Contribution ID: **2** Type: **Talk**

# Imaging with Fast Neutrons (and Gamma Radiation) – State of the Art and Challenges

*Monday, 21 October 2019 10:00 (45 minutes)*

Neutron imaging has matured towards a powerful tool for non-destructive testing, but also for many other kinds for research domains.
Majority of facilities for neutron imaging are using neutrons in the thermal and cold spectrum (similar to neutron scattering devices) because of their availability at the large-scale facilities,. The advantage of using thermal and cold neutrons is the wide range of interaction probabilities between different materials (even isotopes) with wavelength in the order of the atomic distances, enabling contrast features which are complementary to X-ray interactions.
Even if all the nuclear reactions for neutron extraction start with high-energy neutrons in the MeV region, the imaging with fast neutrons is less developed (in comparison to thermal and cold neutrons) and there are only a few facilities around the world with useful performance. One of them is the fission neutron facility at FRM-2, NECTAR, equipped already with a camera based detector and the capability for neutron tomography. In some respect, NECTAR can be taken as benchmark although its performance is not yet characterized completely and a potential for upgrade should be exploited.
On the other hand, neutron sources on the basis of the interaction of accelerated particles or even electrons are available, again starting with fast neutrons (e.g. D-D: 2 MeV; D-T: 14 MeV). Their source strength is limited to less than 1010 s-1 and the collimated beam has much less intensity than NECTAR can deliver. However, the accelerator sources are transportable and not part of a large-scale facility.
Fast neutron imaging has the advantage of very high penetration of large objects even of high-Z materials. The most probable interaction process is neutron scattering where the microscopic cross-sections are very similar for most of the materials. Therefore, it is the difference in the nuclear density of the involved materials which can be distinguished in the imaging process with fast neutrons.
Starting from a fast neutron spectrum, it can be shifted by the slowing-down process in a moderator and neutrons in the thermal and epi-thermal region can be used for imaging purposes. Here, an optimization process is needed, what moderator and which detector are the best combinations for the particular object to be investigated. This can be done either in an experimental way, but also with the help of simulations. Such kind of simulations are very important anyway in order to understand the processes in the sample and the detector in comparison to the available nuclear data. A data base for attenuation coefficients for the particular setup has to be created and its dependency on the sample thickness has to be studied either experimentally or on the way of simulations.
Modern neutron imaging detectors are mostly based on camera systems with high sensitivity for the light from a scintillation converter. Therefore, the scintillator is the key component for the detection process, defining the efficiency and the spatial resolution. Both have to be optimized for the most efficient use of fast neutrons for imaging purpose.
Because nearly all nuclear processes are accompanied by gamma radiation emission, their use for imaging purposes should also be considered as complementary tool to the neutron options.

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**Session Classification:** Welcome Session

**Track Classification:** Neutron sources for fast neutrons