INEL1— Microvolt Spectrometer—Reference Instrument WBS 1.7.8

Technical Note ANL/SNS/98-7

R. K. Crawford – 12/11/98

1 Instrument Description

1.1 Overview

INEL1 is a near-backscattering crystal-analyzer spectrometer designed to provide energy resolution of 5 to 15 μeV . Figure 1 provides a schematic representation of INEL1, and Table 1 gives the parameters for this instrument. Two different analyzer crystal arrays allow two different primary choices of scattered neutron energy, and the possibility of using different orders from these arrays provides even more scattered energy choices.

Fig. 1. Schematic plan view of the microvolt spectrometer INEL1.

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Table 1. Parameters for the microvolt spectrometer INEL1

Component	Parameter	Value
Moderator	Beam line	10TU
	Moderator	Liquid-H ₂ , decoup, pois
Geometry	Source-sample distance	31.0 m
	Crystal analyzer near backscattering	
	Sample-analyzer distance (mica analyzer)	3.0 m
	Analyzer-detector distance (mica analyzer)	2.7 m
T ₀ chopper (probably omit because of guide)	Type	Horizontal-axis T ₀
	Radius to beam center	250 mm
	Length	300 mm
	Distance from moderator	6.0 m
	Frequency	30 to 60 Hz
	Beam width at chopper	40 mm
	Wavelength range to open or close	0.28 Å @ 60 Hz
Bandwidth chopper #1	Type	Disk
	Radius to beam center	250 mm
	Length	10 mm
	Distance from moderator	7.0 m
	Frequency	10 to 120 Hz
	Beam width at chopper	40 mm
	Wavelength range to open or close	0.24 Å @ 60 Hz
Bandwidth chopper #2	Type	Disk
	Radius to beam center	250 mm
	Length	10 mm
	Distance from moderator	10.0 m
	Frequency	10 to 120 Hz
	Beam width at chopper	40 mm
	Wavelength range to open or close	0.17 Å @ 60 Hz
Guide	Type	Curved
	Radius of curvature	1730 m
	Coating, sides and top and bottom	2 × θ_c supermirror
	Channel width	40 mm
	Channel height	60 mm
	Moderator-to-guide distance	2.50 m
	Guide length	26.0 m
	Moderator to end of guide	28.5m
	Filling	Evacuated to <10 ⁻² torr
Guide funnel	Coating, sides and top and bottom	3 × θ_c supermirror
	Width at exit	30 mm
	Height at exit	40 mm
	Funnel length	2.0 m
	Moderator to end of funnel	30.5 m
	Filling	Evacuated to <10 ⁻² torr

Table 1 (continued)

Component	Parameter	Value
Beamline shielding	Steel radial thickness around beam	0.7 m
	Paraffin radial thickness around steel	0.2 m
	Channel for guide	0.2 m $\times$ 0.2 m
	Length	19.5 m
Beam stop	Steel	1.6 m $\times$ 1.6 m $\times$ 2.6 m
	Paraffin radial thickness around steel	0.2 m
	Re-entrant hole in steel	0.2 m $\times$ 0.2 m $\times$ 0.5 m
Sample	Width	10 to 30 mm
	Height	20 to 50 mm
Analyzer crystals	Material and plane for first side	Graphite 002
	Bragg angle	$\sim 87^\circ$
	Wavelength selected	6.69 Å
	Analyzer area	$\sim 3,000 \text{ cm}^2$
	Distance from sample	1.0 m
	Angular coverage	15° to 165°
	Number of independent angle groups	~ 30
	Solid angle coverage	$\sim 0.3 \text{ sr}$
	Cooling	$\sim 20 \text{ K}$
Analyzer crystals	Filter	Cooled beryllium, easily insertable
	Material and plane for second side	Mica 004
	Bragg angle	$\sim 82^\circ$
	Wavelength selected	10 Å
	Analyzer area	$\sim 60,000 \text{ cm}^2$
	Distance from sample	3.0 m
	Angular coverage	15° to 165°
	Number of independent angle groups	~ 30
	Solid angle coverage	$\sim 0.6 \text{ sr}$
Standard detectors	Cooling	None
	Filter	None
	Type	^3He proportional
	Diameter	6 mm
	Length	30 mm
Standard detectors	Number	~ 200
	Location	Below sample plane
Data acquisition		Standard system

Table 1 (continued)

Component	Parameter	Value
Scattering chamber	Geometry	Vertical axis cylinder
	Diameter, excluding shielding	6.2 m
	Height, excluding shielding	1.2 m
	Filling, direct beam portion	Evacuated to $<10^{-2}$ torr
	Filling, remainder	Helium
	Shielding, top	Removable
	Shielding, bottom	Fixed
	Shielding, sides	Removable
	Shielding thickness and composition	TBD
Sample chamber	Depth	~ 0.6 m
	Diameter	~ 0.3 m
	Filling	evacuated to 10^{-6} torr
Resolution	Elastic, graphite analyzer	15 μeV
	Elastic, mica analyzer	5 μeV

1.2 Source

A poisoned decoupled supercritical hydrogen moderator at $\sim 22\text{K}$ provides a polychromatic beam of cold neutrons to the instrument. The design documented here assumes a fwhm pulse width of $\delta t \approx 58 \mu\text{s}$ at $10 \text{ \AA}$, $\delta t \approx 48 \mu\text{s}$ at $5 \text{ \AA}$, $\delta t \approx 35 \mu\text{s}$ at $3 \text{ \AA}$, and $\delta t \approx 11 \mu\text{s}$ at $1 \text{ \AA}$.¹ This moderator was selected for INEL1 because it provides a relatively high intensity of long-wavelength neutrons and the poisoning provides better resolution with these cold neutrons.

Beamline 10TU was chosen for this instrument because this beamline views the poisoned cold TU moderator and provides adequate space for this instrument.

1.3 Choppers

A T_0 chopper may be used to cut out the prompt pulse to reduce background, but this chopper may be eliminated if further simulations indicate that the curved guide does an adequate job of removing this prompt pulse background. A series of bandwidth-limiting choppers is required to limit the incident bandwidth to prevent frame overlap and order contamination. Since larger-wavelength bands can be used if it is known that there is no neutron-energy-gain spectrum from the higher-order plane, this series of choppers must be able to select different bandwidths as well as to vary the wavelength at which the incident bandwidth is centered. The requirement to vary the selected bandwidth means that at least two choppers must be used. This bandwidth can be centered at any wavelength simply by adjusting the phase of the bandwidth choppers.

Preliminary optimization of the chopper locations and speeds was done using a spreadsheet to evaluate the wavelengths for which the chopper system is fully open and the wavelengths for which one or more of the choppers is opening or closing. Table 2 shows the parameters assumed for the choppers, and Table 3 shows the opening and closing wavelengths for each of these

choppers for several different choices of chopper phases. Appendix A of Reference 2 gives the equations used for these calculations.

Table 2. Assumed chopper parameters for INEL1.

T_0 chopper diameter (mm)	500.0
T_0 chopper distance (m)	6.0
beam width at T_0 chopper (mm)	40.0
bandwidth chopper #1 diameter (mm)	500.0
bandwidth chopper #1 distance (m)	7.0
beam width at bandwidth chopper #1 (mm)	40.0
bandwidth chopper #2 diameter (mm)	500.0
bandwidth chopper #2 distance (m)	10.0
beam width at bandwidth chopper #2 (mm)	40.0
distance to sample (m)	31.0
distance sample to detectors (m)	5.7
analyzer wavelength (Å)	10.0

Fig. 2a

Fig. 2b

Fig. 2c

Fig. 2d

Fig. 2e

Figure 2. Timing diagram for INEL1 with the mica 004 analyzers ($10.0 \text{ \AA}$ final wavelength). a) frame 2 (0.46 to $2.41 \text{ \AA}$); b) frame 3 (2.58 to $4.54 \text{ \AA}$); c) frame 4 (4.71 to $6.67 \text{ \AA}$); d) frame 5 (6.84 to $8.79 \text{ \AA}$); e) frame 6 (8.96 to $10.92 \text{ \AA}$). Heavy dashed horizontal lines indicate the chopper-closed periods. In all cases the bandwidth lines indicate the boundaries of both the fully-open and fully closed chopper conditions.

Table 3a. Opening and closing times for different chopper settings for INEL1.*

frame	1	2	3	4	5	6	1-2	1-3	1-4	1-5	1-6	4-6
$t_{\max}$ (μ s)	16667	33333	50000	66667	83333	100000	33333	50000	66667	83333	100000	100000
T_0 freq (Hz)	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
$T_0 \Delta t_{T_0}$ (μ s)	849	849	849	849	849	849	849	849	849	849	849	849
BW1 freq (Hz)	60.0	60.0	60.0	60.0	60.0	60.0	30.0	20.0	15.0	12.0	10.0	20.0
BW1 Δt_{BW1} (μ s)	424	424	424	424	424	424	849	1273	1698	2122	2546	1273
BW2 freq (Hz)	60.0	60.0	60.0	60.0	60.0	60.0	30.0	20.0	15.0	12.0	10.0	20.0
BW2 Δt_{BW2} (μ s)	424	424	424	424	424	424	849	1273	1698	2122	2546	1273
$t_{\min}$ (μ s)	4386	3572	20238	36905	53572	70238	4386	4386	4386	4386	4386	39536
$T_0 t_{c-(N)}$ (μ s)	0	16667	33333	50000	66667	83333						
$T_0 t_{eo-(N)}$ (μ s)	849	17515	34182	50849	67515	84182						
$T_0 t_{sc-(N)}$ (μ s)	15818	32485	49151	65818	82485							
BW1 $t_{so-(N)}$ (μ s)	566	382	4146	7909	11672	15436	141	-283	-707	-1132	-1556	7654
BW1 $t_{eo-(N)}$ (μ s)	990	807	4570	8333	12097	15860	990	990	990	990	990	8928
BW1 $t_{sc-(N)}$ (μ s)	509	4273	8036	11800	15563	19327	4273	8036	11800	15563	19327	19327
BW1 $t_{ec-(N)}$ (μ s)	934	4697	8461	12224	15988	19751	5122	9310	13497	17685	21873	20600
BW2 $t_{so-(N)}$ (μ s)	990	728	6104	11480	16857	22233	566	141	-283	-707	-1132	11480
BW2 $t_{eo-(N)}$ (μ s)	1415	1152	6529	11905	17281	22658	1415	1415	1415	1415	1415	12754
BW2 $t_{sc-(N)}$ (μ s)	728	6104	11480	16857	22233	27609	6104	11480	16857	22233	27609	27609
BW2 $t_{ec-(N)}$ (μ s)	1152	6528	11905	17281	22658	28034	6953	12754	18554	24355	30156	28883

T_0 = t-zero chopper, BW1 = first bandwidth chopper, BW2 = second bandwidth chopper

f = frequency, Δt = time for chopper edge to sweep thru beam

so = start open; eo = end open; c = fully closed; sc = start close; ec = end close

This table assumes $\Delta t_{c1}=0$ for the T_0 chopper.

* See Appendix A of Ref. 2 for definitions and equations.

Table 3b. Accessible wavelengths for different chopper settings for INEL1.*

frame	1	2	3	4	5	6	1-2	1-3	1-4	1-5	1-6	4-6
$t_{\max}$ (μ s)	16667	33333	50000	66667	83333	100000	33333	50000	66667	83333	100000	100000
T_0 freq (Hz)	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
$T_0 \Delta\lambda_{T_0}$ ($\text{\AA}$)	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56
BW1 freq (Hz)	60.0	60.0	60.0	60.0	60.0	60.0	30.0	20.0	15.0	12.0	10.0	20.0
BW1 $\Delta\lambda_{BW1}$ ($\text{\AA}$)	0.24	0.24	0.24	0.24	0.24	0.24	0.48	0.72	0.96	1.20	1.44	0.72
BW2 freq (Hz)	60.0	60.0	60.0	60.0	60.0	60.0	30.0	20.0	15.0	12.0	10.0	20.0
BW2 $\Delta\lambda_{BW2}$ ($\text{\AA}$)	0.17	0.17	0.17	0.17	0.17	0.17	0.34	0.50	0.67	0.84	1.01	0.50
$\lambda_{inc-max}$ ($\text{\AA}$)	0.29	2.41	4.54	6.67	8.79	10.92	2.41	4.54	6.67	8.79	10.92	10.92
$\lambda_{inc-min}$ ($\text{\AA}$)	0.56	0.46	2.58	4.71	6.84	8.96	0.56	0.56	0.56	0.56	0.56	5.04
$T_0 \lambda_{c-(N)}$ ($\text{\AA}$)	0.00	10.99	21.97	32.96	43.95	54.94						
$T_0 \lambda_{eo-(N)}$ ($\text{\AA}$)	0.56	11.55	22.53	33.52	44.51	55.50						
$T_0 \lambda_{sc-(N)}$ ($\text{\AA}$)	10.43	21.41	32.40	43.39	54.38							
BW1 $\lambda_{so-(N)}$ ($\text{\AA}$)	0.32	0.22	2.34	4.47	6.60	8.72	0.08	-0.16	-0.40	-0.64	-0.88	4.33
BW1 $\lambda_{eo-(N)}$ ($\text{\AA}$)	0.56	0.46	2.58	4.71	6.84	8.96	0.56	0.56	0.56	0.56	0.56	5.04
BW1 $\lambda_{sc-(N)}$ ($\text{\AA}$)	0.29	2.41	4.54	6.67	8.79	10.92	2.41	4.54	6.67	8.79	10.92	10.92
BW1 $\lambda_{ec-(N)}$ ($\text{\AA}$)	0.53	2.65	4.78	6.91	9.03	11.16	2.89	5.26	7.63	9.99	12.36	11.64
BW2 $\lambda_{so-(N)}$ ($\text{\AA}$)	0.39	0.29	2.41	4.54	6.67	8.79	0.22	0.06	-0.11	-0.28	-0.45	4.54
BW2 $\lambda_{eo-(N)}$ ($\text{\AA}$)	0.56	0.46	2.58	4.71	6.84	8.96	0.56	0.56	0.56	0.56	0.56	5.04
BW2 $\lambda_{sc-(N)}$ ($\text{\AA}$)	0.29	2.41	4.54	6.67	8.79	10.92	2.41	4.54	6.67	8.79	10.92	10.92
BW2 $\lambda_{ec-(N)}$ ($\text{\AA}$)	0.46	2.58	4.71	6.84	8.96	11.09	2.75	5.04	7.34	9.63	11.93	11.42

T_0 = t-zero chopper, BW1 = first bandwidth chopper, BW2 = second bandwidth chopper

f = frequency, $\Delta\lambda$ = wavelength range for chopper edge to sweep thru beam

so = start open; eo = end open; c = fully closed; sc = start close; ec = end close

This table assumes $\Delta t_{cl}=0$ for the T_0 chopper.

* See Appendix A of Ref. 2 for definitions and equations.

1.4 Guide

1.4.1 Guide Gain

Appendix B of Reference 2 provides the equations used to estimate guide gain. These were used to establish the preliminary set of guide parameters shown in Table 4 for INEL1. The gains calculated using these parameters with the guide starting 2.5 m and 1.5 m from the moderator are shown respectively in Tables 5a and 5b.

Table 4. Preliminary guide parameters for INEL1.

Parameter	Meaning	Value
M_h	moderator width (mm)	100.00
M_v	moderator height (mm)	120.00
L_{inc}	moderator-guide distance (m)	2.50
		1.50
g_h	guide width (mm)	40.00
g_v	guide height (mm)	60.00
m_h	horizontal supermirror "m"	2.00
m_v	vertical supermirror "m"	2.00
λ^*	characteristic wavelength (Angstroms)	2.00
R	radius of curvature (m)	1730.10
L_{sight}	line-of sight distance (m)	23.53
L	source-sample distance (m)	31.00
L_{exit-h}	horizontal guide-sample distance (m)	1.00
L_{exit-v}	vertical guide-sample distance (m)	1.00
S_h	sample width (mm)	20.00
S_v	sample height (mm)	20.00
M_h/L	no-guide collimation horizontal (rad)	0.00323
M_v/L	no-guide collimation vertical (rad)	0.00387
g_h/L_{exit-h}	exit collimation horizontal (rad)	0.04000
g_v/L_{exit-v}	exit collimation vertical (rad)	0.06000
	$(M-g)/2$ (horizontal) (mm)	30.00
	$(M+g)/2$ (horizontal) (mm)	70.00
	$(M-g)/2$ (vertical) (mm)	30.00
	$(M+g)/2$ (vertical) (mm)	90.00
	$(g-S)/2$ (horizontal) (mm)	10.00
	$(g+S)/2$ (horizontal) (mm)	30.00
	$(g-S)/2$ (vertical) (mm)	20.00
	$(g+S)/2$ (vertical) (mm)	40.00

Table 5a. Approximate guide gains for INEL1 ($L_{inc} = 2.5$ m).

λ	0.5	1	2	3	4	5	6	7	8	9	10
$2\theta_{c-eff-h}$ (rad)	0.00340	0.00680	0.01360	0.02040	0.02720	0.03400	0.04080	0.04760	0.05440	0.06120	0.06800
$2\theta_{c-eff-v}$ (rad)	0.00340	0.00680	0.01360	0.02040	0.02720	0.03400	0.04080	0.04760	0.05440	0.06120	0.06800
$L_{inc-full-h}$ (m)	17.65	8.82	4.41	2.94	2.21	1.76	1.47	1.26	1.10	0.98	0.88
$L_{inc-full-v}$ (m)	17.65	8.82	4.41	2.94	2.21	1.76	1.47	1.26	1.10	0.98	0.88
F_{inc-h}	1.00	1.00	1.00	1.00	0.99	0.95	0.89	0.82	0.73	0.65	0.59
F_{inc-v}	1.00	1.00	1.00	1.00	1.00	0.97	0.93	0.88	0.82	0.76	0.70
F_{exit-h}	1.00	1.00	1.00	1.00	0.98	0.94	0.91	0.89	0.88	0.88	0.88
F_{exit-v}	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.98
$G_{ideal-h}$	1.05	2.11	4.22	6.32	8.43	10.54	12.65	14.76	16.86	18.97	21.08
$G_{ideal-v}$	0.88	1.76	3.51	5.27	7.03	8.78	10.54	12.30	14.05	15.81	17.57
$G_{actual-h}$	1.05	2.11	4.22	6.32	8.19	9.46	10.24	10.67	10.84	10.85	10.85
$G_{actual-v}$	0.88	1.76	3.51	5.27	7.00	8.51	9.78	10.79	11.49	11.94	12.16
G_{ideal}	0.93	3.70	14.81	33.33	59.25	92.58	133.31	181.45	237.00	299.95	370.31
G_{actual}	0.93	3.70	14.81	33.32	57.33	80.51	100.15	115.15	124.63	129.52	131.92

Table 5b. Alternate approximate guide gains for INEL1 ($L_{inc} = 1.5$ m).

λ	0.5	1	2	3	4	5	6	7	8	9	10
$2\theta_{c-eff-h}$ (rad)	0.00340	0.00680	0.01360	0.02040	0.02720	0.03400	0.04080	0.04760	0.05440	0.06120	0.06800
$2\theta_{c-eff-v}$ (rad)	0.00340	0.00680	0.01360	0.02040	0.02720	0.03400	0.04080	0.04760	0.05440	0.06120	0.06800
$L_{inc-full-h}$ (m)	17.65	8.82	4.41	2.94	2.21	1.76	1.47	1.26	1.10	0.98	0.88
$L_{inc-full-v}$ (m)	17.65	8.82	4.41	2.94	2.21	1.76	1.47	1.26	1.10	0.98	0.88
F_{inc-h}	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.96	0.93	0.89
F_{inc-v}	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.95	0.93
F_{exit-h}	1.00	1.00	1.00	1.00	0.98	0.93	0.87	0.81	0.75	0.70	0.66
F_{exit-v}	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.96	0.93	0.89
$G_{ideal-h}$	1.05	2.11	4.22	6.32	8.43	10.54	12.65	14.76	16.86	18.97	21.08
$G_{ideal-v}$	0.88	1.76	3.51	5.27	7.03	8.78	10.54	12.30	14.05	15.81	17.57
$G_{actual-h}$	1.05	2.11	4.22	6.32	8.23	9.78	10.97	11.75	12.18	12.36	12.40
$G_{actual-v}$	0.88	1.76	3.51	5.27	7.03	8.78	10.54	12.03	13.16	13.99	14.58
G_{ideal}	0.93	3.70	14.81	33.33	59.25	92.58	133.31	181.45	237.00	299.95	370.31
G_{actual}	0.93	3.70	14.81	33.32	57.84	85.91	115.60	141.41	160.33	173.01	180.76

1.4.2 Guide Curvature

This guide is curved to minimize the transmission of fast neutrons from the prompt pulses. The effect of this curvature on the guide gain is discussed in Appendix B of Reference 2.

1.4.3 Converging Funnel

A converging funnel is used to enhance the flux on the sample. The effects of this funnel are best indicated by the Monte Carlo simulations below.

1.4.4 Monte Carlo Simulations

Monte Carlo simulations were used to obtain a more accurate estimate of the performance of the INEL1 guide system, including the funnel. Parameters were the same as in Table 1 except as noted. For the simulations, neutrons were assumed to be emitted with equal probability from the entire moderator surface, and with equal probability within the angular range ± 0.06 radians about the nominal beam direction. Since the critical angle for natural Ni at 10 Å is only 0.017 radians, this range of angular divergence was more than enough to include all neutrons that could be accepted by the INEL1 guides. The same number of randomly generated initial neutron paths (1,000,000) was used for each 1-dimensional simulation, and total guide performance was obtained by comparing neutrons on sample with and without the guide for the corresponding simulations for the horizontal and vertical direction. For these simulations, the guides were assumed to have reflectivity of 1.0 up to the critical angle θ_c for natural Ni, and a reflectivity of 0.95 from θ_c to $m\theta_c$, where m takes on the appropriate supermirror value for the particular set of guide surfaces. Table 6 shows the results of these simulations.

Table 6a. Simulated guide gains for INEL1 ($L_{inc} = 2.5$ m with 0.5 m gap).

λ	3	6	10
$G_{actual-h}$	6.64	10.58	12.16
$G_{actual-v}$	8.02	12.03	14.14
G_{actual}	53.25	127.28	171.94

Table 6b. Simulated guide gains for INEL1 ($L_{inc} = 2.5$ m with no gap).

λ	3	6	10
$G_{actual-h}$	6.85	11.65	13.50
$G_{actual-v}$	8.41	12.86	15.22
G_{actual}	57.61	149.82	205.47

Table 6c. Simulated guide gains for INEL1 ($L_{inc} = 1.5$ m with no gap).

λ	3	6	10
$G_{actual-h}$	6.87	12.47	14.82
$G_{actual-v}$	8.43	13.17	16.72
G_{actual}	57.91	164.23	247.79

Comparing Tables 5a and 5b with Tables 6b and 6c indicates that the funnel has increased the guide gain by a factor of about 1.5 at all wavelengths considered. The funnel gain is actually probably somewhat more than this, since the overall performance in the simulation is reduced by the use of the more realistic supermirror reflectivity.

Extending the guide to 1.5 m from the moderator makes a small but significant improvement. The inclusion of a gap for a T_0 chopper results in a small, but significant reduction in guide gain.

Somewhat more extensive studies than are indicated in Table 6 were carried out to roughly optimize the funnel parameters for this instrument. However, considerable improvement in the performance of this guide system may be possible with further optimization studies.

1.5 Crystal Analyzer Arrays

Mica analyzer crystals on one side of the instrument are used in near backscattering to select scattered wavelengths of ~ 20 Å, ~ 10 Å, ~ 6.67 Å, ... (mica 002, 004, 006, ... reflections), while the incident wavelength is determined by time-of-flight (TOF). The 004 reflection at ~ 10 Å will be used for most measurements, and this is the reflection for which the mica analyzers will be optimized. On the other side of the instrument pyrolytic graphite crystals are used in near backscattering to select scattered wavelengths of ~ 6.70 Å, ~ 3.35 Å, ~ 2.23 Å, ... (graphite 002, 004, 006, ... reflections). The 002 reflection at ~ 6.7 Å will be used for most measurements, with a beryllium filter provided to eliminate the higher order reflections when required.

The array of graphite crystals is curved in both dimensions to minimize the variations in flight time and Bragg angle for these neutrons. The beryllium filter in front of the detectors eliminates neutrons from the 004 and higher order reflections, leaving a wide incident wavelength range for inelastic scattering measurements. If higher analyzer energies are required, the beryllium filter can be removed to provide access to the 004 and higher order reflections.

The array of mica crystals is also curved in both dimensions to minimize the variations in flight time and Bragg angle for these neutrons. The 002, 004, 006, and higher order reflections all contribute to the scattering pattern, but there is a certain dynamic range of inelastic scattering associated with each of these reflections that is uncontaminated by any data associated with adjacent reflections. The large sample-to-analyzer-to-detector distance increases this dynamic range. The range that is free of contamination can be shifted by changing the phasing of the bandwidth selection choppers. The incident wavelength range associated with the 004 reflection is ~ 0.6 Å or ~ 110 μ eV (greater if up-scattering is negligible).

Optimization of the crystal analyzer array will be discussed in a later Technical Note. The analyzer and detector arrays are designed to minimize path-length and angular uncertainties so that sample sizes can be as large as practical.

1.6 Detectors

The detectors for each of the analyzer arrays are placed on a circular array below the plane of the sample, at a radius of ~ 0.15 to 0.3 m from the sample axis. Collimators in front of the detectors ensure that each of the detectors views only a limited angular range of the analyzer array.

Detector arrays are also provided with no analyzer crystals, so that diffraction from the sample can be measured concurrently with the inelastic data.

Either small ^3He detectors or an array of scintillation detectors based on the ZnS-LiF scintillator can be used. ^3He detectors are likely to be more stable and less sensitive to magnetic fields. A final choice has not yet been made.

2 Performance

2.1 Resolution

For INEL1 the resolution in both the energy transfer E and the wavevector transfer Q are of interest.

$$E = \frac{81.787}{\lambda_{\text{inc}}^2} - \frac{81.787}{\lambda_{\text{scat}}^2} \quad (1)$$

$$Q = 2\pi \left\{ \frac{1}{\lambda_{\text{inc}}^2} + \frac{1}{\lambda_{\text{scat}}^2} - \frac{2}{\lambda_{\text{inc}} \lambda_{\text{scat}}} \cos 2\theta \right\}^{1/2} \quad (2)$$

where 2θ is the scattering angle and

$$\lambda_{\text{scat}} = 2d \sin \theta_B \quad (3)$$

$$\lambda_{\text{inc}} = \frac{3955.4 (t - t_{\text{scat}})}{L_{\text{inc}}} = \frac{3955.4 t}{L_{\text{inc}}} - \frac{\lambda_{\text{scat}} L_{\text{scat}}}{L_{\text{inc}}} \quad (4)$$

Here θ_B is the Bragg angle for the analyzer crystals, d is the spacing of the reflecting planes in the analyzer crystals (in Å), and t is the measured time-of-flight time. The energy resolution is given by

$$\begin{aligned} \frac{\delta E}{E_{\text{scat}}} = 2 \left\{ \left(1 + \frac{\lambda_{\text{scat}}^3 L_{\text{scat}}}{\lambda_{\text{inc}}^3 L_{\text{inc}}} \right)^2 \left[\frac{\delta \lambda_{\text{scat}}}{\lambda_{\text{scat}}} \right]^2 + \frac{\lambda_{\text{scat}}^4}{\lambda_{\text{inc}}^4} \left[\frac{\delta L_{\text{inc}}}{L_{\text{inc}}} \right]^2 + \left(\frac{\lambda_{\text{scat}}^3 L_{\text{scat}}}{\lambda_{\text{inc}}^3 L_{\text{inc}}} \right)^2 \left[\frac{\delta L_{\text{scat}}}{L_{\text{scat}}} \right]^2 \right. \\ \left. + \frac{\lambda_{\text{scat}}^4}{\lambda_{\text{inc}}^4} \left(1 + \frac{\lambda_{\text{scat}} L_{\text{scat}}}{\lambda_{\text{inc}} L_{\text{inc}}} \right)^2 \left[\frac{\delta t}{t} \right]^2 \right\}^{1/2} \quad (5) \end{aligned}$$

where δt is the source pulse width and t is the total source-sample-detector flight time. The full expression for the wavevector resolution can be derived in a similar fashion. However, since the wavevector resolution is dominated by the uncertainty in scattering angle this resolution can be written approximately as

$$\frac{\delta Q}{Q} \approx (\cot \theta) \delta \theta \quad (6)$$

Tables 7a and 7b show the resolution calculated at different scattering angles for this instrument when the graphite 002 or the mica 004 analyzer planes are used.

Table 7a. Resolution and dynamic range using the graphite 002 analyzer in INEL1.^a

2θ	$\delta Q/Q$	$\delta E/E_{\text{scat}}$	$Q \text{ (}\text{\AA}^{-1}\text{)}$
20°	0.15	0.0046	0.33
90°	0.026	0.0046	1.33
160°	0.0046	0.0046	1.85

^a Calculated for $E_{\text{inc}}=E_{\text{scat}}=1.82 \text{ meV}$, $\delta L_{\text{inc}}=\delta L_{\text{scat}}=1 \text{ cm}$, $\theta_B=83^\circ$, $\delta\theta_B=0.86^\circ$, $\delta\theta=1.5^\circ$, and $\delta d=0$. Actual energy resolution will be worse than that calculated here, because several contributing factors have been ignored in these calculations.

Table 7b. Resolution and dynamic range using the mica 004 analyzer in INEL1.^a

2θ	$\delta Q/Q$	$\delta E/E_{\text{scat}}$	$Q \text{ (}\text{\AA}^{-1}\text{)}$
20°	0.15	0.0025	0.22
90°	0.026	0.0025	0.89
160°	0.0046	0.0025	1.24

^a Calculated for $E_{\text{inc}}=E_{\text{scat}}=0.82 \text{ meV}$, $\delta L_{\text{inc}}=\delta L_{\text{scat}}=1 \text{ cm}$, $\theta_B=87^\circ$, $\delta\theta_B=0.29^\circ$, $\delta\theta=1.5^\circ$, and $\delta d=0$. Actual energy resolution will be worse than that calculated here, because several contributing factors have been ignored in these calculations.

For the parameters used here, the energy resolution contribution from the source pulse width is significantly smaller than that from the graphite 002 crystal analyzer. Thus, with this source pulse width the incident flight path could be much shorter without seriously degrading the resolution when this analyzer is used. However, the opposite is true for the mica 004 analyzer, so the present path length choices may be fairly well optimized for overall instrument performance.

2.2 Bandwidth and Dynamic Range

Running the bandwidth-limiting choppers at 30 Hz, 20 Hz, 15 Hz, 12 Hz, or 10 Hz allows reasonable operation using one pulse in two, one pulse in three, one pulse in four, one pulse in five, or one pulse in six with corresponding maximum incident wavelength of 2.41 Å, 4.54 Å, 6.67 Å, 8.79 Å, or 10.92 Å (for 10 Å scattered wavelength). In these modes, some portions of the incident wavelength range starting at 0.29 Å, 2.41 Å, 4.54 Å, 6.67 Å, and 8.79 Å may be contaminated by the intervening prompt pulses.

An alternate mode of operation is to run the bandwidth-limiting choppers at 60 Hz, phased to select a wavelength range that falls between various of the prompt pulses. This wavelength range can be in the first frame (before the following pulse), the second frame (one intervening prompt pulse), and so forth. This chopper scheme provides clean operation in the first, second, third, fourth, fifth, and sixth frames for this instrument, giving access to incident wavelength ranges of ~ 0 Å, ~ 0.46 to 2.41 Å, ~ 2.58 to 4.54 Å, ~ 4.71 to 6.67 Å, ~ 6.84 to 8.79 Å, and ~ 8.96 to 10.92 Å, respectively. These choppers cannot handle all potential frame overlap problems when trying to work beyond the sixth frame at 60 Hz. Accessing some higher wavelengths may be possible by reducing the bandwidth-limiting chopper frequency to 30 Hz or less to eliminate some of the pulses, but this will give at best only spotty coverage at wavelengths above 10.92 Å.

When narrow wavelength bands are used, bandwidth chopper 2 can be run at 120 Hz, reducing the 0.17 Å range of partially obscured beam associated with chopper opening or closing to 0.085 Å.

The process of sample inelastic scattering followed by the mica 004 analyzer reflection can be confused by events due to sample up-scattering followed by the mica 006 reflection. The contamination-free bandwidth associated with the mica 004 reflection is given by

$$\lambda_{\text{inc-max}} L_{\text{inc}} + \lambda_{\text{scat-006}} L_{\text{scat}} = \lambda_{\text{inc-min}} + \lambda_{\text{scat-004}} L_{\text{scat}} \quad (7)$$

or

$$\Delta\lambda_{004} = (\lambda_{\text{inc-max}} - \lambda_{\text{inc-min}}) = (\lambda_{\text{scat-004}} - \lambda_{\text{scat-006}}) \frac{L_{\text{scat}}}{L_{\text{inc}}} \quad (8)$$

A similar expression holds for $\Delta\lambda_{006}$ resulting contamination of scattering associated with the 006 reflection by up-scattering followed by the 008 reflection. These considerations further reduce the usable bandwidth when working with the mica analyzers. There is no similar bandwidth constraint when working with the graphite 002 reflection because a beryllium filter can be used to remove any such higher-order contamination.

Table 8 shows the resulting minimum dynamic ranges in wavelength and energy transfer for the mica analyzers on INEL1.

Table 8 – Minimum Dynamic Range with the Mica Analyzer

E (μeV)	$\Delta\lambda_{u-004}$ ($\text{\AA}$)	ΔE_{u-004} (μeV)	$\Delta\lambda_{u-006}$ ($\text{\AA}$)	ΔE_{u-006} (μeV)
0	0.612	100	0.306	169
500	0.612	207	0.306	243
1000	0.612	334	0.306	324

2.3 Data Rates

Data rate estimates for this instrument will be provided in a later Technical Note.

References

1. SNS Conceptual Design Report values for poisoned decoupled supercritical hydrogen moderator.
2. Technical Note ANL/SNS/98-1