EVALUATION OF A DROPPED RODLET EVENT DURING VOGTLE 2 CYCLE 11

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Abstract

A single control rodlet dropped into the Vogtle 2 Cycle 11 core during part power steady-state operation. Fluxmap measurements along with analytical predictions were used to confirm the presence of the dropped rodlet, as well as provide representative neutronic models to support subsequent safety analysis evaluations.

Keywords: Dropped RCCA Rodlet

1. Introduction

On Saturday, July 31, 2004, Vogtle Unit 2 was operating at 92% power when the plant experienced a small negative reactivity transient (~10 pcm). With the reactor stable, the Reactor Operator reported the following:

1) 0.4 °F decrease in $T_{avg;}$
2) 1% decrease in power range nuclear instrument power;
3) 20 MW_t decrease in calorimetric power;
4) 5 MW_e decrease in generator output;
5) 4 psig decrease in steam pressure and pressurizer pressure;
6) 1% decrease in pressurizer level.

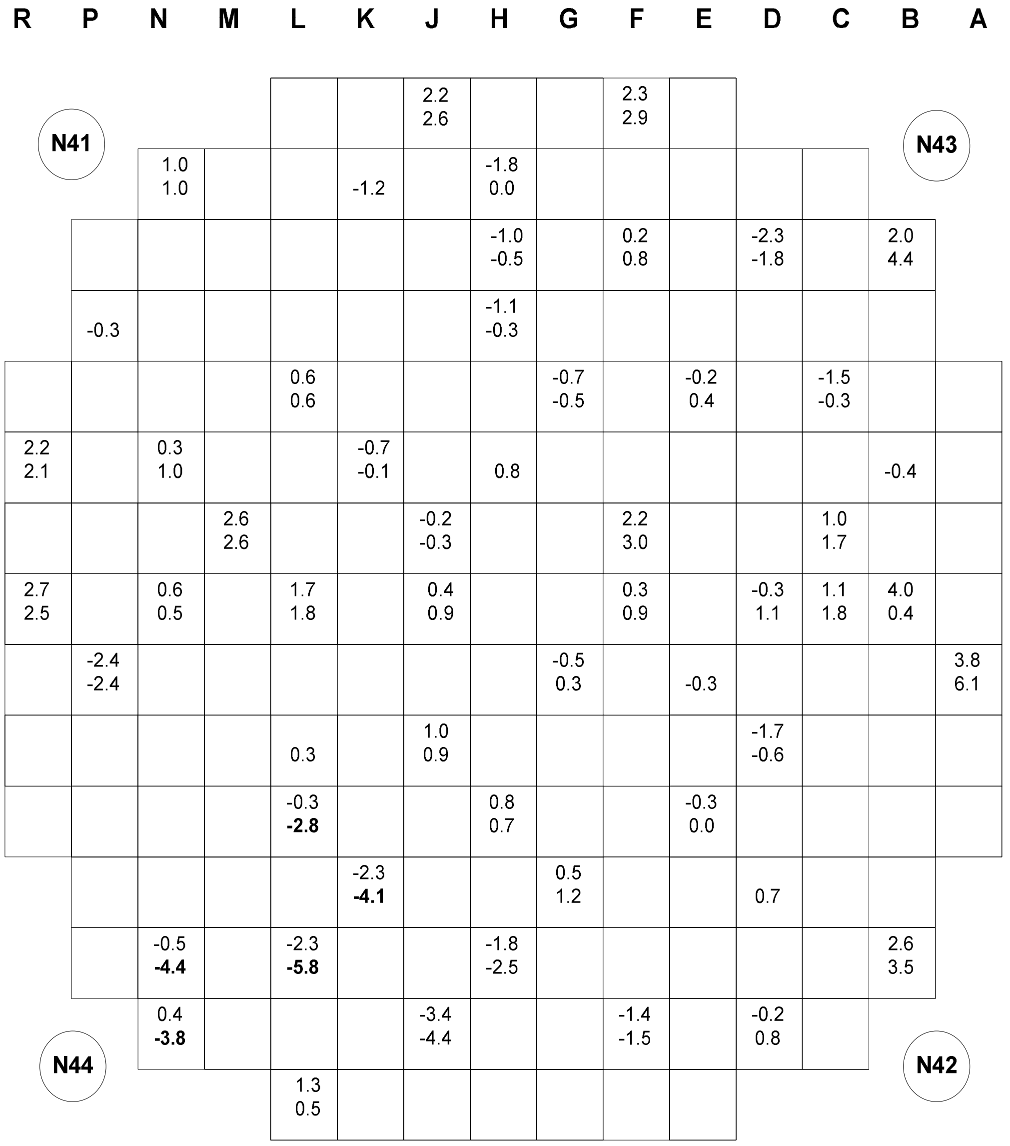
Because the Quadrant Power Tilt Ratio exceeded the Technical Specification (TS) limit of 1.02, reactor power was reduced to 90% in accordance with TS Action Statements. Southern Nuclear and Westinghouse began an investigation to determine the cause of the anomaly and to evaluate safety impacts.

2. Investigation

The reactivity anomaly occurred over 20 seconds. Review of plant data indicated that boration, rod motion, and balance-of-plant transients were not responsible. A fluxmap confirmed a power depression in the quadrant measured by Channel N44 (see Figure 1). Note that up to 58 of the 193 total fuel assembly locations in the Vogtle core are accessible using movable incore detectors. These detectors are miniature fission chambers composed of highly enriched uranium which produce a measured fission reaction rate signal proportional to assembly power. During a fluxmap, these detectors traverse the full height of the core through an instrument thimble in the center of each of the 58 potential instrumented fuel assembly locations. All 58 locations may not be available for a particular fluxmap. Fluxmap results from before and after the reactivity anomaly are presented in Figure 1.

Several potential causes of the anomaly were considered, including a dropped RCCA (Rod Cluster Control Assembly), a change in the inlet temperature distribution or flow, a misaligned RCCA, and dropped RCCA rodlets. A dropped RCCA would have produced a (measured to predicted) reaction rate difference of approximately 50% for the instrumented location, or approximately 25% for an adjacent location. As the observed reaction rate differences were much smaller (approximately 5%), a dropped RCCA was easily ruled out. Dropped rodlets or a flow anomaly, however, could not be excluded from consideration. Based on fluxmap data, neutronic modeling, and a review of Operating Experience Reports, it was concluded that 1 or 2 dropped rodlets had likely occurred. Location M-12 (Control Bank D) was judged to be the most likely location for the dropped rodlet(s).

Figure 1: Percent Differences between Measured and Predicted Reaction Rates from Pre- and Post-Dropped Rodlet Fluxmaps (2704 MWD/MTU, 3241 MWD/MTU)

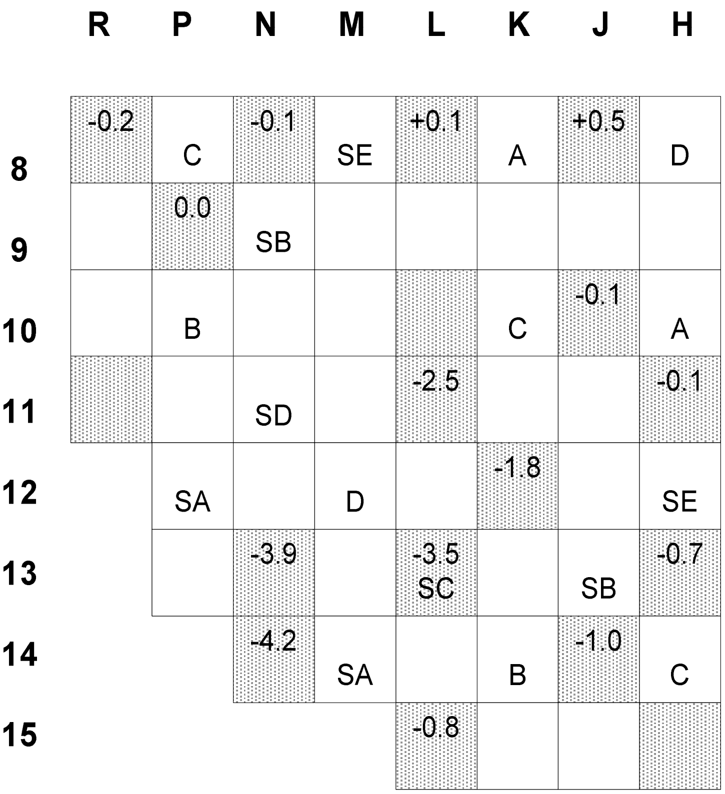


	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1							2.2 2.6			2.3 2.9					
2			1.0 1.0			-1.2		-1.8 0.0							
3								-1.0 -0.5		0.2 0.8		-2.3 -1.8		2.0 4.4	
4		-0.3						-1.1 -0.3							
5					0.6 0.6				-0.7 -0.5		-0.2 0.4		-1.5 -0.3		
6	2.2 2.1		0.3 1.0			-0.7 -0.1		0.8						-0.4	
7				2.6 2.6			-0.2 -0.3			2.2 3.0			1.0 1.7		
8	2.7 2.5		0.6 0.5		1.7 1.8		0.4 0.9			0.3 0.9		-0.3 1.1	1.1 1.8	4.0 0.4	
9		-2.4 -2.4							-0.5 0.3		-0.3				3.8 6.1
10					0.3		1.0 0.9					-1.7 -0.6			
11					-0.3 **-2.8**			0.8 0.7			-0.3 0.0				
12						-2.3 **-4.1**			0.5 1.2			0.7			
13			-0.5 **-4.4**		-2.3 **-5.8**			-1.8 -2.5						2.6 3.5	
14			0.4 **-3.8**				-3.4 -4.4			-1.4 -1.5		-0.2 0.8			
15					1.3 0.5										

3. Analytical Methods

To confirm whether dropped rodlets were present and to determine their most likely locations, 3D core models were generated using ANC, the Westinghouse Advanced Nodal Code [1]. Comparisons were made between the change in predicted assembly average powers of several key instrumented assemblies due to the modeled dropped rodlet(s) and the change in measured instrument thimble reaction rates from fluxmaps taken prior to and following the reactivity event. The fluxmaps indicated that any dropped rodlets were most likely located in RCCA core locations M-12, L-13, M-14 or P-12 (see Figure 2). Therefore, instrument thimble reaction rate differences from nearby core locations L-11, K-12, N-13, L-13, N-14 and L-15 were selected for the comparisons (see Figure 3). Measured instrument thimble reaction rate differences for these core locations are repeated for convenience in Table 1.

Figure 2: Reaction Rate Differences (%) between Pre- and Post- Dropped Rodlet Fluxmaps and RCCA and Movable Incore Detector Locations



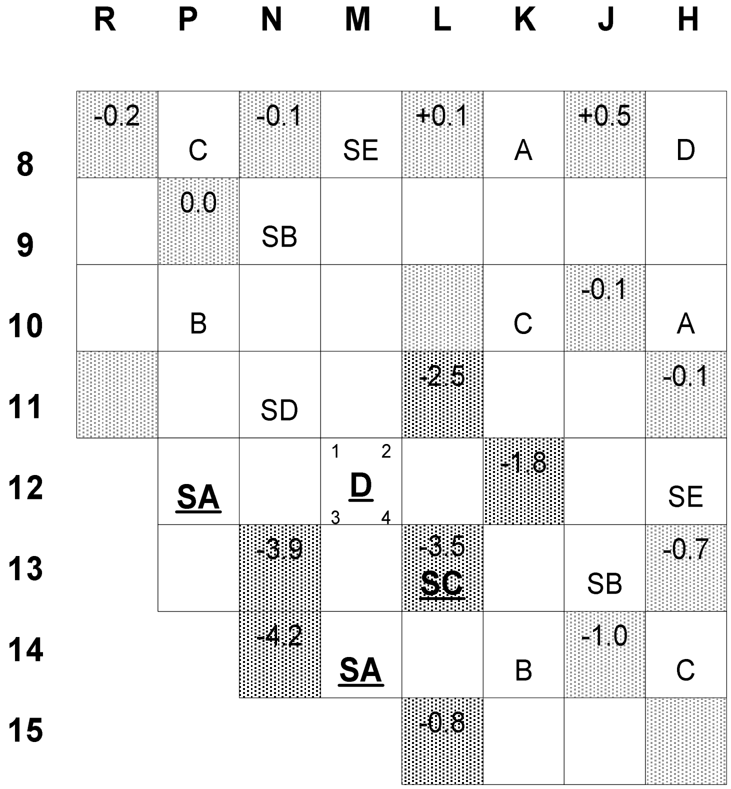
	R	P	N	M	L	K	J	H
8	▨ -0.2	C	▨ -0.1	SE	▨ +0.1	A	▨ +0.5	D
9		▨ 0.0	SB					
10		B			▨	C	▨ -0.1	A
11	▨		SD		▨ -2.5			▨ -0.1
12		SA		D		▨ -1.8		SE
13			▨ -3.9		▨ -3.5 SC		SB	▨ -0.7
14			▨ -4.2	SA		B	▨ -1.0	C
15					▨ -0.8			▨

n.n XX

n.n = Reaction Rate difference between Pre- and Post- Dropped Rodlet Fluxmaps
XX = RCCA Bank Identifier

▨ Movable Incore Detector location

Figure 3: Reaction Rate Differences (%) between Pre- and Post- Dropped Rodlet Fluxmaps Showing Potential Dropped Rodlet Candidates and Nearby Incore Instrument Thimble Core Locations



	R	P	N	M	L	K	J	H
8	-0.2	C	-0.1	SE	+0.1	A	+0.5	D
9		0.0	SB					
10		B				C	-0.1	A
11			SD		-2.5			-0.1
12		**SA**		1 2 **D** 3 4		-1.8		SE
13			-3.9		-3.5 **SC**		SB	-0.7
14			-4.2	**SA**		B	-1.0	C
15					-0.8			

1 2
D
3 4

Numbers (1,2,3,4) indicate quarter assembly node identifier (shown for most likely dropped rodlet location, M-12)

Bold, underlined characters indicate locations modeled as potential dropped rodlet candidates

▨ Movable incore detector location used for delta reaction rate comparisons

The last fluxmap prior to the event was used as a "reference case." The conditions for this “reference case” fluxmap were hot full power (HFP), ARO, and a cycle burnup of 2704 MWD/MTU. The fluxmap obtained shortly after the event was used as the "perturbed case." The map conditions were 87% power, Control Bank D positioned at 204 steps withdrawn, and a cycle burnup of 3241 MWD/MTU. Measured instrument thimble reaction rate differences between these two fluxmaps for core locations believed to be near the dropped rodlet location(s) are listed in Table 1.

Table 1: Measured Reaction Rate Difference between Pre- and Post- Dropped Rodlet Fluxmaps, %

Movable Incore Detector Core Location					
L-11	K-12	N-13	L-13	N-14	L-15
-2.5	-1.8	-3.9	-3.5	-4.2	-0.8

Several methods of modeling the dropped rodlets were considered, including assembly-wise homogenization of the dropped rodlets, node-wise homogenization in which the dropped rodlets were smeared within a radial node (one-quarter of the assembly), and explicit modeling including fuel cross section generation with the dropped rodlets present. Although the assembly-wise homogenization method was the least accurate as the effects of the dropped rodlet(s) were overly exaggerated, it was easy to implement and allowed the partially rodded condition (of Control Bank D partially inserted with one or more dropped rodlets present) to be modeled. The assembly-wise homogenization method was therefore used exclusively for the initial scoping calculations. The explicit modeling technique, while the most accurate, was the most complex and time consuming to model, and was not selected given the need to model various combinations of number and location of dropped rodlet(s).

The nodewise homogenization technique was selected for the final calculations since it was relatively easy to implement and provided sufficient accuracy. Relative to the assembly-wise technique, nodewise homogenization resulted in a smaller exaggeration of the dropped rodlet(s) impact, but was limited in that it did not allow modeling of the partially rodded condition; however, this limitation was overcome by means of a separate adjustment, described below.

The final calculations modeled a total of 32 dropped rodlet(s) cases (8 per assembly) in which 1 or 2 dropped rodlets were fully inserted into each of the four radial assembly nodes (referred to as 1, 2, 3 and 4 in Figure 3). Standard RCCA modeling requires adjustments to assembly absorption, fission, and removal cross sections, diffusion coefficients, and the assembly wet fraction. The cross sections for a single rodlet were determined by simply scaling the full cluster cross section adjustments by $^1\!/_6$, since a full cluster places 6 rodlets (of the 24 total rodlets in each RCCA) in each radial assembly node. Using this approach, linearity is inherently and conservatively assumed due to the effect of smearing the dropped rodlet(s) over a particular node versus the physical reality of the dropped rodlet(s) specific location. Scaling all components of the control rod model, rather than just the absorption cross sections, was necessary to obtain an accurate model.

Table 2 shows the predicted assembly average power differences for the 6 key instrumented assemblies (L-11, K-12, N-13, L-13, N-14 and L-15), corresponding to 8 of the 32 assumed dropped rodlet cases.

Table 2: Predicted Assembly Power Differences (%) for Postulated Dropped Rodlet(s)

		Predicted Assembly Power Difference, %					
(core location M-12)		Movable Incore Detector Core Location					
# rodlets	Node	L-11	K-12	N-13	L-13	N-14	L-15
1	1	-2.0	-1.1	-3.2	-1.7	-3.3	-1.6
1	2	-2.2	-1.3	-2.4	-1.8	-2.7	-1.6
1	3	-1.9	-1.3	-4.3	-2.3	-4.4	-2.1
1	4	-2.0	-1.6	-3.2	-2.6	-3.6	-2.2
2	1	-3.5	-2.1	-6.0	-3.3	-5.8	-2.8
2	2	-4.0	-2.5	-4.6	-3.5	-4.8	-2.8
2	3	-3.4	-2.4	-8.0	-4.4	-7.8	-3.7
2	4	-3.6	-2.9	-6	-5	-6.4	-3.9

Due to limitations of the nodewise homogenization technique, it was not possible to model the Control Bank D insertion which existed at the time of the post-dropped rodlet fluxmap. To compensate for this restriction, the predicted assembly average power differences were adjusted by a prediction of the impact due to Control Bank D insertion (Table 3) on these key assembly powers. The results of this adjustment are shown in Table 4.

Table 3: Predicted Assembly Power Differences (%)
Adjustment for Post-Dropped Rodlet Control Bank D Insertion

	Movable Incore Detector Core Location					
	L-11	K-12	N-13	L-13	N-14	L-15
Correction for ARO vs. D@203 steps	-0.5	0.1	-0.8	-0.1	-1.0	0.0

Table 4: Predicted Assembly Power Differences (%) for Postulated Dropped Rodlet(s), Adjusted for Post-Dropped Rodlet Control Bank D Insertion

		(ANC) Predicted Assembly Power Difference, %					
(core location M-12)		Movable Incore Detector Core Location					
# rodlets	Node	L-11	K-12	N-13	L-13	N-14	L-15
1	1	-2.5	-1.0	-4.0	-1.8	-4.3	-1.6
1	2	-2.7	-1.2	-3.2	-1.9	-3.7	-1.6
1	3	-2.4	-1.2	-5.1	-2.4	-5.4	-2.1
1	4	-2.5	-1.5	-4.0	-2.7	-4.6	-2.2
2	1	-4.0	-2.0	-6.8	-3.4	-6.8	-2.8
2	2	-4.5	-2.4	-5.4	-3.6	-5.8	-2.8
2	3	-3.9	-2.3	-8.8	-4.5	-8.8	-3.7
2	4	-4.1	-2.8	-6.8	-5.1	-7.4	-3.9

Using this information, differences were calculated between the measured instrument thimble reaction rate differences (Table 1) and the predicted assembly average power differences for each of the 6 key instrumented assemblies (Table 4), for each of the 32 dropped rodlet cases. By adding the 6 differences for each of the 32 dropped rodlet cases, it was found that the most likely locations (i.e., minimum value of the summation) of the dropped rodlet were in Control Bank D location M-12, with the best estimate being node 4 of this assembly. These calculations are tabulated in Table 5 (for Control Bank D only).

Table 5: Difference Between Measured and Predicted Reaction Rate Difference (%) for Postulated Dropped Rodlet(s)

		Meas Reaction Rate Diff - Pred Assembly Power Diff, %							
(core location M-12)		Movable Incore Detector Core Location							
# rodlets	Node	L-11	K-12	N-13	L-13	N-14	L-15	Summation	
1	1	0.0	-0.8	0.1	-1.7	0.1	0.8	-1.5	2nd pick
1	2	0.2	-0.6	-0.7	-1.6	-0.5	0.8	-2.4	
1	3	-0.1	-0.6	1.2	-1.1	1.2	1.3	1.9	
1	4	0.0	-0.3	0.1	-0.8	0.4	1.4	0.8	Most Likely
2	1	1.5	0.2	2.9	-0.1	2.6	2.0	9.1	
2	2	2.0	0.6	1.5	0.1	1.6	2.0	7.8	
2	3	1.4	0.5	4.9	1.0	4.6	2.9	15.3	
2	4	1.6	1.0	2.9	1.6	3.2	3.1	13.4	

4. Results

The four cases that provided the closest match to the measured reaction rate differences were as follows: single dropped rodlets in M-12 (node 4), M-12 (node 1), L-13 (node 2), and two dropped rodlets in M-14 (node 2). The observed change in reaction rates ranged from about 2 to 4 percent for instrumented locations near the postulated dropped rodlet.

To support the safety analysis evaluations, two full core depletion models, best estimate (i.e., M-12, node 4) and bounding, were created. For the bounding evaluation, a model with two dropped rodlets in location M-12, node 3, was developed. Assembly average power differences from this ANC model considerably bounded the measured reaction rate differences.

Additional calculations were performed using the explicit modeling method to validate the best estimate and bounding depletion models. The more detailed calculations showed a ~2 ppm difference relative the original core model, as compared with the 3-4 ppm difference from the nodal smearing method, and a slightly smaller impact on assembly average power. This was consistent with expectations and reflects the inherent conservatism of smearing the assumed dropped rodlet over a node. The depletion models, therefore, conservatively represented the effect of the dropped rodlet for the purposes of evaluating previous safety and design calculations.

Using information from these models, a safety evaluation was prepared allowing the plant to return to power and to continue operation for the remainder of the cycle using the original core physics data. During the shutdown the following weekend, the control rods were exercised to successfully demonstrate that all RCCAs could be fully inserted.

5. Conclusions

During the subsequent refueling inspection, one rodlet was found to have dropped into the "node 4" quadrant of assembly M-12. The rodlet had become unthreaded from its vane. This was the expected location of the dropped rodlet and confirms the methods used to diagnose and evaluate the event.

While a single dropped rodlet represents a small power distribution perturbation, these events may be identified by the various changes in plant response as noted above and by subtle changes in fluxmap reaction rates. Identification may have been more difficult if the plant had not been operating at steady state conditions.

All safety analyses were found to remain valid. The unit successfully completed the cycle without further incident.

References

1) Liu, Y. S., et al., ANC: A Westinghouse Advanced Nodal Computer Code, WCAP-10965-P-A, September 1986. (Westinghouse Proprietary)