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First neutron computed tomography with digital neutron imaging systems in a high-radiation environment at the 250 kW Neutron Radiography Reactor at Idaho National Laboratory

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The Neutron Radiography Reactor (NRAD) at Idaho National Laboratory (INL) was designed for epithermal neutron radiography for examination of highly-radioactive irradiated nuclear fuel elements. Radioactive samples are remotely lowered into the East and North Radiography Stations (ERS and NRS, respectively), and a rail transfer system remotely positions radiography cassettes into the detector position for indirect radiography. The indirect transfer method with film has been used at NRAD for around forty years, but recent efforts seek to develop digital camera-based neutron imaging systems. Two initial camera detector systems were built using an inexpensive but high-quality scientific CMOS camera with robust shielding, and tests were performed in collaboration with Heinz Maier-Leibnitz Institut of Technische Universität München.

The first tests were performed in 2017 in the NRAD's ERS using a 10 cm field-of-view camera-based system with an inexpensive scientific CMOS camera shielded by lead bricks and borated polyethylene plates. The camera and motor stages were controlled by a Raspberry Pi computer. The first series of digital neutron images was successfully acquired, but radiation field was so high that the Raspberry Pi computer crashed after acquiring only 44 images despite being shielded behind a 10 cm layer of lead bricks.

A much improved camera box was designed based on lessons learned from the efforts in 2017, which was constructed and installed in NRAD's NRS in 2018. This imaging system included a two-mirror architecture with a longer optical path to reduce scattered radiation to the camera, more robust radiation shielding, and a translation stage for remote focusing of the camera lens. A downscaled version of the ANTARES instrument control at MLZ was installed using a Laptop and three Raspberry Pi computers to control the imaging system components. The very first digital neutron computed tomography at INL was successfully acquired, consisting of 420 neutron radiographs acquired in 4 hours. These first tests with camera-based neutron imaging systems have demonstrated the potential to both increase the throughput of radiography by an order of magnitude and provide higher quality spatial information with three-dimensional tomographic reconstructions compared to two-dimensional radiographic projections, which represent a significant improvement compared to current film radiography capabilities.

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