Thermal Barrier Coatings have been used for decades to impose a thermal gradient between the hot combustion gases and the underlying superalloy substrate in engine turbine blades. Yttria Stabilized Zirconia (YSZ) is an industry standard high temperature ceramic for turbine applications. The protective coating is adhered to the substrate using a nickel based alloy bond coat. Through exposure to high temperature, a Thermally Grown Oxide (TGO) layer develops at the bond coat/YSZ interface. Large residual stresses develop in these layers due to thermal expansion mismatch that occurs during cool down from high temperature spraying and cyclic operating conditions. Despite their standard use, much is to be determined as to how these residual stresses are linked to the various failure modes. This study developed techniques to monitor the strain and stress in these internal layers during thermal gradient and mechanical conditions representing operating conditions. The thermal gradient is applied across the coating thickness of the tubular samples from infrared heating of the outer coating and forced air internal cooling of the substrate. While thermal and mechanical loading conditions are applied, 2-dimensional diffraction measurements are taken using the high-energy Synchrotron X-Rays and analyzed to provide high-resolution depth-resolved strain. This study will include fatigue comparisons through use of samples, which are both 'as-coated' as well as aged to various stages in a TBC lifespan. Studies reveal that variations in thermal gradients and mechanical loads create corresponding trends in depth resolved strains with the largest effects displayed at or near the bond coat/TBC interface. Single cycles as well as experiments targeting thermal gradient and mechanical effects were conducted to capture these trends. Inelastic behavior such as creep was observed and quantified for the different layers at high temperatures. From these studies more accurate lifespan predictions, material behaviors, and causes of failure modes can be determined. The work further develops measurement and analysis techniques for diffraction measurements in internal layers on a coated tubular sample which can be used by various industries to analyze similar geometries with different applications.