ABB CENP CRITICAL EXPERIMENTS IN THE REACTOR CRITICAL FACILITY OF RPI

(NON-PROPRIEATARY)

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1.0 INTRODUCTION

This report describes a proposed set of critical experiments to be carried out in the Reactor Critical Facility (RCF) of RPI under operating license CX-22, Docket No. 50-225. The purpose of these measurments is primarily to measure the reactivity equivalence of erbia (Er_2O_3), an absorber considered for use in fuel manufactured by ABB Combustion Engineering Nuclear Power (ABB CENP).

The report describes:

- The fuel to be used .
- The core layouts and the type of measurements.
- Calculated Technical Specification parameters.

The report concludes that the proposed experiments exhibit no degeneration in the margin of safety as defined in the bases of the Technical Specifications, Ref 1. Therefore, the experiments do not pose an unreviewed safety question or require a change to the facility Technical Specifications.

2.0 DESCRIPTION OF PROPOSED CORES AND CALCULATED TECHNICAL SPECIFICATION PARAMETERS

2.1 Fuel

The experiments will be loaded with two different kinds of fuel:

1)SPERT F1 fuel as described in the current license, Ref.1.

2)ABB CENP fuel, zirconium clad,[ ]with and without[ ]erbia.

Fuel with erbia has previously been manufactured for lead test assemblies in Calvert Cliffs, unit 2, cycle 9, Ref.2.

The ABB CENP fuel is manufactured according to procedures for standard 16x16 reload fuel and, except as noted, is identical to fuel in lead test assemblies slated for insertion into SONGS 2, cycle 6, Ref 3. Except for the length of the tubing and the length of the fuel rod spring there is no difference between the experimental fuel and fuel manufactured for standard reload applications. Top and bottom endcaps have integral extensions that mimic the top and bottom ends of the SPERT fuel thus fitting the RCF lattice plates. The welding of end plugs is done according to standard procedures.

The dimensions for the ABB CENP fuel are shown in the table below:

Pellet diameter	0.325"
Clad OD	0.382
Clad ID	0.332

2.2 Proposed core configurations

Two basic cores are proposed, one with erbia and one without. In both cores the SPERT fuel serves as a driver surrounding the ABB CENP fuel. See Figure 1. The lattice pitches in the two regions are chosen so that a close match of k-infinity is obtained between the two fuels. The pitches chosen also permit the control rods to remain in their current locations.

The central region has a lattice pitch of 1.285 cm and the driver is on a 1.713 cm pitch.

The central region without erbia pins is shown in Figure 2. A representative central region with 44 erbia pins is shown in Figure 3. The maximum number of erbia pins to be used is 56. Several configurations of erbia pins may be measured. The number of driver pins will be constant at about[ ]pins.

The calculations were done with 44 and 0 erbia pins respectively. As will be seen below, rod worths do not vary much with configuration and are somewhat lower with 0 erbia pins. Isothermal Temperature Coefficients (ITCs) and void coefficients are expected to be more negative when erbia is present because of the energy dependence of the Er-167 cross-sections in the thermal region.

2.3 Proposed measurements

The following types of measurement will be done: (Except as noted below, only procedures currently approved will be used.)

- Reactivity and rod worth measurments.

- Fuel pin worth.

- Boron worth.

- Temperature coefficient measurments.

- Fission gamma local pin-by-pin measurments.

- Axial buckling measurments.

The proposed use of low concentrations of soluble boron is not considered to constitute an unreviewed safety question. The potential safety concern with regard to use of soluble boron is the unintentional boron dilution event. This can take two forms; viz., either the addition of completely unborated water or the addition of borated water of lower concentration to a critical or slightly subcritical core. Both of these events are prevented from occurring by the following added administrative procedure:

- All water will be required to be drained from the reactor tank

(including a small subtank at the bottom of the main tank) before the boron concentration can be changed in any direction.

- Mixing boron, as would be required for a new experiment, will be done only with all the reactor system (including tanks and piping) water in the storage tank.

- Before loading a new experiment, the newly added boron will be homogenized in the reactor system by circulating the entire water volume several times between storage tank and reactor tank. Water samples will then be taken in several locations and measured to verify uniform boron concentration.

- Whenever the system contains measurable levels of boron, fresh water intrusion into the system will be prevented by closed, chained and locked inlet valves on the external water supply.

- Removal of boron from the system at the end of a sequence of measurements will be done with ion exchange equipment.

- These procedures will be applied to an existing RCF core configuration before the ABB CENP measurements are undertaken.

As a result of the above measures, only water with a uniform concentration of boron will be available in the reactor system when a new experiment is being loaded and brought to a critical state.

2.4 Calculation methods

Calculations have been made with ABB CENP's assembly lattice code DIT, Ref.4, producing 4-group averaged, pin cell homogenized cross-sections including P1 scattering and with DOT 4.3, Ref.5, for the core-wide calculation. The mesh density in DOT is 4x4 over each pin cell in the driver and 3x3 in the central region.

Spectrum interactions between the reflector and the driver were accounted for in DIT by using a checkerboard geometry of fuel/reflector. The control rods were explicitly represented in both DIT and in DOT.

This calculation method was applied to an all-SPERT core measured at the RCF with 493 fuel pins. The calculated eigenvalue was k-eff = 1.00171. This calculation did not model the control rod guide bars which remain in the core in the all rods out configuration. The worth of the guide bars has been measured to be approximately 0.2% delta-k. Whether this correction is applied or not, the agreement is quite good. The following calculations represent the guide bars explicitly at a conservatively high worth which will underestimate control rod worths.

2.5 Expected properties of proposed cores

Two sets of calculations were done:

a) For the expected critical states. (Described in this section.)

b) For a conservatively high soluble boron content: Section 2.6.

The core shown in Figure 3 with [ ] SPERT pins and [ ] ABB CENP pins of which 44 are with erbia, is expected to be close to critical without soluble boron:

CORE DESCRIPTION	PPM	TEMPERATURE	k-effective	ROD WORTH
44 Erbia/UO_2 [ ] UO_2 CENP [ ] SPERT	0	68 deg F	1.00066	(N) 2.30\$ (N-1) 1.72\$

Reactivity worths are quoted in units of \$ or cents using a beta value of 765pcm/\$.

The core shown in Figure 2, (i.e. with [ ] SPERT pins and [ ] ABB CENP pins with no erbia) is expected to be close to critical with 200 ppm soluble boron:

CORE DESCRIPTION	PPM	TEMPERATURE	k-effective	ROD WORTH
[ ] UO_2 CENP [ ] SPERT	200	68 deg F	1.00057	(N) 2.21\$ (N-1) 1.66\$

The calculated boron worth is about 17 pcm/ppm.

The expected variation of reactivity with moderator temperature for the core with no erbia pins (200 ppm) is:

Temperature	k-effective
50 deg F	1.00123
68	1.00057
100	0.99909

It can be seen that a negative ITC is expected over the entire expected temperature interval and that the ITC will remain negative above 100degF.

Because of its thermal energy cross-section shape, Er, when loaded, causes the ITC to move in the negative direction. The core without erbia is therefore limiting.

The expected total rod worth and the worth with one rod stuck out, are in compliance with the Technical Specifications.

There is little interaction between the rods as demonstrated both by measurement and by calculation.

2.6 Technical Specification parameters

Rod worths and void coefficients are expected to be least favorable at high soluble boron content while ITCs are expected to have little sensitivity because of the small variations in water density in these ambient temperature measurements.

Accordingly, all parameters for comparison with the Technical Specifications were calculated at 300 ppm soluble boron. This represents a conservatively high value compared to the expected value of 200 ppm. The uncertainty in calculated k-effective may be estimated to about 800 pcm for a critical experiment where the leakage represents about 40000pcm reactivity. With the boron worth estimated above, an 800 pcm reactivity error is equivalent to about 50 ppm, clearly lower than the 100 ppm added.

Table 1 shows the calculated parameters and the comparison with the current Technical Specifications. In all cases, the proposed measurments exhibit reactor parameter values within the the current specifications.

TABLE 1

COMPARISON OF CALCULATED AND LICENSED TECHNICAL SPECIFICATION PARAMETERS

Core with [ ] SPERT, [ ] CENP pins (no erbia) and 300 ppm soluble boron.

	CALC	TECH SPEC	NOTE
Excess Reactivity at 68 deg F	0.60$	0.60$	1)
Subcritical reactivity with one rod stuck out	0.99$	>0.70$	2)
Shutdown margin, 4 rods	1.52$	>1.00$	2)
Core average ITC	<0 entire 50<T<100	<0 for T>100 F	
Integrated reactivity	-0.28$	< +0.15$	3)
Core average void coeff	-4.7E-6 -.00061$/cc	<0	4)
Local void coefficient	-3.5E-6 -.00045$/cc	<-3.29E-6 <-0.00043$/cc	5)
Worth of a single pin	0.04$	<0.20$	6)

1) This value is not a calculated value. It is unchanged from the currently licensed value.

2) At 68 deg F.

3) The calculated value is the difference in reactivity from 50 to 100 F. Note that the ITC is negative at all temperatures.
The technical specification value (positive) is the permitted reactivity insertion from 50 F to the point where ITC becomes negative.

4) Units are reactivity per cc void.

5) The most positive calculated value is listed. It occurs for the SPERT fuel. The local void coefficient in CENP fuel is always more negative:

Central 8 ABB CENP pincells voided -6.0E-6 = -.00078$/cc

All ABB CENP pin cells voided -6.9E-6 = -.00090$/cc

6) Calculated for average of 16 SPERT pins at periphery of core.

3.0 SAFETY EVALUATION

Title 10 of the Code of Federal Regulations, Section 50.59 (10 CFR 50.59) states that the licensee may make changes to the facility as described in the SAR, without prior Nuclear Regulatory Commission approval, unless the proposed change involves a change to the Technical Specifications or an unreviewed safety question. A proposed change involves an unreviewed safety question:

i. if the probability of occurrence and the consequences of an accident or malfunction of equipment important to safety previously evaluated in the safety analysis report may be increased, or

ii. if the possibility for an accident or malfunction of a different type than any evaluated previously in the safety analysis report may be created, or

iii. if the margin of safety as defined in the bases for any technical specifications is reduced.

The proposed measurements involve the performance of a secured experiment according to the definition in the license. The fact that the proposed central region is not SPERT fuel does not therefore constitute a change to the facility.

The proposed measurements involve neither a change to the RCF Technical Specifications nor an unreviewed safety question. The bases for the conclusions are addressed below as the standards put forth in 10 CFR 50.59 are negatively answered.

The proposed pitch in the driver region differs slightly from the pitch of currently installed core as described in the Design Features section (5.0) of Ref.1. The difference is not sufficiently large to cause the Technical Specification parameters to be exceeded nor does this difference result in a need for additional specifications. The safety analyses do therefore remain valid and the probability of occurrence and the consequences of an accident or malfunction of equipment important to safety previously evaluated in the safety analysis report do not change.

The proposed use of low levels of soluble boron for reactivity control would constitute an unreviewed safety question because of the possibility of a boron dilution event. This possibility is eliminated by operating the facility without access to unborated water and with uniformly mixed boron only. Therefore, the possibility for an accident or malfunction of a different type than any evaluated previously does not exist.

Calculations show that the proposed experiments do not require changes in the current reactor parameters described in the bases for the technical specifications. All parameters remain within the current specifications. Therefore, the margins of safety as described in the bases have not changed.

4.0 CONCLUSIONS

The proposed measurements do not require changes in the current reactor parameters described in the bases for the technical specifications. All parameters remain within the current technical specifications. It is concluded that the safety analyses for the RCF as currently licensed remain applicable.

5.0 REFERENCES

1. Attachment to Order Modifying License No. CX-22 dated July 7, 1987. Docket No. 50-225.

2. Calvert Cliffs Nuclear Power Plant, Unit No.2; Docket No. 50-318, Request for Amendment, Unit 2 Ninth Cycle license application. Letter, G.C.Creel to U.S. Nuclear Regulatory Commission,2/7/89.

3. "Erbium Burnable Absorber. ABB CENP/NRC Meeting. December 3, 1990". Enclosure (I) to LD-90-095, 12/18/90 letter from S.A.Toelle (C-E) to R.C.Jones, Reactor Systems Branch, Division of Systems Technology, Office of Nuclear Regulation,NRC.

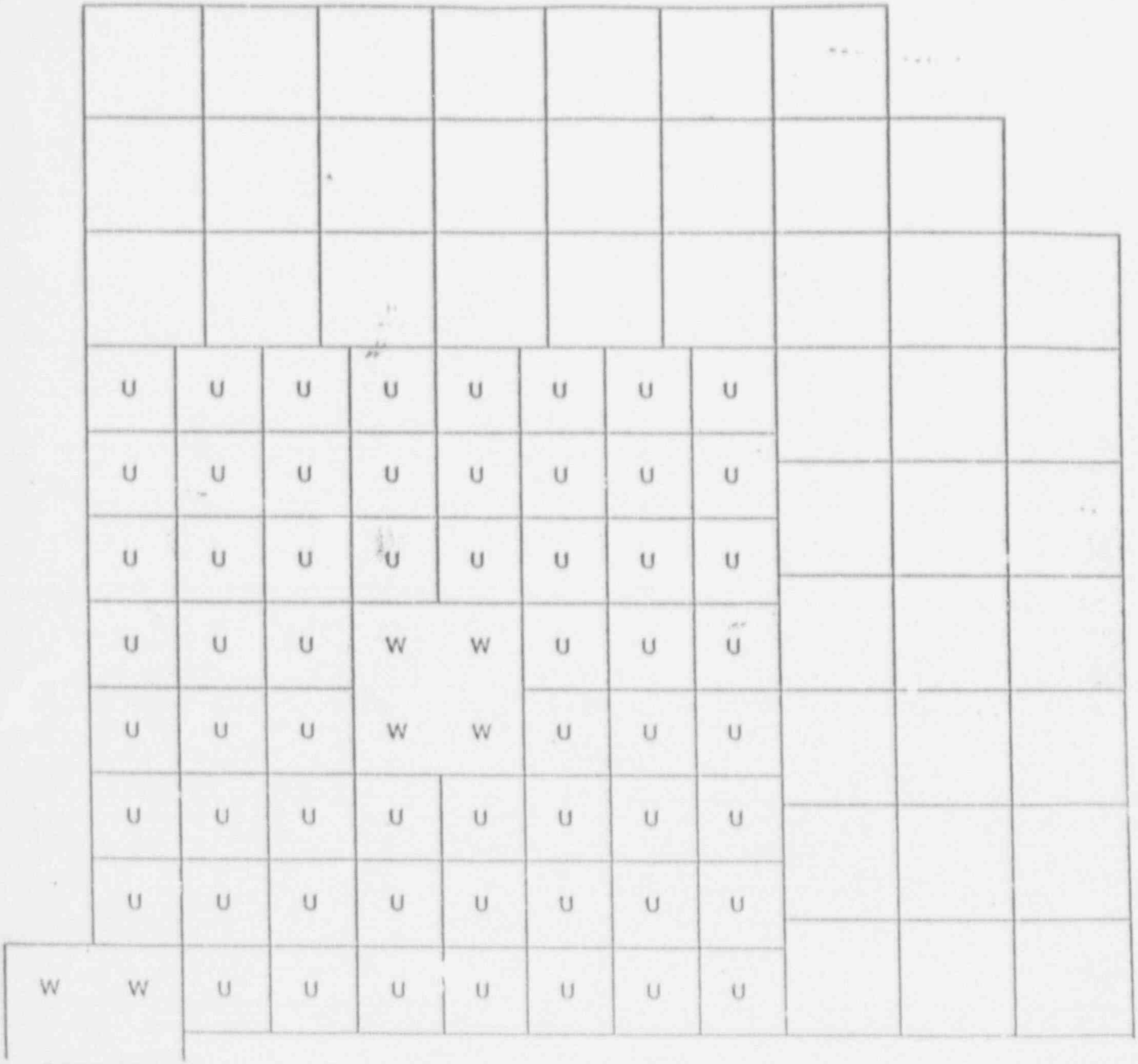
4. "The ROCS & DIT Computer Codes for Nuclear Design" CENPD-266-P-A, 1983.

5. "An Updated Version of the DOT4 One- and Two-Dimensional Neutron/Photon Transport Code", W.A Rhoades, R.L.Childs, ORNL-5851, 1982.

FIGURE 1

FIGURE 2

CORE WITH[ ]SPERT PINS AND[ ]CE PINS (ALL UO2)

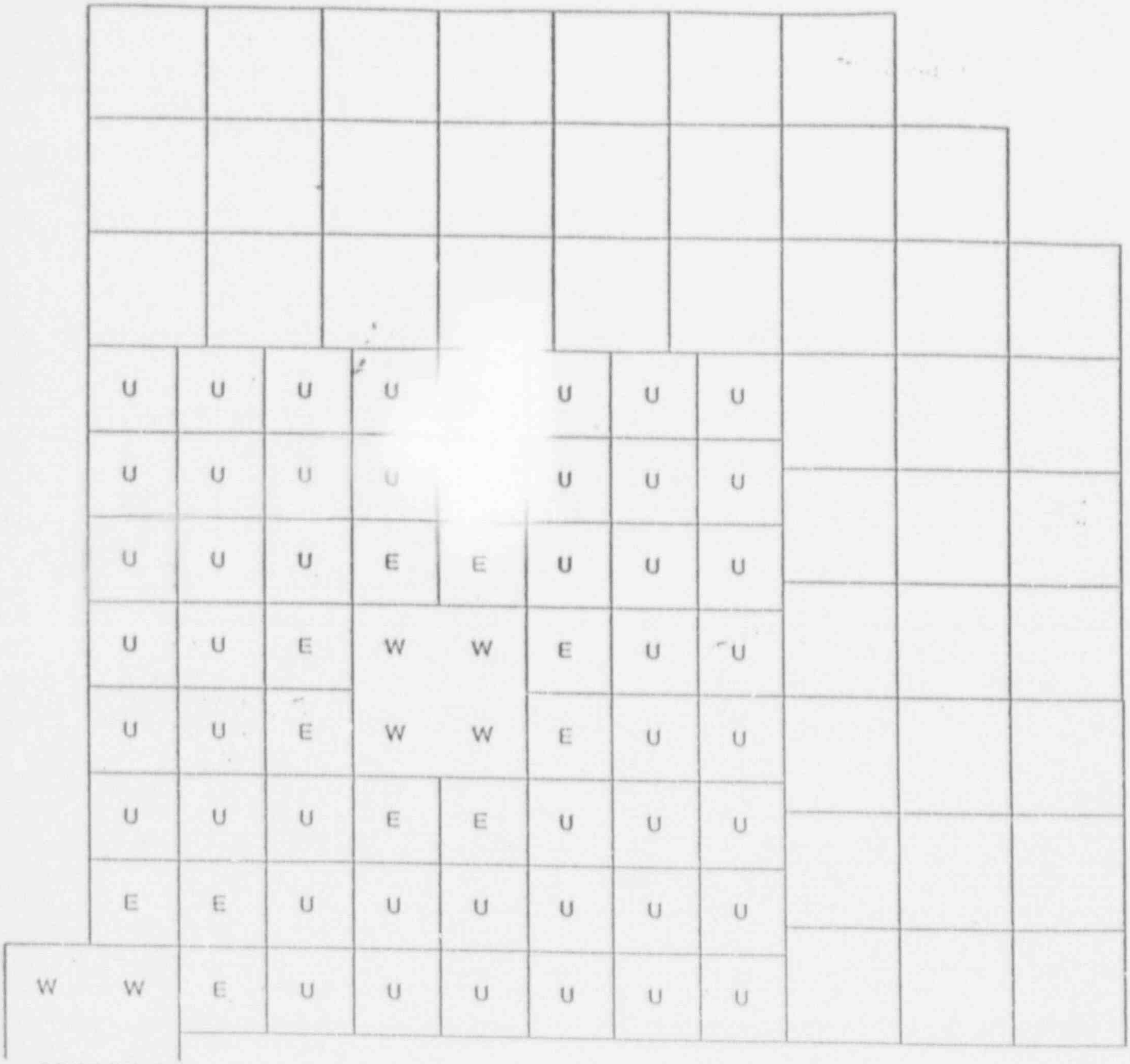


CORE CENTER

W= WATERHOLE
U= CE FUEL[ ]w/o U235 PITCH 1.285485 CM
E= CE FUEL[ ]W/0 235 AND[ ]ERBIUM
BLANK SQUARES REPRESENT SPERT FUEL PITCH 1.71398 CM

FIGURE 3

CORE WITH[ ]SPERT PINS AND[ ]CE PINS (44 ER)



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W= WATERHOLE
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BLANK SQUARES REPRESENT SPERT FUEL PITCH 1.71398 CM

ADDENDUM: Properties of cores with all SPERT fuel. 4/22/91.

The proposed measurments use the resident SPERT (F1) fuel as a driver for the CE fuel located at the center of the core. The lattice pitch for the driver was chosen such that a good spectral match is obtained with the CE fuel. In particular the k-infinities and temperature coefficients are similar in the two regions. The choice of pitch in both regions is such that the temperature coefficients are substantially more negative than in the technical specifications of the license, Ref.1.

The technical specifications parameters do not include the lattice pitch nor do the limiting conditions for operation, Ref.1. Hence the choice of any particular lattice pitch that produces parameters within the limits of the technical specifications will satisfy the safety analyses of the license. It was shown above that the proposed measurments do this with substantial margin.

In the general description of the RCF, Ref.1, a particular lattice pitch (1.49cm) is however mentioned. This is slightly lower than the pitch of the driver (1.71cm) for the proposed measurments. Although not included in the proposed measurments, a core with all SPERT fuel of 1.71 cm pitch could conceivably require a license modification. It is shown in this addendum that this is not so.

Additional Calculations for an all-SPERT core of 1.71cm pitch.

The core proposed in the main text was modified by removing all CE fuel and replacing it by SPERT fuel to form a uniform core with 376 SPERT pins. This core was then calculated at 50,68 and 100 deg F with and without rods.

The all-SPERT core with a pitch of 1.49cm (Ref.1) mentioned in section 2.4 was also calculated to indicate the expected core performance for a range of pitches. In the range 1.48-1.71cm, the SPERT lattice is undermoderated. The larger pitch is expected to have the least negative ITC and the smallest rod worth.

Rod Worth at 68 deg F.

		Core with 1.49cm pitch	Core with 1.71 cm pitch
Worth	(N)	1880 pcm = 2.46$	1622 pcm = 2.12$
	(N-1)	1410 pcm = 1.84$	1216 pcm = 1.59$
Subcritical reactivity with one rod stuck out		1.24$	0.99$
Shutdown margin, 4 rods		1.86$	1.52$

As expected the worth is somewhat lower for the higher pitch. Both are however comfortably within the technical specifications as shown in Table 1, section 2.6. The proposed cores have rod worths slightly higher than the all-SPERT core at the 1.71 cm pitch.

It may be noted that the proposed measurments do not include any unsecured experiments and do not therefore require the assumption of an excess reactivity of 0.60$ as assumed in computing subcritical reactivity and shutdown margin.

Temperature Coefficients

Since the higher pitch will have the least favorable ITC, this quantity was not recalculated at the 1.49 cm pitch. The following results were obtained for the 1.71 cm core:

Temperature deg F	ppm	k-effective
50	200	1.00600
68	200	1.00529
100	200	1.00379

Clearly, the temperature coefficient is negative in this entire interval as well as above 100 deg F. Furthermore, comparing with the corresponding results for the proposed cores, section 2.5, it is also clear that, as expected the temperature coefficients are quite similar.

Voidcoefficients have not been calculated for the all-SPERT cores but it is expected that the local value in Table 1, since it was calculated in the driver, will be quite similar to the value for the all-SPERT core with a 1.71 cm pitch.

Conclusion

It has been shown that, at a slightly higher pitch than that currently described in Ref.1, the rod worth and temperature coefficient will comfortably remain within current technical specifications. It should be noted that all temperature coefficient results in this report are unbiased. ABB/CENP methods, as documented in Ref.4, do normally predict slightly too positive coefficients In a critical experiment where the leakage is a large component of the neutron balance, the situation might however be different. To ensure that temperature coefficients remain within technical specifications they will be measured. Existing measurments on the 1.49cm core indicate a negative ITC of about -10 pcm/deg F.