4.4. Neutron techniques

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4.4.1. Production of neutrons
(By J. M. Carpenter and G. Lander)

The production of neutrons of sufficient intensity for scattering experiments is a 'big-machine' operation; there is no analogue to the small laboratory X-ray unit. The most common sources of neutrons, and those responsible for the great bulk of today's successful neutron scattering programs, are the nuclear reactors. These are based on the continuous, self-sustaining fission reaction. Research-reactor design emphasizes power density, that is the highest power within a small 'leaky' volume, whereas power reactors generate large amounts of power over a large core volume. In research reactors, fuel rods are of highly enriched ^{235}U. Neutrons produced are distributed in a fission spectrum centred about 1 MeV: Most of the neutrons within the reactor are moderated (*i.e.* slowed down) by collisions in the cooling liquid, normally D_2O or H_2O, and are absorbed in fuel to propagate the reaction. As large a fraction as possible is allowed to leak out as fast neutrons into the surrounding moderator (D_2O and Be are best) and to slow down to equilibrium with this moderator. The neutron spectrum is Maxwellian with a mean energy of ~300 K (= 25 meV), which for neutrons corresponds to 1.8 Å since

$$E_n\,(\mathrm{meV}) = 81.8/\lambda^2\ (\text{Å}^2).$$

Neutrons are extracted in beams through holes that penetrate the moderator.

There are two points to remember: (*a*) neutrons are neutral so that we cannot *focus* the beams and (*b*) the spectrum is broad and continuous; there is no analogy to the characteristic wavelength found with X-ray tubes, or to the high directionality of synchrotron-radiation sources.

Neutron production and versatility in reactors reached a new level with the construction of the High-Flux Reactor at the French-German-English Institut Laue-Langevin (ILL) in Grenoble, France. An overview of the reactor and beam-tube assembly is shown in Fig. 4.4.1.1. To shift the spectrum in energy, both a cold source (25 l of liquid deuterium at 25 K) and a hot source (graphite at 2400 K) have been inserted into the D_2O moderator. Special beam tubes view these sources allowing a range of wavelengths from ~ 0.3 to ~17 Å to be used. Over 30 instruments are in operation at the ILL, which started in 1972.

The second method of producing neutrons, which historically predates the discovery of fission, is with charged particles (α particles, protons, *etc.*) striking a target nuclei. The most powerful source of neutrons of this type uses proton beams. These are accelerated in short bursts (< 1 μs) to 500–1000 MeV, and after striking the target produce an instantaneous supply of high-energy 'evaporation' neutrons. These extend up in energy close to that of the incident proton beam. Shielding for spallation sources tends to be even more massive than that for reactors. The targets, usually tungsten or uranium and typically much smaller than a reactor core, are surrounded by hydrogenous moderators such as polyethylene (often at different temperatures) to produce the 'slow' neutrons ($E_n < 10$ eV) used in scattering experiments. The moderators are very different from those of reactors; they are designed to slow down neutrons rapidly and to let them leak out, rather than to store them for a long time. If the accelerated

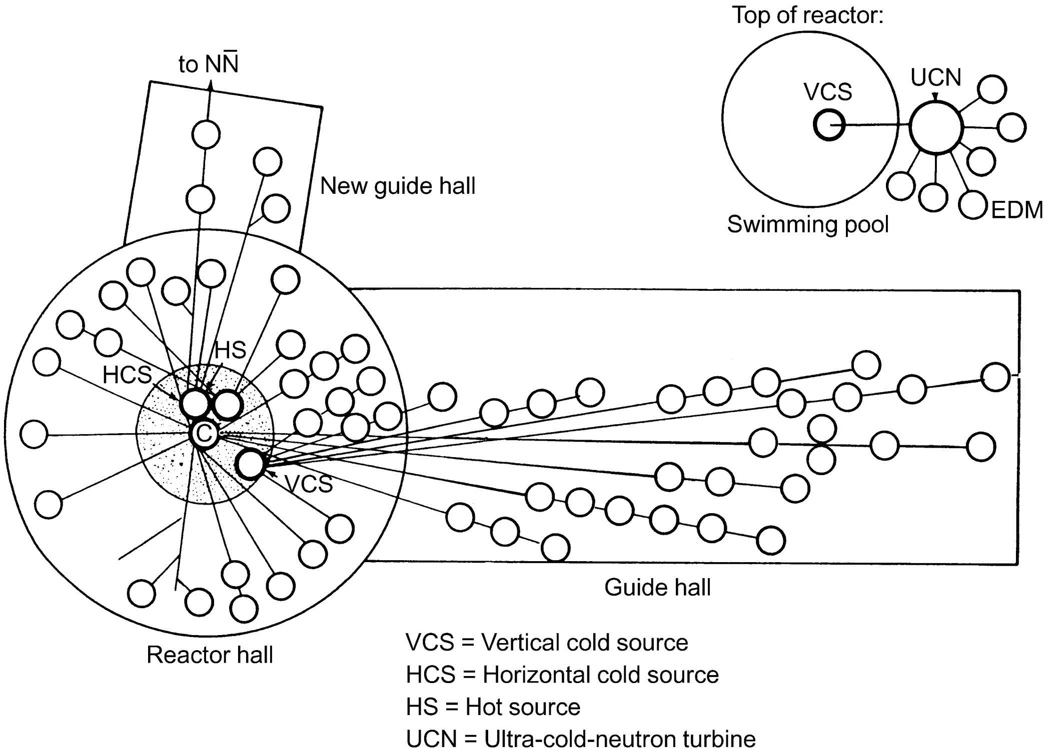

Fig. 4.4.1.1. A plane view of the installation at the Institut Laue–Langevin, Grenoble. Note especially the guide tubes exiting from the reactor that transport the neutron beams to a variety of instruments; these guide tubes are made of nickel-coated glass from which the neutrons are totally internally reflected.