Neutron Spectrometers

The location of seven neutron beam instruments on the main floor of the NRU reactor is shown. Each instrument is identified by the designation of the reactor beam hole on which it is located. More information on each instrument is provided below.

**Source and Main Beam Specifications**

- **C2 High Resolution Powder Diffractometer**
- **C5 Polarized Beam Triple-Axis Spectrometer**
- **D3 Reflectometer**
- **E3 Triple-axis Spectrometer**
- **L3 Stress-Scanning Diffractometer**
- **N5 Triple-Axis Spectrometer**

**Neutron Spectrometer Ancillary Equipment**
Source and Main Beam Specifications

The table below gives the neutron flux for the six available beam ports at NRU. The beams are referred to by letter-number pairs, such as C2 or E3. These identifiers are also used for the spectrometers mounted at each beam port. The main beam (MB) monitor reading is in counts per second with the reactor running at full power. The main beam thermal flux was measured by gold-foil activation at the monochromator in each case.

<table>
<thead>
<tr>
<th>Port</th>
<th>Source size† width × height</th>
<th>Source to mono-chromator</th>
<th>MB thermal flux (n cm⁻²s⁻¹)</th>
<th>Cd ratio</th>
<th>Source flux‡ (n cm⁻²s⁻¹)</th>
<th>MB monitor (counts s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2</td>
<td>2.625″ × 3.656″</td>
<td>260″</td>
<td>5.26E+09</td>
<td>16</td>
<td>5.93E+14</td>
<td>6970$^5$</td>
</tr>
<tr>
<td>C5</td>
<td>2.375″ × 6.125″</td>
<td>262″</td>
<td>4.85E+09</td>
<td>15.3</td>
<td>3.66E+14</td>
<td>2940$^5$</td>
</tr>
<tr>
<td>D3</td>
<td>2.4″ × 6″</td>
<td>200″</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>300</td>
</tr>
<tr>
<td>E3</td>
<td>4″ × 6.125″</td>
<td>221.5″</td>
<td>8.90E+09</td>
<td>112$^6$</td>
<td>2.85E+14</td>
<td>6150</td>
</tr>
<tr>
<td>L3</td>
<td>4.5″ × 12.172″</td>
<td>241.5″</td>
<td>1.35E+10</td>
<td>14.5</td>
<td>2.30E+14</td>
<td>340$^*$</td>
</tr>
<tr>
<td>N5</td>
<td>2.375″ × 6.125″</td>
<td>267″</td>
<td>4.24E+09</td>
<td>10.5</td>
<td>3.32E+14</td>
<td>2725</td>
</tr>
<tr>
<td>T3</td>
<td>--</td>
<td>--</td>
<td>2.33E+09</td>
<td>24</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

† All elliptical except for D3 where 6″diameter circle is trimmed by MB collimator to an effective width of 2.4″.
‡ Derived from measured MB thermal flux and inverse-square law, and normalized to unit-area source.
$ MB filter unit set at “no-filter” position.
* Unusually high because of permanently installed RT sapphire filter in MB.
+ DB monitor reading

[Top]
C2 High Resolution Powder Diffractometer

Instrument Scientist: Roxana Flacau

The DUALSPEC facility was jointly funded by NSERC and AECL, and was transferred to NRC in 1997. It comprises the two spectrometers C2 and C5. C2 is equipped with a curved 800-wire BF$_3$ position sensitive detector. The wire-spacing is 0.1°, so that 80° of scattering angle is measured simultaneously. The detector can be positioned in low- and high-angle settings to collect data from the complete 120° range of scattering angles. Within each setting it can be moved in steps as small as 0.01°. The detector sits in a large 7 ton shielding block. It floats across an epoxy resin dance floor on a cushion of air with the aid of pneumatic pads and can be positioned to 0.002°.

The wavelength can be varied from 4 Å to 1 Å. This instrument is ideally suited to study both long and short range magnetic correlations, with a range in wave vector $Q = 4\pi\sin(\theta)/\lambda$ from 0.15 Å$^{-1}$ to 11 Å$^{-1}$.

Typical Experiments/Uses

Physical Sciences (physics, chemistry, etc.)

- Order-disorder transitions
- Ferroelastic transitions
- Magnetic phase transitions
- Crystal structure refinements
- Atomic site ordering
- Small molecule organics
- Mineral structures

Materials Science

- Quantitative phase analysis
- Corrosion experiments
- Precipitation and phase transformations
- Kinetic studies

Ancillary Equipment Specifically Available to C2

- Continuously rotating sample table. The table may be continuously rotated from 0° to 360° in 10° increments.
- Automatic sample changer. Up to 9 samples may be run unattended under ambient conditions.

Technical Specifications

BEAM SIZE:
3.656" high 2.625" wide (source)
12.5" long (4" high and 1.5" wide) (specimen)
AVAILABLE MONOCHROMATORS AND ANALYZERS:

Be, Cu, Ge, graphite, Si available
Typically the (531) reflection from Si#17.

(monochromating and analyzing crystals are shared among the spectrometers, several crystals of each type are available)

MONOCHROMATOR TAKE-OFF ANGLE:
Continuously variable, 0 - 120°

SPECIMEN SCATTERING ANGLE:
Continuously variable from 0 - 120°

COLLIMATORS:
Three source to monochromator collimations are available

FINE: ~ 0.2°
COARSE: ~ 0.4°
NONE: ~ 0.6° (effective)

PHYSICAL DIMENSIONS:

Principal distances

• source to monochromator, 260"
• monochromator to specimen, 63"
• specimen to detector, 59"
C5 Polarized Beam Triple-Axis Spectrometer

Instrument Scientist: Zahra Yamani

The DUALSPEC facility was jointly funded by NSERC and AECL, and was transferred to NRC in 1997. It comprises the two spectrometers C2 and C5. The C5 spectrometer is a polarized beam triple-axis spectrometer which can operate also as a diffractometer and neutron reflectometer. In addition, conventional non-polarized neutron experiments can be carried out on this instrument.

Typical Experiments/Uses

- Polarized beam triple-axis neutron spectroscopy
- Neutron reflectometry from surfaces and thin films
- Double-axis neutron diffraction

Ancillary Equipment Specifically Available to C5 in the Polarized neutron setup

- Monochromator and analyzer: single-crystals of Cu$_2$MnAl Heusler alloy
- Neutron spin flippers: Mezei-type spin rotators in the incident and scattered beams
- Guide fields: Horizontal or vertical using permanent magnets (maximum field ~ 200 gauss) or superconducting magnet cryostats, M2 and M4. In order to avoid beam depolarization M2 and M4 must operate in asymmetric mode, leading to lower maximum fields of 2.7 T (horizontal) and 6.5 T (vertical).
- Choice of neutron filters: Higher order rejection, and hence the filters, are very important for polarized neutron experiments. The following filters are available on C5.
  - Pyrolytic graphite: works most efficiently at 2.37 Å (equivalent to 3.52 THz neutron energy) and also at 1.55 Å (8.23 THz)
  - Cooled Be filter: works for wavelength >4 Å (equivalent to < 1.2 THz neutron energy)
  - Cooled Sapphire: works for wavelength <0.8 Å (equivalent to >30 THz neutron energy)
- Typical figures of merit (at 2.37 Å):
  - Flipping ratio = 24:1
  - Heusler polarization efficiency = 96.5%
  - Flipper efficiency ~ 99.5%
Ancillary Equipment Specifically Available to C5 in the Neutron Reflectometry setup

- Adjustable slit system to define the direction of incident and scattered beam
- Most experiments carried out at neutron wavelength 2.37 Å, to a dynamic range of >=6 orders of magnitude
- Optimum sample size = 50 x 50 mm
- Smallest sample size that has provided data of sufficient quality for least-squares analysis = 10 x 10 mm (a magnetic multilayer of thickness 35 Å/period x 12 periods)

Technical Specifications

Beam Size (at sample position):
1.5" wide, 3" high (maximum)

Available Monochromators and Analyzers:
Vertically focussing monochromators, graphite (002), and Si (111). Heusler monochromator and analyzer for polarized neutrons (flipping ratio 20-40 depending on wavelength), with Mezei flippers. Be, Cu, Ge, graphite, Si available (these monochromating and analyzing crystals are shared among the spectrometers, several crystals of each type are available).

Filters:
- Liquid N₂ cooled sapphire or Be before the monochromator
- Pyrolytic graphite in monochromatic beams
- Neutron velocity selector as a tunable, higher-order rejection filter in range 4 Å (1.2 THz) to 2.37 Å (3.52 THz)

Monochromator Take-off Angle:
Continuously variable 20 - 115° controlled to 0.001°

Specimen Scattering Angle:
Continuously variable from 0 - 115° controlled to 0.001°

Collimators:
- Source to monochromator collimations are selectable:
  Fine: ~ 0.2°
  Coarse: ~ 0.4°
  None: ~ 0.6° (effective)
- Monochromator to sample, interchangeable, fixed soller collimators are available: 0.2, 0.4, 0.5, 0.6 and 0.8°.
- Sample to analyzer, interchangeable, fixed soller collimators are available: 0.2, 0.4, 0.5, 0.6 and 0.8°.

Detector:
Cylindrical He³, 1.5" diameter, 5" high. Multiwire option in preparation.
PHYSICAL DIMENSIONS:

Principal distances

- source to monochromator, 260"
- monochromator to specimen, adjustable from 70.25" to 85"
- specimen to analyzer, adjustable from 40-56"
- analyzer to detector, 10.5"
**D3 Reflectometer**

**Instrument scientist: Zin Tun**

The D3 reflectometer, officially opened in July 2007, is the newest addition to our suite of instruments. Its construction was funded jointly by the Canadian Foundation for Innovation (CFI), the Ontario provincial government, and the NRC. On behalf of CFI, it is owned by the University of Western Ontario. CNBC is the custodian, responsible for the continuing operation and maintenance of the instrument.

Designed specifically for neutron reflectometry, the instrument operates in a horizontal scattering plane while the sample (i.e. the interface to be studied) is mounted vertically. The incident beam is fixed in wavelength ($\lambda = 2.37 \text{ Å}$), and is focused on the sample by the vertically curved, 30 cm tall monochromator located 152.4 cm upstream from the sample. The strong focusing creates an intense image of the in-reactor neutron source on the sample with a vertical size of $\sim 4.6$ cm. For the experiments where the vertical focusing is not desirable, an adjustable slit allows the user to reduce the monochromator height. For polarized neutron operation, the instrument is equipped with a super-mirror polarizer. Analyzing of reflected neutron spin is currently performed with a Heusler-alloy crystal, but a long-term plan is to install a second super-mirror.

Two detectors are available, each capable of simultaneously recording specular and off-specular reflections. The first is a 32-wire detector where the wires running vertically are long enough to capture all the reflected neutrons diverging vertical after the focal point at the sample. The 2 mm spacing between the wires corresponds to $\Delta 2\theta \sim 0.1^\circ$. The second is a 2-dimensional detector (DENEX 200) with a resolution of 1.5 mm horizontally and 2 mm vertically. The horizontal resolution corresponds to $\Delta 2\theta \sim 0.06^\circ$.

The heavy-duty goniometer for supporting the sample is rated for precision alignment of a load of 725 kg. This enables field reversal reflectometry experiments with the±7.5 T superconducting magnet, M5. For the experiments requiring a horizontal field, an electromagnet can provide 0.85 T with 60 mm gap or 1.05 T with 40 mm gap. A special low-vibration refrigerator (D6) with the temperature range 6 - 300 K is also available.

**Typical Experiments/Users**

- Neutron reflectometry on metal films
- Magnetic order in thin films and multilayers
- Growth of corrosion prevention oxides
- Polymer films and coatings
- Biological thin-films

**Technical Specifications**

**BEAM SIZE**

Vertically focused and $\sim 50$ mm high at sample position

Horizontal width controlled by motorized S2 slit to 4 $\mu$m precision

**MONOCHROMATOR**

Vertically focused and 300 mm tall compound-mirror of (002) graphite

- a vertically limiting slit allows trimming of height if required
- width controlled by motorized S1 slit to 4 $\mu$m precision
MONOCHROMATOR TAKEOFF ANGLE
Fixed at 41.39° delivering $\lambda = 2.37$ Å

INCIDENT POLARIZER
Fe/Si super-mirror in transmission geometry

ANALYZER
Heusler alloy Cu$_2$MnAl (needed only for reflected spin analysis)

DETECTORS
$^3$He 32-wire detector (wire spacing = 2 mm)
$^3$He two-dimensional detector (spatial resolution = 1.5 × 2 mm)

PHYSICAL DIMENSIONS: Principal distances

- source to monochromator = 200" (5080 mm)
- monochromator to specimen = 60" (1524 mm)
- specimen to 32-wire detector = 48" (1220 mm) $^\dagger$
- specimen to 2-D detector = 53" (1350 mm) $^\dagger$

$^\dagger$ slightly larger than distance to detector face to account for extra path length in gas.
E3 Triple-axis Spectrometer

Instrument Class: Materials Science Diffractometer
Instrument Scientist: Michael Gharghouri

The E3 spectrometer was designed as one of the 4 triple-axis spectrometers at NRU. The triple-axis spectrometers at CRL are, by design, very versatile, configurable for various types of experiments and modes of operation. As a point of historical interest, the monochromator shielding drum of E3 is built from components used in the original Brockhouse Spectrometer.

E3 is usually equipped with a 32-wire position sensitive detector. Wire spacing is 2 mm which at E3 corresponds to ~ 0.08°. The detector can also be used as a variable-width single-wire detector. The 32-wire detector can be replaced with a standard detector.

Typical Experiments/Uses

- residual strain/stress mapping
- crystallographic texture
- grain-interaction stresses
- precipitation and phase transformations
- inelastic scattering in triple-axis mode (eg phonons, magnons, solitons, correlations)
- elastic scattering in diffraction mode or triple-axis mode experiments (eg mapping of phase diagrams, magnetization measurements).

Ancillary Equipment Specifically Available to E3

- Strain collimators: A large variety of slits and height limiters are available for defining the sampling volume for residual strain/stress mapping experiments.
- An Eulerian Cradle can be installed on E3 for full control of sample orientation. The addition of the cradle effectively transforms E3 into a 4-circle diffractometer. Primarily used for crystallographic texture and grain interaction measurements, but also useful for examination and pre-alignment of single-crystals.

Technical Specifications

BEAM SIZE:
5 cm high × 5 cm wide (maximum at specimen)

AVAILABLE MONOCHROMATORS AND ANALYZERS:
Be, Cu, Ge, graphite, Si

(monochromating and analyzing crystals are shared among the spectrometers, several crystals of each type are available).

MONOCHROMATOR TAKE-OFF ANGLE:
Continuously variable in 3 ranges, 0 - 30°, 30 - 60°, and 60 - 91°
SPECIMEN SCATTERING ANGLE:
Continuously variable from 0 - 120°.

COLLIMATORS:
No source to monochromator collimator is installed, effective collimation is ~ 0.6°. The remaining beam segments are soller slit adjustable with each soller channel having a minimum blade spacing of 0.050". Soller blades are available in 5.5", 8.0", 14.5" and 19" lengths. The maximum blade length in the beam segments are:

- monochromator to specimen, 19"
- specimen to analyzer, 14.5"
- analyzer to detector, 8"

DETECTOR:
The standard configuration of E3 uses a 32-wire position sensitive detector. This detector can also be used as a variable-width single detector. When required, a true single detector can be installed.
**L3 Stress-Scanning Diffractometer**

**Instrument Scientist: Michael Gharghouri**

Although the L3 spectrometer was designed as a triple-axis instrument, it is now always used in diffraction mode for commercial measurements and Materials Science research. In this capacity, most of L3 beam time is used for strain/stress mapping. L3 can also be equipped with a stress rig for examining specimens under uniaxial load. For strain/stress mapping, a large variety of slit dimensions are available. L3 can also be equipped with a variety of sample orientation devices.

L3 is always equipped with a 32-wire position sensitive detector. Wire spacing is 2 mm which at L3 corresponds to ~0.08°. This detector can also be used as a variable-width single-channel detector.

**Typical Experiments/Uses**

- residual strain/stress mapping
- crystallographic texture
- grain-interaction stresses
- precipitation and phase transformations

**Ancillary Equipment Specifically Available to L3**

- Large capacity x-y table that can handle loads of up to 450 kg (1,000 lbs.) and provides a large 60 cm × 60 cm (2” × 2”) platform for easy mounting (including multiple samples). Various other translation and rotation devices (see general ancillary equipment) can be easily added to the table.
- Stress Rig-for examining specimens under uniaxial load (tension and compression). The stress rig can be used for the determination of diffraction elastic constants for which the rig can be placed on the spectrometer in both the Young’s and Poisson orientations. Maximum applied load is 45 kN (5 tons).
- Strain collimators: A large variety of slits and height limiters are available for defining the sampling volume for residual strain/stress mapping experiments.
- An Eulerian Cradle can be installed on L3 for full control of sample orientation. The addition of the cradle effectively transforms L3 into a 4-circle diffractometer. Primarily used for crystallographic texture and grain interaction measurements, but also useful for examination and pre-alignment of single-crystals.
Technical Specifications

BEAM SIZE:
7.5 cm high × 5 cm wide (maximum at specimen)

AVAILABLE MONOCHROMATORS AND ANALYZERS:
Be, Cu, Ge, graphite, Si

(monochromating and analyzing crystals are shared among the spectrometers, several crystals
of each type are available)

MONOCHROMATOR TAKE-OFF ANGLE:
Continuously variable from 0 - 105°.

SPECIMEN SCATTERING ANGLE:
Continuously variable from 0 - 120°

COLLIMATORS:
No source-to-monochromator collimator is installed, effective collimation is ~ 0.9 deg. The
remaining beam segments have adjustable soller slits with each soller channel having a
minimum blade spacing of 0.050". Soller blades are available in 26", 19", 14.5", 8.0" and 5.5"
lengths. The maximum blade length in each beam segment are:

- monochromator to specimen, 26"
- specimen to analyzer, 14.5"
- analyzer to detector, 8"

DETECTOR:
The standard configuration of L3 uses a 32-wire position sensitive detector. This detector can
also be used as a variable-width single detector. When required, a true single detector can be
installed.
N5 Triple-Axis Spectrometer

Instrument Class: Triple Axis Spectrometer
Instrument Scientist: John Katsaras

The N5 triple-axis spectrometer is used for inelastic and elastic (2-axis) neutron scattering experiments, and extensively used in the study of biologically relevant materials. Importantly, in the last year the N5 spectrometer has the added small angle neutron scattering (SANS) capability.

N5 Triple-Axis Spectrometer with the M2 Horizontal Superconducting Magnet/Cryostat

Typical Experiments/Uses:

- inelastic scattering (e.g. phonons, magnons, solitons, correlations, membrane dynamics)
- elastic scattering (e.g. mapping of phase diagrams, magnetization measurements, location of molecules within biological membranes).
- SANS (e.g. unilamellar vesicles, domains)

The SANS capability is achieved through the use of Confocal Soller Collimator (CSC) which enhances the neutron flux on the sample by a factor of 20, compared to a single beam of the same spot size. Furthermore, smearing effects due to vertical divergence from the slit geometry were reduced through the use of Horizontal Soller Collimators (HSC). As a result, the modified N5 spectrometer enables SANS measurements to a minimum q value 0.006 Å⁻¹ [Nieh et al., Rev. Sci. Instrum. 79, 095102 (2008)].
Schematic of the N5-SANS adapted from a triple-axis spectrometer to an instrument capable of SANS measurements. The components are as follows: (1) sapphire or Be filter. (2) Monochromator. (3) 23-channel CSC. (4) PG filter/21.6 cm long HSC/open. (5) Sample. (6) 48 cm long HSC. (7) 32-wire position sensitive detector.

Technical Specifications

Beam Size: 5 cm high × 5 cm wide (maximum at specimen)
Monochromators and Analyzers: Be, Cu, Ge, pyrolitic graphite, Si
Monochromator Take-off Angle: Continuously variable from 15 - 120°
Speciment Scattering Angle: Continuously variable from 0 - 126°
Analyzer Take-off Angle: Continuously variable from -120 - 120°
Collimators: No source-to-monochromator collimator is installed, effective collimation is ~ 0.6°. The remaining beam segments have adjustable soller slits with each soller channel having a minimum blade spacing of 0.050". Soller blades are available in 26", 19", 14.5", 8.0" and 5.5" lengths. The maximum blade length in each beam segment are:

- monochromator to specimen, 26"
- specimen to analyzer, 14.5"
- analyzer to detector, 8"

In the case of the SANS setup, please see the diagram above.
Detectors: Single or Multichannel $^3$He
Neutron Spectrometer Ancillary Equipment

Summary information on the ancillary equipment is given below. The ancillary equipment listed here can be used with any of the neutron instruments. For information on equipment available to only a subset of instruments, see the pages specific to that instrument (C2, C5, D3, E3, L3 or N5).

### Monochromators
A wide selection of monochromators is available to match the monoenergetic characteristics of the scattered beam to the experiment (e.g. Ge, Si, Pg, Cu).

### Cryostats
- D1, closed cycle (Displex), 10 to 300 K
- D3, closed cycle (CTI), 12 to 300 K
- H6, 10 cm bore, top load, 4 to 300 K
- H8, 5 cm bore, top load, 1.5 to 300 K
- M2, horizontal field (3 T), top load, 1.5 to 300 K
- M4, vertical field (6 T), 4.0 to 300 K
- M5, vertical field (9 T), 0.3 to 300 K
- Cryostat for biological studies (manipulation of both humidity and temperature)

### Furnaces
- FD, cartridge heater based furnace temperature range 300 K to 1000 K vacuum typical 1.0E-2 torr
- F3, radiant heater based furnace temperature range 300 K to 2200 K vacuum typical 1.0E-7 torr

### Filters
- Cold beryllium or sapphire (77 K), before the monochromator
- Cold beryllium (77 K), cryostat can be placed between monochromator and specimen or specimen and analyzer
- Pyrolytic graphite can be placed between monochromator and specimen or specimen and analyzer
- NVS, C5 only, before or after sample, 2.37 to 4 Angstroms

### Mechanical Devices
- XYZ translation tables
- Kappa Goniometer
- C Cradle
- Eulerian Cradle
- Precision collimating devices to study volumes as small as 0.3 mm × 0.3 mm × 0.3 mm
- Chopper to determine higher order contamination in incident beam
M2 Magnet Cryostat

M2 is open to neutron beams throughout 335° apart from a dark angle that occludes 25° for a 38 mm neutron beam width. The M2 dark angle is along the field direction.

The vertical opening is 3° total. The sample height that sees neutron beam is 38 mm and working diameter is 38 mm.

Homogeneity is 10% over 38 mm × 38 mm cylindrical working volume in symmetric mode. Maximum central field (designed to be 3.0 T) is operationally restricted to 2.8 T.

There is an internal motor that allows the field to be placed at any angle to the crystal axis. NRC at Chalk River built a drive and angle-sensing device (independent of magnetic torque) that fits inside the VTI tube. The device design was given to Oxford.

There is only 21 mm of attenuating Al in the beam path. Oxford built this first horizontal field magnet and it was excellently engineered.

This photograph shows the M2 cryostat mounted on the N5 spectrometer. The spectrometer drum is to the right of the picture, and the neutron detector is on the left.
M5 Magnet Cryostat

Magnetic field
Vertical magnetic field with two modes of operation: symmetric mode (same current in both coils) for experiments with unpolarized neutrons and asymmetric mode (higher current in one coil to shift the null point) for experiments with polarized neutrons. For fields above 6 T for the asymmetric and 7.5 T for the symmetric mode a l-plate is used to cool down the liquid He near the coils from 4.2 to 2.2 K. With the l-plate up to 7.2 T for polarized neutrons and up to 9 T for unpolarized neutrons is achievable.

Temperature
From 300 K down to 0.3 K
For temperatures below 1.5 K a special sample stick (Heliox) is needed

Dark angle
21 degrees

Sample size
Diameter < 25 mm for the Heliox insert (T < 1.5 K)
Diameter < 30 mm for the standard sample stick (T > 1.5 K)

Time constants
35 minutes to ramp the field up to asymmetric 6 T
100 minutes to ramp the field up to symmetric 9 T
12 hours to cool from 300 K down to 1.5 K, another hour down to 0.3 K

Hold time
Liquid helium: 3 days without l-plate, 40 hours with l-plate temperature below 1.5 K: 1 day (1 hour is needed to again get below 1.5 K)