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Introduction to Neutron Scattering Instruments – How are they Different?

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Neutron scattering is a complementary technique to x-ray scattering scientifically, but while there are similarities, there are some unique challenges in the design, construction, and operations. This poster will provide a brief description of neutron scattering, describe the technical components of spallation neutron scattering instruments, and discuss the engineering challenges found in the design and construction of these instruments.

Neutrons interact with matter via the strong nuclear force (nuclei) and the dipole-dipole interaction between magnetic moments (unpaired electrons). Neutrons penetrate deeply into samples in comparison to x rays, which interact with electrons.

- **Key differences:**
  - **Weak interaction with matter**
  - **Sources/Generation**
  - **Induced Radioactivity and secondary particle generation**
  - **Time of Flight methodology**

Shielding

Significant shielding is needed around the energetic production of neutrons and the incidental high energy photons (and associated hadron showers). Where most intense, this shielding will be very thick (meters). This shielding is not just for the protection of humans, but to prevent background radiation from interfering with the experiments.

Shielding Composition

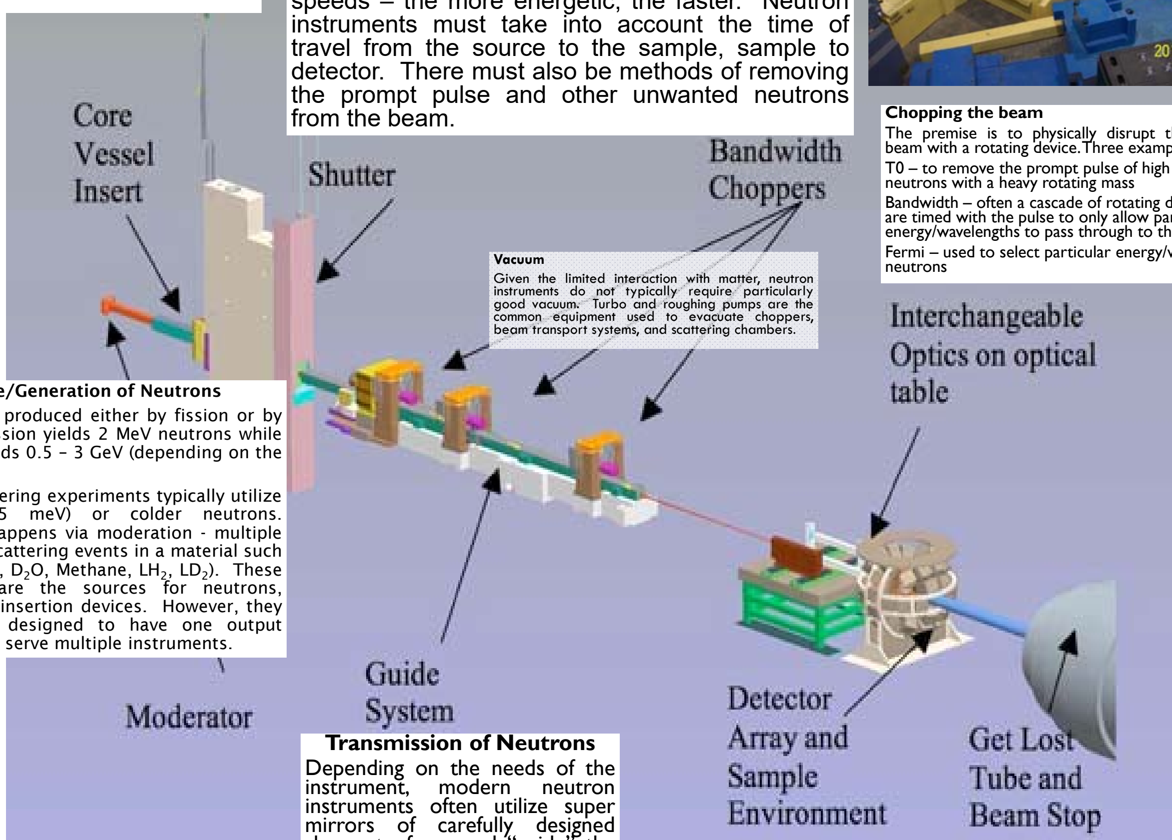
To shield against a range of particles and photons involves using multiple materials to account for the varying ways in which they interact with matter. For high energy neutrons and photons, high Z materials are needed, generally steel. For lower energy neutrons, materials containing a high concentration of hydrogen is best, such as concrete (with water) or high density polyethylene.

Complicated Shapes

Similarly to synchrotron beamlines, the technical components of neutron instruments have varying shapes and need utilities supplies to them. Slow neutrons also have a peculiar scattering property in which they almost appear to be a gas. Thus cracks or edges through the shielding must have multiple bends in them. Given the sheer volume of shielding needed on a instrument, the shapes needed meet all the varying needs often more resemble Tetris blocks than Lego.

Time of Flight Methodology

Unlike photons traveling at the speed of light, neutrons of different energies travel at different speeds – the more energetic, the faster. Neutron instruments must take into account the time of travel from the source to the sample, sample to detector. There must also be methods of removing the prompt pulse and other unwanted neutrons from the beam.



The MaNDi instrument at the Spallation Neutron Source at Oak Ridge National Laboratory. Image courtesy of Scott Keener.

Chopping the beam

The premise is to physically disrupt the neutron beam with a rotating device. Three examples are:

T0 – to remove the prompt pulse of high energy neutrons with a heavy rotating mass

Bandwidth – often a cascade of rotating disks that are timed with the pulse to only allow particular energy/wavelengths to pass through to the sample

Fermi – used to select particular energy/wavelength neutrons

Vacuum

Given the limited interaction with matter, neutron instruments do not typically require particularly good vacuum. Turbo and roughing pumps are the common equipment used to evacuate choppers, beam transport systems, and scattering chambers.

Source/Generation of Neutrons

Neutrons are produced either by fission or by spallation. Fission yields 2 MeV neutrons while spallation yields 0.5 – 3 GeV (depending on the accelerator).

Neutron scattering experiments typically utilize thermal (~25 meV) or colder neutrons. Conversion happens via moderation - multiple energy loss scattering events in a material such as C, Be, H_2O, D_2O, Methane, LH_2, LD_2). These moderators are the sources for neutrons, compared to insertion devices. However, they are typically designed to have one output spectrum and serve multiple instruments.

Transmission of Neutrons

Depending on the needs of the instrument, modern neutron instruments often utilize super mirrors of carefully designed shapes to focus and "guide" the neutrons towards the sample. Guides are generally composed of multiple layers of vacuum deposited coatings of Ni (or similar metals) on top of a glass substrate. These glass housings are installed inside metal vacuum chambers. These guides allow the neutrons to "bounce" or very shallowly reflect off the sides of the guides, increasing the number of neutrons that can reach the sample.

Neutron guides also allow instrument designers to move the neutron beam in space and can be one of the tools used to help discriminate against unwanted neutrons or provide a particular beam shape or profile to the sample.

Get Lost Tubes and Beam Stops

Neutron scattering experiments may only scatter a small portion of the total beam – for really hard experiments the sample could be designed to interact with little as 0.1% of the flux. The remaining neutrons are unwanted and must be "disposed of" in a fashion that prevents them from being noise in the measurement or being a radiological hazard. A "Get Lost Tube" provides an evacuated space for the neutrons to travel to the beam stop. As with all neutron shielding, this will be composed of multiple materials, much of which is heavy. Beam stops on higher energy instruments at high intensity sources can weigh in excess of 15 tons, consisting of a steel core with polyethylene and boron carbide inside a high density concrete shield.

For a basic description of the physics of neutron scattering, read "Neutron Scattering, A Primer" by Roger Pym, produced by the Los Alamos National Laboratory. Available as a free publication on the web in pdf.

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