



PULSED TRANSIENT THERMAL ANALYSIS OF THE ACRR 44-INCH LEAD-BORON BUCKET

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Abstract

The Annular Core Research Reactor (ACRR) is an under moderated pool type reactor capable of pulses with energy yields exceeding 300 MJ. Because the ACRR has an epithermal neutron spectrum, different materials can be used to tailor the neutron energy spectrum to meet experimental needs. These experiment fixtures, colloquially called buckets, have operational limits to prevent softening and melting of materials caused by heating due to neutron and gamma reactions with materials. This work presents a transient thermal analysis performed on the frequently used 44-inch lead-boron bucket (LB-44) using Ansys Mechanical 2022 to more accurately determine operational limits required to prevent melting and softening of the materials. For the analysis the heating of the materials was determined using Monte Carlo N-Particle (MCNP) 6.3.

Introduction

The ACRR, shown in figure 1, is frequently used to perform radiation effects experiments. Specific radiation environments are achieved with the use of spectrum modifying buckets. The LB44 bucket (drawing shown in figure 3) produces a high fast neutron flux ratio (as shown in Fig. 4) within the ACRR's central cavity, as the Pb and B₄C powder lining filter out gamma-rays and thermal neutrons, respectively. The radiation absorption of these materials within the bucket causes heating, which can limit the throughput of experiments at the ACRR. This analysis aims to obtain a transient thermal model and obtain approximate material temperatures of the LB44 bucket during an ACRR 300 MJ pulse. This information will provide further insight regarding operational safety guidelines and material heating during pulsed irradiations in a fast neutron environment.

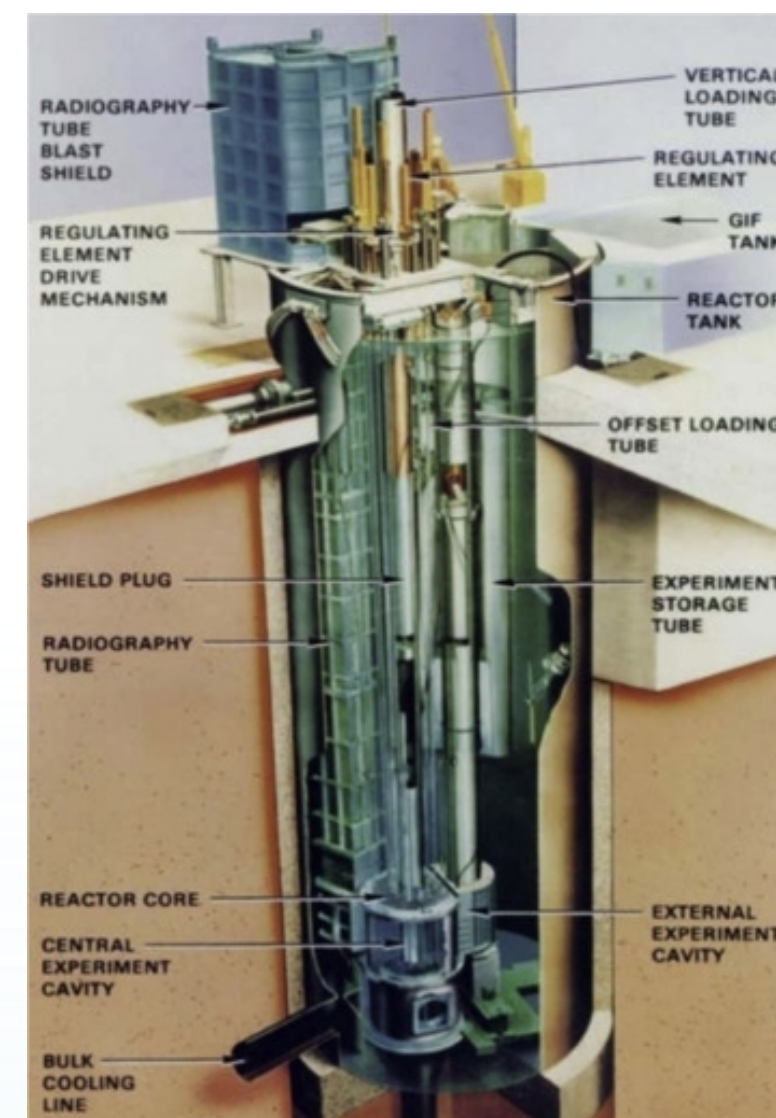


Figure 1: ACRR Conception Sketch

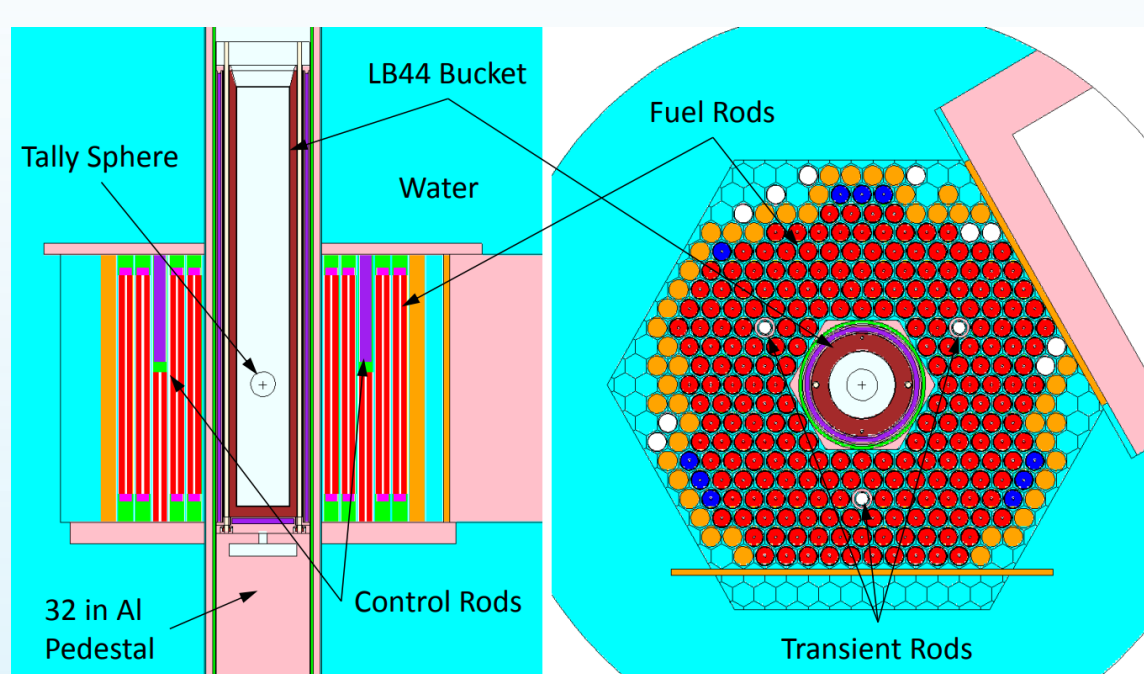


Figure 2: MCNP Model of the LB44 Bucket in the ACRR

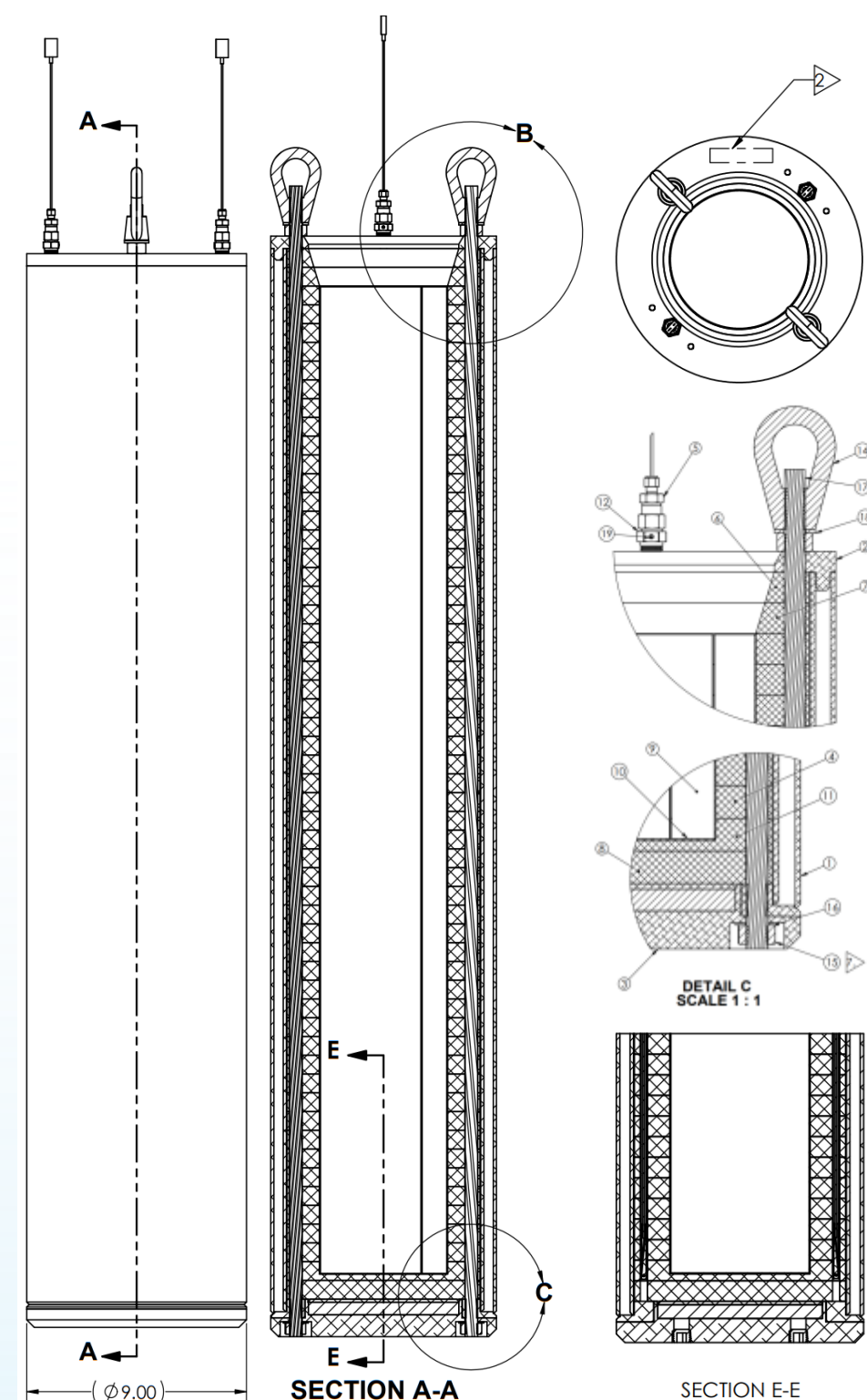


Figure 3: LB44 bucket technical drawing

Methodology

- Material Properties: Ansys Granta MI material database used to obtain thermal properties for B₄C powder, Pb, Al 6061 T6 in bucket, as well air and steel in cavity
- Geometry: LB44 CAD model imported and simplified in Ansys SpaceClaim, hexahedral meshing performed using Ansys Mechanical, surrounding air gap and cavity liner are generated in Ansys Spaceclaim
- Heating Inputs: Energy depositions for each segment calculated using MCNP 6.3, power profile data obtained with Razorback simulations of a maximum pulse (\$3.50)
- Thermal Loads: A constant temperature of 22°C assumed at the outer cavity lining along with a water convection load, conduction acts as primary heat transfer method through air gap, air convection applied to top of LB44 bucket

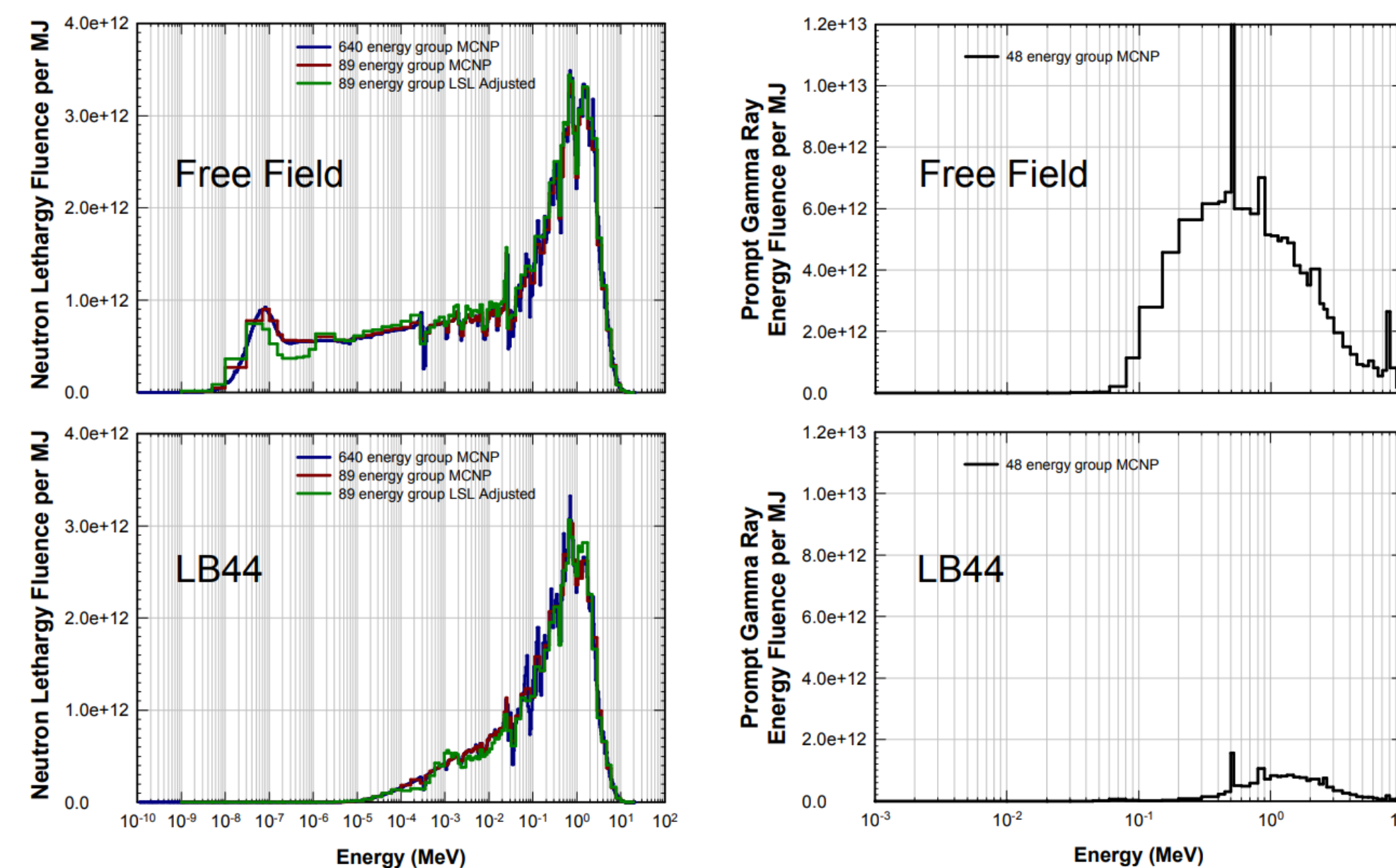


Figure 4: Comparison of the reduction of neutron and gamma fluence in free field (without modifying the spectrum) and the LB44 bucket. Plots obtained from SAND2017-4044C.

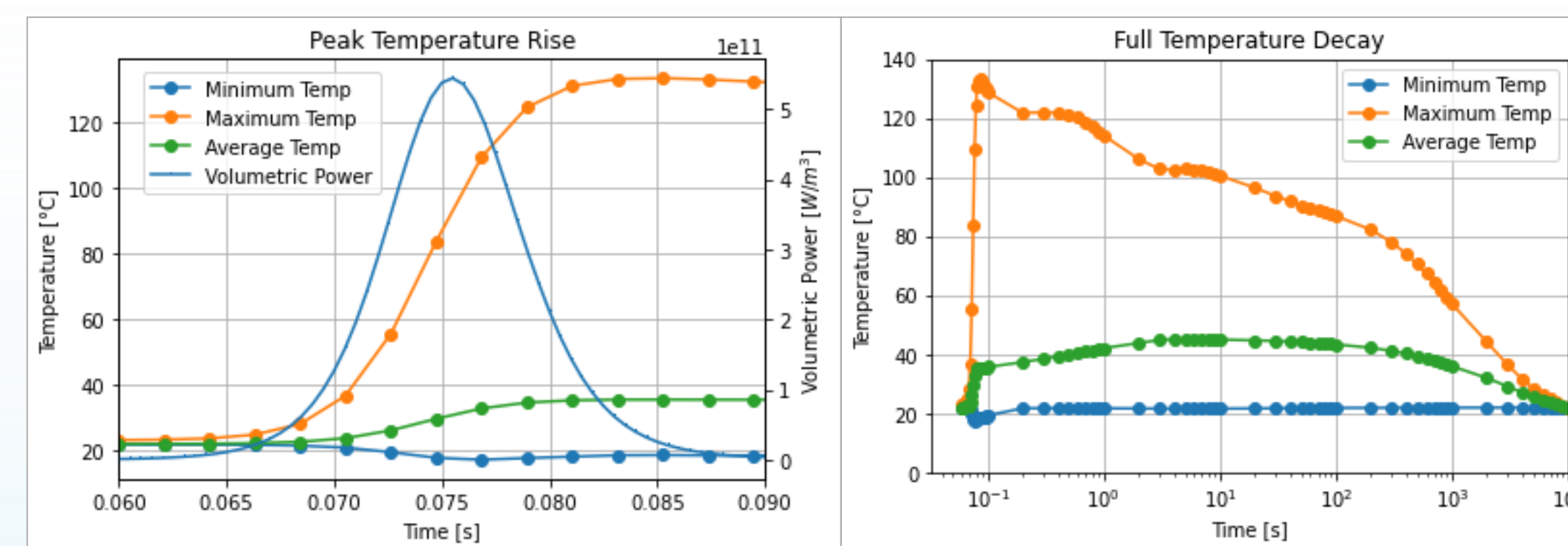


Figure 5: Temperature decay in the LB44 bucket during a \$3.50 pulse with respect to time. The graph demonstrates the quick increase in temperature during the pulse (peak heating value at 75.5 ms) and temperature decay after several hours.

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Results

- P_{mat} equation used to determine internal heat generation for each of the materials, e_{dep} obtained using MCNP
- Figure 7 displays a temperature gradient throughout each of the materials for the LB44 bucket. The temperature and heating graph (figure 4) displays the change in temperature with time
- As expected, the B₄C powder experiences the most heating, since ¹⁰B has a high thermal neutron capture cross section and high energy exoergic reaction (2.79MeV)
- Results from the analysis are validated by the heating equation below

$$P_{mat} = e_{dep} \rho E_{pulse} \left(\frac{P_{vol}}{\int_{t_0}^{t_f} P_{vol} dt} \right)$$

$$Q = mc\Delta T \Rightarrow \Delta T = \frac{Q}{mc} = \frac{e_{dep} E_{pulse}}{c}$$

$$e_{dep} = \text{energy deposited per unit mass per pulse} \left[\frac{J}{g \cdot MJ} \right]$$

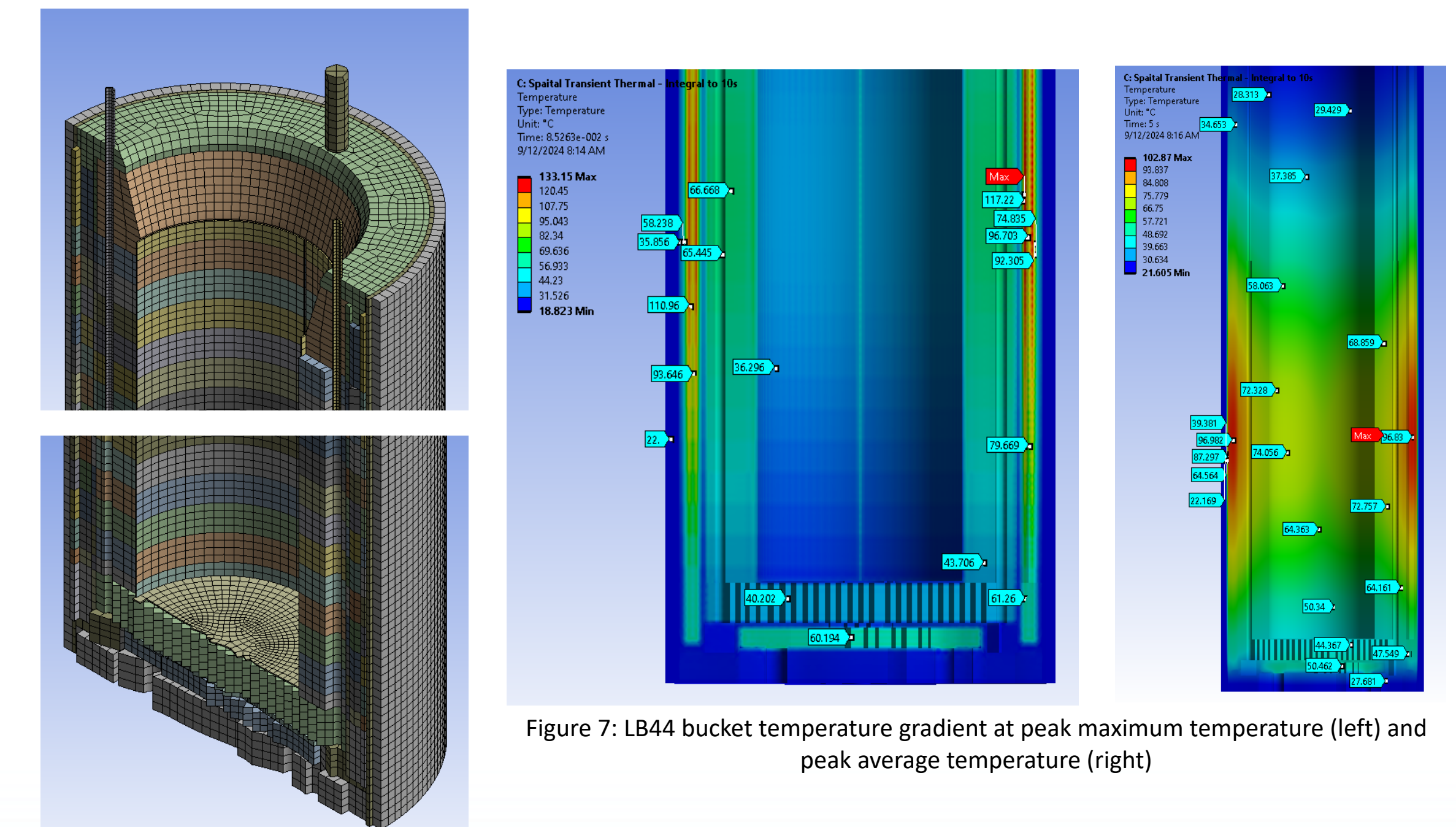


Figure 6: Mesh for the top and bottom half of the LB44 bucket, air gap, and cavity liner

Figure 7: LB44 bucket temperature gradient at peak maximum temperature (left) and peak average temperature (right)

Summary and Future Work

In summary, during a 300 MJ pulse at the ACRR, the LB44 bucket is heated due to absorption of thermal neutrons and gamma radiation within the B₄C powder and lead lining. Heat decay occurs due to the water surrounding the central cavity, and heating in the bucket is conducted outwards through the surrounding air gap. The simulation indicates that each material is heated to a peak temperature (approximately 120°C in B₄C 13 in. above the bottom face of the LB44 bucket), and the temperature is distributed throughout the entire bucket until it reaches uniform temperature throughout. An hour after pulsing, an average temperature of approximately 28.0 °C is reached in the fixture. These estimates can be used to provide a more accurate prediction of temperature with respect to time and potentially be used to increase the throughput at the ACRR. Furthermore, the work could be extended to some of the other buckets frequently used at the ACRR to modify the neutron environment (CdPoly, PLG-1), as well as performing active temperature measurements to compare with empirical data.