***International Tables for Crystallography* (2018). Vol. H, Figure 2.3.8, p. 75.**

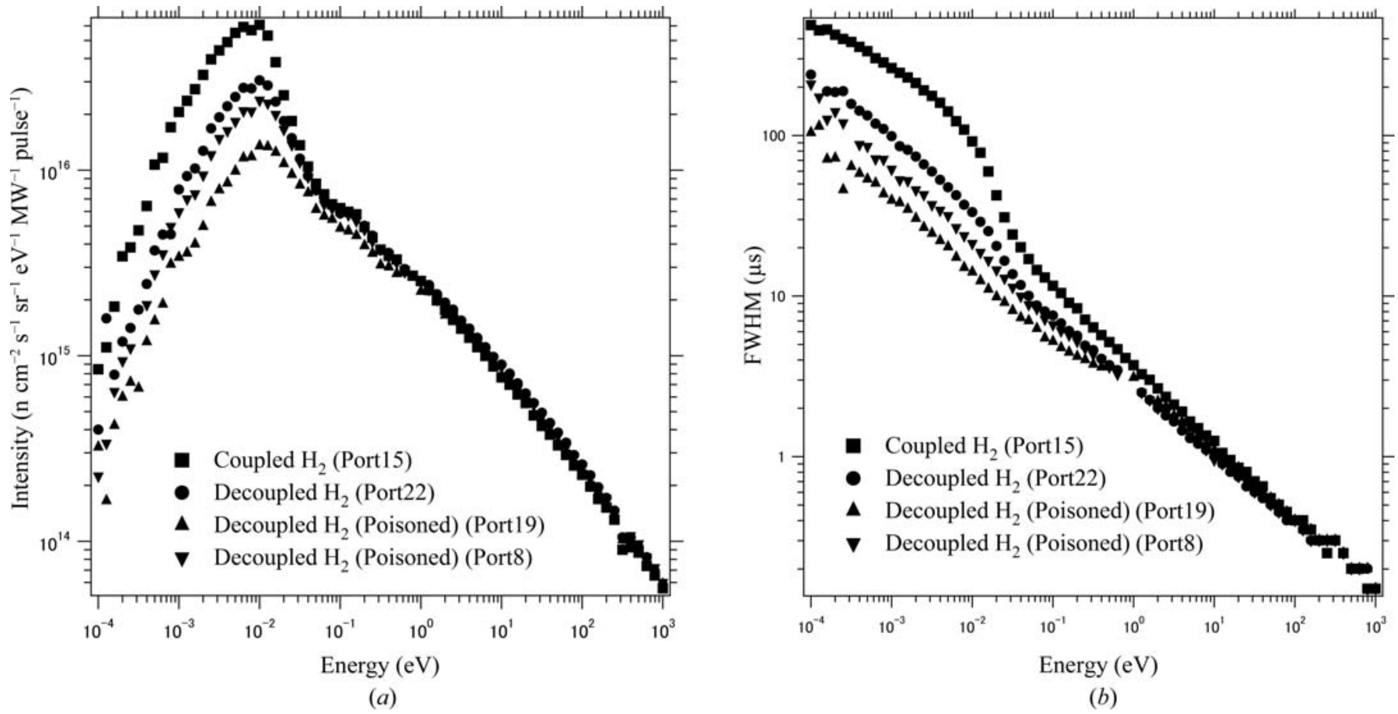

Figure 2.3.8
(*a*) The neutron energy distribution (flux) of the J-PARC neutron source for coupled, decoupled and poisoned decoupled moderators. The flux consists of a Maxwell distribution at low energies and a $1/E$ region at higher energies. (*b*) Pulse duration as a function of energy calculated for the same moderators. For the decoupled moderators, the peak widths vary approximately as $1/E^{1/2}$. Reproduced from Tamura *et al.* (2003).

is independent of flight time (or wavelength), which is a very satisfactory state of affairs (see Section 2.3.4.2.1).

As mentioned earlier, there is the problem for time-of-flight analysis that the slower neutrons from one pulse might be overtaken by the first arrivals from the next – a problem known as 'frame overlap'. Taking the example of 25 meV thermal neutrons, at a speed of 2190 m s^{-1} and a 50 Hz pulse repetition frequency, the neutrons from one pulse will have travelled 44 m when the next pulse occurs. If instrument flight paths are longer than this, or indeed if slower neutrons are involved, then the frame-overlap problem is encountered. A conceptually simple approach is to reduce the pulse frequency, and this has been implemented at the UK's ISIS neutron facility where Target Station 2 takes just one pulse in five from the proton-acceleration system, reducing the effective pulse frequency to 10 Hz; the other four pulses are directed to Target Station 1. Neutron choppers provide an alternative means to address this problem. The simplest kind of chopper is a disc (Fig. 2.3.9), usually of aluminium, nickel alloy or carbon fibre, coated in part with neutron-absorbing material such as boron, cadmium or gadolinium, rotating in a synchronous relationship with the source. A chopper located near to the source can be adjusted to block the fast neutrons and γ-rays that emerge immediately, but allow through neutrons in a restricted time window, from T_0 to $T_0 + \Delta T$, measured from the time of the pulse. Evidently, time $T_0 + \Delta T$ cannot exceed the time for a single rotation of the disc; when the disc is rotating at the pulse-repetition frequency this is the time between pulses. If the disc-rotation frequency is a submultiple of the pulse frequency, *i.e.* the rotation frequency is the pulse frequency divided by n, then the time window ΔT can be set to select only every nth pulse from the source. A two-chopper arrangement is used, for example, in the 96 m flight path of the High Resolution Powder Diffractometer (HRPD) at the ISIS facility; the first chopper at 6 m from the source runs at the pulse frequency and the second at 9 m from the source runs at one-fifth or one-tenth of that frequency, so that only every fifth or tenth pulse is used (HRPD user manual, http://www.isis.stfc.ac.uk/Pages/hrpd-manual.pdf).

Figure 2.3.9
One of the disc choppers in use at the ISIS neutron facility. This is an aluminium (2014A) alloy disc, and the neutron-absorbing coating (the darker region) is boron carbide in a resin. The cut-out on the right-hand side provides the aperture for neutrons. (Credit: STFC.)

Although we have introduced neutron choppers in the context of spallation sources, we should acknowledge that mechanical choppers and velocity selectors have a long history, dating back long before the advent of spallation sources. In fact, the first report on a velocity selector (Dunning *et al.*, 1935) pre-dates even the earliest demonstrations of neutron diffraction. Mechanical systems have long been used at continuous neutron sources to act as velocity (wavelength) selectors, and/or to tailor pulses of neutrons suitable for time-of-flight studies. Two disc choppers can be arranged to serve both purposes – the first chopper has a limited aperture transmitting a short pulse of neutrons, and the second chopper, with a similar aperture and located at some distance from the first, is phased so as to allow through only those neutrons with a particular velocity. This arrangement can provide short pulses of more-or-less monochromatic neutrons to an experiment. The helical velocity selector (Friedrich *et al.*, 1989) is conceptually somewhat similar. This takes the form of a cylinder,