The characterization of post-detonation environments after the detonation of a nuclear device has the potential to provide forensic signatures on device materials to support monitoring nuclear explosion events. Analytical methods in laser spectroscopy offer in-field, standoff detection capabilities to address this nuclear nonproliferation and counterproliferation mission needs by measuring chemical and isotopic compositions of fallout debris. Through the process of pulsed laser ablation, a luminous high-temperature micro-plasma is generated that emits light at characteristic energies as it de-excites. These photons are collected to produce a spectrum of absorption or emission lines that acts as a fingerprint for the vaporized sample. The interpretation of signatures in this optical spectrum is strongly dependent on the complex transient conditions of the laser-produced plasma (LPP), while plasma properties are highly sensitive to experimental parameters and environmental conditions. Intermixing between reactive plasma species and oxygen leads to the formation of oxides that alter the composition of the plasma plume, consequently introducing molecular signatures that can overlap and obscure atomic transitions present in the optical spectrum. Depending on thermodynamic and atmospheric properties, molecular formation may follow different pathways and kinetics, further complicating the spectroscopic analysis. This work aims to explain the hydrodynamical intermixing processes between the plasma and ambient gas species that drives the morphology of the chemical reaction zone and oxidation kinetics in laser ablation plasmas. Experimental measurements using laser-induced breakdown spectroscopy, fast photography, and shadowgraphy will be combined to monitor the rapidly changing chemical composition of the LPP as well as the thermodynamic properties of the shock-heated gas surrounding the plasma plume. In addition, high-fidelity multi-physics simulations using coupled fluid hydrodynamics, thermodynamics, chemical kinetics, and shock physics models will be presented alongside experimental results to further explain turbulent and chemical processes in the reactive multi-phase fireball.tectonic interpretation, earthquake hazard assessment, and tomographic imaging of Earth's internal structural heterogeneity. Traditional methods of event location, employed by global agencies that monitor global seismic activity, are rooted in algorithms developed a century ago, and do not routinely benefit from modern seismogram-cross-correlation approaches to measuring travel times, or from methods that estimate precise relative event locations. Here I describe an application of intermediate-period surface-wave cross correlation to measure inter-event travel-time delays and estimate precise relative earthquake locations in a remote area of the Mid-Atlantic Ridge. A prolific seismic swarm illuminated a 100-km-long stretch of the ridge starting in September 2022 and continuing into 2023. Precise relative locations of more than 100 earthquakes, interpreted together with their moment-tensor source characteristics, are used to register the earthquakes geographically to tectonic features revealed in detailed bathymetric maps of the area. The resulting earthquake locations are probably accurate to within a few kilometers, representing an order-of-magnitude improvement over routine catalog locations. The well-located and geographically registered earthquakes of the swarm are used to locate earlier events with high precision, demonstrating an approach that can be transported to other regions. When a group of earthquakes in a region has adequately registered, future events can be located routinely with improved accuracy.