

REACTIVITY TRANSIENTS DURING A BLOWDOWN  
IN A MSIV CLOSURE ATWS\*H. S. Cheng and D. J. Diamond  
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INTRODUCTION

Anticipated Transients Without Scram, or ATWS events have received considerable attention in the past, and are still a subject of great interest in the severe accident analysis.<sup>1,2</sup> Of special interest is the effect of the low pressure Emergency Core Cooling Systems (ECCS) on the plant response following a blowdown by the Automatic Depressurization System (ADS). There is a potential for positive reactivity insertion due to the cold water injection of the Low Pressure Coolant Injection (LPCI) system and the Low Pressure Core Spray (LPCS) system in a BWR/4. The main concern is whether a power excursion and pressure oscillation can occur in such an event. Furthermore, since thermal-hydraulic feedback plays an important role in these accidents, the uncertainty of the reactivity feedback coefficients used can impact the outcome of the analysis for such a power excursion.

The objectives of the present work are to study the consequences of the reactivity transients during a blowdown in an ATWS event with closure of the Main Steam Isolation Valves (MSIV), and to evaluate the effect of the LPCI system and the sensitivity of plant response to the

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feedback coefficients.

The present work was performed with the BNL Plant Analyzer (BPA).<sup>3,4</sup> The BPA is a on-line, interactive BWR system code which models the non-homogeneous, non-equilibrium two-phase flow with a drift flux mixture model, the reactor kinetics with a point kinetic model, the thermal conduction with an integral method, and the control and plant protection systems with modern control theory. It also models the balance of plant (BOP) as well as the Mark I containment of a BWR/4. Thus, the BPA is a comprehensive engineering plant analyzer capable of simulating realistically both normal and abnormal plant transients as well as accidents (e.g., ATWS and Small Break Loss of Coolant Accidents).

#### TRANSIENT DESCRIPTION

For the present study, we selected a scenario of a 30-min ATWS event induced by the closure of all MSIVs, which after establishing a quasi-steady condition underwent a blowdown via manual ADS actuation, thus potentially bringing into play the LPCI system. In order to see the maximum effect of the reactivity transient, we further assumed the additional failures of both the backup Alternate Rod Insertion (ARI) feature and the Standby Liquid Control System (SLCS), so that the ATWS event has the potential to become a severe accident. Table I lists the sequence of events for the reactivity transient.

TABLE I  
Sequence of Events

<u>Event/Action</u>	<u>Time (s)</u>
1. Steady state at full power	0
2. MSIVs closed, scram failed	12
3. RPT occurred and SRVs lifted	17
4. ARI failed	47
5. Feedwater flow stopped	53
6. HPCI and RCIC started	78
7. SLCS failed	120
8. RHR cooling turned on, HPCI turned off	204
9. ADS activated	204
10. LPCI started the first time	360
11. LPCI was off	430
12. LPCI restarted the second time	660
13. LPCI was off	720
14. LPCI restarted the third time	936
15. LPCI was off	1008
16. LPCI restarted the fourth time	1236
17. LPCI was off	1296
18. LPCI restarted the fifth time	1515
19. LPCI was off	1590
20. ADS closed manually	1680
21. End of transient	1800

## SIMULATION RESULTS

The transient was initiated from the full-power and full-flow steady state conditions as summarized below:

o	Reactor Power	3320 MWt
o	Core Flow Rate	13429 kg/s (106.6 Mlb/hr)
o	System Pressure	6.99 MPa (1014 psia)
o	Steam Flow Rate	1661 kg/s (13.19 Mlb/hr)
o	Feedwater Flow Rate	1661 kg/s (13.19 Mlb/hr)
o	Recirculation Drive Flow Rate	4388 kg/s (34.83 Mlb/hr)
o	Recirculation Pump Speed	169.6 s <sup>-1</sup> (1620 rpm)
o	Downcomer Liquid Level	14.26 m (561.4 in)
o	Core Average Void Fraction	39.38 %
o	Core Average Fuel Temperature	680.7 °C (1257 °F)
o	Core Average Coolant Temperature	285.0 °C ( 545 °F)
o	Core Inlet Subcooling	11.1 °C ( 20 °F)

The key results of the present study are presented in Fig. 1. The first 3 minutes of the transient are characterized by a sharp pressurization due to the MSIV closure, followed by automatic SRV cycling as shown in Fig. 1. Thereafter, the blowdown by ADS rapidly depressurizes the reactor pressure vessel (RPV), which produces more steam due to flashing, thus reducing the reactor power. The depressurization also reduces the saturation temperature (hence the coolant temperature) and the fuel temperature (due to the power

reduction), thus producing positive reactivity insertions. When RPV pressure reaches the shutoff head (346 psia) of LPCI, the RPV is flooded with cold water, thus further contributing to the positive reactivity insertion. As a result, the reactor power increases rapidly, producing steam faster than it can be relieved by the ADS valves. The increased steam production increases RPV pressure above the LPCI shutoff head, terminating its injection. The pressure increases until the remaining SRVs are opened. The Doppler and moderator temperature feedback together with the termination of the LPCI injection terminates the power excursion.

As the reactor power starts to decrease, RPV pressure is relieved by the ADS valves. When RPV pressure drops below the LPCI shutoff head, it again begins cold water injection. The cycle of core flooding, power excursion, RPV pressurization, and pressure relief thus repeats itself as seen in Fig. 1. The power and pressure oscillations continue until the ADS valves are closed (by the operator in this case). From there on, the plant response returns to an oscillating condition due to automatic SRV cycling.

The pressure suppression pool (PSP) temperature steadily increases due to the continuous steam discharge through the ADS valves. It reaches the saturation temperature at the end of the transient. The minimum critical power ratio (MCPR) remains above unity throughout the reactivity transient, indicating no fuel failure.

## SUMMARY AND CONCLUSIONS

The BNL Plant Analyzer has been used to simulate a MSIV closure ATWS undergoing a blowdown via the ADS. In addition to the scram failure, both the ARI and SLCS systems were assumed to fail, making it possible to progress into a severe accident. Reactivity transients in such an event are important because of the potential for sustained power and pressure oscillations due to thermal-hydraulic feedback, enhanced by cold water injection from the LPCI system. Sensitivity studies were performed to the feedback coefficients and the ADS capacity used in the analysis. The following conclusions can be drawn:

1. A sustaining power and pressure oscillation can result from a blowdown via the ADS with or without the activation of the LPCI system in a BWR/4, thus threatening the fuel integrity. Either the SLCS or the ARI would be needed to terminate the reactivity transient.
2. All three thermal-hydraulic feedback (void, Doppler, and moderator temperature) can impact the outcome of such power and pressure oscillations, with the void feedback being the most important. A power oscillation can occur from the delicate balance of the three feedback mechanisms alone without the LPCI injection.
3. The cold water injection by the LPCI system enhances the power excursion and pressure oscillation because of the increased positive moderator temperature feedback and the reduced negative

void feedback.

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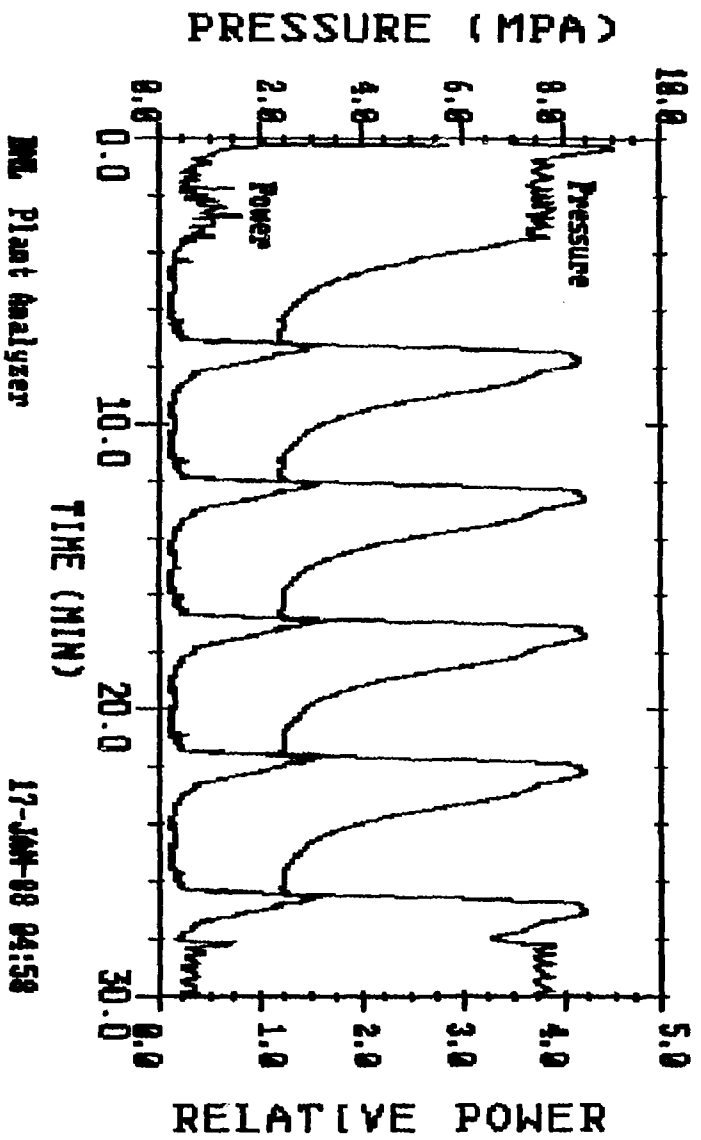


Figure 1. Pressure and Power Response of the Transient