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Reportable Occurrence for the Penn State Breazeale Reactor
Supplement to Letter Dated July 7, 1995
License Number R-2, Docket Number 50-05

Dear Sir or Madame:

On July 7, 1995, we reported an occurrence concerning control rod reactivity worth measurements. At the time the 14 day report was due the root cause of the problem had not been identified but alternative assurances were provided to justify the return to power. We have since determined the root causes and taken corrective action as described below. This updated report is divided into the following sections:

1.0 <u>Sequence of Events</u>

The chronology of relevant events is as follows:

5/10/93 - All control rods were calibrated during the normal annual surveillance measurements. Total control rod worth was measured to be $11.46.

6/94 - The reactor was taken out of service for major bridge modifications and fuel inspection. During the outage the three fuel follower control rods (FFCRs) were replaced with new FFCRs. Two fuel elements that did not meet dimensional tolerances were replaced.

7/5/94 - The control rods were calibrated and found to have a total worth of $10.90. Eight more fuel elements were subsequently added to the periphery because a higher excess reactivity was desired.

7/6/94 - The control rods were again calibrated and found to have a total worth of $11.76 and an excess reactivity of $5.84. (Review of this data in 1995 revealed a calculational error which, when corrected, would have indicated a total rod worth of $12.25 and an excess reactivity of $6.03.)

6/14/95 - Data was taken for the annual control rod calibration. The data processing which was completed later in the week showed a total rod worth of $13.75 (a perceived increase of nearly $2) and an excess reactivity of $6.66. These values were suspected to be in error because they were inconsistent with previous experience.

6/19/95 - The rod calibration procedure was repeated. After data was processed it was found that the total rod worth was $13.74 with excess reactivity of $6.64, essentially the same as that measured the previous week.

6/19/95- 6/28/95 - This time interval was consumed with data reanalysis, rod worth measurements using alternate detectors to verify data acquisition instrumentation for the 1995 measurements, additional rod worth measurements with core configurations like those existing in 1994, and discussions with the FFCR vendor of possible design changes or manufacturing errors. The annual power calibration and other operations were interspersed with the rod calibration investigation.

6/23/95 - The evaluation of data available on this date suggested that the 1995 measurements were correct and that the problem was with the 1994 data. This constituted an unanticipated change in reactivity of greater than one dollar which is a reportable occurrence. The situation was discussed by telephone with the NRC and followed by facsimile the next morning. Normal operation was voluntarily suspended; only operation in support of explaining the reactivity discrepancy was performed until the 6/29/95 safeguards committee review. A subsequent analysis also showed that the core excess reactivity at some point during the previous year when operating against the D_20 tank may have been as high as $7.06, exceeding the Tech Spec limit of $7.00. (The core excess reactivity is one of several parameters that are assumed to be at their Tech Spec limits during an analyzed hypothetical accident. Exceeding the limit by $0.06 had no operational impact since other parameters effecting the analysis were far from their limits, the deviation was very small, and the accident did not occur.)

6/29/95 - The safeguards committee met to review the situation and found that while appropriate action had been taken to return to normal operation, the following actions were recommended:

- Assess the adequacy of the second level review of data reduction and analysis processes,
- Benchmark incremental rod worth measurements to an independent measurement system,
- Measure total rod worth by the rod drop approximation method as part of the rod calibration procedure,
- Statistically evaluate the 1994 data in search of the root cause of the error, and
- Confirm the boron content with the FFCR vendor.

The NRC was informed by telephone the following morning and normal operation resumed.

7/5/95 - The FFCR manufacturer confirmed that the boron loading of the three replacement FFCRs was approximately four times the content of the original FFCRs.

2.0 Root Causes and Corrective Action

Three primary causes of the incident have been identified and are discussed below with the corrective action for each. They are:

- Inadequate operator training and procedural detail
- Inadequate second level review
- Lack of information on core components

In the review additional related issues were identified that are discussed in the subsequent section of this report.

2.1 Inadequate Operator Training and Procedural Detail

After a detailed review of the 1994 data and confirmatory experiments, it was found that insufficient time was allowed for delayed neutrons to equilibrate between rod bump measurements. Training in reactor theory discusses delayed neutron dynamics and the rod calibration procedure calls for the reactor power to be level before initiating a rod bump, but the two issues were not linked in a positive manner to make the operators adequately aware of the implications.

The control rod calibration technique using the rod bump method consists of the following:

- Establish criticality at a low power level (approximately 5 watts).
- Remove a control rod an increment equivalent to approximately 20 cents of reactivity.
- When a stable period is achieved, measure power vs. time, taking numerous data sets to accurately determine the period. Convert the period to reactivity over that increment of rod movement using the Inhour Equation.

- Before reaching the heatup range (approximately 1 kW), terminate data collection and re-establish criticality at low power.
- Repeat this procedure for successive increments of the control rod until the entire rod is calibrated. It is important that the rod bump be initiated with the reactor exactly critical and delayed neutrons at equilibrium. Careful analysis of the data showed scatter in differential rod worth data that was not obvious in the integral worth data. The individual data points showing the greatest scatter were generally recorded very quickly after the preceding rod bump. Delayed neutron effects were suspected as the cause.

A special experiment was designed and performed to measure the error that can result from allowing insufficient time for delayed neutrons to equilibrate between rod bumps. The reactor was placed on successive excursions by the insertion of approximately 20 cents of reactivity. Each transient was terminated at 1 kW and power was returned to 5 watts as quickly as possible. The time between successive rod bumps was reduced from 15 minutes to less than 5 minutes. Control rod movement to maintain constant power during the 15 minute wait time was carefully analyzed. It showed that control rods reached an equilibrium position after 10 minutes. The deviation from equilibrium (due to delayed neutrons) was measured to be 3 cents at 6 minutes, 6 cents at 5 minutes, and 17 cents at 4 minutes. As wait times between rod bumps decreased, the difference between the actual reactivity insertion and the measured insertion matched the deviation measured with the 15 minute wait time experiment.

The same basic procedure for control rod calibration has been in effect for the forty years of operation of the Breazeale Reactor. During the 1994 calibration a cadence was established which reduced power and established apparent equilibrium power in a very short time following a rod bump, providing rapid data acquisition. While the operator believed that the reactor had achieved equilibrium, replication of the data suggests that it was actually slightly subcritical at the time some rod bumps were initiated. The net (measured) reactivity is then the true reactivity for that increment minus the amount the reactor is subcritical. The systematically low differential worths, when totaled for each increment, result in a low integral rod worth. While our training program covers delayed neutron dynamics, the dramatic impact on rod calibration measurements had not been identified previously. As a result, the significance of being critical with the delayed neutron population in equilibrium was not reinforced sufficiently in training and in the rod calibration procedure.

The following corrective action has been done. First, discussion of this incident with reactor operators has made them aware of the importance of ensuring that the reactor is critical when making rod worth measurements. Second, the procedure for control rod calibration has been modified, adding a note to instruct the operator that delayed neutrons can effect the reactivity measurement, stressing the need to ensure that the reactor is critical when the measurement begins. Third, the training program is being systematically evaluated in search of ways to improve its overall effectiveness.

2.2 Inadequate Second Level Review

In retrospect, it is obvious that the 1994 data was of poor quality and should have been rejected both at the data reduction stage and at the second level review. Steps have been taken to improve both of these areas.

The data reduction process has been enhanced by techniques identified in the post-incident investigation. Following a rod bump the power should be an exponential function of time. The correlation factor of a linear least squares fit of the semi-log power versus time data accurately characterizes the quality of the data for the individual rod bumps. In a similar manner, the differential rod worth data can be fit to a sine or polynomial function; the correlation factor of such a curve fit again characterizes the quality of the data. Had such a test been applied to the 1994 rod calibration data the differential worth curve data would have been rejected. Likewise, individual differential rod worth data points would have been rejected if errors of significance had occurred in entering the log power versus time data.

While a routine independent review of the results from the rod calibration procedure was performed in 1994, the review was superficial. The concept of second level review, its importance, and a need to strengthen our process of independent review have been discussed within the staff. As a result, our procedures have been reviewed and modified to more clearly define the appropriate level of independent review and the scope of review for the various aspects of operations.

Beforê identifying the root cause of the incident, we proposed to verify rod worth measurements using alternate, independent measuring instruments and methods. Having identified the cause and taking the above corrective actions, we believe the more effective assurance of quality data is to perform the correlation tests discussed in the previous paragraph and subject these results to a second level review. The use of alternate measurement instruments and methods (other than the rod drop method) in the case of not waiting for delayed neutron equilibrium would not have indicated an error. The rod drop method would have indicated the error since the change was so great but except for control rod changes the expected change in rod worth is not large enough to yield significant results. We therefore intend to terminate our internal requirement to gather rod calibration data using alternate measurement instruments and methods.

2.3 Lack of Information on Core Components

Fuel elements for university reactors are procured and owned by the U. S. Department of Energy. There has historically been a single supplier for TRIGA fuel which maintains records of the type of fuel used by each reactor owner. The procurement process has been to request from the Department of Energy the type of fuel needed in rather general terms and for the vendor to provide the replacement item. The three FFCRs which were replaced in 1994 had been in the reactor since its initial criticality in 1965. The original FFCR design contained B_4C in a graphite powder matrix. In about 1970 a design change called for B_4C slugs without the graphite powder, increasing the boron content by a factor of four. The increased boron density was the reason for the increased reactivity worth. Had we known of the higher boron loading we would have expected higher control rod worths in 1994, rather than accepting those that were similar to the past measurements. Likewise, we would not have questioned the worths we found in 1995. However, we were not notified of the change in design until after measuring the unexplained higher rod worth in 1995 and bringing this to the attention of the vendor.

We have reported this incident to the Department of Energy and asked that their procurement practices be reviewed such that we are informed of design changes and receive certification of the design of fuel elements they provide. (Reference letter from M. H. Voth of Penn State to E. Tourigny of USDOE dated July 15, 1995, with the July 7, 1995, incident report to the USNRC attached.) Corrective action in this area is in progress at the Department of Energy.

3.0 Related Issues

3.1 Pulses with Greater Reactivity Insertion than Planned

Between August 3, 1994, and June 22, 1995, there were a total of 121 pulses performed with incorrect rod worth data used to predict pulse worth. The distribution was as follows:

Number	Desired Worth($)	Actual Worth($)
20	2.50	3.00
13	2.25	2.65
37	2.00	2.30
2	1.85	2.10
9	1.75	2.00
40	<1.75	<2.00

The Technical Specification limit of $3.70 (worth of a pulse, movable experiments, and movable parts of secured experiments) was never exceeded. Our operating philosophy has been to restrict large pulses to those experiments where there is a sound technical justification for doing so, recognizing that each pulse adds incrementally to the lifetime duty factor of the fuel. In this respect the duty factor and stresses on the fuel were somewhat greater than expected due to the higher than specified reactivity insertion but within regulatory limits.

3.2 Effect of the New Control Console

The reactor control and safety system was replaced in 1991 with a digital based control system and hardwired analog scram system. An immediate question was whether the erroneous 1994 data was influenced by the new system. The rods were properly calibrated using the new system in 1992, 1993, and 1995 with no indication of an inherent system deficiency. However, two observations were made. First, since the new control system maintains power so well in the three-rod-auto mode, operators have minimal experience leveling power manually as is done in the rod calibration procedure. Second, the new system gives the operator numerous options in how data is displayed. Displaying the power data with high resolution makes it difficult to see whether the trace is exactly constant with time or if there is a slight slope indicating that the reactor is not exactly critical at the start of a rod bump measurement. Likewise, the high speed data acquisition option results in only a short time increment displayed on the operator's control screen, again making it difficult to detect that the core is not exactly critical. Operators have been instructed on the importance of being exactly critical and at delayed neutron equilibrium at the beginning of a rod bump and selecting display screen options that confirm critical conditions exist. Operating procedures also stress the requirement for being exactly critical and at delayed neutron equilibrium before acquiring rod worth data.

3.3 Human Performance Factors

In this incident a number of human performance factors were involved which should be considered in all aspects of operational activities. In staff meetings the following issues were discussed:

- Greater sharing of operating experience between long term and newly licensed operators
- Judicious use of observations from the past versus over reliance of past observations to the exclusion of new information
- Maintaining a safety culture where safety takes precedence over time pressure to meet schedules
- Maintaining an inquisitive attitude to identify, investigate, and resolve unusual observations

3.4 Dissemination of Lessons Learned

In addition to disseminating the information about this incident and the lessons learned to our staff, there are lessons to be shared with similar facilities subject to the same situation experienced here. To this end, the initial incident report to the Commission has been reproduced in the TRTR Newsletter. A presentation will be made in November 1995 at the annual TRTR conference to share this updated report and allow dialog concerning the incident.

4.0 <u>Conclusion</u>

In our July 7, 1995, report we concluded that we fully understood the reactivity worth of the new FFCRs and their relationship to the old FFCRs. We had not identified the root cause and taken corrective action, resulting in additional measures to provide assurance of safe operations. We have now identified the root causes and taken corrective action which we believe provides full closure of the incident. Should you have questions on this matter please refer them to the Director of our Radiation Science and Engineering Center, Dr. Marcus H. Voth

Sincerely,

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MHV/DAS/ldb4110.95

pc: US NRC Region I Administrator
US DOE, Attn. E. Tourigny