AEOD SPECIAL REPORT

UNIT: LaSalle 2
DOCKET NO.: 50-374
LICENSEE: Commonwealth Edison

SPECIAL REPORT NO.: AEOD/S803
DATE: June 7, 1988
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SUBJECT: AEOD CONCERNS REGARDING THE POWER OSCILLATION EVENT AT LASALLE 2 (BWR-5)

EVENT DATE: March 9, 1988

SUMMARY

The LaSalle event involved power oscillations caused by neutron flux/thermal hydraulic instabilities of a magnitude that were not predicted by design analysis, unanticipated by the operators, and potentially in conflict with General Design Criterion (GDC) 12. Based on vendor analyses, two NRC Generic Issues (GIs) had previously been resolved concerning stability of BWRs; and this event raises questions regarding the adequacy of those resolutions.

Since analyses predicted that these oscillations would not occur, little guidance and training were provided for operator detection and response. Further, operation in unstable areas of the BWR power/flow map has potential adverse safety consequences. Because LaSalle 2's core was calculated to be more stable than the typical BWR core, other BWRs may be more susceptible to this problem.

In light of the present uncertainties, we recommend that BWR licensees should be required to implement procedures to:

a) Immediately insert control rods to below the 80% rod line following reduction or loss of recirculation flow or other transients which result in entry into potentially unstable regions of the power/flow map.

b) Increase recirculation flow during routine reactor startups and insert some control rods prior to reducing recirculation flow below 50% during shutdowns to avoid operation in potentially unstable areas of the power/flow map.

c) Immediately scram the reactor if a) or b) above are not successful in preventing and suppressing oscillations.

We also recommend that NRR revisit GIs B-19 and B-59 and ATWS mitigation in light of the LaSalle operating experience.

Description of the Event (Compiled from licensee's 50.72 report, March 9, 1988, and references 1 through 5).

While performing the functional test on a differential pressure switch, an instrument maintenance technician inadvertently valved in the variable and reference legs with the equalizing valve open, thereby connecting the variable and reference legs. This initiated a "pressure equalization" between the variable and reference legs, and resulted in a high "indicated" level to the feedwater level control system, causing the feedwater pumps to begin reducing flow. Realizing a valving error was made, the reference leg was immediately isolated from the variable leg. This resulted in a low "indicated" level spike. The level spike caused other level switches, utilizing the same reference leg, to also actuate, including the trip of the reactor recirculation pumps from an Anticipated Transient Without Scram (ATWS) signal.

Due to the rapid power reduction from 84% to approximately 40% caused by the trip of both recirculation pumps, feedwater heater high level alarms were received and heaters began automatically isolating. This resulted in reduced feedwater temperature and the insertion of positive reactivity due to the negative moderator temperature coefficient. With feedwater level control adequately handling the level transient, the licensee tried to re-establish feedwater heating and to restart the recirculation pumps. Attempts to restart the recirculation pumps were unsuccessful.

With the unit in a high control rod line condition (power was 85% prior to the event) and low flow condition (natural circulation), the unit started experiencing neutron flux oscillations from rapid creation and collapse of voids in the core region. Approximately 5 minutes into the event, multiple high and low alarms were recorded by the local power range monitors (LPRMs). The average power range monitors (APRM) recorders were oscillating between 25% and 50% of full power with an approximate 2 to 3-second period. Because of limitations of the APRM recorders, the actual neutron flux oscillations (approximately 75% power) were larger than the indications of the APRM recorders. The control room operators were in the process of manually scramming the unit, when an automatic scram occurred on upscale neutron trip (118% on APRMs). Immediately prior to the scram, the operators noticed that a majority of the LPRM Hi alarms were lit. The setpoint for the LPRM Hi alarms is 105% of full scale.

Foreign Operating Experience

A number of power oscillation events have been reported by the NEA IRS system. Power oscillations were reported in 1985 and 1986 at a foreign BWR-3 in IRS-677 and 681. The oscillations were 14% peak to peak during natural circulation testing. In June 1982 in IRS-220, a foreign BWR-4 reported oscillations of 75% of the "mean" flux during forced circulation after moving one control rod. The reactor tripped on APRM High Flux after five APRM half scrams had been reset. These power oscillations had a 2.5 second period. In response, operating limits were established at that facility to prevent operation in the area of instabilities. Another event (IRS-220.2) at this reactor in January, 1983, demonstrated that it is possible to start these power oscillations from normal operating conditions. IRS-363 reported that in October, 1983, during testing at the same reactor, divergent, out-of-phase oscillations were experienced. The report describing this event stated that this was "a potential GDC-12 violation." Again, operating restrictions were implemented that require rapidly maneuvering the reactor to a stable region following a single recirculation pump trip. Information received as followup to these events indicates that operating instructions were also developed for loss of feedwater heating events, loss of all recirculation flow, and low recirculation flow conditions. We have also received information that following startup testing at yet another foreign BWR, operating instructions were implemented to prevent routine entry into potentially unstable areas. In particular, guidance was developed to prevent routine entry into these areas during reactor startups and shutdowns, to require increased monitoring of APRMs and LPRMs in potentially unstable areas, and to provide guidance for operator response to certain transients such as loss of feedwater heaters and recirculation pump trips and restarts. In summary, these foreign plants have taken action to restrict or prohibit operation in areas of instability. Figure 1 is an example of operating restrictions during startup and shutdown in place at one foreign BWR.

U.S. Operating Experience

Other than LaSalle, no events involving diverging power oscillations at BWRs were identified in the SCSS operating experience data base. However, startup testing and other testing have included inducing power oscillations, observing the reactor response, and testing the effectiveness of oscillation suppression methods.

Review of the data base since 1980 did capture 167 events involving a trip of one or two recirculation pumps while the reactor was critical. Thus, when combined with routine startups and shutdowns, it is clear that BWRs are frequently operated in potentially unstable regions. The number of reported events is low since there are no reporting requirements for recirculation pump trips, unless it is in conjunction with some other reportable condition. Small power oscillations are similarly not reportable.

Related GDCs and GIs

The LaSalle event relates to two GDCs and two GIs:

"GENERAL DESIGN CRITERION 10 - Reactor Design. The reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences."

"GENERAL DESIGN CRITERION 12 - Suppression of Reactor Power Oscillations. The reactor core and associated coolant, control, and protection systems shall be designed to assure that power oscillations which can result in conditions exceeding specified acceptable fuel design limits are not possible or can be reliably and readily detected and suppressed."

GI B-19: "Thermal - Hydraulic Stability" and GI B-59: "(N-1) Loop Operation in BWRs and PWRs".

These GIs were closed out by the issuance of Generic Letters 86-02 and 86-09. Generic Letter 86-02 stated that the approved GE and Exxon methods for calculation of core stability decay ratio are uncertain by 20% and 25%, respectively, in predicting the onset of limit cycle oscillations (decay ratio = 1.0). The Generic Letter noted, "...BWR 4, 5, and 6s may not be able to show compliance with GDCs 10 and 12 solely using analysis procedures to prove that thermal hydraulic instabilities are prevented by design." However, the Generic Letter concluded that BWR 1, 2, and 3s should have sufficient margin. It also stated that for cores which do not meet the analytical criteria (decay ratio less than 0.8), the operating limits of GE SIL 380 would be sufficient to provide for detection and suppression of flux oscillations in operating regions of potential instability adequate to demonstrate compliance with GDC 10 and GDC 12 for cores loaded with approved fuel designs.

Generic Letter 86-09 noted that the review of BWR (N-1) loop operation was complicated by potential thermal-hydraulic instability and jet pump vibration problems during single loop operation. In low flow operating regions, it was necessary to develop special operating procedures to assure that GDCs 10 and 12 were satisfied in regard to thermal-hydraulic instabilities. Plant Technical Specifications consistent with these procedures were accepted by the staff for reactors which were not demonstrably stable based on analyses using the then approved analytical methods; details of the operating limitations were developed for GE SIL 380 and contributed to the resolution of GI B-19. In addition, tests at Brown's Ferry demonstrated that single loop operation had similar stability characteristics as two-loop operation under the same power/flow operating conditions. The tests confirmed the staff's finding that Technical Specifications based on GE SIL 380 which were proposed for some BWRs were appropriate for the detection and suppression of thermal hydraulic instabilities. The staff expected to approve single loop operation for licensees who submitted the appropriate ECCS analysis.

Relevant Licensing Actions

The foreign event involving out-of-phase, divergent oscillations, resulted in issuance of a board notification (No. 84-062) in March, 1984. Stability tests demonstrated that "limit cycle oscillations" could occur within permissable operating space below the rated rod line at natural circulation flow. The high power level (120%) scram protection which is based on APRM signals would not necessarily prevent violation of critical heat flux limits if such local instabilities were to occur. The test demonstrated that local thermal hydraulic oscillations which are out of phase with the APRMs could occur. It was unclear at that time (1984) how high a local oscillation could reach before detection by an operating crew using then current monitoring procedures.

This board notification was made after the issuance of GE SIL 380, which is currently used as guidance to operators for these type of events. Plant Technical Specification changes were made for plants undergoing licensing hearings to address the concerns of this board notification.

Previous Vendor Recommendations

General Electric Co., had previously identified in GE SIL 380 and other documents that the condition of high rod line and low flow was susceptible to neutron flux/thermal-hydraulic oscillations. However, based upon analysis, Commonwealth Edison did not believe such oscillations would occur at LaSalle, and as a result, the SIL was not implemented.

Because this event at LaSalle involved large power oscillations, General Electric Co. has issued Rapid Information Communication Services Information Letter (RICSIL) No. 006 Revision 1 pertaining to BWR core thermal hydraulic stability. The RICSIL supplements GE SIL No. 380 Revision 1 on the same subject.

Concerns Regarding This Event

1. Stability analysis methods are highly uncertain. LaSalle 2's calculated decay ratio was approximately 0.6 for this fuel cycle. This means that that the transient reactor behavior that was observed during this event was predicted not to occur. The licensee's review of this event stated that the conditions present at the start of the oscillations appear to be only slightly more severe than the assumptions used to analyze the LaSalle decay ratio. There is also information that indicates that the stability analysis for Vermont Yankee was shown by stability tests as non-conservative (Ref. 6).

2. LaSalle operators were not trained for this type of event. Because GE analyses predicted that this event would not occur at LaSalle, GE SIL 380 was knowingly not in place and operators not trained on GE SIL 380 at LaSalle, as allowed by Generic Letter 86-02.

3. GDC 12 may have been violated. Although chemistry samples following the LaSalle event did not disclose any fuel damage, the event was potentially a violation of GDC 12 in that undampened power oscillations occurred and no procedures or methods were implemented to reliably and readily detect and suppress these power oscillations.

4. Other BWRs may have a susceptibility to unstable power oscillations. Because analyses similar to the ones used at LaSalle are used at other plants to meet GDCs 10 and 12, this transient response could occur at other BWRs with decay ratios less than 0.8. Like LaSalle, these other BWRs may not have implemented procedures to reliably detect and suppress power oscillations. At LaSalle, the operators allowed nearly two minutes of unstable operation before deciding to take action to shut down the unit.

5. GE SIL 380 Revision 1, even if implemented, is inadequate to ensure compliance with GDC-12. This raises the issue of the adequacy of GL 86-02 in assuring that GDC-12 is met for plants with predicted decay ratios greater than 0.8. The SIL has a number of inadequacies:

   --APRM "noise" and not actual rapid power changes is discussed as a result of flow instabilities.

   --This noise is said to normally range between 4-12% (peak-to-peak) of rated power, whereas LaSalle reported power oscillations of nearly full scale (75% power).

   --Some of the terms are not defined or commonly understood by utility operations personnel, e.g. "limit cycle oscillation." This makes it difficult to use as the basis for operator guidance and procedures.

   --Power oscillations may not be readily identified and suppressed. During an event with numerous failures and alarms, it is not certain that operator attention will be promptly called to power oscillations, especially since the APRM instruments typically have large oscillations (noise up to 10% under normal 100% power steady state operation) and the APRM recorders do not show the full magnitude of power oscillations due to time delays. Operators might consider any indicated oscillations as normal.

--The basis for the proposed actions is apparently non-conservative or sensitive to small parameter changes.

--Guidance is provided without explaining in detail why the actions are taken or the bases for the actions. Even in the case where out-ot-phase oscillations were experienced, GE SIL 380 states that "very large margin to safety limits were maintained." This downplaying of the potential severity of thermal-hydraulic instabilities may mislead operators into thinking that the stability concerns are not important.

6. Operator training on recognizing and responding to power oscillations is poor. Few, if any, simulators used by utilities are capable of modeling the type of oscillations that occurred at LaSalle. Since the existing guidance in GE SIL 380 does not state that power oscillations from 0 to 120% power are possible and have been experienced, it is likely that very few licensed operators or training instructors were even aware that oscillation of this magnitude could occur. If operator action is necessary to ensure compliance with the GDCs, it is essential that licensed operators be trained regarding the assumptions, conditions, limitations, etc. of the operating concerns. However, simple guidance - such as: "reduction or loss of recirculation flow resulting in entry into a potentially unstable area, insert control rods to below the 80% rod line" - that ensures avoidance of the unstable or unanalyzed regions is preferable to reliance on operator memory to ensure operation within analyzed regions.

7. Improper operator actions could worsen the event. The operators at LaSalle tried to restart recirculation pumps because their training and procedures allowed them to do sc. In this event, with a downcomer filled with cold feedwater and an unstable reactor, a successful restart of recirculation pumps would lead to further rapid reactivity insertion with potential adverse consequences. We are also concerned about the effects that would have occurred if additional reactivity insertion due to void collapse in response to a turbine trip or an MSIV closure had occurred during the power oscillations. Other operator actions, plant conditions, such as end of cycle or different power distribution, or plant transients may have resulted in fuel damage.

Several calculations using the BWR Nuclear Plant Analyzer were performed by Brookhaven at AEOD request. The simulation of the LaSalle event is shown in Figures 2 through 5. By parametrically increasing loop flow resistances, it was possible to generate power oscillations similar to those experienced at LaSalle. Preliminary results from these runs indicate that large reactivity changes occur during these events. The power oscillations experienced at LaSalle are cyclic interactions of core void formation, flow, and neutron power. The period of the oscillations is about 2.5 seconds while the thermal time constant of the fuel is 5 to 7 seconds; and consequently, direct gamma heating of the coolant is the likely energy feedback mechanism. This phenomena apparently begins with thermal-hydraulic instabilities arising due to relatively large two-phase resistance in the core, while the driving head and flow rate are low due to loss of forced circulation. Formation of voids then drives neutron power down which slows further void formation, resulting in lower two-phase flow resistance, and increased natural circulation flow into the bottom of the core. This cold water increases core reactivity and results in a power increase. The resultant void formation continues the cycle of oscillation. Large neutron power oscillations are the result of large reactivity changes.

Preliminary results from the Brookhaven analyzer indicate that large reactivity changes occur during these events. Figure 4, for example, represents the LaSalle base case, where the analyzer calculated 0.5 dollars total reactivity inserted just prior to the reactor trip.

8. The LaSalle event is an important precursor event. Although the consequences of this particular event were not serious, they could have been worse in other circumstances. First of all, the potential exists for localized power oscillations where one half of the core oscillates 180 degrees out of phase with the other half; and in that case the APRM trip would not trip the reactor until the amplitude of the local power oscillations was much greater. An actual event of this type is noted in the foreign operating experience. Secondly, the potential exists for operator action or plant equipment failure to worsen the event, for example, restart of a recirculation pump or MSIV closure could result in additional reactivity insertion.

9. Previous efforts taken in regard to ATWS mitigation may be inadequate. The action of tripping recirculation pumps automatically and inducing an event similar to the LaSalle event when it is not clear where the power oscillations would stop and what the effects of these oscillations would be in the absence of an automatic scram, necessitates that ATWS mitigation be reviewed in light of this event.

10. The resolution of GIs B-19 and B-59 may be inadequate. The analyses which form the technical bases for the resolution of these issues have been challenged. The LaSalle event was predicted by analyses to be prevented by design, but it occurred.

Potential Actions to Address the Problem

1. We recommend that BWR licensees should be required to develop and implement procedures to:

a) Immediately insert control rods to below the 80% rod line following reduction or loss of recirculation flow or other transients which result in entry into potentially unstable regions of the power/flow map.

b) Increase recirculation flow during routine reactor startups and insert some control rods prior to reducing recirculation flow below 50% during shutdowns to avoid operation in potentially unstable areas of the power/flow map.

c) Immediately scram the reactor if a) or b) above are not successful in preventing and suppressing oscillations.

2. We also recommend that NRR revisit GIs B-19 and B-59 and ATWS mitigation in light of the LaSalle operating experience.

REFERENCES

1. Commonwealth Edison Company, LER 88-003, Docket No. 50-374, dated April 7, 1988.

2. PNO-III-88-18, dated March 10, 1988.

3. PNO-III-88-18A, dated March 17, 1988.

4. PNO-III-88-18B, dated March 25, 1988.

5. NRR Event Followup Report 88-03, dated March 30, 1988. (Not available in PDR)

6. Memorandum from L.E. Phillips (NRC) to M.A. Ring (NRC), dated April 7, 1988. (Not available in PDR)

Figure 1

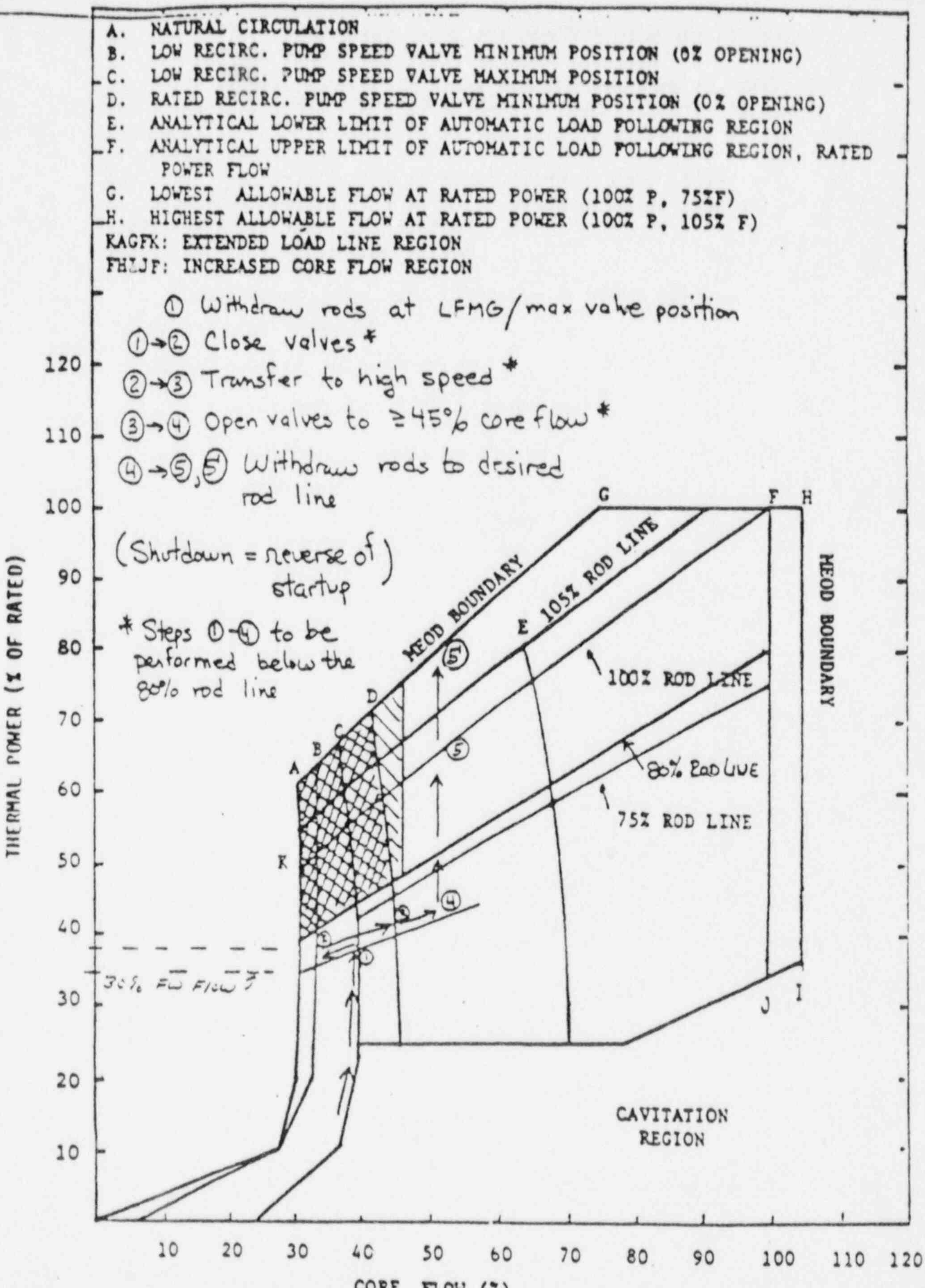

Figure 1. Example of Methods to Avoid Unstable Regions

MAXIMUM EXTENDED OPERATING DOMAIN POWER/FLOW MAP

LASALLE BASE CASE

Figure 2

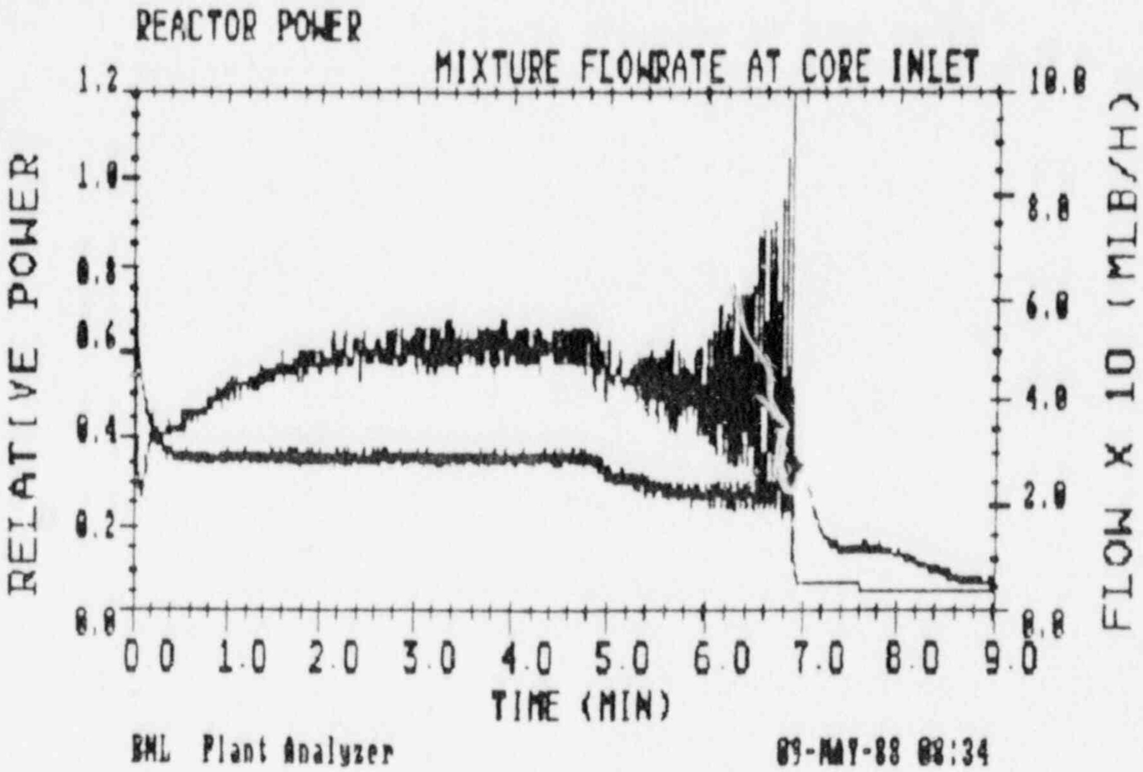

Figure 3

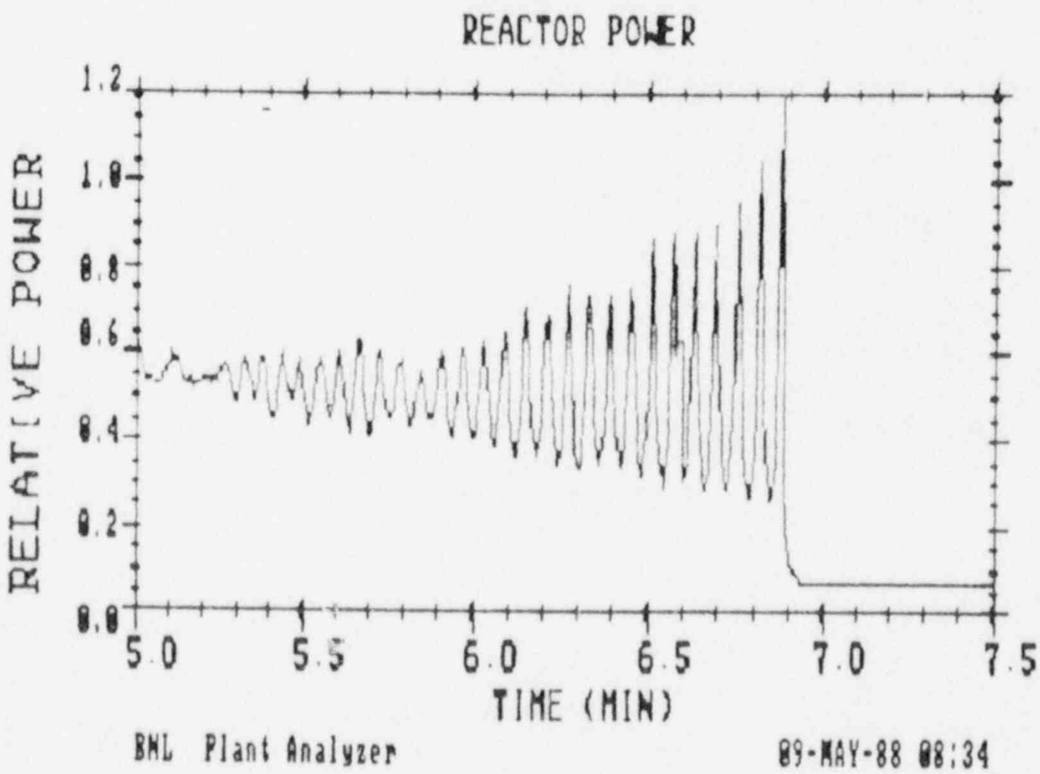

Figure 4

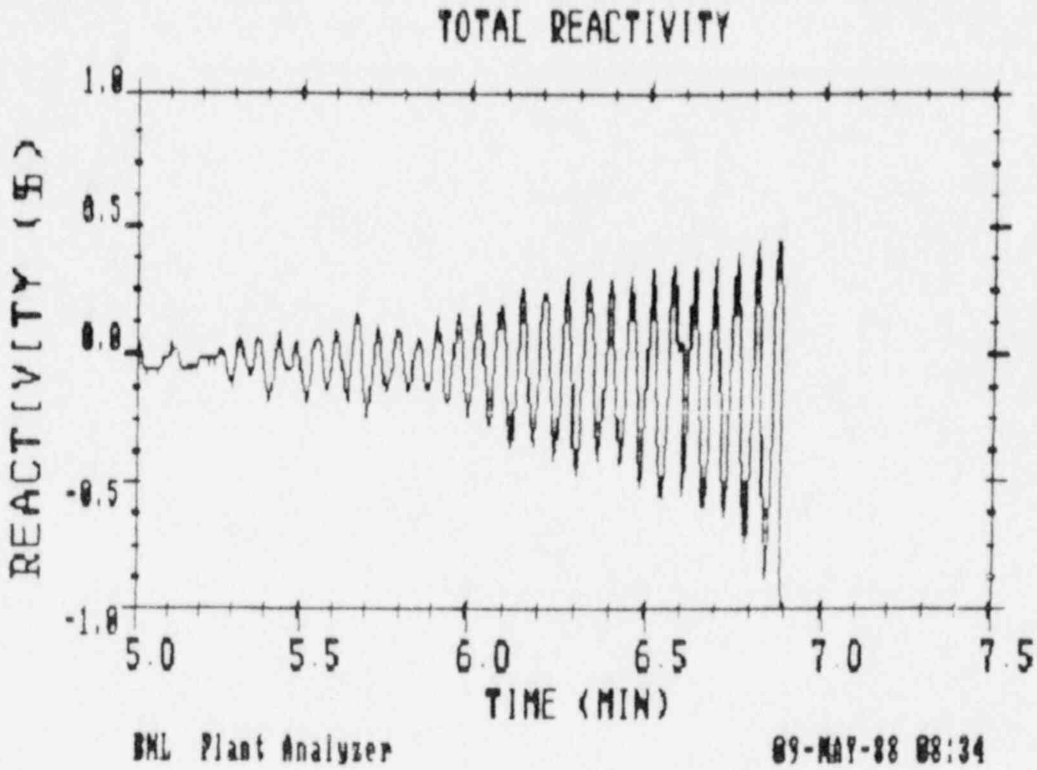

Figure 5