The Disk Chopper Spectrometer (DCS)

- ✶ The DCS is a direct geometry time-of-flight spectrometer, the only instrument of its kind in North America.
- ✶ The DCS is primarily used for studies of low energy excitations and diffusive motions in a wide variety of materials.
- ✶ The DCS is an extremely versatile instrument. Useful incident wavelengths range from < 2Å to at least 9Å; correspondingly the elastic energy resolution (FWHM) varies from ~1500 to ~15 μeV.

Many people have contributed to the design, construction and installation of the DCS. They include:

Felix Altorfer, George Baltic, Paul Brand, Christoph Brocker, Dave Clem, Bill Clow, Jeremy Cook, John Copley, Bud Dickerson, Mark English, Pat Gallagher, Al Heald, Przemek Klosowski, Wayne Knill, Doris Kulp, Howard Layer, Nick Maliszewskyj, Suzi Neal, Don Pierce, Jürgen Räbiger, Jamie Reardon, Mike Rinehart, Connie Runkles, Ivan Schröder, Lyn Shuman, Scott Slifer, Denise Sullivan, Thuan Thai, Pat Tobin, Jeffrey Ziegler …

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What it's used for

The DCS is primarily used for studies of low energy inelastic scattering and quasielastic neutron scattering.

(Whereas *elastic* scattering is scattering with no change in neutron energy, *inelastic* neutron scattering is scattering with a change in neutron energy. *Quasielastic* scattering is a special kind of inelastic scattering that involves the Doppler-like broadening of otherwise elastically scattered neutrons due to reorientational or diffusive motions of atoms in the target material.)

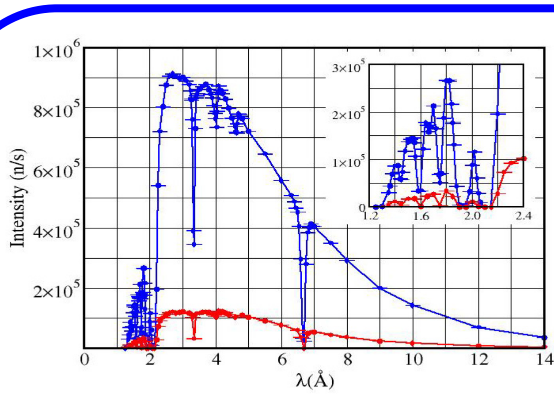
Research areas include

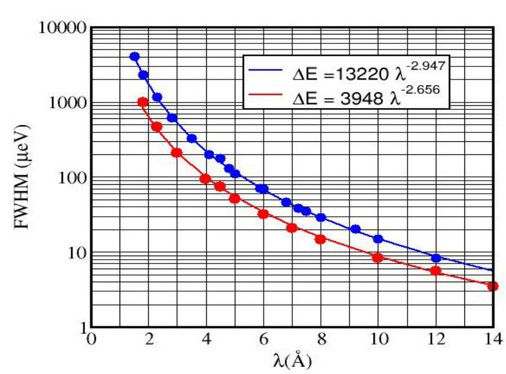
- Chemistry --- e.g. clathrates, molecular crystals, fullerenes
- Polymers --- bound polymers, glass phenomenon, confinement effects
- Biological systems --- protein folding, protein preservation, water dynamics in membranes
- Physics --- adsorbate dynamics in mesoporous systems (zeolites and clays) and in confined geometries, glasses, magnetic systems (crystal field splittings, magnetic excitations, spin waves), etc.
- Materials --- negative thermal expansion materials, low conductivity materials, hydration of cement, carbon nanotubes, proton conductors, metal-hydrogen systems

Phenomena that can be investigated using the DCS include:

- Translational and rotational diffusion processes, where scattering experiments provide information about time scales, length scales and geometrical constraints; the ability to access a wide range of wave vector transfers, with good energy resolution, is key to the success of such investigations
- Low energy vibrational and magnetic excitations and densities of states
- Tunneling phenomena in systems with low potential barriers
- Low Q powder diffraction

What it can do





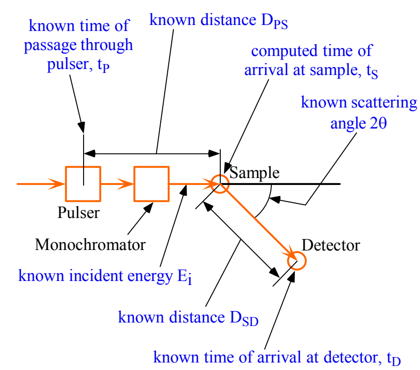
The left-hand figure shows the measured neutron beam intensity (n/s) at the DCS sample position with all the choppers running at 20,000 rpm as a function of incident neutron wavelength (the solid lines are guides to the eye). The right-hand figure shows measured elastic resolution widths (symbols) and corresponding power law fits (lines). The blue and red curves correspond to instrumental resolution configurations generally known as "low resolution" and "medium resolution" respectively; the instrumental resolution configuration is determined by the widths of the chopper slots that have been phased to transmit neutrons.. The sharp dips in the flux at ~3.35 Å and ~6.7 Å are respectively due to the (004) and (002) Bragg reflections in the pyrolytic graphite filter. Notice that there is significant intensity at wavelengths below 2 Å

How it all works, ...

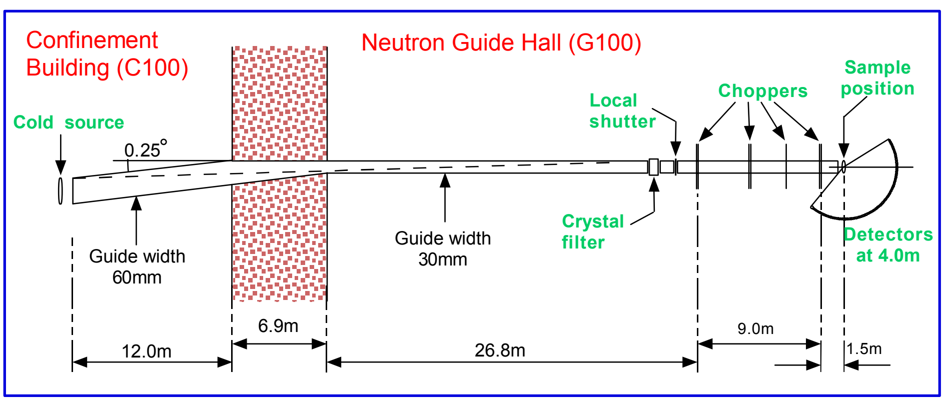
The DCS is a "direct geometry" time-of-flight (TOF) spectrometer. Neutrons with a single well-defined energy arrive at the sample in pulses. The energies that the neutrons acquire, having been scattered by the sample, are determined from their times of flight to an array of detectors.

... in principle ...

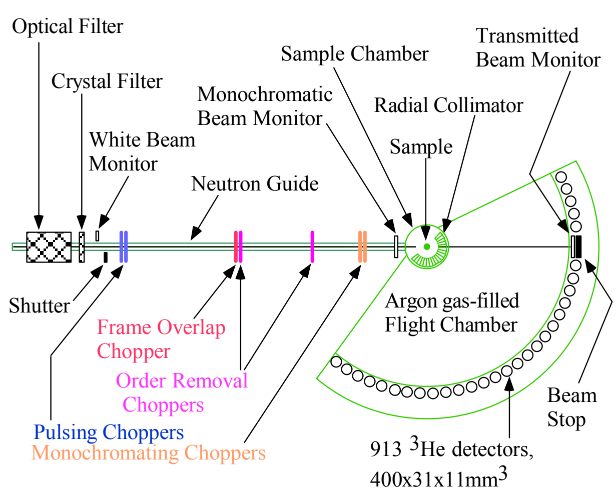
- Neutrons from the source are pulsed and monochromated. Bursts of neutrons of well defined energy E_i reach the sample position at times t_S.
- Some of these neutrons are scattered.
- Many of the scattered neutrons are scattered *elastically*, i.e. without any change in energy. The rest are scattered *inelastically*, meaning that they either lose or gain energy.
- As the experiment proceeds the distribution of times-of-flight $t=t_D-t_S$, for the scattered neutrons that reach the detector(s), is accumulated.
- For each time-of-flight the scattered neutron velocity, the scattered energy E_f and the energy transfer $\hbar\omega = E_i - E_f$ can be derived.
- Knowing the scattering angle 2θ , as well as E_i and E_f, we obtain the vector momentum exchange between the neutrons and the sample, $\hbar\mathbf{Q}$.
- The intensity distribution $I(2\theta,t)$ is converted to the scattering function $S(\mathbf{Q},\omega)$.



... and in practice ...



- The DCS occupies an end position on its own cold neutron guide, NG-4.
- Most of the unwanted fast neutrons and gamma rays are removed from the beam by the "optical filter" design of the neutron guide (no direct line of sight to the cold neutron source).
- The remaining fast neutrons are removed using an oriented pyrolytic graphite filter which is cooled to ~77 K, providing high transmission of the cold neutrons used by the DCS.
- A ~9 m long system of seven disk choppers produces a contaminant-free, pulsed, monochromatic beam at the sample position.
- Scattered neutrons travel through a relatively long (4m) argon-filled flight path to an array of 913 ^{3}He detectors.
- The combination of long flight paths, accurately known spectrometer distances, and state-of-the-art chopper and timing electronics leads to precise measurements of neutron velocities and hence energy changes.

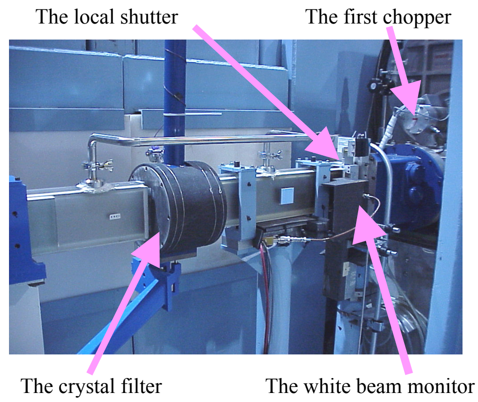


The gory details of the "Primary Spectrometer"

Pre-Shutter Neutron Guide ("Optical Filter")

- 60mm wide, 150mm high guide sections within the reactor confinement building.
- Guide width tapers (asymmetrically) to 30mm over ~7m.
- Within the guide hall the guide continues, at 0.25° to its original direction, now 30mm wide; its height is stepped down to 100mm.
- Net effect is no line of sight from cold source to local shutter.
- Top and bottom guide coatings: "$2\theta_c$" supermirror.
- Side coatings: ^{58}Ni-equivalent (Ni + 6 Ni-Ti bilayers)

A view of the guide, looking toward the cold source.

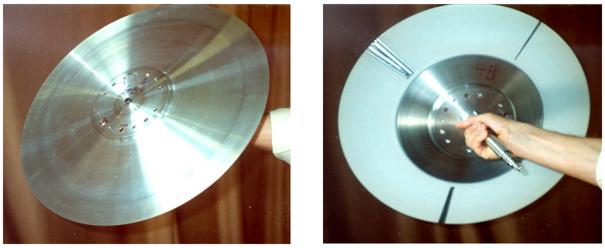


The crystal filter, white beam monitor and local shutter

- The crystal filter comprises 100mm (11 pieces) of 110mm high, 40mm wide blocks of ZYH ("filter grade") pyrolytic graphite, oriented with c axis parallel to beam, cooled to 77K.
- A local shutter, comprising 3mm of LiF and 38.1mm of "heavimet" (mostly tungsten), is located in a guide cut between the crystal filter and the first chopper.
- A white beam monitor is located to one side of the guide, slightly upstream from the guide cut. When the local shutter is open it views the entrance window of the post-chopper guide.

Choppers

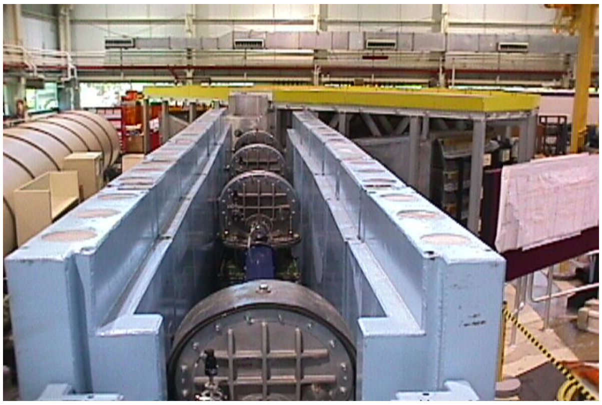
- Complete chopper system, i.e. 7 chopper assemblies (drives, disks etc) in 4 vacuum housings, plus control electronics and software, manufactured outside NIST.
- Disks: 580mm diameter, high strength Al alloy, "non-real" windows.
- For r ≥ 175mm, disks are plasma-coated with Gd_2O_3 (except at windows). Angular widths of windows: 1.35° to 20°.
- Disk thickness: for 175 ≤ r ≤ 240mm, 2.6-1.7mm: 240mm ≤ r, 1.7mm. (Mean thickness < 2 mm.)
- "Master speed": 1200-20000rpm in steps ≤ 8rpm; speed ratios either 1/m or (m-1)/m, m integer (≤ 26).
- Long term σ phase stability at 20000rpm is ~0.01° (~100ns).
- 0 → 20000 rpm or 20000 → 0 rpm takes ~1 hour. "Emergency shutdown" from 20000 rpm takes ~20 min.
- Fixed speed phase adjustments (e.g. change of wavelength) take 6-7 min.



Front and back views of one of the chopper disks. The white material is Gd_2O_3, which is a very strong neutron absorber. Neutrons pass through the wedge-shaped bare metal areas.

Post-shutter neutron guide

- 30mm wide, 100mm high guide sections.
- Top and bottom coatings: "$2\theta_c$" supermirror.
- Side coatings: ^{58}Ni-equivalent.
- From first chopper to sample chamber, two 1mm thick vertical glass plates divide the guide into three channels; plates are coated (both sides) with ^{58}Ni-equivalent reflective material. The central channel is 15mm wide.
- Guide has 20mm cutouts (and partial bottom cutout) for the chopper disks
- Guide is mounted/aligned within steel vacuum casings (from local shutter to sample chamber).
- Guide casings and chopper housings share common vacuum ($\leq 10^{-3}$ mTorr).



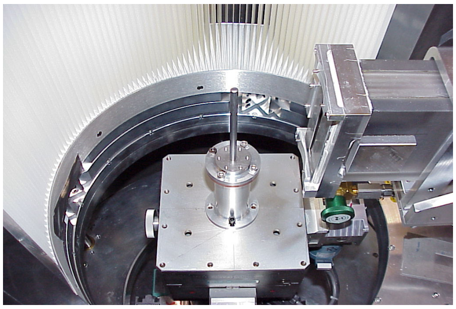
A view of the chopper housings looking away from the cold source. The roof shields have been removed and the secondary spectrometer is under construction.

The gory details of the "Secondary Spectrometer"

Sample Chamber

- Access is both from above and from the side
- Large diameter chamber (ID=864 mm)
- Low efficiency ^{3}He parallel plate beam monitor
- Chamber can be purged with a gas such as argon
- Versatile sample stage
- Radial collimator:

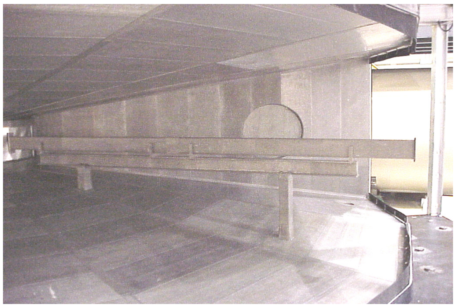
  ID 400mm, OD 600mm, blade separation 2°, blade height 250mm, spans 170°. Oscillated through 2°.
- Thin (0.075mm) Al window to flight chamber



A vanadium cylinder mounted on the sample table. Behind and to the left is the radial collimator. The neutron guide with a cadmium mask at its exit is visible to the right.

Flight Chamber

- Aluminum I-beam construction
- Large welded sections bolted together
- No welding performed in guide hall
- All inside surfaces clad with cadmium
- Continuous array of detectors (no gaps)
- Slow flow of argon at atmospheric pressure (+ ~0.04 mTorr)
- Ultrathin (0.0075mm) Al window (originally teflon)
- "Get lost" pipe to remove unscattered beam
- Downstream beam monitor
- Beamstop (polyethylene, cadmium, lead)
- 10-15 cm polyethylene shielding plus boraflex



The inside of the flight chamber, during its construction. The sloping surfaces are faced with cadmium. The "get lost" pipe extends from the sample chamber window to just inside the flight chamber window (not installed at the time this picture was taken).

Detectors, detector racks

- 913 six atmosphere ^{3}He detectors
- Active dimensions 400mm × ~31mm × ~11mm
- Detectors attached to 15 racks
- Each rack holds 60-70 detectors in 3 banks
- Middle bank from -30° to -5°, +5° to +140°
- Upper and lower banks from -30° to -10°, +10° to +140°
- Identical ~4 m distance from sample to all detectors
- Each detector is tangent to intersection of sphere and Debye-Scherrer cone to minimize spread in polar angle
- Detector racks can be removed and reinstalled reproducibly
- Amplifiers attach directly to detectors

In April 1997, 45 detector mounting rails for the Disk Chopper Spectrometer were machined on the NIST Octahedral Hexapod. This job, performed with the Fabrication Technology Division, was the first application of NIST's Hexapod to make parts to be used in service.

Some of the detectors at the time of their initial installation and alignment, viewed from within the flight chamber. The detectors were subsequently removed to permit installation of the flight chamber window. The detectors were then reinstalled.

The flight chamber and some of the detector racks, together with the flight chamber window and the beam stop, shortly before the outside shielding was installed.