Florida
Power
CORPORATION
Crystal River Unit 3
Docket No. 50-302

October 22, 1996
3F1096-01

U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D. C. 20555-0001

Subject: Response to Generic Letter 96-04, "Boraflex Degradation in Spent Fuel Pool Storage Racks"

Reference: NRC to FPC letter, 3N0696-23, Generic Letter 96-04, dated June 26, 1996

Dear Sir:

As requested by the subject Generic Letter, Florida Power Corporation (FPC) has prepared the enclosed response. The enclosure is structured in four sections providing a description of Crystal River Unit 3's specific fuel rack designs, an assessment of the capability of the Boraflex to maintain a 5% subcriticality margin, current programs in place to monitor Boraflex degradation, and proposed actions under consideration to confirm a 5% subcriticality margin can be maintained.

Sincerely,

P. M. Beard, Jr.
Senior Vice President
Nuclear Operations

PMB/TWC

Enclosure

xc: Regional Administrator, Region II
Project Manager, NRR
Senior Resident Inspector

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STATE OF FLORIDA

COUNTY OF CITRUS

P. M. Beard, Jr. states that he is the Senior Vice President, Nuclear Operations for Florida Power Corporation; that he is authorized on the part of said company to sign and file with the Nuclear Regulatory Commission the information attached hereto; and that all such statements made and matters set forth therein are true and correct to the best of his knowledge, information, and belief.

P. M. Beard, Jr.
Senior Vice President
Nuclear Operations

P. M. Beard, Jr., personally known to me. Subscribed and sworn to before me, a Notary Public in and for the State and County above named, this 22nd day of October, 1996.

LYNNE S. SMITH
Notary Public (print)

Lynne S. Smith
Notary Public (signature)

LYNNE S. SMITH
MY COMMISSION # CC 514380
EXPIRES: December 18, 1999
Bonded Thru Notary Public Underwriters

I. SPECIFIC RACK DESIGN

I.A Overall Description

Crystal River Unit 3 (CR-3) has two spent fuel pools designated as the "A" and "B" pools, which are physically joined together through a transfer canal. The "A" Spent Fuel Pool (SFP) has high density fuel rack modules which do not utilize Boraflex and will not be discussed in this response. The "B" Spent Fuel Pool has eight high density racks which are constructed with Boraflex. This rack arrangement is shown in Figure 1. Fuel storage is divided into two regions within the "B" SFP. Region I (180 original cell locations), depicted as "R1", consists of high density fuel assembly spacing obtained by utilizing a neutron absorbing material and is reserved for loading new fuel assemblies but has been checkerboarded with old fuel. Region II (641 locations), depicted as "R2", also consists of high density fuel assembly spacing and provides normal storage for spent fuel assemblies. These racks were installed during 1991 in the "B" spent fuel pool to increase the capacity to store approximately 815 fuel assemblies. The fuel racks were designed and manufactured by Westinghouse. The Boraflex material is a product manufactured by Brand Industrial Services, Inc. (BISCO).

Region I was designed to accommodate non-irradiated, 4.2 weight percent (wt.%) U235 enriched fuel or fuel which has not experienced a pre-determined burnup as reflected in the BASES for CR-3's Improved Technical Specifications. CR-3 is currently licensed to maintain spent fuel storage with fuel assemblies with enrichments up to 5.0 weight percent per Amendment No. 151 to the Operating License. Region II was designed to accommodate irradiated fuel. Placement of fuel in Region II is determined by burnup calculations. In these cases, vacant spaces surrounding the assembly are controlled administratively to prevent inadvertent assembly insertion. No physical barrier is necessary between the two regions. The racks meet the requirements of the NRC "OT Position for Review and Acceptance of Spent Fuel Storage and Handling Applications," dated April 14, 1978, as modified January 18, 1979, with one exception. For Region II storage, credit is taken for fuel burnup based on the proposed Revision 2 of USNRC Regulatory Guide 1.13 "Spent Fuel Storage Facility Design Basis."

There are two configurations (Region I & II) of Boraflex material installed within the high density fuel racks at two different locations within the "B" spent fuel pool. The first location (Region I racks) is identified as the "N" region and has a double layer of Boraflex within each cell, is 9.0 inches square and has a one inch gap of water between each cell. The second location (Region II racks) is designated as the "B & C" region and has only a single layer of Boraflex, which is used between adjacent walls, is 9.0 inches square and therefore has less water gap.

I.B General Design Considerations

Some technical considerations pertinent to boron loading, and the formation of gaps in the Boraflex were previously addressed by Westinghouse during the fuel rack design phase. The racks were designed for Babcock & Wilcox (B&W) 15 X 15 fuel assemblies, having a maximum initial enrichment of 4.2 wt.% U-235 in Region

I, and the same fuel assemblies with a minimum burnup of 33,000 MWD/MTU in Region II. Specific boron-10 loading calculations were determined as part of the criticality analysis, and were based on the % boron loading determined from an extensive database generated from previous criticality analyses. The boron loading in Region I is between 0.030 and 0.037 g/cm^2 (areal density) while in Region II, the boron loading is between 0.010 and 0.012 g/cm^2.

The time period in which CR-3 procured and installed the high density racks in the "B" Pool provided the opportunity to integrate additional conservative measures into the Westinghouse fuel rack design. Several design enhancements and measures were integrated into the Westinghouse fuel racks designed for Crystal River Unit 3. This included not utilizing glue and/or other adhesives to install Boraflex during rack fabrication. This design accounts for Boraflex shrinkage by a factor of 3 percent, while the BISCO Products Technical Report NS-1-050 shows evidence of a maximum 2 percent shrinkage. The criticality analysis addresses the potential for gap formation. The Westinghouse analysis indicates that approximately two inch gaps in the Boraflex in the most active fuel region would still be acceptable for maintaining $K_{eff} < 0.95$, without taking into account any credit for boron in the water. CR-3 has an additional margin of conservatism based on B&W Report BAW-2209P, "Crystal River Unit 3 Spent Fuel Storage Pool B Criticality Analysis," which assumes a maximum gap in the Boraflex of four inches.

I.C <u>"B" Spent Fuel Pool Region I Fuel Rack Design Considerations</u>

The Region I storage racks are composed of individual storage cells made of stainless steel. These racks utilize a neutron absorbing material, Boraflex, which is attached to each cell. The cells within a module are interconnected by grid assemblies to form an integral structure as shown in Figure 2.

The major components of the cell assembly are the fuel assembly cell, the Boraflex material, and the wrapper. The wrapper is attached to the outside of the cell by spot welding the entire length of the wrapper with nominal distance between spots. The wrapper covers the Boraflex material and also provides for venting of the Boraflex to the pool environment. Depending on the criticality prevention requirements, some cells have a Boraflex wrapper on all four sides, some on three sides, and some on two sides. Figure 3 depicts a nominal cell configuration.

I.D <u>"B" Spent Fuel Pool Region II Fuel Rack Design Considerations</u>

The Region II storage racks consist of stainless steel cells assembled in a checkerboard pattern, producing a honeycomb type structure as shown in Figure 4. The major components are the cell, the Boraflex material, and the wrapper. The cells were welded to a base support assembly and to one another to form an integral structure without use of grids as used in Region I racks. Region II cells are different in design from Region I cells in that adjacent fuel assembly locations share a common cell wall. Rack module data is provided in Table 1 (see Page 9).

II. ASSESSMENT OF PHYSICAL CONDITION OF BORAFLEX

II.A Boraflex - Source of Silica in Spent Fuel Pool/Chronological Trends

High density spent fuel racks which utilize Boraflex as a neutron absorber have been found to degrade as a result of exposure from gamma radiation. Degradation rates appear to increase as total integrated gamma dose (TID) increases, with substantial degradation occurring at $1X10^{10}$ Rads exposure. The degradation reduces the ability to absorb neutrons and also results in silica being released into the spent fuel pool and ultimately entering the Reactor Coolant System (RCS) during refueling activities. Additionally, once exposed to gamma radiation, elevated pool water temperature will increase the silica release (Boraflex degradation) rate.

Given the composition of irradiated Boraflex, it is possible to estimate spent fuel pool silica concentrations assuming small amounts of the Boraflex silica undergo dissolution. For CR-3, the "B" spent fuel pool contains Boraflex fuel racks having a capacity of 815 fuel assembly cells. There are 174 cell locations in Region I racks with a total of 662 Boraflex panels. The balance of the cells (641) are the Region II type, with each cell having two panels of Boraflex for a total of 1282. The total number of panels of Boraflex in the pool is 1944.

Each panel of Boraflex is approximately 144 inches long by 7.5 inches wide. Region I Boraflex panels are 0.085 inches thick and Region II Boraflex panels are 0.058 inches thick. Based on an initial Boraflex density of 1.76 gm/cm^3, there was initially a total of approximately 4069 kg of Boraflex in the pool. Industry experience indicates that after irradiation, the Boraflex consists of 46 wt.% silica or a silica-like material. Therefore, about 1831 kg of silica material has the potential to dissolve into the pool water.

The "B" spent fuel pool is 32.5 feet long on the north side, 19.5 feet long on the south side, 24 feet wide on the west side, 11 feet wide on the east side, and is 43 feet deep. The approximate water volume is 2.44×10^4 ft^3 or 6.92×10^5 liters. To date, it appears that about a tenth of a mil (0.0001 inches) of each Boraflex panel has gone into solution. Based on industry experience and results of initial Boraflex coupon surveillance tests using a total integrated dose at $1 X 10^9$ Rads and a pool temperature at 85°F (See Section III.C), a release rate of 0.2 mg/gm of Boraflex is expected. This value of dissolved material and its relationship to total pool water volume corresponds well to the actual present pool silica concentration of about 10 ppm.

FPC experience to date indicates that the Boraflex material appears to be dissolving at a rate which increases the silica concentration in the SFP approximately 6.60 ppb/day. Figure 5 depicts silica increases since the installation of the high density racks in the "B" Pool. Based on an additional twenty years of operation through 2016, and assuming environmental conditions remain constant, the potential silica concentration could range from approximately 60 ppm to 90 ppm with silica in equilibrium at 85°F. See Section III.C for additional information.

II.B <u>Boraflex - Reactivity Service Life Projections</u>

Panel thinning and the loss of boron carbide results in a net increase in the reactivity of the fuel-rack system. If the panel thinning is assumed to be uniform, the calculations of the panel thinning versus time presented in the previous section provide a means for estimating the useful service life of this material. If panel thinning is not uniform, methods such as blackness testing would need to be considered to further identify the thinning and specific shrinkage to assess reactivity effects.

Table 2 (see Page 10) illustrates the typical margin inherent in the CR-3 spent fuel rack design calculation. The maximum k_{eff} of the Region I fuel rack system is 0.9288 which includes a calculational bias of 0.0156 having two adjacent 4-inch Boraflex gaps, and an uncertainty of 0.00495. A contingency of 0.0088 Δk_{eff} provides additional margin available to accommodate boron carbide loss. Similarly, the maximum k_{eff} of the Region II fuel rack system is 0.9499, and is based on a total bias of 0.010. This meets the NRC acceptance criterion of k_{eff} no greater than 0.95, including all uncertainties at the 95/95 probability/confidence level.

CR-3 spent fuel racks have been designed based on the minimum B-10 areal density as certified by BISCO at 0.023 g/cm^2, worst case. Industry results indicate that the actual supplied B-10 areal density is typically 12 to 15 % higher. When the actual B-10 areal density is used in the design and variations in panel thickness and B_4C uniformity are treated as independent random variables (combined as root mean square), additional margin is obtained.

Analyses have been completed by the B&W Fuel Company using the KENO-4 software program for unirradiated fuel with an enrichment of 5.0 wt.% and indicates a total available margin of 0.0088 Δk_{eff} for Region I. The maximum thinning which can be accommodated for Region I while maintaining k_{eff} < 0.95 is approximately 28%. This can be compared with the results of calculated thinning versus time, or in-pool measurement of B-10 areal density to estimate the useful service life of Boraflex on a plant specific basis. For CR-3, an additional twenty years at 0.1 mils/year thinning rate would equal an overall thickness loss of about two mils. Using 0.0849 inches (initial thickness minus present estimated condition) and allowed loss of 0.002 inches, this results in 2.36% thinning, well within the maximum for Region I cells.

For Region II, the available margin of 0.0001 Δk_{eff} shown in Table 2 corresponds to a maximum thinning of less than 2%. To date, using the 0.1 mils estimated thinning discussed in Section II.A, and an initial thickness of 0.058 inches, the Boraflex in Region II is 0.17%, well within the margin. However, an additional twenty years at 0.1 mils/year thinning rate may result in a 3.5% thickness loss, thereby exceeding the margin. Although the margin will increase when taking into consideration future burnup or potential credit for soluble boron, without these considerations, the maximum thinning in Region II could be reached in approximately ten years. As discussed in Section IV.E, several mitigation measures may be considered including the use of rack savers or neutron absorbing material. In addition, FPC has placed on order a special tool for use in relocating certain assemblies within Region II. Placing these assemblies in

peripheral locations is expected to increase margin. The special tool is necessary since peripheral locations are currently inaccessible using present fuel handling equipment.

Based on the above, FPC concludes that adequate Boraflex is present in the CR-3 pools to preclude violations of reactivity limits until the year 2006.

III. MONITORING PROGRAMS IN EFFECT

III.A Fuel Movement Management Philosophy

Based on industry awareness pertinent to Boraflex degradation, FPC recognized the need to develop and document a fuel movement management philosophy which would minimize the radiation exposure to the Boraflex material. This philosophy involves only placing irradiated fuel into the "B" Pool high density fuel racks containing Boraflex after it has been stored in the "A" pool for two years. After installation of the high density racks the "B" Pool, FPC decided to maintain the total integrated gamma dose (TID) less than 1×10^{10} Rads. This philosophy provided a method to optimize the material condition of the Boraflex, while minimizing the degradation rate. CR-3 has experienced less degradation than most utilities based on installation of our racks later than most nuclear plants. Also, our experience of having a lower total integrated dose and use of an innovative fuel movement management philosophy has contributed to a lower Boraflex degradation rate.

III.B Coupon Surveillance Procedure Results

CR-3 Surveillance Procedure SP-192B, "High Density Rack Poison Sampling (SF Pool B)," is a coupon surveillance procedure that provides a method for verifying the condition of the Boraflex poison material of the high density poison racks in Spent Fuel Pool B. SP-192B provides for accelerated and long-term coupons to be tested on different frequencies. The accelerated tests are keyed to refueling intervals, while long-term and "water" tests are keyed to calendar time. At each accelerated-test sampling time, two coupons are removed for measurement, one representing Region I and the other Region II. For the long-term and "water" tests, two Region I and two Region II coupons are removed, one coupon for each region for each of the two tests.

The results from the 1994 surveillance procedure indicate that the Boraflex in the "B" spent fuel pool is in comparatively good condition by all dose versus degradation predictions and by the sample inspection performed. The visual inspection categorized the Boraflex as acceptable. The material was observed to be intact, with the surface texture uniform on both sides. Visible discoloration and minimum weight change as compared to the control sample were noted.

Based on an FPC calculated prediction for the remaining period of the operating license (until December, 2016), the Boraflex will never be exposed to a radiation dose of 1×10^{10} Rads that is considered to be the threshold dose required to cause serious breakdown of the Boraflex. The assessment indicates that "B" SFP racks have been exposed to 1.2×10^9 Rads which slightly exceeds the 1×10^9 Rads,

where silica begins dissolving out of the Boraflex material. The calculated projected integrated dose for twenty-five years (from installation of high density rack in 1991 to the end of the Operating License) is 3.85 X 10^9 Rads (Figure 6).

III.C <u>Temperature Profile</u>

The SFP temperature profile is continuously monitored through the plant's surveillance program as directed by Surveillance Procedures SP-300, "Operating Daily Surveillance Log" and SP-301, "Shutdown Daily Surveillance Log". The complex process of polymerization and diffusion of reactive silica into the pool is contingent upon dissolution and redeposition equilibrium. Silica release versus time is directly proportional to the temperature (i.e. silica in equilibrium at 85°F is 90 ppm whereas at 150°F it is 165 ppm). Constant temperature is the most desirable. Industry data reveal that silica release (mg of SiO_2/gm of Boraflex) is maintained near zero when temperature is held within the 85°F - 95°F range, and TID is <1 x 10^9 Rads. However, when temperatures reach 150°F, the maximum release rate of about 2 mg/gm occurs at the same integrated dose. Since 1992, CR-3 has maintained the SFP at an average temperature of 90°F for Modes 1 through 4, and 96°F for Modes 5 and 6, while minimizing the TID to 1.2 x 10^9 Rads as depicted on Figure 7. It should be noted that there will be fluctuations (peak temperatures) in the pool temperature based on ambient conditions and heat sink temperatures. The data represented by Figure 7 is based on available data.

III.D <u>Silica Management</u>

As Boraflex degradation occurs due to high levels of gamma radiation, silica is released from the material which then contaminates the spent fuel pool system. During a refueling mode, the pool is connected to the fuel transfer canal where the silica is mixed with RCS and other associated make-up tanks. The silica has the potential to accumulate (at elevated temperatures) onto the fuel cladding such that heat transfer is reduced which may accelerate cladding corrosion. Chemistry Procedure CH-400, "Nuclear Chemistry Master Scheduling Program," schedules weekly silica monitoring for the reactor coolant system, spent fuel cooling system, primary water make-up tanks, and monthly monitoring for the BWST. Quarterly analysis, also required by CH-400, is completed for other corrosive species (i.e. zeolite forming ions such as calcium aluminum and magnesium) to minimize the potential for corrosion-induced cladding failure.

CR-3 has evaluated the potential for flow induced erosion and has concluded it is not an apparent concern at this time. To minimize silica intrusion into the RCS, the silica concentration of primary water make-up tanks must be maintained as low as possible. During refueling, the Borated Water Storage Tank (BWST), having lower silica, is used to flood the reactor cavity and fuel transfer canal. During normal operations, feed and bleed dilution of the RCS is accomplished by utilizing the Reactor Coolant Bleed Tanks (RCBTs) which have been filled from either a demineralized water source, or the Boric Acid Storage Tanks (BASTs). The current CR-3 silica concentration in the SFP is approximately 7.5 ppm and the BWST is 5-6 ppm. CR-3 utilizes three RCBT's which range in silica from 0.1 ppm to approximately 7 ppm. Post Refuel 10 (May 1996) water management techniques

and dilution involved a decrease in the SFP silica concentration by approximately 2.5 ppm, from 10 ppm to 7.5 ppm.

To minimize the overall effects, as recommended by the B&W Water Chemistry Manual, the concentration of RCS silica levels should be maintained below 3.0 ppm at the start of 100 % power operation. FPC startup chemistry guidelines limit the RCS silica concentration to 3 ppm prior to 100% power, with a 1 ppm guideline approximately 30 days after criticality. Based on existing practices of water management, dilution and demineralization, this value has been successfully achieved.

CR-3 has effectively managed the elevated SFP silica concentrations to minimize the effect in the RCS. This was accomplished in 1994 through a cleaning effort utilizing a membrane technology. Post Refuel 10 (May, 1996) cleaning was completed through a feed and bleed dilution process. However, based on industry experiences and projected degradation rate as previously discussed, the estimated silica concentration versus time predicts silica concentration in the SFP will be approximately 20 ppm in the year 2000. Effective post-refueling RCS cleanup and silica removal may become more intense at that concentration. Prior to Refuel 12 in the year 2000, alternate methods for silica reduction in the BWST may need to be implemented. Methods currently being studied include the use of an on-line reverse osmosis or similar membrane technology using the BWST or RCBT's to isolate the source of silica, and removal of Boraflex from the racks. Separating the cooling functions of the SFP and fuel transfer canal would also minimize mixing between these two sources during the two-week refuel evolution.

IV. PROPOSED ACTIONS TO MONITOR/CONFIRM 5% SUBCRITICALITY MARGIN CAN BE MAINTAINED

IV.A <u>Checkerboard Loading</u>

Concurrent with burnup credit, the application of mixed region storage is another means to accommodate boron carbide loss from Boraflex. This concept relies on administrative procedures to selectively load fuel assemblies in the racks according to the burnup they have achieved. This technique has been approved by the NRC for plants to accommodate fuel enrichment increases (CR-3 is approved for a 5.0 wt.% enrichment). In the checkerboard loading scheme, one out of every two assemblies must have accumulated a specified burnup, the value of which will depend on the initial enrichment of the assembly. The alternative storage locations are reserved for new fuel or fuel assemblies which do not meet the enrichment/burnup criterion for Region II. In this manner, the irradiated fuel is used to partially control the reactivity of new fuel assemblies, thereby reducing the required quantity of neutron absorber material.

IV.B <u>Blackness Testing</u>

Blackness testing is a method to determine whether panels of Boraflex have developed gaps or separations, the size of gaps (shrinkage), as well as the axial elevation of gaps. It is not recommended for detection of gradual thinning

and/or loss of boron-carbide, but does provide sufficient sensitivity for identifying gross deterioration.

FPC determined by discussions with its consultants, one of which developed FPC's "B" spent fuel pool inspection program, that blackness testing should not be considered until the total integrated dose reaches 1 X 10^{10} Rads. Our analysis indicates CR-3 will not achieve this level. However, when the last thirty-eight locations in the B and C sections of the "B" pool are filled, FPC may consider blackness testing for baseline purposes to document the condition of the Boraflex. FPC will maintain the general practice that once spent fuel is placed into a Boraflex cell location, it should not be removed. This philosophy is based on the fact that even though Boraflex will become somewhat brittle, it will not shatter if it has not been disturbed by removing a potentially bent fuel assembly.

Presently, several utilities in the Westinghouse Owners Group and Combustion Engineering Owners Group are proposing to the NRC that they be permitted to take credit for soluble boron in the spent fuel pool water. The most recent meeting between the NRC Staff and industry representatives to discuss the first amendment request on this issue (Prairie Island Technical Specification Amendment), took place on August 27, 1996. FPC plans to follow the progress of this activity closely. If credit for soluble boron is permitted prior to the year 2000, FPC will not need to complete further blackness testing but will, in support of a technical specification amendment, need to develop a plant specific criticality analysis and a Probabilistic Safety Analysis (PSA) to calculate the frequency of a spent fuel pool dilution event at CR-3.

If credit for soluble boron is not permitted, additional mitigation measures may be needed to compensate for increased fuel enrichment and partial Boraflex degradation. This could require the use of poison inserts (B_4C) either within the fuel assemblies (i.e. in guide tubes), or between the fuel and the rack structure (i.e. rack savers). This technique has been successfully tested at CR-3, through participation in an EPRI project completed in December 1995 and is available for use, if necessary.

Table 1

Rack Module Data

	Region I	Region II
Number of Storage Locations	174	641
Number of Rack Arrays	(2) 9 x 10	(1) 9x 11 (4) 9x 12 (1) 10X11
Center-to-Center Spacing (Inches)	10.60	9.17
Boraflex Thickness (Inches)	0.085	0.058
Cell Inside Width (Inches)	9.00	9.00
Type of Fuel	B&W 15 x 15 and/or consolidated fuel (2:1 Ratio)	
Rack Assembly Dimensions (inches)	(9x10) 96X107X167	(9x11) 84x102x167 (9x12) 84x111x167 (10X11) 93x102x167
Dry Weights (lbs) Per Rack Assembly	17,800 (9x10)	9,700 (9x11) 10,500 (9x12) 10,800 (10x11)

Table 2

Margin to Accommodate B_4C Loss from Boraflex

	Region I 5 wt. % U-235 w/checkerboard burned fuel	Region II Fuel burnup ≥ 1.63 wt.%
K_{eff} of fuel and rack	0.9200	<0.95
Total Calculational Bias (includes two adjacent 4-inch Boraflex gaps)	0.0156	0.0100
Uncertainty	0.0049	0.0026
Design Basis K_{eff}	0.9288	0.9499
Margin	0.9288 - 0.9200 = 0.0088	0.9500 - 0.9499 = 0.0001
Potential Credit for Actual B-10 Loading (Blackness Testing)		
12% in B-10 Loading	0.0010	0.0001
Total Margin	0.0098	0.0001

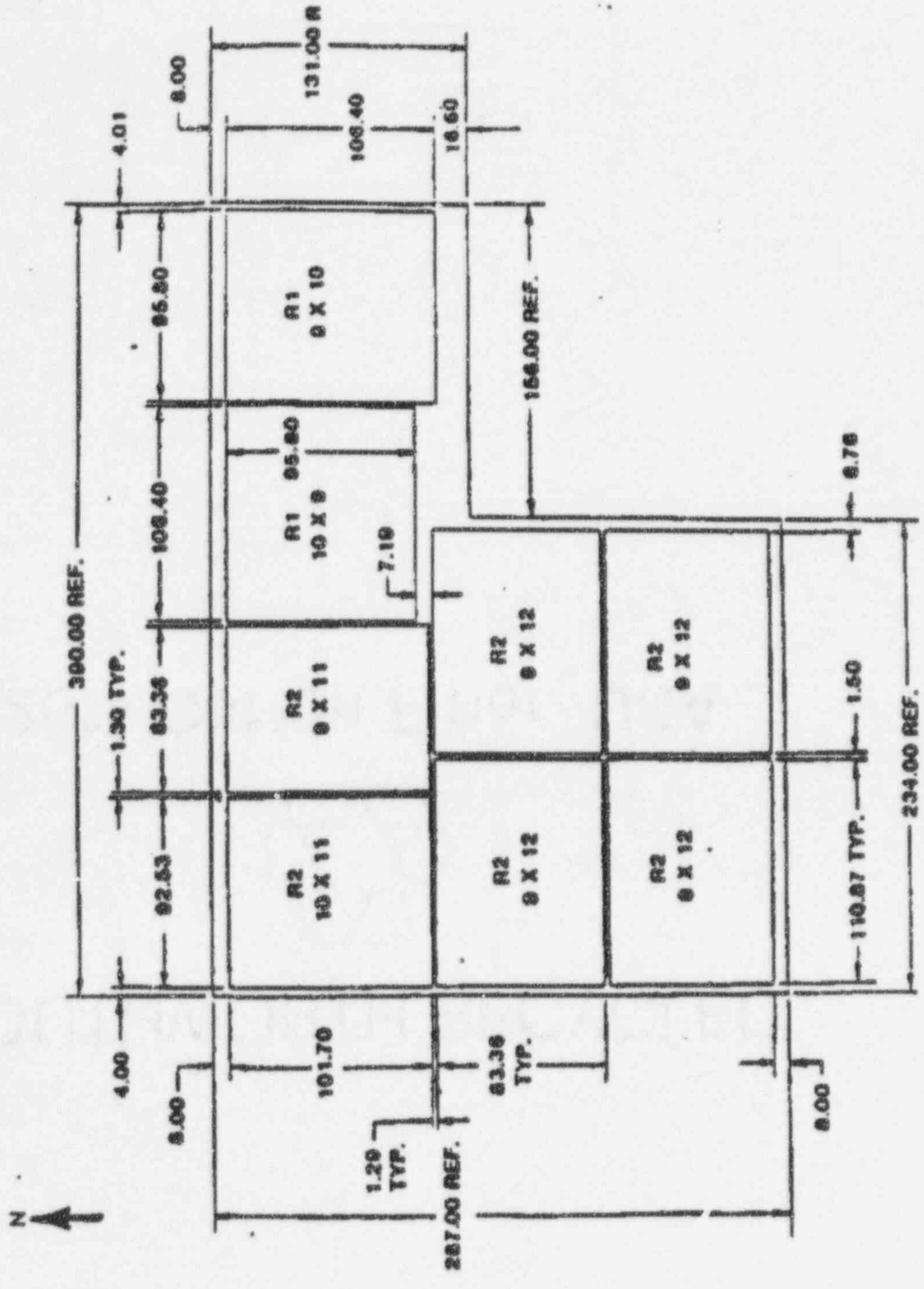

Figure 1 "B" Spent Fuel Rack Arrangement

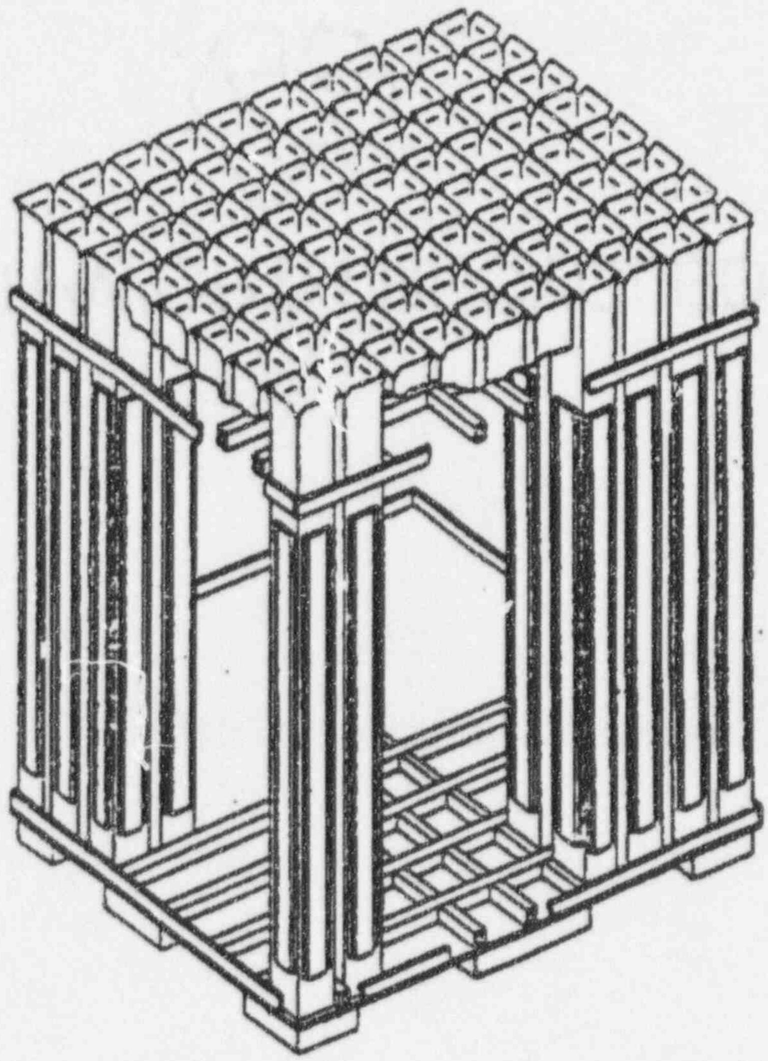

Figure 2 Region I Fuel Storage Rack Module

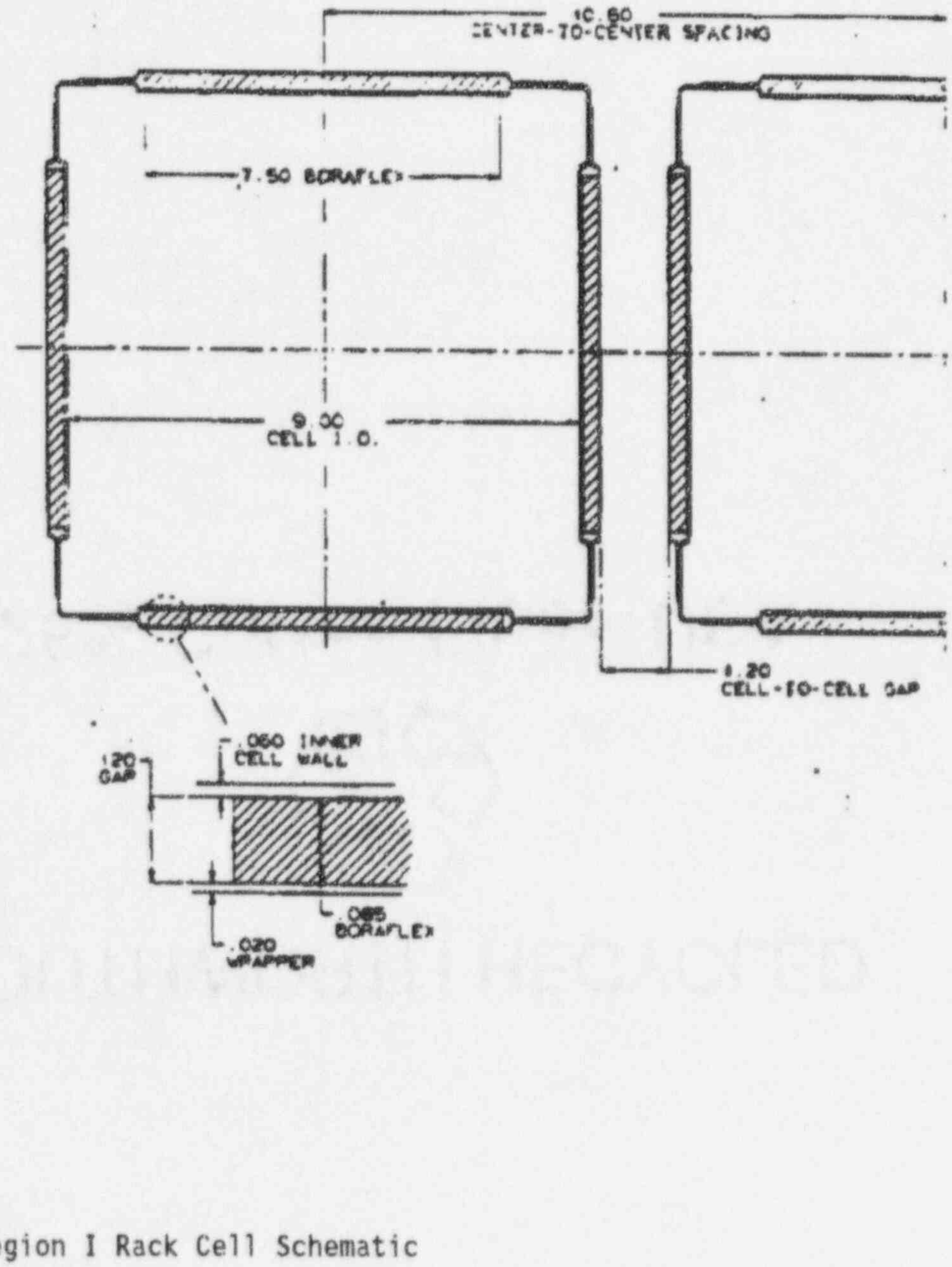

Figure 3 Region I Rack Cell Schematic

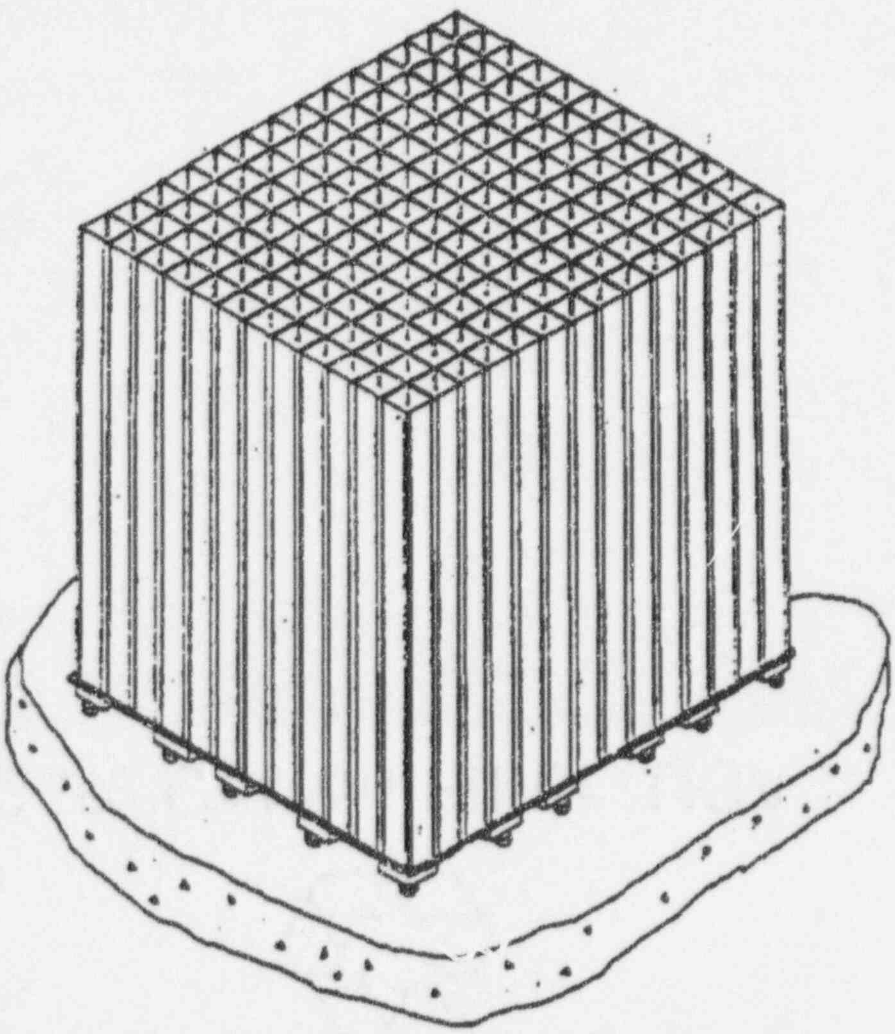

Figure 4 Region II Fuel Storage Rack

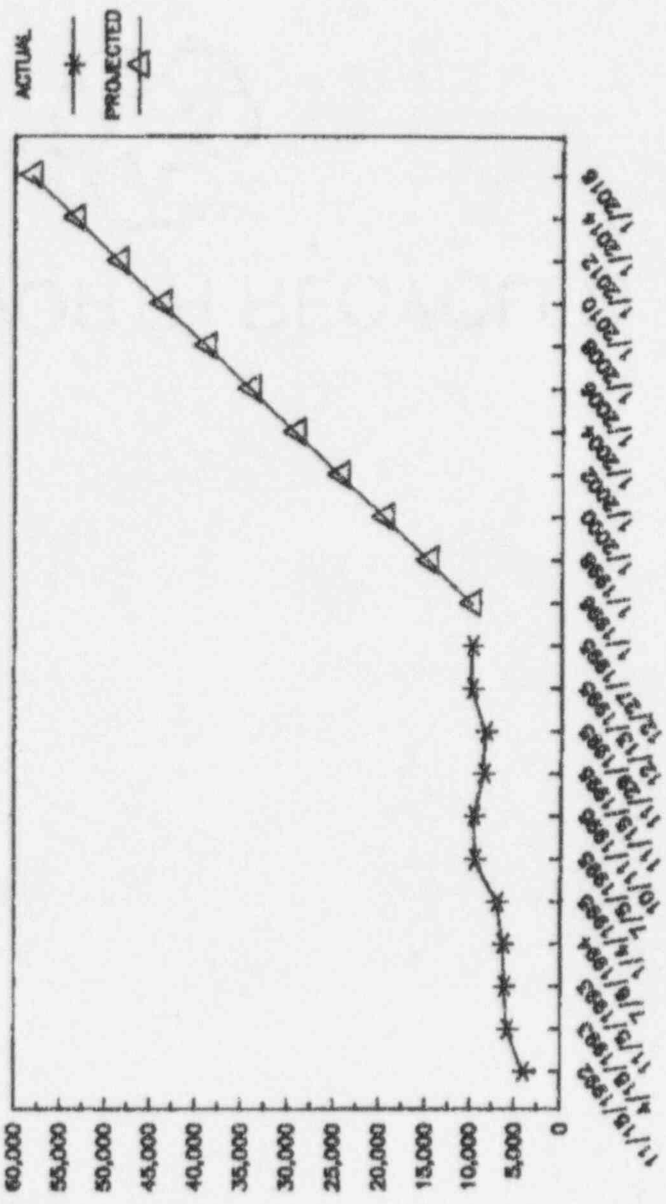

Figure 5 Spent Fuel Pool Silica (PPB)
(Note Time Interval Change After 1/96)

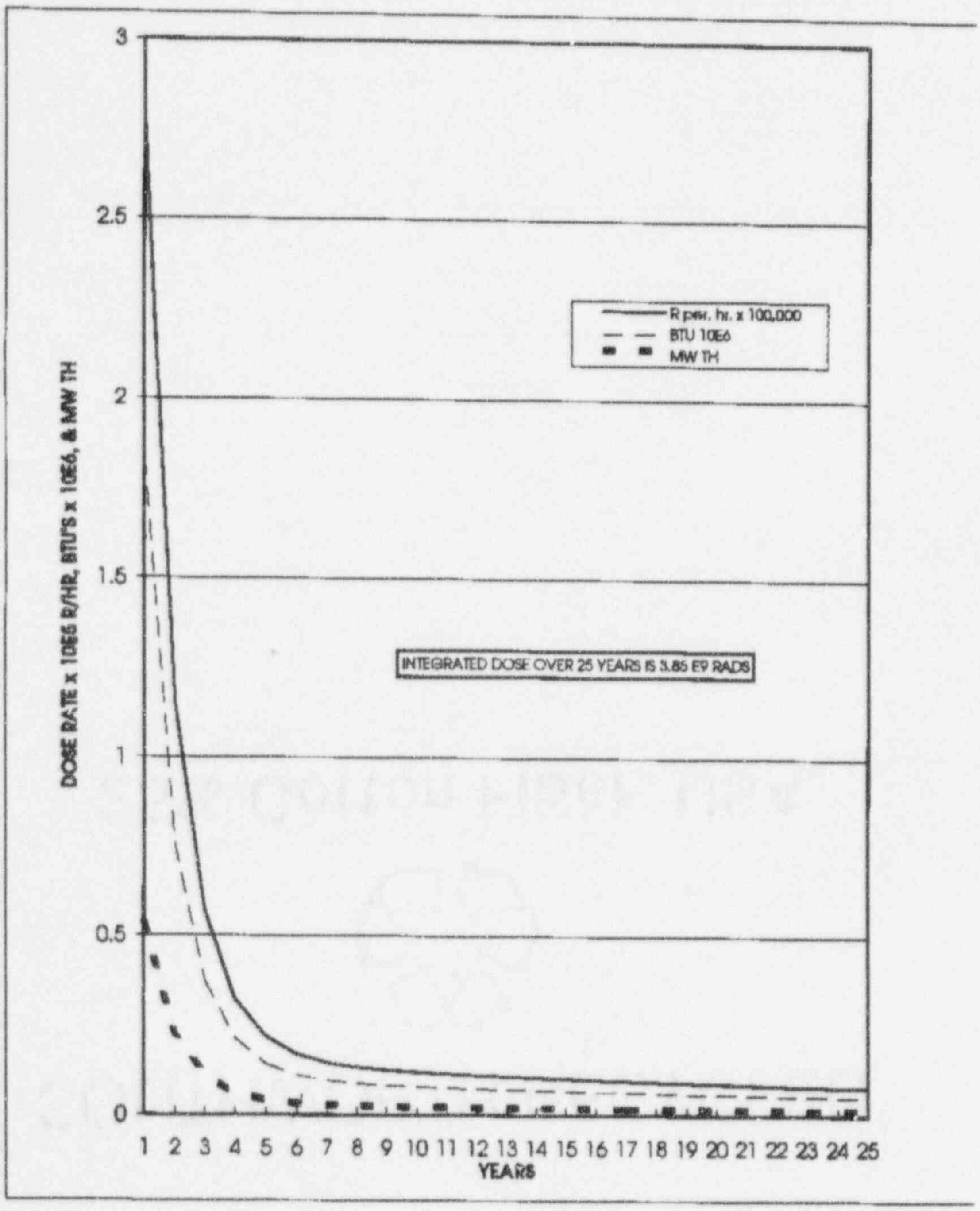

Figure 6 Dose and Heat Load on Boraflex

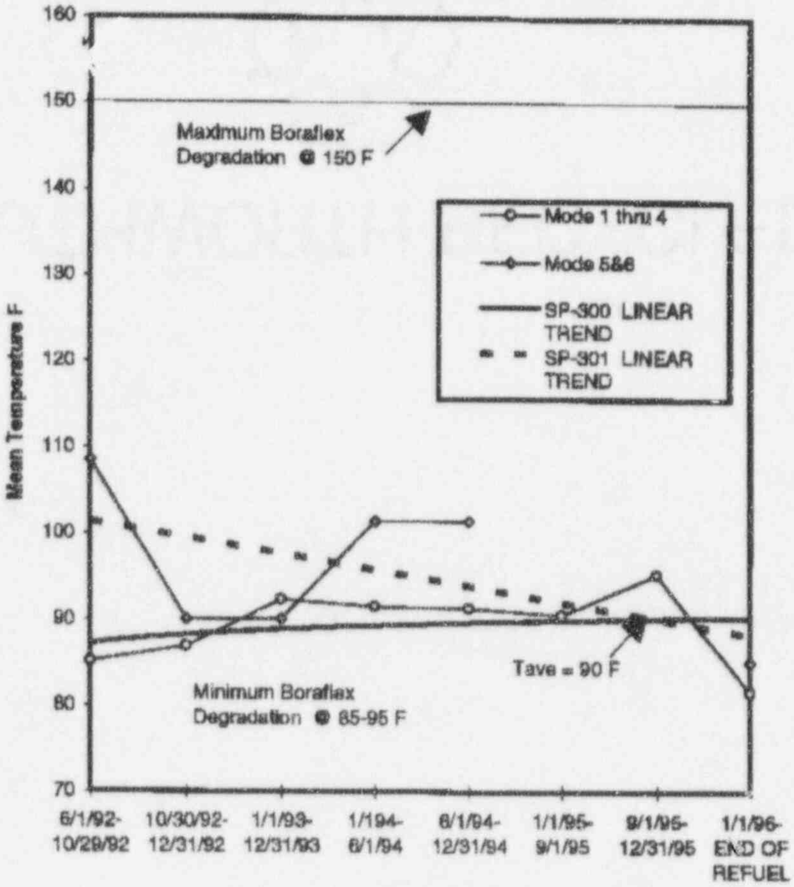

Figure 7 Spent Fuel Pool Temperature Profile