NAD - 2199

DNBR Safety Limit
For COBRA III C Analysis

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1. Introduction

The objective of this investigation is to determine a DNBR limit for thermal hydraulic calculations performed with the COBRA III C code for Turkey Point Units 3 and 4. The Turkey Point core loading consists of Westinghouse 15x15 fuel with L-grid spacers.

On the basis of data from 91 test points obtained from Columbia University test bundle experiments and described in WCAP-7988 (reference 1), Westinghouse, in reference 2, derived a DNBR limit of 1.24 as the value that bounds 95% of the 91 point data base with 95% confidence. The predicted values of critical heat flux were calculated with the THINC computer code using the W-3 critical heat flux correlation and the L-grid correction. However, as reference 1 is a Westinghouse proprietary report, this data base was not available for direct comparison with COBRA III C results. Instead, COBRA III C results have been compared with those obtained with the Westinghouse THINC code for a data base (reference 3) suggested by the NRC (reference 4). This data base consists of 284 DNB data points obtained with 12 different test sections. These test sections covered a variety of heat flux distributions, different heated lengths of rods, and several lengths of axial spacings between grids. Some test sections had spacer grids with mixing vanes and some had no vanes. For the COBRA study, five of these test sections, those corresponding most closely to the L-grid geometry of the Turkey Point fuel, were selected for data comparison. A total of 117 points were thus compared.

2. Results

The statistical analysis of the 117 data points from reference 3 performed by FPL with the COBRA III C/MIT code yielded a DNBR limit of 1.1870 while the DNBR limit calculated from THINC DNB heat fluxes given in reference 3 for the same data points was 1.1564. Therefore, it was concluded that the COBRA DNBR limit is $\frac{1.1870}{1.1564} = 1.0265$ times the DNBR limit obtained with the THINC code. As discussed above, the DNBR limit for the THINC code with the L-grid correction is 1.24. Therefore, the corresponding COBRA III C DNBR limit is 1.24x1.0265=1.273.

TABLE I

(continued)

RUN NO.	PRESSURE (PSIA)	POWER AT DNB (MW)	INLET TEMP. (°F)	INLET BUNDLE AV. MASS VELOCITY (10^6 LBM/HR-FT^2)	LOCAL DNB 10^6 BTU/HR-FT^2 q''_{MEAS}	q''_{PRED}	$\frac{q''_{MEAS}}{q''_{PRED}}$
242	2413	2.286	558.3	2.09	.629	.705	.892
243	2392	2.426	541.0	2.06	.782	.890	.879
244	2412	2.656	514.3	2.07	.856	1.018	.841
245	2112	2.410	537.7	2.04	.663	.699	.948
247	2102	2.713	499.7	2.05	.747	.837	.892
248	1793	2.508	499.7	2.11	.733	.835	.878
249	1813	2.658	477.7	2.02	.777	.892	.871
379	1810	2.700	587.0	3.58	.551	.505	1.091
380	1854	3.049	568.0	3.53	.672	.644	1.044
381	1792	2.688	562.0	3.03	.637	.630	1.011
382	1848	2.827	540.0	3.07	.711	.794	.896
383	2111	2.703	608.0	3.54	.459	.393	1.167
384	2112	3.010	588.0	3.53	.614	.569	1.078
385	2092	2.474	603.0	3.03	.463	.404	1.147
386	2098	2.650	578.0	3.08	.628	.640	.982
387	2111	3.004	573.0	3.03	.613	.568	1.079
388	2417	2.743	624.0	3.71	.465	.402	1.158
390	2408	2.845	602.0	3.10	.483	.433	1.116
391	2425	2.983	592.0	3.00	.558	.508	1.100
392	2403	2.732	584.0	2.53	.511	.467	1.095
393	2393	2.998	563.0	2.51	.561	.531	1.057
246	2102	2.583	515.3	2.06	.711	.784	.907

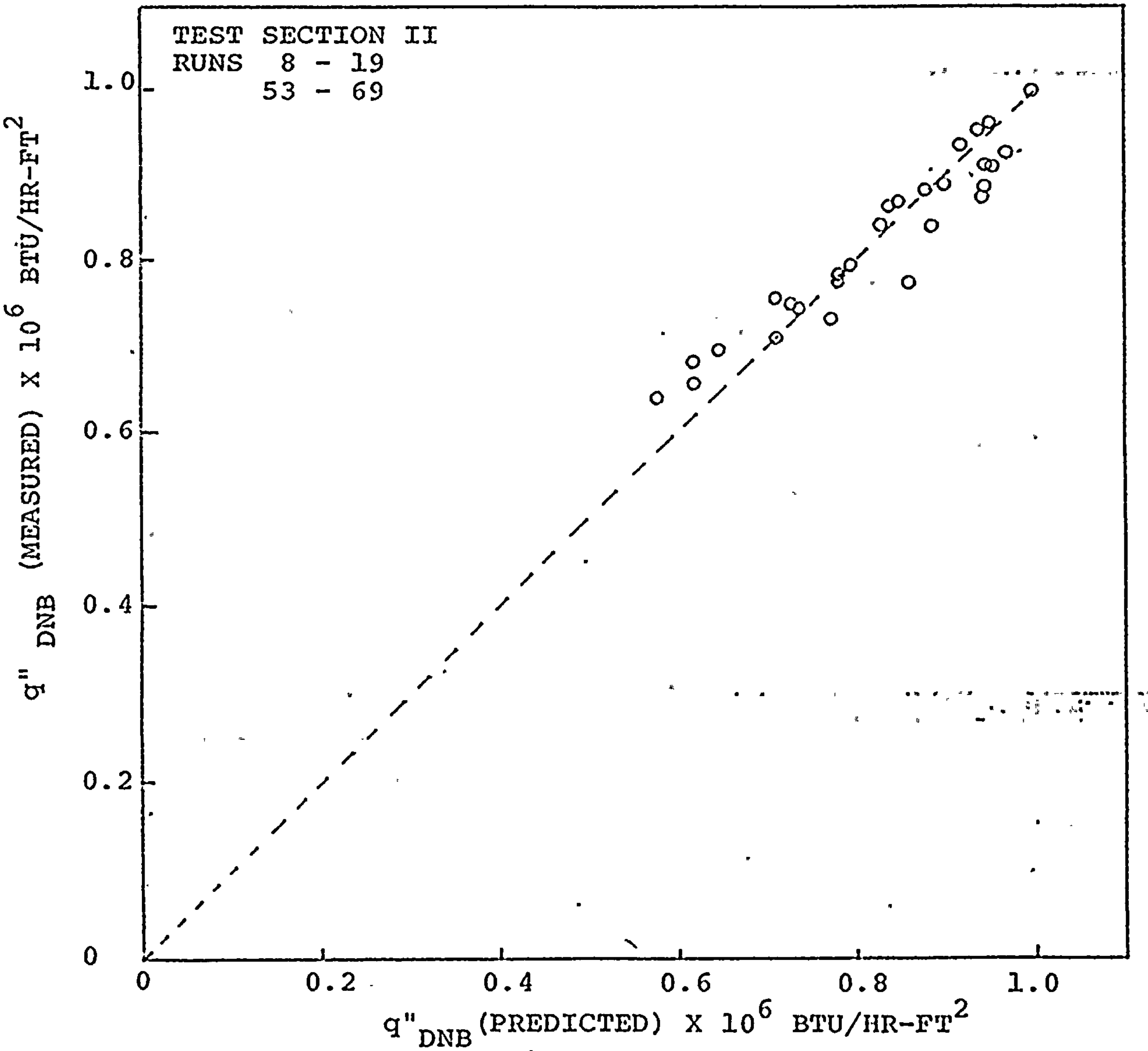

FIGURE 1 8 FT USINE U ROD BUNDLE WITH MIXING GRID AT 20 IN SPACING. COMPARISON OF DNB DATA WITH W-3 PREDICTIONS FROM COBRA III.C SUBCHANNEL ANALYSIS

3. Test Description

A detailed description of the test bundles and experimental arrangement is given in reference 3. Two basic test section configurations were used in this analysis. They were (1) a 9 rod bundle in a 3x3 square array with a 14 foot heated length, and (2) a 16 rod bundle in a 4x4 square array with an 8 foot heated length. The test bundles included both a u sin u and cos u axial heat flux distributions. The 14 foot test section used a uniform radial power distribution and the 8 foot test section used a non-uniform radial power distribution. Various grid designs were utilized to maintain rod spacing for the test bundles. For this analysis, 117 DNB data points from test sections II, III, VII, VIII, and XII of Table IV of reference 3, were used. Only test sections which included mixing vane grids (excluding the T-H type) were considered in order to be representative of FPL fuel assemblies.

4. Data Analysis

The ratio of the measured heat flux for DNB to the predicted heat flux for DNB as well as the values of the heat fluxes, were calculated in a manner similar to that used by Westinghouse and described in reference 3. Briefly, the method will be described here.

A. The ratio of predicted to measured DNB heat flux was calculated by

$$\frac{q''_{meas}}{q''_{pred}} = \frac{Q_I}{Q_{II}}$$

where Q_I is the experimentally measured total bundle power (MW) given in reference 3, at which DNB occurs for specified inlet conditions. Q_{II} is the total bundle power predicted by the COBRA III C code for a minimum DNBR of 1.0 for the specified inlet conditions using the W-3 critical heat flux correlation multiplied by the grid spacer correction factor, Fs, where

$$Fs = 1.0 + 0.03 \left(\frac{G}{10^6}\right) \left(\frac{TDC}{0.019}\right) .35$$

G = Local mass velocity, lbm /hr - ft^2

TDC = Thermal diffusion coefficient

= 0.061 for 20 in. grid span

= 0.051 for 26 in. grid span

As an alternate method, the spacer factor Fs could have been included internally in the COBRA calculation of Q_{II}. Sensitivity studies showed that this would lead to a lower DNBR limit. Following the Westinghouse method described in reference 3, of multiplying the predicted power by the spacer factor external to the code, results in a more conservative value for the DNBR limit.

B. The value of the measured local DNB heat flux, q''_{meas}, was determined at the axial location of minimum DNBR for the bundle power Q_I and the specified inlet conditions. The predicted local DNB heat flux, q''_{pred}, was calculated from q''_{meas} and the ratio described in part A, above.

5. Derivation of DNBR Limit

The experimental inlet conditions and values of q''_{meas}, q''_{pred}, and q''_{meas}/q''_{pred} for 117 cases calculated by FPL using the COBRA III C code are presented in Table 1. The DNBR safety limit for a 95x95 upper tolerance limit (i.e., the value of DNBR which bounds 95% of the data base with a 95% confidence) is given by:

$$\text{DNBR Limit} = \frac{1}{\bar{X} - K_{95x95}\sigma}$$

$\bar{X}$ - is (q''_{meas}/q''_{pred}), the mean value of the measured to predicted DNB heat flux ratios

σ - is the standard deviation of the ratios, q''_{meas}/q''_{pred}

K_{95x95} - is a multiplier to give a 95x95 upper tolerance limit for the number of points, N, in the data base. Values are taken from reference 5.

For the 117 points analyzed:

$N = 117$

$\overline{X} = 0.9864$

$\sigma = 0.0756$

$K_{95x95} = 1.903$ (reference 5)

DNBR Limit = 1.1870

Figures 1 through 5 show comparisons of q''_{meas} vs q''_{pred} for the test assemblies analyzed. Figure 6 is a composite of all the data points analyzed.

The corresponding Westinghouse DNBR limit for the same experimental points is 1.1564. The difference may be due to some of the conservatism in the COBRA calculations. For example, sensitivity studies showed that an increase in the number of axial nodes used in the calculations would have decreased the DNBR safety limit calculated with COBRA and brought it closer to the Westinghouse limit.

TABLE I

RUN NO.	PRESSURE (PSIA)	POWER AT DNB (MW)	INLET TEMP. (°F)	INLET BUNDLE AV. MASS VELOCITY (10^6 LBM/HR-FT^2)	LOCAL DNB 10^6 BTU/HR-FT^2 q" MEAS	q" PRED	q" MEAS / q" PRED
8	1504	2.353	520.0	2.50	.870	.845	1.029
9	1505	2.586	499.0	2.50	.956	.932	1.026
10	2150	2.116	584.0	2.59	.699	.650	1.075
11	2100	2.310	567.0	2.55	.762	.709	1.075
12	2401	2.281	577.0	2.54	.843	.832	1.013
13	2401	2.145	559.0	2.06	.793	.798	.994
14	1508	2.122	560.0	3.43	.732	.775	.945
15	1808	2.259	579.0	3.55	.746	.741	1.006
16	1811	2.333	500.0	1.91	.862	.844	1.022
17	1508	2.400	545.0	3.60	.887	.945	.939
18	1504	2.754	482.0	2.48	1.018	1.000	1.018
19	1532	2.530	466.0	1.97	.935	.918	1.018
20	1504	2.722	495.0	2.55	.762	.821	.929
21	1514	2.837	483.0	2.56	.795	.870	.914
22	1812	2.649	519.0	2.51	.691	.735	.941
23	1843	2.854	501.0	2.49	.799	.861	.928
24	2091	2.414	564.0	2.53	.583	.579	1.007
25	2091	2.708	544.0	2.55	.654	.657	.996
26	2389	2.515	581.0	2.56	.547	.523	1.046
27	2391	2.692	564.0	2.54	.650	.643	1.011
28	2391	2.909	543.0	2.56	.758	.777	.975
29	2397	2.563	620.0	3.43	.496	.421	1.179
30	2391	3.000	601.0	3.58	.581	.519	1.121
31	2394	2.565	605.0	3.01	.497	.439	1.131
32	2395	2.937	582.0	3.03	.639	.592	1.079
33	2394	2.321	560.5	2.01	.560	.547	1.025
34	2394	2.513	543.0	2.04	.607	.609	.997
35	2395	2.677	520.0	2.04	.698	.732	.954
36	2093	2.599	596.0	3.56	.565	.532	1.062
37	2095	2.921	579.0	3.53	.635	.609	1.043
38	2099	2.228	602.0	3.00	.485	.445	1.090
39	2096	2.649	577.0	3.05	.640	.612	1.046
40	2096	2.880	561.0	3.06	.695	.685	1.015
41	2095	2.313	544.0	2.00	.558	.547	1.020
42	2095	2.525	518.0	2.03	.658	.680	.968
43	2095	2.672	501.0	2.04	.697	.736	.947
44	1800	2.341	580.0	3.52	.610	.637	.957
45	1799	2.630	563.0	3.51	.686	.726	.945
46	1799	2.459	559.0	3.01	.641	.665	.964
47	1799	2.777	540.0	3.02	.724	.750	.966
48	2099	2.908	524.0	2.50	.758	.778	.975
49	1796	2.629	494.0	2.06	.685	.709	.967
50	1505	2.565	541.0	3.47	.669	.744	.899
51	1500	3.066	514.0	3.53	.799	.881	.907
52	1796	2.718	482.0	2.03	.709	.737	.962

RUN NO.	PRESSURE (PSIA)	POWER AT DNB (MW)	INLET TEMP. (°F)	INLET BUNDLE AV. MASS VELOCITY (10^6 LBM/HR-FT^2)	LOCAL DNB q" 10^6 BTU/HR-FT^2 q" MEAS	q" PRED	q" MEAS / q" PRED
53	1503.	2.105	558.0	3.58	.778	.864	.901
54	1815.	2.508	560.0	3.62	.927	.967	.958
55	1781.	2.474	481.5	2.03	.914	.944	.968
56	2103.	2.366	502.5	2.02	.874	.944	.926
57	2108.	2.279	517.5	2.04	.842	.888	.948
58	2110.	2.103	541.5	2.03	.777	.785	.990
59	2114.	2.420	545.0	2.53	.894	.907	.986
60	2115.	2.519	567.5	3.06	.869	.853	1.019
61	2129.	2.262	581.0	3.07	.780	.780	1.000
62	2097.	1.999	601.5	3.04	.660	.620	1.064
63	2104.	2.857	566.0	3.58	.964	.954	1.011
64	2108.	2.273	594.0	3.46	.750	.730	1.028
65	2083.	2.563	577.5	3.57	.884	.884	1.000
66	2390	2.476	580.0	3.09	.915	.950	.963
67	2404.	2.158	602.0	3.07	.712	.713	.999
68	2407.	1.949	623.0	3.05	.643	.580	1.109
69	2414.	2.079	627.0	3.56	.686	.625	1.098
206	2084	2.431	579.3	2.60	.603	.587	1.028
208	2026	2.884	536.7	2.61	.795	.833	.953
209	1497	2.686	525.0	2.48	.739	.730	1.013
210	1497	3.058	499.5	2.55	.842	.837	1.005
211	1497	3.340	478.3	2.55	.919	.919	1.000
212	1491	2.498	566.3	3.51	.663	.677	.979
213	1498	2.905	536.7	3.63	.800	.882	.907
214	1801	2.626	566.3	3.62	.745	.840	.887
215	1797	2.836	568.7	3.51	.725	.725	1.000
216	1790	2.782	501.0	2.07	.766	.780	.981
217	1490	2.418	516.7	2.55	.737	.843	.874
218	1490	2.665	496.7	2.56	.779	.889	.876
219	1491	2.861	481.0	2.55	.836	.907	.922
220	1510	2.278	559.7	3.60	.666	.790	.843
221	1512	2.668	539.3	3.59	.780	.905	.862
222	1796	2.257	580.7	3.54	.621	.704	.882
223	1791	2.797	560.0	3.68	.770	.845	.911
224	2103	2.232	583.0	2.56	.593	.601	.986
225	2105	2.428	565.3	2.55	.668	.701	.953
226	2103	2.630	546.0	2.57	.724	.793	.913
227	2103	2.235	599.0	3.10	.571	.582	.981
228	2113	2.513	583.7	3.06	.667	.682	.979
229	2124	2.833	559.3	3.10	.780	.853	.914
232	2115	3.054	566.3	3.56	.873	.942	.927
233	2422	2.391	626.3	3.54	.561	.522	1.075
234	2424	2.786	602.5	3.61	.713	.742	.961
235	2415	3.049	583.7	3.59	.839	.908	.924
236	2432	2.200	624.3	3.03	.516	.477	1.081
237	2424	2.492	602.2	3.06	.637	.648	.983
238	2414	2.790	580.3	3.09	.910	.987	.922
239	2413	2.431	579.3	2.58	.669	.724	.924
240	2413	2.711	553.7	2.57	.874	.993	.880
241	2388	2.835	537.0	2.56	.914	1.067	.857

REFERENCES

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2. Reavis, J.R. et. al., Fuel Rod Bowing, WCAP-8692, December, 1975.

3. Rosal, E.R. et. al., High Pressure Rod Bundle DNB Data With Axially Non-Uniform Heat Flux, Nuc. Eng, Des., Vol 31, 1974.

4. Letter A. Schwencer (NRC) to R.E. Uhrig (FPL), dated September 15, 1978, Dockets No. 50-250 and 50-251.

5. Owen, D.B., Factors for One-Sided Tolerance Limits and for Variables Sampling Plans, SCR-607, Sandia Corp., March 1963.

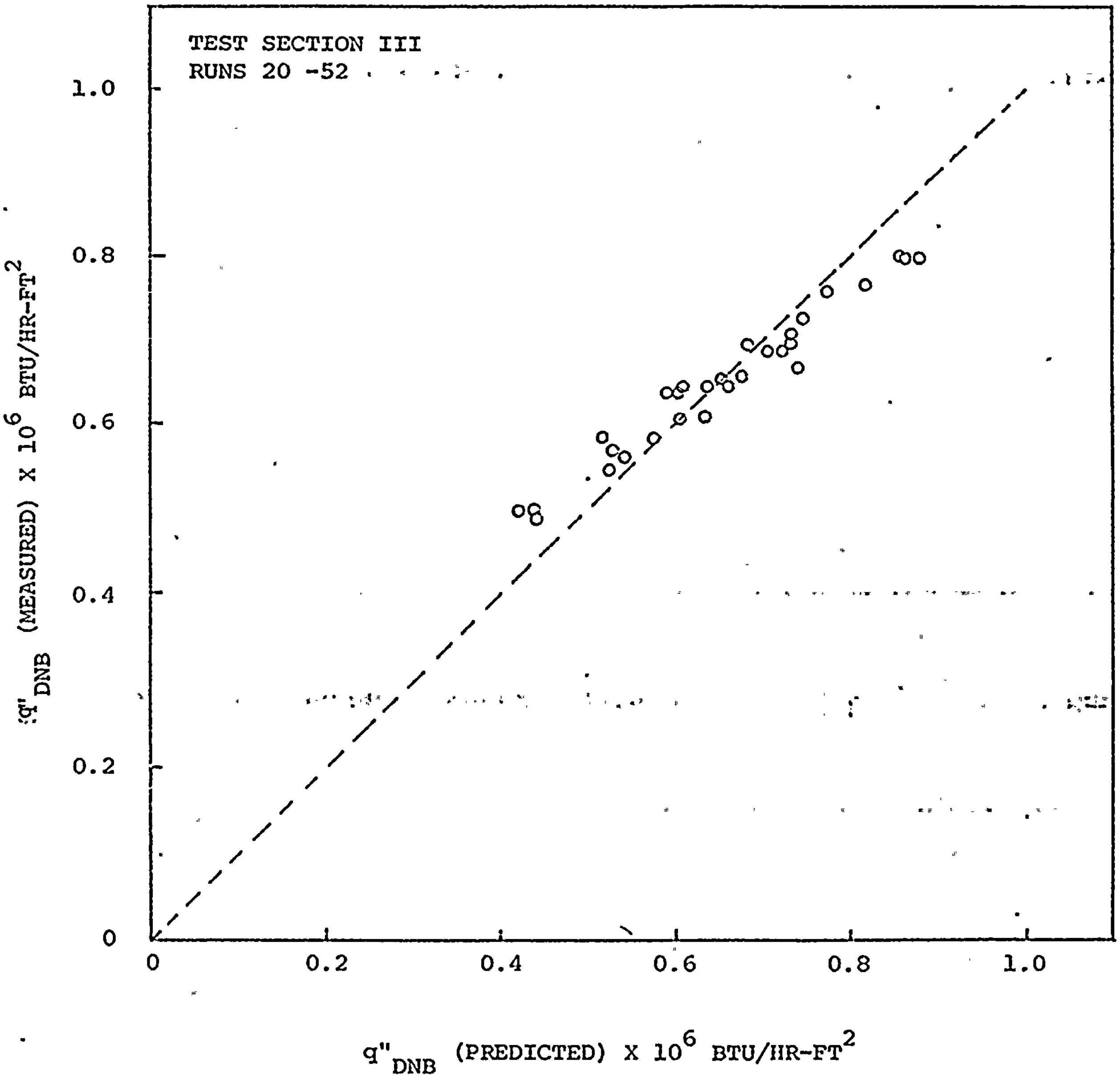

FIGURE 2 14 FT USINU ROD BUNDLE WITH MIXING VANE GRID AT 20 IN SPACING. COMPARISON OF DNB DATA WITH W-3 PREDICTIONS FROM COBRA III.C SUBCHANNEL ANALYSIS.

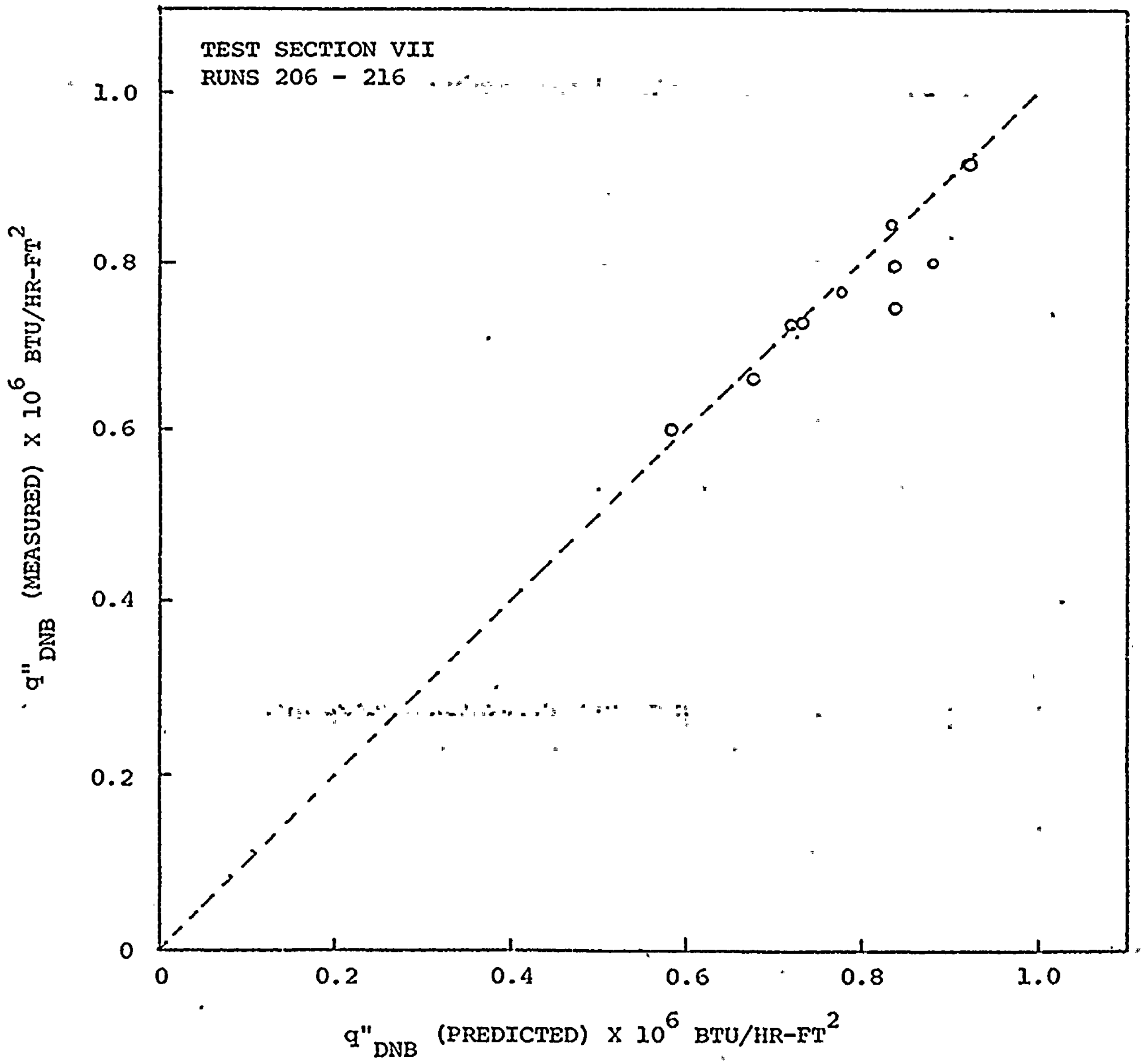

FIGURE 3 8 FT COSINE U ROD BUNDLE WITH MIXING VANE GRID AT 20 IN SPACING. COMPARISON OF DNB DATA WITH W-3 PREDICTIONS FROM COBRA III.C SUBCHANNEL ANALYSIS.

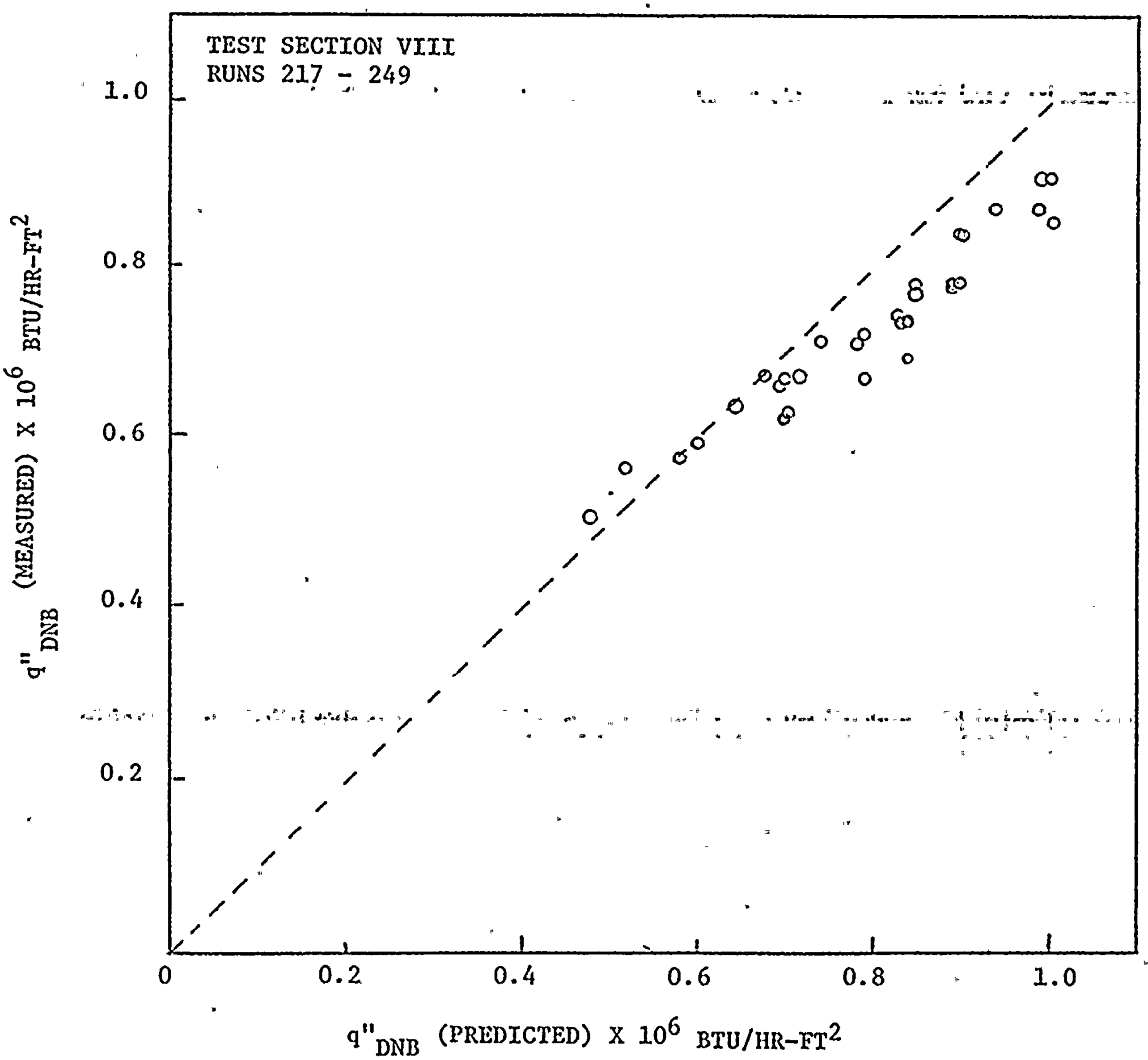

FIGURE 4 8 FT COSINE U ROD BUNDLE WITH MIXING VANE GRID AT 26 IN SPACING. COMPARISON OF DNB DATA WITH W-3 PREDICTIONS FROM COBRA III.C SUBCHANNEL ANALYSIS.

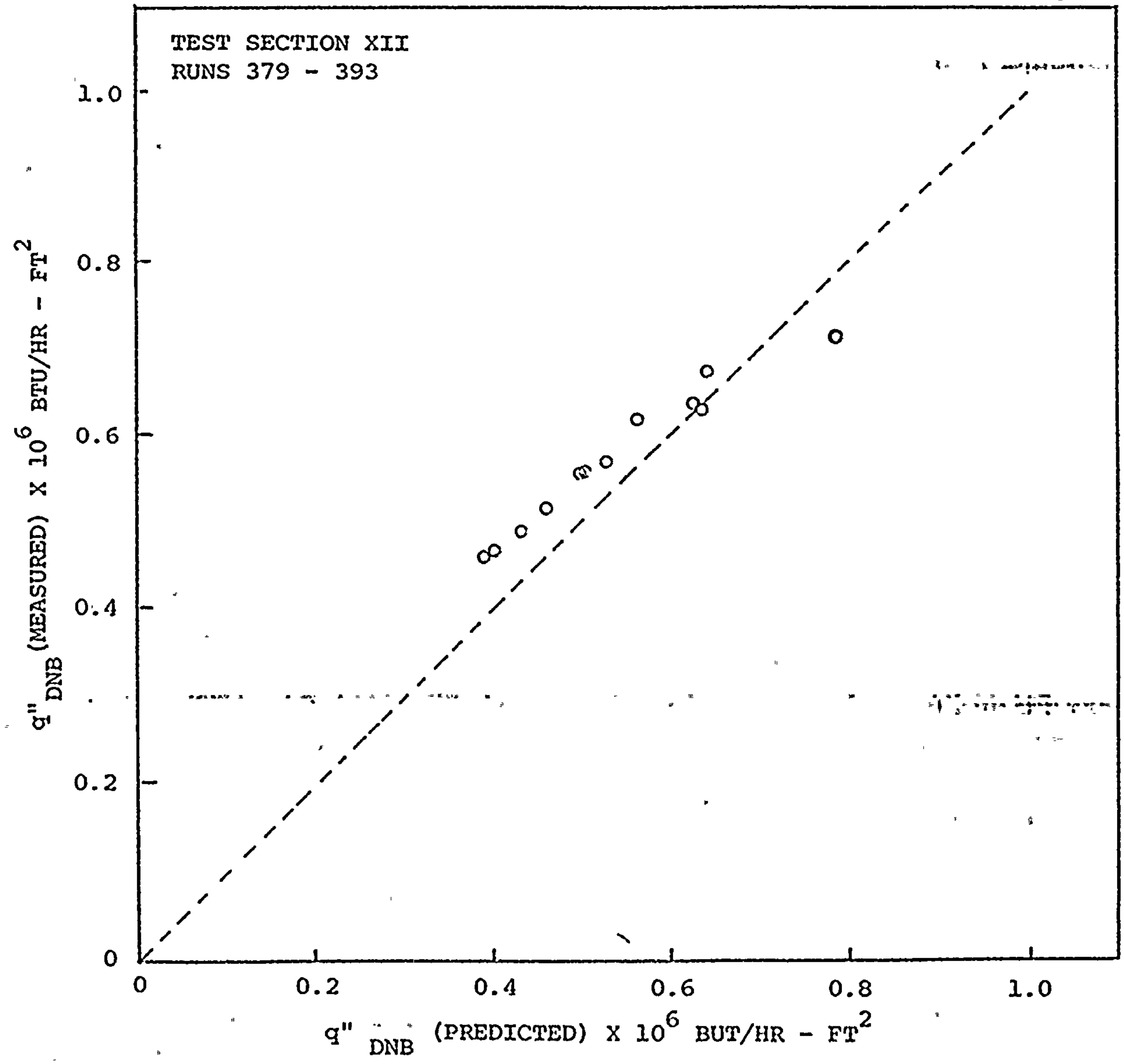

FIGURE 5 14 FT COSINE u ROD BUNDLE WITH MIXING VANE GRID AT 20" SPACING. COMPARISON OF DNB DATA WITH W-3 PREDICTIONS FROM COBRA III.c SUBCHANNEL ANALYSIS.

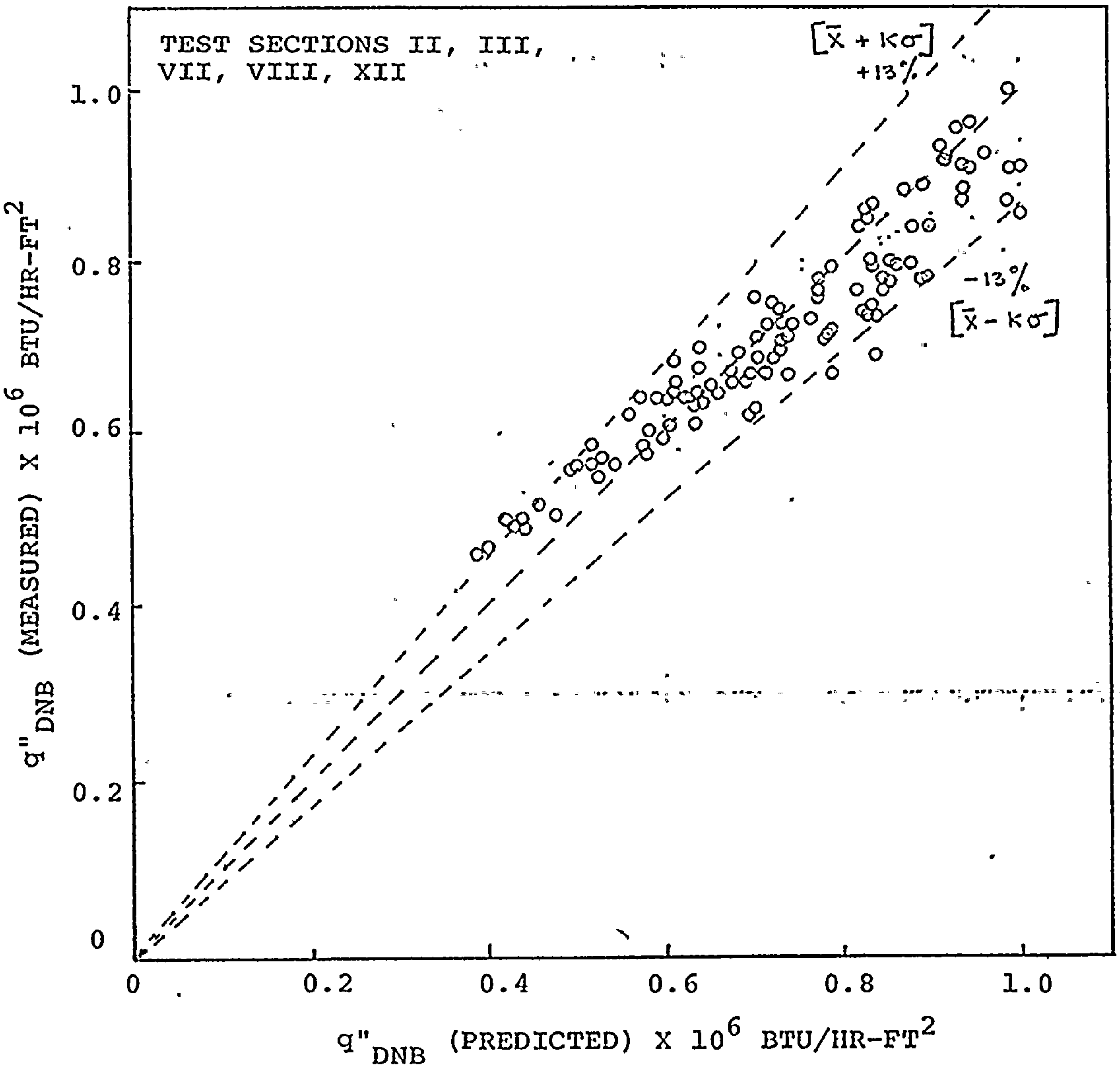

FIGURE 6 COMPARISON OF DNB DATA WITH W-3 PREDICTIONS FROM COBRA III C SUBCHANNEL ANALYSIS FOR TEST SECTIONS II, III, VII, VIII AND XII

STATE OF FLORIDA)
) ss.
COUNTY OF DADE)

Robert E. Uhrig, being first duly sworn, deposes and says:

That he is a Vice President of Florida Power & Light Company, the Licensee herein;

That he has executed the foregoing document; that the statements made in this said document are true and correct to the best of his knowledge, information, and belief, and that he is authorized to execute the document on behalf of said Licensee.

Robert E. Uhrig

Robert E. Uhrig

Subscribed and sworn to before me this

21st day of May, 1979

Betty Brittain

NOTARY PUBLIC, in and for the county of Dade, State of Florida

My commission expires: NOTARY PUBLIC STATE OF FLORIDA at LARGE MY COMMISSION EXPIRES MARCH 27, 1982 BONDED THRU MAYNARD BONDING AGENCY