50-186

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September 5, 2000

Mr. David Matthews, Director
US Nuclear Regulatory Commission
Washington, DC 20555-0001

Dear Mr. Matthews:

This letter transmits, as discussed in telephone conversations between your staff and mine, hard copies of the redacted TRTR and Independent Root Cause Reports.

Sincerely,

Edward A. Deutsch, Ph.D.
Director

EAD:dcp

Attachments

A020

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MISSOURI UNIVERSITY RESEARCH REACTOR

(MURR)

INDEPENDENT ROOT CAUSE ASSESSMENT

August 31, 2000

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EXECUTIVE SUMMARY

On April 12, 2000, a high radiation alarm sounded due to an inadvertent movement of fuel near an unshielded area in the fuel pool. The shielding had been removed in that area to facilitate a pool liner inspection. On June 12, 2000 a control blade was removed from the reactor without meeting the procedural requirement to have two of the eight fuel elements removed from the core. Subsequent to each of these events, the Director of MURR initiated several immediate and long-term corrective actions. These actions are detailed in event reports to the NRC dated May 11, 2000 and July 18, 2000. One of the corrective actions in the July 18, 2000 report committed to performance of a root cause determination to re-assess both individual and common root causes of the events. This report satisfies that commitment.

A team of three individuals ("the Team") experienced in nuclear plant operations, event analysis, and performance assessment prepared this report. The Team has concluded that MURR operations management and staff failed to correlate plant configuration with potential safety impacts associated with reactor-related operations and maintenance work. The event-specific root and contributing causes determined by the Team led to common causes, which can be grouped into four key common cause categories:

1. **Procedures**
   "Procedures do not adequately address their intended purpose(s)."
   "Inadequate attention to existing procedure content and use."
2. **Configuration Control**
   "Inadequate rigor in configuration control and changes to the plant configuration."
3. **Management**
   "Inadequate management oversight of evolving conditions."
   "Use of LSRO concept does not foster ownership and responsibility for ensuring the quality of actions."
4. **Communication**
   "Inadequate formality of communications during shift briefings."
   "Inadequate questioning attitude by management and the workforce."

The Team notes that while on the surface the contributing and common causes may appear to be significant, it also is known to the Team that research reactors typically have a reduced level of procedural rigor as compared to power reactors. If a facility did not experience the types of events seen at

MURR, this reduced level likely would be acceptable. However, considering recent events, this Team concludes that increased focus on rigor, conduct of operations, and configuration control are appropriate.

Finally, readers of this report will note that the language used is direct and to the point. The Team believes that it is in MURR's best interest to receive this information in an un-varnished manner. Regulatory and non-MURR reviewers of this report should understand that this team, through use of direct language, does not question the previous minimum safety significance conclusions reached by MURR and apparently reached by the NRC in its post-event inspection reports. Nor does this team believe that the recommendations in this report are difficult to implement or maintain.

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I. INTRODUCTION

On April 12, 2000, a high radiation alarm sounded due to an inadvertent movement of fuel near an area in the fuel pool from which a section of shielding had been removed. On June 12, 2000 a control blade was removed from the reactor without meeting the procedural requirement to have two of the eight fuel elements removed from the core. Subsequent to each of these events, the Director of MURR initiated several immediate and long-term corrective actions. These actions are detailed in event reports to the NRC dated May 11, 2000 and July 18, 2000. One of the corrective actions in the July 18, 2000 report committed to performance of a root cause determination to re-assess both individual and common root causes of the events. This report satisfies that commitment.

This report was prepared by a team of personnel experienced in nuclear plant operations, event analysis, and performance assessment. John Thies of Time Solutions Corp. led the team regarding satisfaction of its objectives and ensuring the quality of results. Mr. Thies has 20 years experience in assessment of projects for quality, regulatory and safety compliance, and operational readiness. Dr. Peter Mast of Innovative Technology Solutions, Inc. is a senior technical manager with over twenty years of experience in conducting and managing research in the reliability and safety assessment of nuclear reactors. Mr. Thomas Poindexter is an attorney with Winston & Strawn who has over twenty-three years of experience in the nuclear industry. In addition to utilization of his nuclear industry background, Mr. Poindexter also provided legal-based regulatory counsel to the team.

The root cause investigation team ("the Team") began its investigation on June 30, 2000, and completed its analysis on August 23, 2000. The scope of the Team's investigation was to review and analyze the circumstances of the events to determine the common and root causes. The Team conducted its investigation using the following methodology:

- Inspection of the scene of the events.
- Gathering facts through interviews, document and evidence reviews, and walk-downs of the areas.
- Reviewing immediate response and near-term responses.
- Analyzing facts and identifying causal factors.
- Developing judgments of need and corrective actions to prevent recurrence based on analysis of the information gathered.

II. ROOT CAUSE ASSESSMENT PROCESS

A root cause assessment process was implemented which combined personnel interviews, document reviews, and event analysis to determine if similarities existed regarding event causes.

A. EVENT REVIEWS

The April 12th and June 12th events were reviewed and potential contributing factors (that may not have individually caused an event, but may have increased the likelihood of an event) were considered. Event causal factors were identified and evaluated by understanding the sequence of actions and conditions that lead to each event occurrence.

B. DOCUMENTS REVIEWED

The following documents were reviewed during the course of the assessment process.

- MURR Policy and Procedure Manual, September 1, 1998 (with changes through December 17, 1998).
- University of Missouri Research Reactor Facility Technical Specifications, Revision 12, 9/20/99.
- TRTR Report on the University of Missouri Research Reactor, July 12, 2000.
- Letter, May 11, 2000, University of Missouri Research Reactor to US Nuclear Regulatory Commission, Docket No. 50-186, Report Regarding High Radiation Alarm.
- Letter (Draft), July 11, 2000, University of Missouri Research Reactor to US Nuclear Regulatory Commission, Docket No. 50-186, Report as required by Technical Specification 6.1.h (2) regarding reactor operation not meeting the Limiting Conditions for Operation in T. S. 3.2 Control Blade Operation.
- MURR Event Response Team notes from the April 12, 2000 high radiation alarm.
- MURR organization chart, March 15, 2000.
- MURR organization chart, April 10, 2000.
- MURR organization chart, June 6, 2000.
- MURR Standing Order 00-03, Revision of Step C of SOP Section II.2.1, Fuel Handling Procedure, April 13, 2000.
- Maintenance Requirement Card, Reactor System Offset Mechanism, October 14, 1994.
- MURR Reactor Safety Subcommittee Meeting Minutes, April 18, 2000.

C. STAFF INTERVIEWS

The following table lists the sixteen individuals who were formally interviewed by the Team. General, informal discussions were held with several other individuals during shift change, during reactor tours, and during breaks.

Individual Interviewed	Position at The Time of The Event.	April 12th Event	June 12th Event
[redacted]	Assumed LSRO Watch 20 minutes before refueling	X	
	RO that performed the Offset Change Out.	X	
	SRS that performed the Offset Change Out		X
	HP, QA & Occupational Safety Director	X	X
	Assoc. Dir. Income Generating Ops. & Tech. Support Services Interim Leader	X	X
	Reactor Manager & Renewal and Re-Licensing Leader	X	X
	SRO on temporary assignment to help refueling	X	
	HP on shift during April 12 refueling	X	
	LSRO on shift prior to refueling	X	
	Chief Operations Officer, Interim	X	X
	RO Trainee involved in refueling	X	
	Special Assistant to the MURR Director of Re-licensing and Special Projects	1	1
	Reactor Physicist	X	2
	LSRO for Offset Change out on June 12		X
	SRO Participated in refueling on shift prior to Offset Change Out		X
	LSRO on shift that conducted refueling prior to Offset Change Out		X

1. Ms. Crockett provided general information to the MURR Director.
2. Mr. Kutikkad was on vacation on June 11th and 12th.

III. EVENT DESCRIPTION AND CAUSAL ASSESSMENT

The April 12, 2000 and June 12, 2000 event descriptions are based on interviews with MURR personnel.

A. APRIL 12, 2000 EVENT

On the morning of April 12, 2000 a maintenance meeting was held in the MURR Control Room. During the meeting it was stated that the Gamma Radiation Experimental Facility shielding had been removed, that the lower "Z" fuel storage baskets could not be removed as planned, and that no fuel should be stored in the lower Z-baskets until the shielding was replaced (scheduled for April 17, 2000). On the afternoon of April 12, 2000 an unscheduled reactor shutdown occurred involving the inadvertent insertion of a control blade that dislodged from its magnetically held position. Because of xenon build-up at the time of the shut down, a fuel element exchange was required prior to reactor restart. When the shutdown occurred, several off-normal conditions existed: 1) shielding for the Gamma Radiation Experimental Facility had been removed on April 5, 2000 to allow examination of portions of the reactor pool liner; 2) all Z-baskets except the lower Z-baskets had been removed from the pool area; and 3) it had been decided that the fuel element inspection apparatus would be used for fuel storage rather than the remaining Z-baskets. Because all of the Z-baskets could not be removed, the fuel inspection apparatus was to be used for temporary fuel storage during refueling. The reactor physicist noted that it would be more convenient to use the Z-basket for temporary fuel storage and authorized a procedure change to facilitate the operation. The reactor physicist had forgotten that the shielding was removed from the gamma radiation facility to allow for the pool liner inspection and nothing such as a "red-tag" or "lock-out-of-service" served as a reminder that the Z-basket should not be used.

When the first fuel element was moved and placed in the Z-6 position the north ARMS alarm was heard at the refueling area and seen in the control room. A Health Physicist at the scene who was supporting the pool liner inspection confirmed the presence of an unexpected radiation field. Both the Health Physicist and a Reactor Operator Trainee confirmed, visually and verbally, that there were no personnel in the area. A survey of the area by the Health Physicist showed 0.01 rem/hour at the entrance to the beam port floor. The Health Physicist informed the operators of this reading, and the fuel element was moved from the Z-6 position to the Z-2 position without a procedure modification. At the front edge of the Gamma Radiation Experiment Facility another measurement showed radiation levels of 200 rem/hour. The Health Physicist immediately notified the operators who then removed the element from the Z-basket and returned it to its original position.

No personnel were on the beam port floor at the time of the alarm. During the course of the event, reactor operations staff observed no one on the beam port floor. After the fuel movement, health physics personnel contacted staff members who frequent the controlled area. None reported being in the area at the time of the alarm.

1. EVENT-SPECIFIC CAUSES

On April 12, 2000 an experienced MURR manager authorized, and experienced operators did not question, the movement of fuel into an area in the fuel pool from which the shielding blocks had been removed.

a. CONTRIBUTING CAUSES

i. Lack of formal procedure

A formal liner inspection procedure had not been developed to control the pool liner inspection task, although a sequence of tasks to perform the non-routine liner inspection activity had been developed. This lack of a formal procedure resulted in critical information regarding plant configuration to be overlooked.

ii. Procedure changes without adequate review

Fuel movement sequence changes were performed without adequate technical and management review. There was no requirement to have the revision to the step-by-step fuel handling sequence document reviewed and approved by an independent knowledgeable individual. The Team concludes that a lack of an independent review of this change represents a missed opportunity to check plant conditions relative to the planned fuel movement task and impose operating limits such as, hold-points and management-checks. This resulted in a decision affecting safety being initiated <u>and</u> approved by one individual, the MURR Reactor Physicist.

iii. Inadequate Process

The fuel movement sequence instruction did not provide adequate direction that is expected of a formal procedure. The sequence document only provided a fuel movement sequence table and storage location diagram.

There was an inadequate 50.59 screening procedure. If an adequate 10 CFR 50.59 screen/evaluation had been performed, it is likely that the pool liner inspection task plan would have been formalized into a formal procedure.

iv. Management and staff were inattentive to configuration issues and did not question plant conditions

Some shift operations staff were unaware that the shielding had been removed, and those that were aware had an inadequate understanding of operational implications of the removed shielding.

During the previous fuel movement the fuel inspection basket had been successfully used as a temporary storage basket. The shift management and operators apparently saw no relationship at a key time between using the inspection basket and the removed shielding blocks. The Team is unaware of any questioning done at the time regarding the inspection basket, the removal of some Z-baskets and not others, or the missing shielding blocks (which were stacked in the open and therefore, should have been observed during shift inspection rounds). There was no attempt to question plant configuration or operational conditions.

The number of individuals involved in this sequence of events clearly suggests that the staff at the reactor were not "thinking" about what they were doing in the broader context of plant configuration. Apparently, there was no assessment of one's actions relative to what was being done at the facility in general. Everyone operated focusing only on the job they perceived they were responsible for. There was a clear lack of awareness and questioning by management and operations staff regarding their actions and the potential safety impacts they may have relative to plant operating conditions.

v. Inadequate configuration control system

There was no rigorous configuration control system in place that would have indicated to the Reactor Physicist or operators performing the refueling that the reactor configuration was inappropriate for the planned fuel movement sequence. A rigorous configuration control system would have provided a real-time indication of plant status (i.e., shielding blocks are missing and the Z-baskets are red-tagged). Requiring operators to review current plant status prior to initiating any change to reactor configuration provides an extra level of defense against errors in procedure.

vi. Inadequate shift-to-shift communication

The pool liner inspection was an activity that spanned multiple shifts. Therefore multiple shifts must be made aware of the planned activity and its potential impacts to reactor operations. It is clear that a formal mechanism for adequately communicating the status of activities from one shift to another was

inadequate. The Team believes that adequate communication in this regard would have informed all operations personnel that a portion of the reactor pool liner was without shielding.

vii. Inadequate pre-job planning and briefing of shift staff.

The Team did not find evidence that a formal pre-job shift planning meeting occurred, in which the lead Senior Reactor Operator (the supervisor for the shift) briefed all shift operators on the objectives for the shift, the allocation of resources, the expected schedule, or the potential hazards associated with the planned tasks. The lack of a hazard analysis certainly contributed to in inadequate work controls being implemented. Formalization of such pre-job planning would provide an opportunity to review the tasks to be accomplished to ensure that the shift operators fully understand the work to be done. This is especially important during the period of re-licensing and renewal while there are many non-routine activities that must be accomplished.

b. ROOT CAUSES

Procedure Deficiencies

- MURR procedures have not evolved commensurate with increased emphasis in the nuclear industry on rigor in conduct of operations and individual accountability for operational conditions.
- The MURR procedural system, including the procedure hierarchy, quality of instruction, requirements for review, and level of approval is too informal.
- Procedures do not incorporate necessary "hold-points" and checklists.

Configuration Control

- The MURR reactor configuration is in some cases undocumented and managed informally.
- There are limited real-time indicators of MURR plant configuration.
- The MURR "lock-out/tag-out" system is not rigorously applied.

Management

- MURR management has not fostered a "questioning" attitude or individual accountability for plant operations.
- MURR senior management has not consistently communicated minimum expectations for management and staff.
- The MURR organization structure has lead to diffusion of staff accountability and responsibility.

Communication

- MURR reactor operations turnovers do not communicate sufficient plant condition and operational status information.

2. MURR NEAR-TERM EVENT SPECIFIC CORRECTIVE ACTIONS

The following corrective actions were taken by MURR in the near-term following the event: The Team concludes that these corrective actions were timely and minimized the consequences of the event.

- Operators removed the fuel element from the Z basket area, thus immediately ameliorating the high radiation area it caused.
- MURR management administrated a "stand down" to determine how the event happened and the possible direct and contributing causes.
- The MURR Director established an Incident Response Team responsible for heading the internal review of the incident and recommending corrective actions and procedures.
- The MURR Director paused all non-routine maintenance activities.
- The MURR Director mandated that both the Reactor Manager and Health Physics Manager shall authorize all non-routine activity and shall approve all new procedures and all changes to procedures associated with these non-routine activities.
- MURR Reactor Manager issued Standing Order 00-03 requiring that the step-by-step fuel movement procedure approved by the Reactor Physicist, or his approved designee, be reviewed and countersigned by a second individual who is licensed as a Senior Reactor Operator.
- The MURR Reactor Manager required any revision to the step-by-step fuel movement procedure to be approved by two individuals comprised of any combination of the Reactor Physicist or licensed Senior Reactor Operators.
- The MURR Reactor Manager devised a more formal shift turnover status sheet to heighten communication at shift turnover, including identification of unusual plant conditions.
- The MURR Reactor Manager assigned an experienced senior staff member to the Operations Engineer position until a permanent replacement could be recruited.
- MURR management initiated procedure-screening guidelines for delineating the types and methods of review for procedures prior to being implemented.

3. ADDITIONAL EVENT SPECIFIC CORRECTIVE ACTIONS RECOMMENDED BY THE TEAM

- Promptly reinstate the shift supervisor position in place of the rotating Lead SRO.

- Implement a defined work control processes in a procedure that is based on the complexity and importance of the work and the potential for worker hazard, public protection, and protection of facility integrity for both routine and non-routine work. The procedure should include a process to check plant conditions and operational status; ensure that potential worker hazards have been identified and evaluated; and that necessary precautions have been incorporated into work control procedures and instructions and are in fact in place.
- Develop and implement a procedure that requires 10 CFR 50.59 screening of all activities that could impact plant safety systems.
- Implement a procedure that requires a plant configuration status board in the control room. The procedure should specify the plant parameters to be displayed and the frequency for updating the status board. This procedure should also implement a shift change communication checklist that is consistent with, and provides additional detail to the plant status board.
- Employ a comprehensive "systems" based checklist to communicate plant status and conditions.
- Develop and implement training on all new or revised procedures.
- Verify through a feedback mechanism that new training and management expectations are effective.

B. JUNE 12, 2000 EVENT

On June 12, 2000, the reactor was shut down at 0300 and refueled as part of the normal maintenance day activities. On the next shift control blade B was to be removed and inspected to meet the requirement that each control blade is checked once every two years with one shim blade inspected every six months. The six-month maintenance includes a blade inspection for warpage, cladding integrity and blade curvature. During the maintenance check the in-service offset mechanism is also replaced. At about 1100, control blade B was removed from the reactor and at 1210 the lead SRO realized that the control blade had been removed without having two fuel elements removed from the core as required. At that point, a fuel movement procedure was developed and approved. In accordance with the fuel movement procedure, the reactor pressure vessel head was removed and two fuel elements were removed from the core. This was completed at 1352.

For the June 12 maintenance day the replacement of the offset mechanism for Blade B was the primary task scheduled and planned for that day. The reactor was shutdown at 0300 and the reactor was refueled as per procedure approved the previous week. The refueling procedure was typical of a normal maintenance day (eight fuel elements removed and eight elements installed) but was not the type of procedure that was expected prior to replacing an offset mechanism. The refueling sequence for this type activity would normally leave two elements out of the core adjacent to the location of the offset to be

replaced. The Senior Operators on the night shift performing the refueling activity were aware of the plans to replace the offset mechanism but overlooked one of the preconditions necessary to perform the replacement. The oncoming dayshift operators and operations management personnel presumed the refueling had been done as required for the mechanism replacement (i.e., two elements left out of the core). No one verified the fuel configuration prior to initiating the control blade maintenance.

Shortly after reactor shutdown, reactor operators found that there was a leak in the shaft seal for primary pump 501A. This item became a focus of attention for the day shift as well as operations management because it was a major unplanned activity. Investigation of the leakage revealed a failed mechanical seal on the pump. Replacement of this seal is primarily done by persons from the machine shop with reactor operations oversight. A decision was made by operations management to conduct this maintenance activity concurrent with the offset changeout that had been planned and scheduled for several months. It was thought that this activity would have minimal impact on the personnel who were replacing the offset mechanism. The interim Operations Engineer elected to monitor the pump seal removal and replacement activity to allow the reactor shift personnel to focus on the offset mechanism replacement activity.

Reactor operations management attention was divided between preparing for the offset mechanism replacement and tagging out and draining the primary reactor pump leg for the mechanical seal replacement. The two maintenance activities proceeded concurrently, with the offset being removed and the shim blade inspected at 1100. The pump seal replacement was completed shortly thereafter, and a request was made to reactor operations staff to refill the pump leg to check for leaks. At this point in time, approximately 1210, the lead Senior Operator, while considering the conditions necessary to refill the primary, realized that the refueling had not left the reactor in the required precondition (i.e., with two elements removed from the core) for the control blade removal.

The Reactor Manager was immediately contacted and he decided that the quickest way to restore TS compliance was to remove two elements from the core. The Reactor Manager calculated the shutdown margin of the existing core configuration and determined that it was in compliance with the 0.02 delta K Technical Specification. A fuel movement procedure was written, approved, implemented, and removal of two elements from the core was completed at 1352.

1. EVENT-SPECIFIC CAUSES

On June 12, 2000 a control blade was removed from the reactor without meeting the procedural requirement to have two of the eight fuel elements removed from the core. This was accomplished without question from the full compliment of MURR operations management and operators on shift.

a. Contributing Causes

i. The wrong refueling sequence was used

The refueling sequence that was used by the previous shift was the one appropriate for normal operation, i.e.; all eight elements were inserted into the core. Two elements were not left out as is appropriate for preparing for control blade maintenance. This apparently occurred because a) the preparer of the sequence designed the wrong sequence, and b) the reviewer of the sequence did not identify and correct the error.

The fact that the sequence preparer designed the wrong refueling sequence indicates that the purpose for the fuel reload (i.e., pre-maintenance core state vs. normal start-up state) had not been adequately communicated to the preparer or he forgot this key information. The fact that this omission occurred is not surprising to the Team because the "objectives" for a given refueling sequence are not formally documented at MURR. Thus, it would be helpful if the refueling sequence form explicitly documented the purpose for the sequence being designed.

The fact that the reviewer of the refueling sequence did not identify the error indicates either a lack of awareness of the planned activities at the reactor, or a lack of care in reviewing the refueling sequence. Given that the Reactor Manager performed the review, he should have been in a position to be cognizant of the planned maintenance activities. Thus, one would have to conclude that adequate attention was not devoted to the review. Again, it is much more likely that the reviewer would have identified the error had the purpose for the refueling sequence been documented on the information being reviewed.

ii. The procedure used for the control blade maintenance was flawed.

There are a number flaws in the procedure(s) used to actually perform the control blade maintenance. First, the procedure(s) are confusing because they involve multiple procedures and because they cover multiple processes within a single procedure. By jumping from one procedure to another, it is easy to lose sight of the big picture of what the job entails, and inattentive following of isolated procedural steps may become the norm. This may be further exacerbated by coupling distinct aspects of the overall maintenance activities into a single procedure (control blade removal from the reactor vs. dismantlement

and servicing of the blade). It is clear that the overall procedure document hierarchy is in need of simplification, streamlining, and clarification.

By jumping between two procedures, a critical prerequisite (the removal of two fuel elements) was overlooked. Following the procedures line-by-line would not have required the operator to review the need for a six-element fuel-loading configuration.

Finally, the current procedures are inadequate in terms of the requirement to document (via sign-off on a check sheet) that all prerequisites have been met and that the key steps in the procedure have been followed in the correct sequence. Thus for example, there is no requirement to document (procedural step sign-off) that only six elements are loaded into the core.

iii. Complacency regarding the full content of the procedures and their use.

It can be argued that the operators on the night shift who performed the refueling followed the fuel reload procedure (i.e., the sequence they were provided, which was wrong), and the operators on the day shift who performed the control blade removal followed (in a strict line-by-line compliance sense) the appropriate procedure as well. However, there was certainly a sense of complacency on the part of the operators performing the control blade removal. This is evidenced by the fact that they did not thoroughly review the entire procedure (including mandatory prerequisites), even if the review of the prerequisites was not explicitly called for in their detailed instructions. One would expect that a senior operator would review all pertinent sections of a procedure (prerequisites included) even if only a portion of the procedure was to be used.

iv. Inadequate configuration control system

There was no rigorous configuration control system in place that would have indicated to the operators performing the control blade maintenance that the reactor configuration was inappropriate for that activity. A rigorous configuration control system would have provided a real-time indication of plant status (i.e., all eight fuel elements in the core). Requiring operators to review current plant status prior to initiating any maintenance activity provides an extra level of defense against errors in procedure. For this particular incident, the plant status that would have been indicated by a configuration control system would have been inconsistent with the required plant configuration for control blade removal.

v. Inadequate shift-to-shift communication

Maintenance on the control blades is an activity that spans multiple shifts. For example, the night shift must complete a fuel reload using a reload sequence specifically tailored for the planned maintenance. Thus, both shifts are clearly aware of the planned activity. It is clear that a formal mechanism for adequately communicating the status of activities from one shift to another does not exist. Such communication would have addressed the preparatory activities that had been completed for control blade maintenance, or in this case would have indicated that the proper preparatory activities (refueling with only six fuel elements in the core) had not been completed.

vi. Inadequate pre-job planning and briefing of shift staff.

The Team did not find evidence that a formal shift planning meeting occurs, during which the lead Senior Reactor Operator (the supervisor for the shift) briefs all shift operators on the objectives for the shift, the allocation of resources, and the expected schedule. Rather a briefing appears to be performed in an informal manner. Formalization of this type of meeting would provide an opportunity to review the tasks to be accomplished to ensure that the shift operators fully understand the work to be done. This is especially important for non-routine activities such as the control blade maintenance activity.

vii. Inadequate re-assessment of pre-job planning based on unplanned requirements.

The leaking pump that had to be dealt with concurrent to the scheduled control blade maintenance did not result in a formal reassessment of the shift schedule and resource allocation. Again, this unplanned activity appears to have been addressed in an informal manner leading to an inadequate assessment of the impact this would have on already scheduled activities. Consequently, reactor operations management and the lead SRO became involved in the unplanned maintenance activity and neglected the control blade maintenance activity.

viii. Prior week's maintenance planning meeting did not involve all necessary personnel.

Monday morning maintenance activities are planned the week before in a maintenance planning meeting. However, the personnel in attendance at the planning meeting do not necessarily include a representative from the shift that will actually be conducting the maintenance activities. While the maintenance plan can be and is well documented in a maintenance activity log sheet, it is never possible to capture all issues discussed in such a planning meeting. Participation by a representative from the shift that will actually be doing the work (ideally the lead SRO) would serve to highlight non-routine aspects of the maintenance plan, and sensitize the lead SRO to any unusual requirements such as the requirement for only a partial core fuel load.

ix. Lack of adequate shift supervision.

It appears that all personnel involved in the Monday morning maintenance activities were trying to do their jobs to the best of their abilities. However, what was noticeably lacking was the recognition of there being one person in charge and ultimately accountable for the work being done in a safe professional manner. The lead SRO in fact became one of the "workers" to enable all required activities to be completed. It is certainly desirable, and necessary from a resource utilization perspective, that all personnel contribute to performing maintenance activities. However, the supervisor of the shift (the lead SRO) must have as his or her primary job function supervision and integration of all activities on the shift.

Similar comments can be made relative to the Sunday evening shift that was responsible for the fuel reload. The lead SRO did not provide adequate supervision and oversight to be able to assess whether the fuel reload being implemented was correct in light of the known scheduled control blade maintenance. Because the assignment of lead SRO is somewhat arbitrary, a clear understanding of the job requirements for being "shift supervisor" does not exist. As a result, all SROs on a shift appear to work as a team, and no one individual stays focused on the "big picture."

x. Unplanned work impacted supervisor effectiveness.

See items vii. and ix above.

xi. Lack of a questioning attitude on the part of the staff.

This incident required that errors of commission or omission occur by at least 7 people.

- The need for developing a reload sequence for control blade maintenance was not communicated to the Reactor Physicist
- The Reactor Physicist developed the wrong sequence
- The Reactor Manager approved the wrong sequence
- The operator(s) on the Sunday shift implemented the wrong reload sequence
- The lead SRO on the Sunday shift was not aware that the wrong reload sequence had been implemented
- The operator(s) on the Monday shift did not ensure that the prerequisites for control blade maintenance (only 6 elements in the core) had been met
- The lead SRO on the Monday shift was not aware that the prerequisites had not been met.

The number of individuals involved in this sequence of events clearly suggests that the staff at the reactor were not "thinking" about what they were doing in the broader context of reactor operations. There was no assessment of one's actions relative to what was being done at the facility in general. Everyone operated myopically focusing only on the job they perceived they were responsible for. There was a clear lack of awareness and questioning by management and operations staff regarding their actions and the potential safety impacts they may have relative to plant operating conditions.

b. ROOT CAUSES

Procedure Deficiencies

- MURR procedures have not evolved, consistent with the nuclear industry, with an increased emphasis on rigor in conduct of operations and individual accountability for operational conditions.
- The MURR procedural system including, the procedure hierarchy, quality of instruction, requirements for review, and level of approval needs improvement.
- MURR procedures do not incorporate necessary "hold-points" and checklists.

Configuration Control

- The MURR reactor configuration is in some cases undocumented and managed informally.
- There are limited real-time indicators of MURR plant configuration.
- The MURR "lock-out/tag-out" system is not rigorously applied.

Management

- MURR management did not foster a "questioning" attitude or individual accountability for plant operations.
- MURR senior management does not appear to consistently communicate minimum expectations to management and staff, nor does it appear to periodically confirm the effectiveness level of understanding of management expectations, e.g., roles and responsibilities of rotating lead SRO.
- The MURR organization structure appears to have led to diffusion of staff accountability and responsibility.

Communication

- MURR reactor operations turnovers did not appear to communicate sufficient plant condition and operational status information.

2. MURR NEAR-TERM EVENT SPECIFIC CORRECTIVE ACTIONS

- The Reactor Manager declared the reactor "in stand-down" and scheduled a meeting of all Reactor Operations staff for the following morning, June 13 at 0630 to discuss the event, contributing causes and to solicit information for the root cause determination. The offset B installation was completed at 0215 on June 13.

- At 0630 on June 14, a second Reactor Operations meeting was held with all operators (except one on vacation). The purpose of this meeting was to provide training regarding the root cause determination, corrective actions, and expectations for the LSRO position. This training addressed attention to detail, questioning attitude, complacency, performance of infrequent activities and other corrective actions to be implemented.

- At 0800 on June 14, the Action Subcommittee (subset of the Safety Subcommittee) was convened to discuss the event and review corrective actions implemented and planned at that point.

- Also on June 14, the Acting Reactor Manager issued Standing Orders 00-09 and 00-10. Standing Order 00-10 affirmed that the Standard Operating Procedures had been reviewed to determine whether there were misstatements or omissions in them that would have adverse safety implications for reactor operations.

- The Reactor Manager authorized the reactor for restart on June 14 at 2200 after verifying all pre-startup corrective actions had been taken. The Reactor Manager completed a briefing of the Operating crew for the performance of startup and control blade worth measurement at 2230. The reactor returned to full power at 0505 on June 15.

3. ADDITIONAL EVENT SPECIFIC CORRECTIVE ACTIONS RECOMMENDED BY THE TEAM

In addition to the recommended actions listed in section III. A. 3;

- Require the purpose of a fuel movement sequence to be explicitly stated at the top of the refuel movement sequence form.

IV. COMMON CAUSE ASSESSMENT

Previous discussions have focused on event-specific root and contributing causes. It is evident based on a review of those discussions that both events are similar from a causation perspective. The following matrix compares contributing causes and summarizes the basis for common cause conclusions subsequently discussed.

The matrix is structured as follows. For each event (April 12, 2000 and June 12, 2000) previously discussed contributing causes are summarized. Similar contributing causes are listed next to their counterpart for the other event. If a common cause exists for a group of contributing causes, it has been indicated by a broad block that spans the relevant contributing cause listing. Contributing causes that do not appear to support a common cause conclusion are not spanned by the common cause block and are marked "none."

PROCEDURES/PROGRAMS		
Root Causes • MURR procedures have not evolved, consistent with the nuclear industry, with an increased emphasis on rigor in conduct of operations and individual accountability for operational conditions. • The MURR procedural system including, the procedure hierarchy, quality of instruction, requirements for review, and level of approval needs improvement. • MURR procedures do not incorporate necessary "hold-points" and checklists.		
Contributing Causes April 12, 2000 Event	**Contributing Causes June 12, 2000 Event**	**Common Causes**
Procedure changes performed without adequate review (e.g., hold points, checklists)		Procedures did not adequately address intended purpose
Inadequate procedures for determining appropriate process to be used during work evolution	Wrong refueling sequence procedure approved (no purpose stated; review inadequate)	
	Flawed offset change-out procedure (e.g., sequencing, documentation of step performance)	
No formal liner inspection procedure		
Inadequate determination of whether formal procedure or maintenance sequence plan should be used (inadequate procedural guidance) and reliance on inadequate maintenance and sequence instructions (wrong decision absent that guidance)		
Inadequate 50.59 screening procedure		
Absence of operating limits for off-normal evolutions		
Poor (i.e., informal) work planning and preparation processes	Complacency regarding procedure use and content	Inadequate attention to existing procedure content and use

CONFIGURATION CONTROL

Root Causes

- The MURR reactor configuration is in some cases undocumented and managed informally.
- There are limited real-time indicators of MURR plant configuration.
- The MURR "lock-out/tag-out" system is not rigorously applied.

Contributing Causes April 12, 2000 Event	Contributing Causes June 12, 2000 Event	Common Cause
A rigorous reactor plant configuration control process was not applied, but rather, relied upon operator knowledge rather than documentation	Inadequate rigor regarding configuration control and changes to known/expected configuration	Inadequate rigor in controlling changes to plant configuration.
Z-basket not red-tagged as out of service/non-use		
No documentation of reactor plant configuration status		

MANAGEMENT

Root Causes

- MURR management does not foster a "questioning" attitude or individual accountability for plant operations.
- MURR senior management does not consistently communicate minimum expectations for management and staff.
- The MURR organization structure led to the diffusion of staff accountability and responsibility.

Contributing Causes April 12, 2000 Event	Contributing Causes June 12, 2000 Event	Common Causes
Wrong refueling sequence modification initiated and approved by MURR management	Unplanned work impacted supervisor effectiveness	none
Failure to question the implications of operational changes by operations management and staff (e.g. evolving plant conditions)	Work overload resulting from emergent events	Inadequate management oversight of evolving conditions
Inadequate LSRO management/oversight of shielding removal	Inadequate ownership of activity (LSRO vs. Shift Supervisor)	Use of LSRO concept does not foster ownership and responsibility for ensuring the quality of activities
The MURR reactor operations organization structure (LSRO vs. Shift Supervisor) has led to a diffusion of operator accountability and responsibility	LSRO in lieu of Shift Supervisor did not allow for consistent, clear ownership and accountability	

COMMUNICATIONS		
Root Cause • MURR reactor operations turnovers do not employ a comprehensive "systems" based checklist to communicate plant status and conditions.		
Contributing Causes April 12, 2000 Event	**Contributing Causes June 12, 2000 Event**	**Common Causes**
Poor shift turnover communications	No formal briefing of shift staff	Inadequate formality of communications during shift briefings
All shift personnel were not formally informed of shielding removal	Inadequate inter-shift communication	
Inadequate pre-job briefing	Inadequate pre-job planning	
	Inadequate re-assessment of pre-job planning based on emergent events	
	Maintenance planning meeting did not involve nor formally communicate key areas of awareness to other shifts/workers	
Inadequate questioning attitude regarding impact of stuck basket	Inadequate questioning attitude regarding confirmation of prerequisite performance.	Inadequate questioning attitude by management and the workforce
Inadequate questioning attitude regarding existence of shielding outside of the gamma radiation experimentation facility		

A. Discussion of Common Causes

Consistent with previous discussions on event-specific root and contributing causes, common causes were addressed based on four key categories: (1) Procedures/programs, (2) Configuration Control, (3) Management, and (4) Communications. The following provides a general summary of how broad common causes were developed. Reference to the above matrix provides an illustration of this thought process.

1. Procedures/Programs

- "Procedures do not adequately address their intended purpose(s)."

Noted in this report and the Common Cause Matrix are several examples where long-standing MURR procedures have been determined in hindsight to be inadequate. This issue actually has two parts: (a) inadequate procedures already in written form and (b) inadequate informal procedures that may be captured in the minds of MURR personnel. Regarding the first category, it is clear based on interviews of employees and a review of documents that generally speaking, the decision on what type of "procedure" to use, or whether a formal procedure was used, was a discretionary act by the cognizant manager. For

years this approach usually resulted in a decision that did not have adverse consequences. However, on two separate occasions, this choice appears to have led to regulatory noncompliances due in great part because the actual written procedure was either outdated, had unclear steps that had been addressed through "skill of the craft," or had errors that were known, but went unresolved. This team concludes that the skill of the craft safety net likely masked these deficiencies for many years, until the April 12 and June 12, 2000 events occurred.

Certain informal procedures may only be captured in the minds of MURR personnel. The team concludes that this represents a lack if initiative to keep pace with the rest of the nuclear community, which has long since concluded that additional rigor in procedure development and use is necessary. MURR has a distinct advantage in that several of its personnel have worked at the facility for decades. However, along with that experience comes the potentially negative result from over-reliance on inherent knowledge of how certain evolutions are performed.

Consistent with the nuclear industry twenty-five years ago, many reactor operations were performed based on this knowledge and was not required to be documented in a detailed procedure. However, this approach to nuclear facility operation has passed. It does not appear that MURR kept pace with this change -- primarily, this team speculates, because what had been used in the past appeared to still be working (until the events). On the contrary, the team concludes that for years, MURR has basked in a false sense of security and that sooner or later; events such as those that occurred were inevitable. It does not go without notice that it appears that the NRC accepted this informal approach in that the team was unable to document significant examples cited by the NRC (prior to this event) where the NRC took issue with MURR's procedures and procedure development/validation efforts.

- "Inadequate attention to existing procedure content and use."

This conclusion is based primarily on the fact that personnel were aware of inconsistencies in the control blade Standard Operating Procedure step sequences and that fact that it was generally believed to be acceptable to plan and perform most work at the facility with informal procedures.

2. Configuration Control

- "Inadequate rigor in configuration control and changes to the plant configuration."

The team is rigid in its view that the plant configuration must be known at all times by at least the on-shift Operations crew. This would include the ability to provide a snapshot summary of everything that is

occurring regarding the reactor. The obvious examples of not having a complete configuration snapshot involves the removal of the bricks from the gamma experimentation tunnel, the temporary open storage of those bricks, and the failure to have available processes that force the recall of that information before other configuration changing decisions are made. Another example of less than desirable rigor is the failure to red-tag the z-basket as not being available. We conclude that the ability of the Reactor Physicist to make a configuration-based decision absent input from a cognizant Operations shift person places an unacceptable decision burden on one individual and dilutes command and control of the reactor.

Regarding the control blade, the team concludes that the common cause statement is supported by the fact that a document providing the required configuration prior to blade removal was not available. Instead, memory was relied upon to ensure that all configuration prerequisites were met. Adding to the problem was the fact that the Operations Engineer, who was supposed to stand back and assess activities from an overall perspective, became too involved in the sequence of events and therefore, was unable to provide an assessment of the requisite configuration before the control blade evolution was initiated.

3. Management

- "Inadequate management oversight of evolving conditions."
- "Use of LSRO concept does not foster ownership and responsibility for ensuring the quality of actions."

While these common causes are significant, their basis is simple. At MURR, the change from Shift Supervisor to lead SRO has caused a lack of consistency in identifying the responsible management individual who takes personal ownership in ensuring that operations proceed acceptably. This absence did not result in clear ownership for assessing necessary changes in approach when the fuel basket was stuck and did not provide for clear ownership when the emergent maintenance activity was performed concurrent with the control blade removal effort.

4. Communications

- "Inadequate formality of communications during shift briefings."

The team noted that the potential impact of configuration control deficiencies were escalated due to poor communications during shift turnovers. In this instance, poor is defined as either inconsistent or non-existent. For the shielding removal event, it is acknowledged that generally speaking most personnel were aware of the shielding status. However, key personnel did not appropriately consider the impact of

that status when it was the most critical. This issue also relates to the above discussion on Operations ownership of all reactor-related activities. If that ownership were clear, the team postulates that the individual responsible and accountable for ensuring safety would have recognized a potentially adverse situation and ensured that others were aware of the limitations of Z-basket usage. The decision would not have solely relied upon the informal judgement of the Reactor Physicist.

Contributing to the impact of inadequate formality was the fact that no management or procedures had documented minimum expectations during shift turnovers. Largely, the level of detail and the type of information provided were at the discretion of the personnel involved in the meeting. This same symptom existed regarding the absence of documented minimum expectations (procedurally or as expressed by management) regarding the Control Room log.

- "Inadequate questioning attitude by management and the workforce."

The team concludes that for the April 12, 2000 event, there were multiple opportunities to question the impact of the shielding being removed from the gamma radiation experimental facility. Also, there were multiple opportunities to challenge and confirm that the reactor was in its proper configuration prior to control blade removal.

V. COMMON CAUSE CORRECTIVE ACTIONS

The following common cause corrective actions are captured in the corrective action plan presented in section VI.

A. Procedures do not adequately address intended purpose

1. Implement a comprehensive procedure improvement program. First, procedures should be prioritized by potential impact on safety. The more significant procedures should be revised first and promptly.
2. Assess the total set of MURR operations procedures to determine overlaps, redundancy, and usefulness

B. Inadequate attention to existing procedure content and use

1. Periodically issue management expectations for procedure adherence.
2. Institute a general procedure philosophy of using check off sheets or signoffs for key procedural steps.
3. Re-train all operations personnel on the use of specific procedures. Focus of procedures with a greater impact on safety first.

4. Improve/enhance the MURR training program as appropriate and perform an independent assessment of the training effectiveness.

C. Inadequate rigor in configuration control and changes to the plant configuration

1. Develop a configuration control procedure that enables operations personnel to be able to determine plant configuration (e.g., system operation, out-of-service components, shielding, core status) at any point of time and in a prompt manner.
2. Improve reporting of research activities on the beam port floor. This would include operations knowledge of what experiments are ongoing and the status of beam port shielding.
3. Improve beam port floor housekeeping such that only equipment/components necessary to the conduct of operations are in the area.

D. Inadequate management oversight of evolving conditions/use of LSRO concept does not foster ownership and responsibility for ensuring the quality of activities.

1. Re-institute (within the next quarter) a permanent shift supervisor position.
2. Document (periodically) management expectations regarding all corrective action issues.
3. Develop an effectiveness assessment and feedback mechanism that confirms that personnel understand management expectations.

E. Inadequate formality of communications during shift briefings; inadequate questioning attitude by management and the workforce.

1. Develop/revise relevant procedure that provides minimum management expectations regarding shift briefings
2. Develop/revise relevant procedure to provide minimum management expectations regarding log entries.
3. Ensure that potential vulnerabilities and contingency options are discussed during pre-job briefings

VI. ROOT CAUSE CORRECTIVE ACTION PLAN

These actions should be scheduled and progress tracked weekly with status reports to the COO and Director of MURR. Prompt action should be taken to remedy behind schedule conditions.

Procedure Deficiencies

- The Team recommends that MURR implement a comprehensive reactor operations and maintenance procedure improvement program to ensure clear, useful procedures. Procedure development/revision should proceed based on a given procedures potential impact on plant safety. The general philosophy

toward procedure upgrades should incorporate the use of hold-points, check-sheets, one-over-one review, and management sign-off to control key procedure steps. Operations personnel should be re-trained on the new/revised procedures focusing on those procedures with a greater impact on safety first.

- The Team recommends that a formal procedure be implemented that ensures corrective action effectiveness is verified and documented.

Configuration Control

- The Team recommends that MURR develop a configuration control procedure that enables operations personnel to be able to determine plant configuration (e.g., system operation, out-of-service components, shielding, core status, etc.) at any point of time and in a prompt manner.

- The Team recommends, given the magnitude of change MURR is experiencing and the physical upgrades anticipated to support Renewal and Re-Licensing, conducting comprehensive facility inspections every six months. These reviews should address all aspects of operations including, ALARA, housekeeping, and storage of radioactive material.

- The Team recommends eliminating office space on the beam port floor as a risk management and ALARA action.

Management

- The Team recommends that the MURR Director and COO define the performance expectations, roles, responsibilities and authority of each MURR manager; and that the managers do the same until each individual working at MURR has a clear documented statement of his and her performance expectations, roles, responsibilities and authority.

- The team recommends quarterly Reactor Manager, Reactor Engineer, Reactor Physicist, Shift Supervisor, and SRO proficiency reviews by the Chief Operations Officer during the course of MURR's re-licensing and renewal efforts. The review should include an effectiveness assessment and feedback mechanism that confirms that personnel understand management expectations for procedure compliance and a questioning attitude.

- The Team recommends that a detailed plan be developed to implement the COO's responsibilities to ensure that MURR operations and maintenance activities are consistent with applicable Federal regulations, state laws, University Policy, and established facility procedures. The plan should consist of an integrated assessment approach that is intended to ensure a broad-based and systematic review of all aspects of MURR management, safety, and facility operations.

- The Team recommends that the roles, responsibilities and accountability of a Shift Supervisor be permanently reinstated in place of the current rotating lead SRO.

- The Team recommends that all MURR nuclear related operations and maintenance functions report to the COO.

<u>Communication</u>

- The Team recommends that MURR implement a formal reactor operations turnover procedure that communicates sufficient plant condition and operational status information to enable operations management and staff to understand plant configuration including, formal reporting of experiments and other research activities on the beam port floor.

- The Team recommends that the MURR COO implement a formal process to develop and communicate to the MURR workforce the concepts and principles of integrated safety management focusing on tools, processes and techniques to improve:
  - Worker involvement.
  - Work control and hazards analysis.
  - First line supervisor/management commitment/accountability/support.
  - Task level feedback for improvement (lessons-learned, work record input, and self-assessment).

VII. CORRECTIVE ACTION EFFECTIVENESS CONFIRMATION

The Team recommends quarterly independent unannounced assessments of reactor operations and maintenance activities for at least the next 12 months. If the assessments indicate satisfactory progress is being made, the assessment frequency would be reduced to annually there after for the duration of reactor re-licensing and renewal activities. This is recommended because of the amount of non-routine activities that will take place during this period. The assessments should focus on plant configuration management and documentation; pre-job planning, including identification and control of hazards; quality of management oversight; communication of expectations from management to staff and communication

during shift turnover; quality of operations and maintenance procedures and procedure compliance; and operator proficiency.

TRTR Report on the University of Missouri Research Reactor

29 June 2000

Background

A High Radiation Area condition created by a fuel transfer was judged by MURR staff as requiring an immediate report to NRC under 10CFR20.2202(a)(1). There were no unplanned personnel exposures and the radiation field was detected, controlled, and removed in a sufficiently short time so as to limit any potential exposure to less than 10% of 10CRF20 limits.

Because of the circumstances leading to the production of this field, and to related concerns by the MURR management, TRTR was requested to perform a review of MURR operations related to this event. T. Raby and L. Slaback of NIST and D. Rorer of Brookhaven National Lab visited MURR on 15–16 May 2000 for this review.

Interviews

Extensive discussions were held with the following individuals during this review:

[redacted]

The Event

A brief outline of the event is as follows:

Prior to 5 April, a plan was developed to perform examinations on portions of the reactor pool liner. This included removal of shielding for the the gamma radiation experimental facility (subsequently referred to as the gamma cavity in this report) to allow examination of the external surface of the liner and removal of all of the fuel element storage racks in the region viewed by the gamma cavity. This plan was coordinated through the relevant organization elements, but was not formalized into an official procedure.

5–6 April: All "Z" fuel baskets, except the lower Z baskets, were removed from the pool area viewed by the gamma cavity.

6 April: The gamma cavity shielding was removed.

7 April: Following an unscheduled shutdown a reactor refueling operation was conducted without using the remaining lower Z baskets by using the fuel element inspection apparatus, as provided by the loading procedure.

10 April: A routine reactor refueling operation was again conducted without using the lower Z baskets by using the fuel element inspection apparatus (again, as specified by the approved loading procedure).

12 April: A maintenance meeting was held in the control room to allow all current shift operators to attend (including the Lead SRO at the time of the event). During this meeting it was stated that the gamma cavity shielding had been removed, that the lower Z baskets could not be removed, and that no element should be stored in them until the shielding was restored (as scheduled for April 17).

Later that day the reactor tripped, necessitating a refueling. Reactor refueling was initiated after an authorized change to the refueling procedure was made to permit the use of a lower Z basket. The north ARMS alarm was heard at the refueling area and seen in the control room when the first element to be moved was placed in the Z basket. The north ARMS is about 120° from the gamma cavity area. The initial ARM reading was 8 mrem/h, with an alarm point of 4 mrem/h. An initial HP survey confirmed the presence of an unusual radiation field and the absence of anyone in the immediate area. The HP identified the source to be the element in the Z basket because of the absence of the cavity shielding. At the same time the operator trainee verified by direct observation that the rest of the beam port floor, i.e., the High Radiation Area controlled area, was clear of any personnel. The element was transferred to what was thought to be a more shielded location in the Z basket, but the field was still present. The HP measured 200 rem/hr at the edge of the gamma cavity. The north ARMS was still alarmed (A reading of 1.23 rem was later obtained from a TLD located on the wall opposite the gamma cavity.) The element was then transferred back to its original location.

The operations crew then reverted to the original fuel transfer plan and began positioning the inspection rig in the pool in preparation to continue refueling. The Reactor Physicist returned to the refueling bridge and learned about the event from the operators. Both he and the HP then left the bridge to find their respective managers and inform them of the event. Some time later the Reactor Physicist found the Interim Reactor Manager in his office and informed him of the event, and moments later, the HP Manager arrived at the office of the Interim Reactor Manager to consult with him. All three individuals then went to the control room level, whereupon the Interim Reactor Manager halted the refueling process. This occurred about 40 minutes after the high radiation event, and 12 of 17 fuel element transfer steps had already been completed in the refueling process

About an hour later the refueling was ordered to be resumed and was completed. At about 1746 the Interim Reactor Manager and HP Manager reported the event to the NRC. Shielding was replaced in the gamma cavity. The reactor returned to routine operation at 2022.

Findings and Observations

1. A detailed plan was developed for preparation and conduct of the pool liner inspection. This plan addressed all the essential elements for safe operation but did not address any contingency situations. The plan specified HP support for selected aspects of the operation, e.g., placement of fuel in the Z baskets after the shielding had been replaced, but did not specify any additional HP or Operations surveillance for the duration of the operation.

2. Many of the reactor operating staff were largely unaware of the details of the inspection plan, in part because the plan was not promulgated as an approved procedure as defined by the MURR Administrative Operating Policies, and in part because of the schedule of the operators. Although the plan was discussed at the regular maintenance meeting which is normally attended by one or possibly more SRO's as operating staff representatives, not all members of the operating staff were informed of the discussions at that meeting. On the day of the event, 12 April, a maintenance meeting was held in the control room to allow all current shift operators to attend (including the Lead SRO at the time of the event). During this meeting it was stated that the shielding still had not been replaced, that the lower Z baskets could not be removed, and that no element should be stored in these baskets until the shielding had been restored, which was not scheduled until 17April.

3. A rather lengthy list of missed opportunities that would have prevented this event was tabulated. It should be noted that MURR management self-identified all of these and has instituted interim corrective measures for many of them.

   a. Management did not recognize that once one of the plan elements could not be achieved (removal of all of the Z baskets), the plan needed to be reassessed. As a minimum, some form of positive control of the use of the Z-basket, such as a lockout/tagout, should have been established.
   b. By using an informal plan rather than a procedure, not all involved personnel were assured of being informed of the plan requirements. In particular, at least several of the reactor operators were unaware of the need to keep fuel out of the Z basket region because of absence of the gamma cavity shielding. .
   c. While the change in the refueling plan which led to this event was authorized by the reactor physicist after he forgot about the cavity condition, in fact any SRO had the authority to change the refueling plan, and therefore could have used the Z basket since it was present and apparently available for use. Neither of the two SRO's who concurred with the change to the refueling plan was aware of the prohibition on using the lower Z-baskets because of the absence of the gamma cavity shielding.
   d. The facts that the shielding had been absent for six days prior to the event and that two refuelings had been successfully conducted using the specific refueling plan, were almost certainly factors contributing to the event. There apparently was an implicit presumption by management of universal understanding of the plant condition and the

reasons for the unusual refueling procedure. However, most of the SRO's interviewed were not aware the inspection rig had been used for refueling instead of the Z basket, or the reason why.

e. All the personnel directly involved in event (except one SRO) had performed regular shifts and inspection rounds during the 6-day period that the shielding was removed. While it is easy to presume that they should have noticed the absence of shielding, the area of the gamma cavity has not been an active experiment area for the life of the facility. As such, it is possible to understand how a few operators might inattentively pass through it unless specific requirements were established to inspect the area during this inspection operation. Nevertheless it stretches the bounds of credulity that all of the operators on this particular shift were completely unaware of the removal of the shielding, and therefore had no reason to question the proposed fuel transfer into the Z basket.

f. Even those who were aware of the shielding absence did not note the lack of shielding on the rounds report. However, several SRO's indicated that the operating crews do not routinely review this report. The SRO making the plant inspection is expected to verbally report any unusual conditions to the other operators, which was not done in this instance. And there was no other information mechanism, e.g., a status board, that could have provided a natural mechanism for identifying such plant conditions and reminding the operators about these conditions over an extended period of time.

g. The absence of an operations log entry on the 6 April shielding removal prevented the most obvious means of informing the operating staff, since this log is routinely reviewed by all operators. However, the fill-in SRO also did not review this log nor was he briefed prior to the refueling operation. This standard communication practice failed totally, i.e., both at the input and at the output.

h. A number of SRO's were aware of the shielding removal. Despite this, the failure to make a log entry was not corrected.

i. Based on questions of representatives of at least 4 crews, the shielding removal was not mentioned as part of any of the shift turnovers. As a secondary note, the practice of rotating the Lead SRO, often to a different person each day of the 3-day shift schedule, appears to have diluted central knowledge of plant conditions. Turnovers are routinely conducted with all operators present, which presumably results in everyone's knowing everything. Again, a potential means of communication failed to function.

j. The lack of an Operations Engineer who oversees day-to-day reactor operations activities placed more responsibility on the Interim Reactor Manager, the Reactor Physicist, the operations staff, and health physics to anticipate unusual plant conditions. While some of these duties were assigned to the reactor physicist, he did not perceive that he had authority on issues relating to this particular event (other than the fuel transfer plan). In general, the impression gained from discussions with the SRO's was that no added responsibilities were given to the operating staff or to the Lead SRO to compensate for this vacancy. This organizational deficiency contributed to the failure of another barrier that could have prevented this event.

k. Aside from the reactor physicist, each of the operators in the crew could have prevented the event, but failed to do so for various reasons.

One operator on the crew at the time of the change in the refueling plan was aware of the shielding removal but did not relate that condition to a need to avoid the use of the Z basket.

Another operator, while very experienced, had not been involved with recent plant operations because of another work assignment. Hence, he was unaware of current plant conditions at the time of his assignment to the refueling crew (necessitated by the temporary absence of another SRO).

The temporary absence of the initial Lead SRO, who was explicitly familiar with the gamma cavity condition, was particularly unfortunate. Had he been present when the reactor tripped, thereby necessitating the refueling, he would have had the opportunity to act as the last barrier to the fuel transfer that initiated this event.

Following the unscheduled reactor shutdown the Engineer/SRO coordinating the liner inspection specifically cautioned one (or perhaps both) of the two remaining crew members to use the inspection rig during the refueling. His scheduled absence prevented him from being present during the refueling.

The Lead SRO during the event was present during the maintenance meeting discussion 4 hours earlier that day when the gamma cavity and the absent shielding were explicitly discussed. He asserts that he was not aware of the cavity condition. Further, he remained unaware of the cavity condition following the event, until the stand-down ordered by the Interim Reactor Manager, despite information from the HP and the operator trainee during the event.

1. Once the ARMS alarm occurred, there was a fast response to survey the area (by an HP who was present for other reasons), to clear the beam port floor area of any personnel (by the HP and by a reactor operator trainee), and to move the element out of the storage location from where it was creating the radiation field at the beam port. The operator trainee checked the alarm in the control room, then proceeded to the level above the beam port floor to warn any occupants to leave. Finding no one on the beam port floor he returned to the bridge. At the same time the Health Physicist who was at the refueling bridge at the time of the alarm entered the control room, checked the source of the alarm, and then proceeded to the beam port floor to perform a survey at the request of the operators. As soon as she noticed radiation levels of 10 mrem/h near the bottom of the stairs she recognized the cause, went back to the control area, and notified the operators, who had already moved the element to what was thought to be a more shielded section of the Z basket. The operators asked the HP to make further surveys. There was little change in the radiation level at the stairs. The edge of the gamma cavity was 200 rem/h. She reported these results to the operators who had by that time moved the element back to its original position. Noticing that they were preparing to resume refueling, she asked whether they should. Receiving no answer, she immediately left to find the Health Physics Manager. We consider the actions of both the Health Physicist and the Trainee to be commendable.

2. Movement of the element to a second Z rack location might be questioned, but in essence access to the High Radiation Area was specifically controlled at that point. Both the HP and the operator trainee reported the absence of cavity shielding to the refueling crew at that time. There was no clear explanation as to why the element was moved to the second basket position (Z-2) rather than returning it to its original position. The fill-in SRO noticed a

change in the ARM reading during the transfer, which was a positive clue that the element was the source of the radiation.

3. We were unable to resolve a discrepancy in reconstructing the exact chronology of events from the time that refueling was resumed by the operating crew until the Interim Reactor Manager halted the refueling. Based on the refueling record, we estimate that 30-40 minutes elapsed from the initiation of the revised refueling to the stand-down, i.e., the completion of 12 of the refueling steps. But it seems unlikely that it would have taken that long for the Interim Reactor Manager to be found, informed, and for him to come to the refueling bridge. Despite this discrepancy, it is very clear that the operating staff did not report this event to the Interim Reactor Manager in a timely and direct manner, as required by MURR procedures and standard industry practice. He was only informed of the event via two secondary sources (the reactor physicist and the HP manager). Of concern is that there were other SRO's who were not aware of this requirement. Prior to the stand-down, no action was initiated to investigate the cause of the error in moving the fuel into the Z-basket.

4. A 40-minute stand-down was invoked, before resumption of refueling operations.

5. The HP staff contacted all persons who might have been present, or read the dosimetry of those that could not be directly contacted, and confirmed that no one had been present during the event.

6. Very critical remarks, regarding management and conduct of operations, were made in private by a SRO who was involved in the event. Subsequently (within two weeks), similar critical remarks were made by two researchers separately who sought out two individual members of the Review Team. The researchers indicated that they and others did not have the opportunity to meet with the team during the May visit but still would like to do so. We have not pursued any of these contentions since they fall outside the scope of the review requested by the University. They are included here to provide the University with a complete record.

7. The immediate corrective actions initiated by MURR management include, among others:
   a. An immediate stand-down event review and a follow-up direct briefing of all four shifts were carried out by the Interim Reactor Manager.
   b. A response team for an internal review was identified.
   c. Dual approval of non-routine activities is required from the Interim Reactor Manager and the Health Physics Manager.
   d. A second independent approval by an SRO is required for the fuel transfer procedure.
   e. Approval of any revision to the fuel transfer procedure is required by any two of the reactor physicist and SRO's.
   f. A more formalized shift turnover process has been established.
   g. A senior staff member has been assigned to temporarily fill the Operations Engineer vacancy.

   However, we consider the presence of an Operations Engineer to be the most significant corrective action in this immediate response, both in terms of placing a person with that

dedicated operations responsibility at that organizational level and in terms of freeing the Interim Reactor Manager for more overall facility management and less direct involvement in day-to-day operations.

1. The reactor restart was authorized by the Interim Reactor Manager who was present at the restart.

Discussion

1. The two dose measurements and the finger ring result gave reasonably consistent data, e.g., within ±25%. While a High Radiation Area clearly was present as a result of this event, and the area was posted and controlled as a High Radiation Area, the long history of inactivity in this area would not have led MURR personnel using this area to be aware of the condition, or to take normal precautionary measures, based on these postings and controls. The post-event placement of an ARM in the area opposite the gamma cavity was a particularly relevant corrective action.

2. Independent review of the dose data and MURR calculations indicates that a Very High Radiation Area condition did not exist. The timely response of the staff (thereby limiting the exposure period), the relatively low alarm point setting of the ARMS (thereby limiting the dose rate that might have gone undetected), and the relative inaccessibility of the 1-meter reference point inside the gamma cavity area resulted in the event radiation condition as not meeting the definition requirements for a Very High Radiation Area. However, this is clearly a fortuitous result of accidental circumstances rather than the product of careful forethought and design. Again, an appropriate engineered solution, i.e., the installation of a local ARM, has been carried out as an immediate remediation measure.

3. The immediate circumstances creating this event border on the incredible, e.g., four responsible people (three operators and the physicist) knew or should have known that the plant condition would result in a major radiation field if an element were placed in the Z rack. While the actions of each single person could reasonably be found to be a credible event, the actions of the four individuals taken together suggests an interpretation other than that. When combined with the multitude of opportunities to anticipate the possibility of this event prior to the involvement of the specific crew, this leads to a conclusion of one or more underlying and indirect causes in addition to those of the direct actions of operating staff. These include:

    a. Inadequate management oversight and control, as evidenced by the poor plan implementation, the generally mixed understanding among the operating staff of ongoing activities, and the lack of reporting of unusual events to management. While the plan was adequate and detailed, it was not followed. The lower Z basket could not be removed and no provisions were made to prevent an element from being stored in it. This is clearly a breakdown of management control.
    b. It does not appear that any one person, e.g., the Lead SRO, was specifically in charge of the refueling operations. It appears to have been a joint effort by the Lead SRO and the more experienced fill-in SRO. This may be attributed to the dilution of management

authority by the abolition of the former position of Shift Supervisor, which weakened the management of shift crew activities.

c. Inadequate involvement of operations staff in the planning of the liner inspection. Both the planning for the inspection job and the corrective actions taken following the event were primarily top-down directives. A true commitment by the operations staff to take responsibility for all aspects of facility operations would require involvement in the planning of these operations.
d. Inadequate awareness by operating staff of facility operations and plant conditions, as evidenced by the mixed awareness of the gamma cavity condition, the general unawareness of the impact of the shielding removal on the overall inspection plan, and the failure by a number of operators to relate the special loading procedure to an unusual plant condition . While this is another aspect of management oversight, it also reflects a lack of "ownership" by the operating staff in terms of viewing all activities involving the plant as being within their purview. With several notable exceptions, several of the operators give the impression that to them, it is "only a job."
e. Inadequate involvement of Health Physics in a non-routine operation is evidenced simply by the potential personnel exposure related to this event. Health Physics should maintain an aggressive program of full awareness of all aspects of facility operations, regardless of management actions. Unless HP functions are explicitly assigned elsewhere, the HP group should maintain an oversight awareness that can anticipate events such as this.
f. The decision to proceed with the refueling and to restart the reactor within a few hours after the event was apparently based on the steps taken to restore the shielding and return the facility to normal thereby eliminating the cause of the event. While the physical plant was in fact returned to pre-inspection, pre-event conditions and immediate corrective steps taken, there were, in our opinion, serious questions remaining regarding the overall conduct of operations that needed to be addressed prior to resumption of routine operations and to prevent reoccurrence of similar events.

1. The use of the Lead SRO concept instead of fewer supervisory SRO's places much more dependence upon the Operations Engineer in terms of awareness of plant status and communication among the operating staff. Clearly, every SRO does not have the aptitude and attitude to be a supervisory SRO, so that the rotating Lead SRO concept is not equivalent to that of having selected supervisory SRO's (i.e., not every SRO is a leader). Also, with 12-hour operating shifts, the burden on the Operations Engineer to complement and supplement the function of Lead SRO would seem to be a substantial challenge. The Operations Engineer is certainly an essential position whose functional responsibilities need to be clearly defined, but the ramifications this issue were not explored during this event review beyond the subject of transfer of information between Lead SRO's.

2. The only time the operators assemble as a group is for the biennial relicensing training, and then it is done it two shifts. While this is undoubtedly more efficient from the viewpoint of operations scheduling, the lack of a full staff meeting and the attendant interaction among all personnel compounds the communication and ownership challenges presented by the shift schedule.

3. It was stated that the liner inspection is carried out infrequently, i.e., once in 25 years. For that very reason the inspection should have been carefully planned, executed and managed.

4. Vacancies in the Reactor Manager and Operations Engineer positions should not have been allowed to reduce the level of supervision of the operators and of special operations, nor should they have been allowed to be a contributing cause to the occurrence of this event.

5. The Reactor Physicist did not stop the refueling operation prior to its resumption even though he was aware of the event at that point and acknowledged that he had the authority and responsibility to stop work. Instead he elected to notify the Interim Reactor Manager. During this time ¾ of the refueling was completed without proper evaluation and management. The 30-40 minute delay before refueling was suspended remains unexplained. It appears difficult for the Reactor Physicist to perform both that function and a number of the duties of the Operations Engineer.

6. It can be taken as a given that each operating shift needs a supervisor, and this person is the first level representative of line management. Among this person's responsibilities is the need to assure that the reactor is operated safely and within the prescribed limits of the license, tech specs, and operating procedures. This person has the responsibility to identify conditions that present potential problems and to ensure that appropriate administrative measurers are taken to correct them. If MURR's assertion is accepted that every SRO acts in this role when they function as Lead SRO, then it must be concluded that every SRO has that responsibility. Given the failure of essentially every SRO on the staff to identify and correct the potential condition that existed for six days it must be concluded that at least one or more of the following is true: 1) the presumption of equal qualification among SRO's is not accurate, 2) there is an inherent deficiency in this particular management structure, and 3) there is a generic deficiency in the training and operations attitude of the staff. Although upper management must assume a significant share of responsibility for this event, we believe that the SRO's must also recognize that their failure to perceive and carry out their management responsibilities (within the scope of a Lead SRO) was also a contributing factor. This is supported by the fact that a number of them were aware of the shielding condition and did not take steps to initiate an administrative action to inform the staff and to force administrative corrective controls.

Conclusion

In our view this event, or something similar, was assured of happening due to a wide-spread loss of focus of individual responsibilities, caused by the organizational stress brought on by a number of staff vacancies, and the breakdown of management control related to these vacancies. While the stated ultimate and overall responsibility by the MURR director is acceptable and the norm, in practice, this organizational position is too distant to be relevant to the day-to-day performance of the operating staff. A closer focal point of responsibility and authority is needed, and with the number of existing vacancies and the extended use of acting personnel, it is clear that such a focal point was not present.

In addition, the practice of rotating the Lead SRO, often to a different person on each day of the 3-day shift schedule, diffused ownership and accountability, diluted central knowledge of plant conditions, and weakened management control at the most fundamental level of plant operation.

The immediate cause of the event was the inability to remove the Z basket as called for in the plan, and the failure by management to institute necessary alternative administrative and protective controls.

We consider this event, and particularly the circumstances surrounding it, most serious. It should not happen at this or any other research reactor facility. We believe, however, that the immediate and interim measures taken, and the augmented and refocused management team, provide adequate assurance that the reactor is being and can be operated safely.

Finally, based on careful examination of findings and analysis of available data related to this event, we have determined that there was no overexposure, no potential for overexposure, and a Very High Radiation Area did not exist.

Recommendations

Note: Some of these recommendations have already been implemented. They are included here to reinforce them. Also, several of these recommendations were passed on during the exit interview and subsequent telephone conversations.

Our major recommendations consist of the following. We consider that it is essential that these be promptly addressed.

1. A line management organizational structure with clearly defined and documented responsibilities should be established. The management head and line management should have complete responsibility and be accountable for all reactor activities. This includes reactor and radiation safety, adhering to the license requirements, technical specifications and applicable regulations, and safeguarding personnel and the public. Once established, the organizational structure should be incorporated into the reactor procedures and disseminated widely to all concerned. Contact with regulatory agencies and other relevant groups should be made by line management. ANSI standards, ANS-15.1, and ANS-15.11 provide very useful information and guidance.

2. Stronger leadership within the operations group, e.g., the operators and the Operations Engineer, is essential. A single SRO as Lead or Reactor Shift Supervisor should be designated by management for each shift. There should not be a general rotation among the SRO's on the shift into this position. The selection should be based on qualifications, experience, and leadership. The individual, preferably called the Shift Supervisor, should clearly be in charge of the shift with line management responsibility and authority. The Shift Supervisor as the representative of management should be the focal point for all activities at the facility and should be notified beforehand and approval sought for any activity that might affect the reactor facility.

3. Resumption of the refueling operation by the operating staff as if nothing had happened and without careful evaluation and without notification of management is inexcusable. This is clearly a significant error that reflects deeper deficiencies. Accordingly, the quick return to routine operation even with corrective measures was not the best course of action. A deliberate and a more in-depth evaluation of the circumstances relating to the event to make certain that there would be no re-occurrence would have been a better course.

   Under no circumstances should the production schedule override safety considerations or create the slightest potential for unsafe conditions. The reactor should remain in a stand-down until all relevant issues are resolved and safety is assured. This should continue to be the policy for MURR operations. The Director or the Licensee should issue a directive to this effect to all MURR personnel.

   The following added recommendations should also be seriously considered by the University:

Strengthening Management Control

4. Upper management, e.g., the Operations Engineer and above, should have direct involvement in the day-to-day activities. Upper management should review all logs, records, and data sheets at least weekly.

5. A procedure should be established to clearly indicate who in management is authorized to approve procedures and changes thereto. Dual approval is not recommended.

6. Only one individual should approve the refueling loading procedure and sheet, and changes thereto. If changes by the SRO are permitted beforehand, such as altering storage locations, these should be indicated on the loading sheet and any such changes should be documented. Only the authorized individual should make all other changes.

Improving Response to Off-normal Events

7. The following should be emphasized during training or by other means regarding any out-of--the-ordinary condition or situation: prompt notification of management, prompt notification of Health Physics, and immediate investigation, reporting, mitigation, correction, and protective measures.

Strengthening Operations

8. The MURR director should conduct a detailed staffing review to ensure that adequate staffing is present to safely operate the facility, both at the operator level and at the supervisory levels. Based on the staffing for the 6-12 April period, there is an indication of frequent staffing adjustments that could reflect inadequate operator staffing.

9. Activities having potential safety impact should be conducted under a formal plan that has complete organization review and control. In most organizations this consists of two choices: an approved procedure or a Radiation Work Permit. However, any equivalent MURR

alternative (such as Standing Orders) would be acceptable.

10. More direct and widespread involvement by the operating staff in planning non-routine operations and in revising normal operating procedures should be seriously considered. The operators represent the first line of defense in the safe operation of the facility and should continue to be fully involved with all aspects of operations conduct. MURR should consider expanding the operating staff to allow greater participation by the operators in planning and carrying out maintenance and facility modifications.

Improving Communications

11. A summary of shift activities should be prepared and documented, preferably in a bound logbook. This should form the basis for the shift turnover. Incoming personnel should review previous logs, records, and instructions.

12. On rounds, anything out of the ordinary should be recorded and continue to be recorded until it is corrected. All rounds information should be reported to and reviewed by the shift supervisor.

13. A plant status board should be installed in the control room. The board should reflect plant status at all times including changes, out-of-service equipment and other unusual conditions, and any other information pertinent to the operation of the facility. The status board should be kept current.

14. A mechanism for communication among various personnel should be considered. For example, the HP came back up three flights of stairs to report survey results while the element had already been moved without her report. This occurred again at the next survey. The amount of time could have been considerably reduced had there been direct communications available.

15. Formal, structured meetings with the full operating staff should be held on a regular basis, e.g., at least biennially, to discuss all aspects of facility operations. Such a meeting should be held at the earliest possible date to do an in-depth and detailed review of all issues related to this event.