PACIFIC GAS AND ELECTRIC COMPANY

PG&E + 77 BEALE STREET • SAN FRANCISCO, CALIFORNIA 94106 • (415) 781-4211 • TWX 910-372-6587

JAMES D. SHIFFER
VICE PRESIDENT
NUCLEAR POWER GENERATION

July 30, 1985

PGandE Letter No.: HBL-85-035

Mr. John A. Zwolinski Chief
Operating Reactors Branch No. 5
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

Re Docket No. 50-133, OL-DPR-7
Humboldt Bay Power Plant, Unit No. 3
Additional Information on SAFSTOR Decommissioning

Dear Mr. Zwolinski:

NRC letters dated January 23 and February 14, 1985 requested additional information on SAFSTOR decommissioning of Humboldt Unit 3. PGandE provided responses on February 28, March 20, April 3, and July 11, 1985 (HBL-85-005, HBL-85-009, HBL-85-014, and HBL-85-030, respectively).

A partial response was provided in HBL-85-005 to Item 75 of the January 23 request. PGandE letter HBL-85-014 stated that a complete response to that item would be submitted by the end of July 1985. Enclosed is a complete response to Item 75. This submittal completes PGandE's responses to the NRC's questions on SAFSTOR decommissioning.

Kindly acknowledge receipt of this material on the enclosed copy of this letter and return it in the enclosed addressed envelope.

Sincerely,

for J. D. Shiffer

Enclosure

cc: P. B. Erickson
J. B. Martin
Service List (Decommissioning)

A001
1/40

ENCLOSURE

PACIFIC GAS AND ELECTRIC COMPANY
HUMBOLDT BAY POWER PLANT UNIT 3
CRITICALITY ANALYSIS
FOR SAFSTOR DECOMMISSIONING

0436S/0035K

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A. INTRODUCTION

Item 75 of NRC letter dated January 23, 1985 requested the following information:

"Discuss the likelihood of a reactivity accident in the spent fuel storage pool due to heavy load drop or seismic event. If sufficient likelihood (_10^{-6} per year) of such events exists, then, assuming step and/or ramp reactivity insertions in the stored spent array due to reduction in undermotion of stored fuel in the pool, in turn due to fuel reconfiguration initiated by a heavy load drop or strong seismic event, calculate offsite radiological consequences assuming:

a) upward spray of all pool water without the presence of the building roof, and

b) pool boiling without spray and without the presence of the building roof."

PGandE's response dated February 28, 1985 stated the following: "PGandE is actively evaluating design alternatives that would prevent possible criticality due to seismic and heavy load events." This report provides a complete response to Item 75.

This report describes the design, fabrication, and safety analysis performed for the addition of neutron-absorbing material in the Humboldt Bay Power Plant (HBPP) Unit 3 spent fuel storage pool. The purpose of the modification is to ensure subcriticality following any event which results in a rearrangement of fuel assemblies from the existing criticality safe storage rack configurations.

The modification consists of enclosing each fuel assembly in a can fabricated from a neutron-absorbing material, so that a k-effective greater than 0.95 can not be achieved for any possible fuel configuration.

The criticality analysis associated with this project was prepared by Pacific Gas and Electric Company (PGandE). The goal of this analysis was to find the appropriate boron loading to ensure subcriticality. The General Electric Company performed an independent analysis using their own approved calculational methods and has verified the PGandE results.

B. OVERALL DESCRIPTION

1. Existing Rack Configuration

The HBPP spent fuel storage racks have a total capacity of 486 fuel assemblies. This includes 351 central pool locations in 88 groups of 4*, and 135 peripheral pool locations in 45 groups of 3. The central racks are designed to individually support each fuel assembly. The peripheral racks support fuel assemblies in groups of three.

The central storage racks (Figure 1) are constructed of aluminum and consist of pairs of storage units approximately 5 feet high and 12 inches square. Each storage unit is able to hold four fuel assemblies. The peripheral racks are similarly constructed except that they can hold either three fuel assemblies or one full fuel storage can.

The fuel storage racks are welded and/or bolted to cross members of aluminum channels. The fuel storage racks are spaced to be "criticality safe."

There are currently 390 irradiated fuel assemblies in the HBPP spent fuel storage pool, with exposures ranging from 1,307 to 22,876 MWD/MTU.

2. Proposed Modifications

In order to preclude criticality in the spent fuel storage pool following an event which results in movement or damage to the fuel assembly storage racks, each fuel assembly will be enclosed in a can fabricated from a neutron-absorbing material. The can will contain an areal density (0.005 gm/cm^2) of boron (B-10) such that a k-effective greater than 0.95 cannot be achieved for any possible configuration.

A drawing of the can is shown in Figures 2, 3 and 4. The walls of the can will be fabricated from Boral^{tm}. Three bands will be attached at the top, middle, and bottom of the can to provide structural strength. Additional support may be provided by corner angles, as necessary, as shown in Figures 2 and 3. A band will be attached to the bottom of the can to prevent the fuel assembly from coming out of the bottom. The top band will be fabricated with locking tabs which will be bent over to prevent inadvertent removal of the fuel assembly from the can. This design will ensure that the poisoned material is an integral part of the fuel assembly.

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* (However, pool location 64-07 cannot be used due to a bolt protruding into the bottom of this location and inadvertent use of this location is prevented by a triangular plate welded over the top.)

C. MATERIAL CONSIDERATIONS

Most of the material used in fabrication of the fuel bundle enclosure can is Boral, which is a thermal neutron poison material composed of boron carbide and 1100-alloy aluminum. Boron carbide is a compound having a high boron content in a physically stable and chemically inert form. The 1100 alloy aluminum is a lightweight metal with high tensile strength which is protected from corrosion by a highly resistant oxide film. The boron carbide and aluminum are chemically compatible and suited for long-term use in the radiation, thermal, and chemical environment of the HBPP spent fuel storage pool.

The Boral is provided in flat sheets and is formed to enclose the full length of each of the four sides of each individual fuel assembly. Physical integrity of the poisoned can is maintained by use of type 304 stainless steel bands which are attached to the Boral with aluminum rivets and encircle the can at the bottom, the approximate center, and the top.

The materials contained in the Boral, as well as the stainless steel, are compatible with all parts of the spent fuel storage system, including the fuel assemblies, the cooling system, the cleanup system, the pool liner, and the storage racks. The useful life of the Boral will exceed 40 years when in contact with the storage pool water. The corrosion resistance of Boral is provided by the protective film on the aluminum cladding that is an integral part of the Boral panels. Testing performed by the Boral supplier confirms that the effects are negligible from general corrosion, galvanic corrosion of the Boral/stainless steel interface, pitting corrosion, stress corrosion, and intergranular corrosion.

Boral is manufactured under the control and surveillance of a computer-aided quality assurance/quality control program that conforms to the requirements of 10 CFR 50, Appendix B, entitled "Quality Assurance Criteria for Nuclear Power Plants."

Boral has been licensed by the USNRC for use in BWR and PWR spent fuel storage racks, and is also used around the world for spent fuel shipping and storage containers.

D. NUCLEAR CONSIDERATIONS

1. Overview

The criticality analysis for these proposed modifications was performed by PGandE using the CASMO-2E (Ref. 1) computer code. These calculations were performed using a conservative set of assumptions and resulted in a maximum k-infinity of 0.894.

An independent analysis was then performed by General Electric using their MERIT code. The results of that evaluation indicated a maximum k-infinity of 0.884.

The details, assumptions, and code inputs for each of the analyses are described in the following sections.

2. PGandE Criticality Analysis With CASMO-2E

CASMO-2E is a multigroup, two-dimensional (2-D) transport theory, fuel assembly analysis code. It was used to design a B-10 loading for poison cans to be attached to the fuel assemblies in the HBPP Unit 3 spent fuel storage pool. A 25-energy group library, supplied with CASMO and based on ENDF/B-III cross-sections, was used. A worst case analysis was performed to bound all possible fuel assembly rearrangements by analyzing an infinite array of the most reactive fuel assembly in its most reactive configuration. The effects of moderation between assemblies and within assemblies were analyzed to obtain the most reactive geometry. Additionally, effects of uncertainties in fuel density and poison can design were analyzed and included in a conservative manner. The following conservative assumptions were made:

1. All fuel was assumed to have the highest as-built enrichment (2.52% U-235) and contain the greatest U-235 mass (GE Type III-4).
2. All fuel assemblies were at beginning of life (BOL), cold and clean, and contained no gadolinia (no credit for exposure, fission products, or burnable poisons).
3. No credit was taken for neutron absorption in the materials of the fuel storage racks, the fuel channel, or the aluminum outside of the B_4C containing core of the Boral.
4. The 2-D transport calculation assumed an infinite array of infinitely tall fuel assemblies, thus bounding all geometries (no credit for radial or axial leakage).
5. Optimal moderation was imposed by varying the gap between assemblies, the inner dimension of the poison can, and the fuel rod pitch within the poison can.

a. Achieving Optimal Moderation

The effect of fuel assembly separation was investigated by analyzing several gap thicknesses between assemblies with as-built lattice dimensions at several B-10 loadings. These results, shown in Table 1, indicate the most reactive situation to be the zero separation case. This is due to the fact that water outside the poison cans serves as a flux trap.

Table 1

EFFECT OF OUTER WATER GAP ON K-INFINITY

(Model - As-Built Lattice, Poison Can 60 Mils Thick, Inner Dimension = 4.54 inches)

Outer Water Gap (cm)	B-10 Loading (gm/cm^2) 0.003	0.005	0.010
0.0	0.92992	0.86875	0.79089
0.5	0.86889	0.80850	0.73443
1.0	0.81790	0.75703	0.68492
2.0	0.72857	0.66708	0.59912

Using the results from Table 1, a B-10 loading of 0.005 gm/cm^2 was chosen for further investigation. The fuel rod pitch was perturbed to test the effects of moderation within the poison cans. Table 2 results show the assembly to be undermoderated within the poison cans as increasing pitch increases k-infinity.

Table 2

EFFECT OF FUEL ROD PITCH ON K-INFINITY

(Model - 0.005 gm B-10/cm^2, Zero Outer Water Gap, Poison Can 60 Mils Thick, Inner Dimension = 4.54 inches)

Pitch	K-infinity
102% as-built pitch	0.87237
100% as-built pitch	0.86875
98% as-built pitch	0.79619

The maximum pitch possible is determined by the inner dimension of the poison can. The poison can must fit within a fuel rack storage cell so the 5.125-inch inner dimension of the largest cell serves as an absolute upper bound on the poison can design. The pitch was varied within the poison can area to find the highest k-infinity. The results of this optimal pitch search are shown in Table 3 as well as results for two other poison can dimension cases. These results indicate a maximum k-infinity due to moderation occurs with a maximum poison inner dimension of 5.125 inches and a pitch of 2.1168 cm (98% of the maximum pitch possible for this case).

Table 3

EFFECT OF POISON INNER DIMENSION AND PITCH ON K-INFINITY

(Model - 0.005 gm B-10/cm^2, Zero Outer Water Gap, Poison Can 60 Mils Thick)

Poison Inner Dimension Maximum Pitch	4.8935 in. (2.06 cm)	5.039 in. (2.125 cm)	5.125 in. (2.16 cm)
% of Maximum Pitch			
100	0.88908	0.89097	0.89238
99	0.89149	0.89575	0.89771
98	0.89056	0.89695	0.89943
97	0.88557	0.89292	0.89580
95	0.87558	0.88379	0.88702
90	0.84465	0.85513	0.85939
83			0.80635
79			0.75818
74			0.70369
69			0.64559

The Boral poison was modelled as being 60 mils thick with the mass density needed to obtain an areal density of 0.005 gm B-10/cm^2. Using a mass density typical of Boral manufacturing, a thickness of 11 mils was necessary to reach the same areal density. This case was explicitly modelled at the previously determined optimal moderation conditions to account for a lack of conservatism in the model due to Boral thickness. The results are shown in Table 4.

Table 4

EFFECT OF BORAL THICKNESS ON K-INFINITY

[Model - 0.005 gm B-10/cm^2, Zero Outer Water Gap, Poison Can Inner Dimension = 5.125 inches, Pitch = 2.1168 cm (optimal)]

Boral Thickness	K-Infinity
60 mils	0.89943
11 mils	0.90217

The HBPP Unit 3 fuel has a nominal density of 10.3 gm/cc with an upper bound of 10.5 gm/cc. The final consideration of the worst case analysis was to model the extreme fuel density in the optimal moderation. The maximum k-infinity was found to be 0.90624. Table 5 illustrates the magnitude of this effect.

Table 5

EFFECT OF FUEL DENSITY ON K-INFINITY

[Model - 0.005 gm B-10/cm^2, Zero Outer Water Gap, Poison Can 11 Mils Thick, Inner Dimension = 5.125 inches, Pitch = 2.1168 cm (optimal)]

Fuel Density (gm/cc)	K-Infinity
10.3	0.90217
10.5	0.90624

b. Analysis of Final Design

Additional analyses were performed to model the actual dimensions of the poison can as designed. The design for the poison can specifies an outer dimension of 5.0 inches and a total Boral thickness of 100 mils. The tube material will consist of roughly 16 mils of a mixture of 35 weight percent B_4C and 65 weight percent aluminum, sandwiched between two aluminum sheets 42 mils thick. The CASMO-2E model neglects the sandwiching aluminum and conserves the inner dimension of the poison tube design. Results of the optimal pitch search are shown in Table 6. Using optimal moderation and the extreme fuel density results in a maximum k-infinity of 0.894 for the design.

Table 6

OPTIMAL PITCH SEARCH FOR POISON TUBE DESIGN

(Model - 0.005 gm B-10/cm^2, Zero Outer Water Gap, Poison Can 16 Mils Thick, Inner Dimension = 4.8 inches)

Pitch	Fuel Density (gm/cm^3) 10.3	10.5
2.022	0.88823	---
2.00178	0.89006	0.89400
1.995	---	0.89412
1.99167	0.89018	0.89407
1.98156	0.88850	---

c. PGandE Benchmark of CASMO-2E

The CASMO-2E prediction of k-effective was tested against 61 experiments using the 25-group production cross-section library. These experiments are uniform cold critical or exponential water-moderated UO_2 lattices reported by Strawbridge and Barry (Ref. 2) and by Price (Ref. 3). Table 7 lists these experiments by case number as presented in Reference 2 and by page number as presented in Reference 3. All these cases are UO_2 fuel pins with enrichment ranging from 1.3 to 4.0 w/o U-235, an H_2O:U ratio of from 2.10 to 9.3, and natural boron concentration from zero to 3396 ppm. The mean k-effective value for 59 independent experiments (cases 18 and 19 and pages 169 and 170 of References 2 and 3, respectively, are repeated measurements on identical lattices) is 0.9981. The standard deviation is 0.0100.

An analysis of eight critical cores of close proximity water-moderated fuel storage experiments (Ref. 4) was conducted with the 25-group production cross-section library. These cores are composed of nine assemblies of 14 by 14 fuel pins each with boron/aluminum separation sheets between them, and borated water as moderator. (See Figures 5-8). The CASMO-2E/PDQ evaluation of k-effective for these eight cores is presented in Table 8. The B-10 loading and two sets of KENO results (for comparison) are also listed. The calculated k-effective values have a mean of 1.0014 and a standard deviation of 0.0030.

d. Previous Use of CASMO to Support Licensing Activities

Yankee Atomic Electric Company and Northern States Power are currently performing reload licensing using NRC-approved (Refs. 6, 7) CASMO-based physics methods (Refs. 8, 9).

Duke Power Company has submitted a partially CASMO-based physics method topical (Ref. 10) for NRC review.

TABLE 7

Characteristics of Critical and Exponential Lattice Experiments and the CASMO-2E Calculated K-effective

Case Number or Page Number	Enrichment weight %	H_2O:U Volume Ratio	Fuel Density g/cm^3	Pellet Diameter cm	Clad Material	Clad OD cm	Clad Thickness cm	Boron concentration ppm	Lattice Pitch cm	Critical Buckling m^{-2}	CASMO-2 k-effecti
1	1.311	3.02	7.53	1.5265	Al	1.6916	0.0711	0.00	2.205[a]	28.37	0.99438
2	1.311	3.95	7.53	1.5265	Al	1.6916	0.0711	0.00	2.359[a]	30.17	0.99765
3	1.311	4.95	7.53	1.5265	Al	1.6916	0.0711	0.00	2.512[a]	29.06	0.99748
4	1.311	3.93	7.52	0.9855	Al	1.1506	0.0711	0.00	1.558[a]	25.28	0.99379
5	1.311	4.89	7.52	0.9855	Al	1.1506	0.0711	0.00	1.652[a]	25.21	0.99340
6	1.311	2.88	10.53	0.9728	Al	1.1506	0.0711	0.00	1.558[a]	32.59	0.99776
7	1.311	3.58	10.53	0.9728	Al	1.1506	0.0711	0.00	1.652[a]	35.47	0.99757
8	1.311	4.83	10.53	0.9728	Al	1.1506	0.0711	0.00	1.806[a]	34.22	0.99741
9	2.700	2.18	10.18	0.7620	SS-304	0.8594	0.04085	0.00	1.0287	40.75	1.00394
10	2.700	2.93	10.18	0.7620	SS-304	0.8594	0.04085	0.00	1.1049	53.23	1.00421
11	2.700	3.86	10.18	0.7620	SS-304	0.8594	0.04085	0.00	1.1938	63.26	1.00199
12	2.700	7.02	10.18	0.7620	SS-304	0.8594	0.04085	0.00	1.4554	65.64	1.00909
13	2.700	8.49	10.18	0.7620	SS-304	0.8594	0.04085	0.00	1.5621	60.07	1.01249
14	2.700	10.38	10.18	0.7620	SS-304	0.8594	0.04085	0.00	1.6891	52.92	1.01015
15	2.700	2.50	10.18	0.7620	SS-304	0.8594	0.04085	0.00	1.0617	47.5	1.00173
16	2.700	4.51	10.18	0.7620	SS-304	0.8594	0.04085	0.00	1.2522	68.8	0.99663
17	3.699	2.50	10.37	0.7544	SS-304	0.8600	0.0406	0.00	1.0617	68.3	1.00657
18	3.699	4.51	10.37	0.7544	SS-304	0.8600	0.0406	0.00	1.2522	95.1	1.00473
19	3.699	4.51	10.37	0.7544	SS-304	0.8600	0.0406	0.00	1.2522	95.68[b]	1.00318
20	3.699	4.51	10.37	0.7544	SS-304	0.8600	0.0406	456.1	1.2522	74.64[b]	0.99873
21	3.699	4.51	10.37	0.7544	SS-304	0.8600	0.0406	709.1	1.2522	63.66[b]	0.99698
22	3.699	4.51	10.37	0.7544	SS-304	0.8600	0.0406	1261.4	1.2522	40.99[b]	0.99544
23	3.699	4.51	10.37	0.7544	SS-304	0.8600	0.0406	1332.7	1.2522	38.39[b]	0.99485
24	3.699	4.51	10.37	0.7544	SS-304	0.8600	0.0406	1475.2	1.2522	33.38[b]	0.99349
25	4.020	2.55	9.46	1.1278	SS-304	1.2090	0.0406	0.00	1.5113	88.0	0.99674
26	4.020	2.55	9.46	1.1278	SS-304	1.2090	0.0406	3396.3	1.5113	17.2	1.00019
34	4.020	2.14	9.46	1.1278	SS-304	1.2090	0.0406	0.00	1.450	79.0	0.99208
37	2.460	2.84	10.24	1.0297	Al	1.2060	0.0813	0.00	1.5113	70.10	1.01783
42	3.000	2.64	9.28	1.1268	SS-304	1.2701	0.07163	0.00	1.555	50.75	0.99233
43	3.000	8.16	9.28	1.1268	SS-304	1.2701	0.07163	0.00	2.198	68.81	0.98588
44	4.020	2.59	9.45	1.1268	SS-304	1.2701	0.07163	0.00	1.555	69.25	1.00209
45	4.020	3.53	9.45	1.1268	SS-304	1.2701	0.07163	0.00	1.684	85.52	0.99700
46	4.020	8.02	9.45	1.1268	SS-304	1.2701	0.07163	0.00	2.198	92.84	1.01207
47	4.020	9.90	9.45	1.1268	SS-304	1.2701	0.07163	0.00	2.381	91.79	1.00051
50	2.460	2.84	10.24	1.0297	Al	1.2060	0.0813	1677.2	1.5113	20.2	1.00323
51	2.070	2.06	10.38	1.524	Al	1.6916	0.07112	0.00	2.1737	58.0	1.05321
52	2.070	3.09	10.38	1.524	Al	1.6916	0.07112	0.00	2.4032	80.6	1.00749
53	2.070	4.12	10.38	1.524	Al	1.6916	0.07112	0.00	2.6162	85.7	0.99453
54	2.070	6.14	10.38	1.524	Al	1.6916	0.07112	0.00	2.9891	77.0	0.98924
55	2.070	8.20	10.38	1.524	Al	1.6916	0.07112	0.00	3.3255	61.6	0.98467

[a]Hexagonal lattices; all others are square.

[b]These bucklings were not measured directly but were inferred from critical loadings.

TABLE 7 (cont'd)

Characteristics of Critical and Exponential Lattice Experiments and the CASMO-2E Calculated K-effective

Case Number or Page Number	Enrichment weight %	H_2O:U Volume Ratio	Fuel Density g/cm^3	Pellet Diameter cm	Clad Material	Clad OD cm	Clad Thickness cm	Boron concentration ppm	Lattice Pitch cm	Critical Buckling m^{-2}	CASMO-2E k-effective
165	3.006	2.990[c]	9.299	1.128014	SS-304	1.26746	0.0696722	0.0	1.718818[a]	56.6	0.99154
166	3.006	2.990[c]	9.299	1.128014	SS-304	1.26746	0.0696722	670.3	1.718818[a]	36.71	0.98999
167	3.006	2.990[c]	9.299	1.128014	SS-304	1.26746	0.0696722	1336.5	1.718818[a]	18.26	0.98908
168	3.006	3.700[c]	9.299	1.128014	SS-304	1.26746	0.0696722	0.0	1.819402[a]	65.81	0.98637
169	3.006	3.700[c]	9.299	1.128014	SS-304	1.26746	0.0696722	471.2	1.819402[a]	46.41	0.98667
170	3.006	3.700[c]	9.299	1.128014	SS-304	1.26746	0.0696722	471.2	1.819402[a]	45.00	0.99109
171	3.006	3.700[c]	9.299	1.128014	SS-304	1.26746	0.0696722	995.2	1.819402[a]	26.20	0.98991
172	3.006	3.700[c]	9.299	1.128014	SS-304	1.26746	0.0696722	1349.0	1.819402[a]	14.62	0.98925
173	3.006	4.740[c]	9.299	1.128014	SS-304	1.26746	0.0696722	0.0	1.957324[a]	70.49	0.99029
174	3.006	4.740[c]	9.299	1.128014	SS-304	1.26746	0.0696722	431.0	1.957324[a]	46.34	0.99107
175	3.006	4.740[c]	9.299	1.128014	SS-304	1.26746	0.0696722	806.0	1.957324[a]	27.70	0.99142
176	3.006	4.740[c]	9.299	1.128014	SS-304	1.26746	0.0696722	1144.0	1.957324[a]	12.94	0.99019
177	3.006	4.740[c]	9.299	1.128014	SS-304	1.26746	0.0696722	0.0	2.169668[a]	70.22	0.99598
178	3.006	6.490[c]	9.299	1.128014	SS-304	1.26746	0.0696722	289.1	2.169668[a]	47.61	0.99489
179	3.006	6.490[c]	9.299	1.128014	SS-304	1.26746	0.0696722	604.3	2.169668[a]	25.22	0.99502
180	3.006	6.490[c]	9.299	1.128014	SS-304	1.26746	0.0696722	772.7	2.169668[a]	15.05	0.99277
181	3.006	9.229[c]	9.299	1.128014	SS-304	1.26746	0.0696722	0.0	2.465578[a]	61.73	0.99834
182	3.006	9.229[c]	9.299	1.128014	SS-304	1.26746	0.0696722	173.0	2.465578[a]	41.18	1.00086
183	3.006	9.229[c]	9.299	1.128014	SS-304	1.26746	0.0696722	260.5	2.465578[a]	32.41	0.99961
184	3.006	9.229[c]	9.299	1.128014	SS-304	1.26746	0.0696722	390.9	2.465578[a]	20.51	0.99633
185	3.006	9.229[c]	9.299	1.128014	SS-304	1.26746	0.0696722	540.5	2.465578[a]	6.04	0.99796

[a]Hexagonal lattices; all others are square.

[b]These bucklings were not measured directly but were inferred from critical loadings.

[c]Recalculated by PGandE to agree with definition given in Reference [2].

TABLE 8

Comparison of k-effective for the 8 Cores From Reference [4]

Core Number	B&W KENO(a)	B&W "Measured"(a)	N.S&E KENO(b)	PGandE	Boron Loading. B-10 Density in Boral(d) Sheets. grams/cm²
II	1.007 ± .004	1.0001 ± .0005	.995 ± .004	1.0039	0
III	.999 ± .004	1.0000 ± .0006	1.009 ± .004	1.0054	0
XIII	1.008 ± .005	1.0000 ± .0001	1.008 ± .006(c) 1.011 ± .006 1.003 ± .005	1.0034	5.582×10^{-3}
XIIIa				1.0012	5.603×10^{-3}
XIV	1.003 ± .004	1.0001 ± .0001	.999 ± .004 .997 ± .004	1.0001	4.348×10^{-3}
XV	.995 ± .005	.9998 ± .0016	.996 ± .005	0.9956	1.387×10^{-3}
XVII	.993 ± .005	1.0000 ± .0010	.997 ± .004	.9997	0.837×10^{-3}
XIX	.991 ± .004	1.0002 ± .0010	.995 ± .003	1.0021	0.346×10^{-3}

(a)Reference 4, Tables IX and XI.

(b)Reference 5, Table III.

(c)Cases XIII and XIIIa are "combined by Reference 5. The soluble boron concentration in these cases are different; 15 and 18 ppm.

(d)B-10 is 19.8 a/o of Boron.

3. General Electric Criticality Analysis With MERIT

MERIT is a Monte Carlo program which solves the neutron transport equation as an eigenvalue or a fixed source problem. This program was written for the analysis of fuel lattices in thermal nuclear reactors. A geometry of up to three space dimensions and neutron energies between 0 and 10 MeV can be handled. MERIT uses cross-sections processed from the ENDF/B-IV library tapes.

A check was made of the results of the PGandE optimum moderation configuration.

The following assumptions and input values were used in this analysis:

1. 2.52% enriched fuel (fuel density 10.5 gm/cc, reduced to 10.0422 gm/cc to include gap)
2. Fuel pellet radius - 0.63373 cm
3. Zirconium 2 clad - outer radius 0.71501 cm
4. Rod pitch - 1.995 cm
5. Square poison can (outside dimension 12.7 cm) on each bundle
6. Channel thickness - 0.253 cm (0.10668 cm Al, 0.03965 cm Boral core, 0.10688 cm Al)
7. Boral core 35 w/o boron carbide, 65 w/o aluminum
8. B-10 areal density - 0.005 gm/cm^2
9. Infinite array of fuel bundles of infinite length
10. Water density - 1.0 gm/cm^3

The MERIT case was run for 35,000 neutron histories and predicted a k-infinity of 0.878767 + 0.00313 (1σ). The MERIT code has been benchmarked with numerous criticality experiments and has been shown to underpredict k by 0.005 $\pm$ 0.002 (1σ). Thus, the MERIT-predicted lattice k-infinity for the 5-inch poison can with all uncertainties added would be 0.883767 $\pm$ 0.00371 (1σ).

This is a very conservative upper limit for this case since it assumes the maximum fuel density, the minimum thickness Boral core in the can wall, and that the fuel pins in all cans can expand to the optimum pitch even though they are held in the fuel bundle design pitch by the upper and lower tie plates and the fuel spacers.

A sketch of the MERIT model is shown in Figure 9. A copy of the input file for MERIT is given in the Appendix.

a. MERIT Benchmarking

The qualification of the MERIT program rests upon extensive qualification studies including Cross Section Evaluation Work Group (CSEWG) thermal reactor benchmarks (TRX-1, -2, -3, and -4) and Babcock and Wilcox (B&W) UO_2 and PuO_2 criticals, Jersey Central experiments, CSEWG fast reactor benchmarks (GODIVA, JEZEBEL), the KRITZ experiments, and comparison with alternate calculational methods. Boron was used as solute in the moderator in the B&W UO_2 criticals, and as a solid control curtain in the Jersey Central experiments. The MERIT qualification program has established a bias of 0.005 ± 0.002 (1σ) Δk with respect to the above critical experiments. Therefore, MERIT underpredicts k-effective by approximately 0.5 percent Δk.

b. Previous Use of MERIT to Support Licensing Activities

MERIT has been used to license Boral-poisoned high density fuel storage racks at several reactor sites and has been reviewed and checked by the NRC and found to be acceptable. These sites are listed in Table 9.

Table 9

SUMMARY OF GENERAL ELECTRIC HIGH DENSITY FUEL STORAGE RACK EXPERIENCE

Plant	Scope of Work	Status
Monticello	13 racks, storage capacity 2,237 spaces	Licensed and in use since April 1978
Browns Ferry 1, 2, and 3	57 racks, storage capacity 10,413 spaces	Licensed and in use since Sept. 1978
Hatch 1 and 2	30 racks, storage capacity 6,026 spaces	Licensed and in use since April 1980
Brunswick 1 and 2	10 racks, storage capacity 3,642	Licensed and in use December 1983
Hartsville A1, A2, B1, B2	60 racks, storage capacity 11,804 spaces (Plant cancelled)	Approved for installation through GESAR II FDA July 1983
Phipps Bend 1 and 2	30 racks, storage capacity 5,902 spaces (Plant cancelled)	Approved for installation through GESAR II FDA July 1983
Kuosheng 1 and 2	6 racks, storage capacity 1,326 spaces	Scheduled for 1985 installation

E. CONCLUSIONS

As demonstrated in the preceeding analyses, the proposed Boral cans will provide a neutron-absorbing material as an integral part of the HBPP fuel assemblies, and will ensure that k-effective will be less than 0.95 for the worst possible rearrangemen of fuel. This analysis was done using conservative assumptions and was independently checked by General Electric.

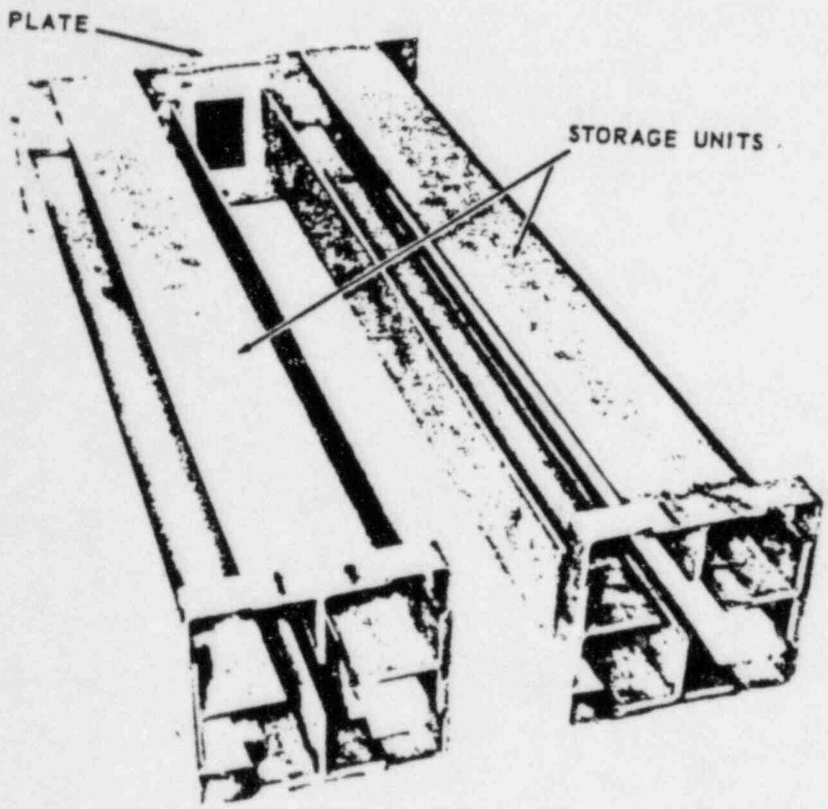

FIGURE 1 Humboldt Bay Power Plant Storage Racks

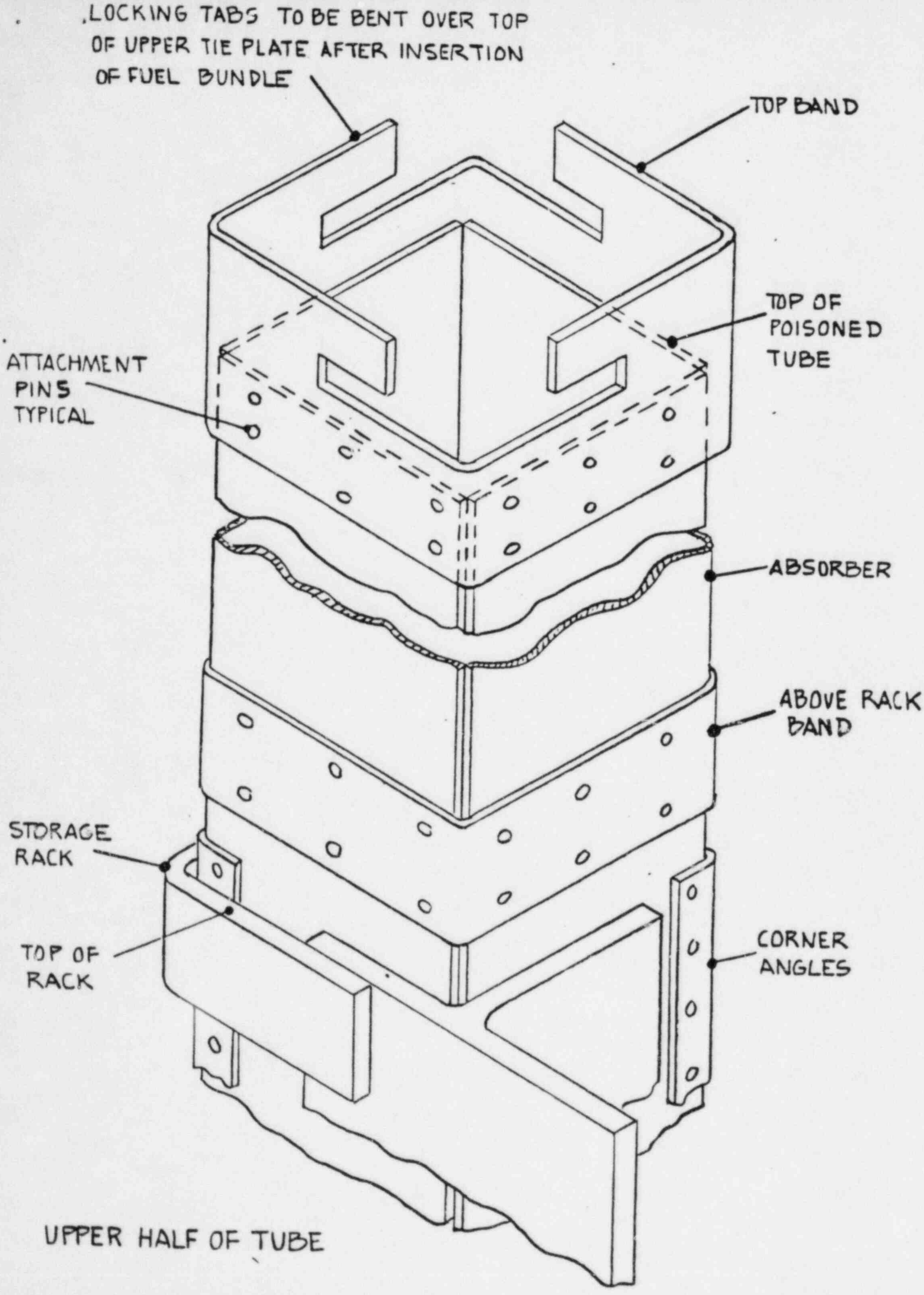

FIGURE 2 Fuel Assembly Protective Can (Upper View)

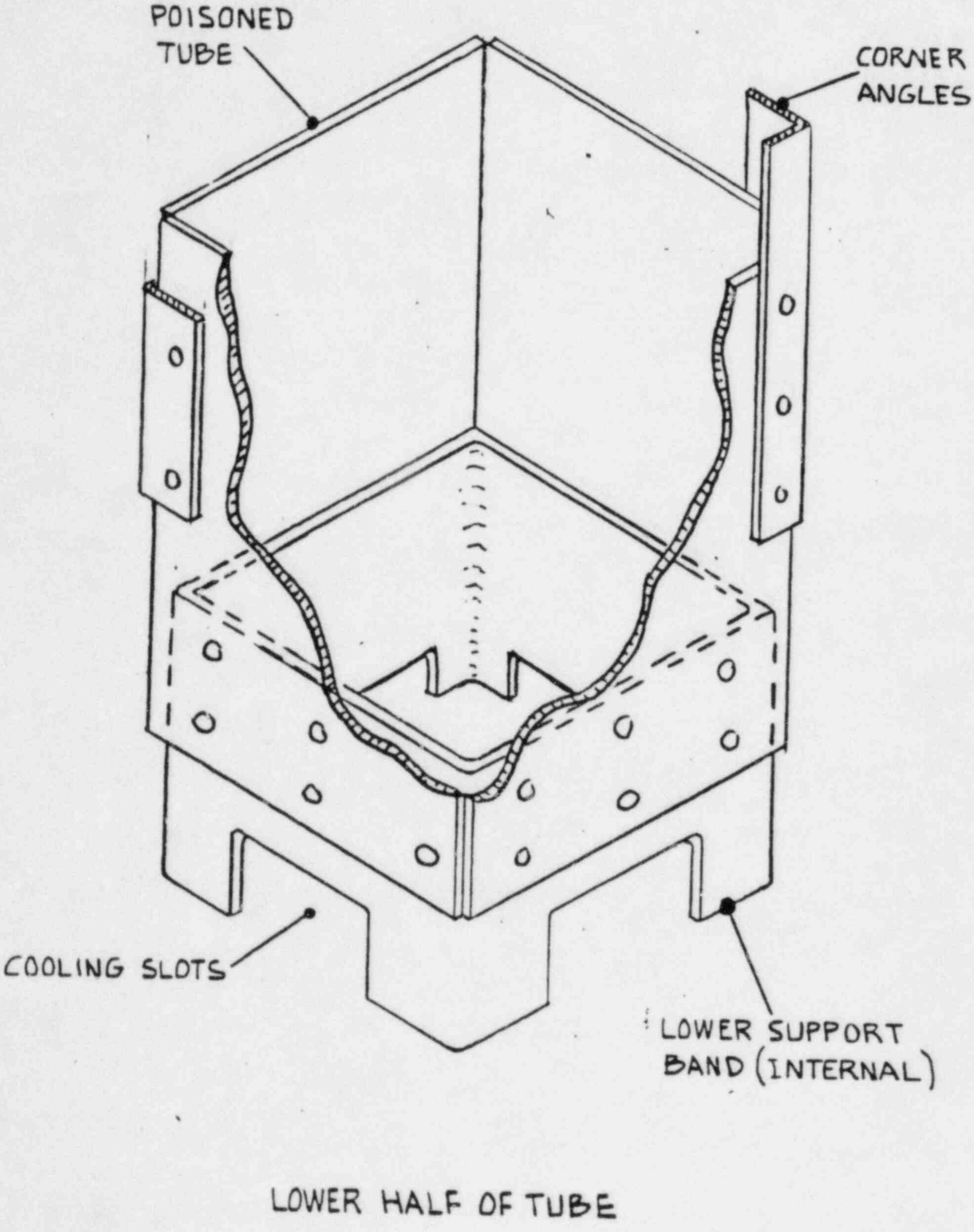

FIGURE 3 Fuel Assembly Protective Can (Lower View)

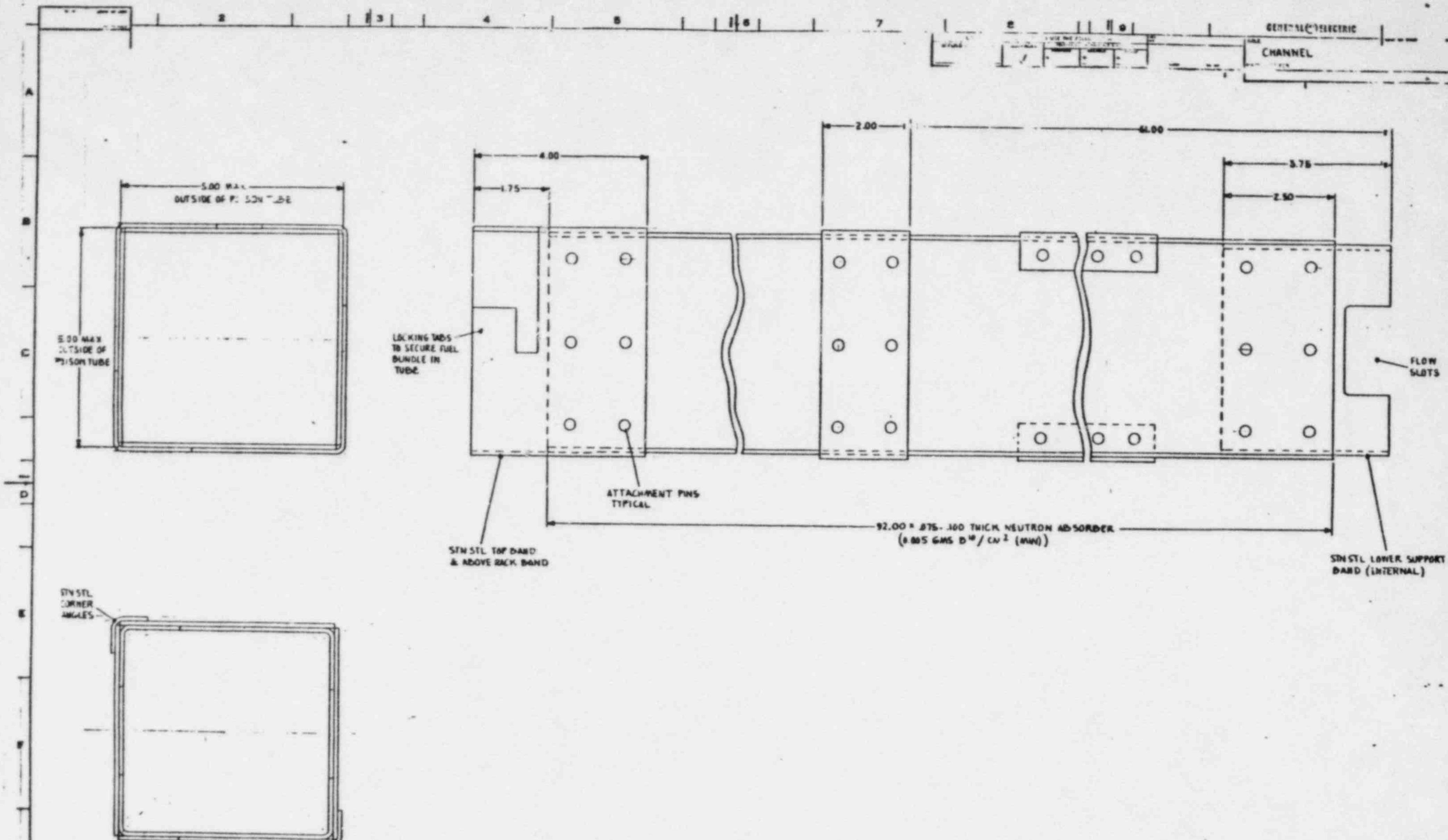

FIGURE 4 Fuel Assembly Protective Can (Cross-section)

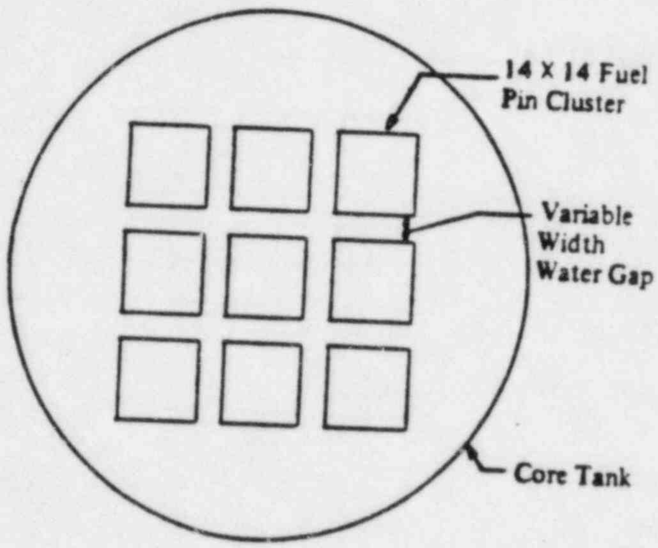

FIGURE 5 Typical Core Loading Diagram (Plan View)

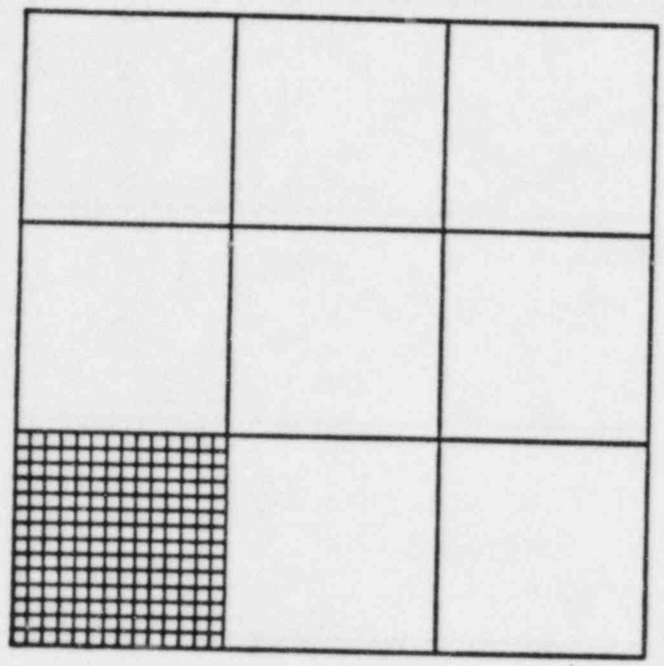

FIGURE 6 Core II Loading Diagram - Nine Arrays With Zero Pin Pitch Separation

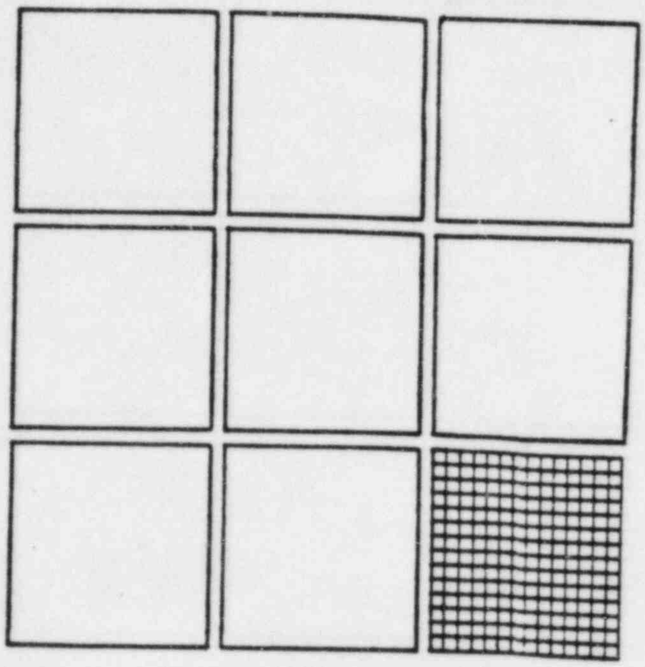

FIGURE 7 Core III Loading Diagram - Nine Arrays Separated by One Pin Pitch

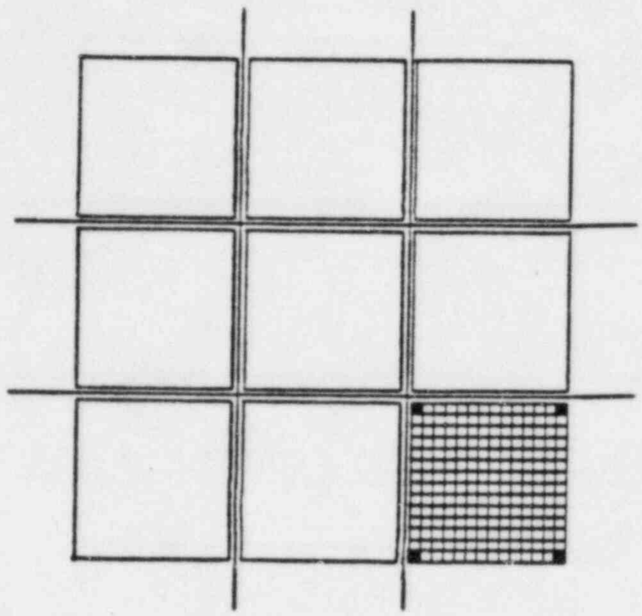

FIGURE 8 Cores XIII, XIV, XV, XVII, and XIX - Nine Unit Assemblies Separated by One Pin Pitch and Boral Plates

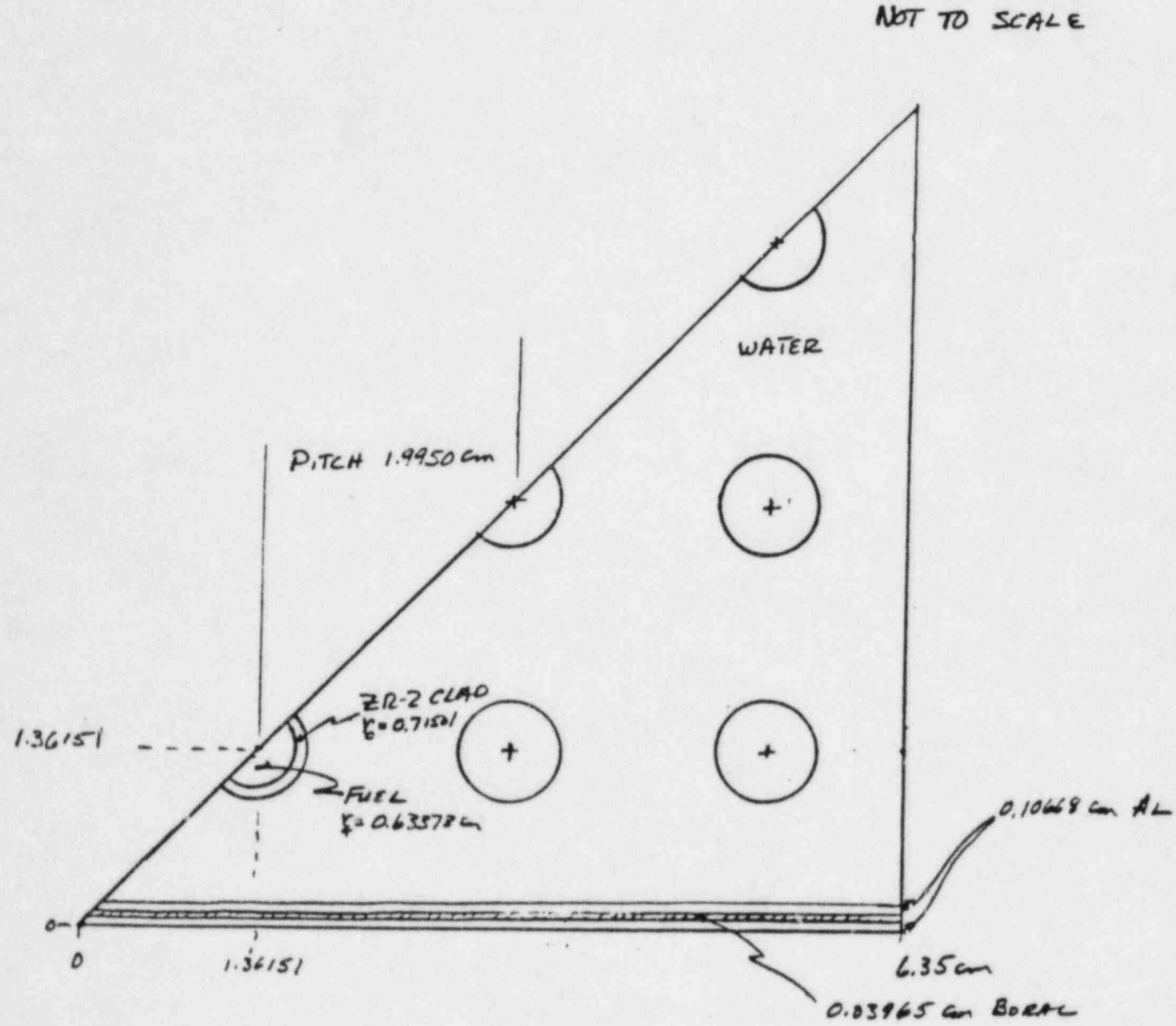

FIGURE 9 MERIT Model

REFERENCES

1. M. Edenius, A. Ahlin, H. Haggblom, "CASMO-2 A Fuel Assembly Burnup Program Users Manual," Studsvik/NR-81/3 with Revision 1984-09-01.

2. L. E. Strawbridge and R. F. Barry, "Criticality Calculations for Uniform Water - Moderated Lattices", Nuclear Science and Engineering, 23, pp. 58-73 (1965).

3. Glenn A. Price, "Uranium - Water Lattice Compilation Part 1, BNL Exponential Assemblies," BNL-50035, December 30, 1966.

4. Hoovler et al., "Critical Experiments Supporting Close Proximity Water Storage of Power Reactor Fuel," Nuclear Technology, 51, pp. 217-237 December 1980.

5. S. E. Turner and M. K. Gurley, "Evaluation of AMPX-KENO Benchmark Calculations for High-Density Spent Fuel Storage Racks," Nuclear Science and Engineering, 80, pp. 230-237 (1982).

6. Letter from D. B. Vassallo (NRC) to J. B. Sinclair (YAEC), File NVY-82-157, Docket #50-271, September 15, 1982.

7. Letter from R. A. Clark (NRC) to B. M. Musolf (NSP), February 17, 1983.

8. E. E. Pilat, "Methods for the Analysis of Boiling Water Reactors Lattice Physics," YAEC-1232, December 1980.

9. "Qualification of Reactor Physics Methods for Application to Praire Island Units," NSPNAN-8101, December 1982.

10. Duke Power Company, "Nuclear Physics Methodology for Reload Design," DPL-NF-2010, April 1984.

APPENDIX

MERIT INPUT LISTING

MERIT01C

MARCH 1, 1979

PG&E Safe Store MERIT (Input File MERIT03)

5.0 inch Poison Can

0.005 gm B-10/cm^2

Optimum Fuel Rod Pitch 1.9950 cm

Fuel Density 10.5 gm/cc

```
CARD 2   NPRBTP  1234   IDENT. NO. OF PROBLEM TAPE.
         LSTRT      0   0 = INITIAL START , IMCT=B
                        1 = RESTART, NO CHANGES . IMCT=A
                            (IF LCOPY = 1, IMCT=B)
                        2 = RESTART BUT DO INPUT CALCULATIONS , IMCT=B
                        3 = RESTART BUT DO INPUT CALCULATIONS EXCEPT FOR MATERIAL INFORMATION , IMCT=B
         LCONT      0   0 OR 1 = GO ON TO MONTE CARLO AFTER BMCIN.
                        2 = GO ON TO BMCOUT AFTER BMCIN.
         LSTOP      0   0 = DO COMPLETE PROBLEM.
                        1 = DO INPUT ONLY.
                        2 = DO INPUT AND MONTE CARLO ONLY.
         LCOPY      0   1 = COPY TAPE A TO TAPE B AND USE B.
                            (ACTIVE ONLY IF LSTRT = 1.)
         LSKNS      0   0 = FOR NORMAL POSITIONING TO THE LAST RESTART CASE.
                        1 = START THE TALLIES ANEW.
                        N = USE THE NTH BATCH FOR RESTART.
         LSKSV      0   MUST = 77 IF LSKNS DOES NOT = 0 OR LSKNS WILL NOT BE PERFORMED.
         ICXTSV     0   0 = RESTART TAPE WILL BE SAVED.
                        68 = RESTART TAPE WILL NOT BE SAVED.
         IMPRD      0   55 = READ NEW SET OF WEIGHTING PARAMETERS WITH NORMAL RESTART.
         IDUMP      1   1 = DUMP MONTE CARLO BLANK COMMON.
         NERCV     10   NO. OF RECOVERABLE ERRORS BEFORE TERMINATING.
                            (IF EQUAL TO 0 NERCV WILL BE SET TO 10)
         NTSPL      1   NUMBER OF GEOMETRY TEST PLOTS.
```

CARD 3	NBTCH	35	NUMBER OF BATCHES.
	NPTPB	1000	NUMBER OF PARTICLES IN EACH BATCH.
	RTHRT	0.	THE RATIO OF WEIGHT LEAVING THE THERMAL TALLY RANGE TO THAT OF ENTERING. (IF 0.0, ALL PARTICLES FOLLOWED. IF 1.0, NONE FOLLOWED.)
	ETHRT	0.	THE ENERGY TO WHICH NEUTRONS MUST BE SLOWED DOWN BEFORE THEY ARE USED FOR THE THERMAL TALLY RANGE.
	ETHRTX	0.	THE MAXIMUM ENERGY NEUTRONS MAY ACHIEVE WHILE CONTRIBUTION TO THE THERMAL FLUX TALLY.
CARD 4	LPRB	0	0 = FISSION DESCENDENT CALCULATION. 1 = DIRECT SOURCE CALCULATION.
	MODTH	293	MODERATOR TEMPERATURE IN DEGREES KELVIN. (USED TO INTERPOLATE THERMAL HYDROGEN SCATTERING KERNEL.)
	NBGPX	0	NUMBER OF BROAD ENERGY GROUPS. (IF ONLY ONE, USE NPGPX = 0.)
	JMAXX	4	NUMBER OF MACRO ENERGY GROUPS.
	NHMAX	4	NUMBER OF REGIONS.
	MMAX	5	NUMBER OF MATERIALS.
	NSPRG	1	NUMBER OF SPECIAL REGIONS.
	NFMAX	5	NUMBER OF TALLY REGIONS.
	NLKTLY	0	NUMBER OF LEAKAGE TALLY SETS.
	LTALY	0	NUMBER OF SETS TO BE TALLIED.
	NBNDX	6	NUMBER OF BOUNDARIES.
	NOMGX	0	NUMBER OF ALBEDO SETS.
CARD 4A	NRX,NRY	3, 3	MAX NUMBER OF RODS IN X AND Y IN LATTICES
	NWTZX	0	NUMBER OF WEIGHTING ZONES
	NERGX	0	MAX NUMBER OF ENERGY WEIGHTING RANGES
	NBR	15	SUM OF BOUNDARIES FOR REGION SPECIFICATION

****

MINIMUM ENERGY OF EACH MACRO ENERGY GROUP.

GROUP	ENERGY	GROUP	ENERGY
1	1.000000E+06	3	6.250000E-01
2	5.530800E+03	4	0.

****

THE FOLLOWING ISOTOPES HAVE BEEN LOADED FROM CCT TAPE NO. 1234

ISOTOPE ID.NO.	NAME	ENDF/B ID.NO.	DATED	SIGMA POTENTIAL
1	H1	1269	21 JUNE 1976	2.0447E+01
10	B10	1273	05 MAY 1976	2.1060E+00
11	B11	1160	05 MAY 1976	5.0350E+00
12	C12	1274	05 MAY 1976	4.7300E+00
16	O16	1276	04 MAY 1976	3.7040E+00
131	AL	1193	23 APR 1976	1.3480E+00
401	ZIRC-2	1284	23 APR 1976	6.1580E+00
2351	U235	1261	21 APR 1976	1.1500E+01
2381	U238	1262	12 APR 1976	1.0599E+01

****

MATERIAL DESCRIPTION

MATERIAL NO. 1 FUEL ONE

NO. ISOTOPES 3, TEMP. 293, FIS SPEC. 1, RF 6.3373E-01, DG 1.0000E+00, HEAVY AWT. 236.0

ISOTOPE	CONCENTRATION	SIG M EFF.	ETHRM	IHVYM	LTHRMM	LANMM	LINMM
2351	5.719000E-04	6.9430E+02	0.	0	0	0	0
2381	2.183800E-02	7.8847E+00	0.	0	0	0	0
16	4.471100E-02	0.	1.275E+00	0	1	0	0

MATERIAL NO. 2 ZIRC

NO. ISOTOPES 1, TEMP. 293, FIS SPEC. 1, RF 0. , DG 0. , HEAVY AWT. 236.0

ISOTOPE	CONCENTRATION	SIG M EFF.	ETHRM	IHVYM	LTHRMM	LANMM	LINMM
401	4.333300E-02	0.	0.	0	0	0	0

MATERIAL NO. 3 MODERATOR

NO. ISOTOPES 2, TEMP. 293, FIS SPEC. 1, RF 0. , DG 0. , HEAVY AWT. 236.0

ISOTOPE	CONCENTRATION	SIG M EFF.	ETHRM	IHVYM	LTHRMM	LANMM	LINMM
16	3.344400E-02	0.	1.275E+00	0	1	0	0
1	6.688800E-02	0.	2.102E+00	0	2	0	0

MATERIAL NO. 4 BORAL

NO. ISOTOPES 4, TEMP. 293, FIS SPEC. 1, RF 0. , DG 0. , HEAVY AWT. 236.0

ISOTOPE	CONCENTRATION	SIG M EFF.	ETHRM	IHVYM	LTHRMM	LANMM	LINMM
12	9.580320E-03	0.	2.000E+00	0	1	0	0
11	3.071440E-02	0.	2.000E+00	0	1	0	0
10	7.587600E-03	0.	2.000E+00	0	1	0	0
131	3.637750E-02	0.	0.	0	0	0	0

MATERIAL NO. 5 ALUMINUM

NO. ISOTOPES 1, TEMP. 293, FIS SPEC. 1, RF 0. , DG 0. , HEAVY AWT. 236.0

ISOTOPE	CONCENTRATION	SIG M EFF.	ETHRM	IHVYM	LTHRMM	LANMM	LINMM
131	6.026810E-02	0.	0.	0	0	0	0

11

****
GEOMETRY INPUT

DIMENSIONS ARE IN CM.

BOUNDARY DATA

BOUNDARY	TYPE	ALBEDO	DESCRIPTION
1	4	3	PLANE, Y = 0. + 1.000000E+00 . X
2	1	3	PLANE, X = 6.350000E+00
3	2	3	PLANE, Y = 0.
4	2	0	PLANE, Y = 1.066800E-01
5	2	0	PLANE, Y = 1.463300E-01
6	2	0	PLANE, Y = 2.530100E-01

REGION DATA

REGION	BOUNDARY	SPECIAL BOUNDARY	MATERIAL	TALLY SET	G.D	BH	Q1	Q2
1	3	1	3	3	1	1	1	0
					1	2	1	0
					-1	6	4	0
2	4	0	5	5	1	1	2	0
					1	4	3	0
					1	2	2	0
					-1	3	2	0
3	4	0	4	4	1	1	3	0
					1	5	4	0
					1	2	3	0
					-1	4	2	0
4	4	0	5	5	1	1	4	0
					1	6	1	0
					1	2	4	0
					-1	5	3	0

11

****
SPECIAL INPUT FOR A SQUARE LATTICE

FOR REGION 1

LTSPS	1	TYPE OF SPECIAL REGION (1 = SQUARE LATTICE OF CLAD FUEL RODS)
NRX	3	NUMBER OF ROWS OF RODS IN THE X DIRECTION
NRY	3	NUMBER OF ROWS OF RODS IN THE Y DIRECTION
MATCL	2	MATERIAL NUMBER OF CLADDING
IFTSL	2	TALLY REGION OF CLADDING
MATFL	1	MATERIAL NUMBER OF FUEL
IFTFL	1	TALLY REGION OF FUEL
XC	1.3815	X COORDINATE OF LOWER LEFT CORNER
YC	1.3615	Y COORDINATE OF LOWER LEFT CORNER
DXC	1.9950	LATTICE SPACING IN THE X DIRECTION
DYC	1.9950	LATTICE SPACING IN THE Y DIRECTION
RDF	.6337	RADIUS OF THE FUEL ROD
RDC	.7150	RADIUS OF THE OUTER EDGE OF CLADDING

MATXYS MATERIAL NUMBERS OF ALL THE RODS IN REGION 1

Y/X	1	2	3
3	1	1	1
2	1	1	1
1	1	1	1

IFTXYS TALLY REGIONS OF ALL THE RODS IN REGION 1

Y/X	1	2	3
3	1	1	1
2	1	1	1
1	1	1	1

A-8

****
IMPORTANCE WEIGHTING, SPLITTING AND RUSSIAN ROULETTE PARAMETERS.

NO IMPORTANCE WEIGHTING OR SPLITTING.

WEIGHTING ZONE PARAMETERS FOR WEIGHTING ENERGY RANGE 1.

ZONE	MINIMUM WEIGHT	SURVIVAL WEIGHT	SPLITTING WEIGHT	MINIMUM BEAM STRENGTH	SURVIVAL BEAM STRENGTH	IMPORTANCE WEIGHT
1	2.5000E-01	7.5000E-01	0.	2.0000E-01	5.0000E-01	0.

INTERPOLATED VALUES FOT H-1 SCATTER AT 293.0 REQUIRED 0 SECONDS

THE RANDOM NO. USED TO START THIS CASE WAS 17171274321477413155

****

CELL REACTION RATE

REACTION TYPE	TOTAL		GROUP 1		GROUP 2		GROUP 3		GROUP 4	
TOTAL	3.04364E+04	.008	1.96827E+03	.014	7.95721E+03	.020	9.64494E+03	.021	1.08660E+04	.008
SCATTER	2.91760E+04	.008	1.75583E+03	.013	7.84468E+03	.020	9.37172E+03	.021	1.02038E+04	.006
CAPTURE	6.37941E+02	.023	8.95692E+00	.081	2.22827E+01	.009	2.36576E+02	.012	3.72126E+02	.019
ABSORPTION	9.94269E+02	.034	3.30537E+01	.029	2.57872E+01	.010	2.73224E+02	.013	6.62204E+02	.035
FISSION	3.56327E+02	.020	2.60967E+01	.022	3.50444E+00	.014	3.66489E+01	.025	2.90077E+02	.021
N.FISSION	8.72429E+02	.049	7.35453E+01	.065	8.59410E+00	.033	8.86489E+01	.059	7.01641E+02	.051
INELASTIC	2.64653E+02	.014	1.77911E+02	.013	8.67418E+01	.048	0.	0.000	0.	0.000
N2N	1.48065E+00	.094	1.48065E+00	.094	0.	0.000	0.	0.000	0.	0.000

****

K-INFINITE= 8.78787E-01 .0313 ← 1σ = 0.00313 (FORMAT IS σ ×10)

****

K-EFFECTIVE=8.78767E-01 .0313

K EFF. FOR EACH BATCH USED.

8.7947E-01	8.6257E-01	8.9046E-01	8.6271E-01	9.1854E-01	8.8148E-01	8.7113E-01	9.1079E-01	8.7015E-01	8.7890E-01
8.9316E-01	8.7674E-01	8.8646E-01	8.5324E-01	8.8181E-01	8.7346E-01	8.4323E-01	8.8469E-01	8.8689E-01	8.8340E-01
8.8470E-01	8.7112E-01	8.5400E-01	8.4042E-01	8.8121E-01	9.0602E-01	8.7108E-01	8.8927E-01	8.8568E-01	8.8793E-01

11