ENGINEERING CHANGE NOTICE

S

1. ECN 657936

Proj. ECN

2. ECN Category (mark one) Supplemental ○ Direct Revision ◉ Change ECN ○ Temporary ○ Standby ○ Supersedure ○ Cancel/Void ○	3. Originator's Name, Organization, MSIN, and Telephone No. Dale M. Johnson, Site Wide SNF, R3-11 373-9614	4. USQ Required? ○ Yes ◉ No	5. Date 2/16/00
	6. Project Title/No./Work Order No. Spent Nuclear Project	7. Bldg./Sys./Fac. No. SSFC	8. Approval Designator E,SN,Q
	9. Document Numbers Changed by this ECN (includes sheet no. and rev.) HNF-3043, Rev 0	10. Related ECN No(s). N/A	11. Related PO No. N/A

12a. Modification Work	12b. Work Package No.	12c. Modification Work Completed	12d. Restored to Original Condition (Temp. or Standby ECNs only)
○ Yes (fill out Blk. 12b) ◉ No (NA Blks. 12b, 12c, 12d)	N/A	N/A Design Authority/Cog. Engineer Signature & Date	N/A Design Authority/Cog. Engineer Signature & Date

13a. Description of Change   13b. Design Baseline Document? ◉ Yes ○ No

USQ screening not required. AP NS-4-001 Catagorical Exclusion F applies.

1. Change of nomenclature for consistency of documentation: Shippingport PWR Core 2 Canister to Shippingport Spent Fuel Canister (SSFC)
2. Deleted NUREG-1567 DRAFT from Applicable Government Documents
3. Replaced HNF-PRO-516 with HNF-PRO-704 under Non-Government Documents and added HNF-259
4. Deleted duplicate reference
5. Added section for references to replace footnotes
5. Specifically called out helium as the cover gas.
6. Added the purity specification for helium.
7. Added the bounding amount of water in the canister to be removed by the vacuum drying system.
8. Expanded on the drying operations and removed specifics of dryness verification.
9. Added cover gas purity requirements
10. Changed design life from 25 drying and inereting cycles to 100 drying and inerting cycles by interpreting cycles to reflect more than one cycle per canister and to add contingency.
11. Deleted unnecessary sentence referencing storage system in section on Nuclear Criticality Safety.
12. Added QA requirements:10CFR72 Subpart G, 10CFR830, 10CFR820, QAPP-OCRWM-001, & QA-OCRWM-1
13. Added Attachment 1 with calculations for residual surface water.

14a. Justification (mark one)	14b. Justification Details
Criteria Change ◉ Design Improvement ○ Environmental ○ Facility Deactivation ○ As-Found ○ Facilitate Const. ○ Const. Error/Omission ○ Design Error/Omission ○	NUREG 1657 is for dry storage facilities and doesn't include canister requirements. HNF-PRO-516 was replaced by HNF-PRO-704 HNF-PRO-259 was added for quality levels Helium is basis of cover gas purity specification and leak test. Criteria detail was enhanced to reflect requirements identified in NUREG 1536.

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16. Design Verification Required	17. Cost Impact — ENGINEERING	17. Cost Impact — CONSTRUCTION	18. Schedule Impact (days)
○ Yes	Additional ○ $ N/A	Additional ○ $ N/A	Improvement ○ N/A
◉ No	Savings ○ $ N/A	Savings ○ $ N/A	Delay ○ N/A

19. Change Impact Review: Indicate the related documents (other than the engineering documents identified on Side 1) that will be affected by the change described in Block 13. Enter the affected document number in Block 20.

SDD/DD	☐	Seismic/Stress Analysis	☐	Tank Calibration Manual	☐
Functional Design Criteria	☐	Stress/Design Report	☐	Health Physics Procedure	☐
Operating Specification	☐	Interface Control Drawing	☐	Spares Multiple Unit Listing	☐
Criticality Specification	☐	Calibration Procedure	☐	Test Procedures/Specification	☐
Conceptual Design Report	☐	Installation Procedure	☐	Component Index	☐
Equipment Spec.	☐	Maintenance Procedure	☐	ASME Coded Item	☐
Const. Spec.	☐	Engineering Procedure	☐	Human Factor Consideration	☐
Procurement Spec.	☐	Operating Instruction	☐	Computer Software	☐
Vendor Information	☐	Operating Procedure	☐	Electric Circuit Schedule	☐
OM Manual	☐	Operational Safety Requirement	☐	ICRS Procedure	☐
FSAR/SAR	☐	IEFD Drawing	☐	Process Control Manual/Plan	☐
Safety Equipment List	☐	Cell Arrangement Drawing	☐	Process Flow Chart	☐
Radiation Work Permit	☐	Essential Material Specification	☐	Purchase Requisition	☐
Environmental Impact Statement	☐	Fac. Proc. Samp. Schedule	☐	Tickler File	☐
Environmental Report	☐	Inspection Plan	☐	N/A	☒
Environmental Permit	☐	Inventory Adjustment Request	☐		☐

20. Other Affected Documents: (NOTE: Documents listed below will not be revised by this ECN.) Signatures below indicate that the signing organization has been notified of other affected documents listed below.

Document Number/Revision	Document Number/Revision	Document Number/Revision

21. Approvals

	Signature	Date		Signature	Date
Design Authority	D.M. Johnson [signature]	2/28/00	Design Agent		
Cog. Eng.			PE		
Cog. Mgr.	R.L.McCormack [signature]	3/6/00	QA		
QA	D.W.Smith [signature]	2/28/00	Safety		
Safety	L.J.Garvin [signature]	2/28/00	Design		
Environ.	J.S.Turnbaugh per telecon [signature]	2/28/00	Environ.		
Other			Other		
Opn's: O.M. Serrano [signature]		000301			
T-Plant: W.S.Ayers per telecon [signature]		3/6/00			

DEPARTMENT OF ENERGY

Signature or a Control Number that tracks the Approval Signature: [signature] 3/13/00

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Total page 23

S

SPECIFICATION FOR
Fuel Drying and Canister Inerting System for Shippingport PWR Core 2 Blanket Fuel Assemblies Stored within Shippingport Spent Fuel Canisters

Building:

Project: Site Wide Spent Nuclear Fuel

MAR 14 2000
DATE
STA: 4
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Prepared By:

Fluor Hanford, Inc.

Approved By:

	Date
D.M.Johnson, D.A. [signature]	2/28/00
ECN 657936, page 2 for approvals	

INFORMATION CLEARANCE FORM

A. Information Category

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- [ ] Other Specification

B. Document Number HNF-3043

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Fuel Drying and Canister Inerting System for Shippingport Pressurized Water Reactor (PWR) Core 2 Blanket Fuel Assemblies Stored Within Shippingport Spent Fuel Canisters

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A-6001-401 (02/98)

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HNF-3043
Revision 1

Performance Specification Fuel Drying and Canister Inerting System for Shippingport Pressurized Water Reactor (PWR) Core 2 Blanket Fuel Assemblies Stored Within Shippingport Spent Fuel Canisters

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

Fluor Hanford
P.O. Box 1000
Richland, Washington

HNF-3043
Revision 1

Performance Specification Fuel Drying and Canister Inerting System for Shippingport Pressurized Water Reactor (PWR) Core 2 Blanket Fuel Assemblies Stored Within Shippingport Spent Fuel Canisters

D. M. Johnson
Fluor Hanford

Date Published
February 2000

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

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Performance Specification

Fuel Drying and Canister Inerting System for Shippingport Pressurized Water Reactor (PWR) Core 2 Blanket Fuel Assemblies Stored Within Shippingport Spent Fuel Canisters

Date Published
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Prepared for the
U.S. Department of Energy
Office of Environmental Restoration and Waste Management

Prepared by

Fluor Hanford, Inc.
P.O. Box 1000
Richland, WA 99352

Table of Contents

1.0 SCOPE

This specification establishes the performance requirements and basic design requirements imposed on the fuel drying and canister inerting system for Shippingport Pressurized Water Reactor (PWR) Core 2 blanket fuel assemblies (BFAs) stored within Shippingport spent fuel (SSFCs) canisters (fuel drying and canister inerting system). This fuel drying and canister inerting system is a component of the U.S. Department of Energy, Richland Operations Office (RL) Spent Nuclear Fuels Project at the Hanford Site. The fuel drying and canister inerting system provides for removing water and establishing an inert environment for Shippingport PWR Core 2 BFAs stored within SSFCs.

A policy established by the U.S. Department of Energy (DOE) states that new SNF facilities (this is interpreted to include structures, systems and components) shall achieve nuclear safety equivalence to comparable U.S. Nuclear Regulatory Commission (NRC)-licensed facilities. This will be accomplished in part by applying appropriate NRC requirements for comparable NRC-licensed facilities to the fuel drying and canister inerting system, in addition to applicable DOE regulations and orders.

2.0 APPLICABLE DOCUMENTS

The following documents, of the exact issue shown, form a part of this specification. Conflict between documents referenced herein and the requirements of this specification shall be identified for resolution or clarification.

2.1 GOVERNMENT DOCUMENTS

Code of Federal Regulations (CFR):

Title 10 CFR 72 Subpart G	Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste
Title 10 CFR 820	Procedural Rules for DOE Nuclear Activities
Title 10 CFR 835	Occupational Radiation Protection
Title 10 CFR 830.120	Nuclear Safety Management, Quality Assurance

U. S. Nuclear Regulatory Commission (NRC):

Regulatory Guide 3.53 (7/82)	Applicability of Existing Regulatory Guides to the Design and Operation of an Independent Spent Fuel Storage Installation
Regulatory Guide 8.8, Rev. 3 (6/78)	Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations Will Be As Low As Is Reasonable Achievable
NUREG-1536 (1/97)	Standard Review Plan for Dry Cask Storage Systems

U.S. Department of Energy (DOE):

DOE Order 6430.1A (4/89)	General Design Criteria
DOE/RW-0333P	Office of Civilian Radioactive Waste Management Quality Assurance Requirements Document (OCRWM QARD)

2.2 NON-GOVERNMENT DOCUMENTS

Fluor Hanford, Inc. (FH):

HNF-MP-599	Project Hanford Quality Assurance Program Description, Codes and Standards
HNF-PRO-259	Graded Quality Assurance
HNF-PRO-704	Hazard and Accident Analysis Process
HNF-SD-SNF-RPT-007	Application of the Office of Civilian Radioactive Waste Management QA Requirements to the Hanford Spent Nuclear Project
QAPP-OCRWM-001	Quality Assurance Program Plan for Implementation of the OCRWM QARD for the Spent Nuclear Fuel Project
QA-OCRWM-1	OCRWM QARD Requirements Matrix

Drawings: N/A

Other:

ANSI/ANS 57.9-1992 (1992)	Design Criteria for an Independent Spent Fuel Storage Installation (Dry Type)
NEPA 70	The National Electric Code
PNL-6365	Evaluation of Cover Gas Impurities and Their Effects on the Dry Storage of LWR Spent Fuel

3.0 DEFINITION

The section defines the purpose of the fuel drying and canister inerting system and the relationship of the fuel drying and canister inerting system to other structures, systems, and components associated with storage of the Shippingport PWR Core 2 BFAs within SSFCs.

3.1 ITEM DEFINITION

Currently 72 Shippingport PWR Core 2 BFAs are stored in a water-filled pool within the 221-T (T Plant) canyon facility. These assemblies are to be removed from the water-filled pool and placed within SSFCs for dry storage within the Canister Storage building.

The fuel drying and canister inerting system provides for removing water and establishing an inert environment (helium) for Shippingport PWR Core 2 BFAs stored within SSFCs. Water must be removed and an inert environment established within the canisters prior to transferring the canisters to dry storage.

This performance specification is expressly for the fuel drying and canister inerting system. This specification does not provide requirements for any other structures, systems or components, such as the SSFCs.

3.2 INTERFACES

The fuel drying and canister inerting system will have to interface with the SSFC and the T-Plant facility. Connections of the fuel drying and canister inerting system will have to be compatible with connection points on the SSFC. The fuel drying and canister inerting system will have to be compatible with the capabilities of the T Plant canyon facility (e.g., electrical requirements, helium supply requirements, hoisting requirements, etc).

4.0 REQUIREMENTS

4.1 FUNCTIONAL REQUIREMENTS

The SSFC must provide a non-reactive environment to protect fuel assemblies against fuel cladding degradation, which might otherwise lead to gross rupture [Knoll, *et al.*, 1987]. Measures for providing a non-reactive environment within the confinement canister include drying, evacuating air and water vapor, and backfilling with a non-reactive cover gas (such as helium). For dry storage condition, experimental data have not demonstrated an acceptably low oxidation rate for $U0_2$ spent fuel, over the 20-year licensing period, to permit safe storage in an air atmosphere. Therefore, to reduce the potential for fuel oxidation and subsequent cladding failure, an inert atmosphere (e.g., helium cover gas) has been used for storing $U0_2$ spent fuel in a dry environment.

4.1.1 Fuel Drying

The system shall provide fuel drying consistent with NRC-accepted methods. The NRC staff has accepted vacuum drying methods comparable to those employed in cask performance testing for cover gas compositions reported in [Knoll, *et al.*, 1987] for commercial light-water reactor (LWR) fuel. The report evaluates the effects of oxidizing impurities on the dry storage of LWR fuel and recommends a limiting maximum quantity of oxidizing gases (O_2, CO_2, and CO) of 0.25% vol. This limit reduces the amount of oxidants below levels where any cladding degradation is expected.

Moisture removal is inherent in the vacuum drying process, and levels at or below about 7 grams H_2O are expected if adequate vacuum drying is performed (NUREG 1536).

The fuel drying system shall be capable of evacuating the SSFC cavity to less than 0.4 kPa (3 mm Hg or Torr). After initial evacuation and backfilling with helium, the canister shall be evacuated a second time (minimum). Before final backfill a pressure hold test with equivalency to the test described in NUREG-1536 shall be performed to verify adequate moisture removal consistent with NRC requirements.

The system shall reflect the potential for blockage of the evacuation system as a result of icing during evacuation. Icing can occur from the cooling effects of water vaporization and system depressurization during evacuation. Icing is more likely to occur in the evacuation system lines than in the canister because of decay heat from the fuel. A staged draw down or other means of preventing ice blockage of the canister evacuation path may be used.

4.1.2 Canister Inerting

The system shall provide canister inerting consistent with NRC-accepted methods. Upon completion of fuel drying and canister evacuation, the system shall be capable of backfilling the canister with helium. The system shall be designed to preserve the purity of the helium. The system shall allow re-evacuation and re-backfilling with helium and shall be designed to allow sampling to verify helium purity after backfilling, before final closure. The system shall be compatible with a helium quality specification that ensures a known maximum of impurities, which will minimize the source of contaminants. Purity specification of 99.9% for He cover gas for light water reactor, commercial PWR fuel has been accepted by NRC to meet requirements of 10 CFR 72.122 (h), for protection of fuel cladding against failure. Standard vendor supplied helium (>99.95% He) and the drying procedure described in 4.1.1 meet this requirement. Only a fraction of the 0.05% helium impurities represents the reactive gas concentration.

The system shall provide the capability for repetition of the evacuation and repressurization cycles. This capability is necessary if the canister interior is opened to an oxidizing atmosphere following the evacuation and repressurization cycles (as may occur in conjunction with seal repairs, etc.).

The system shall be capable of verifying that upon completion of canister loading, drying and inerting, the gas fill of the canister interior is at a pressure level that is expected to maintain a non-reactive environment for at least the 40-year storage life of the canister interior under both normal and off-normal conditions and events. The NRC has previously accepted specification of an overpressure of approximately 14 kiloPascals (~2 psig) and cask leak testing as conditions of use for satisfying this requirement.

4.2 DESIGN LIFE

The fuel drying and canister inerting system shall be designed to provide a minimum of 100 fuel drying and canister inerting cycles without component failure, or availability of parts that can be quickly replaced shall be assured.

4.3 DESIGN BASIS CAPACITY

The fuel drying and canister inerting system shall be designed to service a single SSFC at a time. The design basis for quantity of water to be removed from each canister[1] by drying shall be:

> 1075 cc free standing water contained in the upper fuel assembly extensions and the lower extensions spring casings (assumes the ability to remove standing water from the open top of each assembly extension down to a water depth of approximately 1 cm., before loading into the canister).

[1] Attachment 1

990 cc in surface film in the fuel assembly flow channels after 60 minutes of draining and evaporation.

300 cc collected at the bottoms of the fuel assembly flow channels

130 cc in surface film on the outside surfaces of the assemblies after 60 minutes of draining and evaporation.

4.4 PHYSICAL CHARACTERISTICS

The system shall be designed to be located in available space within the T-Plant Canyon railroad cut allowing for access and location of the Cask Transporter trailer for positioning the cask for loading.

4.5 MAINTAINABILITY

The fuel drying and canister inerting system shall be designed to minimize the need for preventative maintenance throughout its design life.

4.6 HUMAN FACTORS

The fuel drying and canister inerting system shall be designed to facilitate handling of connections and for ease of operations.

4.7 ENVIRONMENTAL CONDITIONS

The fuel drying and canister inerting system shall be designed to operate under the prevailing environmental conditions of the T Plant canyon railroad cut.

4.8 SAFETY REQUIREMENTS

4.8.1 Safety Classification and Quality Level

As part of the safety analysis process specific structures, systems and components of the fuel drying and canister inerting system shall be classified in accordance with the requirements of HNF-PRO-704, *Safety Structures, Systems and Components*. Quality levels will be determined using HNF-PRO-259. This classification has yet to be completed.

4.8.2 Nuclear Criticality Safety

No requirements are placed on the fuel drying and canister inerting system to maintain subcriticality of the Shippingport PWR Core 2 SNF in any storage configuration.

4.9 DOSE MANAGEMENT

The fuel drying and canister inerting system shall be designed to minimize dose to workers to levels as low as reasonable achievable. Air emissions from the fuel drying and canister inerting systems shall be controlled to reduce emissions.

4.10 DECONTAMINATION PROVISIONS

The fuel drying and canister inerting system shall facilitate its decontamination. Blind or hidden surfaces in areas potentially exposed to contamination that cannot be readily accessed by hand held spray devices shall be minimized.

4.11 ELECTRICAL/INSTRUMENTATION

Electrical components including installation shall comply with NFPA 70 and any additional requirements established in DOE 6430.1A.

Electrical connections shall be compatible with and interface with available electrical power supply within the T Plant canyon.

5.0 QUALITY ASSURANCE

5.1 GENERAL REQUIREMENTS

All contractors involved in the development and design activities defined by this specification shall formulate and execute quality assurance programs that provide the following assurances:

- Performance requirements and design criteria are established, documented, and clearly understood.
- Studies, analyses, and design decisions are fully documented.
- Design meets performance requirements and design criteria, is complete and adequate, and is properly documented in the construction specification, drawings, and plans.
- Traceability to the requirements of this specification is maintained.

5.2 QUALITY ASSURANCE REQUIREMENTS

Quality assurance activities shall be in accordance with 10 CFR 830.120, *Nuclear Safety Management, Quality Assurance* and the applicable portions of:

- 10 CFR 72 Subpart G, *Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste* and

- DOE/RW-0333P, *Office of Civilian Radioactive Waste Management Quality Assurance Requirements Document* (OCRWM QARD).

PHMC organizations must have a QAPP (approved by FH QA) that implements HNF-MP-599 for 10 CFR 830.120 compliance. To meet the requirements of 10 CFR 72 Subpart G and DOE/RW-0333P the PHMC organizations must comply with QAPP-OCRWM-001 and QA-OCRWM –1 or have an OCRWM QAPP and Matrix which have been approved by SNF Management and FH QA.

External contractors are subject to 10 CFR 830.120 requirements and enforcement under 10 CFR 820. External contractors are required have a QA program that implements the applicable portions of NQA-1-1994 Basics and Supplements and DOE/RW-0333P. Implementation of these requirements will fulfill the requirements of 10 CFR 72 Subpart G. The buyer reserves the right to access and inspect work performed by the contractor and his subcontractors, as well as to direct additional inspections.

6.0 REFERENCES

Knoll, R.W. *et al.*, 1987, "Evaluation of Cover Gas Impurities and Their Effects on the Dry Storage of LWR Spent Fuel," PNL-6365, Pacific Northwest Laboratory, Richland, Washington.

ATTACHMENT I

RESIDUAL WATER IN SHIPPINGPORT FUEL ASSEMBLIES

Residual Water in Shippingport Fuel Assemblies

M. G. Piepho
Fluor Federal Services, Inc.
Richland, Washington

1.0 Introduction

The purpose of this attachment is to estimate the total undrained residual water volume per four Shippingport fuel assemblies which will be stored in one SSFC. There are five major sources of residual water in the Shippingport fuel assemblies after they are pulled out of the T-plant pool. These five sources are the following:

1) Residual water clinging to fuel plate surfaces

2) Residual water clinging to other (non-fuel) surfaces

3) Residual water between the fuel plates

4) Standing water below large metal spring in lower extension bracket

5) Standing water in upper extension bracket bottom.

1.1 Residual Water Clinging to Fuel Plate Surfaces

1.1.1 Water Film Thickness

Since the fuel plates in the Shippingport fuel assemblies are stored in water, some water will cling to the fuel plate surface areas. To determine how much water remains on the fuel plate surface, a draining model was employed. The draining model is described in the HANSF code manual (HNF-3650) and determines the rate of water movement given a film thickness. The model is good for the water film greater than some minimum film thickness which is determined by the surface roughness of material. Hence, the problem is to determine the rate of draining as a function of film thickness and estimate the residual film thickness that doesn't have enough to drain, and also to determine how much water is contained in the minimum film thickness that won't drain.

The mass flow rate from the drain model is expressed by the following equation:

$$M_R = Y \;_{w}\; g F^3 / (3\ n) \qquad (1)$$

where

M_R = mass flow rate for one fuel plate (kg/s)
Y = wetted horizontal distance of one fuel plate, one side (0.083 m)

$_w$ = mass density of water (1000 kg/m^3)
g = gravitation acceleration constant (9.8 m/s^2)
F = film thickness above some minimum film (m)
n = viscosity of water at 30 °C (8.0E-7 m^2/s).

Equation 1 can be simplified by substituting the values above to obtain the following equation:

$$M_R = 3.39 \times 10^{+8} F^3 \qquad (2)$$

Equation 2 is now used to determine the percentage of water that drains per second from a fuel plate surface as a function of film thickness, F:

$$P = 100\, M_R/(F\ Y\ X\ _w) \qquad (3)$$

where

P = percentage of water drained per second from one side of fuel plate (%/s)
X = height of fuel plate (2.482 m),

and substituting all known values into Equation 3 yields the following equation:

$$P = 1.65 \times 10^{+8} F^2 \qquad (4)$$

Different film thicknesses were substituted into Equation 4 to determine a percentage drain in the range of 20 to 100% on an hourly basis. Each fuel assembly will be removed from the pool and hang over the pool for draining purposes for at least an hour. Using Equation 4 for a 10-micron film thickness ($F=10^{-5}$ m), gives the percentage of water drained per second as 0.0165%/s or 59.4%/hr. Hence, a 10-micron film of water on the fuel plate is expected to drain at a reasonable rate and will be much smaller after an hour. The film thickness is expected to average no more than 7.5 microns (33.3%/hr) after one hour, which is 25% less than the 10-micron film. Actually, the film thickness will be at least 33.3% smaller than the 10 micron thickness after one hour, but some time will be needed to get down to 10 microns, so only a 25% smaller film thickness (7.5 microns) was selected.

There is also a water film that is retarded by the surface roughness of the metal and deposits on the metal. Based on the photogrammetry measurements of roughness and surface deposits (WAPD-335), a median roughness for the end of fuel plate, which has the thickest deposit of 12.5 microns (0.5 mils), is about 2.5 microns (100 micro-inch). Since the deposit over most of the plate is much smaller (0.03 mils) than the thickest deposit on the fuel plate end, the 2.5 microns for the roughness of the entire plate is considered conservative.

In summary, the water film thickness on the fuel plates is comprised of two parts; 1) drainable liquid and 2) stagnant film based on roughness. After one hour, the drainable flowing film should be no thicker than 7.5 microns, and the minimum stagnant film is bounded by 2.5 microns. Hence, the total film thickness after one hour of draining is bounded by 10 microns.

1.1.2 Surface Areas

The fuel plates are 0.0828 m (3.26 in) wide and 2.482 m (97.7 in) high for surface area of 0.2055 m^2 per surface. Since there are two sides per fuel plate, the total surface area for each fuel plate is 0.411 m^2. There are 60 fuel plates per fuel assembly, so the total fuel plate surface area for each fuel assembly is 24.66 m^2. Since there will be 4 fuel assemblies in each SSFC, the total fuel plate surface area in the SSFC is 98.64 m^2.

1.1.3 Total Residual Water

The total residual water clinging to the fuel plates in the four fuel assemblies in an SSFC is just the surface area times the water film thickness (98.64 m^2 x 10^{-5} m), which gives a total volume of water of 0.000986 m^3 or 0.986 liters (0.986 kg).

1.2 Residual Water Clinging to Other (Non-Fuel) Surfaces

In addition to the fuel plates, there is the surface area of the fuel assembly which consists of 3 vertical segments (mid fuel section bundle, upper and lower extension brackets).

The divider plate and each interior wall has a surface area of 0.443 m^2 (2.49 m x 0.178 m) and for 6 surfaces (4 walls and 2 sides of interior divider plate), the total area is 2.66 m^2 per fuel assembly. For the 4 fuel assemblies in each SSFC, the total interior non-fuel surface area for the fuel section bundle is about 10.6 m^2 per SSFC. The outer surface of assembly wall is not included since this water film is expected to evaporate in less than an hour while the interior of assembly is draining. The outer surface will evaporate since the fuel assembly will be at a temperature of 30 °C (86 °C) with a decay heat rate of at least 90 W, and the air temperature is cooler.

The upper extension bracket has an exterior surface area of about 0.3 m^2, so the interior surface is conservatively estimated to be the same. The lower extension bracket has an exterior surface area of about 0.24 m^2, so the interior surface area is estimated to be the same which will include the surface area of large spring. Hence, the interior surface area of the upper and lower extension brackets is 0.54 m^2 per fuel assembly, which is 2.16 m^2 per SSFC.

The total interior surface area of the non-fuel parts of 4 assemblies is 12.76 m^2 (10.6 + 2.16). With a film thickness of 10 microns, the total water volume clinging to the non-fuel surfaces of 4 fuel assemblies per SSFC is 0.128 liters (12.76 m^2 x 10^{-5} m x 1000 L/m^3).

1.3 Residual Water Between Fuel Plates

There could be some water retention in the small gap between the fuel plates because of the surface tension of water. Using pore theory (GROUNDWATER), the bounding estimate of a water column height in a fracture is given by the following equation:

$$H_p = 2\ T_w /(\ _w\ g\ D) \qquad (5)$$

where

H_p = water height (cm) in fracture
T_w = surface tension of water (72 dynes/cm)
$_w$ = density of water (1.0 g/cm^3)
g = gravitational acceleration constant (980 cm/s^2)
D = fracture aperture or gap (cm).

Using Equation 5 for a gap size of 0.23 cm (0.09 in), the water height is calculated to be about 0.6 cm (0.25 in) under hydrostatic conditions. There are about 30 gaps per fuel assembly or 120 for 4 fuel assemblies per SSFC, with each gap about 17.8 cm long, 0.23 cm wide and 0.6 cm high for a total gap volume of 300 cm^3 or 0.3 liters for all 120 gaps in 4 fuel assemblies. Since this number is based on hydrostatics, a dynamic draining process will probably result in no water in the gaps, but to be conservative, 0.3 liter is estimated as the bounding water volume in the gaps.

1.4 Standing Water Below Large Metal Spring in Lower Extension Bracket

The volume underneath the bottom of large spring is estimated by multiplying its height, which is less than the diameter (1.9 cm) of the large spring since a drain slot is located below the top part of the bottom spring wrap. The bottom area is the area between two concentric cylinders with the larger cylinder having a diameter of 17.8 cm and the inner cylinder having a diameter of 10.8 cm. Hence, the surface of channel bottom is 157.25 cm^2 (pi (8.9^2 - 5.4^2)), which yields a volume below 300 cm^3 or 0.3 liter, after multiplying by its estimated height of 1.9 cm, for each fuel assembly. However, this volume includes the volume of the large spring which has an approximate length of one wrap of 40 cm and a diameter of 1.9 cm. The volume of one wrap of spring is about 113 cm^3 (40 cm x pi x 0.95^2 cm^2) which must be subtracted from the channel volume of 300 cm^2 to obtain the water volume of 187 cm^2. Since there are 4 assemblies in each SSFC, the total water per SSFC is about 750 cm^3 or 0.75 liter.

1.5 Standing Water in Upper Extension Bracket Bottom

There is a cup-like channel in the upper extension bracket that will not drain by itself when the fuel assembly is removed from the pool.. With a syphoning device or some other water removing apparatus, the water height is expected to be reduced down to at least 1 cm. The circular channel has an outer radius of 6.35 cm and the inner cylinder has a radius of 3.8 cm for a surface area of 81.3 cm^2 (pi (6.35^2 - 3.8^2)) and a volume of 81.3 cm^3 for each fuel assembly. Thus, the total volume of water in upper extension bracket channels is about 325 cm^3 or 0.325 liter for four assemblies per SSFC.

2.0 Total Water Remaining in Four Shippingport Fuel Assemblies Per SSFC

The total volume of water left in four fuel assemblies after draining for at one hour is the sum of the five parts described above. This total water volume per SSFC is about 2.50 liters which is the sum of the following water quantities:

1) 0.986 liter, fuel plate surfaces,
2) 0.128 liter, non-fuel surfaces,
3) 0.300 liter, gaps between fuel plates,
4) 0.750 liter, channel below large spring in lower extension bracket,
5) 0.325 liter, channels on bottom of upper extension bracket.

Total 2.50 liters

3.0 References

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