UNIVERSITY *of* MISSOURI

RESEARCH REACTOR CENTER

January 17, 2011

U.S. Nuclear Regulatory Commission
Attention: Document Control Desk
Mail Station P1-37
Washington, DC 20555-0001

Reference: Docket 50-186
University of Missouri – Columbia Research Reactor
Amended Facility License R-103

Enclosed is a report, as required by University of Missouri Research Reactor Technical Specification 6.1.h (2), regarding the discovery of a variance in the performance specifications contained in the Hazards Summary Report and Technical Specifications.

If you have any questions, please contact John L. Fruits, the facility Reactor Manager, at (573) 882-5319.

Sincerely,

Ralph A. Butler, P.E.
Director

RAB/djr

Enclosures

NOTARY PUBLIC NOTARY SEAL STATE OF MISSOURI
MARGEE P. STOUT
My Commission Expires
March 24, 2012
Montgomery County
Commission #08511436

Margee P. Stout

A020
NRR

1513 Research Park Drive Columbia, MO 65211 Phone: 573-882-4211 Fax: 573-882-6360 Web: http://web.missouri.edu/~murrwww

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REFERENCE: Docket 50-186
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SUBJECT: Written communication as required by the University of Missouri Research Reactor Technical Specification 6.1.h (2) regarding the discovery of a variance in the performance specifications contained in the Hazards Summary Report and Technical Specifications

University of Missouri Research Reactor (MURR) Technical Specification (TS) 6.1.h (2) states that "*The Directorate of Licensing shall be informed in writing within thirty (30) days of its observed occurrence any substantial variance disclosed by operation of the reactor from performance specifications contained in the Hazards Summary Report or the Technical Specifications*." The following report details an error that was discovered in the MURR Safety Limit Analysis while answering a relicensing Request for Additional Information (RAI) question and the subsequent actions after the error was confirmed. The current MURR Safety Limit curves were developed in 1973 by the NUS Corporation[1] for the 1974 uprate in power from 5 to 10 MW. The curves establish the maximum allowable power limits for safe operation under different combinations of four (4) measureable operating parameters – reactor power, primary coolant flow, reactor inlet water temperature, and pressurizer pressure. These limits provide the basis for determining the Limiting Safety System Settings (LSSS) and operating limits for 10 MW operation. This error will therefore require a license Amendment to revise the Safety Limits and the LSSS for reactor inlet water temperature; however, it should be noted that at <u>no</u> time did MURR exceed or have the potential to exceed the Safety Limits.

In December 2010 while assisting MURR in answering relicensing RAI 16.1, Dr. Earl Feldman, Argonne National Laboratory (ANL), felt that he may have identified a potential error in the 1973 NUS Corporation Safety Limit Analysis. The NUS Corporation used the Advanced Test Reactor (ATR) preliminary flow tests, which were performed in 1964 and 1966 by Croft and Waters, to show that the subcooled burnout heat flux was 0.6 of the burnout heat flux predicted

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[1] F. R. Vaughan, *Safety Limit Analysis for the MURR Facility*, NUS-TM-EC-9, prepared for the University of Missouri by the NUS Corporation, 4 Research Place, Rockville, Maryland, 20850, May 1973.

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by the Bernath correlation. This supported using a more conservative 0.5 of the Bernath correlation to develop the MURR Safety Limits. If the local value of heat flux anywhere in the fuel element exceeds 50% of the local value of critical heat flux (CHF), as predicted by the Bernath correlation, then flow instability is assumed to have occurred. The error that Dr. Feldman discovered is a discrepancy between the variable D_i as it is defined by Bernath and how it was apparently misinterpreted by the NUS Corporation when developing the Safety Limit curves.

In the Bernath paper[2] D_i is defined in the nomenclature section to be the "diameter of heated surface (heated perimeter divided by π), ft. (in.)". Other authors define "heat diameter", D_{heated}, to be four (4) times the flow area divided by the heated perimeter. This definition, D_{heated}, is analogous to hydraulic diameter, D_e, which is defined as four (4) times the flow area divided by the wetted perimeter. For a test section consisting of liquid flowing inside a round heated-wall tube, the two definitions of heated diameter lead to the same value. However, when the flow cross section is a thin annulus formed by a round heating element inside a round enclosure or in the case of a thin rectangular duct heated along the two longer sides, such as a fuel element coolant channel, this alternative definition can produce a value of heated diameter that is an order of magnitude smaller. In the case of MURR, Bernath's D_i for MURR fuel element coolant channel No. 2 is equal to 1.1294 inches whereas D_{heated}, as used by the NUS Corporation, produces a value of 0.1755 inches.

Correcting to the Bernath heated diameter definition with three (3) of the four (4) LSSS variables at their corresponding limits (i.e., pressurizer pressure at 75 psia, total core flow rate at 3200 gpm, and reactor inlet temperature at 155 °F) the Safety Limit for power was recalculated using the NUS methodology, which includes the current Hazards Summary Report's extremely conservative peaking factors. The recalculated power is reduced from 14.892 MW to 12.376 MW (our LSSS for power is 12.5 MW).

On January 3rd, new Safety Limit curves were immediately developed based on the correct Bernath D_i definition. By reducing the reactor inlet temperature LSSS from 155 °F to 142 °F, a Safety Limit of 14.942 MW was established with the other three (3) LSSS variables set at their limits. This provides a 2.44 MW margin between the 12.5 MW LSSS and the Safety Limit. This margin is actually slightly greater than the previous NUS calculated Safety Limit of 14.89 MW. A Reactor Operations Standing Order was issued which instructed the control room operators to manually scram the reactor should reactor inlet temperature reach 136 °F (normal operating value is 120 °F, which is automatically maintained). The Standing Order would remain in effect until such time as the exact discrepancy could be verified. Also on this date, MURR contacted the U.S. Nuclear Regulatory Commission (NRC) to apprise them that an error may exist in the Safety Limit analysis and that our revised analysis was currently being reviewed by ANL.

These new Safety Limits are based on new peaking factors developed by the ANL/MURR team. As described in the August 31, 2010 submittal to RAI 4.17 regarding the NUS Corporation

[2] Louis Bernath, "A Theory of Local-Boiling Burnout and Its Application to Existing Data," *Chemical Engineering Progress Symposium*, Series No. 30, Volume 56, pp. 95-116 (1960).

developed Safety Limits, the peaking factors used were extremely conservative because they utilized a combination of unrealistic or impossible peaking factors determined by three different two-dimensional diffusion code models, which was the only code method available in the early 1970's. Since 2006, MURR has been actively collaborating with the Reduced Enrichment for Test and Research Reactor (RERTR) Program on the conversion from highly-enriched uranium (HEU) to low-enriched uranium (LEU) fuel. During this time, the ANL/MURR team has benchmarked the MURR HEU fuel and reactor core design performance. We now have more accurate peaking factors that can be used in determining appropriate Safety Limits based on the following:

- The ANL/RERTR group and MURR have completed HEU benchmarking work using REBUS/DIF3D, MCNP and PLTEMP to support the LEU conversion analysis.
- We have excellent agreement for our current 775 gram U-235 fuel element operating in both the earlier 1971 reflector arrangement and the current "2008" reflector arrangement.
- We have benchmarked the MURR mixed core burnup fuel cycle and determined the peaking factors. Our worst case peaking is in a mixed core with a fresh fuel element running adjacent to one in its last week of operation before reaching the 150 MWD burnup limit.
- *Combining the new MURR/ANL Feasibility Analysis*[3] *peaking factors with the corrected Bernath/BOLERO/Waters & Croft methodology for safety limits, a new set of Safety Limits were developed that meet the current criteria.*

On January 4th, a teleconference was held between staff of the NRC, Washington Safety Management Solutions and MURR. MURR further explained the potential error to the NRC and shared the more conservative Safety Limits and reactor inlet temperature LSSS that the MURR was currently operating under until the error could be reviewed and validated by ANL.

Later that day, after his review was complete, Dr. Feldman identified the following error in our initial recalculations: the azimuthal hot stripe to hot plate peaking factor of 1.07 had been multiplied to two different component peaking factors that were then combined to calculate the overall peaking factor. This resulted in an effective hot strip to hot plate peaking factor of 1.145 instead of the actual factor of 1.07. Correcting for this error by using the actual 1.07 hot stripe factor only once, the MURR Safety Limits were again recalculated. It was determined that based on the new limits the only change required was reducing the reactor inlet temperature LSSS from 155 °F to 153 °F. The actual scram set points are set more conservatively than the LSSSs and the current reactor inlet temperature scram set point is 148 °F, so no adjustment was necessary to meet this proposed revision to the LSSS. Only revising the Safety Limit table values and curves is required.

On January 5th, a teleconference was held between staff of the NRC and MURR. MURR informed the NRC that ANL had identified the above error in our new Safety Limit calculations.

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[3] Feasibility Analysis for HEU to LEU Conversion of the University of Missouri Research Reactor (MURR), University of Missouri-Columbia Research Reactor, Columbia Missouri, September 30, 2009.

With the new Safety Limit curves, in conjunction with reducing the reactor inlet temperature LSSS from 155 °F to 153 °F, MURR has a new Safety Limit of 14.955 MW with all four (4) LSSS variables at their limits. This provides a 2.45 MW margin between the 12.5 MW LSSS and the Safety Limit (actual high power scram is set at 119% of 10 MW, or 11.9 MW). This new Safety Limit with the other three (3) variables at the LSSS is actually greater than the previous NUS calculated Safety Limit of 14.89 MW.

Based on this analysis, the current scram set point of 148 °F provides a sufficient margin for safety and does not need to be adjusted to meet a reduction in the new reactor inlet temperature LSSS of 153 °F. Also on this day, a Reactor Operations Standing Order was issued that administratively implements the new reduced Safety Limit curves and LSSS for reactor inlet temperature until such a time when a license Amendment can be submitted. The following table provides a comparison of the four (4) LSSS variables with the administratively established scram set points and least conservative scram set point, based on its range.

	Temp.	Pressure	Flow[1]	Power
LSSS	155 °F	75 Psia	1625 gpm/loop 3200 gpm total core flow	125%
Actual Scram Set Point	148 ± 2 °F	63 ± 1 Psig	1700 ± 25 gpm/loop 3400 ±50 gpm	119 ± 1%
Least Conservative Scram Set Point	150 °F	62 Psig/ 76.7 Psia	1675 gpm/loop 3350 gpm	120%

Note 1: There are two primary coolant loops and 50 gallons of their combined flow goes through the demineralizer flow loop, hence bypassing the reactor core. Therefore 1625 gpm/loop corresponds to 3200 gpm through the core.

With the Bernath correlation D_i corrected to its proper value, and using the extremely conservative peaking factors determined by three different two-dimensional diffusion code models and with the scram set points at their least conservative settings, the Safety Limit would be 13.236 MW. Therefore, with all of the LSSS variables at their least conservative scram settings, a 1.24 MW margin exists between the high power scram set point of 120% and the Safety Limit. Using the ANL/MURR team's conservative benchmarked peaking factors, and with all of the LSSS variables at their least conservative scram settings, a 3.82 MW margin exists between the high power scram set point of 120% and the Safety Limit

On January 7th, the Reactor Action Subcommittee was convened to apprise them of the situation. The Reactor Action Subcommittee is a subset of the Reactor Safety Committee, which acts in behalf of the Reactor Advisory Committee in an advisory capacity to the Director of MURR in matters that pertain to the safe operation of the reactor and that may require immediate consideration. Only one member of the Reactor Safety Subcommittee was unable to attend this meeting. Details of the error, including development of the new Safety Limits and the teleconferences with the NRC, where discussed with the Subcommittee.

MURR is currently developing the license Amendment that will revise TS 2.1, "Reactor Core Safety Limit," and TS 2.2, "Limiting Safety System Settings." If there are questions regarding this report, please contact me at (573) 882-5319 or fruitsj@missouri.edu. I declare under penalty of perjury that the foregoing is true and correct.

Sincerely,

John L. Fruits
Reactor Manager

ENDORSEMENT:
Reviewed and Approved

Ralph A. Butler, P.E.
Director

xc: Reactor Advisory Committee
Reactor Safety Subcommittee
Dr. Robert Duncan, Vice Chancellor for Research
Mr. Craig Basset, U.S. NRC
Mr. Alexander Adams, U.S. NRC

NOTARY PUBLIC NOTARY SEAL STATE OF MISSOURI

MARGEE P. STOUT
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