0 = 1.17 ft2
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft2
	f =	1.00	n2 =	28.00	A1c = 5.72 ft2
			n3 =	280.00	Ac = 18.33 ft2
			n4 =	280.00	Ams = 170 ft2
					As = 208 ft2
Initial guess:	CFM =	300000 cfm			
Tout =	38.2 F	Tsleeve =	48.5 F	=	9.1 C air
		Tmco =	107.1 F	=	41.7 C air
		Tcanister =	107.9 F	=	42.1 C water
		Tinner =	108.6 F	=	42.5 C water
		" "	109.1 F	=	42.8 C water
ROout =	0.0799 lb/ft3				
ROin =	0.0804 lb/ft3				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 51

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W		
No. of elements =	104846	Qtota =	320 kW = 1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in c = 1.1
Tin =	35 F	D =	2.06 in
qx =	253.56 Btu/h-ft3	A(2 vaults) =	1920.00 ft2 hms = 0.33 Btu/h-ft2-F
		Vair =	3.04 fpe hsa = 1.63 Btu/h-ft2-F
			Lamda(ur) = 17.3 Btu/h-ft-F
=>Temporary 1(Const)	Grx ==> 9E+09	1.00E+09	1.4E+09
Water data:	L = 1.87 ft	Ro = 61.2 lbm/ft3	k = 0.384 BTU/h-ft-F
	mu = 2.90E-04 lbm/ft-s	g = 32.2 ft/s2	Beta = 3.1E-04 1/F
	Grx = 1.5E+09	2.16E+09	2.3E+09
	Pxx = 2.74	Prt = 2.74	Pro = 2.74
	hxx = 19.74	h1 = 22.44	hc = 22.62 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==> 0	0	-21926.2
Coefficients:			
	f0 = 1	rx = 1.00	AD = 1.17 ft2
	f1 = 1.17	n1 = 7.00	A1 = 7.04 ft2
	f2 = 1.00	n2 = 26.00	A1c = 5.72 ft2
		n3 = 260.00	Acn = 18.33 ft2
		n4 = 260.00	Ams = 170 ft2
			As = 208 ft2
Initial guess:			
	CFM =	350000	cfm
Tout =	37.7 F	Tsleeve =	47.4 F = 8.6 C air
		Tmco =	106.0 F = 41.1 C air
		Tcanister =	106.8 F = 41.5 C water
		Tinner =	107.6 F = 41.9 C water
		" =	108.1 F = 42.2 C water
ROout =	0.0800 lb/ft3		
ROin =	0.0804 lb/ft3		

- Notice: 1) Tsleeve is calculated at the end of the vault.
2) Free area for airflow is calculated for 2 vaults.
3) Water inside the MCO and air between MCO and sleeve

Table 52

c:\Sidd\2D_4

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W		
No. of elements =	104846	Qtotal =	320 kW = 1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in c = 1.1
Tin =	35 F	D =	2.06 in
qx =	253.56 Btu/h-ft3	A(2 vaults) =	1920.00 ft2 hms = 0.33 Btu/h-ft2-F
		Vair =	3.47 fps hsa = 1.72 Btu/h-ft2-F
=>Temporary 1(Const.)	Grx ==> 9E+09		Lamda(ur) = 17.3 Btu/h-ft-F
Water data:	L = 1.87 ft	1.00E+09	1.4E+09
	mu = 2.90E-04 lbm/ft-s	Ro = 81.2 lbm/ft3	k = 0.384 BTU/h-ft-F
	Grx = 1.5E+09	g = 32.2 ft/s2	Beta = 3.1E-04 1/F
	Prx = 2.74	2.18E+09	2.3E+09
	hx = 19.74	Pr1 = 2.74	Prco = 2.74
=>Temporary 2(Formulas)	Grx ==> 0	h1 = 22.44	hc = 22.82 BTU/h-ft2-F
		0	-21753.5
Coefficients:	f0 = 1	nx = 1.00	A0 = 1.17 ft2
	f1 = 1.17	n1 = 7.00	A1 = 7.04 ft2
	f = 1.00	n2 = 28.00	A1c = 5.72 ft2
		n3 = 280.00	Acm = 18.33 ft2
		n4 = 280.00	Ams = 170 ft2
			As = 208 ft2
Initial guess:	CFM =	400000	cfm
Tout =	37.4 F	Tsleeve =	48.6 F = 8.1 C air
		Tmco =	105.2 F = 40.8 C air
		Tcanister =	106.0 F = 41.1 C water
		Tinner =	106.7 F = 41.5 C water
		" " =	107.2 F = 41.8 C water
ROut =	0.0800 lb/ft3		
ROin =	0.0804 lb/ft3		

Notice: 1) Tsleeve is calculated at the end of the vault.
2) Free area for airflow is calculated for 2 vaults.
3) Water inside the MCO and air between MCO and sleeve

Table 53

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104846	Qtotals =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.06 in		
qrx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft-F
		Vair =	3.91 fps	hss =	1.81 Btu/h-ft-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft3	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta = 3.1E-04 1/F
	Grx =	1.5E+09	2.16E+09		2.3E+09
	Prx =	2.74	Pr1 =	2.74	Pr = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==>	0	0		-21605.1
Coefficients:	fo =	1	rx =	1.00	AO = 1.17 ft2
	fi =	1.17	n1 =	7.00	A1 = 7.04 ft2
	fa =	1.00	n2 =	28.00	A1c = 5.72 ft2
			n3 =	280.00	Ac = 18.33 ft2
			n4 =	280.00	Ams = 170 ft2
					As = 208 ft2
<hr/>					
Initial guess:	CFM =	450000 cfm			
Tout =	37.1 F	Tsleeve =	45.9 F	=	7.7 C air
		Tmco =	104.5 F	=	40.2 C air
		Tcanister =	105.2 F	=	40.7 C water
		Tinner =	106.0 F	=	41.1 C water
ROout =	0.0801 lb/ft3	" " =	106.5 F	=	41.3 C water
ROin =	0.0804 lb/ft3				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 59

TH- 7/1

SSF FUEL STUDY

Forced ventilation - MCO/Water - Sleeve/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104848	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.06 in		
qx =	253.58 Btu/h-ft ³	A(2 vaults) =	1920.00 ft ²	hms =	0.33 Btu/h-ft ² -F
		Vair =	4.34 fps	hsa =	1.90 Btu/h-ft ² -F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft ³	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s ²	Beta = 3.1E-04 1/F
	Grx =	1.5E+09		2.16E+09	2.3E+09
	Prc =	2.74	Pri =	2.74	Prc = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft ² -F
=>Temporary 2(Formulas)	Grx ==>	0	0		-21477.3
Coefficients:	f0 =	1	nx =	1.00	A0 = 1.17 ft ²
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft ²
	f =	1.00	n2 =	28.00	A1c = 5.72 ft ²
			n3 =	280.00	Acm = 18.33 ft ²
			n4 =	280.00	Ams = 170 ft ²
					As = 208 ft ²
<hr/>					
Initial guess:	CFM =	500000	cfm		
Tout =	36.9 F	Tsleeve =	45.2 F	=	7.3 C air
		Tmco =	103.8 F	=	39.9 C air
		Tcanister =	104.6 F	=	40.3 C water
		Tinner =	105.4 F	=	40.7 C water
		" "	105.9 F	=	41.0 C water
ROout =	0.0801 lb/ft ³				
ROin =	0.0804 lb/ft ³				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 55

TA-78

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SSF FUEL STUDY

Forced air - MCO/Air- SLEEVE/Air- 880 MCO's- 2 vaults - Canister at the End of the Vault

Element Load = 3.44 W
 No. of elements = 104848
 q = 11.74 Btu/h
 T_{in} = 35 F
 q_{ex} = 253.58 Btu/h-ft²
 Q_{total} = 320 kW = 1092160 Btu/h
 D₁₇ = 2.4 in c = 1.1
 D = 2.08 in k = 0.711 Btu/h-ft²-F
 A(2 vaults) = 1920.00 ft² hms = 0.33 Btu/h-ft²-F
 V_{air} = 0.43 fps hse = 1.08 Btu/h-ft²-F
 Lamda(ur) = 17.3 Btu/h-ft-F

Coefficients:

f0 = 1	rx = 1.00	A0 = 1.17 ft ²
f1 = 1.17	n1 = 7.00	A1 = 7.04 ft ²
f = 1.00	n2 = 28.00	A1c = 5.72 ft ²
	n3 = 280.00	Acm = 18.33 ft ²
	n4 = 280.00	Ams = 170 ft ²
		As = 208 ft ²

Initial guess: CFM = 50000 cfm

T _{out} = 54.2 F	T _{sleeve} = 65.9 F = 20.5 C	air
	T _{mco} = 127.5 F = 53.0 C	air
	T _{canister} = 152.7 F = 67.0 C	air
	T _{inner} = 176.3 F = 80.1 C	air
	" " = 180.4 F = 87.9 C	air
RO _{out} = 0.0775 lb/ft ³		
RO _{in} = 0.0804 lb/ft ³		

- Notice: 1) T_{sleeve} is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Air inside the MCO and air between MCO and sleeve

Table 56

T canister as a function of CFM

Figure 5

c:\Sidd\air_2

SSF FUEL STUDY

Forced air - MCO/Air- SLEEVE/Air- 880 MCO's- 2 vaults - Canister at the End of the Vault

Element Load = 3.44 W
 No. of elements = 104846
 q = 11.74 Btu/h
 Tin = 35 F
 qx = 253.58 Btu/h-ft²

Qtotal = 320 kW
 D17 = 2.4 in
 D = 2.06 in
 A(2 vaults) = 1920.00 ft²
 Vair = 0.87 fps
 Lambda(ur) = 17.3 Btu/h-ft-F

= 1092160 Btu/h
 c = 1.1
 k = 0.711 Btu/h-ft-F
 hms = 0.33 Btu/h-ft-F
 hsa = 1.17 Btu/h-ft-F

Coefficients:	r0 =	1	rx =	1.00	A0 =	1.17 ft ²
	r1 =	1.17	n1 =	7.00	A1 =	7.04 ft ²
	r =	1.00	n2 =	28.00	A1c =	5.72 ft ²
			n3 =	280.00	Acm =	18.33 ft ²
			n4 =	280.00	Ams =	170 ft ²
				As =	208 ft ²	

Initial guess:		CFM =	100000	cfm
Tout =	44.5 F	Tsleeve =	58.0 F	= 14.4 C air
		Tmco =	116.6 F	= 47.0 C air
		Tcanister =	141.9 F	= 61.0 C air
		Tinner =	185.5 F	= 74.1 C air
		" "	179.5 F	= 81.9 C air
ROout =	0.0790 lb/ft ³			
ROin =	0.0804 lb/ft ³			

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Air inside the MCO and air between MCO and sleeve

Table 57

TA 80

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SSF FUEL STUDY

Forced air - MCO/Air- SLEEVE/Air- 880 MCO's- 2 vaults - Canister at the End of the Vault

Element Load = 3.44 W
 No. of elements = 104846
 q = 11.74 Btu/h
 Tin = 35 F
 qx = 253.58 Btu/h-ft2
 Qtotal = 320 kW
 D17 = 2.4 in
 D = 2.06 in
 A(2 vaults) = 1920.00 ft2
 Vair = 1.30 fps
 c = 1.1
 k = 0.711 Btu/h-ft2-F
 hms = 0.33 Btu/h-ft2-F
 hsa = 1.26 Btu/h-ft2-F
 Lambda(ur) = 17.3 Btu/h-ft-F

Coefficients:	f0 = 1	nx = 1.00	A0 = 1.17 ft2
	ft = 1.17	n1 = 7.00	A1 = 7.04 ft2
	fs = 1.00	n2 = 28.00	A1c = 5.72 ft2
		n3 = 280.00	Acn = 18.33 ft2
		n4 = 280.00	Ams = 170 ft2
			As = 208 ft2

Initial guess:	CFM = 150000 cfm
Tout = 41.3 F	Tsleeve = 53.9 F = 12.1 C air
	Tmco = 112.5 F = 44.7 C air
	Tcanister = 137.7 F = 58.7 C air
	Tinner = 161.3 F = 71.8 C air
	" " = 175.4 F = 79.6 C air
ROout = 0.0794 lb/ft3	
ROin = 0.0804 lb/ft3	

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Air inside the MCO and air between MCO and sleeve

Table 58

TA 31

c:\Sidd\air_2

SSF FUEL STUDY

Forced air - MCO/Air- SLEEVE/Air- 880 MCO's - 2 vaults - Canister at the End of the Vault

Element Load = 3.44 W
 No. of elements = 104846
 q = 11.74 Btu/h
 Tin = 35 F
 qpr = 253.58 Btu/h-ft³

Qtotal = 320 kW = 1092160 Btu/h
 D17 = 2.4 in c = 1.1
 D = 2.06 in k = 0.711 Btu/h-ft²-F
 A(2 vaults) = 1920.00 ft² hms = 0.33 Btu/h-ft²-F
 Vair = 1.74 fps hsa = 1.35 Btu/h-ft²-F
 Lamda(ur) = 17.3 Btu/h-ft-F

Coefficients:	fo = 1	no = 1.00	AO = 1.17 ft ²
	fi = 1.17	n1 = 7.00	A1 = 7.04 ft ²
	fm = 1.00	n2 = 28.00	A1c = 5.72 ft ²
		n3 = 280.00	Acm = 18.33 ft ²
		n4 = 280.00	Ams = 170 ft ²
			As = 208 ft ²

Initial guess:		CFM = 200000 cfm	
Tout = 39.7 F	Tsleeve = 51.4 F	= 10.8 C	air
	Tmco = 110.0 F	= 43.3 C	air
	Tcanister = 135.3 F	= 57.3 C	air
	Tinner = 158.9 F	= 70.4 C	air
	" " = 172.9 F	= 78.2 C	air
ROout = 0.0797 lb/ft ³			
ROin = 0.0804 lb/ft ³			

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Air inside the MCO and air between MCO and sleeve

Table 59

TA-82

c:\Sidd\air_2

SSF FUEL STUDY

Forced air - MCO/Air- SLEEVE/Air- 880 MCO's- 2 vaults - Canister at the End of the Vault

Element Load = 3.44 W
 No. of elements = 104846
 q = 11.74 Btu/h
 Tin = 35 F
 qcr = 253.58 Btu/h-ft²
 Qtotal = 320 kW = 1092160 Btu/h
 D17 = 2.4 in c = 1.1
 D = 2.08 in k = 0.711 Btu/h-ft²-F
 A(2 vaults) = 1920.00 ft² hms = 0.33 Btu/h-ft²-F
 Vair = 2.17 fps hsa = 1.45 Btu/h-ft²-F
 Lambda(ur) = 17.3 Btu/h-ft-F

Coefficients:	f0 = 1	rx = 1.00	A0 = 1.17 ft ²
	f1 = 1.17	n1 = 7.00	A1 = 7.04 ft ²
	f = 1.00	n2 = 28.00	A1c = 5.72 ft ²
		n3 = 280.00	Acn = 18.33 ft ²
		n4 = 280.00	Ams = 170 ft ²
			As = 208 ft ²

Initial guess:	CFM = 250000 cfm
Tout = 38.8 F	Tsleeve = 49.7 F = 9.8 C air
	Tmco = 108.4 F = 42.4 C air
	Tcanister = 133.8 F = 56.4 C air
	Tinner = 157.2 F = 69.5 C air
	" " = 171.3 F = 77.3 C air
RCout = 0.0798 lb/ft ³	
RCin = 0.0804 lb/ft ³	

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Air inside the MCO and air between MCO and sleeve

Table 60

TA 83

SSF FUEL STUDY

Forced air - MCO/Air- SLEEVE/Air- 880 MCO's- 2 vaults - Canister at the End of the Vault

Element Load =	3.44 W				
No. of elements =	104846	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.06 in	k =	0.711 Btu/h-ft2-F
qx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	2.60 fps	hsa =	1.54 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F

Coefficients:	f0 =	1	rx =	1.00	A0 =	1.17 ft2
	f1 =	1.17	n1 =	7.00	A1 =	7.04 ft2
	f =	1.00	n2 =	28.00	A1c =	5.72 ft2
			n3 =	280.00	Asm =	18.33 ft2
			n4 =	280.00	Ams =	170 ft2
				As =	208 ft2	

Initial guess:		CFM =	300000 cfm		
Tout =	38.2 F	Tsleeve =	48.5 F	=	9.1 C air
		Tmco =	107.1 F	=	41.7 C air
		Tcanister =	132.3 F	=	55.7 C air
		Tinner =	155.9 F	=	68.8 C air
		" "	170.0 F	=	76.6 C air
ROut =	0.0799 lb/ft3				
ROin =	0.0804 lb/ft3				

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Air inside the MCO and air between MCO and sleeve

Table 61

TA 84

SSF FUEL STUDY

Forced air - MCO/Air- SLEEVE/Air- 880 MCO's- 2 vaults - Canister at the End of the Vault

Element Load =	3.44 W				
No. of elements =	104846	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.06 in	k =	0.711 Btu/h-ft2-F
qcr =	253.58 Btu/h-ft2	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	3.04 fps	hac =	1.63 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F

Coefficients:	f0 =	1	nm =	1.00	A0 =	1.17 ft2
	f1 =	1.17	n1 =	7.00	A1 =	7.04 ft2
	f2 =	1.00	n2 =	28.00	A1c =	5.72 ft2
			n3 =	280.00	Acn =	18.33 ft2
			n4 =	280.00	Ams =	170 ft2
					As =	208 ft2

Initial guess:	CFM =	350000 cfm			
Tout =	37.7 F	Tsleeve =	47.4 F	=	8.6 C air
		Tmco =	106.0 F	=	41.1 C air
		Tcanister =	131.3 F	=	55.1 C air
		Tinner =	154.9 F	=	68.2 C air
		" " =	188.9 F	=	76.0 C air
ROout =	0.0800 lb/ft3				
ROin =	0.0804 lb/ft3				

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Air inside the MCO and air between MCO and sleeve

Table 62

TA 85

c:\Sidd\air_2

SSF FUEL STUDY

Forced air - MCO/Air- SLEEVE/Air- 880 MCO's- 2 vaults - Canister at the End of the Vault

Element Load = 3.44 W
 No. of elements = 104848
 q = 11.74 Btu/h
 T_{in} = 35 F
 q_{ex} = 253.58 Btu/h-ft²
 Q_{total} = 320 kW = 1092160 Btu/h
 D₁₇ = 2.4 in c = 1.1
 D = 2.06 in k = 0.711 Btu/h-ft²-F
 A(2 vaults) = 1920.00 ft² hms = 0.33 Btu/h-ft²-F
 V_{air} = 3.47 fps hsa = 1.72 Btu/h-ft²-F
 Lamda(ur) = 17.3 Btu/h-ft-F

Coefficients:	r0 =	1	r0 =	1.00	A0 =	1.17 ft ²
	r1 =	1.17	n1 =	7.00	A1 =	7.04 ft ²
	r =	1.00	n2 =	28.00	A1c =	5.72 ft ²
			n3 =	280.00	Acm =	18.33 ft ²
			n4 =	280.00	Ams =	170 ft ²
					As =	208 ft ²

Initial guess:		CFM =	400000 cfm
T _{out}	37.4 F	T _{sleeve}	46.8 F = 8.1 C air
		T _{mco}	105.2 F = 40.6 C air
		T _{canister}	130.4 F = 54.6 C air
		T _{inner}	154.0 F = 67.7 C air
		" "	168.1 F = 75.5 C air
RO _{out}	0.0800 lb/ft ³		
RO _{in}	0.0804 lb/ft ³		

- Notice: 1) T_{sleeve} is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Air inside the MCO and air between MCO and sleeve

Table 63

TA 87

c:\Siddair_2

SSF FUEL STUDY

Forced air - MCO/Air- SLEEVE/Air- 880 MCO's- 2 vaults - Canister at the End of the Vault

Element Load = 3.44 W
 No. of elements = 104846
 q = 11.74 Btu/h
 Tin = 35 F
 qx = 253.56 Btu/h-ft²
 Qtotal = 320 kW
 D17 = 2.4 in
 D = 2.06 in
 A(2 vaults) = 1920.00 ft²
 Vair = 4.34 fps
 c = 1.1
 k = 0.711 Btu/h-ft²-F
 hms = 0.33 Btu/h-ft²-F
 hsa = 1.90 Btu/h-ft²-F
 Lambda(ur) = 17.3 Btu/h-ft-F

Coefficients:

f0 = 1	rx = 1.00	A0 = 1.17 ft ²
f1 = 1.17	n1 = 7.00	A1 = 7.04 ft ²
f2 = 1.00	n2 = 28.00	A1c = 5.72 ft ²
	n3 = 280.00	Acn = 18.33 ft ²
	n4 = 280.00	Ams = 170 ft ²
		As = 208 ft ²

Initial guess: CFM = 500000 cfm

Tout = 36.9 F	Tsleeve = 45.2 F	= 7.3 C	air
	Tmco = 103.6 F	= 39.9 C	air
	Tcanister = 129.1 F	= 53.9 C	air
	Tinner = 152.6 F	= 67.0 C	air
	" " = 166.7 F	= 74.8 C	air
ROut = 0.0801 lb/ft ³			
ROin = 0.0804 lb/ft ³			

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Air inside the MCO and air between MCO and sleeve

Table 65

TA-88

c:\Siddair_2

SSF FUEL STUDY

Forced air - MCO/Air- SLEEVE/Air- 880 MCO's- 2 vaults - Canister at the End of the Vault

Element Load =	3.44 W	Qtotal=	320 kW	=	1092160 Btu/h	
*No. of elements=	104846	D17=	2.4 in	c =	1.1	
q=	11.74 Btu/h	D=	2.06 in	k =	0.711 Btu/h-ft-F	
Tin=	-37.3 F	A(2 vaults)=	1920.00 ft ²	hms=	0.33 Btu/h-ft-F	
qpc=	253.56 Btu/h-ft ³	Vair=	1.74 fps	hss=	1.35 Btu/h-ft-F	
				Lamda(ur)=	17.3 Btu/h-ft-F	
<hr/>						
Coefficients:	fD=	1	nx=	1.00	AD=	1.17 ft ²
	f1=	1.17	n1=	7.00	A1=	7.04 ft ²
	f=	1.00	n2=	28.00	A1c=	5.72 ft ²
			n3=	280.00	Acm=	18.33 ft ²
			n4=	280.00	Ams=	170 ft ²
				As=	208 ft ²	
<hr/>						
Initial guess:		CFM=	200000 cfm			
Tout=	-33.2 F	Tsleeve=	-21.5 F	=	-29.7 C	air
		Tmco=	37.1 F	=	2.8 C	air
		Tcanister=	62.4 F	=	16.8 C	air
		Tinner =	85.9 F	=	29.9 C	air
		" " =	100.0 F	=	37.8 C	air
RCout=	0.0917 lb/m ³					
RCin =	0.0924 lb/m ³					

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Air inside the MCO and air between MCO and sleeve

Table 66

TIA 89

c:\Sidd\air_4

SSF FUEL STUDY

Natural convection - MCO/Air- SLEEVE/Air- 880 MCO's- 2 vaults - Canister at the End of the Vault

Element Load =	3.44 W				
No. of elements =	104846	Qtotal =	270 kW	=	921510 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	115 F	D =	2.06 in	k =	0.711 Btu/h-ft-F
qx =	253.58 Btu/h-ft ³	A(2 vaults) =	1920.00 ft ²	hms =	0.33 Btu/h-ft ² -F
Hstack =	184 ft	Vair =	0.47 fps	hss =	1.09 Btu/h-ft ² -F
		K1 =	2.65E-11	Lamda(ur) =	17.3 Btu/h-ft-F

Coefficients:	f0 =	1	n0 =	1.00	A0 =	1.17 ft ²
	f1 =	1.17	n1 =	7.00	A1 =	7.04 ft ²
	f =	1.00	n2 =	28.00	A1c =	5.72 ft ²
			n3 =	280.00	Ac =	18.33 ft ²
			n4 =	280.00	Ams =	170 ft ²
					As =	208 ft ²

Initial guess:	CFM =	53600 cfm			
Tout =	132.5 F	Tsleeve =	147.1 F	=	63.9 C air
dP =	0.0761 in.WG	Tmco =	205.7 F	=	96.4 C air
Pstack =	0.0759 in.WG	Tcanister =	230.9 F	=	110.4 C air
ddP =	0.0002 "	Tinner =	254.5 F	=	123.5 C air
ROout =	0.0671 lb/ft ³	" =	268.6 F	=	131.3 C air
ROin =	0.0692 lb/ft ³				

- Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Air inside the MCO and air between MCO and sleeve
 4) Ten canisters per sleeve
 5) Total heat load due to nuclear decay only. No heat from structures.

Table 67

TA 90

CASDDATime2

Transient Analysis

Total heat load, Btu/h

320 kW=

1092160 Btu/h

	Element	Cylinder Water	Assembly	Sleeve	Air	Total	Time
Mass per sleeve, lb	14330	2233	3178	5498	-	-	
Total mass in vaults, lb	6305200	982520	1398320	2419120	11618	-	
Specific heat, Btu/lb-F	0.027	0.11	0.11	0.11	0.24	-	
T initial, F	111.8	110.8	110.0	51.4	37.4	-	
T1, F	123.0	122.0	121.2	62.6	41.8	-	
T2, F	133.0	132.0	131.2	72.6	46.4	-	
T3, F	143.0	142.0	141.2	82.6	51.2	-	
T4, F	153.0	152.0	151.2	92.6	56.1	-	
T5, F	163.0	162.1	161.3	102.7	61.6	-	
T6, F	173.0	172.0	171.2	112.6	66.1	-	0
Enthalpy 1-in, Btu	1906692	1210465	1722730	2980356	12269	7832512	7.2
Enthalpy 2-in, Btu	3609096	2291237	3260882	5641388	25095	14827698	13.6
Enthalpy 3-in, Btu	5311500	3372009	4799034	8302420	38618	21823581	20.0
Enthalpy 4-in, Btu	7013904	4452781	6337186	10963452	52281	28819604	26.4
Enthalpy 5-in, Btu	8716308	5544360	7890720	13651094	67617	35870100	32.8
Enthalpy 6-in, Btu	10418712	6614325	9413490	16285516	80164	42812207	39.2

Table 68

Figure 6

TA 91

SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104846	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.08 in		
qpr =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	1.74 fps	hss =	1.35 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	R =	61.2 lbm/ft3	k = 0.364 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta = 3.1E-04 1/F
	Grc =	1.5E+09		2.2E+09	2.3E+09
	Prx =	2.74	Pr1 =	2.74	Pr = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==>	0	0		-22737.3
Coefficients:					
	f0 =	1	rx =	1.00	A0 = 1.17 ft2
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft2
	f =	1.00	n2 =	28.00	A1c = 5.72 ft2
			n3 =	280.00	Ac = 16.33 ft2
			n4 =	280.00	Ams = 170 ft2
					As = 208 ft2
<hr/>					
Initial guess:	CFM =	200000	cfm		
Tout =	39.7 F	Tsleeve =	51.4 F	=	10.8 C air
		Tmco =	110.0 F	=	43.3 C air
		Tcanister =	110.8 F	=	43.7 C water
		Tinner =	111.6 F	=	44.2 C water
		" "	112.1 F	=	44.4 C water
ROout =	0.0797 lb/ft3				
ROin =	0.0804 lb/ft3				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 25.69

SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load = 3.44 W		Qtotal= 320 kW		= 1092160 Btu/h	
No. of elements= 104848		D17= 2.4 in		c = 1.1	
q= 11.74 Btu/h		D= 2.06 in			
Tin= 35 F		A(2 vaults)= 1920.00 ft ²		hms= 0.33 Btu/h-ft ² -F	
qr= 253.55 Btu/h-ft ²		Vair= 0.62 fps		hac= 1.12 Btu/h-ft ² -F	
				Lamda(ur)= 17.3 Btu/h-ft-F	
=>Temporary 1(Const)		Grx ==> 9E+09		1.00E+09	
Water data:		L= 1.67 ft		Ro= 61.2 lbm/ft ³	
		mu= 2.90E-04 lbm/ft-s		g= 32.2 ft/s ²	
		Grx= 1.5E+09		2.2E+09	
		Prx= 2.74		Pr1= 2.74	
		hx= 19.74		h1= 22.44	
=>Temporary 2(Formulas)		Grx ==> 0		0	
				hc= 22.82 BTU/h-ft ² -F	
				-25004.4	
Coefficients:		f0= 1		A0= 1.17 ft ²	
		f1= 1.17		A1= 7.04 ft ²	
		f= 1.00		A1c= 5.72 ft ²	
				Acm= 18.33 ft ²	
				Ams= 170 ft ²	
				As= 208 ft ²	
Initial guess:		CFM= 71000 cfm			
Tout= 48.5 F		Tsleeve= 62.6 F		= 17.0 C	
		Tmco= 121.2 F		= 49.5 C	
		Tcanister= 122.0 F		= 50.0 C	
		Tinner = 122.7 F		= 50.4 C	
		" " = 123.3 F		= 50.6 C	
RCout= 0.0784 lb/ft ³					
RCin = 0.0804 lb/ft ³					

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 26.70

Element Load =	3.44 W		
No. of elements =	104848	Qtotal =	320 kW = 1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in c = 1.1
Tin =	35 F	D =	2.06 in
qr =	253.58 Btu/h-ft ²	A(2 vaults) =	1920.00 ft ² hms = 0.33 Btu/h-ft ² -F
		Vair =	0.37 fps hsa = 1.07 Btu/h-ft ² -F
			Lambda(ur) = 17.3 Btu/h-ft-F
=>Temporary 1(Const)	Grx ==> 9E+09	1.00E+09	1.4E+09
Water data:	L = 1.87 ft	Ro = 61.2 lbm/ft ³	kn = 0.384 BTU/h-ft-F
	mu = 2.80E-04 lbm/ft-s	g = 32.2 ft/s ²	Beta = 3.1E-04 1/F
	Grx = 1.5E+09	2.2E+09	2.3E+09
	Prx = 2.74	Pri = 2.74	Prco = 2.74
	hx = 19.74	h1 = 22.44	hc = 22.82 BTU/h-ft ² -F
=>Temporary 2(Formulas)	Grx ==> 0	0	-27025.6
Coefficients:	fo = 1	no = 1.00	AO = 1.17 ft ²
	fi = 1.17	n1 = 7.00	A1 = 7.04 ft ²
	fb = 1.00	n2 = 28.00	A1c = 5.72 ft ²
		n3 = 280.00	Acm = 18.33 ft ²
		n4 = 280.00	Ans = 170 ft ²
			Ass = 208 ft ²

Notice:

- 1) Tsleeve is calculated at the end of the vault.
- 2) Free area for airflow is calculated for 2 vaults.
- 3) Water inside the MCO and air between MCO and sleeve

Table 2771

TA 94

SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104846	Qtotal =	320 kW	=	1082180 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.06 in		
qx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	0.26 fps	hse =	1.04 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft3	k = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta = 3.1E-04 1/F
	Grx =	1.5E+09	2.2E+09		2.3E+09
	Pnx =	2.74	Pr1 =	2.74	Prce = 2.74
	hx =	18.74	h1 =	22.44	hce = 22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==>	0	0		-28054.6
Coefficients:	r0 =	1	ru =	1.00	AO = 1.17 ft2
	r1 =	1.17	n1 =	7.00	A1 = 7.04 ft2
	r =	1.00	n2 =	28.00	A1c = 5.72 ft2
			n3 =	280.00	Acm = 18.33 ft2
			n4 =	280.00	Ams = 170 ft2
					As = 206 ft2
<hr/>					
Initial guess:	CFM =	30000	cfm		
Tout =	67.4 F	Tsleeve =	82.6 F	=	28.1 C air
		Tmco =	141.2 F	=	60.6 C air
		Tcanister =	142.0 F	=	61.0 C water
		Tinner =	142.7 F	=	61.4 C water
		" "	143.2 F	=	61.7 C water
ROout =	0.0758 lbm/ft3				
ROin =	0.0804 lbm/ft3				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 28.72

TH 95

SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44	W	Qtotal=	320 kW	=	1092180 Btu/h
No. of elements=	104846		D17=	2.4 in	c =	1.1
q=	11.74	Btu/h	D=	2.06 in		
Tin=	35	F	A(2 vaults)=	1920.00 ft ²	hms=	0.33 Btu/h-ft ² -F
qr=	253.56	Btu/h-ft ²	Vair=	0.20 fps	hsa=	1.03 Btu/h-ft ² -F
					Lamda(ur)=	17.3 Btu/h-ft-F
=>Temporary 1(Const)	Grx ==>	9E+09		1.00E+09		1.4E+09
Water data:	L=	1.87 ft	Ro=	61.2 lbm/ft ³	k=	0.384 BTU/h-ft-F
	mu=	2.90E-04 lbm/ft-s	g=	32.2 ft/s ²	Beta=	3.1E-04 1/F
	Grx=	1.5E+09		2.2E+09		2.3E+09
	Prx=	2.74	Pr1=	2.74	Pro=	2.74
	hx=	19.74	h1=	22.44	hc=	22.62 BTU/h-ft ² -F
=>Temporary 2(Formulas)	Grx ==>	0		0		-31095.3
Coefficients:						
	f0=	1	rx=	1.00	A0=	1.17 ft ²
	f1=	1.17	n1=	7.00	A1=	7.04 ft ²
	f=	1.00	n2=	28.00	A1c=	5.72 ft ²
			n3=	280.00	Acm=	18.33 ft ²
			n4=	280.00	Ams=	170 ft ²
					As=	208 ft ²
<hr/>						
	Initial guess:		CFM=	23200	cfm	
Tout=	77.3 F		Tsleeve=	92.6 F	=	33.7 C air
			Tmco=	151.2 F	=	66.2 C air
			Tcanister=	152.0 F	=	66.6 C water
			Tinner =	152.6 F	=	67.0 C water
			" " =	153.3 F	=	67.3 C water
ROout=	0.0742 lb/ft ³					
ROin =	0.0804 lb/ft ³					

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 29 73

TA 96

c:\Sidd\2D_4

SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104846	Qtotal =	320 KW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.06 in		
qx =	253.58 Btu/h-ft ²	A(2 vaults) =	1920.00 ft ²	hms =	0.33 Btu/h-ft ² -F
		Vair =	0.16 fps	hsa =	1.02 Btu/h-ft ² -F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft ³	ic = 0.384 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s ²	Beta = 3.1E-04 1/F
	Gnx =	1.5E+09	2.2E+09		2.3E+09
	Pnx =	2.74	Prj =	2.74	Pro = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft ² -F
=>Temporary 2(Formulas)	Grx ==>	0	0		-33136.3
Coefficients:					
	f0 =	1	nx =	1.00	AD = 1.17 ft ²
	f1 =	1.17	n1 =	7.00	A1 = 7.04 ft ²
	f =	1.00	n2 =	28.00	A1c = 5.72 ft ²
			n3 =	280.00	Acn = 18.33 ft ²
			n4 =	280.00	Ams = 170 ft ²
					As = 208 ft ²
<hr/>					
	Initial guess:	CFM =	18950 cfm		
Tout =	87.2 F	Tsleeve =	102.7 F	=	39.2 C air
		Tmco =	161.3 F	=	71.8 C air
		Tcanister =	162.1 F	=	72.2 C water
		Tinner =	162.8 F	=	72.6 C water
		" "	163.3 F	=	72.9 C water
ROout =	0.0729 lbm ³				
ROin =	0.0804 lbm ³				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 3Q74

SSF FUEL STUDY

Forced ventilation - MCO/Water - SLEEVE/Air - 880 MCO's - Canister at the End of the Vault - 5 high/2 vaults

Element Load =	3.44 W				
No. of elements =	104846	Qtotal =	320 kW	=	1092160 Btu/h
q =	11.74 Btu/h	D17 =	2.4 in	c =	1.1
Tin =	35 F	D =	2.06 in		
qx =	253.58 Btu/h-ft3	A(2 vaults) =	1920.00 ft2	hms =	0.33 Btu/h-ft2-F
		Vair =	0.14 fpa	hss =	1.02 Btu/h-ft2-F
				Lamda(ur) =	17.3 Btu/h-ft-F
=>Temporary 1(Const.)	Grx ==>	9E+09	1.00E+09		1.4E+09
Water data:	L =	1.87 ft	Ro =	61.2 lbm/ft3	k = 0.364 BTU/h-ft-F
	mu =	2.90E-04 lbm/ft-s	g =	32.2 ft/s2	Beta = 3.1E-04 1/F
	Grx =	1.5E+09	2.2E+09		2.3E+09
	Prx =	2.74	Pr1 =	2.74	Pr = 2.74
	hx =	19.74	h1 =	22.44	hc = 22.82 BTU/h-ft2-F
=>Temporary 2(Formulas)	Grx ==>	0	0		-35151.9
Coefficients:	fo =	1	nx =	1.00	A0 = 1.17 ft2
	fi =	1.17	n1 =	7.00	A1 = 7.04 ft2
	f =	1.00	n2 =	28.00	A1c = 5.72 ft2
			n3 =	280.00	Ac = 18.33 ft2
			n4 =	280.00	Am = 170 ft2
					As = 208 ft2
Initial guess:	CFM =	16080 cfm			
Tout =	97.1 F	Tsleeve =	112.8 F	=	44.7 C air
		Tmco =	171.2 F	=	77.3 C air
		Tcanister =	172.0 F	=	77.7 C water
		Tinner =	172.8 F	=	78.1 C water
		" "	173.3 F	=	78.4 C water
ROout =	0.0715 lb/ft3				
ROin =	0.0804 lb/ft3				

Notice: 1) Tsleeve is calculated at the end of the vault.
 2) Free area for airflow is calculated for 2 vaults.
 3) Water inside the MCO and air between MCO and sleeve

Table 3475

1 TUTORIAL

EasyFlow 2.01

**2 PROBLEM
LIBRARY**

ACTIVE PROBLEM

**3 DEFINE
PROBLEM**

FILENAME : **SSF_2D**

DESCRIPTION : **2 VAULTS, 2D CASE, 270 KW, 115 INLET**

**4 PREPARE
INPUT**

5 ANALYZE

**6 GRAPHIC
RESULTS**

REVIEW RESULTS

This post processor allows you to graphically review the results of your CFD analysis. You can display any solved or stored dependent variable results as colored contour plots or as a colored filled contour plots at any plane of interest. Velocities can be shown as color coded vectors at any plane. This step runs the PHOTON program. Refer to PHOTON User Manual TR140.

**7 RETURN
TO DOS**

Select Option and Press <Return>

FIGURE 8

7A-99

FIGURE 9

TA-100

Viewpoint: 1.00 0.000 -0.254E-05
Up vector: 0.254E-05 0.127E-05 1.00
Command? vs ix 1 colour 1
Vector 1 created.
Command?

46.1
47.6
48.4
49.1
49.9
50.7
51.4
52.2
53.0
53.7
54.5
55.3
56.0
56.8
Z

→: 2.62 m/s.

2 VAULTS, 2D CASE, 270 KW, 115 INLET

PHOENICS

FIGURE 10

7A-101

FIGURE 11

7A-102

Command?

2 VAULTS, 2D CASE, 270 KM, 115 INLET
PHONICS

: 0.87 m/s

46.1
47.6
48.4
49.1
49.9
50.7
51.4
52.2
53.0
53.7
54.5
55.3
56.0
56.8

Y

FIGURE 12

MHC-SD-W379-ES-003 Rev. 0

TA 103

Command?

46.1
47.6
48.4
49.1
49.9
50.7
51.4
52.2
53.0
53.7
54.5
55.3
56.0
56.8

Z
Y

→: 0.87 m/s.

2 VAULTS, 2D CASE, 270 KW, 115 INLET

PHOENICS

FIGURE 13

32 1993 32
104K

0 1

PRINCIPLES OF HEAT TRANSFER

Frank Kreith

University of Colorado and National Conference of State Legislatures
Denver, Colorado

Mark S. Bohn

National Renewable Energy Laboratory
Golden, Colorado

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LOS ANGELES

REF. 1a

This is similar to the result obtained previously by simplifying the general conduction equation (see Eq. (2.21)). Integration yields

$$\frac{\dot{q}_G r^2}{2} = -k r \frac{dT}{dr} + C_1$$

from which we deduce that, to satisfy the boundary condition $dT/dr = 0$ at $r = 0$, the constant of integration C_1 must be zero. Another integration yields the temperature distribution

$$T = -\frac{\dot{q}_G r^2}{4k} + C_2$$

To satisfy the condition that the temperature at the outer surface, $r = r_o$, is T_o , $C_2 = (\dot{q}_G r_o^2 / 4k) + T_o$. The temperature distribution is therefore

$$T = T_o + \frac{\dot{q}_G r_o^2}{4k} \left[1 - \left(\frac{r}{r_o} \right)^2 \right] \quad (2.50)$$

The maximum temperature at $r = 0$, T_{max} , is

$$T_{max} = T_o + \frac{\dot{q}_G r_o^2}{4k} \quad (2.51)$$

In dimensionless form Eq. (2.50) becomes

$$\frac{T(r) - T_o}{T_{max} - T_o} = 1 - \left(\frac{r}{r_o} \right)^2 \quad (2.52)$$

For a hollow cylinder with uniformly distributed heat sources and specified surface temperatures, the boundary conditions are

$$T = T_i \quad \text{at} \quad r = r_i \quad (\text{inside surface})$$

$$T = T_o \quad \text{at} \quad r = r_o \quad (\text{outside surface})$$

It is left as an exercise to verify that for this case the temperature distribution is given by

$$T(r) = T_o + \frac{\dot{q}_G}{4k} (r_o^2 - r^2) + \frac{\ln(r/r_o)}{\ln(r_o/r_i)} \left[\frac{\dot{q}_G}{4k} (r_o^2 - r_i^2) + T_o - T_i \right] \quad (2.53)$$

If a solid cylinder is immersed in a fluid at a specified temperature T_∞ and the convection heat transfer coefficient at the surface is specified and denoted by $\bar{h}_c$, the surface temperature at r_o is not known a priori. The boundary condition for this case requires that the heat conduction from the cylinder equal the rate of convection at the surface, or

$$-k \frac{dT}{dr} \Big|_{r=r_o} = \bar{h}_c (T_o - T_\infty)$$

Using this condition to evaluate the constants of integration yields for the dimensionless temperature distribution

$$\frac{T(r) - T_\infty}{T_o - T_\infty} = \frac{\dot{q}_G r_o}{4\bar{h}_c T_\infty} \left\{ 2 + \frac{\bar{h}_c r_o}{k} \left[1 - \left(\frac{r}{r_o} \right)^2 \right] \right\} \quad (2.54)$$

5. /B

TABLE 12 Metallic Elements*

Thermal Conductivity k (W/m K) ^b					Properties at 293 K or 20°C or 68°F				
200 K	273 K	0°C	127°C	527°C	927°C	ρ	c_p	k	$\alpha \times 10^6$
$\times 0.5777$					$\times 6.243 \times 10^{-4}$				
= (Btu/hr ft °F)					= (lb _m /ft ³)				
$\times 0.5777$					$\times 2.388 \times 10^{-4}$				
= (Btu/hr ft °F)					$\times 0.5777$				
$\times 3.874 \times 10^4$					$\times 0.5777$				
= (ft ² /hr)					$\times 0.5777$				
Melting Temperature (K)					Melting Temperature (K)				

REF. 1c

WIC-SD-4379-ES-003 Rev. 0

Aluminum	237	236	240	232	220	2.702	896	236	97.5	933
Antimony	30.2	25.5	21.2	18.2	16.8	6.684	208	24.6	17.7	904
Beryllium	301	218	161	126	107	1.850	1750	205	63.3	1550
Bismuth	9.7	8.2				9.780	124	7.9	6.51	545
Boron	52.5	31.7	18.7	11.3	8.1	2.500	1047	28.6	10.9	2573
Cadmium	99.3	97.5	94.7			8.650	231	97	48.5	594
Cesium	36.8	36.1				1.873	230	36	83.6	302
Chromium	111	94.8	87.3	80.5	71.3	7.160	440	91.4	29.0	2118
Cobalt	122	104	84.8			8.862	389	100	29.0	1765
Copper	413	401	392	383	371	8.933	383	399	116.6	1356
Cerium	96.8	66.7	43.2	27.3	19.8	5.360		61.6		1211
Cold	327	318	312	304	292	19.300	129	316	126.9	1336
Flatinum	24.4	23.3	22.3	21.3	20.8	13.280		23.1		2495
Indium	89.7	83.7	74.5			7.300		82.2	48.8	430
Iridium	153	148	144	138	132	22.500	134	147		2716
Iron	94	83.5	69.4	54.7	43.3	7.870	452	81.1	22.8	1810
Lead	36.6	35.5	33.8			11.340	129	35.3	24.1	601
Lithium	88.1	79.2	72.1			534	3391	77.4	42.7	454
Magnesium	159	157		149	146	1.740	1017	156	88.2	923
Manganese	7.17					7.290	486	7.78	2.2	1517

Mercury	28.9					13.546				
Molybdenum	143	139	134	126	118	10.240	251	138	53.7	2883
Nickel	106	94				8.900	446	91	37.9	1734
Niobium	52.6									234

TFA-106

Tungsten	143	139	134	126	118	112	105	251	138	53.7	234
Tantalum	106	94	80.1	65.5	67.4	71.8	76.1	446	91	22.9	2883
Tin	52.6	53.3	55.2	58.2	61.3	64.4	67.5	8,570	53.6	23.2	1726
Palladium	75.5	75.5	75.5	75.5	75.5	75.5	75.5	12,020	75.5	25.4	2741
Platinum	72.4	71.5	71.6	73.0	75.5	78.6	82.6	21,450	71.4	25.0	1825
Potassium	104	104	52					860	741	103	2042
Rhenium	51	48.6	46.1	44.2	44.1	44.6	45.7	21,100	137	48.1	337
Rhodium	154	151	146	136	127	121	115	12,450	248	150	3453
Rubidium	58.9	58.3						1,530	348	58.2	2233
Silicon	264	168	98.9	61.9	42.2	31.2	25.7	2,330	703	153	312
Silver	403	428	420	405	389	374	358	10,500	234	427	1685
Sodium	138	135						971	1206	133	1234
Tantalum	57.5	57.4	57.8	58.6	59.4	60.2	61	16,600	138	57.5	371
Tin	73.3	68.2	62.2					5,750	227	67.0	3269
Titanium	24.5	22.4	20.4	19.4	19.7	20.7	22	4,500	611	22.0	505
Tungsten	197	182	162	139	128	121	115	19,300	134	179	1953
Uranium	25.1	27	29.6	34	38.8	43.9	49	19,070	113	27.4	3653
Vanadium	31.5	31.3	32.1	34.2	36.3	38.6	41.2	6,100	502	31.4	1407
Zinc	123	122	116	105				7,140	385	121	2192
Zirconium	25.2	23.2	21.6	20.7	21.6	23.7	25.7	6,570	272	22.8	693
											2125

* Purity for all elements exceeds 99%.

* The expected percent errors in the thermal conductivity values are approximately within $\pm 5\%$ of the true values near room temperature and within about $\pm 10\%$ at other temperatures.

* For crystalline materials, the values are given for the polycrystalline materials.

Source: E.R.G. Eckert and R.M. Drake, *Analysis of Heat and Mass Transfer*, McGraw-Hill, New York, 1972; K. Raznjević, *Handbook of Thermodynamic Tables and Charts*, 3d ed., McGraw-Hill, New York, 1976; Y.S. Touloukian, ed., *Thermophysical Properties of Matter*, IFI/Plenum, New York, 1970.

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REF. 2a

This useful relationship gives a rough idea of the spectral energy distribution from a black surface; 25% of the energy is radiated at wavelengths shorter than the maximum, and 75% is radiated at wavelengths longer than the maximum.

Actual Radiation

Substances and surfaces diverge variously from the Stefan-Boltzmann and Planck Laws. W_b and W_{bl} are the maximum emissive powers at a surface temperature. Actual surfaces emit and absorb less readily and are called *nonblack*. The emissive power of a nonblack surface, at temperature T , radiating to the hemispherical region above it is written as:

$$W = \epsilon W_b = \epsilon \sigma T^4 \quad (36)$$

where ϵ is called the *hemispherical emittance*. The term emittance conforms to physical and electrical terminology; the suffix "ance" denotes a property of a piece of material as it exists. The ending "ivity" denotes a property of the bulk material independent of geometry or surface condition. Thus, emittance, reflectance, absorptance, and transmittance refer to actual pieces of material. Emissivity, reflectivity, absorptivity, and transmissivity refer to properties of materials which are optically smooth and thick enough to be opaque.

The emittance is a function of the material, the condition of its surface, and the temperature of the surface. Table 3 lists selected values; Siegel and Howell (1981) have more extensive lists.

The monochromatic emissive power of a nonblack surface is similarly written as:

$$W_\lambda = \epsilon_\lambda W_{bl} = \epsilon_\lambda (C_1 \lambda^{-5} / e^{C_2/\lambda T} - 1) \quad (37)$$

where ϵ_λ is the monochromatic hemispherical emittance. The relationship between ϵ and ϵ_λ is given by:

$$W = \epsilon \sigma T^4 = \int_0^\infty W_\lambda d\lambda = \int_0^\infty \epsilon_\lambda W_{bl} d\lambda$$

or

$$\epsilon = (1/\sigma T^4) \int_0^\infty \epsilon_\lambda W_{bl} d\lambda \quad (38)$$

If ϵ_λ does not depend on λ , then, from Equation (38), $\epsilon = \epsilon_\lambda$. Surfaces with this characteristic are called *gray*. Gray-surface characteristics are often assumed in calculations. Several classes of surfaces approximate this condition in some regions of the spec-

trum. The simplicity is desirable, but care must be exercised, especially if temperatures are high. Assumption of grayness is sometimes made, because of the absence of information relating ϵ_λ and λ .

When radiant energy falls on a surface, it can be absorbed, reflected or transmitted through the material. Therefore, from the First Law of Thermodynamics:

$$\alpha + \tau + \rho = 1 \quad (39)$$

where

α = fraction of incident radiation absorbed or *absorptance*

τ = fraction of incident radiation transmitted or *transmittance*

ρ = fraction of incident radiation reflected or *reflectance*

If the material is opaque, as most solids are in the infrared, $\tau = 0$ and $\alpha + \rho = 1$. For a black surface, $\alpha = 1$, $\rho = 0$ and $\tau = 0$. Platinum black and gold black have absorptances of about 98% in the infrared, which is as black as any actual surface is. Any desired degree of blackness can be simulated by a small hole in a large enclosure. Consider a ray of radiant energy entering the opening. It will undergo many internal reflections and be almost completely absorbed before it has a reasonable probability of passing back out the opening.

Certain flat black paints also exhibit emittances of 98% over a wide range of conditions. They provide a much more durable surface than gold or platinum black and are frequently used on radiation instruments and as standard reference in emittance or reflectance measurements.

Kirchhoff's law, relating emittance and absorptance of any opaque surface from thermodynamic considerations, states that for any surface where the incident radiation is independent of angle or where the surface is diffuse, $\epsilon_\lambda = \alpha_\lambda$. If the surface is gray, or the incident radiation is from a black surface at the same temperature, then also $\epsilon = \alpha$, but many surfaces are not gray. For most surfaces listed in Table 3, absorptance for solar radiation is different than emittance for low temperature level radiation. This is because the wavelength distributions are different in the two cases, and ϵ_λ varies with wavelength.

The foregoing discussion relates to total hemispherical radiation from surfaces. Energy distribution over the hemispherical region above the surface also has an important effect on the rate of heat transfer in various geometric arrangements.

Table 3 Emittances and Absorptances for a Few Surfaces^a

Class	Surfaces	Total Normal Emittance ^b		Absorptance for Solar Radiation
		At 50 to 100°F	At 1000°F	
1	A small hole in a large box, sphere, furnace, or enclosure	0.97 to 0.99	0.97 to 0.99	0.97 to 0.99
2	Black nonmetallic surfaces such as asphalt, carbon, slate, paint, paper	0.90 to 0.98	0.90 to 0.98	0.85 to 0.98
3	Red brick and tile, concrete and stone, rusty steel and iron, dark paints (red, brown, green, etc.)	0.85 to 0.95	0.75 to 0.90	0.65 to 0.80
4	Yellow and buff, brick and stone, firebrick, fire clay	0.85 to 0.95	0.70 to 0.85	0.50 to 0.70
5	White or light cream brick, tile, paint or paper, plaster, whitewash	0.85 to 0.95	0.60 to 0.75	0.30 to 0.50
6	Window glass	0.90		c
7	Bright aluminum paint; gilt or bronze paint	0.40 to 0.60		0.30 to 0.50
8	Dull brass, copper, or aluminum; galvanized steel; polished iron	0.20 to 0.30	0.30 to 0.50	0.40 to 0.65
9	Polished brass, copper, monel metal	0.02 to 0.05	0.05 to 0.15	0.30 to 0.50
10	Highly polished aluminum, tin plate, nickel, chromium	0.02 to 0.04	0.05 to 0.10	0.10 to 0.40
11	Selective surfaces			
	Stainless steel wire mesh	0.23 to 0.28		0.63 to 0.86
	White painted surface	0.92		0.23 to 0.49
	Copper treated with solution of NaClO ₂ and NaOH	0.13		0.87
	Copper, nickel, and aluminum plate with CuO coating	0.09 to 0.21		0.08 to 0.93

^a See also Chapter 37, McAdams (1954) and Siegel and Howell (1981).

^b Hemispherical and normal emittance are not equal in many cases. The hemispherical emittance may be as much as 30% greater for polished reflectors to 7% lower for nonconductors.

^c Absorbs 4 to 40% depending upon its transmittance.

laboratory test conditions. Air gaps in these types of insulation systems can seriously degrade thermal performance as a result of air movement due to both natural and forced convection. Sabine *et al.* (1975) found the tabular values are not necessarily additive for multiple-layer, low-emittance airspaces, and tests on actual constructions should be conducted to accurately determine thermal resistance values.

Values for foil insulation products supplied by manufacturers must also be used with caution because they apply only to systems that are identical to the configuration in which the product was tested. In addition, surface oxidation, dust accumulation, and other factors that change the condition of the low-emittance surface can reduce the thermal effectiveness of these insulation systems. Deterioration results from contact with several types of solutions, either acidic or basic (e.g., wet cement mortar or the preservatives found in decay-resistant lumber). Polluted environments may cause rapid and severe material degradation. However, site inspections show a predominance of well-preserved installations and only a small number of cases in which rapid and severe deterioration has occurred.

CALCULATING OVERALL THERMAL RESISTANCES

Relatively small conductive elements within an insulating layer or thermal bridges can substantially reduce the average thermal resistance of a component. Examples include wood and metal studs in frame walls, concrete webs in concrete masonry walls, and metal ties or other elements in insulated wall panels. The following examples illustrate how to calculate R-values and U-factors for components containing thermal bridges.

The following conditions are assumed in calculating the design R-values:

- (1) Equilibrium or steady-state heat transfer, disregarding effects of heat storage;

- (2) Surrounding surfaces at ambient air temperature;
- (3) Exterior wind velocity of 15 mph for winter (surface with $R = 0.17^\circ\text{F}\cdot\text{ft}^2\cdot\text{h}/\text{Btu}$) and 7.5 mph for summer (surface with $R = 0.25^\circ\text{F}\cdot\text{ft}^2\cdot\text{h}/\text{Btu}$); and
- (4) Surface emittance of ordinary building materials is 0.90.

Table 1 Surface Conductances, $\text{Btu}/\text{h}\cdot\text{ft}^2\cdot^\circ\text{F}$, and Resistances, $^\circ\text{F}\cdot\text{ft}^2\cdot\text{h}/\text{Btu}$, for Air^{a,b,c,d}

Position of Surface	Direction of Heat Flow	Surface Emittance, ϵ^e					
		Non-reflective			Reflective		
		$\epsilon = 0.90$			$\epsilon = 0.20$	$\epsilon = 0.05$	
		h_i	R	h_i	R	h_i	R
STILL AIR							
Horizontal	Upward	1.63	0.61	0.91	1.10	0.76	1.32
Sloping—45°	Upward	1.60	0.62	0.88	1.14	0.73	1.37
Vertical	Horizontal	1.46	0.68	0.74	1.35	0.59	1.70
Sloping—45°	Downward	1.32	0.76	0.60	1.67	0.45	2.22
Horizontal	Downward	1.08	0.92	0.37	2.70	0.22	4.55
MOVING AIR (Any Position)							
15-mph Wind (for winter)	Any	6.00	0.17	—	—	—	—
7.5-mph Wind (for summer)	Any	4.00	0.25	—	—	—	—

^aNo surface has both an airspace resistance value and a surface resistance value. No airspace value exists for any surface facing an airspace of less than 0.5 in.

^bFor ventilated attics or spaces above ceilings under summer conditions (flow down), see Table 5.

^cConductances are for surfaces of the stated emittance facing virtual blackbody surroundings at the same temperature as the ambient air. Values are based on a surface-air temperature difference of 10°F and for surface temperature of 70°F.

^dSee Chapter 3 for more detailed information, especially Tables 5 and 6, and see Figure 1 for additional data.

^eCondensate can have a significant impact on surface emittance (see Table 3).

Table 2 Thermal Resistances of Plane Airspaces^{a,b,c}, $^\circ\text{F}\cdot\text{ft}^2\cdot\text{h}/\text{Btu}$

Position of Airspace	Direction of Heat Flow	Airspace Mean Temp. ^d , °F	Temp. Diff. ^e , °F	0.5-in. Airspace ^c						0.75-in. Airspace ^c					
				Effective Emittance, $E^{d,e}$						Effective Emittance, $E^{d,e}$					
				0.03	0.05	0.2	0.5	0.82		0.03	0.05	0.2	0.5	0.82	
Horiz.	Up	90	10	2.13	2.03	1.51	0.99	0.73	2.34	2.22	1.61	1.04	0.75		
		30	30	1.62	1.57	1.29	0.96	0.75	1.71	1.66	1.35	0.99	0.77		
		30	10	2.13	2.05	1.60	1.11	0.84	2.30	2.21	1.70	1.16	0.87		
		0	20	1.73	1.70	1.45	1.12	0.91	1.83	1.79	1.52	1.16	0.93		
		0	10	2.10	2.04	1.70	1.27	1.00	2.23	2.16	1.78	1.31	1.02		
		-30	20	1.69	1.66	1.49	1.23	1.04	1.77	1.74	1.55	1.27	1.07		
45° Slope	Up	-30	10	2.04	2.00	1.75	1.40	1.16	2.16	2.11	1.84	1.46	1.20		
		90	10	2.44	2.31	1.65	1.06	0.76	2.96	2.78	1.88	1.15	0.81		
		30	30	2.06	1.98	1.36	1.10	0.83	1.99	1.92	1.52	1.08	0.82		
		30	10	2.55	2.44	1.83	1.22	0.90	2.90	2.75	2.00	1.29	0.94		
		0	20	2.20	2.14	1.76	1.30	1.02	2.13	2.07	1.72	1.28	1.03		
		0	10	2.63	2.54	2.03	1.44	1.10	2.72	2.62	2.08	1.47	1.12		
Vertical	Horiz.	-30	20	2.08	2.04	1.78	1.42	1.17	2.05	2.01	1.76	1.41	1.16		
		-30	10	2.62	2.56	2.17	1.66	1.33	2.53	2.47	2.10	1.62	1.30		
		90	10	2.47	2.34	1.67	1.06	0.77	3.50	3.24	2.08	1.22	0.84		
		30	30	2.57	2.46	1.84	1.23	0.90	2.91	2.77	2.01	1.30	0.94		
		30	10	2.66	2.54	1.88	1.24	0.91	3.70	3.46	2.35	1.43	1.01		
		0	20	2.82	2.72	2.14	1.50	1.13	3.14	3.02	2.32	1.58	1.10		
45° Slope	Down	0	10	2.93	2.82	2.20	1.33	1.15	3.77	3.59	2.64	1.73	1.26		
		-30	20	2.90	2.82	2.35	1.76	1.39	2.90	2.83	2.36	1.77	1.39		
		-30	10	3.20	3.10	2.54	1.87	1.46	3.72	3.60	2.87	2.04	1.56		
		90	10	2.48	2.34	1.67	1.06	0.77	3.53	3.27	2.10	1.22	0.84		
		30	30	2.64	2.52	1.87	1.24	0.91	3.43	3.23	2.24	1.39	0.99		
		30	10	2.67	2.55	1.89	1.25	0.92	3.81	3.57	2.40	1.45	1.02		
Horiz.	Down	0	20	2.91	2.80	2.19	1.32	1.15	3.75	3.57	2.63	1.72	1.26		
		0	10	2.94	2.83	2.21	1.33	1.15	4.12	3.91	2.81	1.80	1.30		
		-30	20	3.16	3.07	2.52	1.86	1.45	3.78	3.65	2.90	2.05	1.57		
		-30	10	3.26	3.16	2.58	1.89	1.47	4.35	4.18	3.22	2.21	1.66		
		90	10	2.48	2.34	1.67	1.06	0.77	3.53	3.27	2.10	1.22	0.84		
		30	30	2.66	2.54	1.88	1.24	0.91	3.77	3.52	2.38	1.44	1.02		

REF. 2C

Table 6 Equations for Forced Convection (Concluded)

Description	Reference			Equation
	Author	Page	Eq. No.	
IV. Simplified Equations for Air				
(a) Vertical plane surfaces, V of 16 to 100 fps (room temperature) ^b	McAdams	249	(9-42)	$h' = 0.5 (V)^{0.75}$ (18)
(b) Vertical plane surfaces, $V < 16$ fps (room temperature) ^b	McAdams	249	(9-42)	$h' = 0.99 + 0.21 V^{0.75}$ (19)
(c) Single cylinder cross flow (film temperature = 200°F) $1000 < GD/\mu_f < 50,000$	McAdams	261	(10-3c)	$h = 0.026 (G^{0.6}/D^{0.4})$ (20)
(d) Single sphere $17 < GD/\mu_f < 70,000$	McAdams	265	(10-6)	$h = 0.37 \frac{k_f}{D} \left(\frac{GD}{\mu_f} \right)^{0.6}$ (21)
V. Gases Flowing Normal to Pipes (Dimensionless)				
(a) Single Cylinder Re from 0.1 to 1000	McAdams	260	(10-3)	$\frac{hD}{k_f} = 0.32 + 0.43 \left(\frac{GD}{\mu} \right)^{0.52}$ (22)
Re from 1000 to 50,000	McAdams	260	(10-3)	$\frac{hD}{k_f} = 0.24 \left(\frac{GD}{\mu_f} \right)^{0.6}$ (23)
(b) Unbaffled Staggered Tubes, 10 rows, Approximate Equation for Turbulent Flow ^c	McAdams	272	(10-11a)	$\frac{hD}{k_f} = 0.33 \left(\frac{G_{max} D}{\mu_f} \right)^{0.6} \left(\frac{\mu_c}{k} \right)^{1/3}$ (24)
(c) Unbaffled In-Line Tubes, 10 Rows, Approximate Equation for Turbulent Flow ^c ($G_{max} D/\mu_f$) from 2000 to 32,000	McAdams	272	(10-11a)	$\frac{hD}{k_f} = 0.26 \left(\frac{G_{max} D}{\mu_f} \right)^{0.6} \left(\frac{\mu_c}{k} \right)^{1/3}$ (25)

^a McAdams (1954) recommends this equation for heating and cooling. Other authors recommend an exponent of 0.4 for heating and 0.3 for cooling.

^b h' is expressed in Btu/h·ft²·°F initial temperature difference.

^c G_{max} is based on minimum free area. Coefficients for tube banks depend greatly on geometrical details. These values approximate only.

The characteristic length, D_c , is the diameter of the tube outside or inside, or the length of the plane plate. For other shapes, the hydraulic diameter, D_h , is used, where:

$$D_c = 2r_h = 4 \frac{\text{Cross-sectional area for flow}}{\text{Total wetted perimeter}}$$

This reduces to twice the distance between surfaces for parallel plates or an annulus.

Simplified equations applicable to common fluids under normal operating conditions appear in Equations (8) through (25) of Table 6. Figure 11 gives graphical solutions for water.

Techniques to Augment Forced Convection

Turbulence promoters in smooth flow passages, such as coiled wires, twisted tapes, discs, baffles, configured surfaces, and packing, increase forced convection heat transfer coefficients for single- and two-phase flows. Pumping power is usually increased relative to that of smooth surfaces, the amount depending on the device.

Techniques applied to commercial heat exchange equipment to improve heat transfer to flow inside of tubes, usually at the expense of pumping power or external power applied to the system, include: (1) surface promoters, (2) displaced promoters, (3) vortex flows, (4) surface vibration, (5) fluid vibration, and (6) electrostatic fields. Methods requiring external power (items 4, 5, and 6) are difficult to apply to large-scale heat exchange equipment, and information on increased equipment cost and power requirements is

lacking. Of the methods requiring no external power (items 1, 2, and 3), displaced promoters are difficult to install inside tubes, and generally have large friction factors; surface promoters and vortex flow appear most suited for commercial use. Surface promoters range from selective finishing of the surface to increasing surface area by adding fins.

EXTENDED SURFACE

Heat transfer from a prime surface can be increased by attaching *fins* or *extended surfaces*, to increase the area available for heat transfer. Fins provide a more compact heat exchanger with lower material costs for a given performance. To achieve optimum design, fins are generally located on the side of the heat exchanger where the heat transfer coefficients are low (such as the air side of an air-to-water coil). Equipment with extended surface includes natural and forced convection coils and shell-and-tube evaporators and condensers. Fins are also used inside tubes in condensers and dry expansion evaporators.

Fin Efficiency

As heat flows from the root of a fin to its tip, temperature drops because of the thermal resistance of the fin material. The temperature difference between the fin and the surrounding fluid is therefore greater at the root than at the tip, causing a corresponding variation in the heat flux. Therefore, increases in fin length result in proportionately less additional heat transfer. To account

REF. 2e