Low enriched uranium (LEU) fuels are being developed to reduce the use of highly enriched uranium in power generation to reduce proliferation risks. Challenges arise in providing sufficient fissile U in LEU without reactor redesign. As such, a novel monolithic fuel plate design employs LEU alloyed with 10 wt. % Mo. Throughout fabrication of these fuel plates, metallurgical transformations and reactions take place as a result of elevated temperatures during processing. The transformations include decomposition of the metastable body-centered cubic $\gamma$ phase in the fuel and metallurgical interactions at interfaces between fuel plate components. This work aims to provide further understanding into physical and mechanical behavior of these constituents as they relate to fuel plate processing and performance. Fuel plate processing includes alloying the U, applying a Zr diffusion barrier, and cladding in AA6061 via hot isostatic press. Experimental Zr barriers were applied via electroplating, plasma-spraying, or roll-bonding and characterized using optical and electron microscopy, demonstrating that roll-bonded Zr exhibits the most favorable properties. During fabrication, regions of the $\gamma$-U decompose into $\alpha$ and $\gamma'$ which revert to $\gamma$ during annealing or irradiation and heat treatments were designed to induce similar transformations and characterize them using x-ray diffraction and electron microscopy, resulting in a model describing the reversion as a function of time and temperature. The mechanical properties of the fuel and other constituent phases were investigated via instrumented indentation of fuel plates. Phases that occurred in small, discontinuous regions were fabricated in diffusion couples for more reliable indentation. The kinetic and mechanical data produced from this study can be used to estimate the phase constitution of the fuel plates and subsequently, its behavior in response to fabrication and irradiation.