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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 2, 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 1) produces a high fast neutron flux ratio (as shown in Fig. 3) within the ACRR's central cavity, as the Pb and B_4C 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.

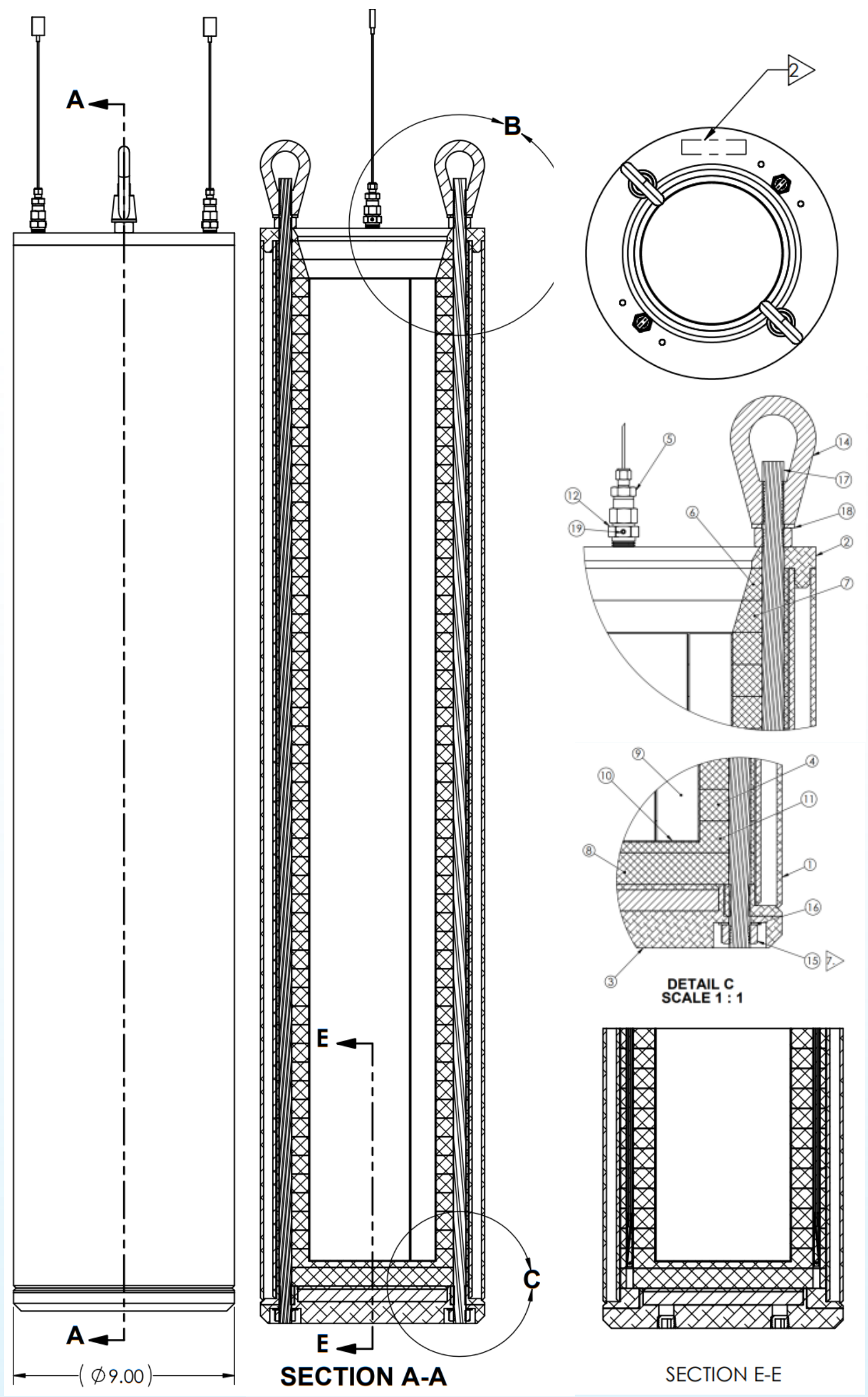

Figure 1: LB44 bucket technical drawing

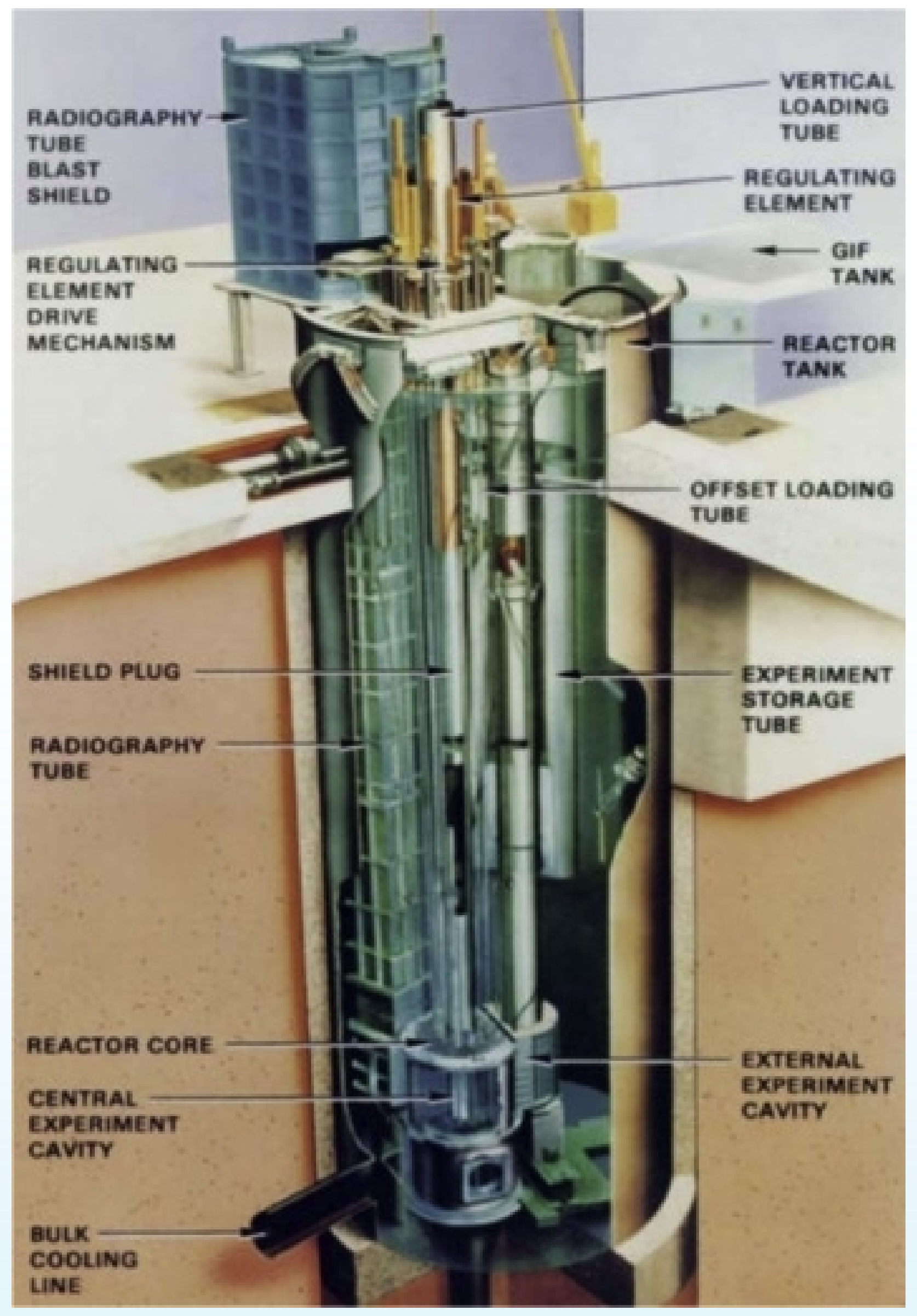

Figure 2: Conception sketch of ACRR

Methodology

- Material Properties: Ansys Granta MI material database used to obtain thermal properties for B_4C powder, Pb, Al 6061 T6 in bucket
- Geometry: CAD model imported and simplified in Ansys SpaceClaim, hexahedral meshing performed using Ansys Mechanical
- Heating Inputs: Energy depositions in material calculated using MCNP 6.3, power profile data obtained from Razorback simulations of a \$3.50 pulse
- Thermal Loads: Stagnant, horizontal air convection load applied at the PbB top, constant temperature assumed at base

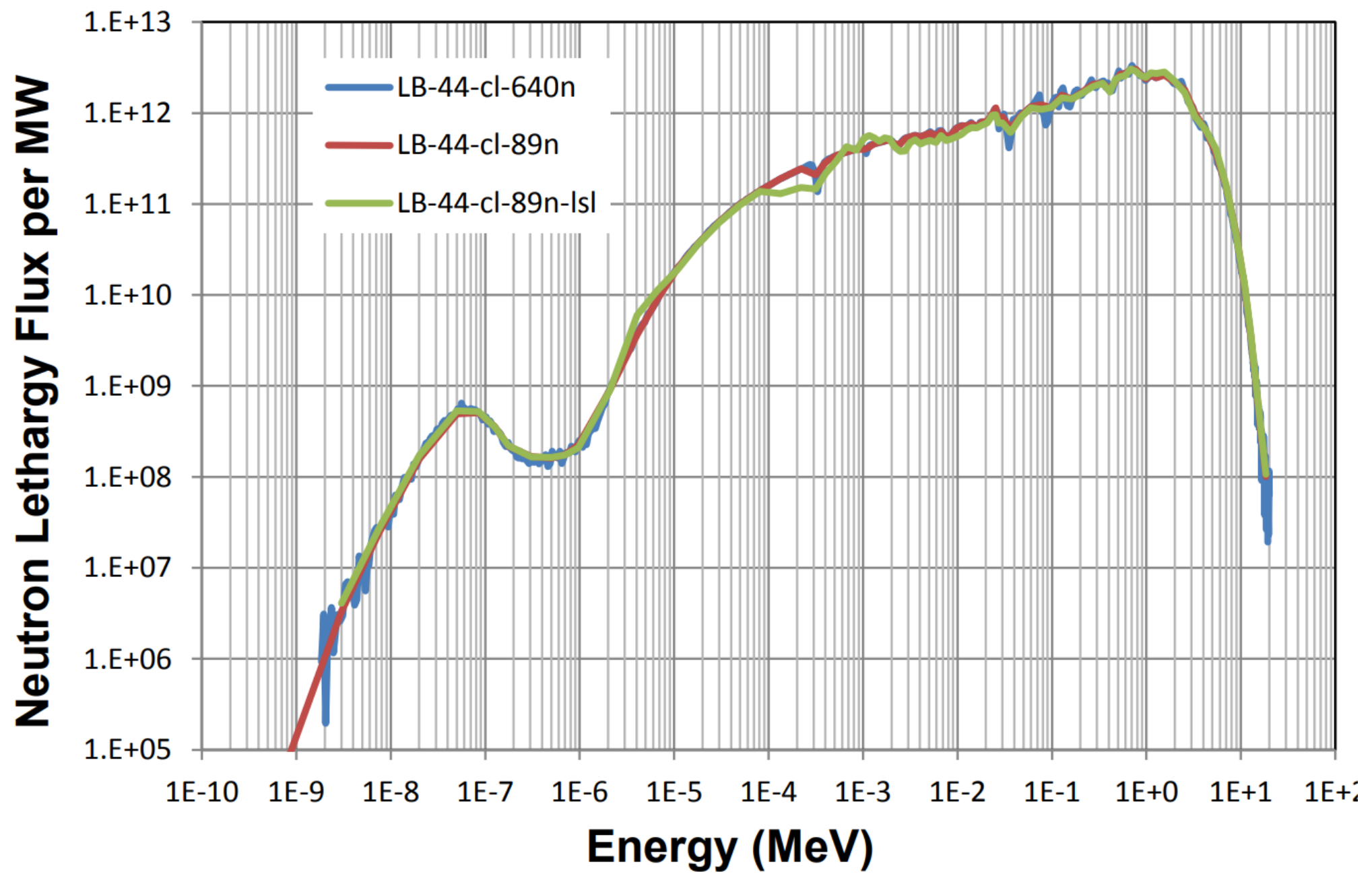

Figure 3: Modified neutron flux with the LB44 bucket in a log-log scale. Note the significant reduction in thermal neutrons (2.5E-8 MeV) and peak near the fast neutron range of 1 MeV.

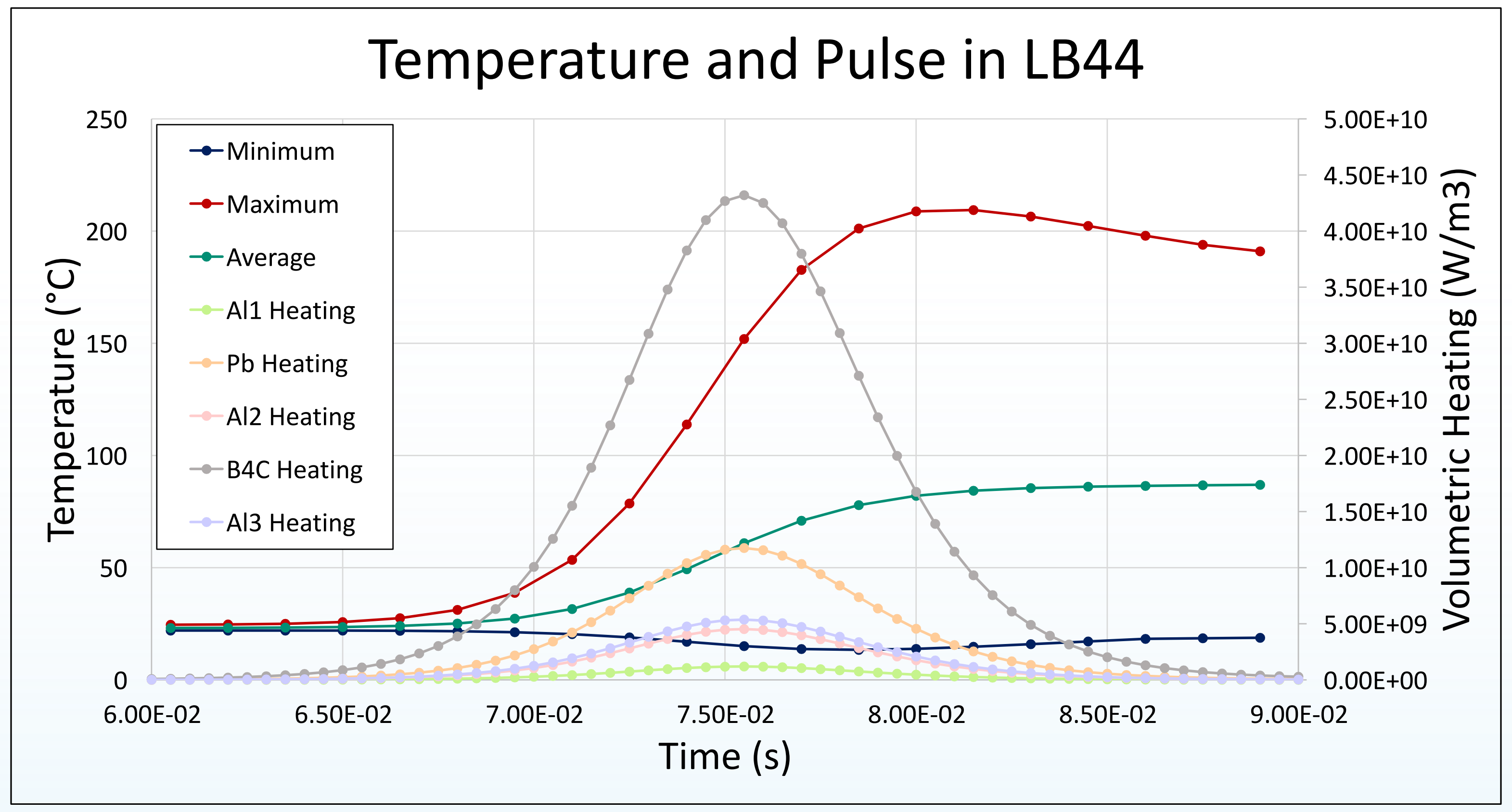

Figure 4: Temperature and Heating in the LB44 bucket during a \$3.50 pulse with respect to time. The graph demonstrates the maximum temperature (peaks at 209.39°C) and average temperature graphs overlapped with the volumetric power plot.

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Results

- P_{mat} determines equation used to determine internal heat generation for each of the materials, e_{dep}- obtained using MCNP
- Figure 6 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 B_4C powder experiences the most heating, since ^{10}B has a high neutron capture cross section
- Results from the analysis are validated by the heating equation below

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

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

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

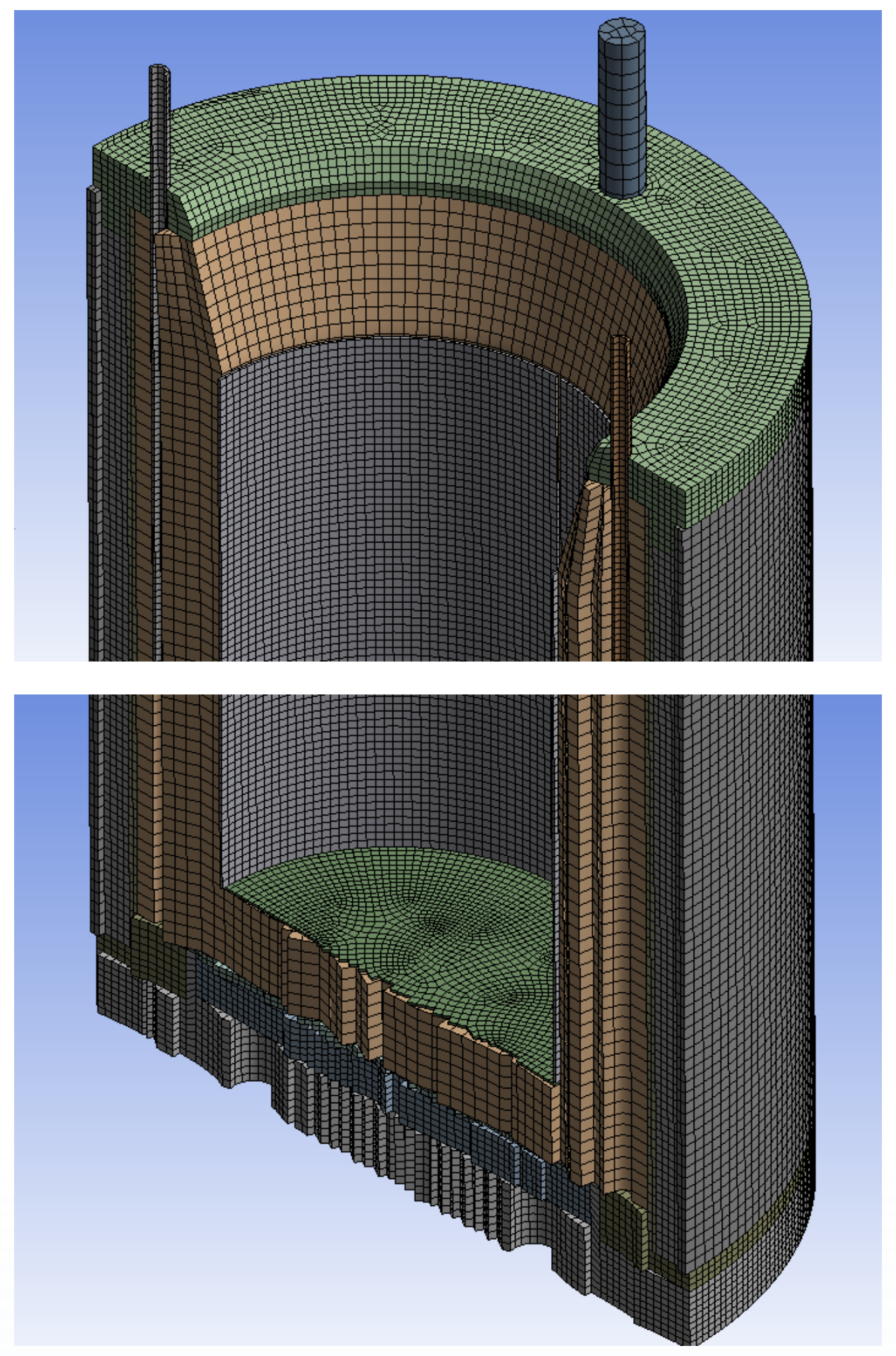

Figure 5: Top and bottom half of the LB44 bucket after meshing in Ansys

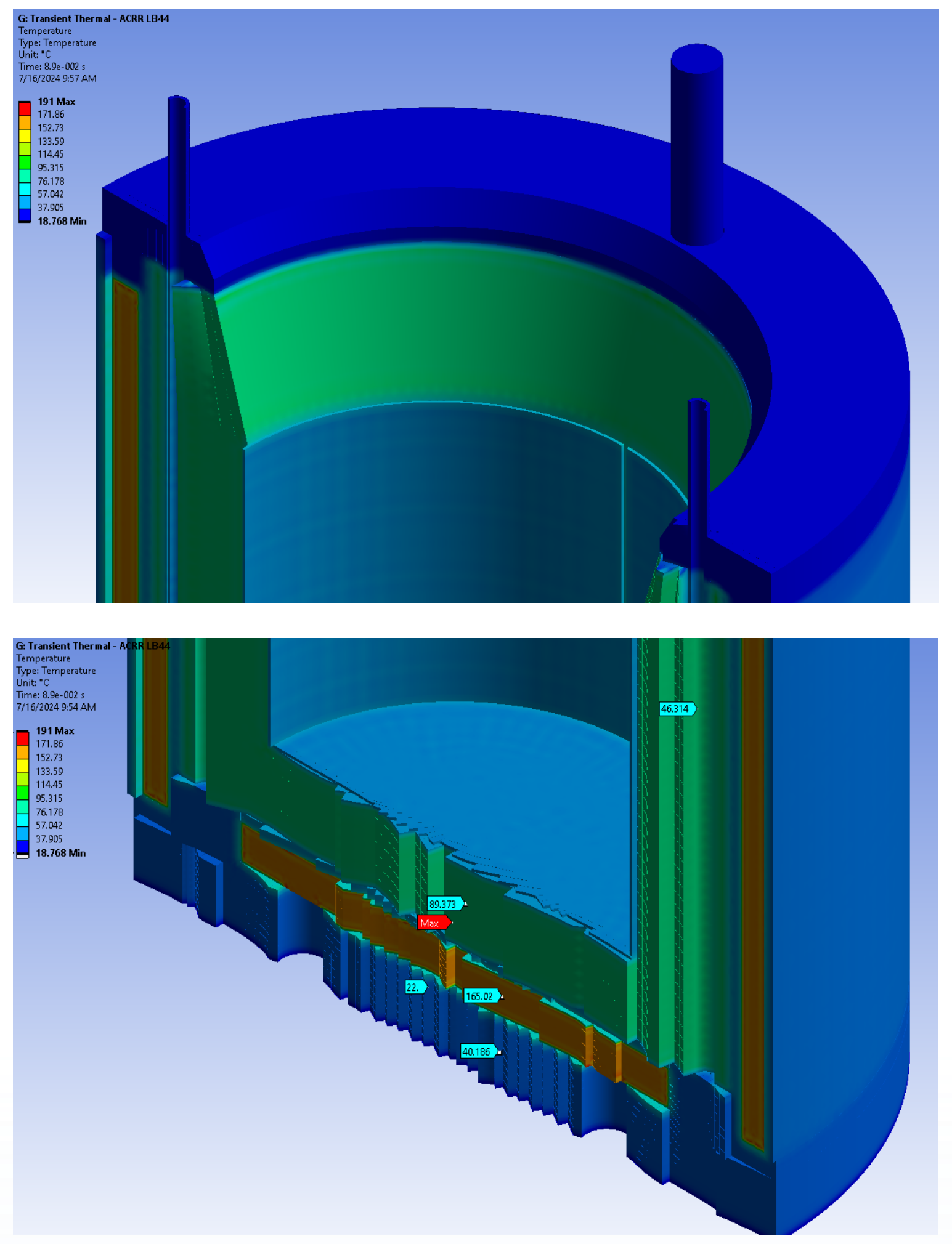

Figure 6: Top and bottom half of the LB44 bucket temperature gradient from the transient thermal analysis

Summary and Future Work

In summary, during a 300 MJ pulse at the ACRR, the LB44 is heated due to absorption of thermal neutrons and gamma radiation within the B_4C powder and lead linings within the bucket. Notably, the B_4C is seen to rise to temperatures that are, on average, around 165°C, and the lead walls to approximately 89°C. The aluminum varies in temperature, depending on its location, but the top maintains near constant room temperature (due to a convection load), the inner sleeve heats to around 47°C, the outer walls to around 42°C, and inner wall/disk to approximately 50°C. 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).