RCM Apvd ISSUED 2011/08/01

911206
Revision 0

UNIVERSITY OF MARYLAND REACTOR ANALYSIS AND SUPPORT

Support Calculations for MUTR's Maximum Inlet Temperature

Prepared by: TRIGA Reactor Division of General Atomics
Address: PO Box 85608
San Diego, CA 92186-5608

Prepared under
Contract No. 00096970
for the U.S. Department of Energy

GA PROJECT 39364

GENERAL ATOMICS

GENERAL ATOMICS

GA 1485 (REV. 08/06E)

ISSUE/RELEASE SUMMARY

☐ R & D ☐ DV&S ☒ DESIGN ☐ T&E ☐ NA	APPVL LEVEL	DISC	QA LEVEL	SYS	DOC. TYPE	PROJECT	DOCUMENT NO.	REV
	2	N	IB	-	DCR	39364	911206	0

TITLE:
Support Calculations for MUTR's Maximum Inlet Temperature

CM APPROVAL/ DATE	REV	PREPARED BY	APPROVAL(S) ENGINEERING	QA	PROJECT	REVISION DESCRIPTION/ W.O. NO.
7 ISSUED AUG 01 2011	0	J. Crozier	J. Bolin	K. Partain	T. Vega	Initial Issue A39364 -0410

CONTINUE ON GA FORM 1485-1

NEXT INDENTURED DOCUMENT(S)

COMPUTER PROGRAM PIN(S)

☐ GA PROPRIETARY INFORMATION
THIS DOCUMENT IS THE PROPERTY OF GENERAL ATOMICS. ANY TRANSMITTAL OF THIS DOCUMENT OUTSIDE GA WILL BE IN CONFIDENCE. EXCEPT WITH THE WRITTEN CONSENT OF GA, (1) THIS DOCUMENT MAY NOT BE COPIED IN WHOLE OR IN PART AND WILL BE RETURNED UPON REQUEST OR WHEN NO LONGER NEEDED BY RECIPIENT AND (2) INFORMATION CONTAINED HEREIN MAY NOT BE COMMUNICATED TO OTHERS AND MAY BE USED BY RECIPIENT ONLY FOR THE PURPOSE FOR WHICH IT WAS TRANSMITTED.

☒ NO GA PROPRIETARY INFORMATION

TABLE OF CONTENTS

LIST OF FIGURES

ACRONYMS/ABBREVIATIONS

Acronym/Abbreviation	Description
DNBR	Departure from Nucleate Boiling Ratio
GA	General Atomics
MUTR	University of Maryland TRIGA Reactor
PRNC	Puerto Rico TRIGA reactor
RAI	Request for Additional Information
SAR	Safety Analysis Report
TAMU	Texas A&M University
TRIGA	Training Research Isotope General Atomics

1 PURPOSE

The purpose of this calculation file is to document the thermal hydraulic analyses that were performed by General Atomics (GA) in support of the activities necessary to answer the University of Maryland TRIGA Reactor (MUTR) Safety Analysis Report (SAR) submittal Request for Additional Information (RAI) question regarding the maximum inlet temperature. The nuclear analyses used in these analyses are reported in "Support Calculations for MUTR's Request for Additional Information" (Ref. 1).

Additional explanation and calculations were requested for the question: "For a DNBR of 2.0, what is the inlet (bulk fluid) temperature under natural circulation conditions? This temperature would be used as the Limiting Condition for Operation."

2 METHODS - RELAP5 /MOD3.3-PATCH03 CODE

RELAP has been an industry standard code for the analysis of power reactors. Its development and improvements have occurred over at least 25 years. The code performs steady state and transient reactor neutronics, thermal hydraulics and fuel rod thermal analysis. It allows for very general modeling – multiple rod and channel configurations and heat structures for rod thermal performance. The code has sophisticated single and two phase flow modeling both in its continuity, momentum and energy formulations, as well as for wall and interfacial friction and heat transfer correlations. The version RELAP5/MOD3.3-Patch03 is the latest available validated version of the code (Ref. 2) (Ref.3).

3 RESULTS - RELAP5

The latest version of the RELAP Code (RELAP5/MOD3.3-Patch03) was used to evaluate the MUTR thermal/hydraulic performance for this RAI.

The RELAP model for this request contains an average powered rod representing the entire core and a hot rod representing the maximum powered rod. The MUTR TRIGA reactor uses four rod fuel element clusters as used in the Neutron Radiography Facility at Idaho National Laboratory (Ref. 4), Puerto Rico Nuclear Center (PRNC) (Ref. 5), and Texas A&M University (TAMU) TRIGA reactors (Ref. 6). As such, the RELAP modeling of the average and hot rods used in the RELAP model for these previous HEU-to-LEU conversions is used for the MUTR RELAP model, see Figure 3-1.

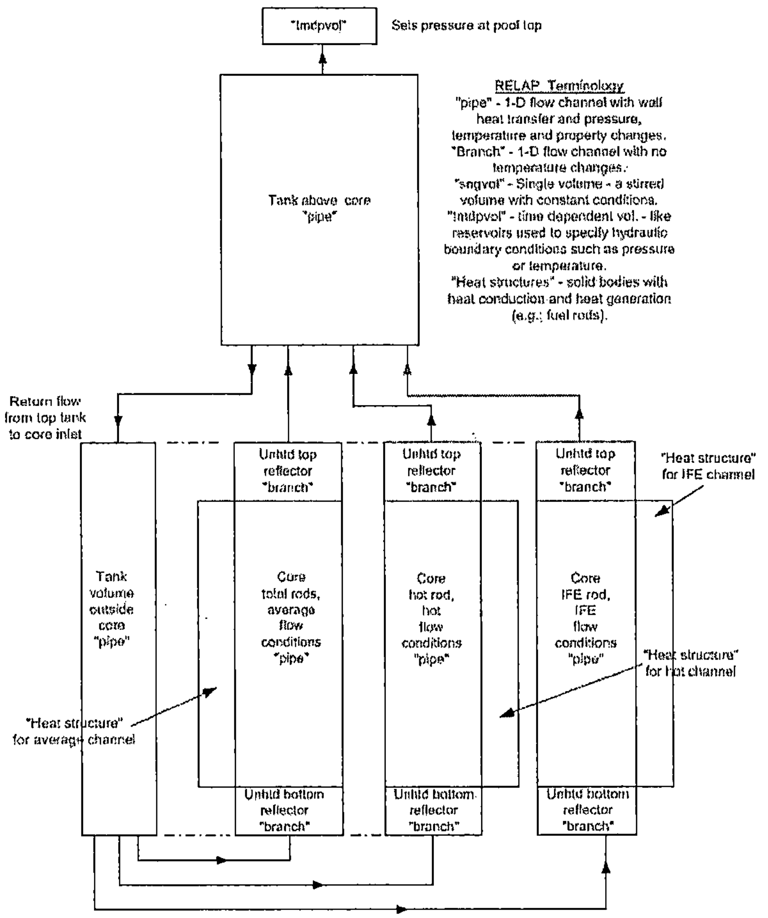

Figure 3-1 RELAP Natural Convection (No Primary Coolant Flow) Block Diagram

Some of the important conditions in the MUTR RELAP model include:

- The average powered rod represents 93 rods fuel rods.
- Hot rod power factor taken as 1.597.
- Departure from Nucleate Boiling Ratio (DNBR) calculated using Bernath correlation, (Ref. 7)
- Natural circulation core cooling.
- Tank diameter – 7 ft., water depth from surface to reactor top – 17.1 ft.
- 14.7 psia pressure above tank water.

Using these conditions, a RELAP run was performed at a reactor power of 600 kW for various pool temperatures. The RELAP results were used to construct a plot of pool temperature versus DNBR, Figure 3-2. The plot shows that the inlet pool temperature can reach 92 °C and only yield a DNBR of 2.96, at 600 kW. This is approximately equal to a DNBR of 5.92 for a reactor power level of 300 kW. At a pool inlet temperature of 95 °C, the RELAP5 code fails to generate a stable solution due to the large vapor volume. The results demonstrate significant vapor formation. Additionally, the hot channel flow rate, quality, and bulk temperature vary irregularly along the flow channel. This RELAP5 behavior may be indicative of parametric fluctuations in the actual core at this power level and pool inlet temperature. Based on the RELAP model, the maximum theoretical achievable inlet temperature of the MUTR reactor would be 92 °C, at which point DNB would be predicted to occur. Associated RELAP run files and MathCad calculations are listed in Appendix B and included in a local subdirectory.

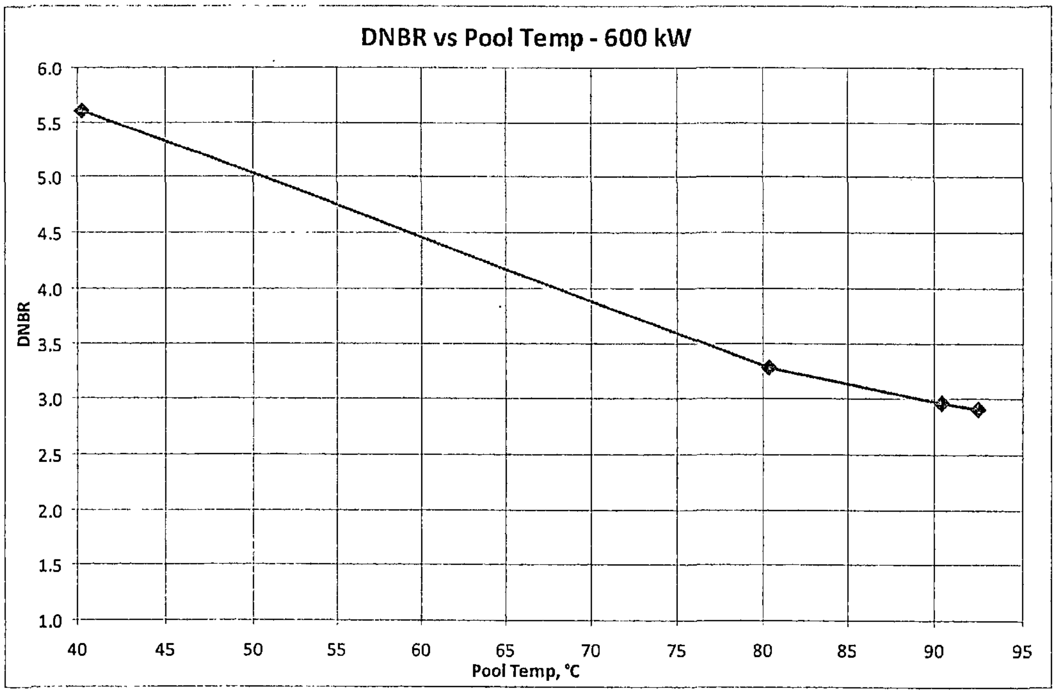

Figure 3-2: MUTR DNBR as a Function of Pool Inlet Temperature

4 CONCLUSIONS

The analyses herein demonstrates that the MUTR TRIGA reactor reaches a DNBR of 2.96 when operating at a maximum pool inlet temperature of 92 °C and a power level of 600 kW. Hence, for normal operations at a power level of 300 kW and a maximum pool inlet temperature of 92 °C, the DNBR is greater than 2.0. Based on the data from Figure 3-2, with a maximum pool inlet temperature of 92 °C, a DNBR of 2.0 could not occur.

5 REFERENCES

1. Ellis, C. "Support Calculations for MUTR's Request for Additional Information," GA 911199, December 2010.
2. "RELAP5/MOD3.3 Code Manual Volume 3: Developmental Assessment Problems," NUREG-CR-5535/Rev. P3 – Volume III, 2006.
3. Tuey, J. "RELAP5/MOD 3.3 Code Verification Report," General Atomics, 09490R00001, Rev. A, July 2011
4. Crozier, J. and Ellis, C., "LEU Upgrade of the NRAD Reactor Final Report," GA Document No. 911193 Revision 0, February 2011
5. Safeguards Summary Report for the TRIGA Reactor at the Puerto Rico Nuclear Center, Mayaquez, Puerto Rico, PRNC 123, April 1969.
6. "Safety and Accident Analyses Report Texas A&M University (TAMU) Conversion from HEU to LEU Fuel," Texas A&M University, Docket 50-128, December 2005.
7. Bernath, L.B., "A Theory of Local Boiling Burnout and Its Application to Existing Data", Chem. Eng. Progress Symposium Series No. 30, Vol. 56, pp 95-116., 1960

6 INDEPENDENT REVIEW

John Bolin –

Review results (Thermal Hydraulics):

No comments on the thermal hydraulic analyses.

APPENDIX A - INDEPENDENT REVIEW REPORT

CALCULATION REVIEW REPORT

GA 1543 (12/99E)

TITLE	DOCUMENT NUMBER	REV
Support Calculations for MUTR's Maximum Inlet Temperature	911206	0

INDEPENDENT REVIEWER:

NAME: John Bolin

ORGANIZATION: 480 MODULAR HELIUM REACTOR

REVIEWER SELECTION APPROVAL:

MANAGER: Tony Veca (NAME) [signature] (SIGNATURE)

REVIEW CRITERIA	YES	NO	COMMENT
REVIEW CALCULATION METHOD	☒	☐	
COMPARE CALCULATION METHOD WITH SIMILAR APPROVED METHOD	☐	☒	
PREPARE ALTERNATE CALCULATION USING DIFFERENT METHOD	☐	☒	
REVIEW ASSUMPTIONS:			
- UNIQUELY IDENTIFIED	☒	☐	
- ADEQUATELY DESCRIBED	☒	☐	
- REASONABLE	☒	☐	
- UNCONFIRMED SPECIFICALLY IDENTIFIED	☒	☐	
REVIEW INPUTS	☒	☐	
REVIEW RESULTS/CONCLUSIONS	☒	☐	
VERIFY COMPUTER CODE INFORMATION CORRECT	☐	☒	
VERIFY QUALITY ASSURANCE LEVEL	☒	☐	
	☐	☐	
	☐	☐	
	☐	☐	

RECORD OR ATTACH ☐ LIST OF DOCUMENTS USED IN REVIEW (AND/OR) ☐ ALTERNATE CALCULATIONS

OTHER REMARKS:

☒ CALCULATION FOUND TO BE VALID AND CONCLUSIONS TO BE CORRECT (OR) ☐ EXCEPT AS NOTED ABOVE.

INDEPENDENT REVIEWER John M Bolin (SIGNATURE) DATE 7/28/11

FINAL REVIEW BEFORE ISSUE/RELEASE:

INDEPENDENT REVIEWER John M Bolin (SIGNATURE) DATE 7/28/11

APPENDIX B - CALCULATION FILE LISTINGS

Calculation files in support of Section 3.

File Description	File Type	DVD Directory Location
MUTR RELAP DNBR input file 600kW, 40C	RELAP5 input	MUTR_dnbr_600kW_40C.inp
MUTR RELAP DNBR output file 600kW, 40C	RELAP5 output	MUTR_dnbr_600kW_40C.out
MUTR RELAP DNBR input file 600kW, 80C	RELAP5 input	MUTR_dnbr_600kW_80C.inp
MUTR RELAP DNBR output file 600kW, 80C	RELAP5 output	MUTR_dnbr_600kW_80C.out
MUTR RELAP DNBR input file 600kW, 90C	RELAP5 input	MUTR_dnbr_600kW_90C.inp
MUTR RELAP DNBR output file 600kW, 90C	RELAP5 output	MUTR_dnbr_600kW_90C.out
MUTR RELAP DNBR input file 600kW, 92C	RELAP5 input	MUTR_dnbr_600kW_92C.inp
MUTR RELAP DNBR output file 600kW, 92C	RELAP5 output	MUTR_dnbr_600kW_92C.out
MUTR MathCAD file	MathCAD	Bernath dnbr.mcd

GENERAL ATOMICS
P.O. BOX 85608 SAN DIEGO, CA 92186-5608 (858) 455-3000