NAC INTERNATIONAL

RESPONSES TO THE

UNITED STATES
NUCLEAR REGULATORY COMMISSION

REQUEST FOR ADDITIONAL INFORMATION

(RAI-1 December 21, 1999)

NAC UNIVERSAL STORAGE SYSTEM (NAC-UMS) MAINE YANKEE AMENDMENT

(TAC. NO. L22979, DOCKET NO. 72-1015)

FEBRUARY 2000

NAC
INTERNATIONAL

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February 4, 2000

U.S. Nuclear Regulatory Commission
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Attn: Document Control Desk

Subject: Docket No. 72-1015

Submittal of Responses to the Request for Additional Information (RAI-1) for the UMS® Universal Storage System Amendment for Maine Yankee Atomic Power Company Site Specific Spent Fuel (TAC No. L22979)

References:

1. Submittal of Changed Pages Incorporating Maine Yankee Site Specific Fuel into the UMS® Universal Storage System Safety Analysis Report, Revision UMSS-99MY, NAC International, July 16, 1999
2. Submittal of UMS® Universal Storage System Safety Analysis Report, Revision 1, NAC International, October 1, 1999
3. Submittal of UMS® Universal Storage System Safety Analysis Report, Revision UMSS-99D (Maine Yankee Amendment incorporated in Revision 1), NAC International, October 20, 1999
4. Submittal of Revision UMSS-99E Changed Pages for the UMS® Universal MPC System Safety Analysis Report (with the Maine Yankee Amendment incorporated) for the UMS® Universal Storage System, NAC International, November 16, 1999
5. Request for Additional Information for the UMS® Universal Storage System, U.S. Nuclear Regulatory Commission, December 21, 1999

NAC International (NAC) herewith submits the responses to the Reference 4, U.S. Nuclear Regulatory Commission (NRC) Request for Additional Information (RAI) for the UMS® Universal Storage System Amendment for Maine Yankee Atomic Power Company Site Specific Spent Fuel. The RAI was issued by the NRC based on a review of the NAC Application for an Amendment (Reference 1) to the UMS® Universal Storage System Certificate of Compliance. That initial application was supplemented by the Reference 3 submittal.

NAC has prepared this submittal to be fully responsive to the Request for Additional Information and in complete accord with all NRC/NAC discussions that have been held since the RAI was issued. These responses have been reviewed by representatives of Stone & Webster Engineering Corporation and Maine Yankee Atomic Power Company. Their comments and suggestions have been incorporated, as appropriate.

Also, included in this submittal are copies of the SAR changed pages, including two revised drawings, which incorporate all of the responses to the RAI. In addition, the SAR changed pages include two other changes in Chapter 12: (1) the Definitions in Section B1.0 are deleted because they

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duplicate those in Section A1.1 and Section B1.0 is [Reserved]; and (2) the OR REQUIRED ACTION, B2.2, in LCO 3.1.6 and BASES 3.1.6 is removed because it is unnecessary, since the thermal analysis documents the performance of the UMS® Storage System upon completion of ACTION B.2.1, the CONCRETE CASK Heat Removal System is restored to OPERABLE status. The SAR changed pages are to be inserted into the current revision, UMSS-99E, of the NAC-UMS® Safety Analysis Report Amendment for Maine Yankee Atomic Power Company Site Specific Spent Fuel. Please note that for the convenience of double-sided copying, some "front or back" pages that have not changed from the previous revision are included in this submittal.

The revised pages have been prepared in accordance with the following conventions:

- Revision indicators (shading and revision bars) are used to highlight changes. Shading indicates a revision from the Reference 2 submittal; a revision bar indicates a change in the SAR text flow from the Reference 2 submittal or a change from a previous Maine Yankee Amendment revision of the Reference 2 submittal (i.e., all Maine Yankee Amendment revisions are indicated).
- The changed pages for this submittal are designated as Revision UMSS-00A to provide a unique identification of the changed pages.

This submittal includes Proprietary Information as a part of the responses to some of the RAIs. The copies of the volume containing the Proprietary Information Attachments are provided in appropriately marked separate packaging. The executed Proprietary Information Affidavit is enclosed.

The Proprietary Information Attachments included in this submittal are:

1. Evaluation of Burnup Extension in Maine Yankee Fuel
2. Evaluation of Maine Yankee Fuel Rod Oxide Thickness and Wear Measurements
3. Summary Report on Maine Yankee High Burnup Fuel (burnup between 45,000 and 50,000 MWD/MTU)
4. VCC Tip-Over Analysis for Maine Yankee (NAC Calculation 12412-2001)

As was discussed during our meeting of January 18, 2000, NAC has included the definition of intact fuel, which was proposed by NEI to the NRC in their draft fuel classification protocol. We acknowledge, based upon the dialog during the meeting, that additional detail will be required regarding the user determinations necessary to support fuel classification (i.e., the "engineering evaluation" methodology). In accordance with that understanding, NAC, Stone & Webster Engineering Corporation, and Maine Yankee are working cooperatively to develop supplemental information on both fuel inspection results and the fuel classification Engineering Evaluation methodology discussed during the meeting.

Currently, implementation of the UMS® Storage System is a critical path item for successful completion of the decommissioning of the Maine Yankee site. Therefore, NAC requests that the NRC continue the technical review on a priority basis for the approval of the Maine Yankee Amendment of the UMS® Storage System.

If you have any comments or questions, please contact me at (770) 447-1144.

Sincerely,

T. C. Thompson

Thomas C. Thompson
Director, Licensing and Competitive Assessment
Engineering & Design Services

Enclosures

Attachments

cc:	P. Bemis	(SWEC)
	E. Washer	(SWEC)
	M. Meisner	(MY)
	G. Zinke	(MY)
	D. Jones	(NUTUG)

AFFIDAVIT

IN SUPPORT OF PROPRIETARY INFORMATION CONTAINED IN THE ATTACHMENT TO THE RESPONSES TO A REQUEST FOR ADDITIONAL INFORMATION FOR THE UMS® UNIVERSAL STORAGE SYSTEM AMENDMENT FOR MAINE YANKEE ATOMIC POWER COMPANY SITE SPECIFIC SPENT FUEL

State of Georgia, County of Gwinnett

Willington J. Lee (Affiant), Vice President and Chief Engineer of NAC International, hereinafter referred to as NAC, at 655 Engineering Drive, Norcross, Georgia 30092, being duly sworn, deposes and says that:

1. Affiant is personally familiar with the trade secrets and privileged information contained in the Attachment being submitted in conjunction with the Responses to the Request for Additional Information for the UMS® Universal Storage System, Amendment for Maine Yankee Atomic Power Company Site Specific Spent Fuel. Affiant requests that the Nuclear Regulatory Commission, pursuant to Chapter 10 of the Code of Federal Regulations, Part 2.790 (10 CFR 2.790) "Public Inspections, Exemptions, Request for Withholding," withhold the information contained within the supplemental information, hereafter referred to as the Proprietary Information, from public disclosure.

2. This information has been and is held in confidence by NAC.

3. The information contained within the proprietary material is the result of design calculations and components design details and critical dimensions that were developed by NAC or by nuclear fuel vendors. This type of information is held in confidence based on the significant commercial investment of time and money expended in its development.

4. The Proprietary material is transmitted to the Nuclear Regulatory Commission in confidence.

5. The information that is being claimed as trade secrets and privileged information has not been and is not available in public sources.

AFFIDAVIT
(continued)

6. NAC and the nuclear fuel vendors have invested a considerable amount of time, engineering labor, and money in the development of the information. Public disclosure of this information would cause substantial harm to the competitive position of NAC or the nuclear fuel vendors. Others seeking to develop similar calculations and fuel design details would have to make similar investments to develop the information on their own, as long as the information is not disclosed to the public.

Willington J. Lee

Willington J. Lee
Vice President and Chief Engineer
NAC International

Subscribed and sworn to before me this 4th day of February 2000.

Donna G Fowler

Notary Public in and for the
County of Forsyth
State of Georgia

My commission expires the 16th day of April, 2003

Notary Public, Forsyth County, Georgia
My Commission Expires April 16, 2003

NAC INTERNATIONAL

RESPONSE TO THE

UNITED STATES NUCLEAR REGULATORY COMMISSION

REQUEST FOR ADDITIONAL INFORMATION

(RAI December 21, 1999)

NAC-UMS® UNIVERSAL STORAGE SYSTEM

(TAC NO. L22979, DOCKET NO. 72-1015

NAC INTERNATIONAL RESPONSE
TO
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NAC INTERNATIONAL RESPONSE
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CHAPTER 1: GENERAL INFORMATION

Section 1.0 Terminology

1-1 Modify definitions No. 5 and 6 of "intact fuel assembly" to indicate that these types of fuel assemblies will be placed inside a Maine Yankee fuel can since they contain damaged fuel.

Interim Staff Guidance (ISG) No. 1 defines damaged fuel and specifies that it should be canned. It is unclear whether intact fuel assemblies containing damaged fuel will be placed directly in the transportable storage canister (TSC), without being placed in a Maine Yankee fuel can.

<u>NAC Response</u>

Consistent with the discussions during our January 18, 2000, meeting, the definition of "Intact Fuel" is revised to incorporate the current draft industry protocol for fuel classifications.

The revised definitions incorporate the use of an Engineering Evaluation, when necessary, to establish the fuel classification.

See the response to RAI 12-1.

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CHAPTER 1: GENERAL INFORMATION

Section 1.0 Terminology

1-2 Add definitions for intact fuel rod and damaged fuel.

It is unclear whether the application complies with the definition of damaged fuel as described in ISG-1, "Damaged Fuel."

NAC Response

The definition of "Intact Fuel" is revised to include intact fuel rods. Consistent with the discussions during our January 18, 2000, meeting, the revised definitions of "Intact Fuel" and "Damaged Fuel" incorporate the current draft industry protocol for fuel classifications.

The revised definitions incorporate the use of an Engineering Evaluation, when necessary, to establish the fuel classification.

See the Response to RAI 1-1.

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CHAPTER 1: GENERAL INFORMATION

Section 1.0 Terminology

1-3 Redefine fuel debris to include it as a classification of damaged fuel.

The definition of Fuel Debris includes an individual fuel rod which may not have cladding defects. Otherwise, the Fuel Debris definition falls into the category of damaged fuel. All Fuel Debris should be classified as Damaged Fuel, and Damaged Fuel should be canned in accordance with ISG-1.

NAC Response

The definition of "Damaged Fuel" is revised to include fuel debris as a classification of damaged fuel. As shown in Table 1-1, "Damaged Fuel" is placed in a Maine Yankee Fuel Can.

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CHAPTER 1: GENERAL INFORMATION

Section 1.0 Terminology

1-4 Modify the definition of consolidated fuel to specify whether this type of fuel will contain damaged fuel.

It is unclear whether Consolidated Fuel contains damaged fuel rods, and it should be characterized with respect to ISG-1 and the necessity for canning.

<u>NAC Response</u>

The description of consolidated fuel in Table 1-1 is revised to show that the consolidated fuel configuration includes only intact fuel rods. However, consolidated fuel is placed in a Maine Yankee Fuel Can prior to loading it into the Transportable Storage Canister. This ensures that, in the unlikely event of a design basis accident, gross particulate material that could theoretically escape from the individual rods, is precluded from release into the canister cavity.

See also the response to RAI 1-7.

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CHAPTER 1: GENERAL INFORMATION

Section 1.0 Terminology

1-5 Modify the definition of Maine Yankee Fuel Can so it does not imply that the Maine Yankee Fuel Can functions as a confinement boundary.

Section 72.11 requires that the SAR contain complete and accurate information. The words "to provide confinement" imply the fuel can may be intended to serve as a confinement boundary. It is unclear whether this is the purpose of the fuel can.

NAC Response

The description of the Maine Yankee Fuel Can provided in Table 1-1 is revised to show that the can is intended to prevent the release of gross particulate material that could theoretically escape from fuel rods placed in the can. Since the can ends are screened, the can does not provide a confinement boundary.

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CHAPTER 1: GENERAL INFORMATION

Section 1.0 Terminology

1-6 The meaning of the definitions for "skeleton damage" and "handled by normal means" is not clear and is not consistent with the guidance in ISG-1.

Section 72.11 requires that the SAR contain complete and accurate information. Without clear critieria for establishing "skeleton damage" and "handled by normal means," the inclusion of such criteria in the definition of damaged fuel assembly is arbitrary. It is also unclear how fuel assemblies with skeleton damage can be handled by normal means.

<u>NAC Response</u>

Reference to "skeleton damage" is deleted from the definitions provided in Table 1-1, but was originally intended to refer to minor defects in the fuel assembly lattice, such as a torn grid strap or bent upper end fitting hardware, that did not materially compromise the structural integrity of the fuel assembly.

As shown in the Table 1-1 definition for "Damaged Fuel," fuel that cannot be "...grappled, handled, and moved in a normal manner ..." is classified as damaged and is placed in a Maine Yankee fuel can. Fuel that cannot be handled in a normal manner is intended to include fuel having significant defects in the fuel assembly lattice such that the fuel assembly cannot be grappled using the standard fuel handling fixture designed to mate with the upper end fitting, or a fuel assembly that if grappled and moved, may not retain the fuel in the normal fuel assembly geometry.

As discussed during our January 18, 2000, meeting, the inclusion of this fuel as damaged fuel is consistent with the current draft industry protocol for fuel classifications, which may rely on an Engineering Evaluation to establish the fuel classification.

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CHAPTER 1: GENERAL INFORMATION

Section 1.8.2 Site-Specific Spent Fuel License Drawings

1-7 Submit license drawings for the consolidated fuel lattice referenced in SAR Section 2.1.3.1.3.

Drawings should be submitted for configuration control to ensure that a structural restraint is provided to maintain the configuration of consolidated fuel in its analyzed envelope. Information relative to materials of construction, general arrangement, dimensions of principal structures, systems, and components important to safety, in sufficient detail to support a safety finding, should be included in the SAR per 10 CFR 72.24(c)(3).

NAC Response

The consolidated fuel lattices were designed and fabricated by a contractor to Maine Yankee. NAC has received permission from Maine Yankee to provide three Maine Yankee drawings of the consolidated fuel lattices to the NRC. The nonproprietary drawings provided are:

MY-D-00-014, "Grid Assembly, Fuel Pin Storage," Revision 5,
MY-D-00-015, "Fuel Pin Storage, Cage Assembly," Revision 4, and
MY-D-00-016, "Miscellaneous Details, Fuel Pin Storage," Revision 10.

The drawings are provided for information only because each consolidated fuel lattice will be placed in a Maine Yankee Fuel Can. No credit is taken for the lattice structure. Analysis is presented to document the acceptability of the fuel can, basket and canister assuming 100 percent failure of the lattice and the fuel rods.

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CHAPTER 1: GENERAL INFORMATION

Section 1.8.2 Site-Specific Spent Fuel License Drawings

1-8 Clarify which NAC-UMS canister assembly components are used in conjunction with the Maine Yankee fuel can.

The tabulation presented in Drawing 790-501 does not include the Maine Yankee fuel can. A site-specific tabulation would provide the requested clarification.

Per 10 CFR 72.24(c), the application must provide the information relative to materials of construction, general arrangement, and dimensions of principal structures, systems, and components important to safety in sufficient detail to support a safety finding.

NAC Response

The Canister/Basket Assembly Table (Drawing 790-501) does not include the Maine Yankee Fuel Can as it is not an assembly or subassembly of the general NAC-UMS Storage System. As described in the Safety Analysis Report, the Maine Yankee Fuel Can is used only for certain Maine Yankee site specific fuel and is used only in the PWR Class 1 canister and basket.

The use of the Maine Yankee Fuel Can (Drawings 412-501 and 412-502) with the Class 1 Canister and Basket is illustrated in the following table:

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Canister / Basket Assembly Table for Maine Yankee

Component (Drawing Number)	PWR Class 1		PWR Class 2		Required For:
	DRAWING	ASSEMBLY	DRAWING	ASSEMBLY	
Assembly, UTC, Overpack, Cask Body Assembly (790500)	502	99	502	99	Transport
Cask Body, Transport Cask Nameplate (790509)	509	--	509	--	Transport
Cask Body, Transport Cask, Primary Trunnion (790505)	505	--	505	--	Transport
Lid Assembly, Cask Lid, (790503)	503	99	503	99	Transport
Lid Assembly, Cask, Port Cover Plate (790503)	504	99	504	99	Transport
Impact Limiter Assembly, Upper, Cask (790506)	506	99	506	99	Transport
Impact Limiter Assembly, Lower, Cask (790507)	507	99	507	99	Transport
Transport Cask Spacer Weldment (790520)	520	98	520	99	Transport
Package Assembly, Universal Transport Cask (UTC) (790570)	585	95	585	96	Transport
TSC, Shell Weldment (790585)	582	95	582	96	Both
TSC, Fuel Basket Ass'y (790585)	595	99	595	98	Both
TSC, Drain Tube Ass'y ((790585)	583	95	583	96	Both
TSC, Lid Support Ring (790585)	584	6	584	6	Both
TSC, Shield Lid Ass'y (790585)	584	99	584	99	Both
TSC, Cover (790585)	584	5	584	5	Both
TSC, Structural Lid (790585)	584	4	584	4	Both
TSC, Backing Ring (790585)	584	7	584	7	Both
TSC, Key (790585)	584	8	584	8	Both
Fuel Basket Ass'y. 24 Element PWR, Bottom Weldment (790595)	591	99	591	99	Both
Fuel Basket Ass'y. 24 Element PWR, Top Weldment (790595)	592	97	592	98	Both
Fuel Basket Ass'y. 24 Element PWR, Support Disk (790595)	593	1	593	1	Both
Fuel Basket Ass'y. 24 Element PWR, Tube (790595)	581	99	581	98	Both
Fuel Basket Ass'y. 24 Element PWR, Spacer (790595)	593	3	593	3	Both
Fuel Basket Ass'y. 24 Element PWR, Split Spacer (790595)	593	2	593	2	Both
Fuel Basket Ass'y. 24 Element PWR, Top Nut (790595)	593	4	593	4	Both
Fuel Basket Ass'y. 24 Element PWR, Tie Rod (790595)	593	5	593	6	Both
Fuel Basket Ass'y. 24 Element PWR, Heat Transfer Disk (790595)	594	1	594	1	Both
Fuel Basket Ass'y. 24 Element PWR, Top Spacer (790595)	593	8	593	8	Both
Spent Fuel Can Assembly, Maine Yankee (MY), NAC-UMS (412501)	**501**	**99**	**--**	**--**	**Both**
Assembly, Transfer Adapter, NAC-UMS (790559)	559	99	559	99	Both
Assembly, Transfer Cask (TFR) NAC-UMS (790560)	560	99	560	98	Both
Weldment, Structure, Vertical Concrete Cask Layout (790561)	561	95	561	96	Storage
Reinforcing Bar and Concrete Placement, (VCC) Layout (790562)	562	95	562	96	Storage
Lid, Vertical Concrete Cask (VCC) NAC-UMS (790563)	563	99	563	99	Storage
Shield Plug, Vertical Concrete Cask (VCC) NAC-UMS (790564)	564	99	564	99	Storage
Loaded Vertical Concrete Cask (VCC) NAC-UMS (790590)	590	95	590	96	Storage

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CHAPTER 2: PRINCIPAL DESIGN CRITERIA

Section 2.1.1 Bounding Fuel Evaluation - PWR

2-1 Specify the minimum enrichment for the Maine Yankee spent fuel and how enrichment was used to calculate the decay heat loading for Maine Yankee.

The last sentence in SAR Section 2.1.1 states that fuel that does not meet the enrichment and burnup limits of Tables 2.1.1-2 and -3 must be separately evaluated to establish loading limits. It is apparent that the Maine Yankee spent fuel burnup exceeds the 45 GWD/MTU limit, but it is not apparent whether the enrichment value utilized in the decay heat loading is bounding. Per 10 CFR 72.24(c), the application must provide information relative to materials of construction, general arrangement, and dimensions of principal structures, systems, and components important to safety in sufficient detail to support a safety finding.

<u>NAC Response</u>

Maine Yankee fuel with initial enrichment as low as 1.9 wt. % is acceptable for loading in the UMS storage system, subject to the cool time limits established in Section 5.6.1. The loading tables provided in Section 5.6.1, Tables 5.6.1-10 and 5.6.1-12, give the minimum acceptable cool time for any given Maine Yankee assembly based on its initial enrichment and burnup.

The loading tables are established based on a detailed analysis of: (1) the decay heat source terms; and, (2) the computed one-dimensional cask dose rates for each initial enrichment and burnup combination. That is, at each tabulated initial enrichment and burnup combination, an explicit source term is computed as a function of decay time. For each combination, the minimum cool time required for both the decay heat and the computed one-dimensional dose rates to fall below design basis limiting values is determined. The most limiting cool time is then rounded up to the next whole year and reported in the tables. The detailed evaluation process is described below.

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NAC Response to RAI 2-1 (Continued)

The limiting values for both decay heat and calculated one-dimensional dose rates for the design basis fuel are established based on the results of a detailed three-dimensional analysis of a Maine Yankee CE 14 x 14 fuel assembly with 3.7 wt % ^{235}U initial enrichment, 40,000 MWD/MTU burnup, and 5 year cool time. A bounding physical description of the Maine Yankee fuel is determined based on initial ^{235}U mass loading. The resulting fuel model is analyzed in full three-dimensional detail at design basis conditions of initial enrichment, burnup, and cool time for both the transfer cask and the vertical concrete cask. The three-dimensional results establish the suitability of the design basis fuel for loading in the UMS system.

One-dimensional dose rates are then computed for the design basis fuel conditions for both the storage and transfer cask. These dose rates become the limiting dose rate values for the loading table analysis. One-dimensional dose rates are calculated for Maine Yankee fuel at other initial enrichment and burnup combinations to establish that the fuel is cooled long enough to meet the design basis dose rate values.

In addition to the dose rate limits, a decay heat constraint is also applied in the loading table analysis. Each fuel combination must be cooled long enough that the decay heat for the fuel falls below the decay heat limits as shown in Table 4.4.7-8 and Table 4.5.1.2-3 through Table 4.5.1.2-5. The decay heat limits vary depending on the loading pattern, fuel burnup, and cool time.

In summary, the minimum enrichment considered in the analysis is 1.9 wt % ^{235}U. However, Maine Yankee fuel is subject to a minimum cool time constraint based on initial enrichment and burnup. The minimum cool times are established based on actual computed decay heat and radiation source terms for the fuel at various initial enrichment and burnup combinations. The analysis is further refined in that, with respect to radiological issues, the minimum cool time assessment is based on actual computed dose rates for the transfer and storage casks rather than on source term magnitudes alone. Hence, the analysis captures the effects of radiation spectra variation as a function of the fuel parameters (initial enrichment, burnup, and cool time), the relative importance of neutron and gamma sources, and the effects of cask shielding materials.

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CHAPTER 2:PRINCIPAL DESIGN CRITERIA

Section 2.1.3.1 Maine Yankee Site Specific Spent Fuel

2-2 Add "Fuel Debris" to the "Site Specific Fuel Configuration" entries in SAR Table 2.1.3.1-1.

Per 10 CFR 72.24(c), the application must provide information relative to materials of construction, general arrangement, and dimensions of principal structures, systems, and components important to safety in sufficient detail to support a safety finding.

NAC Response

The definition of Damaged Fuel is revised to include fuel debris. See the Response to RAI 1-3. Damaged fuel is already an entry in Table 2.1.3.1-1, which requires damaged fuel be placed in a Maine Yankee Fuel Can. Therefore, no revision to Table 2.1.3.1-1 is required.

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CHAPTER 2: PRINCIPAL DESIGN CRITERIA

Section 2.1.3.1 Maine Yankee Site Specific Spent Fuel

2-3 Provide a safety analysis of the two lattices, CF1 and CA3, in the current Maine Yankee fuel inventory for damaged fuel rods.

SAR Page 2.1.3-4 states that the two lattices for damaged fuel rods could be loaded in the Maine Yankee fuel can. The safety analysis of the fuel lattices, however, is not presented in the SAR to ensure that the lattices are capable of maintaining the damaged fuel rods in their analyzed configuration under the design basis loading conditions. Complete information, including the deceleration g-loads associated with the cask and drop accident during the operation of lifting the Vertical Concrete Cask should be provided in the SAR, per 10 CFR 72.24(d), for evaluating the cask structural performance.

NAC Response

Section 2.1.3.1.1 is revised to show that the CF1 and CA3 damaged fuel lattices are placed in a Maine Yankee Fuel Can for storage in the UMS® System. The analysis for design basis loading conditions assumes no credit for the lattices, CF1 and CA3. Rather, the analysis assumes the dispersal of the fuel material within the specific Maine Yankee Fuel Can. (Note that the Maine Yankee Fuel Can is designed to preclude the release of gross particulate material into the canister.) Therefore, a safety analysis for lattices CF1 and CA3 is not required.

See also the NAC response to RAIs 2-4 and 2-5.

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CHAPTER 2: PRINCIPAL DESIGN CRITERIA

Section 2.1.3.1 Maine Yankee Site Specific Spent Fuel

2-4 Clarify the contents and configuration of individual intact or damaged fuel rods in a Maine Yankee fuel can.

The SAR states that a Maine Yankee fuel can may contain individual intact or damaged fuel rods and that these fuel rods must be placed in a rod-type structure, which may be a guide tube. However, this section of the SAR fails to adequately specify (i) how many individual fuel rods may be placed in guide tubes, (ii) the dimensions and compositions on the non-guide-tube rod-type structures that house individual fuel rods, and (iii) the allowed loadings of individual fuel rods in the non-guide-tube rod-type structures. In particular, additional information is needed on dimensions, compositions, and allowed loadings of the rod-type structures in the CF1 and CA3 lattices. Clarification is also needed on whether the CF1 and CA3 lattices are the only rod-type structures, other than guide tubes, that will contain individual intact or damaged fuel rods.

Per 10 CFR 72.24(c), the application must provide information relative to materials of construction, general arrangement, and dimensions of principal structures, systems, and components important to safety in sufficient detail to support a safety finding.

<u>NAC Response</u>

Assembly B042 has fuel rods from positions J12 and L5 in guide tube #1 and fuel rods from positions K2 and N2 in guide tube #2. In addition, there is a poison rod in guide tube #1. Assembly B069 has fuel rods from positions B11 and E12 in guide tube #1. Up to two fuel rods may be placed in a guide tube. Fuel assemblies with fuel rods or poison rods inserted in the guide tubes are placed in a Maine Yankee fuel can for storage. (The fuel rods and poison rods are considered to be damaged fuel.)

CF1 is a 9x9 array fuel rod storage canister, designed and fabricated by Combustion Engineering using Type 304 stainless steel. It consists of 81 tubes approximately

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NAC Response to RAI 2-4 (Continued)

150-inches long, spaced at a pitch of 0.917 inch in an 8.25-inch square array. Four tubes are 0.875-inch outside diameter with a 0.049-inch thick wall. The assembly includes upper and lower end fittings, resulting in a total length of approximately 159 inches. No credit is taken for the array structure in the analysis.

CF1 currently contains 21 damaged fuel rods from assemblies N420, N842, N868, R032, R439, R444, U01, U05, U16, U37, U51 and U60, plus 1 poison rod from R444. Should it be necessary, additional damaged fuel rods and fuel debris may be placed into CF1.

CA3 is a previously used standard fuel assembly lattice originally designated H208, and fabricated by Combustion Engineering. There are currently 43 fuel rods in this lattice from assemblies G123 (4), G132 (5), H208 (19), H214 (9), H218 (6). There are also seven poison rods inserted in this lattice. No credit is taken for the lattice structure in the analysis. Should it be necessary, additional fuel rods may be placed in the CA3 lattice.

Individual intact or damaged fuel rods may be stored in the CF1 or CA3 lattices, in a consolidated fuel lattice, or in assembly guide tubes.

See also the Response to RAIs 2-3 and 2-5.

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CHAPTER 2: PRINCIPAL DESIGN CRITERIA

Section 2.1.3.1 Maine Yankee Site Specific Spent Fuel

2-5 Clarify the contents and configurations of fuel debris in a Maine Yankee fuel can.

The SAR does not limit the quantities or configurations of fuel debris that may be loaded into a Maine Yankee fuel can. Any structures that limit the configuration of fuel debris in a fuel can should be described in enough detail to permit a criticality analysis.

Per 10 CFR 72.24(c), the application must provide information relative to materials of construction, general arrangement, and dimensions of principal structures, systems, and components important to safety in sufficient detail to support a safety finding.

NAC Response

The contents of a Maine Yankee fuel can are limited to the equivalent of 283 fuel rods. The Maine Yankee fuel can may hold:

(1) Either of the consolidated fuel lattices (283 fuel rods or 172 fuel rods plus 76 stainless steel dummy rods):
(2) Either of the damaged fuel lattices (up to 176 fuel rods or up to the equivalent of 81 fuel rods in a 9 x 9 array); or,
(3) An intact or damaged fuel assembly (up to 176 fuel rods).

No credit is taken for the consolidated fuel lattice structures or the damaged fuel lattice structures in the analyses, i.e., all of the material in the fuel can is treated as fuel debris.

See also the Response to RAIs 2-3 and 2-4.

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CHAPTER 2: PRINCIPAL DESIGN CRITERIA

Section 2.1.3.1 Maine Yankee Site Specific Spent Fuel

2-6 Provide a safety analysis of the two consolidated fuel lattices to be used to house the fuel rods taken from three fuel assemblies as discussed in SAR Section 2.1.3.1.3.

SAR Page 2.1.3-4 states that two lattices are used for this purpose. The safety analysis of the fuel lattices, however, is not presented in the SAR to ensure that the lattices are capable of maintaining the damaged fuel rods in their analyzed configuration under the design basis loading conditions. Complete information, including the deceleration g-loads associated with the cask end drop accident during the operation of lifting the Vertical Concrete Cask should be provided in the SAR, per 10 CFR 72.24(d), for evaluating the cask structural performance.

NAC Response

The consolidated fuel lattices do not contain damaged fuel rods. Each consolidated fuel lattice is placed in a Maine Yankee fuel can for storage in the transportable storage canister. No credit is taken for the lattice structure in the analysis.

See the Response to RAI 1-7.

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CHAPTER 2: PRINCIPAL DESIGN CRITERIA

Section 2.1.3.1 Maine Yankee Site Specific Spent Fuel

2-7 With respect to Note 3 for SAR Table 2.1.3.1-1, submit license drawings and a safety analysis for the stainless steel fuel spacer used to load the design basis standard 14x14 fuel assemblies plus the Control Element Assemblies in a Class 2 pressurized water reactor (PWR) cask configuration.

The structural integrity of the stainless steel spacer should be demonstrated for the design basis loading conditions, including the deceleration g-loads associated with the cask end drop accident during the operation of lifting the Vertical Concrete Cask. Per 10 CFR 72.24(d), complete information should be provided in the SAR for evaluating the cask structural performance.

NAC Response

The portion of Note 3 in Table 2.1.3.1-1 requiring the use of a spacer to axially position a fuel assembly that does not have a Control Element Assembly inserted is deleted. Loading of the Class 2 canister is restricted to spent fuel assemblies with a Control Element Assembly installed. Consequently, separate steel axial spacers are not used with the loading of any Maine Yankee fuel configuration.

See the Response to RAI 2-8.

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CHAPTER 2: PRINCIPAL DESIGN CRITERIA

Section 2.1.3.1 Maine Yankee Site Specific Spent Fuel

2-8 With respect to Note 3 for SAR Table 2.1.3.1-1, evaluate the effects of the resulting vertical shifting of center-of-gravity locations of the TSC components on the determination of design basis decelerations for the cask.

The effects of vertical shifting of center-of-gravity locations of the TSC components should be evaluated for the corresponding change of deceleration g-forces. Per 10 CFR 72.236(m), to the extent practicable in the design of storage casks, consideration should be given to compatibility with cask operations, including removal of the stored spent fuel from a reactor site, transportation, and ultimate disposition.

NAC Response

The portion of Note 3 in Table 2.1.3.1-1 requiring the use of a spacer to axially position a fuel assembly that does not have a Control Element Assembly inserted is deleted. Loading of the Class 2 canister is restricted to spent fuel assemblies with a Control Element Assembly installed. Consequently, separate steel axial spacers are not used with the loading of any Maine Yankee fuel configuration.

As shown in Table 3.2-1, the center-of-gravity evaluation of the Class 2 canister already considers the effect of an inserted Control Element Assembly.

See the Response to RAI 2-7.

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CHAPTER 4: THERMAL

Section 4.5.1 Maine Yankee Site Specific Spent Fuel

4-1 Justify the assumption that only 25% of the fuel rods in a damaged fuel assembly lose configuration and fall to the bottom of the fuel can, or provide a revised thermal analysis which considers 100% rod failure and reconfiguration.

As defined in the application, a damaged fuel assembly is one with cladding defects greater than hairline cracks & pinhole leaks, and/or damage to the skeleton, and may or may not be handled by normal means. The ruggedness of this damaged fuel assembly under normal, off-normal, or accident conditions is not quantified. Therefore, assuming a 25% failure of rods appears to be an unjustified assumption and more rods could possibly fail since there is no structural analysis of damaged fuel to substantiate this assumption. Per 10 CFR 72.24(c), the application must provide information relative to materials of construction, general arrangement, and dimensions of principal structures, systems, and components important to safety in sufficient detail to support a safety finding.

NAC Response

The Safety Analysis Report, including Section 4.5.1.1.8, which presents the thermal evaluation for damaged fuel in the Maine Yankee Fuel Can, is revised to incorporate analysis that considers 100% failure of the damaged fuel. The analysis considers 50% and 100% compaction factors for the failed fuel.

As shown in Section 4.5.1.1.8, the maximum temperatures for the fuel cladding and the support and heat transfer disks in the 100% failure case are well within the allowable temperature limits for those components.

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CHAPTER 4: THERMAL

Section 4.5.1 Maine Yankee Site Specific Spent Fuel

4-2 Provide a Table(s) showing cooling time limits as functions of burnup and initial enrichment.

The last sentence of Section 4.5.1.2 states that the maximum decay heat is combined with the dose rate limits of Chapter 5 to establish cool time limits as a function of burnup and initial enrichment. However, this information is not provided for the Maine Yankee spent fuel but was done for the design basis fuel in Table 2.1.1-3. Also, it would be helpful to identify for each cooling time entry whether it was determined from a thermal or shielding basis. Per 10 CFR 72.24(c), the application must provide information relative to materials of construction, general arrangement, and dimensions of principal structures, systems, and components important to safety in sufficient detail to support a safety finding.

NAC Response

Table 5.6.1-10 presents the cool time limits as functions of burnup and initial enrichment for Maine Yankee fuel assemblies that do not have installed control element assemblies (CEAs). Cool time limits as functions of burnup and initial enrichment for fuel assemblies with installed CEAs are shown in Table 5.6.1-12. For comparison purposes, Table 5.6.1-12 includes a column providing cool time limits for Maine Yankee fuel assemblies without inserted CEAs installed in the Class 2 canister. As noted in Tables 2.1.3.1-1 and in Table 12B2-6, Maine Yankee fuel assemblies with inserted CEAs must be loaded in the Class 2 canister and assemblies without inserted CEAs must not be loaded in the Class 2 canister.

The last sentence in Section 4.5.1.2 is revised to provide a direct reference to Tables 5.6.1-10 and 5.6.1-12.

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CHAPTER 4: THERMAL

Section 4.5.1 Maine Yankee Site Specific Spent Fuel

4-3 Provide a copy of the reference for the statement in Section 4.5.1.2.1 that "Combustion Engineering places a maximum oxide layer thickness limit of 120 microns on fuel for incore operations."

Per 10 CFR 72.24(c), the application must provide information relative to materials of construction, general arrangement, and dimensions of principal structures, systems, and components important to safety in sufficient detail to support a safety finding.

NAC Response

The document from which the oxide layer dimensions is taken is the proprietary information property of the Maine Yankee Atomic Power Company. By agreement with the Maine Yankee Atomic Power Company, it is provided as a separate submittal marked as "Proprietary Information."

See also the Response to RAI 4-4.

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CHAPTER 4: THERMAL

Section 4.5.1 Maine Yankee Site Specific Spent Fuel

4-4 List Reference 36, cited in Section 4.5.2.2.1, in Section 4.6 "References" and submit it for staff's review.

Per 10 CFR 72.24(c), the application must provide information relative to materials of construction, general arrangement, and dimensions of principal structures, systems, and components important to safety in sufficient detail to support a safety finding.

NAC Response

Reference 36 is added to Section 4.6 and is submitted as an attachment to this RAI Response. The reference, "Contribution of Pellet Rim Porosity to Low-Temperature Fission Gas Release at Extended Burnups," is from the American Nuclear Society Topical Meeting on LWR Fuel Performance, held in Williamsburg, Virginia in April, 1988. It is a nonproprietary reference for the maximum gas release rate used in Section 4.5.1.2.1. (Note that Section 4.5.2.2.1 cited above does not exist.)

The maximum gas release rate is also provided as a proprietary information property of the Maine Yankee Atomic Power Company, in the same document provided in the NAC Response to RAI 4-3. It is provided by agreement with the Maine Yankee Atomic Power Company and is separately submitted as "Proprietary Information."

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CHAPTER 4: THERMAL

Section 4.5.1 Maine Yankee Site Specific Spent Fuel

4-5 In the second paragraph of Section 4.5.1.2.2.1, correct the reference from Table 4.5.1-3 to Table 4.5.1.2-3 (editorial).

NAC Response

The second paragraph of Section 4.5.1.2.2.1 is revised to refer to Table 4.5.1.2-3.

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CHAPTER 5: SHIELDING

Section 5.6.1 Shielding Evaluation for Maine Yankee Site Specific Spent Fuel

5-1 Describe the fuel assemblies with variable radial enrichment and axial blankets. Describe how enrichment varies, what axial blankets are, and what axial blankets are made of.

SAR Section 2.1.3.1.5, "Maine Yankee Spent Fuel with Unique Design," describes fuel assemblies with variable radial enrichments and axial blankets. SAR Section 5.6.1 states that these components do not result in additional sources without providing any supporting information. This information is necessary to ensure that the cask design establishes adequate criteria for radiation protection in accordance with 10 CFR 72.126.

NAC Response

Variable radial enrichment and axial blanket are described in Sections 6.6.1.2.2 and 6.6.1.2.3, respectively. As noted in Section 6.6.1.2.2, two batches of fuel used at Maine Yankee (identified as batches "U" and "T") incorporated variable radial enrichment. One of these batches, batch "U," also incorporated top and bottom active fuel axial blankets.

Variable radial enriched fuel assemblies in batch "T" incorporate fuel rods that are enriched to either 4.21 wt % ^{235}U or 3.5 wt % ^{235}U. In batch "U," the fuel rods are enriched to either 4.0 wt % ^{235}U or 3.4 wt % ^{235}U. The lower enriched fuel rods are generally placed around the fuel assembly guide tubes in the fuel rod array.

The batch "U" fuel assemblies also incorporate an axial blanket. The axial blanket consists of annular fuel pellets enriched to only 2.6 wt % ^{235}U that occupy the top and bottom 5% (approximately 7 inches on either end) of the active fuel length. The enrichment of the central portion of the active fuel length corresponds to the variable enrichment of the subject fuel rod (either 4.0 wt % ^{235}U or 3.4 wt % ^{235}U).

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NAC Response to RAI 5-1 (Continued)

The annular fuel pellets are formed from UO_2, but have a central hole approximately 0.183 inches in diameter. The central hole gives the pellet a "doughnut" shape.

With the exception of the use of the axial blanket, neither fuel batch employs axial enrichment variations with a given fuel rod.

Given the small enrichment variation between fuel rods (maximum 0.7 wt % ^{235}U), the shielding impact of the variations is minimal. When choosing the minimum allowable cool times of the fuel assembly, the use of the average enrichment (3.9 wt % ^{235}U) is acceptable. For conservatism, the minimum fuel mid-plane enrichment may be employed when selecting the minimum cool time. Use of the axial blanket enrichment (2.6 wt % ^{235}U) to establish the minimum cool time is not required since this material is located in low neutron flux regions of the reactor and experiences only a fraction of the assembly average burnup, i.e., the axial blankets have very low burnups.

Reference to the descriptions of variable radial enrichment and axial blankets provided in Sections 6.6.1.2.2 and 6.6.1.2.3 are incorporated in Sections 2.1.3.1.4 and 5.6.1.

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CHAPTER 5: SHIELDING

Section 5.6.1 Shielding Evaluation for Maine Yankee Site Specific Spent Fuel

5-2 Provide a source term evaluation using site-specific information based on the spent fuel at Maine Yankee. Additionally, provide the basis as to why 3.7 wt % is the minimum initial enrichment, since a lower initial enrichment will result in a higher neutron source term and, therefore, a higher overall source term.

SAR Section 5.6.1.1, "Fuel Source Term Description," states the bounding fuel has been determined to be a CE 14x14 assembly with a nominal burnup of 40,000 MWD/MTU and an initial enrichment of 3.7 wt % U-235 and is based on data provided in Table 2.1.1-1. This table provided generic data for the various types of PWR fuel. The site-specific fuel evaluation should be based upon site-specific parameters. This information is necessary to ensure that the cask design establishes adequate criteria for radiation protection in accordance with 10 CFR 72.126.

NAC Response

The design basis CE 14x14 fuel assembly model is bounding because the initial ^{235}U mass loading of this assembly (0.4037 MTU) exceeds the reported maximum initial uranium loading of all of the fuel in the Maine Yankee spent fuel inventory (0.397 MTU). Therefore, for any given initial enrichment and assembly burnup, the CE 14 x 14 fuel assembly generates the bounding source terms. The shielding analysis for the Maine Yankee fuel actually evaluated fuel source terms at many combinations of initial enrichment and burnup using the model for the design basis fuel assembly.

The reference to nominal fuel burnup and enrichment conditions (40,000 MWD/MTU and 3.7 wt % ^{235}U) in Section 5.6.1.1 does not characterize the limiting conditions of the fuel. Instead, reference to the fuel conditions is provided to allow correlation with the input parameters specified in the sample SCALE SAS2H input file provided in Figure 5.6.1-1. Reference to Table 2.1.1-1 is provided to explain the origin of the various fuel assembly geometrical parameters used in the SAS2H model.

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NAC Response to RAI 5-2 (Continued)

Similar SAS2H models are developed for fuel at other combinations of initial enrichment and burnup. All combinations of the following parameters are considered in the analysis:

Initial Enrichment (wt % ^{235}U):	1.9, 2.1, 2.3, 2.5, 2.7, 2.9, 3.1, 3.3, 3.5, and 3.7
Burnup (GWD/MTU):	30, 35, 40, 45, and 50

These combinations bound all fuel in the Maine Yankee spent fuel inventory because for any given Maine Yankee assembly, its initial enrichment (rounded down to an analyzed value) and burnup (rounded up to an analyzed value) correspond to an analyzed combination.

The analysis of the Maine Yankee fuel for each combination of initial enrichment and burnup consists of determining the cool time required for the assembly decay heat and for the computed dose rates to fall below the design basis values. The design basis dose rates are obtained by evaluating 3.7 wt % ^{235}U enriched, 40,000 MWD/MTU, 5 year cooled fuel. Hence, the additional source term associated with fuel enrichments below 3.7 wt. % is explicitly considered in the analysis, since this fuel will require a longer cool time before its decay heat and dose rates fall below the design basis values. The results of this analysis are shown in Tables 5.6.1-10 (fuel assemblies without inserted control components) and 5.6.1-12 (fuel assemblies with inserted control components).

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CHAPTER 5: SHIELDING

Section 5.6.1 Shielding Evaluation for Maine Yankee Site Specific Spent Fuel

5-3 Explain what is meant by the statement in Section 5.6.1.4.1, "Only the storage cask dose rate limit is adjusted to account for Control Element Assemblies (CEAs) inserted in fuel assemblies."

Technical Specification 3.2.2 limits the average surface dose rate on the side of the concrete cask to less than or equal to 50 mrem/hr. The additional CEA source results in localized peak near the bottom of the cask. This information is necessary to ensure that the cask design establishes adequate criteria for radiation protection in accordance with 10 CFR 72.126.

NAC Response

A three-dimensional shielding analysis of the transfer cask containing design basis fuel with control element assemblies inserted shows that the localized peak dose near the bottom of the transfer cask is comparable to the dose rate at the bottom of the cask in the no-control element assembly case. Therefore, the transfer cask dose rate limit used in constructing the loading table (Table 5.6.1-12) need not be adjusted downward to account for an increased dose due to the presence of the control element assemblies.

The dose rate contribution of the control element assemblies to the storage cask surface dose rate is also evaluated using a detailed, three-dimensional analysis. The results of this calculation are used to adjust downward the storage cask one-dimensional dose rate limits for the fuel. This effectively forces fuel having inserted control element assemblies to be cooled longer than the standard fuel assembly before being acceptable for loading in the transportable storage canister.

As shown in Table 5.6.1-12, the adjustment in cool time due to the presence of control element assemblies is slight. Section 5.6.1.4.1 is revised to clarify the transfer cask evaluation.

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CHAPTER 6: CRITICALITY

Section 6.6.1 Criticality Evaluation for Maine Yankee Site Specific Spent Fuel

6-1 Justify the SAR Section 6.6.1.3 assumption that only 25% of the fuel rods in a damaged Maine Yankee fuel assembly are damaged.

The justification should include information on how many of the fuel rods in each damaged assembly are known to be damaged or intact, respectively. Axial shifting or relocation of damaged fuel rods (and materials from damaged rods) should be considered in showing that the allowed contents are within the analyzed safety basis with regard to axial coverage of fissile material by the Boral panels.

Per 10 CFR 72.24(c), the application must provide information relative to materials of construction, general arrangement, and dimensions of principal structures, systems, and components important to safety in sufficient detail to support a safety finding.

NAC Response

Section 6.6.1.3 is revised to incorporate the assumption that 100% of the fuel rods placed in a Maine Yankee Fuel Can are failed. The revised analysis is based on 100% failure of the 176 rods in a Maine Yankee fuel assembly. These analyses demonstrate that 100% failure of the fuel rods loaded in the Maine Yankee fuel can does not affect the reactivity of the system, since the Maine Yankee fuel cans are physically restricted to loading in the four corner positions on the periphery of the basket. These analyses consider complete dispersal of the fuel from damaged fuel rods within the Maine Yankee fuel can with an optimal H/U ratio with no credit taken for structural components of the assembly, including the fuel rod cladding. Only fuel and water are considered within the cavity of the fuel can. The model conservatively extends the height of the fuel can cavity from the floor to the lid of the canister. Thus, the analyses also consider dispersal of the fuel from the damaged fuel rods outside of BORAL sheet coverage. Since the H/U ratio is optimized, the analysis bounds the consolidated fuel configuration, as the additional fuel rods undermoderate the system, resulting in a lower k_{eff}.

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CHAPTER 6: CRITICALITY

Section 6.6.1 Criticality Evaluation for Maine Yankee Site Specific Spent Fuel

6-2 Justify the statement (Section 6.6.1.3.1) that the accident scenarios described in Section 11.1 and 11.2 will not result in release of fuel material from damaged fuel rods.

The requested justification should include information on the durability of damaged fuel rods and damaged fuel assemblies. Consideration should be given to individual damaged fuel rods in tube structures as well as damaged rods within the fuel lattice of a damaged Maine Yankee fuel assembly.

Per 10 CFR 72.24(c), the application must provide information relative to materials of construction, general arrangement, and dimensions of principal structures, systems, and components important to safety in sufficient detail to support a safety finding.

<u>NAC Response</u>

Section 6.6.1.3.1 is revised to incorporate an assumption of 100% failure of fuel rods in the Maine Yankee fuel can.

See the response to RAI 6-1.

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CHAPTER 6: CRITICALITY

Section 6.6.1.3.2 Criticality Evaluation for Maine Yankee Site Specific Spent Fuel

6-3 Clarify the SAR Section 6.6.1.3.2 reference to the "screened canister." The staff assumes that this refers to the fuel can, not the canister. The SAR should be corrected accordingly.

Per 10 CFR 72.24(c), the application must provide information relative to materials of construction, general arrangement, and dimensions of principal structures, systems, and components important to safety in sufficient detail to support a safety finding.

NAC Response

The correct reference is to the "screened Maine Yankee fuel can." Section 6.6.1.3.2 is revised to delete the reference to the canister and incorporate the reference to the Maine Yankee fuel can.

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CHAPTER 6: CRITICALITY

Section 6.6.1 Criticality Evaluation for Maine Yankee Site Specific Spent Fuel

6-4 Clarify how axial poison coverage is evaluated for fuel debris (and fuel material from damaged fuel rods) in the Maine Yankee fuel can.

The SAR provides no information on axial dimensions and structures in the fuel can that contain and axially locate fuel debris (or damaged fuel rods) in relation to the fuel basket poisons. Any analysis assumptions regarding the potential for damaged fuel rods, or fuel material escaping from damaged fuel rods, to relocate to positions below (or above) the ends of the Boral panels should be stated and justified. The applicant should clearly show that criticality analysis models represent the most reactive credible arrangements of fissile materials and poison panels within the basket.

Per 10 CFR 72.24(c), the application must provide information relative to materials of construction, general arrangement, and dimensions of principal structures, systems, and components important to safety in sufficient detail to support a safety finding.

NAC Response

The analysis of the Maine Yankee fuel can is revised to consider 100% failure of the fuel rods (in any configuration) held in the fuel can. The model conservatively extends the length of the fuel can from the floor of the canister to the canister lid. Therefore, the analyses consider the dispersal of the optimally moderated fuel outside of the area covered by the BORAL.

See the response to RAI 6-1.

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CHAPTER 8: OPERATING PROCEDURES

Section 8.1.4.1 Preferential Loading of Maine Yankee Site Specific Spent Fuel

8-1 Revise the preferential loading of Maine Yankee fuel provisions of SAR Section 8.1.4.1 to reflect loading tables which provide limits for decay heat on a per assembly basis as a part of the Technical Specifications (see related RAI 12-3). This information is requested in accordance with the provisions of 10 CFR 72.24(d).

NAC Response

Section 8.1.4, including Section 8.1.4.1, of the Operating Procedures is deleted. As shown in Step 9 of the procedure for loading and closing the Transportable Storage Canister (Section 8.1.1), the fuel to be loaded must be in accordance with the Approved Contents provisions of Appendix 12B, Section B2.0 of the Technical Specifications. The Note associated with Step 9 is revised to state that preferential loading is controlled as described in Sections B2.1.2 and B2.1.3 of Appendix 12B.

Since the loading procedure appropriately invokes the Approved Contents requirements of Appendix B, and since the information provided in Section 8.1.4 is previously provided in Section 2.1.3 of the Principal Design Criteria, Section 8.1.4 is unnecessary.

See the Response to RAI 12-3.

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CHAPTER 11: ACCIDENTS

Section 11.2.15.1 Accident and Natural Phenomena Events Evaluation for Maine Yankee Site Specific Fuel

11-1 Submit the LS-DYNA analyses performed to account for the three sets of concrete material properties on SAR Page 11.2.15-3, and discuss how the results were evaluated to arrive at a single set of maximum cask decelerations on SAR Page 11.2.15-4 for the PWR Class 1 and Class 2 cask configurations.

The SAR is not clear as to whether a sensitivity analysis was performed by considering three sets of soil properties for determining maximum cask decelerations. Per 10 CFR 72.24(d), complete information should be provided in the SAR for evaluating the cask structural performance.

NAC Response

The LS-DYNA analysis of the hypothetical concrete cask tip-over event is based on a set of parametric evaluations for each of three sets of ISFSI pad concrete material properties (as shown on Page 11.2.15-3 of the SAR), using concrete compressive strengths of 3000 psi and 4000 psi, for each of the concrete cask configurations (Class 1 and Class 2) used to store the Maine Yankee fuel.

This set of parametric evaluations is performed considering two soil density combinations:

(1) Upper 4.5-foot deep layer = 135 pcf and Lower 10.0-foot deep layer = 127 pcf; and

(2) Upper 4.5-foot deep layer = 130 pcf and Lower 10.0-foot deep layer = 127 pcf.

Considering these parameters in combination results in a total of 24 separate runs.

Since the maximum impact force occurs at or near the top of a body (the concrete cask containing the canister in this case) that is rotating about its bottom edge to a horizontal surface, the impact forces (g) at the top of the canister and at the location of the top

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NAC Response to RAI 11-1 (Continued)

(uppermost) support disk are summarized for all of the runs. From the summary tabulation of g-loads, the single set of maximum decelerations for the top of the canister and for the top support disk for the Class 1 and Class 2 configurations are selected for use in the bounding evaluation of the canister and the support disk.

The maximum decelerations presented on Page 11.2.15-4 for both the Class 1 and Class 2 configurations occur for the following set of pad and soil parameters:

ISFSI concrete pad density = 140 pcf
Compressive strength = 3,000 psi
Upper 4.5-foot soil layer density = 135 pcf
Lower 10-foot soil layer density = 127 pcf.

As identified in the previous paragraph, two sets of soil properties were evaluated in combination with each of the three sets of ISFSI concrete pad densities to determine bounding case results for the canister g-loads during the hypothetical concrete cask tip-over event.

The LS-DYNA analysis - NAC Calculation No. 12412-2001, "VCC Tip-over Analysis for Maine Yankee," – is provided as a NAC Proprietary Information attachment to these responses.

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CHAPTER 11: ACCIDENTS

Section 11.2.15.1 Accident and Natural Phenomena Events Evaluation for Maine Yankee Site Specific Fuel

11-2 Considering sectional (primary membrane and membrane-plus-bending), in lieu of nodal, stresses in the support disk ligaments, reevalute normalized stress ratios in SAR Table 11.2.15.1.2-1 for the Maine Yankee consolidated fuel.

The PWR support disk ligaments are evaluated with sectional stresses for the design basis spent fuel assemblies. When normalized stress ratios are considered in comparing relative structural performance, a consistent evaluation basis should be maintained throughout the SAR, including that for the Maine Yankee consolidated fuel. Complete and consistent information should be provided in the SAR, per 10 CFR 72.24(d), for evaluating the cask structural performance.

NAC Response

The parametric study of support disk evaluation in Section 11.2.15.1.2 is revised to consider sectional stresses, in lieu of nodal stresses, in the support disk. The normalized stress ratios in Table 11.2.15.1.2-1 are also revised based on the sectional stress results.

Note that the number of cases evaluated is reduced from 12 to 4, since the consolidated fuel assembly can only be placed in one of the four corner locations of the basket. In addition, the bounding case for the consolidated fuel configuration is considered:

- the basket is loaded with one consolidated fuel assembly (inside a fuel can in one of the corner positions)
- three damaged Maine Yankee standard fuel assemblies (inside fuel cans in the remaining corner positions), and
- 20 Maine Yankee standard fuel assemblies in the remaining positions of the basket.

As shown in Table 11.2.15.1.2-1, the stresses in the support disk for this configuration are bounded by the stresses in the support disk for the design basis PWR configuration.

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CHAPTER 11: ACCIDENTS

Section 11.2.15.1 Accident and Natural Phenomena Events Evaluation for Maine Yankee Site Specific Fuel

11-3 Clarify the SAR statement on Page 11.2.15-5, "This study shows that a consolidated fuel lattice can be located in any position of the PWR basket, based on structural loading considerations."

Under a side drop, stresses in the support disk ligaments appear to be governed predominantly by the locally applied equivalent inertia load of a spent fuel assembly. As a result, because of the relatively large weight of the consolidated fuel lattice, some of the normalized stress ratios for the 12 fuel tube locations are expected to exceed 1.00, the stress ratio for the Base Case. Complete and consistent information should be provided in the SAR, per 10 CFR 72.24(d), for evaluating the cask structural performance.

NAC Response

Section 11.2.15.1.2 is revised to indicate that the consolidated fuel is stored in a Maine Yankee fuel can placed in one of the corner positions of the basket.

The stresses in the support disk ligaments during a tip-over accident are governed predominantly by displacement (ovalization) of the disk, rather than the locally applied equivalent inertia load of a fuel assembly.

The pressure on the support disk ligament due to the inertia load (1g) of the UMS system design basis fuel assembly (including the fuel tube) is 12.26 psi. The thickness of the support disk is 0.5 inch. There are three different heights of the ligament: 0.875 inch, 1.0 inch and 1.5 inches. The length of the ligament is 9.272 inches. Considering the support disk ligament to be a beam with both ends fixed and subjected to a 40g side impact condition, the maximum bending moment (M) and bending stress (σ) in the ligament are:

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NAC Response to RAI 11-3 (Continued)

Ligament Height (inch)	M (inch-kip)	S ($inch^3$)	σ (ksi)
0.875	1.755	0.0638	27.5
1.0	1.755	0.0833	21.1
1.5	1.755	0.1875	9.4

In this table, $M = wL^2/12$, S is the Section Modulus, and σ is the bending stress (M / S).

Where,

w is the force per unit length (40g) on the ligament $(0.01226\times0.5)\times40 = 0.245$ kips/inch) and,

L is the length of the ligament (9.272 inches)

$S = bt^2/6$, where b is the ligament thickness and t is the ligament height.

As shown in the table, the maximum stress in the support disk ligament due to the locally applied inertia load is 27.5 ksi, which is well below the maximum stresses calculated by the three-dimensional canister/basket model for the tip-over condition (see Section 11.2.12.4.1). As shown in Table 11.2.12.4.1-4, "Summary of Maximum Stresses for PWR Support Disk for Tip-over Condition," the maximum P_m+P_b stress in the PWR support disk ligaments is 81.9 ksi, 111.6 ksi, 124.6 ksi and 129.1 ksi for the 0°, 18.22°, 26.28° and 45° basket drop orientations, respectively. Therefore, it can be concluded that stresses in the support disk ligaments for a side impact (tip-over accident) are governed predominantly by the displacement (ovalization) of the disk

The pressure on the support disk ligament due to equivalent inertia load (1g) of the Maine Yankee consolidated fuel, including the fuel can and the fuel tube, is 17.0 psi. The consolidated fuel is limited to the corner position of the basket, where the support disk ligament height is 1.5 inches.

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NAC Response to RAI 11-3 (Continued)

Using the formula above, the maximum bending stress in the ligament is calculated to be 13.0 ksi, an increase of only 3.6 ksi, compared with the maximum stress of 9.4 ksi for the UMS design basis loading as shown in the table above.

Since the total weight (≈ 35,800 lbs.) on the basket for the configuration of 20 Maine Yankee standard fuel assemblies, one consolidated fuel lattice and three damaged Maine Yankee fuel assemblies (including the weight of fuel tubes and fuel cans) is much less than the total weight of 24 UMS design basis fuel assemblies and fuel tubes (≈ 40,900 lbs.), it is concluded that the maximum stress in the support disk for the Maine Yankee configuration is bounded by the maximum stress in the support disk for the UMS design basis configuration. This is demonstrated by re-performing the analysis using the three-dimensional canister/basket model for the worst case basket orientation (26.28°) for the tip-over condition (Section 11.2.12.4.1).

See also the NAC Response to RAI 11-4.

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR ADDITIONAL INFORMATION

CHAPTER 11: ACCIDENTS

Section 11.2.15.1 Accident and Natural Phenomena Events Evaluation for Maine Yankee Site Specific Fuel

11-4 Provide a stress summary table for a representative corner-location case to demonstrate adequate stress margins for the corner-location preferential loading of the consolidated fuel.

An evaluation of normalized stress ratios, in SAR Table 11.2.15.1.2-1, alone may not be sufficient to substantiate the SAR conclusion, and explicit stress margins should be considered for the evaluation. Complete and consistent information should be provided in the SAR, per 10 CFR 72.24(d), for evaluating the cask structural performance.

NAC Response

An analysis is performed for the Maine Yankee consolidated fuel configuration assumed in the NAC Response 11-2, using the three-dimensional PWR canister/basket model for the worst case basket orientation (26.28°) in the tip-over condition (Section 11.2.12.4.1).

The loading condition corresponds to Case 4 of the parametric study for the support disk as presented in Section 11.2.15.1.2. The analysis results of the P_m and P_m+P_b stresses are summarized in Tables 11.2.15.1.2-2 and 11.2.15.1.2-3, respectively. The minimum Margin of Safety for the P_m stress is + 1.12. The minimum Margin of Safety for the P_m + P_b stress is + 0.11.

The minimum margin of safety for the corresponding analysis for the support disk for the UMS® System design basis PWR configuration is +0.97 and +0.05 for P_m and P_m + P_b stresses, respectively (See Table 11.2.12.4.1-4). This comparison further substantiates the conclusion of the parametric study based on the normalized stress ratios using a two-dimensional model (Table 11.2.15.1.2-1).

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR ADDITIONAL INFORMATION

CHAPTER 11: ACCIDENTS

Section 11.2.15.1 Accident and Natural Phenomena Events Evaluation for Maine Yankee Site Specific Fuel

11-5 Justify the SAR Section 11.2.15.1.4 use of a friction coefficient of 0.5, between the broom-finish concrete surface and the cask bottom plate, for evaluating cask seismic stability against tipover and sliding.

Sufficient basis should be provided for selecting the friction coefficient for cask seismic stability analysis. Section 72.24(d) requires complete information be provided in the SAR for evaluating the cask structural performance. If a cask sliding evaluation program is to be used to demonstrate the design friction coefficient by testing under the administrative control, the test standards and acceptance criteria should be considered part of the evaluation program.

NAC Response

The static coefficient of friction between the vertical concrete cask bottom plate and the ISFSI pad is assumed based on a published value of 0.70 for generic clean steel on concrete. As discussed during the meeting on January 18, 2000, the coefficient of friction will be demonstrated to be 0.5 or greater by physical testing. That testing will consider the appropriate concrete cask and pad surfaces and weight/contact area ratio. Section B 3.4.2(6) of Chapter 12 is revised to specify a "broom finish"/"brushed surface" on the ISFSI concrete pad surface as defined in ACI 116R-90 and described in Sections 7.12 and 7.13.4 of ACI 302.1R.

The (static) coefficient of friction applied in analysis to demonstrate that the loaded concrete cask does not slide on the ISFSI pad under wind, water current or earthquake loading conditions resulting in a horizontal acceleration of 0.38g, is 0.5 (including a factor of safety of 1.10).

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR ADDITIONAL INFORMATION

CHAPTER 12: TECHNICAL SPECIFICATIONS

Appendix 12A Technical Specifications for the NAC-UMS System

12-1 There are two different definitions of "intact fuel assembly" and "damaged fuel assembly" in SAR Appendix 12A, Section A 1.1. Correct the inconsistency.

Section 72.11 requires that the SAR contain complete and accurate information.

NAC Response

Consistent with the discussions during our January 18, 2000 meeting, the definition of "Intact Fuel" is revised to incorporate the current draft industry protocol for fuel classifications.

The revised definitions incorporate the use of an Engineering Evaluation, when necessary, to establish the fuel classification.

See the NAC Responses to RAIs 1-1 through 1-6.

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR ADDITIONAL INFORMATION

CHAPTER 12: TECHNICAL SPECIFICATIONS

Appendix 12B Approved Contents and Design Features for the NAC-UMS System

12-2 Append post-irradiation cooling time and average burnup per assembly information for fuels having burnups greater than 45,000 MWD/MTU to Table 12B2-4, as appropriate.

Section 72.11 requires that the SAR contain complete and accurate information. The post-irradiation cooling times and average burnups per assembly can be found in Table 12B2-4, as referenced in Table 12B2-1. However, Table 12B2-4 does not contain the cooling time and average burnup per assembly for fuels having burnups greater than 45,000 MWD/MTU. This information is requested in accordance with the provisions of 10 CFR 72.24(d).

NAC Response

Section 12B2 is revised to add Tables 12B2-8 and 12B2-9. These tables are the loading tables for Maine Yankee spent fuel that are also presented in Section 5.6.1 as Tables 5.6.1-10 and 5.6.1-12. Table 5.6.1-10 provides the loading table for Maine Yankee fuel assemblies that do not have inserted non-fuel bearing hardware (i.e., control element assemblies). Table 5.6.1-12 is the loading table for fuel assemblies that do have a control element assembly (CEA) inserted. Both tables include the cool time loading limits for Maine Yankee fuel with a burnup between 45,000 MWD/MTU and 50,000 MWD/MTU.

Table 12B2-4 is not revised as it refers to the UMS® System design basis PWR spent fuel, which is not evaluated for a burnup above 45,000 MWD/MTU.

Table 5.6.1-12 includes a column showing the cool time limits for a fuel assembly with no inserted CEA in the Class 2 canister for in formation and comparison purposes only. Fuel assemblies without inserted CEAs cannot be loaded in the Class 2 canister.

See the Response to RAI 12-3.

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR ADDITIONAL INFORMATION

CHAPTER 12: TECHNICAL SPECIFICATIONS

Appendix 12B Approved Contents and Design Features for the NAC-UMS System

12-3 Include Tables 4.5.1.2-3, -4, and –5 in SAR Appendix 12B, as appropriate.

These tables define the maximum heat load per canister and the canister heat load distribution limits for the Maine Yankee site specific fuel. Without these tables included in the technical specifications it isn't clear how these heat load limitations would be maintained. See related RAI 12-2. This information is requested in accordance with the provisions of 10 CFR 72.24(d).

NAC Response

The information provided in the subject tables is also provided in Tables 5.6.1-10 and 5.6.1-12. Table 5.6.1-10 provides the loading table for Maine Yankee fuel assemblies that do not have inserted non-fuel bearing hardware (i.e., control element assemblies). Table 5.6.1-12 is the loading table for fuel assemblies that do hold a control element assembly (CEA).

Section 12B2 is revised to incorporate Tables 5.6.1-10 and 5.6.1-12 as Tables 12B2-8 and 12B2-9, respectively. These tables are preferred to the tables provided in Section 4.5.1.2 since they conform to the format of the loading tables used for the design basis UMS® System PWR and BWR design basis spent fuel.

Table 5.6.1-12 includes a column showing the cool time limits for a fuel assembly with no inserted CEA in the Class 2 canister. This column is provided for comparison purposes only. Fuel assemblies without inserted CEAs cannot be loaded in the Class 2 canister.

See the response to RAI 12-2.

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR ADDITIONAL INFORMATION

CHAPTER 12: TECHNICAL SPECIFICATIONS

Appendix 12B Approved Contents and Design Features for the NAC-UMS System

12-4 Change "burnup above 45,000 MWd/MTU" to "burnup from 45,000 to 50,000 MWd/MTU."

Throughout this chapter it would appear that any burnup above 45,000 is permissible, when in fact, an upper limit of 50,000 MWd/MTU is apparently the limit being requested. This information is requested in accordance with the provisions of 10 CFR 72.24(c)(3).

NAC Response

The appropriate sections of Chapters 2 and 12 are revised to incorporate reference to the range of burnup between 45,000 and 50,000 MWD/MTU for the higher burnup Maine Yankee spent fuel.

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR ADDITIONAL INFORMATION

CHAPTER 12: TECHNICAL SPECIFICATIONS

Appendix 12B Approved Contents and Design Features for the NAC-UMS System

12-5 Add "Fuel Debris" to the "Site Specific Spent Fuel Configuration" entries in the SAR Table 12B2-6.

Per 10 CFR 72.24(c), the application must provide information relative to materials of construction, general arrangement, and dimensions of principal structures, systems, and components important to safety in sufficient detail to support a safety finding.

NAC Response

Fuel Debris is classified as "Damaged Fuel" in the NAC Response 1-3. The number of assemblies shown in Table 12B2-6 as Damaged Fuel includes one Maine Yankee Fuel Can that is expected to hold all of the material considered to be debris as well as other fuel rods classified as damaged. As described in Section 6.6.1.3.2, debris material is first placed in a rod type structure to confine the material to a known volume.

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR ADDITIONAL INFORMATION

CHAPTER 12: TECHNICAL SPECIFICATIONS

Appendix 12B Approved Contents and Design Features for the NAC-UMS System

12-6 With respect to SAR Table 12B2-7:

(a) Explain the basis for limiting the acceptance of Maine Yankee fuel assemblies with axial end blankets to those having variable enrichment between the end blankets and a nominal enrichment in the end blanket of 2.6 wt % ^{235}U. Clarify whether the intent is to exclude assemblies that have (i) uniform enrichment between the end blankets or (ii) end blankets with a nominal enrichment that differs from 2.6 wt % ^{235}U.

(b) For assemblies with axial end blankets, specify the limiting annular blanket dimensions that affect the criticality analysis. Such dimensions should include the annulus radius and axial length of the blankets.

Per 10 CFR 72.24(c), the application must provide information relative to materials of construction, general arrangement, and dimensions of principal structures, systems, and components important to safety in sufficient detail to support a safety finding.

<u>NAC Response</u>

(a) Item A(5) of Table 12B2-7 is revised to remove the inference that fuel rods having axial end blankets also have variable enrichment in the remaining length of active fuel. The enrichment of the fuel between the axial end blankets is uniform and is either 3.4 wt % ^{235}U or 4.0 wt % ^{235}U.

(b) The annular blanket regions are approximately 5% (≈ 7 inches) of the active fuel region at each end of the fuel rod. The blanket outer diameter is the same as the outer diameter of the other fuel pellets (0.380 inches) in the fuel rod. The maximum diameter of the pellet annulus is 0.183 inches. The annulus length is conservatively modeled as 9.6 inches in the criticality analysis.

NAC INTERNATIONAL RESPONSE
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CHAPTER 12: TECHNICAL SPECIFICATIONS

Appendix 12B Approved Contents and Design Features for the NAC-UMS System

12-7 Clarify, in Item 6 of SAR Section 12B 3.4.2, the use of "minimum thickness" for specifying the upper-layer subsoil configuration for the ISFSI pad.

On the basis of the analysis presented in SAR Section 11.2.15, it appears that the maximum, in lieu of minimum, subsoil thickness should be specified for site parameter evaluation. Complete and consistent information should be provided in the SAR, per 10 CFR 72.24(d), for evaluating the cask structural performance.

NAC Response

Item 6 of Section 12B 3.4.2 is revised to specify the 4.5-foot upper-layer subsoil thickness as the maximum thickness.

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR ADDITIONAL INFORMATION

HIGH BURNUP FUEL

Appendix 12B Approved Contents and Design Features for the NAC-UMS System

HB-1 Estimate and justify the concentration of hydrogen absorbed by the cladding during reactor operation.

The amount of hydrogen in the Zircaloy cladding may result in changes to the mechanical properties and creep behavior of high burnup fuel. This information is needed to determine how the mechanical properties and creep behavior of fuel with burnups up to 50,000 MWd/MTU differ from the properties and behavior of fuels with burnups less than 45,000 MWd/MTU.

<u>NAC Response</u>

Please see attached "Summary Report on Maine Yankee High Burnup Fuel (Burnup between 45,000 to 50,000 MWD/MTU)".

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR ADDITIONAL INFORMATION

HIGH BURNUP FUEL

Appendix 12B Approved Contents and Design Features for the NAC-UMS System

HB-2 Estimate the changes in the mechanical properties (i.e., tensile strength, yield strength, ductility, fracture toughness, uniform elongation, etc.) of cladding that contains hydrogen concentrations at the levels estimated in the response to the previous RAI question. In the discussion, the analysis should address the mechanical properties that are affected by each of the following:

a. the potential for dissolution of the hydrides during the short-term higher temperatures encountered during the vacuum drying and transfer operations,
b. the subsequent re-precipitation and/or re-orientation of the hydrides as the temperature decreases during storage, and
c. the effects of hydriding on the creep behavior of the cladding.

NAC Response

Please see attached "Summary Report on Maine Yankee High Burnup Fuel (Burnup between 45,000 to 50,000 MWD/MTU)".

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR ADDITIONAL INFORMATION

HIGH BURNUP FUEL

Appendix 12B Approved Contents and Design Features for the NAC-UMS System

HB-3 Calculate the amount of creep strain in the cladding after 20 years of storage. The calculation should be performed using creep equations and creep phenomena that are supported by experimental data. Consideration of the increase in creep strain associated with vacuum drying and storage temperatures above 300°C should be included in the calculation.

NAC Response

Please see attached "Summary Report on Maine Yankee High Burnup Fuel (Burnup between 45,000 to 50,000 MWD/MTU)".

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR ADDITIONAL INFORMATION

HIGH BURNUP FUEL

Appendix 12B Approved Contents and Design Features for the NAC-UMS System

HB-4 Describe and justify the potential failure modes and the quantities of failed rods, if any, that are likely to occur during storage if the calculated cladding creep strain exceeds the creep strain capacity of the cladding material. This assessment should include a discussion of the most likely failure modes of the cladding under internal rod pressure conditions and the relatively high temperature experienced during vacuum drying and storage.

NAC Response

Please see attached "Summary Report on Maine Yankee High Burnup Fuel (Burnup between 45,000 to 50,000 MWD/MTU)".

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR ADDITIONAL INFORMATION

DUAL-PURPOSE CANISTER

DP6-1 For the Maine Yankee contents, provide an analysis of the most reactive configurations of damaged fuel and fuel debris under normal and accident conditions of transport.

The requested analysis should consider the nonuniform preferential flooding configurations made possible by the obstruction of drain holes at the top or bottom of the Maine Yankee fuel can. The staff notes that the 250-mesh wire screen covering the drain holes can retain a significant head of water as a result of surface-tension effects. Fuel debris and rubble from damaged fuel will tend to accumulate over the drain holes in a flooded package, further obstructing the free flow of water. Therefore, uneven flooding may result when water densities and levels inside the Maine Yankee fuel can vary independently from those outside the fuel can.

In evaluating the configurations of Maine Yankee damaged fuel and fuel debris, the applicant's analysis should explicitly consider the potential axial locations of fissile materials in relation to the ends of the basket poison panels.

Section 71.55(b) requires evaluation of the most-reactive credible configurations of package contents and materials as well as moderation by water to the most reactive credible extent.

NAC Response

An analysis of the most reactive configuration of the transportable storage canister holding damaged fuel and fuel debris in the Maine Yankee fuel can, for both normal and accident conditions, will be provided in NAC's submittal of supplemental information for Maine Yankee damaged fuel in the UMS® Transport Cask Safety Analysis Report.

NAC-UMS
Docket # 72-1015
TAC #L22979

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR ADDITIONAL INFORMATION

Attachments to the NAC RAI Response

A. Nonproprietary Attachments

1. Maine Yankee Atomic Power Company Drawings
   Grid Assembly Fuel Pin Storage, Revision 5
   Fuel Pin Storage, Cage Assembly, Revision 4
   Miscellaneous Details, Fuel Pin Storage, Revision 6

2. "Contribution of Pellet Rim Porosity to Low-Temperature Fission Gas Release at Extended Burnups," American Nuclear Society Topical Meeting on LWR Fuel Performance, April, 1988, Williamsburg, Virginia

3. ACI Manual of Concrete Practice, Part 2 – 1997, American Concrete Institute, Farminton Hills, Michigan.

B. Proprietary Attachments (Provided Under Separate Cover)

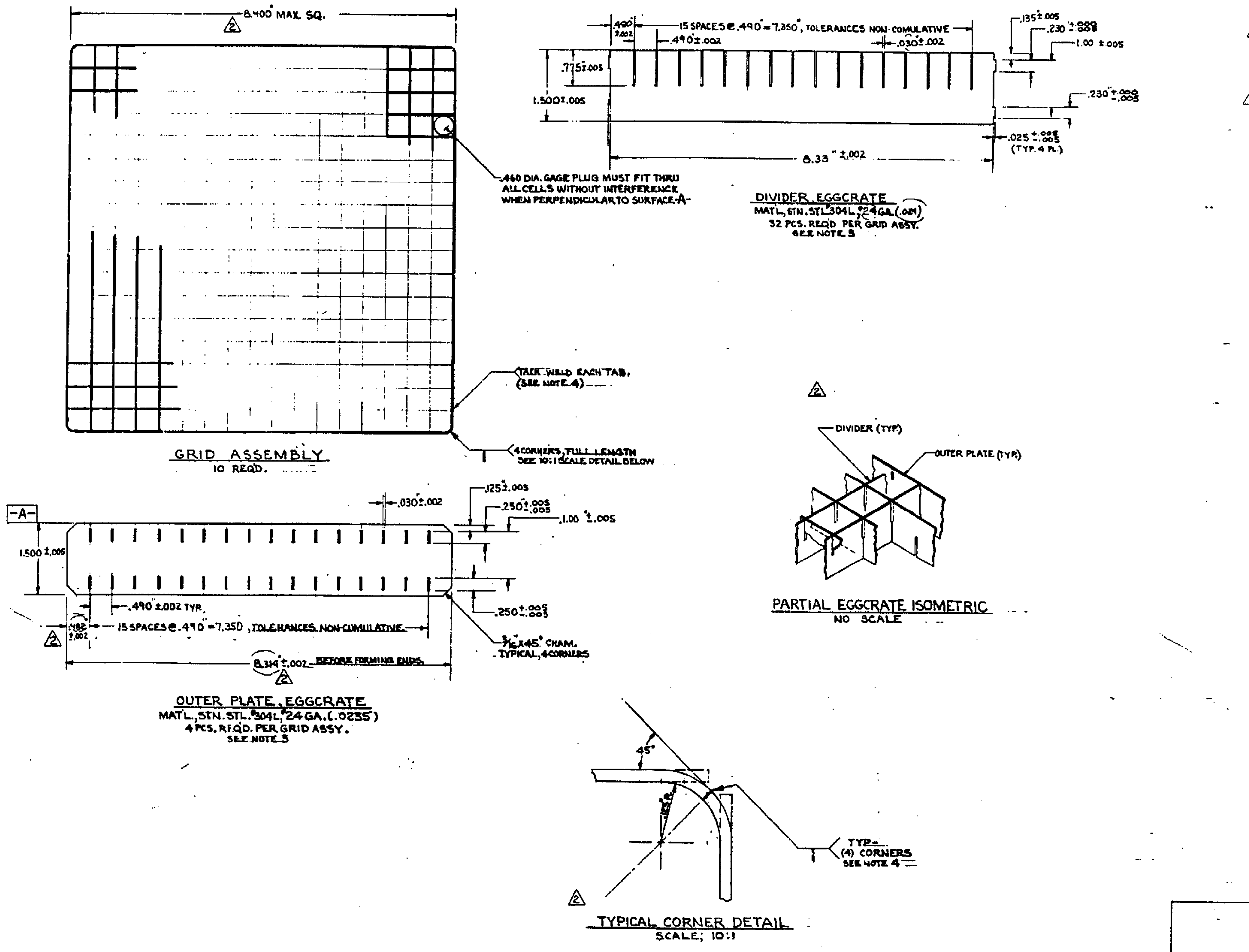
1. Evaluation of Burnup Extension in Maine Yankee Fuel

2. Evaluation of Maine Yankee Fuel Rod Oxide Thickness and Wear Measurements

3. Summary Report on Maine Yankee High Burnup Fuel (burnup between 45,000 and 50,000 MWD/MTU)

4. VCC Tip-Over Analysis for Maine Yankee (NAC Calculation 12412-2001)

MYD-00-014



NOTES

1. REMOVE ALL BURRS & SHARP EDGES

2 2.

3. MATERIAL MUST BE TESTED & ACCEPTED IN ACCORDANCE WITH PRACTICE A OF ASTM A-262, STANDARD RECOMMENDED PRACTICES FOR DETECTING SUSCEPTIBILITY TO INTERGRANULAR ATTACK IN STAINLESS STEELS.

2 4. EACH WELD SHALL SHOW EVIDENCE OF COMPLETE FUSION BETWEEN THE PARTS WITH NO EVIDENCE OF LAPS OR CRACKS AT 5X MAGNIFICATION. THE INSPECTION AREA SHALL BE ILLUMINATED TO A MINIMUM LEVEL OF 100 FOOTCANDLES.

REV. NO.	DESCRIPTION	BY	CHKD	APPR	QQAD
5	REV PER RAY SIBLEY	LFC	DLG	DPL	
4	REV PER RAY SIBLEY	DSF	MR	DPL	☒
3	REV PER RAY SIBLEY	DSF	DPL	DPL	☒
2	REMOVED NOTE 2, ADDED NOTE 4, TUNGSTEN GAS ARC WELD was BRAZE, 8.250 was 8.188, .443 was .468, 8.086 was 8.136, ADDED CORNER DETAIL	5-6-80 [illegible]	[illegible]	[illegible]	6-3-80
1	REMOVED RIBS FROM OUTER PLATE, 8.188 was 8.315	[illegible]	[illegible]	[illegible]	[illegible]

YANKEE ATOMIC ELECTRIC COMPANY
20 TURNPIKE ROAD. WESTBORO, MASSACHUSETTS
NUCLEAR SERVICES DIVISION

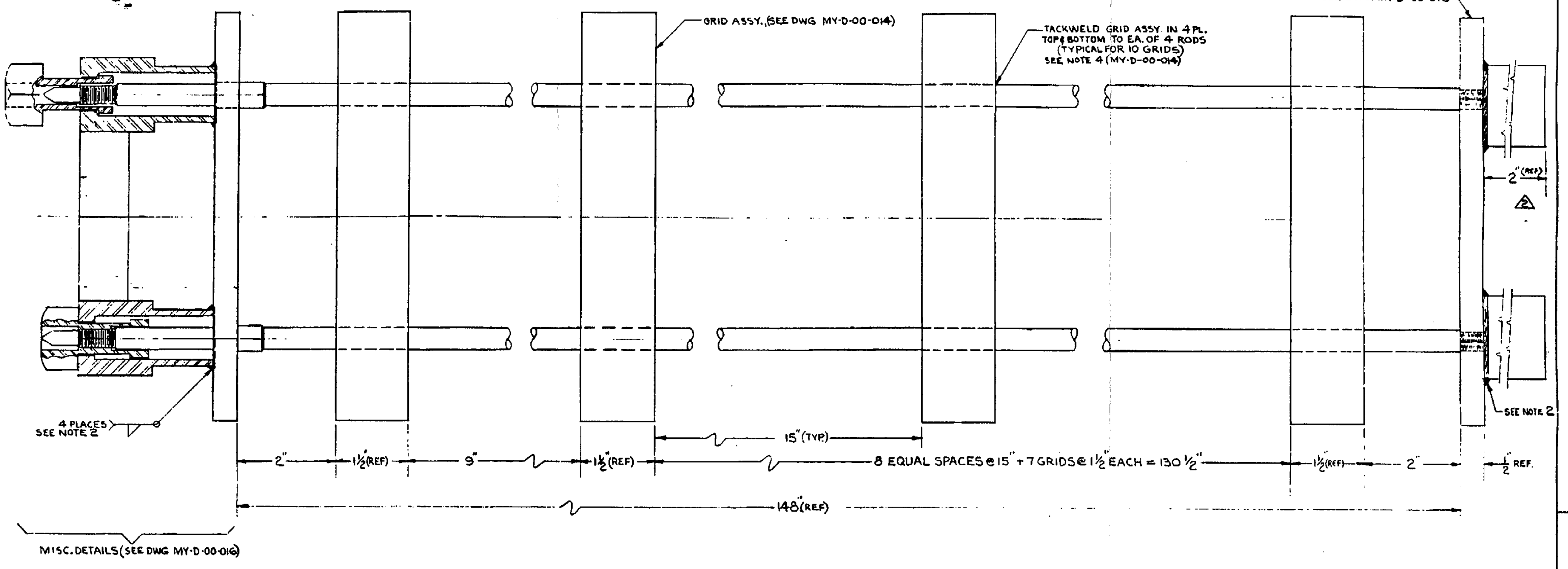
MAINE YANKEE ATOMIC POWER COMPANY
WISCASSET, MAINE.

GRID ASSEMBLY
FUEL PIN STORAGE

DESIGNED BY	DATE	CHECKED BY	DATE	ENG. APPROVAL	DATE	QQAD	DATE
E. VIDITO	4-22-79	DAR		[illegible]	7-2-79	[illegible]	7-7-79

ORIGINAL ISSUE DATE	ACCOUNT NO.	PLANT	DWG. SIZE	CATEGORY	DWG. NO.	REV. NO.
		MY	D	00	014	5

MY-D-00-015



NOTES: 1
1. ASSEMBLY TO PASS THRU AN 8.460" SQ. GAGE WITH A MAXIMUM 15 LB. DRAG.
2. FILLER MATERIAL SHALL BE #308 STN. STL.

REV. NO.	DESCRIPTION	BY	CHK'D	APPR	CQAD
4	REV PER RAY SIBLEY	1/5/89 DSF	1/5/89 MR	1/9/89 DRC	☒
3	REV PER RAY SIBLEY	[illegible] DSF	[illegible]	[illegible]	☒
2	ADDED PIPE LEGS TO BASE PL.	E.U. 5-21-80	[illegible]	[illegible]	[illegible]
1	NOTE 1, 8.310" WAS 8.4375"	[illegible]	8-21-79 E.U.	8-21-79	[illegible]

YANKEE ATOMIC ELECTRIC COMPANY
20 TURNPIKE ROAD. WESTBORO, MASSACHUSETTS
NUCLEAR SERVICES DIVISION

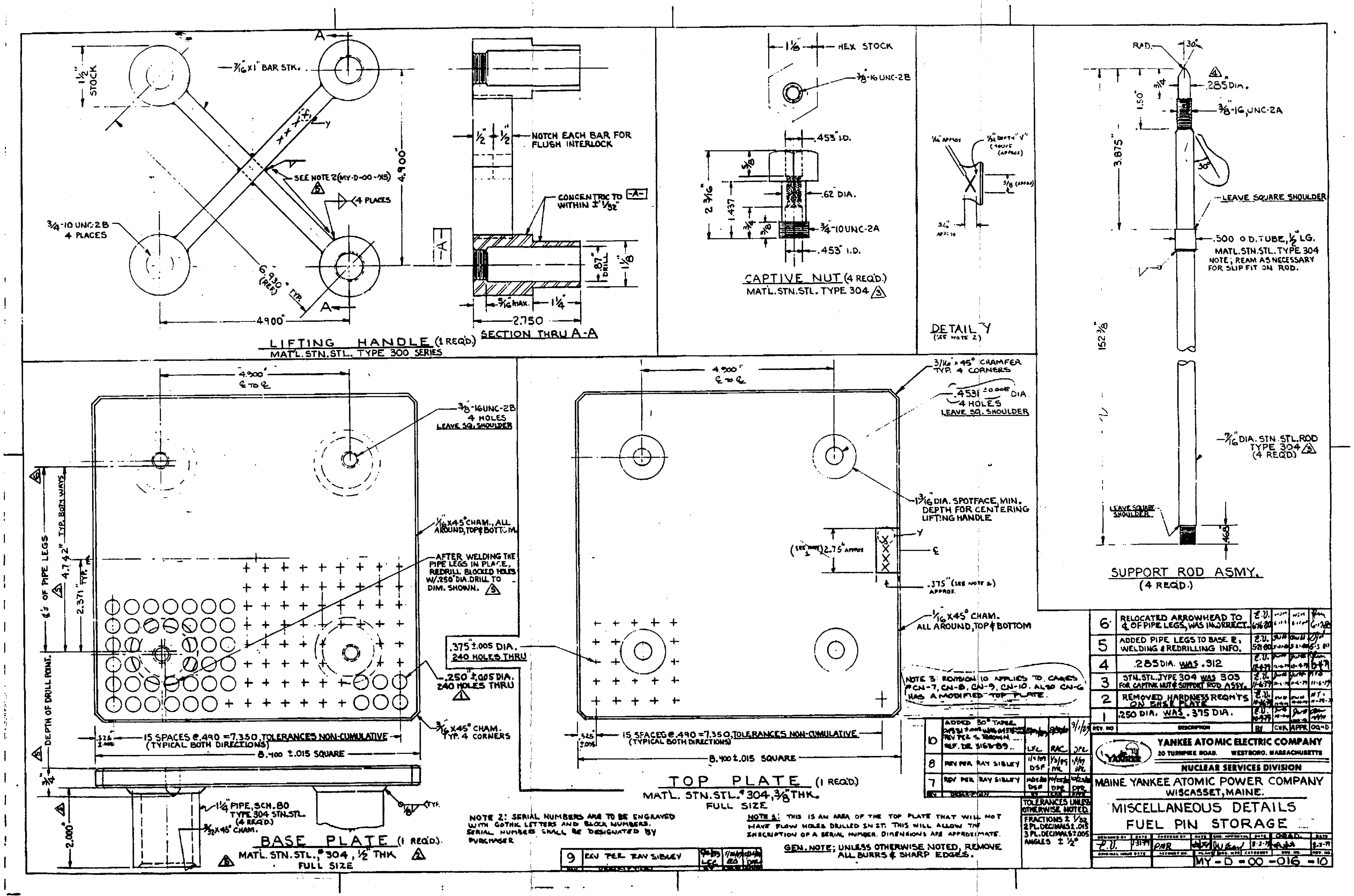
MAINE YANKEE ATOMIC POWER COMPANY
WISCASSET, MAINE.

FUEL PIN STORAGE
CAGE ASSEMBLY

DESIGNED BY	DATE	CHECKED BY	DATE	ENG. APPROVAL	DATE	CQAD	DATE
E.U.	1-31-79	OHR	[illegible]	Quillian	8-2-79	[illegible]	8-2-79

ORIGINAL ISSUE DATE	ACCOUNT NO.	PLANT	DWG. SIZE	CATEGORY	DWG. NO.	REV. NO.
		MY	D	00	015	4

MY-D-00-016



NOTE 2: SERIAL NUMBERS ARE TO BE ENGRAVED WITH GOTHIC LETTERS AND BLOCK NUMBERS. SERIAL NUMBERS SHALL BE DESIGNATED BY PURCHASER

NOTE 1: THIS IS AN AREA OF THE TOP PLATE THAT WILL NOT HAVE FLOW HOLES DRILLED IN IT. THIS WILL ALLOW THE INSCRIPTION OF A SERIAL NUMBER. DIMENSIONS ARE APPROXIMATE.

GEN. NOTE; UNLESS OTHERWISE NOTED, REMOVE ALL BURRS & SHARP EDGES.

NOTE 3: REVISION 10 APPLIES TO CAGES #CN-7, CN-8, CN-9, CN-10. ALSO CN-6 HAS A MODIFIED TOP PLATE.

REV. NO	DESCRIPTION	BY	CHK	APPR	OQ-D
10	ADDED 50° TAPER. .4531 ±.005 WAS .4375 [illegible] REV PER S. BROWN REF. DR. 5163-89	LFC	RAC	9/1/89 JPL	
9	REV PER RAY SIBLEY	LFC	RA	DPL	
8	REV PER RAY SIBLEY	DSF	ML	JPL	
7	REV PER RAY SIBLEY	DSF	DPE	DPE	
6	RELOCATED ARROWHEAD TO ℄ OF PIPE LEGS, WAS INCORRECT.	E.V. 6-16-80	WJM	WJM	6-17-80
5	ADDED PIPE LEGS TO BASE PL, WELDING & REDRILLING INFO.	E.V. 5-21-80	[illegible]	[illegible]	6-3-80
4	.285 DIA. WAS .312	E.V. 12-4-79	[illegible]	[illegible]	[illegible]
3	STN.STL. TYPE 304 WAS 303 FOR CAPTIVE NUT & SUPPORT ROD ASSY.	E.V. 11-6-79	[illegible]	[illegible]	11-6-79
2	REMOVED HARDNESS REQM'TS ON BASE PLATE	E.V. 10-26-79	[illegible]	[illegible]	[illegible]
1	.250 DIA. WAS .375 DIA.	E.V. 10-9-79	[illegible]	[illegible]	[illegible]

TOLERANCES UNLESS OTHERWISE NOTED.
FRACTIONS ± 1/32
2 PL. DECIMALS ± .015
3 PL. DECIMALS ± .005
ANGLES ± 1/2°

YANKEE ATOMIC ELECTRIC COMPANY
20 TURNPIKE ROAD. WESTBORO, MASSACHUSETTS
NUCLEAR SERVICES DIVISION

MAINE YANKEE ATOMIC POWER COMPANY
WISCASSET, MAINE.

MISCELLANEOUS DETAILS
FUEL PIN STORAGE

DESIGNED BY	DATE	CHECKED BY	DATE	ENG. APPROVAL	DATE	QRAD.	DATE
E.V.	7-31-79	PMR	[illegible]	W. Ward	8-2-79	[illegible]	8-2-79

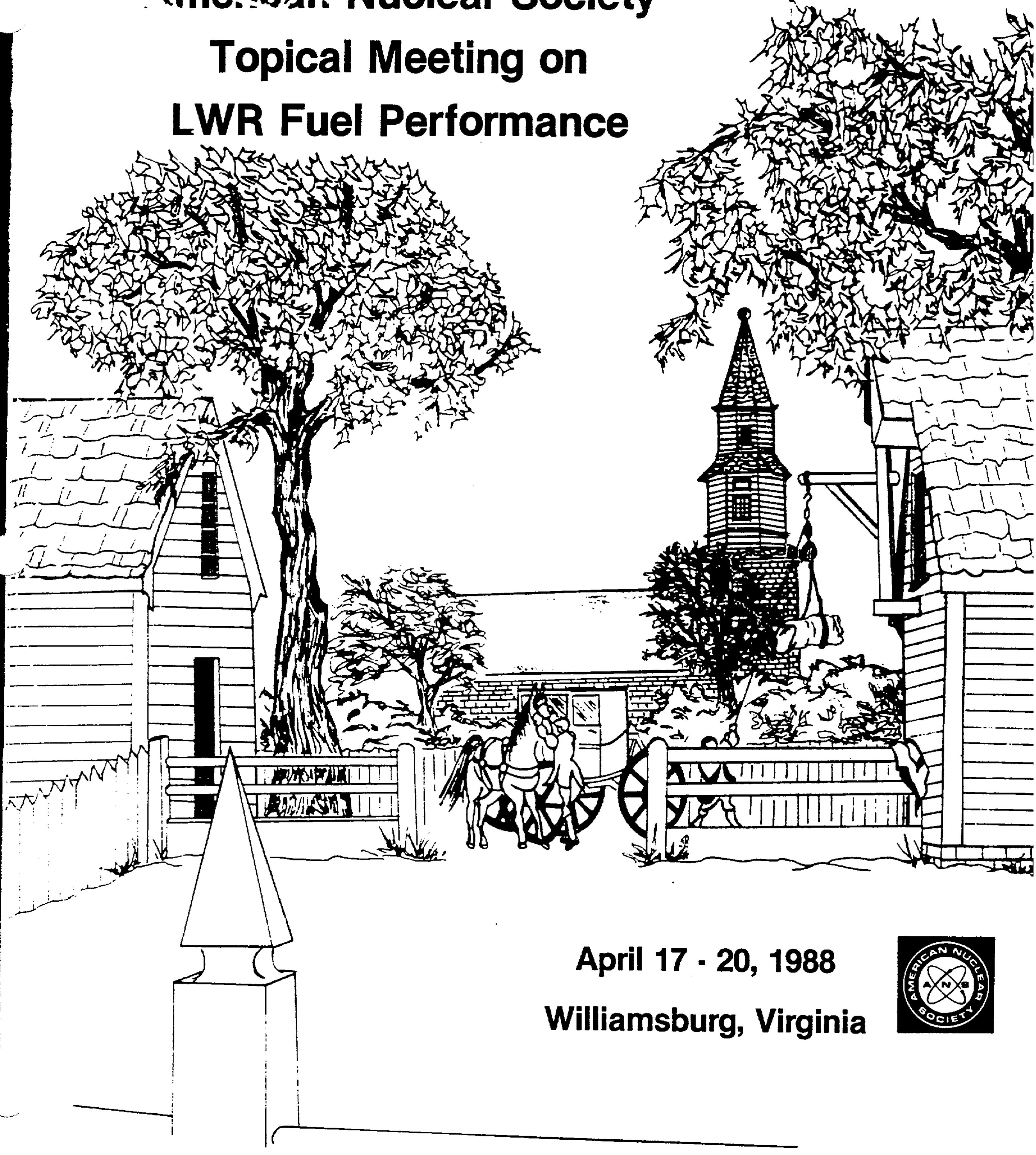
ORIGINAL ISSUE DATE	ACCOUNT NO.	PLANT	DWG. NO.	CATEGORY	REV. NO.
		MY	D	00-016	10

R.P. JORDAN

MAINE

ATOMIC Po

American Nuclear Society Topical Meeting on LWR Fuel Performance



April 17 - 20, 1988

Williamsburg, Virginia

Williamsburg Hilton & National Conference Center

CONTRIBUTION OF PELLET RIM POROSITY TO LOW-TEMPERATURE FISSION GAS RELEASE AT EXTENDED BURNUPS

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ABSTRACT

Fission gas release data are presented for PWR fuel rods that were irradiated at Fort Calhoun for six cycles with rod-averaged burnups up to 56 MWd/kgU. These data are compared to the data obtained from several other PWRs. The measurements showed that the fission gas release fraction remained low ($\leq 2\%$) for normal operating conditions. The gas release fraction exhibited a weak linear dependence on burnup up to 40 MWd/kgU, beyond which the sensitivity to burnup increased. Ceramographic examination revealed the development of a porous rim at the UO_2 pellet periphery above a pellet-averaged burnup of 40 MWd/kgU. Depletion of retained xenon concentration was observed in the porous rim compared to that in the pellet interior. High local release of fission gases from the fuel pellet rim as well as the burnup dependence of fuel rod gas release were explained by considering the role of the additional porosity through a knockout mechanism.

INTRODUCTION

Over the last decade, the batch average discharge burnup of PWR fuel has increased gradually from approximately 33 MWd/kgU to 40-45 MWd/kgU. The peak fuel rod burnup in some of the recently delivered batches of fuel is likely to exceed 50 MWd/kgU. The utilities' interest to extend the reactor operating cycle length to 24 months may promote even further increases in the burnup levels. This increase in discharge burnup has provided a greater impetus for an improved understanding of the dependence of fission gas release on burnup and fuel microstructure. Fission gas release measurements and microstructural evaluations of fuel at different levels of burnup from well-characterized fuel rods irradiated in commercial PWRs are essential for developing such an understanding.

Starting in the mid-1970s Combustion Engineering (C-E) has been involved in a number of fuel performance surveillance programs that have yielded fission gas release data from fuel rods that were characterized before irradiation with respect to fuel attributes and fuel rod design parameters. The fuel rods were irradiated in operating PWRs to a number of cycles of exposure and fission gas release was measured in a selected number of rods of each fuel-rod design at the end of each cycle of exposure. Thus, fission gas release data were obtained on the same fuel type with increasing burnup. Results from two such programs, one sponsored jointly by C-E and the Electric Power Research Institute (EPRI)[1,2] and the other sponsored by the U.S. Department of Energy (DOE) and C-E[3] were reported earlier.

Recently, under a separate program sponsored by the DOE, C-E and the C-E Owners Group Utilities, fission gas release data have been measured in fuel rods irradiated for six cycles in Fort Calhoun.[4] In order to examine the influences of the irradiated fuel microstructure on the burnup dependence of fission gas release, the microstructures of a number of fuel cross sections were evaluated in detail. In particular, above a threshold local fuel pellet burnup, the development of a high-porosity rim at the fuel-pellet

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West Mifflin, PA 15122

periphery was noted. The porosity distribution in the rim was analyzed to estimate the changes in the surface-to-volume ratio that may be occurring in the fuel and, thereby, affecting the fission gas release through the knockout mechanism.

The high burnup gas release data are discussed in this paper with an emphasis on the relationship of microstructural changes and fission product redistribution in the fuel to the observed burnup dependence of gas release. The area of the fuel pellet being analyzed has been divided into three zones to calculate fission gas released in each zone through the knockout mechanism, and, thereby, the role of the high-porosity rim formed at the pellet periphery in the low-temperature fission gas release process has been evaluated.

FISSION GAS RELEASE DATA

As part of the DOE-sponsored programs to improve fuel utilization by demonstrating increased burnup capability of standard PWR fuels in power reactors, C-E fuel of 14x14 design was irradiated in Fort Calhoun for three, four, five and six cycles. Fuel examinations, at the reactor poolside, were performed on selected assemblies during the scheduled refueling outages and selected rods were further examined at a hot cell. Twelve fuel rods, with nondensifying fuel of 95% theoretical density, were irradiated for three to five cycles and punctured for the measurement of fission gas release at burnup levels of 29.4 to 48.3 MWd/kgU. Fission gas release data from these fuel rods were reported earlier.[2-3] Fission gas release data from an additional twelve fuel rods irradiated for six-cycles (burnups up to 55.7 MWd/kgU) have recently been obtained.[4] The fission gas release fractions (based on the inventory at the end of life) together with time-averaged heat ratings and rod-averaged burnups for the six-cycle rods are given in Table 1.

The data in Table 1, show that the fission gas release from the six-cycle Fort Calhoun fuel rods remained low (<1.4%) up to rod-averaged burnups of 55.7 MWd/kgU.

Fission gas release data obtained from the Fort Calhoun fuel rods can be compared with the previously published data obtained from Calvert Cliffs-1[1,2] since the pressurized fuel rod design was used in the both sets of fuel rods and the linear heat generation rates for most of the operating periods were comparable. Data from the Fort Calhoun fuel rods (including the

Table 1. Fission Gas Release Data On Six-Cycle Fort Calhoun Fuel Rods.

Rod Number	Rod-Averaged Burnup MWD/kgU	Rod Time-Avg. Heat Rating W/cm (kW/ft)	Fission Gas Released Fraction, %[a]
KJD008	51.5	164 (5.38)	0.68
KJD015	51.4	152 (4.98)	0.56
KJD072	53.4	156 (5.12)	0.62
KJD075	51.5	-[b]	0.67
KJE051	55.7	163 (5.36)	1.26
KJE077	55.4	164 (5.39)	1.33
KJE052	54.6	160 (5.25)	0.91
KJE006	49.7	159 (5.23)	0.95
KJE109	52.9	160 (5.26)	1.31
KJE068	52.6	-[b]	0.78
KJE089	53.1	168 (5.50)	1.15
KJE088	52.9	166 (5.45)	1.04

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[a] Assumes production rate of 30 atoms of Xe+Kr per 100 fissions and 200 MeV per fission.

[b] Data used to calculate the time-averaged heat rating are not available for these rods.

three- through five-cycle data obtained earlier) are plotted against burnup in Figure 1 together with the data obtained from 23 Calvert Cliffs-1 fuel rods. The two data sets show consistently low fission gas release, i.e., less than about 2% gas release up to burnups of ~56 MWd/kgU. Note that the vertical axis of Figure 1 is expanded so that finer variations in the fission gas release values and burnup dependence are discernible. All fission gas release data points represented in the figure are less than or equal to 2% and, therefore, the discussion pertains to release behavior in the low gas release regime. Figure 1 shows a weak linear dependence of fission gas release fraction with burnup up to about 40 MWd/kgU and a somewhat greater dependence with burnup above that level. The correlation between the as-fabricated open porosity and the extent of fission gas release, previously reported for Calvert Cliffs-1 fuel rods at lower burnups,[2] appears to be applicable for the six-cycle Fort Calhoun data. This point is discussed further in a later section.

COMPARISON WITH DATA FROM OTHER PWRs

The fission gas release data from C-E fuel rods irradiated in Calvert Cliffs-1 and Fort Calhoun are compared with the available data from seven other PWRs (H. B. Robinson,[5] Point Beach-1,[6] Oconee-1,[7] Oconee-2,[8] Surry,[9] Zion,[9] and Zorita,[10]) in Figure 2.

In the case of the Calvert Cliffs-1 data, differences in individual release values observed within a given set of fuel rods could be related to differences in operating histories and fuel microstructures among the different rods.[1] However, at any burnup, the spreads in gas release among the Calvert Cliffs-1 and Fort

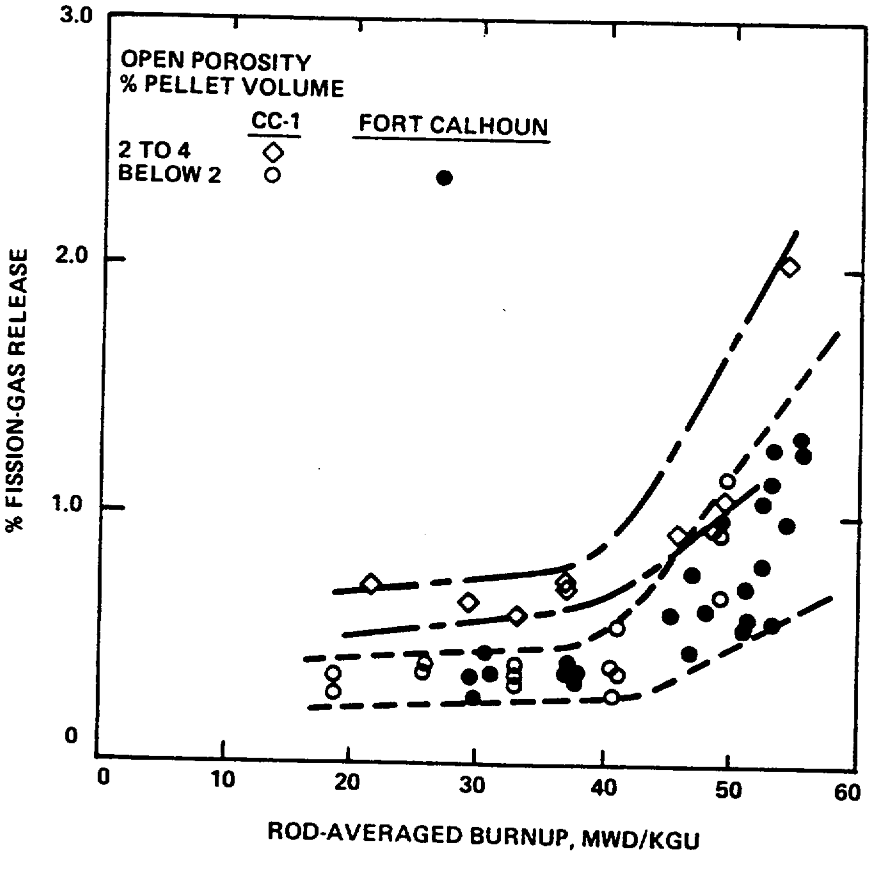

Figure 1. Fission gas release as a function of rod-averaged burnup for fuel rods irradiated Calvert Cliffs-1 and Fort Calhoun.

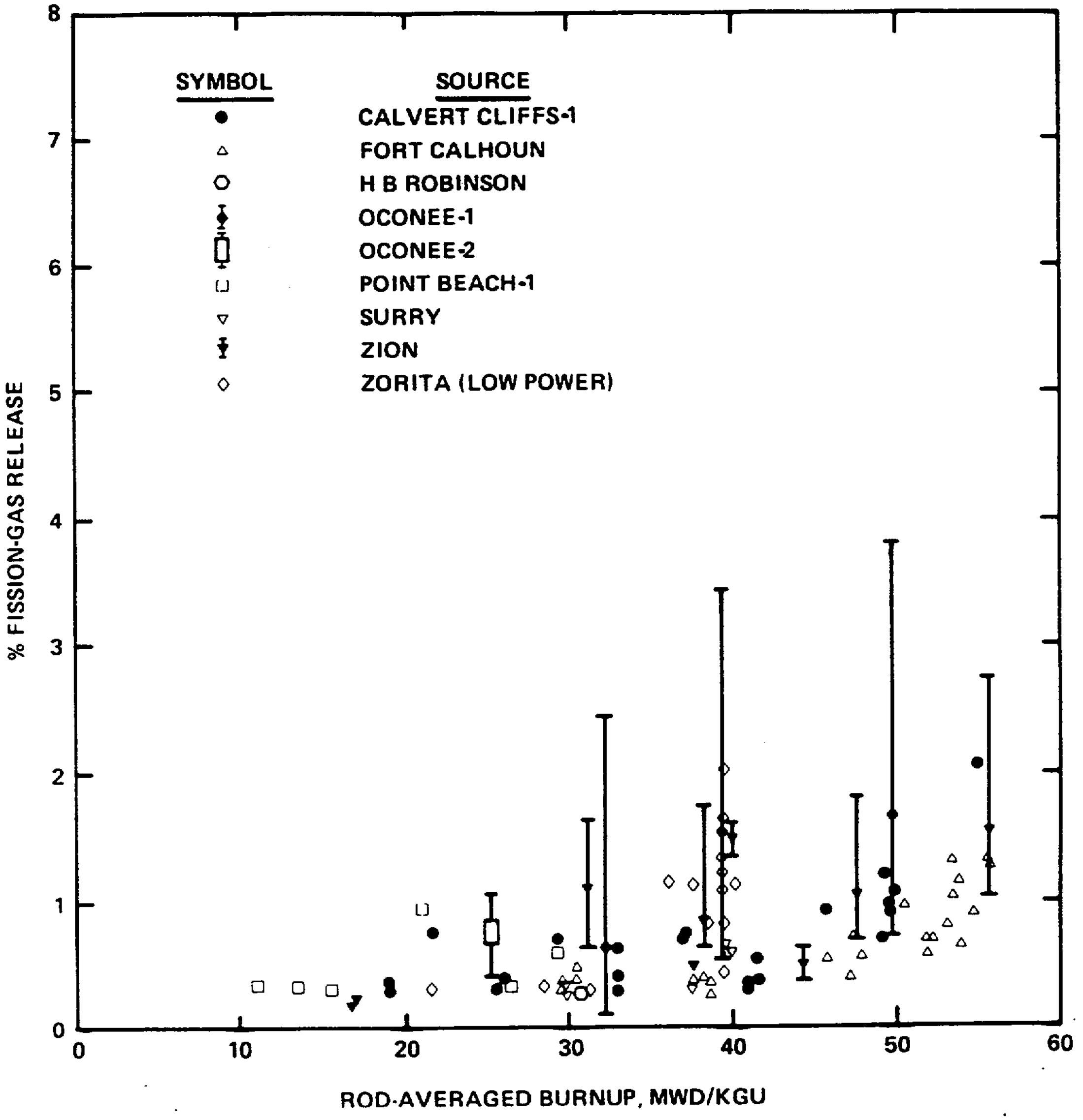

Figure 2. Fission gas release as a function of rod-averaged burnup for PWR fuel Rods.

Calhoun data sets are smaller than some of the other sets. For example, in the 50 MWd/kgU regime, the spread in gas release for the Calvert Cliffs-1 fuel rods is 0.6% compared to approximately 3% (absolute) for Oconee-1 fuel rods. The variability in Oconee-1 data has been attributed by the authors[7] to differences in heat rating arising from location variations of the rods within the fuel assembly. Fuel microstructural examinations also showed a significant amount of grain growth in the central part of fuel pellets in the higher gas release rods and no such grain growth was observed in the lower gas release fuel.[7] In the case of Calvert Cliffs-1 fuel rods, the differences in heat rating among the rods were relatively minor, especially after the first cycle, and this resulted in a relatively narrow spread in gas release values.

BURNUP AND MICROSTRUCTURAL DEPENDENCES OF FISSION GAS RELEASE

As shown in Figure 1, there appears to be a correlation between the extent of fission gas release and as-fabricated open porosity. At a given burnup, higher fission gas release values are associated with higher open porosity values. The absolute values of gas release and a lack of a pronounced increase in gas release fraction with burnup are consistent with the power history of both rod groups in Figure 1. The heat ratings for both groups of rods decreased with increasing cycles of exposure. This led to decreasing fuel temperatures with increasing burnups. Thus, low fuel temperatures, that prevailed for most of the operating periods beyond the first cycle, were primarily responsible for the low gas release values observed in all of these rods.

The experimental evidence for low fuel operating temperatures includes a lack of significant grain growth in the UO_2 as revealed by ceramography and an absence of volatile fission product (Cs) gamma activity peaks at pellet/pellet interfaces on axial gamma scans.[3,4] At these low temperatures (below 873 to 1073°K or 1112 to 1472°F), the contribution to fission gas release from processes other than knockout and recoil were minimal. The insensitivity of gas release to grain sizes (Calvert Cliffs-1 fuel grain size ranged from 2.5 to 15 μm, Fort Calhoun fuel grain size ranged from 12 to 14 μm) suggests that the diffusional contribution to gas release was minimal and supports the dominance of knockout and recoil mechanisms. However, in one set of rods with higher enrichment (and therefore higher heat ratings during the first cycle) there were indications of a diffusional contribution to the total amount of gas released during the first cycle.[1] This diffusional contribution to the total end-of-life gas release fractions was accounted for in the calculations using the knockout model discussed later.

Based on the theoretical considerations related to the knockout and recoil mechanisms, the fission gas release fraction is expected to be linearly dependent on burnup and on the surface-to-volume ratio in the fuel.[11] Both of these relationships are observed to be valid for the data presented in Figure 1.

A higher rate of increase in gas release fraction with burnup is observed at rod-averaged burnups greater than 40 MWd/kgU. This is believed to be related to the new porosity developing near the outer surface of fuel pellets at these burnups.

CERAMOGRAPHY AND QUANTITATIVE ANALYSIS

The microstructures of a number of fuel cross sections were examined by optical ceramography at the hot-cell facilities of Battelle Columbus Laboratories. To study the evolution of microstructure with increasing burnups, fuel cross sections were obtained from four-, five- and six- cycle fuel rods. In a few cases, several cross sections obtained from different axial elevations from the same fuel rod were examined. The microstructure was examined at the pellet periphery, pellet center and several intermediate radial positions. Specimens were examined in the as-polished condition to evaluate the as-irradiated porosity distribution. Specimens were also examined in the chemically-etched condition to examine the grain structure and the evidence for possible radial transport of fission products. Microstructural observations for burnups up to 45 MWd/kgU have been described earlier.[2-3] Recent observations[4] on higher-burnup (>45 MWd/kgU) fuel are presented below.

At these higher burnups, the as-polished fuel microstructures at the pellet periphery and the pellet interior were distinctly different. Microstructures at the periphery, mid-radius and center of a UO_2 pellet (pellet-averaged burnup ~60 MWd/kgU) from a six-cycle Fort Calhoun fuel rod are shown in Figure 3. At the pellet cladding interface, a dense pore-free interaction layer is formed which was not present at lower (<45 MWd/kgU) burnups. In the pellet rim, adjacent to the interaction layer, new, intragranular, round-shaped porosity (pore size up to 1μm) was observed. Such porosity was not observed at the pellet mid-radius or center. The thickness of the porous rim was estimated from several micrographs and was of the order of 150 to 250 μm. These specimens were taken from fuel rods listed in Table 1. Some as-fabricated micropores (6 to 15 μm) remained even at these high burnups (above 50 MWd/kgU) at all radial locations in the pellets. Also, near the pellet periphery, some needle-shaped features were observed in the fuel microstructure. Although the oxygen concentration along the pellet radius was not measured, these needle-shaped microstructural features may be associated with the U_4O_9 phase formed under hyperstoichiometric conditions.[12,13] In the center of the fuel pellet, where temperatures were highest, very fine pores (size of the order 0.1 μm) were observed apparently decorating the UO_2 grain boundaries. Due to the long residence time in reactor,some migration of fission gases to the grain boundaries was occurring, even at the low fuel operating temperatures (~873°K or 1112°F). Decoration of grain boundaries by fine pores at the pellet center indicates an increase in the surface

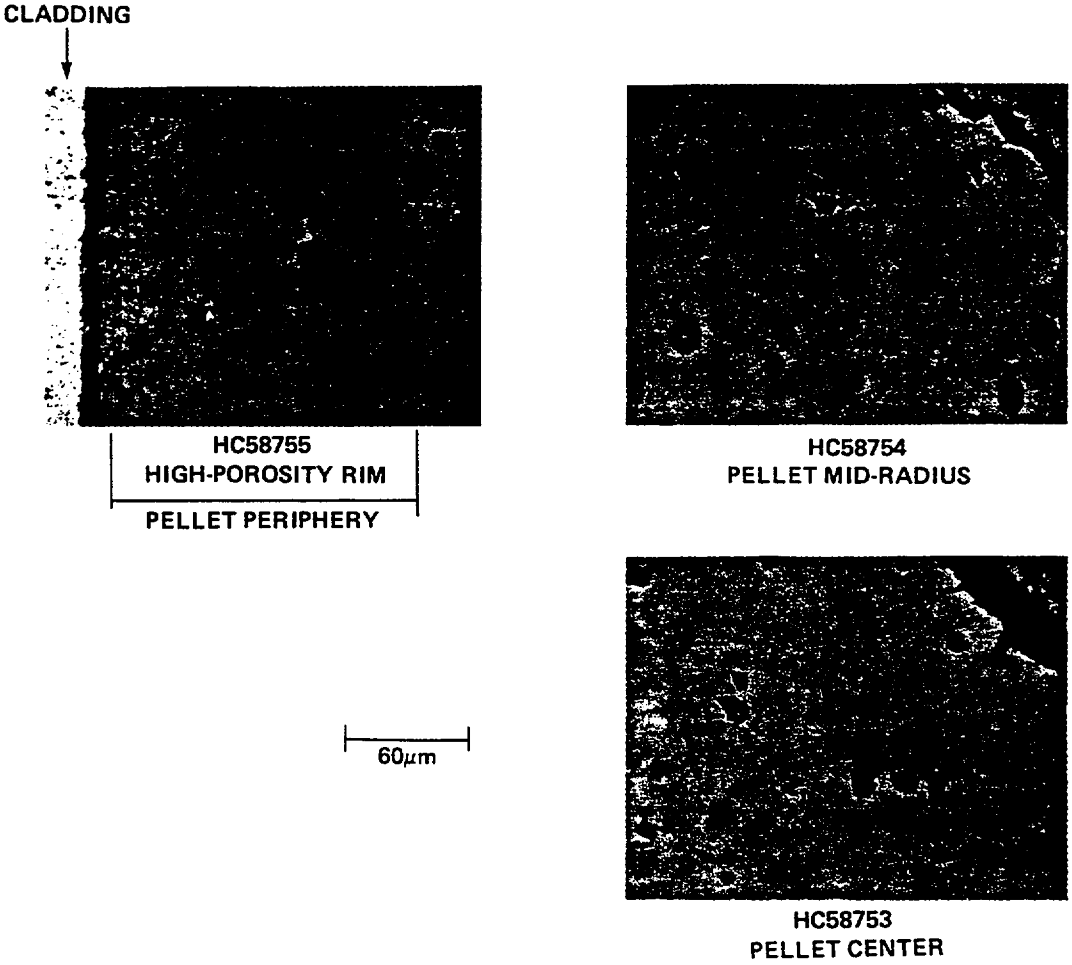

Figure 3. As-polished microstructures at the periphery, mid-radius and center for a pellet irradiated to a pellet-averaged burnup of 60.1 MWd/kgU in Fort Calhoun.

area per unit volume over the as-fabricated value. However, a quantitative evaluation of pore volume fraction, or pore surface area, at the pellet center was not possible.

Micrographs from the pellet rim area were subjected to quantitative microscopic analysis to estimate the pore volume fraction in the rim as well as to calculate the pore surface area per unit pellet volume. A line grid was imposed on several high magnification (500x) pictures of the rim. The pore volume fraction was estimated by the point count method. The estimated pore volume fractions in the rim region of several fuel pellets are given in Table 2. The average pore volume fraction of the rim was generally 22%. For this volume fraction, experimental evidence[14] implies a significant interconnection between pores. These observations suggest that a significant fraction of the fine rim porosity was open to the fuel pellet surface through interconnection.

The surface area of the newly-generated pores per unit pellet volume (S_v) was estimated by counting the number of intersections per unit length of random lines with the pore boundaries (N_L). The classical relationship[15] of $S_v = 2N_L$ was used to calculate S_v and the values are given in Table 2. On the average, the pore surface area per unit pellet volume in the rim region was approximately 7800 cm^2/cm^3.

Examination of chemically-etched fuel microstructures of high burnup (~60 MWd/kgU) pellets, showed that fuel grain size at all radial locations was close to the as-fabricated fuel grain size, and

Table 2. Quantitative Microscopic Data on the Rim Region of UO_2 Pellets Irradiated in Fort Calhoun.

Fuel Rod Number	Pellet Elevation From The Rod Bottom cm	Pellet-Averaged Burnup MWd/kgU	Pore Volume Fraction, %	Surface Area of Pores Per Unit Pellet Volume, cm^2/cm^3
KJE051	259	60.1	21.4	7480
KJD015	239	58.0	23.5	8690
KJD015	239	58.0	22.2	7640
KJE089	259	56.3	22.7	7640
KJE089	259	56.3	22.7	7680
KJE089	259	56.3	20.2	-[a]
KJE089	259	56.3	23.5	-[a]

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[a] The microphotograph covered an insufficient area of the rim region so that a meaningful calculation of the pore surface area in the rim was not possible.

therefore, no grain growth was evident. The lack of fuel grain growth and the absence of solid fission product particles in the microstructure are consistent with the low power levels experienced by these PWR fuel rods.

The etching response of different radial regions of the high burnup (>45MWd/kgU) pellets was distinctly different. In order to reveal the microstructure, it was necessary to increase the etching time with increasing radial distance from the pellet/cladding interface. This observation gave the first indication that the chemical composition was varying across the fuel pellet radius. Microprobe examinations were made to characterize the fission product distribution.

MICROPROBE ANALYSIS

Cross sections in the form of thin UO_2 discs were examined with an electron microprobe analyzer to measure the fission product distribution within fuel pellets. As expected, the plutonium concentration was higher at the pellet periphery than at the pellet center. The radial profile of retained xenon concentrations was similar to that of plutonium, i.e., the concentration of retained xenon was higher in outer regions of the pellets. For fuel pellets from rods with fission gas release values of <1% and local pellet-averaged burnups up to 49 MWd/kgU, xenon depletion (relative to the pellet interior) was not observed at the pellet periphery, and the plutonium concentration at the pellet periphery was less than 2.20 w/o. For fuel pellets from rods with fission gas release values above 1%, the plutonium concentration at the pellet periphery was between 2.3 and 2.6 w/o, and xenon depletion was observed over a peripheral ring of approximately 300 μm in thickness.

The xenon concentration measured as a function of radius for a fuel pellet from the latter group of rods (with fission gas release values above 1%) is shown in Figure 4. Also shown in the figure is an estimated profile of generated xenon that was derived from the radial burnup distribution. The burnup distribution was calculated from the time-dependent radial power profiles as discussed later. For the estimated profile of generated xenon, the approximately 9% higher yield of xenon from plutonium fissions relative to uranium fissions was not considered. Also, the reduction in the fissile atom density due to the development of porosity near the fuel pellet periphery was not included in the estimate. The generated xenon inventory in the rim would have been reduced by approximately 5%, had this factor been taken into account. The combined effect of the above two factors was considered negligible for this study.

An inspection of Figure 4 shows that there are discrepancies between the retained and the generated xenon profiles in the interior region of the examined fuel

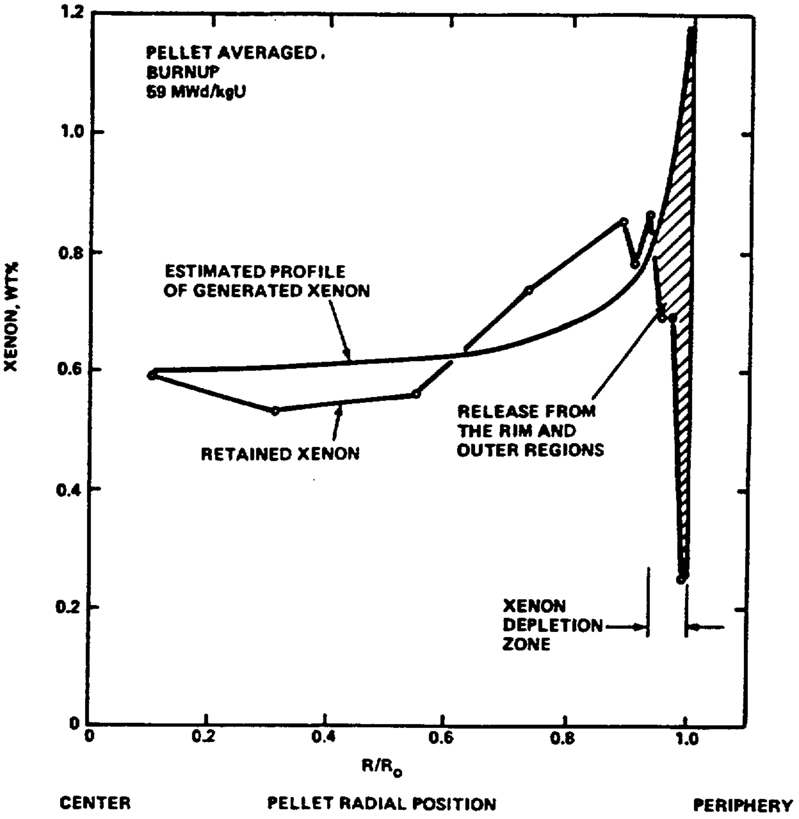

Figure 4. Radial distribution of xenon in a UO_2 pellet with pellet-averaged burnup of 59 MWd/kgU.

pellet. These discrepancies are believed to be largely associated with the experimental errors in the measured values. These discrepancies are relatively small compared to the large depletion in xenon inventory that is observed in the peripheral region of the fuel pellet. Comparing the profiles of retained and generated xenon in Figure 4, the average release fraction of xenon for the porous rim and outer surface region (hatched area in the figure) is approximately 40%. Thus, there was correspondence among (1) higher gas release to the rod plenum, (2) higher pellet surface plutonium concentration, and (3) xenon depletion at the pellet periphery. The thickness of the xenon-depleted region was approximately the same as the thickness of the porous rim.

Higher pellet surface plutonium concentration would result in a higher surface fission rate in the pellet. This leads to a significantly higher power and local burnup (fission product inventory) in the pellet periphery compared to that in the interior. It is hypothesized that the higher concentration of insoluble xenon atoms the pellet periphery helps to stabilize the radiation-induced vacancies into intragranular, spherical-shaped, fine pores. When the porosity volume fraction is significant (∿22%), the resulting interconnection between the pores facilitates release of xenon to the rod plenum. Local chemistry variations within the pellet may be influencing the above process. The depletion of retained xenon in the porous rim suggests an association between the higher pore surface area measured in the rim regions and the higher release of xenon to the rod plenum.

MICROSTRUCTURE DEPENDENT KNOCKOUT MODEL

A knockout model for fission gas release was used to quantitatively evaluate the contribution of the additional surfaces created in the fuel pellets to the fission gas release. The knockout mechanism is operative with species that are near surfaces that have paths to the fuel rod internal void space. The fraction that is released is proportional to the surface area available for knockout, and can be represented by:[11]

$$F = C\,(S/V)ft \qquad (1)$$

where

F = fraction released from the fuel
S = surface area available for release by knockout
V = fuel volume associated with surface S
f = fission rate per unit volume of fuel
t = time
C = proportionality constant

To account for the observed radial variation in porosity, a model was developed that divided the fuel pellet cross section into three radial regions: (See Figure 5) (1) a 5 μm thick region at the outer pellet surface (the thickness of this region was selected to take into account the release due to knockouts occurring within the linear travel distance of fission fragments from the pellet outer surface), (2) a 200 μm thick porous rim inside and adjacent to the surface region, and (3) an interior region occupying the balance of the pellet cross section. Time-dependent radial power profiles that took into account flux depression and the buildup of plutonium in the peripheral regions of the pellet were used to calculate the knockout rate and the rate of generation of stable fission products in each of the three regions.

Fission gas release and irradiation history data obtained in an earlier program[1,2] for five fuel rods irradiated from one to five cycles in a PWR were used in these calculations. The measured fission gas release values for this set of rods, which had the same fuel type and irradiation histories, were within 0.7% up to three cycles and increased to 2.0% at the end of five cycles. Data on the operating history of these fuel rods are summarized in Table 3. The radial power and burnup distributions that resulted from flux depression and plutonium generation are also shown. For example, for a

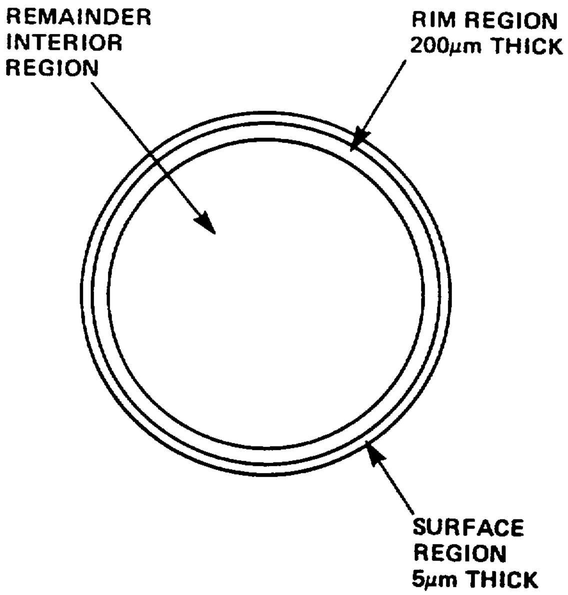

Figure 5. A schematic representation of the three pellet zones used to calculate the fission gas release by knockout mechanism.

Table 3. Fission Gas Release Calculation Using a Knockout Model With a Three-Zone Pellet For Fuels Irradiated for One to Five Cycles.

No. of Cycles	Cycle Length Days	Cycle-Average Linear Heat Rating[a], W/cm		Cumulative Burnup MWd/KgU		Surface-to-Volume[b] Ratio, cm^{-1}		Calculated Gas Release, %				Measured Fuel Rod Gas Release[c] %
		Rod-Averaged	Rim	Pellet-Averaged	Rim	Inner	Rim	Inner	Rim	Outer Surface	Total	
1	817	223	364	23.7	38.9	10	10	0.5	0.6	57.4	0.7	0.7
2	1117	117	308	30.7	50.9	10	10	0.4	0.5	48.0	0.6	0.6
3	1499	159	279	38.3	64.8	116	1746	0.5	4.2	42.1	0.8	0.7
4	1961	135	246	46.4	79.7	265	3983	0.6	11.6	38.3	1.3	0.9
5	2422	128	233	54.1	93.7	520	7800	0.9	21.7	35.7	2.1	2.0

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[a] The operating history is specifically for the five-cycle fuel rod showing 2.0% gas release at the end of fifth-cycle.

[b] For the outer surface region, the surface-to-volume ratio was kept constant at the value equal to 2000 cm^{-1}. This value was derived by dividing the geometric surface area by the volume of the outer ring region for a right cylinder.

[c] The gas release values for one through five cycles are from fuel rods of identical design irradiated concurrently in the same reactor in symmetrical positions with nearly identical operating history.

pellet-averaged burnup of 54 MWd/kgU, the calculated burnup in the porous rim region of the pellet approaches 94 MWd/kgU (averaged over the rim region thickness of 200 μm).

Using Equation (1), the fractional fission gas released for each of the three regions of fuel pellet cross sections was calculated. The total release was obtained by weighting the local release by taking into account the appropriate volume fractions of fuel and the respective inventories. Constant C was evaluated by equating the calculated release with the release measured in the one-cycle rod after subtracting a 0.35% fractional release to account for the diffusion-induced component. The diffusional release component was estimated from comparison of time-dependent temperature histories and fission gas release measured at the end of one cycle of exposure in several sets of fuel rods, irradiated concurrently in the same fuel assembly as that of the subject rods in Table 3.[1]

Calculations of release due to knockout for each cycle of operation were performed and the results are shown in Table 3. For the Cycle 1, an S/V value of 10 cm^{-1} was used for the rim and inner regions. Typically,[11] S/V of 6 cm^{-1} is assumed for LWR fuel in the as-fabricated condition. A value of 10 cm^{-1} was used in the current investigation considering that this fuel had higher open porosity compared to other batches of fuel.[1] As shown in Table 3, use of the same S/V as that for Cycle 1 provided a close agreement between the calculated and measured releases for the two-cycle fuel rod. Beginning with Cycle 3, increases in the S/V in the rim and interior regions of the fuel pellet were needed to obtain agreement with the measured gas release values. No quantitative microscopic data on porosity distribution were available for comparison of inferred surface-to-volume ratios to the measured values in the burnup range for three and four cycles. For the five-cycle fuel (pellet-averaged burnup of 54 MWd/kgU), a surface area per unit volume increase in the rim region to 7800 cm^{-1} and an increase to 520 cm^{-1} in the inner region were sufficient to account for the observed enhancement in fission gas release. The above value of surface-to-volume ratio for the rim region is consistent with the average measured value deduced from the data in Table 2. The high value of 21.7% gas release calculated for the rim region of the fuel pellet with a pellet-averaged burnup of 54 MWd/kgU is qualitatively consistent with the xenon concentration profile shown in Figure 4.

No data were available on the surface-to-volume ratio associated with the fission product induced porosity in the inner region of the fuel pellets. For calculations, beginning with Cycle 3, this parameter was kept constant at 1/15 of the value for the rim region. The use of this ratio resulted in a surface-to-volume ratio of 520 cm^{-1} at the end of five cycles. It is of interest to compare the above value with the ratio of the grain boundary surface to the grain volume ratio associated with the grain size of this fuel. Using the measured as-irradiated grain size of 15 μm, a surface to-volume ratio of 1300 cm^{-1} is obtained using the same relationship as used for estimating surface-to-volume ratios of pores. The above considerations suggest that approximately 40% (i.e. 520/1300) of the grain boundary area is covered with fission gas bubbles. This is qualitatively consistent with the extent of decoration of grain boundaries with fission gas bubbles that was observed in the inner region of the fuel pellets examined.

It is of interest to note that, in addition to providing additional surface for the release of fission gases, the highly porous rim region filled with low-conductivity fission gases may affect the temperature distribution in high burnup fuel. Data on the kinetics of the evolution of the porous rim with additional characterization of the porosity and fission product distribution in the rim region would be valuable. Such information would lead to an improved understanding of the impact of the pellet-rim porosity on the overall performance of high burnup UO_2 fuel.

CONCLUSION

The following conclusions have been reached as a result of this work:

- Recently-obtained fission gas release data from fuel rods irradiated in the Fort Calhoun reactor to burnups up to 56 MWd/kgU showed similarities to previously obtained data, that is, fission gas release fractions remained low ($\leq$ 2%) and the burnup dependence accelerated beyond 40 MWd/kgU.
- Ceramographic examination of fuel pellets revealed that, for pellet-averaged burnups greater than about 40 MWd/kgU, a porous rim formed at the UO_2 pellet periphery. The thickness of porous rim varied between 150 to 250 μm. The surface-to-volume ratio associated with the porous rim was several hundred times larger (∿800) than that associated with the as-fabricated porosity.
- Although the overall gas release in fuel rods remained low, high local release fractions were observed in the porous rim region (averaging about 40% over this region which had calculated average burnup of 94 MWd/kgU corresponding to a pellet-averaged burnup of ∿ 54 MWd/kgU).
- The high local gas release in the pellet rim and the observed burnup dependence of gas release could be accounted for with a knockout model that took into consideration evolution of porosity with burnup at different radial locations within the pellet.

ACKNOWLEDGEMENTS

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Foreword

This report is the authoritative glossary for cement and concrete technology. It is to be used generally and specifically in ACI technical communications, correspondence, and publications. One mission of Committee 116 is to produce and maintain a list of terms with their meaning in the field of cement and concrete technology.

Committee 116 has tried to produce a glossary that will be useful, comprehensive, and up-to-date. However, it recognizes that the listing may not be complete and that some definitions may be at variance with some commonly accepted meanings.

Users of the glossary are invited to submit suggestions for changes and additions to ACI Headquarters for consideration by Committee 116 in preparing future editions. In the event that a user disagrees with any of the definitions, it is hoped that the reasons for such will be given to the committee.

The committee is aware that some of the definitions included may seem entirely self-evident to an expert in the concrete field. This occurs because no term has been discarded if there was reason to believe it would appear to be technical in nature to a casual reader of the ACI literature.

In November 1986 the committee voted to use the following editorial rules:

1. Each definition shall be stated in one sentence.
2. Each definition shall consist of the term printed in boldface, a dash, and the definition statement.
3. The definition statement does not repeat the term and should state the class or group and identify the features unique to the term; as "mathematics—the science of numbers and spaces."
4. Verbs should be stated in the infinitive rather than the participle, for example the term to be defined should be "abrade" not "abrading."
5. Notes may be appended to definition statements.
6. Cross references may take the place of a definition as "green concrete—See concrete, green." They also may call attention to related items as "flint—a variety of chert. (See also chert)."
7. Generally where there are a number of terms, the last word of which is the same, the definitions are given where the terms are given in the inverted form as "cement, low-heat" rather than "low-heat cement" but under the latter entry there will be a cross reference "See cement, low-heat."

The invaluable contributions of the past chairmen of Committee 116, R. D. Mielenz, D. L. Bloem, W. H. Price, R. E. Davis, Jr., J. R. Dise, K. F. Gibbe, and Robert L. Henry as well as those of all the present members and especially the unusually diligent efforts of Henri Isabelle, Bill Lorman, Jim Libby, and Lew Tuthill, are gratefully acknowledged.

For drafting this edition, all members, both associates and voting, participated.

This report supercedes ACI 116R-85.

bond breaker—a material used to prevent adhesion of newly placed concrete and the substrate. (See also **form oil** and **release agent.**)

bond length—see **development length.**

bond plaster—a specially formulated gypsum plaster designed as first coat application over monolithic concrete.

bond prevention—measures taken to prevent adhesion of concrete or mortar to surfaces against which it is placed.

bond strength—resistance to separation of mortar and concrete from reinforcing and other materials with which it is in contact; a collective expression for all forces such as adhesion, friction due to shrinkage, and longitudinal shear in the concrete engaged by the bar deformations that resist separation.

bond stress—the force of adhesion per unit area of contact between two bonded surfaces such as concrete and reinforcing steel or any other material such as foundation rock; shear stress at the surface of a reinforcing bar, preventing relative movement between the bar and the surrounding concrete.

bond stress, average—see **average bond stress.**

bond stress, development—see **anchorage bond stress.**

bonded member—a prestressed concrete member in which the tendons are bonded to the concrete either directly or through grouting.

bonded post-tensioning—post-tensioned construction in which the annular spaces around the tendons are grouted after stressing, thereby bonding the tendon to the concrete section.

bonded tendon—a prestressing tendon which is bonded to the concrete either directly or through grouting.

bonder—a masonry unit which ties two or more wythes (leaves) of a wall together by overlapping. (See also **header** and **wythe (leaf).**)

bonding agent—a substance applied to a suitable substrate to create a bond between it and a succeeding layer as between a subsurface and a terrazzo topping or a succeeding plaster application.

bonding layer—a layer of mortar, usually ⅛ to ½ in. (3 to 13 mm) thick, which is spread on a moist and prepared, hardened concrete surface prior to placing fresh concrete.

bored pile—see **drilled pier**.

boron frits—clear, colorless, synthetic glass produced by fusion and quenching, containing boron. (See also **concrete, boron-loaded.**)

boron-loaded concrete—see **concrete, boron-loaded**.

box out—to form an opening or picket in concrete by a box-like form.

brace—a structural member used to provide lateral support for another member, generally for the purpose of assuring stability or of resisting lateral loads.

bracing—see **brace**.

bracket—an overhanging member projecting from a wall or other body to support weight acting outside the wall, or similar piece to strengthen an angle. (See also **corbel.**)

breccia—rock composed of angular fragments of older rock cemented together.

bredigite—a mineral, alpha prime dicalcium silicate ($2CaOSiO_2$), occurring naturally at Scawt Hill, Northern Ireland; and at the Isle of Muck, Scotland; also in slags and portland cement.

breeze—usually clinker; also fine divided material from coke production.

brick, calcium-silicate—see **calcium-silicate brick.**

brick, concrete - solid concrete masonry units of relatively small prescribed dimensions.

brick, rubbing—see **rubbing brick.**

brick, sand-lime—see **calcium-silicate brick.**

brick seat—ledge on wall or footing to support a course of masonry.

bridge deck—the structural concrete slab or other structure that is supported on the bridge superstructure and serves as the road way or other travelled surface.

briquette (also **briquet**) - a molded specimen of mortar with enlarged extremities and reduced center having a cross section of definite area, used for measurement of tensile strength.

broadcast—to toss granular material, such as sand, over a horizontal surface so that a thin, uniform layer is obtained.

broom finish—the surface texture obtained by stroking a broom over freshly placed concrete. (See also **brushed surface.**)

brown coat—the second coat in three-coat plaster application.

brown out—to complete application of basecoat plaster.

brown oxide—a brown mineral pigment having an iron oxide content between 28 and 95 percent. (See also **limonite.**)

brownmillerite—a ternary compound originally regarded as $4CaO \cdot Al_2O \cdot Fe_2O_3(C_4AF)$ occurring in portland and calcium-aluminate cement; now used to refer to a series of solid solutions between $2CaO \cdot Fe_2O_3(C_2F)$ and $2CaO \cdot Al_2O_3(C_2A)$.

brucite—a mineral having the composition magnesium hydroxide, $Mg(OH)_2$, and a specific crystal structure.

brushed surface—a sandy texture obtained by brushing the surface of freshly placed or slightly hardened concrete with a stiff brush for architectural effect or, in pavements, to increase skid resistance. (See also **broom finish.**)

buck—framing around an opening in a wall; a door buck encloses the opening in which a door is placed.

buckling—failure by lateral or torsional instability of a structural member, occurring with stresses below the yield or ultimate values.

bug holes—small regular or irregular cavities, usually not exceeding 15 mm in diameter, resulting from entrapment of air bubbles in the surface of formed concrete during placement and consolidation. (See also **sack rub.**)

buggy—a two-wheeled hand or motor-driven cart usually rubber-tired, for transporting small quantities of concrete from hoppers or mixers to forms; sometimes called a concrete cart.

f. Water-cement ratio if concrete is subject to freezing and thawing while saturated with water; see Section 5.2.3

11. Mixing, measuring, and placing procedures (usually by reference to specifications or recommended practices)

12. Recommended finishing methods and tools, where required

13. Special finishes and finishing techniques

14. Curing procedures, including length of curing and time of opening the slab to traffic. (Reference should be made to this guide for curing and finishing requirements because other ACI standards and guides may not include the special requirements for floors)

15. Testing and inspection requirement

Responsibility for the preceding items should be clearly established in the project specifications. The preconstruction conference, for all responsible parties, immediately prior to commencement of the work, also affords an excellent opportunity to re-examine specification requirements and performance responsibilities in light of existing job conditions.

Tests and inspections should be delineated, as should the responsibility of the parties responsible for the tests and inspections.

CHAPTER 1 — CLASSES OF FLOORS

1.1 — Classification of floors

Table 1.1 classifies floors on the basis of intended use. These requirements should be considered when selecting properties for the concrete as recommended in Section 5.2. Because at present there are no standard criteria for evaluating the wear resistance of a floor, it is not yet possible to specify quality in terms of ability to resist wear. However, wear resistance of a floor is directly related to the construction techniques used. Table 1.1 suggests special finishing techniques for each class of floor. Chapter 7 gives the step-by-step procedure to be followed closely.

1.2 — Single-course monolithic floors

The first six classes of floors are monolithic concrete with some variation in strength and finishing techniques. If abrasion from grit or other materials will be unusually severe, a higher quality floor surface may be required for satisfactory service.[1] Under these conditions, a higher class floor, a special mineral or metallic aggregate monolithic surface treatment, or a higher cement factor or strength is recommended.

Table 1.1 — Floor classifications

Class	Anticipated type of traffic	Use	Special considerations	Final finish
1	Light foot	Residential surfaces; mainly with floor coverings	Grade for drainage; level slabs suitable for applied coverings; curing	Single troweling
2	Foot	Offices and churches; usually with floor covering	Surface tolerance (including elevated slabs); nonslip aggregate in specific areas	Single troweling; nonslip finish where required
		Decorative	Colored mineral aggregate; hardener or exposed aggregate; artistic joint layout	As required
3	Foot and pneumatic wheels	Exterior walks, driveways, garage floors, sidewalks	Grade for drainage; proper air content; curing. See Chapter 5 for specific durability requirements	Float, trowel, or broom finish
4	Foot and light vehicular traffic	Institutional and commercial	Level slab suitable for applied coverings; nonslip aggregate for specific areas and curing	Normal steel trowel finish
5	Industrial vehicular traffic — pneumatic wheels	Light-duty industrial floors for manufacturing, processing, and warehousing	Good uniform subgrade; surface tolerance; joint layout; abrasion resistance; curing	Hard steel trowel finish
6	Industrial vehicular traffic — hard wheels	Industrial floors subject to heavy traffic; may be subject to impact loads	Good uniform subgrade; surface tolerance; joint layout; load transfer; abrasion resistance; curing	Special metallic or mineral aggregate; repeated hard steel troweling
7	Industrial vehicular traffic — hard wheels	Bonded two-course floors subject to heavy traffic and impact	*Base slab* — Good uniform subgrade; reinforcement; joint layout; level surface; curing	Clean-textured surface suitable for subsequent bonded topping
			Topping — Composed of well-graded all-mineral or all-metallic aggregate.; Mineral or metallic aggregate applied to high-strength plain topping to toughen; surface tolerance; curing	Special power floats with repeated steel trowelings
8	As in Class 4, 5, or 6	Unbonded toppings — Freezer floors on insulation, on old floors, or where construction schedule dictates	Bond breaker on old surface; mesh reinforcement; minimum thickness 3 in. (nominal 75 mm); abrasion resistance and curing	Hard steel trowel finish
9	Superflat or critical surface tolerance required. Special materials-handling vehicles or robotics requiring specific tolerances	Narrow-aisle, high-bay warehouses; television studios	Varying concrete quality requirements. Shake-on hardeners cannot be used unless special application and great care are employed. Proper joint arrangement. F,35 to F,125 (F,100 is "superflat" floor)	Strictly follow finishing techniques as indicated in Section 7.15

that the supplier will use enough trucks to insure an uninterrupted concrete supply. In addition, since environmental factors can significantly alter the setting rate of concrete, an effort is usually made to construct superflat floors out of the weather.

The flatness exhibited by any concrete floor will be determined almost exclusively by the effectiveness of the corrective straightedging employed after each of the successive strikeoff, floating, and troweling steps. Without corrective straightedging, each step performed in a conventional concrete floor installation tends to make the surface less flat. Straightedges are the only tools capable of flattening the plastic concrete, since they alone embody a reference line against which the resulting floor profile may be compared. In contrast, bullfloats, power floats, and power trowels are by nature wave-inducing devices.

A dramatic improvement in concrete floor flatness can be obtained at no cost simply by using a highway straightedge in place of the bull float — regardless of the placement width. This simple substitution of tools will routinely produce a 50 percent increase of F_F. To the extent that further restraightedgings can only reduce floor wave amplitudes and enlarge floor wave lengths, F_F may be further improved until superflatness (F_F100) is obtained.

On most superflat projects, floor profiles are measured for flatness and levelness immediately after the final troweling is completed.

In any case, it is imperative that profile testing and defect identification be accomplished on each new slab as soon as possible. To maintain satisfactory results, the contractor requires continuous feedback to gage his methodology against ever-changing job conditions (see also Section 7.16).

7.10 — Toppings for precast floors

There are a number of types of precast floors that require toppings. These include double-tees, planks, and other kinds of precast floor elements. When these are to be covered with bonded toppings, the procedure in Section 7.7.2 should be followed as appropriate.

7.11 — Finishing lightweight structural concrete

This section concerns finishing lightweight structural concrete floors, not the finishing of very lightweight insulating-type concretes [having fresh weights of 60 lb/ft^3 (960 kg/m)^3 or less], which are sometimes used below slabs and which generally require no finishing other than screeding.

Structural lightweight concrete for floors usually contains expanded shale, clay, slate, or slag coarse aggregate. The fine aggregate may consist of manufactured lightweight sand, natural sand, or a combination of the two. The finishing procedures vary somewhat from those used for a normal weight concrete;[19] in lightweight concrete the density of the coarse aggregate is generally less than that of the sand and cement. Working the concrete has a tendency to bring coarse aggregate rather than mortar to the surface. This must be taken into account in the final finishing operations. Observing the following simple rules will control this tendency so that lightweight structural concrete will finish as easily as normal weight concrete, provided the mix has been properly proportioned.

1. Do not oversand the mix in an effort to bring more mortar to the surface for finishing. This usually will aggravate rather than eliminate finishing difficulties.
2. Do not undersand the mix in an attempt to meet the unit weight requirements. Neither mixing to the recommended slump nor entrainment of air will effectively control segregation in such a mix.
3. Place lightweight concrete with the lowest practical slump to minimize segregation or the tendency for the lighter coarse aggregate to rise above the heavier mortar.
4. Some lightweight aggregates may require further control of segregation or bleeding, or both. For this purpose, use 3 to 8 percent entrained air (ACI 211.2) in accordance with Table 5.2.7.b.
5. Do not overwork or overvibrate lightweight concrete. A well-proportioned mix can generally be placed, screeded, and bull floated with approximately half the effort considered good practice for normal weight concrete. Excess darbying or bull floating are often principal causes of finishing problems, since they only serve to drive down the heavier mortar that is required for finishing, and to bring an excess of the lighter aggregate to the surface.
6. Use a magnesium darby or bull float in preference to wood. Metal will slide over coarse aggregate and embed it rather than tear or dislodge it.
7. Float and flat trowel the surface as soon as surface moisture has disappeared and while the concrete is still plastic. If floating is being done by hand, use a magnesium float. If evaporation is not taking place soon enough (while concrete is still plastic) other measures should be taken. Water and excess moisture should be removed from the surface with as little disturbance as possible. A simple but reliable method is to drag a loop of heavy rubber garden hose over the surface.

7.12 — Nonslip floors

Nonslip surfaces are produced by using the following finishing procedures: swirl or broom design (Section 7.13.4), nonslip dry shake (Section 7.13.2), or early-age power grinding (Section 7.14). The nonslip dry shake is recommended for heavy foot traffic.

References 40 through 42 describe methods of measuring and evaluating slipperiness of floors.

7.13 — Decorative and nonslip treatments; monolithic surface treatments for wear resistance

7.13.1 *Monolithic surface treatments for color (sometimes referred to as "dry shakes")* — Premixed materials are available (Section 4.5) for producing monolithic colored surface treatments. The colored surface is achieved by applying the dry premixed material to the surface of freshly floated concrete, allowing some absorption of water, then floating additional required moisture up through it.

After the concrete has been screeded, consolidated, and further smooth and filled; leveled by highway straightedge, bull float, or other device; and any free water has evaporated or been removed, the surface should be floated by hand wood or power float (see Section 7.2.10 for guidance in the proper timing of floating). Dry shakes should never be applied into free water or on an unfloated surface. The first floating embeds the coarse aggregate with a proper mortar to which the dry shake material can be applied to become an integral part of the floor or slab. Floating also removes any ridges or depressions that might cause variations in color intensity. Immediately following this floating operation, shake the premixed material evenly by hand over the surface. If too much material is applied in one spot, nonuniformity of color, and possibly surface peeling, will result. However, no water should ever be added after applying the dry shake. The first application of the colored material should use about two-thirds of the total needed. In a few minutes this dry material will absorb some moisture from the freshly mixed concrete and should then be thoroughly floated into the surface, preferably by a power float. Immediately following this, the remainder of the specified amount of the premixed material should be distributed evenly over the surface at right angles to the previous application. This should also be thoroughly floated and made part of the surface, taking care to obtain a uniform color.

All tooled edges and joints should be "run" both before and after the monolithic surface treatment.

For outdoor slabs or ramps, the surface may be left with a swirl, power float, hand wood or hand magnesium float, or flat trowel finish, depending upon the texture and degree of traction desired.

If a smooth troweled finish is desired, the first troweling should be flat. Additional trowelings are then made as needed to provide a smooth, dense surface of uniform color. Final troweling is best done by hand. Do not burnish (hard) trowel colored surfaces as this will cause uneven color and/or the trowel will leave dark marks. If a broom finish is desired, a soft-bristled broom should be drawn over the surface after the first troweling.

Colored surfaces must also be cured thoroughly. Cure with a nonyellowing membrane-curing compound recommended by the manufacturer of the colored dry-shake material. Do not cure colored floors with plastic sheeting, curing paper, damp sand, wet burlap, or ponding, since uneven coloring, serious staining, or efflorescence will usually result.

7.1.3.2 *Nonslip monolithic surface treatment*[40-42] — Before being applied to the surface, the slip-resistant material (Section 4.2.4) should be mixed with dry portland cement. Proportions usually range from 1:1 to 1:2; however, the manufacturer's directions, if given, should be followed. The nonslip monolithic surface treatment procedure is exactly the same as that outlined for the colored treatment (Section 7.13.1). A swirl finish of dry-shake colored material or natural colored mineral or metallic aggregate used for increased wear resistance also produces a long-lasting, non-slip finish (Sections 7.13.1 and 7.13.5).

7.13.3 *Exposed aggregate* — Exposed aggregate surfaces are commonly used for decorative effects.[43-45] Both the selection of the aggregates and the techniques employed for exposing them are important to the effect obtained, and test panels should be made before the job is started. Colorful, uniform-sized gravel or crushed aggregate is recommended. Such aggregates should not be reactive with cement (ACI 201.2R). When in doubt, they may be tested by following ASTM C 227, or by petrographic examination (ASTM C 295). Flat or sliver-shaped particles, or particles smaller than ¾ in. (19 mm) do not bond well and easily become dislodged during the operation of exposing the aggregate. It is not satisfactory to expose the aggregate ordinarily used in concrete unless the aggregate is sufficiently uniform in size, bright in color, closely packed, and properly distributed.

Concrete with a maximum slump of 3 in. (75 mm) should be used. For exterior work in climates subject to freezing weather, it should be air entrained (Tables 5.2.7.a and 5.2.7.b). Immediately after the slab has been screeded, and darbied or bull floated, the selected aggregate should be scattered by hand and evenly distributed so that the entire surface is completely covered. The initial embedding of the aggregate is usually done by patting with a darby or the broad side of a 2 x 4 in. (50 x 100 mm) piece of lumber. After the aggregate is thoroughly embedded and as soon as the concrete will support the weight of a finisher or kneeboards, the surface should be hand floated using a magnesium float or darby until all aggregate is entirely embedded and mortar completely surrounds and slightly covers all of it, leaving no holes in the surface.

Shortly after floating, a reliable surface set retarder may be sprayed or brushed over the surface, following the manufacturer's recommendations. Retarders may not be necessary on small jobs, but they are usually used on large jobs to insure better control of exposing operations. Use of a surface set retarder ordinarily permits several hours to elapse before brushing and hosing the surface with water to expose the aggregate. However, the proper time for exposing the aggregate is critical whether or not a retarder has been used. The retarder manufacturer's recommendation should be followed closely.

Exposing operations should begin as soon as the surface can be brushed and hosed without overexposing or dislodging the aggregate. If it becomes necessary for finishers to move about on the newly exposed surface, kneeboards should be used, gently brought into contact, and neither slid nor twisted on the surface. If possible, however, finishers should stay off the surface entirely because of the risk of breaking aggregate bond.

If a smooth surface is desired, as in an interior area, no retarder is used, and the aggregate is not exposed until the surface has hardened. Exposure is then accomplished entirely by grinding. If grinding is followed by polishing, it produces a surface similar to terrazzo.

In an alternative method of placement, a top course 1 in. (24 mm) or more thick that contains the special aggregate is applied.

Because the aggregate completely covers the surface, tooled joints are not practical in exposed aggregate concrete. Decorative or working joints are best produced by sawing (Section 7.2.9). Another method of providing joints is to install permanent strips of redwood before placing concrete (Fig 2.3.2).

Exposed aggregate slabs should be cured thoroughly. Care should be taken that the method of curing does not stain the surface. Straw, earth, and any type of sheet membrane, such as polyethylene or building paper, may cause discoloration (Section 8.2.1).

7.13.4 *Geometric designs and other patterns* — For patios, garden walks, and areas around swimming pools, concrete surfaces are frequently scored or tooled with a jointer in various decorative patterns.[43-46] For random geometric designs the concrete should be scored after it has been screeded and bull floated or darbied, and the excess moisture has left the surface. This may be done with a jointer, groover, or a piece of pipe bent to resemble an S-shaped jointer tool. The tool is made of ½ or ¾ in. (12 or 19 mm) pipe, about 18 in. (460 mm) long.

A flagstone design or random ashlar pattern in the colored surface may be produced by temporarily embedding 1 in. (25 mm) strips strips of 15 lb (7 kg) roofing felt in the concrete. After the usual operations of screeding, darbying or bull floating, and floating are complete, the precut strips of roofing felt should be laid flat on the surface in the pattern desired whether random ashlar, flagstone, or geometric. These are patted in and floated over. Color is then applied (Section 7.13.1) and the slab finished. The strips are then carefully removed, leaving uncolored joints, before the slab is cured.

Other patterns can be impressed in the surface by the "branding iron" method.

The swirl-float finish or swirl design is produced by a magnesium or aluminum float or a steel finishing trowel. After the concrete surface has been struck off and darbied or bull floated, a float should be worked flat on the surface in a semicircular or fanlike motion using pressure. A finer textured swirl design is obtained with the same motion by using a steel finishing trowel held flat. An alternative is to draw a soft-bristled broom across the slab in a wavy motion.

After the concrete has set sufficiently so that these surface textures or patterns will not be marred, the slab must be moist cured. Plastic membranes or waterproof curing paper should not be used on colored concrete (Sections 8.2.1 and 8.2.2).

7.13.5 *Monolithic surface treatments for wear resistance* — These materials, depending on their type and manufacturer, are available in premixed and job mixed form (Sections 4.2.4 and 4.2.4.1). If they are job mixed, they must be proportioned and thoroughly dry mixed according to the aggregate manufacturer's directions, usually by weight rather than by volume.

The application of these wear-resistant or slip-resistant dry shakes is essentially the same as for colored dry shakes (Section 7.13.1) with other important considerations. The slabs or floors employing these dry shakes in most cases will be subjected to considerably heavier and more frequent traffic. Proper floating to provide a suitable mortar on the surface on which to apply and bond the material into an integral part of the concrete is therefore extremely important. Air content of the concrete should be not more than 3 percent. As with any commercial or industrial floor subjected to wheeled traffic, special care should be exercised to obtain level surfaces and joints. Materials containing metallic aggregate should not be applied to concrete containing significant amounts of calcium chloride; contact the metallic-aggregate manufacturer for concrete mix proportion and chloride content recommendations for the specific material.

Application and finishing of materials should follow these basic procedures:

1. Following screeding and bull floating, and after all free water has evaporated or been removed, float all surfaces by hand wood and/or power floats. (See Section 7.2.10 for guidance in the proper timing of floating.)
2. Evenly distribute approximately two-thirds of the amount specified for the area immediately behind the floating.
3. As soon as the material darkens slightly from absorbed moisture, it should be floated using hand wood and/or power floats.
4. Immediately apply the remaining one-third of the specified amount at right angles to the first application.
5. Float as in Paragraph 3.
6. Apply a flat troweling by hand or power (Section 7.2.11).
7. Apply a first raised troweling, and successive trowelings as required, to produce a smooth, dense, wear-resistant surface (Section 7.2.11).
8. Burnish (hard) trowel.
9. Cure immediately after finishing, following the material manufacturer's printed recommendations or directions.

7.14 — Early-age power grinding (2 to 7 days' age)

An alternate finishing technique is power grinding concrete slabs at an early age, which is used in Europe. The grinding removes the top $\frac{1}{32}$ to $\frac{1}{16}$ in. (about 1 mm) of the surface that may be weak, and can produce a strong, durable finish. For maximum hardness and wear resistance, however, follow the guidelines in Section 7.13.5.

C 595-86	Standard Specification for Blended Hydraulic Cements
C 618-85	Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete
C 685-86a	Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing
C 845-80	Standard Specification for expansive Hydraulic Cement
C 989-87a	Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
D 994-71 (Reapproved 1982)	Standard Specification for Preformed Expansion Joint Filler for Concrete (Bituminous Type)
D 1751-83	Standard Specification for Preformed Expansion Joint Filler for Concrete Paving and Structural Construction (Nonextruding and Resilient Bituminous Types)
D 1752-84	Standard Specification for Preformed Sponge Rubber and Cork Expansion Joint Fillers for Concrete Paving and Structural Construction
D 2240-86	Standard Test Method for Rubber Property-Durometer Hardness
E 96-80	Standard Test Methods for Water Vapor Transmission of Materials
E 1155-87	Standard Test Method for Determining Floor Flatness and Levelness Using the F-Number System

The preceding publications may be obtained from the following organizations:

American Association of State Highway and Transportation Officials
444 W. Capitol St., NW, Suite 225
Washington, DC 20001

American Concrete Institute
P.O. Box 19150
Detroit, MI 48219-0150

American National Standards Institute
1430 Broadway
New York, NY 10018

American Society of Heating, Refrigerating, and Air-Conditioning Engineers
1791 Tullie Circle, NE
Atlanta, GA 30329

ASTM
1916 Race St.
Philadelphia, PA 19103

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This report was submitted to letter ballot of the committee, and approved according to Institute balloting procedures.