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DESIGN REPORT AND SAFETY EVALUATION FOR HIGH DENSITY FUEL STORAGE SYSTEM AMENDMENT NO. 1

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DESIGN REPORT AND SAFETY EVALUATION FOR HIGH DENSITY FUEL STORAGE SYSTEM

Amendment No. 1

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1. INTRODUCTION

This first amendment to the General Electric Company Licensing Topical Report NEDE-24076-P, "Design Report and Safety Evaluation for High Density Fuel Storage System," is being provided to present new information and design changes. The information has been derived from experience with systems installed and in use, and from testing and analyses of system parameters.

2. BROWNS FERRY HIGH DENSITY FUEL STORAGE SYSTEM

The Tennessee Valley Authority (TVA), General Electric Company (GE), Brooks and Perkins and others met with the Nuclear Regulatory Commission (NRC) staff on August 24, 1978 to discuss a tube swelling phenomenon observed in GE high density fuel storage modules. GE explained that the swelling of the tube inner wall was caused by the accumulation of gas formed by the reaction of water in leakage with the aluminum cladding of the Boral. It was further explained that the swelling could be prevented by providing vent openings at the top of the tube, allowing gas to escape. A review of the design and manufacture of the tubes concluded that a design change should be made to leave the corners of the inner and outer tube walls unwelded, providing an open passage between the top and bottom of the inner and outer walls on all four corners of each storage tube (Appendix A).

Questions considered and resolved in the design review are the following:

1. Is the structural integrity of the modified tube affected?

   The structural integrity of the tube and the module is unaffected by the presence or absence of the weld between inner and outer tube walls. The structural analysis was made considering only the outer wall of the storage tube. Credit was not taken for the presence of the Boral or the inner wall in the calculations.

2. What is the velocity of water flow from bottom to top of the tube through the vent passages, and what is its effect on corrosion?

   The velocity of the water flow through the corner passages was calculated. The maximum cross section of the passage was calculated from the minimum Boral sheet width and the maximum tube dimensions and assuming an open passage full length of all four corners of each tube. The thermal gradient was taken from the cooling flow calculations for an irradiated bundle of 26,000 MWd/MTU and a cooling time of 3 days. The calculated velocity of water flow was about 5 in./min. This low flow will have no significant effect upon the Boral corrosion rates, which were developed in Appendix B.

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3. What are the long-term corrosion effects on the Boral due to exposure to pool water?

Long-term corrosion effect were confirmed by General Electric Company in Appendix B. The results of the 2022-hour test in a Boiling Water Reactor (BWR) pool environment conclude that the Boral corrosion rates are low and therefore represent an acceptable material loss over the 40-year lifetime. An additional examination by scanning electron microscopy (SEM) was performed on two of the corrosion test sample coupons to determine the extent of the edge corrosion which had occurred (Appendix C). An edge corrosion rate was established from the measured maximum penetration between B_4C particles extrapolated to 40 years using the exponential corrosion law for 1100 Aluminum. This approach predicted loss of Boral of as much as 0.3 mm over the 40-year life of the storage tube (Appendix D).

4. What are the potential effects on criticality control from edge corrosion of the Boral sheets?

Criticality (MERIT) calculations of the effect of the extrapolated edge loss of Boral were made assuming an edge reduction of 3.4 mm and the minimum center to center pitch. This edge reduction is a factor of ten (10) greater than the predicted corrosion for the Boral plate. The results (below) indicate the resultant k_∞ is within the statistical accuracy of the nominal case.

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2.1 SINGLE CELL HIGH DENSITY FUEL STORAGE CRITICALITY RESULTS

Case Description	k_∞ (+ 2 σ)*
Nominal Rack Dimensions Nominal Material Thickness 6.563-inch Pitch Without Flow Channel 20°C	0.8674 ± 0.0086
Minimum Material Thickness Boral Sheet Width Reduced 0.135 in. (3.4mm) per Edge 6.508-inch Pitch Without Flow Channel 20°C	0.8650 ± 0.0088

2.2 CONCLUSIONS

In summary, it is concluded that the storage tube design change (Appendix D) does not reduce significantly the previous design margins.

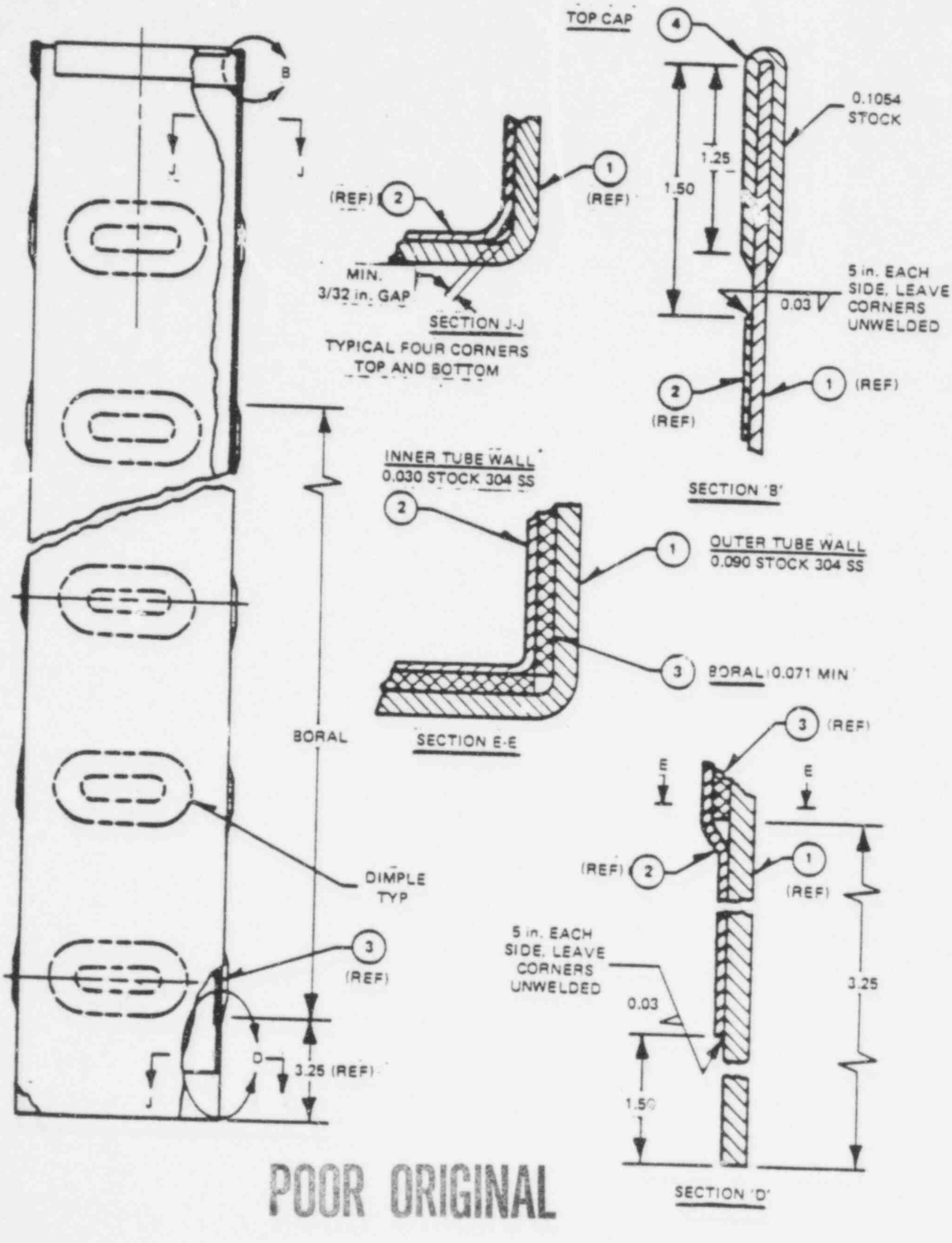
*k_∞ includes MERIT program bias and uncertainty

APPENDIX A

SPENT FUEL STORAGE TUBE - TYPE II

The spent fuel storage tube has been modified as shown in Figure A-1 to provide openings at both top and bottom of the tube in each of the four corners. Section J-J and notes on Section B and Section D indicate that the openings will be provided by not welding the inner and outer walls together in the corners.

The inner tube wall was made thinner (from 0.036 stock to 0.030 stock) to improve material costs as indicated on Section E-E.



POOR ORIGINAL

Figure A-1. Spent Fuel Storage Tube-Type II (10-10-78)

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APPENDIX B

PLANT MATERIALS ENGINEERING
BORAL CORROSION TEST: 2022-HOUR RESULTS

A. J. Jacobs

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B.1 INTRODUCTION

Boral is used as a neutron absorber material in the current, joint Boiling Water Reactor Systems Engineering Department (BWRSED) Spent Fuel Services Operation (SFSO) spent fuel storage rack design. "Boral" is a Brooks and Perkins trademark for a dispersion of boron carbide in aluminum, the dispersion being clad in 1100-aluminum sheets.

Prior to the initiation of this test program, a review of the open literature indicated that Boral had essentially unknown corrosion properties in the BWR fuel pool environment. A recently issued Brooks and Perkins report Reference B-1 contains 2000-hour and 1-year corrosion data for Boral exposed to "BWR-type" water. There was obviously a need to obtain long-term corrosion data under conditions directly applicable to BWR 6 and other GE reactor models having a projected 40-year lifetime.

Testing was authorized at Vallecitos Nuclear Center (VNC) to determine the corrosion tendency of Boral enclosed in welded stainless steel, as in the hardware design.

* * *

Unwelded couples and uncoupled Boral samples were included in the tests to show the effect of the stainless steel cladding on Boral corrosion rate.

The test was interrupted after the first test period for initial observation and weight-loss measurements. The results of this test were presented in Reference B-2. Testing was interrupted again * * * for examination and weighing of those samples not weighed at the end of the first examination period. The results of the latter test appeared in Reference B-3. The present report deals with the final period of testing, at the end of which all samples were reexamined and reweighed.

B.2 SUMMARY AND CONCLUSIONS

Uncoupled Boral samples showed a higher corrosion rate than either unwelded Boral/304 SS couples or welded couples. The welded couples with the smallest

(*** - Indicates General Electric Company proprietary information has been deleted.)

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access holes displayed the lowest corrosion rate. Corrosion rates decreased with time,

* * *

Extrapolation of the test data led to a determination of acceptable material loss over a 40-year service life.

B.3 TEST PROCEDURE

The test procedure is detailed in P.M.E. Transmittal No. 77-688-19.

Four (4) uncoupled (single) Boral samples and 16 samples consisting of Boral coupled to 304 stainless steel were prepared for testing.

* * *

The test matrix is shown in Table B-1.

Table B-1
TEST MATRIX

	Boral Singles	304 Stainless Steel Couples Hole Size (in.)			
		1	2	3	4
Number of Samples	4	4	4	4	4

* * *

Corrosion testing was carried out in the Corning glass loop system at Vallecitos.

* * *

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* * *

(a) Exposed Edges

* * *

(b) Stainless Steel Clad

Figure B-1. Boral Sample Construction

* * *

Two samples from each of the B-2 five groups shown in Table B-1 were examined and weighed after the first test period B-1(b). These samples were returned to test * * *
Furthermore, two 1100-aluminum samples were placed in the test at the start of the second * * * test period, for comparison with Boral. At the end of the second test period, the remaining half of the Boral samples and the two aluminum samples were examined and weighed B-3. There was one deviation from the test procedure outlined in P. M. E. Transmittal No. 77-688-19, and that involved the cleaning procedure and determination of the sample weight loss. The ASTM method outlined in Reference B-4 was adopted because of its greater reliability.

The Boral samples removed from the loop at the end of the second test period were returned to test, * * *
the aluminum samples were also returned to test. All 22 samples were reexamined and reweighed at the end of the third and final * * * test period.

B.4 TEST RESULTS

* * * Corrosion rates (in mpy) were calculated using the formula:

$$mpy = \frac{534\ W}{DAT},$$

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where W = weight loss, mg

D = density, g/cm^3

A = area, $in.^2$

T = exposure time, hr

* * *

The average corrosion rate of Boral in each of the five groups of Boral-containing samples is observed * * * to decrease with time.

* * *

At any given time, the average corrosion rate of Boral decreases in the following order: Boral single; unwelded couple; welded couple,

* * *

Differences among the various groups are a maximum * * * after the first test period and remain more or less constant after narrowing down at the second test period.

* * *

The 2000-hour Boral corrosion data reported by Brooks and Perkins

* * *

were obtained in "BWR-type" water at a pH of 7.0 * * * and a temperature of 190°F

* * *

The present data for Boral singles were seen (Figure B-2) to lie near the lower end of the range cited by Brooks and Perkins.

* * *

The visual observations made at the end of the third * * * test period were qualitatively similar to those made at the end of the second * * * period B-3. There was little or no corrosion of the aluminum cladding of Boral in the welded couples.

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* * *

Figure B-2. Boral and 1100-Aluminum Corrosion Rates As a Function of Time

* * *

* * *

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* * *

B.5 ACKNOWLEDGMENT

The author wishes to express his appreciation to N. R. Young for his extremely competent performance in the laboratory and his unflagging spirit of cooperation and helpfulness.

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REFERENCES

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B-2. A. J. Jacobs, "Boral Corrosion Test," P.M.E. Transmittal No. 77-688-74, August 4, 1977.

B-3. A. J. Jacobs, "Boral Corrosion Test," P.M.E. Transmittal No. 77-688-86, September 20, 1977.

B-4. ASTM Committee G-1 on Corrosion of Metals, Recommended Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens, 1967.

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APPENDIX C

SEM EXAMINATION OF CORRODED BORAL

U. E. Wolff

634 027

C.1 INTRODUCTION

Two Boral coupons were received, identified B116 and B117. Both had undergone a * * * corrosion test * * * . The coupons consisted of a core of Boral (a trademark for a dispersion of boron carbide (B_4C) in aluminum) clad with an 1100-Aluminum 1 sheet.

Object of the investigation was to determine the depth of the corrosion attack in the Boral.

C.2 TEST PROCEDURES

* * *

C.3 RESULTS

* * *

The overall depth of corrosion of the Boral material was determined by examination of metallographic cross sections of the test pieces. The maximum combined depth of attack was determined.

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* * *

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* * *

Cutting Diagram

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* * *

(a)

* * *

(b)

Figure C-1. Sample I.D. Boral B116 After Corrosion Test, Long Edge

* * *

(a)

* * *

(b)

Figure C-2. Sample I.D. Boral B116 After Corrosion Test, Long Edge

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* * *

(a)

* * *

(b)

(c)

Figure C-3. Sample I.D. Boral B116 After Corrosion Test, Short Edge

* * *

(a)

* * *

(b)

(c)

Figure C-4. Sample I.D. Boral B117 After Corrosion Test, Long Edge

* * *

(a)

* * *

(b) (c)

Figure C-5. Sample I.D. Boral B117 After Corrosion Test, Short Edge

* * *

Figure C-6. Sample I.D. Boral B116 After Corrosion Test

* * *

Figure C-7. Sample I.D. Boral B117 After Corrosion Test, Polished Cross Section

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* * *

(a) (b)

* * *

(c) (d)

Figure C-8. Sample I.D. Boral B116, Midplane Met. No. 8B6-7

* * *

Figure C-9. Sample I.D. Boral B116, Midplane Met. No. 8B6-7

* * *

(a)

* * *

(b)

Figure C-10. Sample I.D. Boral B116, Midplane Met. No. 8B6-7

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* * *

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APPENDIX D

PLANT MATERIALS ENGINEERING
CLASS I
BORAL CORROSION TEST SUMMARY

A. J. Jacobs

D.1 INTRODUCTION

Boral is used as a neutron absorber material in General Electric's high density spent fuel storage rack (HDSFSR) design. "Boral" is a Brooks and Perkins trademark for the dispersion of boron carbide in aluminum, the dispersion (or core) being clad in 1100-aluminum sheets.

Corrosion data for Boral in BWR - type water have been reported elsewhere (D-1). In these * * * tests conducted at * * * to accelerate the acquisition of data, a corrosion rate of was obtained * * *

* * * The expected life of a * * * Boral sheet used in the General Electric rack design exceeds 235 years.

* * *

Recently, additional corrosion tests have been performed by the General Electric Company, to determine the corrosion tendency of Boral enclosed between welded stainless steel sheets. * * * A leak was simulated by drilling holes of various sizes in the stainless steel portion of the Boral/stainless steel couples. Unwelded couples and uncoupled Boral specimens were included in the tests to show the effect of the stainless steel clad on Boral corrosion rate.

* * *

In the General Electric tests, uncoupled Boral specimens showed a higher corrosion rate than either unwelded or welded couples. The welded couples with the smallest access holes displayed the lowest corrosion rate.

* * *

Figure D-1. Weight Loss With Time for Boral Samples

The * * * Boral specimens showing the highest corrosion rates were examined in the scanning electron microscope (SEM).

* * *

The purpose of this report is to summarize those results of General Electric's Boral corrosion testing program that have the most direct bearing on the present HDSFSR design, and to quantitatively predict from the results the adequacy of the Boral components from a corrosion standpoint.

D.2 SUMMARY AND CONCLUSIONS

The results of corrosion tests conducted by General Electric Company on Boral exposed to BWR-type water indicate an acceptable material loss over the projected 40-year lifetime of a BWR.

* * *

D.3 PREDICTION OF BORAL LOSS OVER THE BWR LIFETIME

The most conservative possible estimate of Boral loss over the 40-year projected lifetime of a BWR was made by: (1) basing it on the SEM observation of a 0.25 mm penetration depth in the Boral core after * * * extended of exposure to water; (2) assuming a uniform penetration of

* * *

and (3) selecting the * * * Boral samples, which showed the highest rates of all those tested.

* * *

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Aluminum alloy 1100 is known to follow a logarithmic corrosion rate law in low-temperature (30° to 100°C) (86° to 212°F) water.[D-6] Assuming that the aluminum phase in Boral also obeys such a law, * * * an equation was derived using available data points

* * *

Substituting 14,600 days (40 years) for t in the equation yielded an acceptable weight loss over the 40-year lifetime.

* * *

Additional conservatism was introduced into the extrapolated 40-year penetration value of * * * by the accelerated nature of the corrosion test.

* * *

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D-1. Leslie Mollon, **Spent Fuel Storage Module Corrosion**, Brooks and Perkins, Inc., Report No. 554, June 1, 1977.

D-2. L. Marti-Balaguer and W. R. Smalley, **Evaluation of Control Rod Materials; CVTR Project**, CVNA-86, Carolinas-Virginia Nuclear Power Associates, Inc. (1960).

D-3. Brooks and Perkins, Inc., Report No. 551, February 1977, **Corrosion Resistance of Boral to 1 Year Exposure to BWR Pool.**

D-4. A. J. Jacobs, **Boral Corrosion Tests: 2022-Hour Results**, General Electric Co. report No. P.M.E. 77-7688-120, December 15, 1977.

D-5. U. E. Wolff, **SEM Examination of Corroded Boral**, General Electric Co. Report No. CME-78-212-0034, June 26, 1978.

D-6. L. E. Link, Ed. U.S. **Behavior of Cladding Materials in Water and Steam Environments**, Selected Reviews of Reactor Technology, Atomic Energy Commission, 1964.

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