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Docket No. 50-335

Dr. Robert E. Uhrig
Vice President
Advanced Systems & Technology
Florida Power & Light Company
P. O. Box 529100
Miami, Florida 33152

Dear Dr. Uhrig:

During our review of your proposal to operate St. Lucie Unit 1 at 2700 Mwt, we requested and received (L-81-477 dated November 13, 1981) your commitment to install start up flux channel alarms for the detection of boron dilution events by the next (Cycle 6) refueling outage. Our review of this issue was documented in section D.7.1.1 of the Safety Evaluation accompanying our approval to operate St. Lucie Unit 1 at 2700 Mwt (Amendment No. 48 issued November 23, 1981).

At that time we indicated that we were evaluating the capability of operating PWRs to provide adequate protection against uncontrolled boron dilution events. That evaluation has proceeded to the point where we no longer require that licensed operating reactors install the subject alarms. Our basis for this revised position is contained in Enclosure 1.

Therefore we no longer require that you install the alarms as committed to in your letter of November 13, 1981. Further evaluation of this issue or future events at nuclear power plants could affect this position; however, we do not expect any evaluations we have planned to restore the requirement for alarms at St. Lucie Unit 1. In light of the above you are requested to inform us, in writing and by May 28, 1982 of your intent with respect to installation of the subject alarms.

Sincerely,

Original signed by
Robert A. Clark

Robert A. Clark, Chief
Operating Reactors Branch #3
Division of Licensing

Enclosure: As stated

cc: See next page

4/22/82

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DATE	4/ /82	4/ /82	4/ /82	4/23/82		

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ENCLOSURE

INADVERTENT BORON DILUTION

1. Introduction and background

Boron dilution events are routinely analysed in every PWR's FSAR.[1] The analyses cover two rather different circumstances: Inadvertent boron dilution with the reactor at power and inadvertent boron dilution with the reactor subcritical (i.e, while in shutdown or refueling modes). It is the latter that has been questioned.[2]

There have been 25 reported instances of inadvertent boron dilution during maintenance and refueling.[2] Although none has yet occurred, the safety concern is the possibility of an inadvertent criticality. If the boron is sufficiently diluted and the reactor core is near beginning of cycle, it is possible to bring the reactor to criticality with all of the control rods inserted into the core. The only way to shut the core down again in such a circumstance would be to re-borate the moderator, which could take considerable time.

The events have occurred with sufficient frequency to raise the question whether, considering their possible consequences, the degree of protection is appropriate. Several branches have engaged in a dialogue on this matter.[2,3,4]

2. Safety significance

2.1 Estimated frequency of inadvertent criticality.

Boron dilution events during a shutdown or refueling have usually been caused either by human error or by failures of special, non-process equipment such as inflatable seals. Therefore, event frequencies cannot be easily calculated by fault tree analysis. Moreover, because no event has yet resulted in criticality, it is not possible to simply add up the number of events in operating history.

The fact that no inadvertent criticalities have happened in 337 PWR-years allows us to estimate an upper bound to the frequency. By assuming a Poisson distribution and using the conventional 95% confidence level, it is straightforward to demonstrate that the frequency of inadvertent criticalities is, at most, 9×10^{-3} events per PWR-year.

However, an upper limit is not sufficient to gauge the significance of boron dilution events; a "best estimate" (in some sense) is needed. The only information available is contained in the frequency of boron dilution events which have happened but which did not result in criticality. Most of these events can be considered "precursor" events to an actual inadvertent criticality.

The severity of a precursor event is defined here in terms of the shutdown margin remaining at the end of the event. That is, an event which was halted with 2% shutdown remaining is considered more severe than event which was halted with 10% remaining shutdown margin.

In the figure attached, we have plotted the number of events of a given severity vs. the severity using the information in the ORNL/NSIC report.[5] Final shutdown margins were calculated from final boron concentrations (where available) using "typical" values of boron worth taken from RESAR and from the Midland SAR. Initial boron concentrations were used to estimate the point in the fuel cycle when the event occurred.

It was assumed that all control rods were inserted for events which occurred during shutdown mode (vessel head in place). However, we assumed that one rod was removed for events which took place during refueling--which is, of course, a realistic assumption for fuel handling operations.

Not suprisingly, the number of events goes down as the severity classification increases. To estimate an expectation value for the number of critical events, a two-parameter exponential distribution was fitted to the data. Extrapolation of this distribution to the point of zero shutdown margin gives a value of 0.67 events in a time interval of (currently) 337 PWR-years. Thus, we expect the frequency of inadvertent criticalities to be on the order of 2×10^{-3} events per PWR-year.

This calculation, although rough, gives an answer that is reasonable. With 46 PWRs presently operating, we would expect an inadvertent criticality roughly every 11 years, if nothing were done.

However, this number does not take into account the effect of the neutron monitoring instrumentation. As a reactor core approaches criticality, neutron flux does not rise linearly. Instead, the reciprocal of the flux drops linearly as shutdown margin decreases. The net effect is that neutron flux rises slowly as the reactor core goes from 10% to 9% shutdown, but rises very dramatically as shutdown margin drops below 0.5%. None of the events tabulated in Reference 5 came close enough to criticality for the neutron monitoring channels to trigger alarms. Thus, to realistically estimate the frequency of an event that continues in dilution to criticality, we must give some credit for the neutron flux channel alarms, which are usually set one half to one decade above background.

Since the control rods are already fully inserted into the core in this event, the only actions which will prevent criticality are stopping the dilution or reborating the moderator. Both are done by the operator. Thus, the credit to be given for neutron flux alarms is governed by the reliance which can be placed on the operator. We will assume (based purely on judgment) that the operator will be able to correctly diagnose the problem and successfully prevent criticality 90 percent of the time. This drops the frequency of a criticality by one order of magnitude, to 2×10^{-4} events per PWR-year.

2.2 Consequences of an inadvertent criticality

An inadvertent criticality event, whatever its implications concerning plant operations and procedures, is not hazardous because of the fact of criticality. In actual fact, the achievement of criticality is a rather subtle and unspectacular event. If the event were terminated by scram (as has actually happened in BWRs), there would be no significant safety hazard associated with the event at all.

In the PWR case under consideration here, all rods are either already in the core or are disconnected from their drives. Either way, there is no scram reactivity available. Shutdown by emergency boration will take much more time than shutdown via scram. The important parameter is the peak power level achieved by the core.

Once the core becomes critical, it will heat up with a positive period governed by the rate of dilution and by moderator temperature and Doppler feedback. Eventually the coolant may boil and the peak power level will be limited by void generation in the moderator. Preliminary calculations indicate that, assuming BOC parameters (worst case), a power level of about 3% of rated would be reached.(6) (These calculations are limited in their ability to model the multidimensional aspects of void feedback.)

Two aspects of safety significance result from such an event. First, the neutrons and fission gammas (and possible airborne activity from any leaking fuel pins) are a hazard to workers in the vicinity of the reactor. Second, should reactor thermal power become high enough to fail fuel, there is a possibility that activity will be released to the environment, especially if the event occurred when the reactor vessel head was removed.

We have not yet been able to quantify the hazard to workers in containment. However, it is doubtful that the hazard is serious since evacuation alarms connected to the source range excore neutron flux monitors will in most cases give workers warning before conditions become hazardous. Moreover, the water and shielding located around the core are probably enough to shield workers from neutrons and gammas with a core power of on the order of 3% of rated.

Similarly, a core power of 3% of rated is not likely to fail fuel that must withstand decay heat rates of this same order. The only likely consequence is the release of gap activity from any leaks already present. If we make the standard assumption of users of the GALE codes that 0.16% of the fuel leaks, the total activity released to the coolant would be roughly 69,000 ci. This is not enough activity to be significant unless the vessel head is removed. (In Reference 5, one sixth of the cold shutdown/refueling events took place in the refueling mode, and thus presumably took place with the vessel head removed.) If the vessel head were not in place, about 10%

of this activity, or 6900 ci, would escape from containment, based on analyses of dropped fuel assembly events.

3. Possible fixes

Since these events are caused by a wide spectrum of causes, it is not practical to reduce the frequency of boron dilution events other than by bringing the matter to the attention of plant operations personnel and having them upgrade their procedures (if and where appropriate). It has been proposed to install a microprocessor-based monitor on the source range neutron flux instrumentation. Such a monitor, if connected to a display panel such as the Safety Parameter Display System (SPDS), could give earlier warning of loss of shutdown margin than is possible with the present instrumentation, and thus would reduce the probability of a boron dilution event leading to criticality.

We have evaluated the cost of such a system.[7] The results are:

control grade instrument, alarm only ....$50,000.

safety grade instrument, alarm plus automatic initiation of emergency boration $300,000

4. Priority score

With these numbers in hand, it is relatively straightforward to estimate a priority score for this issue. (see Reference 8 for a description of the basis and significance of these scores.)

Frequency:

We expect inadvertent criticalities to occur at a rate of 2×10^{-4} events per PWR-year. Of these, roughly one sixth will take place with the vessel head removed. Thus, the frequency of radioactivity-releasing events is 3×10^{-5}/PWR-Y.

The upper limit (95% confidence) on inadvertent criticality frequency without credit for neutron flux alarms was a factor of 5 over the "best" estimate. If we assume a symmetrical distribution and also assume a factor of 5 error in the credit for the neutron flux alarms and a factor of 3 error in the chance of the head being off the vessel, the estimated error in the frequency of radioactive release is plus or minus a factor of 8.

Consequences:

The release is expected to be on the order of 6900 curies, primarily noble gases. We will use an estimated error of a factor of 5, again based on judgment.

Costs:

We have estimated a cost of $50,000 per plant for the cheapest hardware fix. Roughly one half of this figure represents the cost of paperwork,(7) and is thus relatively insensitive to the exact nature of the fix. The cost to the NRC is estimated to be two staff months plus one staff week for each of 46 operating PWRs. This corresponds to an NRC cost of $84,000. The uncertainty in the costs, which are dominated by the $50,000 per plant, is at most a factor of two.

Score:

Using the numbers above, the results are:

Score	Range
4×10^{0} Ci/Y/10^{6}\$	4×10^{-1} to 4×10^{1}

These scores are in the low priority range when compared to other issues competing for NRR's attention.

5. Withdrawn but trippable control rods

The issue of withdrawn but trippable control rods has also been raised in connection with boron dilution events.(9) The essence of the issue is that the definition of shutdown margin in the Standard Technical Specifications allows a plant to take credit for control rods which are not actually inserted in the core, provided they are trippable. In such a case, if a boron dilution event were to occur with the plant in shutdown or refueling modes, the absence of one or more control rods would allow criticality to occur sooner than assumed in the analyses described in Section 1 above.

This issue is somewhat peripheral to the basic issue of inadvertent boron dilution. Nevertheless, several comments can be made:

First, the issue is not very realistic. It is physically impossible to remove a control rod but still have it trippable when the head is removed. When the vessel head is in place, it does not appear likely that significant consequences will arise from an inadvertent criticality, even if the missing rod were not trippable.

Second, the fact that the withdrawn rods <u>are</u> trippable means that the reactor will be scrammed by the neutron flux channels before the power level could become significant. (This is true even if the highest-worth rod sticks.) The analagous event has actually happened in BWRs, with no safety consequences.

Third, the Standard Review Plan[1] calls for refueling mode analysis which assume all rods are removed from the core. Thus, the validity of analyses which conform to SRP 15.4.6 is not altered by withdrawn rods, at least during refueling mode.

Fourth, the concept of having some negative reactivity "cocked" and ready to shut the reactor down is not necessarily a bad one. We have allowed LACBWR to do this during core alterations, for example. The reason for this is that shutdown margin is not easy to measure directly even with sophisticated laboratory-type equipment such as pulsed neutron sources. (Note that a microprocessor was necessary to give early warning in ghe hardware fixes described in Section 3.) Having negative reactivity ready to insert rapidly allows one to terminate an inadvertent criticality early in the event, allowing time for worker evacuation, event diagnosis and, if necessary, emergency boration. This "cocked rod" concept, although virtually never used during PWR core alterations, is in effect what is done during certain physics startup tests.

Therefore, we conclude that there is no basis for not allowing credit for withdrawn but trippable rods.

6. Conclusions and Recommendations

6.1 Occurrence of non-severe boron dilution events

25 boron dilution events in 337 PWR-years, coupled with the fact that 46 PWRs are now operating, imply that we must expect a boron dilution event every three months or so. This is not a cause for concern, since the likelihood of the dilution resulting in criticality is very low. The real significance of the event is its implications regarding the plant's procedures during shutdown and refueling.

6.2 Occurrence of inadvertent criticality

An estimated frequency of 2×10^{-4} (one event every 5000 PWR-years) is not high enough to justify emergency action. Even with 100 PWRs operating, events would occur only every 50 years or so.

Nevertheless, the frequency is high enough that an inadvertent criticality would be predicted to take place before the last PWR now in the CP stage is decommissioned.

6.3 Significance for reload reviews

Based on the low estimated frequency and low estimated consequences of an inadvertent criticality, we conclude that boron dilution events do not constitute a significant risk to the public. The licensing process need not wait while this matter is resolved. Reference 10 discusses the legal and procedural aspects of such situations.

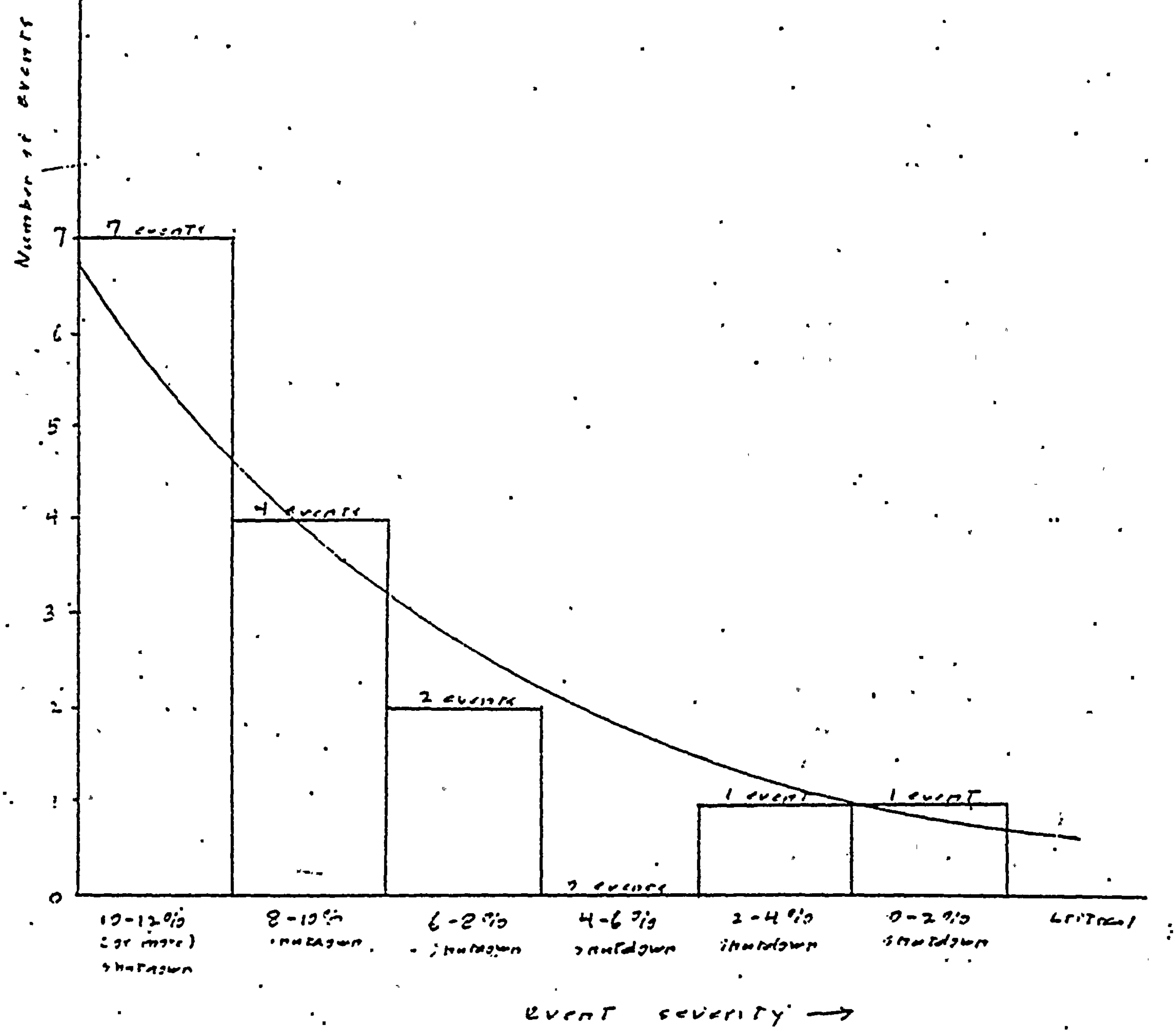
7. Future work

The future work discussed here is not intended to imply that the conclusions reached in Section 6 above will change. Instead, it is intended to confirm some figures and bring the task to completion.

The only outstanding issue is the significance of an inadvertent criticality to workers within containment. This is being investigated by AEB. Even though the hazard is expected to be small a confirming calculation should be completed. When this is done, RSB and PTRB should prepare needed revisions to SRP 15.4.6.

Severity of Boron Dilution Events

Number of events vs. [12% - SDM]



References:

1. Standard Reveiw Plan, NUREG-0800, Section 15.4.6, issued July 31, 1981.
2. Memo, R. J. Mattson to T. E. Murley, dated September 15, 1981.
3. Memo, R. A. Clark to T. P. Speis, dated October 6, 1981.
4. Memo, R. J. Mattson to D. G. Eisenhut, dated October 23, 1981.
5. E. W. Hasen, "Evaluation of Events Involving Unplanned Boron Dilutions in Nuclear Power Plants," prepared under contract W-7405-emg-26 (NRC FIN B0755), in press.
6. Letter, N. S. DeMuth (Los Alamos National Laboratory) to R. T. Curtis (NRC, dated November 18, 1981.
7. Final Report, "Determination of the Cost of Modifications Needed to Mitigate Boron Dilution Events in PWRs during Cold Shutdown, "DOE Work Order 20-81-297 (NRC FIN A6452) dated December 14, 1981.
8. Enclosure 3 of "Plan for Early Resolution of Safety Issues," SECY-81-513, dated August 25, 1981.
9. Memo, R. J. Mattson to S. H. Hanauer, dated January 26, 1982.
10. Note, S. F. Scimto to W. Butler, dated March 10, 1977.