ENCLOSURE

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INTRODUCTION

This report documents the results of our analysis of noise data recorded at the Susquehanna-2 boiling water reactor (BWR) at the end of Cycle 4. The most significant result of this analysis is an estimate of the reactor stability at the particular operating point at which the data was recorded. During Cycle 4 the Susquehanna-2 reactor used a full core of Advanced Nuclear Fuels (ANF) 9 by 9 fuel. Previous test data have indicated that the 9 by 9 fuel has little significant effect on the reactor stability.[1-3]

The present experimental program began in 1986 to determine whether loading 9 by 9 fuel elements could significantly destabilize a reactor. The 9 by 9 fuel has a faster fuel temperature response (due to its smaller thermal inertia) and a smaller (i. e. less negative) void reactivity coefficient compared to conventional 8 by 8 fuel. A faster fuel temperature response decreases the reactor stability while a smaller void reactivity coefficient tends to stabilize the reactor. It is not obvious how these two competing effects would combine to affect the reactor stability, thus, a series of measurements were made, beginning during Cycle 2, to experimentally determine the effect of the 9 by 9 fuel on reactor stability.

TEST DATA AND ANALYSIS RESULTS

The test data were recorded on January 4, 1991 by Susquehanna personnel using the General Electric Transient Analysis Recorder (GETARS) data acquisition system. The reactor was operating at approximately 64% power with a total core flow of 45.8 M-lb/h. Appendix A lists in detail the reactor conditions during recording. The data, which consisted of average power range monitor (APRM), core flow, and core pressure signals, were sent in digital form on magnetic tape to the Oak Ridge National Laboratory (ORNL) for analysis. The recorded signals and their units are listed in Table 1.

Table 1. List of signals and their units.

Channel	Description	Units
1	APRM-A	% Nominal
2	APRM-B	% Nominal
3	APRM-C	% Nominal
4	APRM-D	% Nominal
5	APRM-E	% Nominal
6	APRM-F	% Nominal
7	Core Flow	Mlb/h
8	N.R. Pressure	psi

The data were analyzed in the frequency domain to produce noise descriptors such as power spectral densities (PSDs), coherences, autocorrelation functions, and transfer functions. The stability was then calculated from these descriptors using the ORNL stability analysis methodology.[4] The main results of the analysis are summarized in Table 2.

Figures 1 and 2 show the PSD and the autocorrelation function calculated for the APRM-A signal. The results shown in these figures are typical of all the APRM data used in this analysis.

DISCUSSION OF RESULTS

The results of this analysis show that the Susquehanna-2 reactor was very stable (i.e. decay ratio less than 0.3) at the end of Cycle 4. The relatively stable condition is indicated by the broad peak in the PSD at approximately 0.4 Hz and by the rapid damping shown in the autocorrelation function.

Table 3 shows results from previous stability analyses performed by ORNL for the Susquehanna-2 reactor. These analyses include data from Cycles 2, 3, and 4 in which the core contained 33%, 66%, and 100% 9 by 9 fuel. Similar power and flow conditions were used in each

Table 2. Decay ratios and natural oscillation frequencies estimated from noise data. Susquehanna-2, EOC 4.

Channel	Description	Decay Ratio	Oscillation Frequency (Hz)
1	APRM-A	0.24±0.06	0.68±0.08
2	APRM-B	0.22±0.05	0.68±0.08
3	APRM-C	0.22±0.06	0.68±0.08
4	APRM-D	0.23±0.04	0.68±0.07
5	APRM-E	0.22±0.05	0.68±0.10
6	APRM-F	0.23±0.05	0.6[illegible]±0.07

test. Comparison of the results in Tables 2 and 3 shows that the Susquehanna-2 reactor had the smallest decay ratio and highest oscillation frequency at the end of Cycle 4. The local power range monitor (LPRM) data given in Appendix A show that the reactor had a top-peaked axial power shape when the data was collected. This is the most likely explanation for the low decay ratio and high oscillation frequency. BWR stability is heavily influenced by the axial power shape; bottom-peaked axial power shapes are destabilizing and top-peaked axial power shapes are stabilizing. Furthermore, the oscillation frequency is inversely proportional to resident time for steam bubbles in the core. Top-peaked power shapes result in the average axial position of steam bubble formation being shifted upward. Thus, the steam bubbles, on average, have a shorter distance to travel before leaving the core when the axial power shape is top-peaked. Since the total core flow (and thus the flow velocity) for this analysis is approximately the same as in previous analyses, the shorter distance traveled by the steam bubbles translates into a shorter average residence time for steam bubbles in the core and in a correspondingly higher oscillation frequency.

These results agree with our previous conclusions that the 9 by 9 fuel does not produce major changes in stability behavior compared to BWRs loaded with standard 8 by 8 fuel.

Table 3. Reactor conditions, decay ratios, and oscillation frequencies from previous analyses of Susquehanna-2 GETARS data[1-3].

Cycle	9 by 9 elements loaded (%)	Date	Power (% of nominal)	Flow (Mlb/hr)	Decay Ratio	Oscillation Freq. (Hz)
2(TLO)[a]	33	2-NOV-86	61	46.7	0.33±0.03	0.39±0.02
2(SLO)[b]	33	9-NOV-86	56	43.9	0.37±0.02	0.34±0.02
3(TLO)[a]	66	23-JUL-88	60	46.0	0.48±0.05	0.48±0.04
4(TLO)[a]	100	8-DEC-89	63	44.6	0.27±0.07	0.27±0.01

[a] Two loop operation, minimum recirculation pump speed.
[b] Single loop operation.

REFERENCES

1. "Grand Gulf-1 and Susquehanna-2 Stability Tests," J. March-Leuba and D. N. Fry, Oak Ridge National Laboratory Letter Report ORNL/NRC/LTR-87/01, April 1987.

2. "Susquehanna-2 Stability Measurements During Cycle 3 ," J. March-Leuba and B. Damiano, Oak Ridge National Laboratory Letter Report ORNL/NRC/LTR-90/3, January 1990.

3. "Evaluation of 9 by 9 Fuel Impact on the Stability of Susquehanna-2 during Cycles 2, 3, and 4," B. Damiano and J. March-Leuba, Oak Ridge National Laboratory Letter Report ORNL/NRC/LTR-91/11, August 1991.

4. "Development of a Real-Time Stability Measurement System for Boiling Water Reactors," J. March-Leuba and W. T. King, Trans. Am. Nucl. Soc. 54 370-371, June 1987.

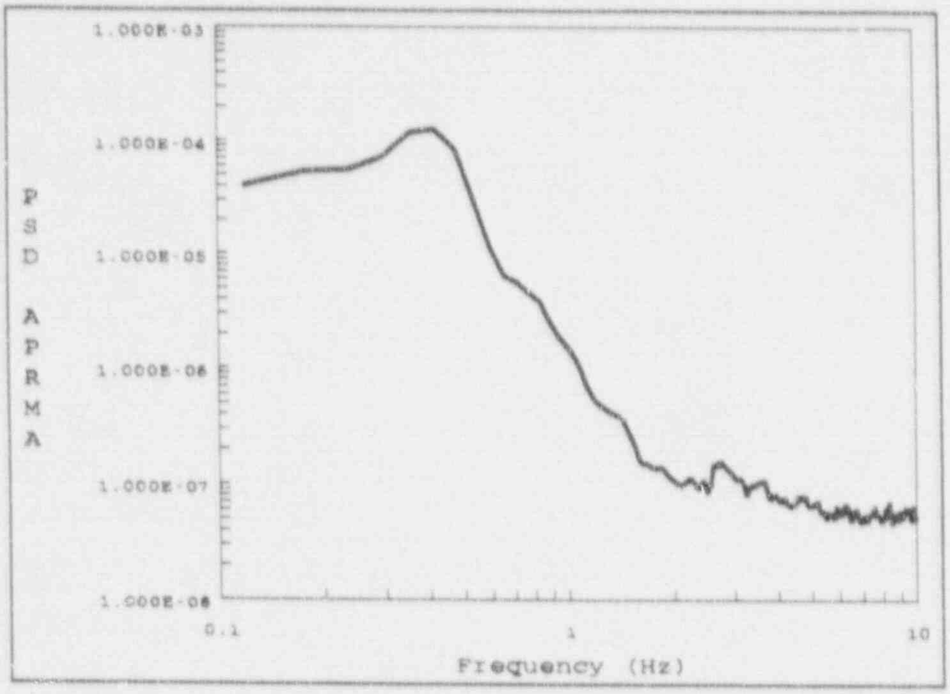

Figure 1. Power spectral density of APRM-A.

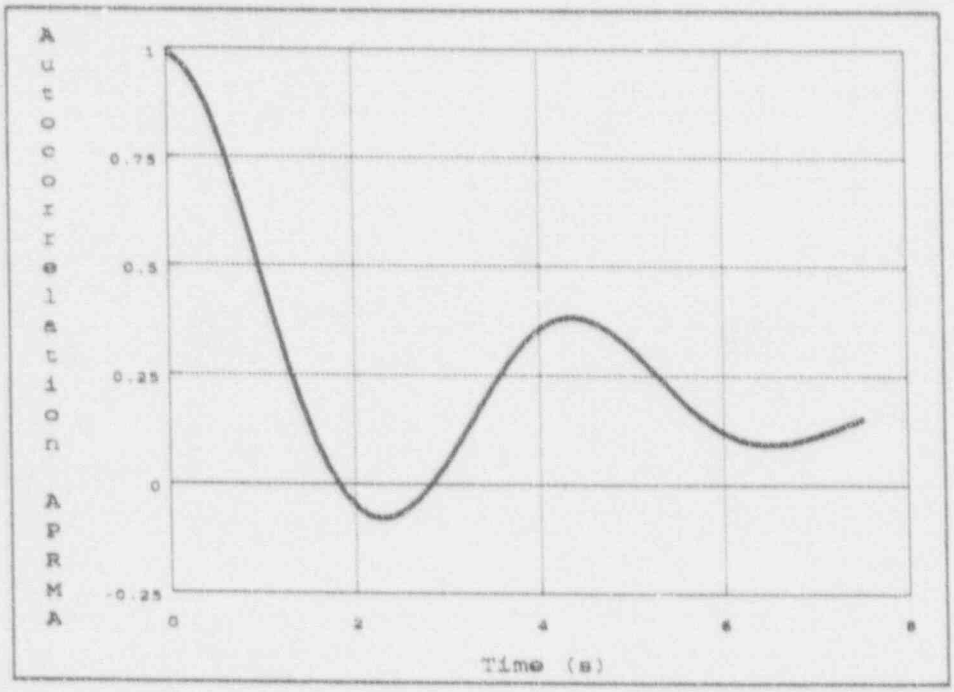

Figure 2. Autocorrelation function of APRM-A.

APPENDIX A

Test point operating conditions

NAME OR POINT ID	DESCRIPTION (ALL FLOWS IN MLB/HR ALL TEMPERATURES IN DEG F)	VALUE
%WT	TOTAL CORE FLOW USED IN H.B.	45.814
%WL	ACTIVE/TOTAL CORE FLOW FRAC	0.90000
NFP51	REACTOR PRESSURE (PSIA)	967.20
%MWT	CORE THERMAL POWER (MWT)	2077.4
%DHS	CORE INLET SUBCOOLING (BTU/LB)	-37.525
%ENDEL	CORE ENERGY INCREMENT (MWHT)	42.595
NM551	APRM READING(A)-CHAN 01 (%PWR)	63.562
NM553	APRM READING(C)-CHAN 02 (%PWR)	62.875
NM555	APRM READING(E)-CHAN 03 (%PWR)	63.750
NM552	APRM READING(B)-CHAN 04 (%PWR)	63.612
NM554	APRM READING(D)-CHAN 05 (%PWR)	63.675
NM556	APRM READING(F)-CHAN 06 (%PWR)	63.062
%HBFLAG	CTP CALC. (0-HT BAL, 1-APRM)	0.00000
NJP51	REACTOR CORE PRES. DROP (PSID)	2.7191
NEF51%K1	CRD FLOW (MLB/HR)	0.31594E-01
NLF51%K2	CLEANUP LOOP FLOW (MLB/HR)	0.10430
NLT52	CLEANUP LOOP INLET TEMP (DEGF)	526.27
NLT51	CLEANUP LOOP EXIT TEMP (DEGF)	438.75
NFL01(DCS)	REACTOR WATER LEVEL (INCHES)	36.015
NFF51	REACTOR STEAM FLOW	8.2619
GNJ02	GROSS GENERATOR POWER (MWE)	292.50
DFWFA	FW FLOW A,WGHTD AVE (MLB/HR)	2.7356
DFWFB	FW FLOW B,WGHTD AVE (MLB/HR)	2.7165
DFWFC	FW FLOW C,WGHTD AVE (MLB/HR)	2.6099
NRJ51	RECIRC PUMP A POWER (MW)	0.20172
NRJ52	RECIRC PUMP B POWER (MW)	0.26892
NFF52	FEEDWATER FLOW, A (MLB/HR)	2.7392
NFF53	FEEDWATER FLOW, B (MLB/HR)	2.7154
NFF54	FEEDWATER FLOW, C (MLB/HR)	2.6090
NBT51	FW TEMP 1 ,BRANCH A (DEGF)	347.45
NBT52	FW TEMP 2 ,BRANCH A (DEGF)	347.04
NBT53	FW TEMP 1 ,BRANCH B (DEGF)	345.07
NBT54	FW TEMP 2 ,BRANCH B (DEGF)	344.74
NBT55	FW TEMP 1 ,BRANCH C (DEGF)	345.04
NBT56	FW TEMP 2 ,BRANCH C (DEGF)	344.37

NRF51#K3	RECIRC FLOW, A1 (MLB/HR)	5.0833
NRF53#K3	RECIRC FLOW, A2 (MLB/HR)	4.9699
NRF52#K3	RECIRC FLOW, B1 (MLB/HR)	6.6864
NRF54#K3	RECIRC FLOW, B2 (MLB/HR)	6.5313
NRT51	RECIRC TEMP, A1 (DEGF)	485.01
NRT52	RECIRC TEMP, A2 (DEGF)	511.01
NRT53	RECIRC TEMP, B1 (DEGF)	508.41
NRT54	RECIRC TEMP, B2 (DEGF)	508.54
#GENDEL	GENERATOR ENERGY INCR. (MWHE)	6.0000
BHR	HEAT RATE (MWT/MWE)	7.1022

+ XTG INPUTS AND SCAN DATA EDIT FOR SUSQUEHANNA-2 +

NAME OR POINT ID	DESCRIPTION (ALL FLOWS IN MLB/HR ALL TEMPERATURES IN DEG F)	VALUE
#WTSUB	CORE FLOW FROM FUNCTION F4	45.810
NJF51	WT FROM J.P. OR INPUT (MLB/HR)	45.814
WD	TOTAL RECIRC FLOW	11.635
#WTFLAG	CORE FLOW FLAG	2.0000
#CRD	CONTROL ROD DENSITY	0.36937E-01
#CRDSYM	CONTROL ROD SYMMETRY FLAG	0.00000

+ LPRM READINGS - UNCALIBRATED FOR SUSQUEHANNA 2 +
+ (PROCESS COMPUTER COORDINATES) +

(1657)	(2457)	(3257)	(4057)
14.7	17.8	18.4	17.4
20.8	26.7	26.6	26.2
19.8	28.0	26.4	25.6
12.7	20.5	17.7	16.5

(0849)	(1649)	(2449)	(3249)	(4049)	(4849)
16.3	-0.0	26.7	27.4	27.1	27.5
23.7	35.0	39.3	-0.1	40.6	29.8
20.8	30.8	31.2	32.2	30.4	26.5
12.0	20.7	25.9	25.4	22.2	15.7

(0841)	(1641)	(2441)	(3241)	(4041)	(4841)	(5641)
23.5	28.9	31.8	29.8	30.3	26.8	17.9
34.8	42.3	39.1	35.2	38.6	40.7	28.[illegible]
32.4	30.4	29.1	27.7	28.6	30.6	26.6
22.4	20.7	21.1	20.0	20.6	20.2	15.8

(0833)	(1633)	(2433)	(3233)	(4033)	(4833)	(5633)
73.2	29.0	31.6	31.2	30.0	27.6	18.4
34.0	39.7	37.7	36.6	36.6	43.8	27.4
32.1	32.9	-0.4	27.5	29.4	33.3	27.2
22.2	22.7	18.2	21.9	21.2	25.1	16.5

(0825)	(1625)	(2425)	(3225)	(4025)	(4825)	(5625)
23.2	29.4	31.7	29.9	29.8	26.5	17.9
35.4	42.1	36.5	35.9	37.1	42.3	27.2
33.0	30.6	27.3	27.0	28.5	32.0	29.8
25.3	22.1	19.6	18.3	-0.1	24.2	19.1

(0817)	(1617)	(2417)	(3217)	(4017)	(4817)	(5617)
20.7	26.3	28.8	28.2	27.9	23.7	14.2
31.6	39.4	40.7	36.7	38.3	36.3	21.7
29.6	33.0	30.0	29.7	28.5	31.5	20.5
17.2	23.3	23.0	22.7	20.8	19.5	11.2

(1609)	(2409)	(3209)	(4009)	(4809)
20.2	22.5	23.2	22.8	16.1
30.5	33.6	33.7	0.2	23.0
29.8	32.7	32.0	32.4	20.7
18.7	27.9	24.2	24.2	11.7

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