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Non-Invasive Imaging of Reactor Cores Using Cosmic Ray Muons

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Cosmic ray muons penetrate deeply in material, with some passing completely through very thick objects. This penetrating quality is the basis of two distinct, but related imaging techniques. The first measures the number of cosmic ray muons transmitted through parts of an object. Relatively fewer muons are absorbed along paths in which they encounter less material, compared to higher density paths, so the relative density of material is measured. This technique is called muon transmission imaging, and has been used to infer the density and structure of a variety of large masses, including mine overburden, volcanoes, pyramids, and buildings. In a second, more recently developed technique, the angular deflection of muons is measured by trajectory-tracking detectors placed on two opposing sides of an object. Muons are deflected more strongly by heavy nuclei, since multiple Coulomb scattering angle is approximately proportional to the nuclear charge. Therefore, a map showing regions of large deflection will identify the location of uranium in contrast to lighter nuclei. This technique is termed muon scattering tomography (MST) and has been developed to screen shipping containers for the presence of concealed nuclear material. Both techniques are a good way of non-invasively inspecting objects. A previously unexplored topic was applying MST to imaging large objects. Here we demonstrate extending the MST technique to the task of identifying relatively thick objects inside very thick shielding. We measured cosmic ray muons passing through a physical arrangement of material similar to a nuclear reactor, with thick concrete shielding and a heavy metal core. Newly developed algorithms were used to reconstruct an image of the "mock reactor core," with resolution of approximately 30 cm.