Canadian Light Source
Centre canadien de rayonnement synchrotron

Canadian Light Source

Activity Report

1999 – 2001

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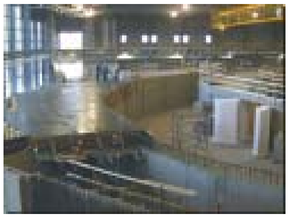
University of Saskatchewan



The cover photo shows the Canadian Light Source storage ring tunnel (in the foreground) under construction in March, 2001. The massive white doors on the right provide access to the booster ring tunnel. Some of the windows in the north wall can be seen on the left.

Canadian Light Source Activity Report 1999–2001
Emil Hallin, Editor
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Foreword

This is the first public report of the Canadian Light Source (CLS). It presents highlights of the technical development and scientific programs at the CLS as of the end of 2001, 33 months after the project was launched in March, 1999. This first report summarizes the status of our project and describes the tools the Canadian Light Source will make available to the Canadian and international research community. Canada has a sophisticated and broad-ranging community of synchrotron researchers who will soon have access to an exciting collection of powerful tools engineered to their needs.

In addition to facility-derived documents, members of the synchrotron community have submitted representative examples of their current work related to the research that will occur at the CLS. These submissions are incorporated into chapters describing the current status of each beamline.

I am proud to be a part of this dynamic community of researchers. I look forward to working with CLS users in the years to come.

Emil Hallin
Editor
CLS Activity Report 1999–2001

Acknowledgements

Capital Funding Partners

Alberta Heritage Foundation for Medical Research
Alberta Innovation & Science (Government of Alberta)
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City of Saskatoon
Government of Canada (Western Economic Diversification Canada)
Government of Ontario
Government of Saskatchewan (Saskatchewan Economic and Co-operative Development)
National Research Council
Natural Resources Canada
SaskPower
University of Alberta
University of Saskatchewan
University of Western Ontario

Operating Partners

Canadian Institutes of Health Research
National Research Council (NRC)
NSERC (Natural Sciences and Engineering Research Council)
University of Saskatchewan

Supportive Groups

Alberta Synchrotron Institute
B.C. Synchrotron Institute
Canadian Institute for Synchrotron Radiation
GlaxoSmithKline
Ontario Synchrotron Consortium
Saskatchewan Structural Sciences Centre
Saskatoon Regional Development Authority

Supportive Universities

Eighteen major universities (in addition to the University of Saskatchewan) have endorsed the CLS:

University of Alberta
University of British Columbia
University of Calgary
Dalhousie University
Universite Laval
University of Manitoba
McMaster University
University of Montreal
University of Northern British Columbia
Queen's University
University of Regina
St. Mary's University
St. Francis Xavier University
Simon Fraser University
University of Toronto
University of Victoria
University of Waterloo
University of Western Ontario

Project Design Team

Project/Construction Manager: UMA Projects
Synchrotron Designers and Engineers: Canadian Light Source Inc.

Engineers: UMA Engineering Ltd.
Architect: AODBT Architects Ltd.
Geotechnical Engineers: AGRA Earth & Environmental

Canadian Light Source under construction (November 2001).

Part I: Facility Reports

1

Report of the Director

G. M. Bancroft
University of Western Ontario

Fundamentals

This extraordinarily demanding project is proceeding very well indeed. Impressive progress has been made in areas of major importance since the start of the project on March 31, 1999. All of the $141M funding needed to complete the initial construction phase has been identified, and the project is on time and on budget. A group of 35 talented employees have been hired to complement the fine core group of 25 remaining from the Saskatchewan Accelerator Laboratory (SAL). Over 150 academics from across Canada have coordinated with Canadian Light Source Inc. (CLSI) employees to design and build the beamlines for the facility by the end of 2003. Lastly, a significant amount of industrial business has been identified, and an impressive marketing and communication operation has been established.

Funding and Schedule

The project is on schedule and in good financial shape. In 1999, $18.9M still needed to be raised to complete the $141M funding, and only the $56.4M contract with the Canada Foundation for Innovation (CFI) had been signed. This $18.9M was required as matching funds for $12.6M of the CFI funding, so the project was actually short $31.5M. I made an application to Ontario for $9.4M; Ron Cavell of the University of Alberta spearheaded an application to Alberta for $9.2M; Dennis Johnson (University of Saskatchewan, or U. of S.) began fundraising from the pharmaceutical companies; and Matt Webster (U. of S.) worked on getting most of the major contracts drafted and signed by July of 2000. The Ontario and Alberta monies have since been awarded, and the Alberta contract has been signed. Together with $0.5M from Boehringer-Ingelheim (Canada) Ltd., the total CFI matchable funding is $19.1M—just over the $18.9M target.

Even though the schedule and budget are quite tight, the project is on time and on budget. Expenditures of over $80M have now been committed, with over $54M to be spent in Saskatchewan. The building was finished and officially opened in February of 2001. Nearly all major contracts for the electron accelerator portions of the facility have been signed. Our international Review Oversight Committee (ROC) has confirmed that there is every indication the facility will have at least six beamlines in operation by January of 2004.

Personnel

The project is very fortunate to have excellent staff, with tremendous cooperation, enthusiasm and dedication. Many new people have come from Saskatchewan and other parts of Canada, and we have also been able to hire outstanding scientists from Denmark and the USA, including six repatriated Canadians. We now have the majority of the staff needed. The U. of S. and the National Research Council Canada (NRC) Plant Biotechnology Institute have now hired proven synchrotron scientists. Other Canadian laboratories and universities are also appointing researchers who will use the CLS.

Such progress could have taken place only through the outstanding efforts of several hundred people: the CLS staff, the UMA project manager and employees, many

Dr. G. M. Bancroft, founding CLS Executive Director, at the CLS building completion celebration in February of 2001. (Photo courtesy Lawrie McMahen, On Campus News, *U. of S.)*

senior U. of S. employees, several local lawyers and businessmen, the representatives from our financial partners, our Board and its Chair (Arthur Carty), and the academic community across Canada. Since the U. of S. has accepted responsibility for successful completion of this massive project, it is managing the construction phase at the highest level: through the President's Committee (Table 1·1).

After completion of the project in 2004, the management and ongoing development of the CLS will be entrusted to the Canadian Light Source Incorporated (CLSI), a corporation wholly owned by the U. of S. The CLSI Board of Directors (Table 1·2) is the ultimate authority on the selection of senior management for CLSI and on the setting of its key policies.

Beamline Development

With the help of several dedicated Canadian academics (initially these were CLS senior scientific consultants Ron Cavell, Adam Hitchcock and T. K. Sham) and the CLS staff, many proposals for beamlines have been developed. Following scientific peer review by our international Facility Advisory Committee (FAC), seven beamlines have been approved by the Board of CLSI and have been awarded design resources. These are already fully funded, and are on an accelerated development schedule in order to meet the CFI requirement of at least six working beamlines by December of 2003. The other approved beamlines, along with further projects currently in the proposal stage (such as X-ray emission spectroscopy), will be built in the next phase of capital funding.

In addition, CLSI staff and beamline team leaders have worked together to establish policies for the development and operation of the facility in 2004. They have also worked to raise further capital for the CLS, with fund-raising targets ranging from provincial governments in Canada to institutions in Australia.

Table 1·2 CLSI Board of Directors

Arthur Carty (chair)	President, NRC
Celerino Abad-Zapatero	Abbott Laboratories
Mike Bancroft	U. of Western Ontario; CLS
Ron Cavell	U. of Alberta; CISR
Michael Corcoran	VP Research, U. of Saskatchewan
R. Gary Kachanoski	VP (Research), U. of A.
Doug Maley	Western Economic Diversification Canada
T. K. Sham	U. of Western Ontario; CISR
Dennis Skopik	Jefferson Lab, USA
Larry Spannier	Saskatchewan Economic and Co-operative Development
Hans Vogel	U. of Calgary
Tony Whitworth (secretary)	VP Finance and Resources, U. of Saskatchewan

Table 1·1 President's Committee

Peter MacKinnon (chair)	President, U. of Saskatchewan
Mike Bancroft	U. of Western Ontario; CLS
Arthur Carty	President, NRC
Ron Cavell	U. of Alberta; CISR
Michael Corcoran	VP Research, U. of Saskatchewan
Walter Davidson	Coordinator (National Facilities), NRC
Adam Hitchcock	McMaster U.
Doug Maley	Western Economic Diversification Canada
Dennis Skopik	Jefferson Lab, USA
Larry Spannier	Saskatchewan Economic and Co-operative Development
Tony Whitworth	VP Finance and Resources, U. of Saskatchewan

Student employees of CLSI in 2001.

Industrial Outreach

The mandate of CLSI is to achieve 25% of its operating revenue from industrial research and other fee-for-service activities. This is a very ambitious target, probably the highest in the world for a national synchrotron facility. A strong marketing, communication, business, and financial effort was immediately required to make industries aware of the great utility of the CLS. The only industrial sector that was already well aware of synchrotron radiation as a research tool was the pharmaceutical sector, represented by several large companies in Eastern Canada.

Initially, we have targeted the mining industries. We have now convinced several mining companies (including COGEMA and Cameco in Saskatoon) that synchrotron radiation techniques are powerful and unique probes of the chemistry of the heavy elements of interest to them, such as arsenic in mine tailings. The area of mining and environmental science will provide significant worldwide business opportunities for the CLSI in the future.

Initiatives

Scientific interest in the CLS facility is evident in the participation of many Canadian researchers on various committees and beamline team efforts. Beamline development is being led by teams of scientists from across Canada: such contributions of excellence are indicative of the importance and the national character of the CLS.

Seven beamlines have been approved for construction in the initial project budget. The beamline names, energy ranges, and team leaders are summarized in Table 1·3.

Academic Users

The CLS will be a truly remarkable scientific facility: it will be critically important to Canadian scientists in nearly all scientific disciplines, including chemistry, physics, geology, biochemistry, materials science, surface science, engineering, radiology and medicine. The CLS will also be vital to many industries nationwide: pharmaceuticals, biotechnology, environmental science, mining, biomedical imaging, advanced materials and coatings, semiconductors, micromachining and nanotechnology.

Building strong links with the U. of S.and other universities across Canada will be crucial to the ultimate success of the CLS. A number of CLSI personnel hold faculty positions at the University of Saskatchewan. These include Jack Bergstrom (Professor Emeritus, Physics), Mohamed Benmerrouche (Adjunct Professor, Physics), Pawel Grochulski (Adjunct Professor, Biochemistry), De-Tong Jiang (Adjunct Professor, Physics), and Jeff Cutler (Adjunct Professor, Chemistry). CLSI also employs students from the University of Saskatchewan, such as (in 2001) a physics graduate student and eight summer students with a range of academic backgrounds including Engineering and Commerce. Further links will be built through helping to train graduate students: CLSI will coordinate programs with interested parties.

Table 1·3 Summary of approved Canadian Light Source beamlines

Beamline	Energy range	Coordinator	E-mail address
Approved, funded, and to be operational in 2004:			
Facility Diagnostic	—	Jack Bergstrom	jack.bergstrom@lightsource.ca
High Resolution Far Infrared Spectroscopy (IR-1)	10–4000 cm^{-1}	Tom Ellis Bob McKellar	thomas.hill.ellis@umontreal.ca robert.mckellar@nrc.ca
Infrared Spectromicroscopy (IR-2)	450–6000 cm^{-1}	Tom Ellis Mike Jackson	thomas.hill.ellis@umontreal.ca mike.jackson@nrc.ca
Plane Grating Monochromator	5.5–250 eV	T. K. Sham	tsham@uwo.ca
Spherical Grating Monochromator	200–1900 eV	T. K. Sham	tsham@uwo.ca
Soft X-ray Spectromicroscopy	250–2000 eV	Adam Hitchcock	aph@mcmaster.ca
Macromolecular Crystallography	6.5–18 keV	Louis Delbaere	louis.delbaere@usask.ca
X-ray Absorption Spectroscopy	5–40 keV	De-Tong Jiang	detong.jiang@lightsource.ca

CLS User Meetings and Workshops

The users of a synchrotron facility are its most important resource. There have been four CLS Users' Meetings to date (Montreal in April of 1998, and Saskatoon in November of 1999, 2000, and 2001). The CLS Users' Advisory Committee is responsible for organizing the programs and hosting the meetings, with the assistance of CLSI. These annual meetings are a forum for reviewing progress on the accelerators and beamlines of the facility, and for learning about scientific opportunities at the CLS. CLSI has also organized several University of Saskatchewan Synchrotron Radiation Applications Workshops: one on medical applications was in December of 2000 and another on earth science was in October of 2001. These initiatives are especially oriented towards engaging the interest of local researchers.

A user liaison office has been established to provide administrative support for scientific users. It also publishes a periodic electronic newsletter to keep the user community informed and to stimulate discussion of synchrotron science among Canadian researchers.

Prime Minister Jean Chrétien, University of Saskatchewan President Peter MacKinnon, and CLSI Director Michael Bancroft at the celebration for the CLS building opening.

(Photo courtesy of the Office of Communications, U. of Saskatchewan)

Industrial Users

Development of the base of industrial users has focused on demonstration research. Several samples have been analyzed at other synchrotron facilities for potential industrial clientele. This research yielded results that were well received. Development efforts have been mostly in the mining and environmental sectors, given the concentration of head offices of these operations in Saskatoon and the potential market growth for synchrotron work in these areas. Key relationships have been established with other synchrotron facilities to allow proprietary access for our future clientele until the CLS is operational.

The usefulness of synchrotron science to the mining industry is highlighted in the publications of CLSI scientists Jeff Cutler and De-Tong Jiang. More than a dozen reports to industry have been completed, and another half dozen are in process. A jointly funded industry-CLSI postdoctoral fellowship appointment has been made to further develop synchrotron techniques in environmental geochemistry. In time, these and other collaborations with industry will build the industrial revenue base to provide the targeted 25% of operational funding and to contribute to financing facility expansion.

CLS shielding tunnel during fabrication.

CLS Outreach

Canadian researchers, industries and the public at large have shown overwhelming interest in the CLS. Frequent CLS tours and presentations have heightened the excitement and the understanding of the importance of this facility to the University of Saskatchewan, to other Canadian universities, and to industry. CLSI employees have made presentations at trade shows and conferences throughout Canada to increase the awareness of synchrotron science and its potential applications. Numerous newspaper and magazine articles have also focused on the CLS facility.

Our open house in February of 2001, held in conjunction with the building inauguration, was an enormous success: over 3000 people toured the facility.

Dignitaries from various governments and government departments, including Prime Minister Jean Chrétien, have toured the CLS and have received information regarding the construction and operation of the facility.

Provincial synchrotron institutes to promote the use of CLS have been formed in Alberta, Saskatchewan, Quebec, Ontario and British Columbia.

Technical Services

CLSI personnel have been contracted to provide the technical and scientific services to the U. of S. for construction of CLS. The following sections of this report highlight the progress in delivering these services.

Capital Project Status

New building construction is essentially complete: commissioning of the heating, ventilation and air conditioning systems by U. of S. Facilities Management is continuing. The building was turned over to the U. of S. in August of 2001. Renovations to the old SAL building have been carried out. Discussions are ongoing between the University and CLSI regarding the maintenance and control of those building systems that are highly integrated with the technical systems of the facility. Landscaping has been completed.

The upgrade to the linear accelerator (linac) and the modifications of the former SAL complex are complete. Recommissioning of the linac started in June of 2001 and is proceeding.

All parts of the booster ring have been delivered. The linac to booster transfer line (LTB) and the booster ring will be commissioned in the spring of 2002.

Storage ring design is in progress. The prototype of the dipole magnet underwent acceptance tests in Spain, and they have gone well. All magnets are now on order. Other major components that have been ordered include

A new dawn on the prairie.

the superconducting radio-frequency (RF) cavities, the high-power RF amplifier system, and most of the beam diagnostic electronics. Work on the control and diagnostic systems is continuing. Additional staff members have been hired to provide sufficient support for all the required control system development.

Beamline design and development is led by CLSI scientists and by beamline teams made up of scientists from across Canada. All of the first-round beamlines have passed the preliminary design stage and are undergoing final engineering.

Review Oversight Committee

The Review Oversight Committee (ROC) is an international committee that reports to the CLSI Board of Directors. It was established to oversee the technical construction of CLS and to advise on new developments in synchrotron science. In its semi-annual reports, the ROC has generally been positive about the progress in facility design and development:

> Emil (Hallin) and the rest of the CLS management are commended for the progress made in beamline design and development since September, 2000. . . . They have selected designs for CLS beamlines which will compete well internationally and achieve the best science.
>
> —ROC report (March, 2001)

The ROC has reported its concerns with the availability of adequate personnel and resources for some CLS development and operational functions. It has also commented on possible delivery delays of some critical components. These concerns are still valid and present an ongoing challenge for CLS management.

The ROC has emphasized the importance of scientific involvement in the facility by the U. of Saskatchewan and has encouraged further involvement.

The Facility Advisory Committee

The Facility Advisory Committee is an international committee that reports to the CLSI Executive Director. Its current mandate is to advise on the scientific merit of proposals for experimental facilities at the CLS and to assist the CLS in defining appropriate directions for coordinated development. It has met three times since it was founded.

Health, Safety and Environment

In July of 2000, the Canadian Nuclear Safety Commission (CNSC) issued to CLSI a license to construct the synchrotron facility. A license to operate the linear accelerator was granted in May of 2001, and the license to commission the booster ring was issued in December, 2001. The CNSC required some clarification of the relationship and responsibilities of the U. of Saskatchewan and CLSI, resulting in a Supplemental Technical Service Agreement. Under this agreement, the CLSI has assumed all responsibility for health and safety issues.

A Personal Note

The last two years have been remarkably challenging and rewarding for me. I look forward to continued involvement in a part-time role with the CLS while based in London, Ontario. The whole community should be extremely grateful to Mark de Jong, who took over in October of 2001 as Interim Director while continuing his responsibilities as Project Leader. I congratulate Mark on his yeoman effort since he came to the CLS in September of 1999.

[Editor's note: Dr. Bancroft was appointed acting Associate Director of Science for the CLS in October, 2002.]

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CLS Accelerators and Insertion Devices

Les Dallin
Canadian Light Source Inc.

The Canadian Light Source has four main components: a 250 MeV linac, a full energy booster, a storage ring, and an array of beam lines serving interests ranging from infrared light to hard X-rays. The 2.9 GeV storage ring is a compact design of twelve double-bend "achromats" incorporating twelve 5.2-metre straight sections. Nine straights are for insertion devices (IDs) and three are for injection, diagnostics and the RF cavity. RF power will be supplied by a single 500 MHz superconducting cell.

Construction and commissioning will be complete by the end of 2003. At that time, an initial complement of five insertion devices and two bending magnet sources will supply light to seven beamlines and ten experimental endstations. High brightness will be achieved through a combination of low electron-beam emittance (18 nm·rad), high circulating current (500 mA in 2008), and small vertical coupling. The use of small-gap undulators will result in bright beams at photon energies of up to 40 keV.

Table 2·1 CLS Storage Ring Design Parameters

Circumference	170.88 m
Periodicity	12
Tunes: ν_x , ν_y	10.22, 3.26
Momentum compaction	0.0038
Number of straights	12
Length of straights	5.2 m
β_x , β_y , η_x (functions at centre)	8.5, 4.6, 0.15 m
RF frequency	500 MHz
Harmonic number	285
Energy acceptance	1.54%
Dipole field	1.354 T
Horizontal emittance	18.1 nm·rad
Energy spread	0.11 %

Injection System and Booster Ring

The linear accelerator (linac) is the electron source at the CLS. This linac was in operation for over 30 years as part of the Saskatchewan Accelerator Laboratory. The 250 MeV, 2856 MHz linac will produce pulse trains of up to 132 ns in duration, corresponding to 68 buckets at 500 MHz. The energy spread of the electron beam from the linac will be compressed [1] to about ±0.15%, which will ease the beam transport [2] to the booster and increase the booster injection efficiency.

A partially installed section of the CLS booster ring is viewed by a group from the CLS Users' Meeting (Nov. 17, 2001).

The booster ring [3] accelerates the electrons from 250 MeV to the full energy of the storage ring, 2.9 GeV. The beam extracted from the booster is expected to have an average current of 10 mA over the duration of the pulse train. The booster repetition rate will be 1 Hz. Pulse trains from the booster will be stacked tail-to-tail in the storage ring over $(3 \times 68 =)$ 204 buckets, up to an average circulating current of 500 mA. The booster ring was constructed by Danfysik in Denmark and was installed in fall 2001; it will be commissioned in early 2002.

Storage Ring

The storage ring is a double bend achromat (DBA) design. The basic lattice is unchanged relative to the published design [4], except that the circumference was increased to 170.9 metres in order to increase the length of the dipole magnets and the straight sections. The basic machine parameters [5] are summarized in Table 2·1.

This cell structure produces a fairly compact lattice. Three straight sections will be used for injection, the RF cavity, and diagnostics. The remaining nine sections are available for insertion devices. Each cell is a DBA tuned to allow some dispersion in the straights, thus reducing the overall beam size. Each cell has the two bend magnets, three families of quadrupole magnets, and two families of sextupole magnets [4]. One family of sextupoles has extra windings for horizontal and vertical orbit correction. All sextupoles have extra windings to produce skew quadrupoles for coupling control. In addition to the sextupole correctors, there are 24 X-Y corrector magnets.

Magnets

The dipoles are curved magnets with an arc length of 1.87 metres. To supply vertical focusing, the dipoles have a gradient of 3.87 T/m at 2.9 GeV. A prototype dipole met the specified magnetic characterisitics in testing at a precision measurement facility [6] at the Laboratori de Llum de Sincrotró (LLS) at Barcelona, Spain. The dipole magnets will be delivered to CLS early in 2002. All quadrupoles have the same cross-section using an open-sided "C" design. Two different lengths of quadrupoles are required for the three families. All the sextupole magnets are identical and also use a "C" configuration. Details of the magnet designs are given in [7].

Other components of the CLS are in the final design stage. These include the injection septum, injection kickers, and X-Y orbit correctors. An injection septum prototype built at Danfysik indicates that a septum with very low leakage (about 2 gauss·m) is possible.

Vacuum System

To achieve adequate beam lifetimes, a pressure of less than 10^{-9} torr is required. The vacuum system will use discrete absorbers that will intercept approximately 98% of all photons produced by the dipole magnets. The remaining photons will be directed down the beamlines. The absorbers will be removable for access to the absorber or for replacement. The ultimate base pressure should be achieved quicker with discrete absorbers than with distributed absorbers. The base pressure is a function of thermal out-gassing and pumping speed. Prior to installation, the vacuum chambers will be baked to reduce thermal desorption rates. No *in situ* bake-out system is planned.

The vacuum system provides one port per dipole and one insertion device (ID) port for each straight section. The ID ports will accommodate two IDs in each straight. The majority of the vacuum system will be constructed of stainless steel. The high mechanical strength and ease of welding of stainless steel will outweigh the opposing benefits of the high thermal and electrical conductivity of aluminum. Construction of the chambers will be similar to that of other labs (ANKA, BESSY II, and SLS). ID chambers may be constructed of aluminum or copper.

The general shape of the chamber includes the electron beam chamber, neck, and antechamber. The neck dimensions provide low chamber impedance, a large enough gap for unrestricted exit of photons, suitable conductance for pumping, and allowance for all magnet pole tips. The majority of the electron chamber has a fixed geometry. Transitions between sections have a minimum 5:1 ratio transition piece to minimize RF impedance. In addition, flanged connections will have either an inserted RF shield or a minimized gap to reduce impedance.

Orbit Control

Global beam position correction will be accomplished with four horizontal and four vertical orbit correctors in each of the storage ring cells, optimized for each transverse plane. Horizontal and vertical position monitoring will be done at four locations in each cell as well. The horizontal and vertical position monitors are the same, each containing four buttons. Extra vertical correction (per unit phase advance) is required because of the stringent requirements to accurately position the much smaller vertical beam size. An early description of the orbit correction is given in [5], where only three vertical monitors and correctors were used per cell.

Global and local coupling correction [8] will be accomplished with 36 skew quadrupole magnets. The skew quadrupoles are created by separate windings on one family of sextupole magnets.

RF System

The CLS storage ring RF system will operate at exactly 500 MHz, and will use a higher order mode (HOM) damped superconducting (SC) RF cavity based on the Cornell cavity design used in CESR [9]. The Cornell design features a low-impedance, large aperture niobium cavity which allows potentially beam-perturbing HOMs to propagate out of the cavity volume to HOM loads located external to the cavity, where they can be very effectively damped. The CLS expects to avoid the use of a longitudinal damping system with the Cornell-type cavity.

The Cornell cavity has proven its reliability through its service in CESR and is well-suited for use in high current storage rings. Current work at Cornell has demonstrated RF power in excess of 260 kW per cavity delivered to the circulating beam, with plans to increase this value in the near future. As a rough guideline, the CLS storage ring will require approximately 110 kW of RF power per every 100 mA of circulating beam. Thus, one installed cavity will allow the CLS to operate at currents in excess of 200 mA, with the possibility of greater currents in the future.

The Cornell cavity design is capable of large gradients, with operation in the 6 to 10 MV/m range considered almost routine. The CLS requires an RF voltage of 2.4 MV, which places it in the middle of that range (8 MV/m). The CLS has opted to begin operation with one Cornell-type SC RF module installed in the storage ring, and one full module to act as a spare in case of a major system malfunction. Future operations may employ the second cavity in the CLS storage ring when very high current operation is desired.

Using a superconducting RF system offers many challenges to the CLS. Expertise in the area of SC and cryogenics will be a necessity to ensure reliable operation. As well, unlike many others using SC cavities, the CLS will be commissioning with SC cavities installed. Extra attention will have to be given to the operation of the cavity under the poorer vacuum conditions expected in the early commissioning phases of the machine.

Daylight filters through beam ports into the CLS storage ring tunnel (November, 2001).

Panoramic view of the shielding tunnels of the CLS storage ring and booster ring (November, 2001).

Insertion Devices

Nine straight sections are available for IDs. To maximize the number of ID beamlines, most straights will have two IDs with a chicane separating the beams by 1.25 mrad. The initial IDs are the following:

- an in-vacuum undulator with a 22-mm period, a 5-mm minimum gap, and 145 poles covering 6 to 18 keV;
- an undulator with a 45-mm period, a minimum gap of 12.5 mm, and 53 poles covering 250 to 1900 eV;
- an undulator with a 185-mm period, 19 poles and a 25-mm minimum gap covering 5.5 to 250 eV (in the same straight as the undulator with the 45-mm period);
- a helical APPLE-II undulator with a 75-mm period, a 15-mm minimum gap, and 43 poles, capable of delivering circularly polarized light from 100 to 1000 eV and linearly polarized light from 100 to 3000 eV; and
- a high-energy superconducting wiggler with a period of 33 mm, a maximum field of 1.917 T, and 63 poles covering the photon energy range up to 40 keV.

The *ex vacuo* IDs are being designed for APS-type ID vacuum chambers.

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* CLS Technical Design Notes may be viewed at http://www.cls.usask.ca/research/technotes.shtml.

3

Commissioning Report

Les Dallin
Canadian Light Source Inc.

Phase I Commissioning included recommissioning of the linear accelerator (linac), recommissioning of the Energy Compression System (ECS), recommissioning of the new Energy Spectrometer System (ESS), and commissioning of the Linac-to-Booster (LTB) transfer line to Optical Point 2 (OP2). OP2 is the point where the beam is bent in the vertical direction to exit the linac vault. These systems are described in the CLS Phase I Commissioning Plan.

Linac

Several major systems were changed on the existing 300 MeV linac. These were a new cooling system and a new modulator system, both optimized for 1 Hz operation; a new trigger system; a new control system; and new controllers for the magnet power supplies. All these systems now work as designed, resulting in stable accelerator operation.

A license to operate was received June 14, 2001. Linac commissioning began shortly thereafter on June 29, but technical difficulties impeded progress for several weeks. Several minor technical adjustments were made and the new modulator system was thoroughly investigated. At the same time, the commissioning team became familiar with the new operating system. Some debugging and reconfiguration of this new system was required, which also caused some delays. On June 30, a major source of RF noise was discovered and corrected. The noise had produced phase modulation in the RF sections, and that lead to a wide energy spread in the accelerated beam. Once corrective measures were taken, the accelerator worked well and commissioning proceeded quickly, leading to a beam suitable for transport beyond the ECS by August 28.

It soon became apparent that there was insufficient power in three accelerating sections, and the maximum beam energy that could be achieved using only these three sections was around 180 MeV. However, they could still produce a beam suitable for all of the Phase I commissioning, albeit at an energy slightly lower than that indicated in the commissioning plan. Commissioning continued until September 23 to test all systems up to Optical Point 2 (OP2) and to determine the radiation levels in the CLS environment. For these and subsequent tests, the linac produced a consistent beam over several weeks of operation.

The planned injection into the booster will require up to 250 MeV available from the linac. This will require the use of five or six accelerating sections.

Energy Compression System

The calibration of the energy compression system magnets was checked and upgraded. The first magnet of the ECS was used to determine the energy of the beam after it had left the linac. During linac commissioning this magnet was routinely used, and the energy deficiencies of sections were characterized. Ease of operation of the ECS was improved by the upgraded magnet calibrations. Setting the ECS magnets to the energy value of the first magnet resulted in a clean transport of the beam through

Noel Craddock taking a break from booster ring assembly.

Chief accelerator designer Les Dallin (left) discussing the CLS storage ring with Allen Hodges.

the ECS. The phase and attenuation of the ECS were adjusted by maximizing the beam transport through the energy spectrometer system (ESS).

Energy Spectrometer System

The ESS was designed to give a more exact value of the beam energy and energy spread. The system was crudely operated to test that the components were working and to deliver beam to a beam dump at the end of the ESS for radiation experiments. The ESS is ready to be a central tool for beam analysis.

Transport to Optical Point 2

Transport from the ECS to OP2 was straightforward. A vacuum valve partially protruding into the beam transport caused some delay. Inspection of the switchyard dipoles determined that the polarity of one magnet was reversed. Once this was corrected the beam was bent through the switchyard magnets with no difficulty. Since the beam was now pointed in the direction of the new linear-to-booster (LTB) tunnel, special care was taken to determine that radiation levels were safe at points external to the locked-up area. Detailed analysis of the linac beam has yet to be made.

Conclusion

The linac and subsequent systems up to OP2 in the LTB transfer line were commissioned to the point where all systems can be said to run. A beam suitable for making measurements of beam-induced radiation was delivered for several weeks, and extensive radiation monitoring was completed. Sufficient information was obtained to fulfill the requirements of this aspect of the Phase I commissioning. The next phase of commissioning will follow the installation of new klystrons where required. An operating energy of between 200 and 250 MeV will be reached at that time. Beam commissioning will then resume in order to characterize the beam quality and prepare the beam for the onset of Phase II (booster) commissioning.

4

Beamline Development

Emil Hallin
Canadian Light Source Inc.

Principal CLS Contacts

Users' Office	+1 306 657–3558	clsuo@lightsource.ca
Science Director	+1 306 657–3500	science@lightsource.ca
Beamline Manager	+1 306 657–3539	blman@lightsource.ca

This chapter describes the procedures for developing a beamline at the CLS. Principal contacts are indicated above, and the principal planning, review, and oversight committees are described in the first section below. The steps in proposing, reviewing, building and operating a beamline at the CLS are outlined in the second section. The final section gives a history of the process that resulted in the first group of CLS beamlines currently under construction, and then introduces each of these beamlines. More detailed descriptions of the approved beamlines and the science that they enable are presented in subsequent chapters of this report. Information about accessing the approved beamlines can be obtained from the Beamline Manager, the appropriate beamline team leader, or the CLS Users' Office.

Principal Committees

There are four key committees that are especially important to the beamline development process at the CLS. This section describes these committees and their mandates, and provides their membership lists.

Beamline Planning Advisory Committee (BPAC)

The BPAC is a scientific planning and advisory group appointed by and reporting to the Executive Director. This committee helps to establish beamline development policies and oversees progress.

The duties of the BPAC include formulating beamline planning and development procedures, and developing appropriate policy documentation. The BPAC examines all policy and planning documents that impact users. Other roles of the BPAC are the following:

- to advise and assist with the establishment of the CLS;
- to help with implementation of Facility Advisory Committee (FAC) recommendations;
- to advise the Director on the required common beamline services (including machine/beamline interfaces, laboratories, and computing services) and also on the coordination required between beamlines;
- to oversee the progress of beamline development by reviewing the minutes of design meetings;
- to promote the CLS with workshops and lectures for academia, government and industry;
- to assist with CLS fundraising activities; and
- to advise on hiring for beamline-related positions.

The minutes of BPAC meetings are sent to the members of the Users' Advisory Committee (UAC) for their information. The chair of that Committee is also an ex-officio member of the BPAC.

Users' Advisory Committee (UAC)

This committee serves the following functions:

- to provide advice to the Director on the operation and management of the synchrotron and the beamlines;
- to provide feedback to CLS management on the development and operation of the CLS;
- to represent the interests of CLS users;
- to assist CLSI in providing feedback to users about issues related to the CLS; and
- to plan and host the CLS Users' Meetings, with assistance from CLSI.

The Users' Advisory Committee consists typically of eight to ten people who are generally current or future CLS users. UAC members are elected democratically for a three-year term via an e-mail ballot of all CLS users each December. Terms have been staggered so that about one third of the membership changes each year. The candidates for election are nominated by the existing UAC and by the CLS user community at the annual Users' Meeting. Efforts are made to achieve a balanced representation. CLSI staff members are eligible to be members of the UAC.

Beamline Planning Advisory Committee*

Mark DeJong (Chair)	CLSI Executive Director
Ron Cavell	University of Alberta
Jeff Cutler	Canadian Light Source
Louis Delbaere	University of Saskatchewan
Tom Ellis	University of Montreal
Kathy Gough	University of Manitoba
Emil Hallin	Canadian Light Source
Adam Hitchcock	McMaster University
De-Tong Jiang	Canadian Light Source
T. K. Sham	University of Western Ontario
John Tse	National Research Council Canada

* BPAC members as of December 31, 2001

Users' Advisory Committee 2002

Member	Institution	Until
Stephen Urquhart (Chair)	University of Saskatchewan	2002
Kathy Gough	University of Manitoba	2002
De-Tong Jiang	Canadian Light Source	2002
Emil Hallin	Canadian Light Source	2003
Dennis Klug	Steacie Institute (NRC)	2003
Jeanette See	Alcan International Ltd.	2003
Tom Tiedje	University of British Columbia	2003
Alan Anderson	St. Francis Xavier University	2004
Gerald Audette	University of Alberta	2004
Adam Hitchcock	McMaster University	2004
Brett Moldovan	Cameco Corporation	2004
Jeanne Percival	Natural Resources Canada	2004

Facility Advisory Committee (FAC)

Members of this external strategic planning group are appointed by and report to the CLS Executive Director. During the CLS construction period, the FAC advises on state-of-the-art synchrotron research, evaluates beamline proposals, and provides recommendations as to which should be developed. After commissioning, the FAC will

- continue to review and recommend beamline proposals;
- perform periodic reviews of the scientific performance of the beamline teams; and
- provide ongoing advice on CLS scientific programs in view of the continuing evolution of synchrotron-related research fields.

Review Oversight Committee (ROC)

This committee is charged with monitoring the construction of the CLS, and reports directly to the CLSI Board of Directors. Members of the ROC are appointed by the CLSI Board, on the advice of the CLSI Executive Director. The ROC is responsible for

- reviewing the various technical plans and specifications for the CLS;
- reviewing the progress in achieving technical goals with the linear accelerator, the booster ring, the storage ring, the vacuum system, system integration, the control systems, the information technology infrastructure, the insertion devices, the front end design, and the beamlines; and
- considering those issues (such as policy or administration) that may have a direct impact on the technical performance of the synchrotron.

It is anticipated that the FAC and the ROC will be merged after the CLS is commissioned. Any additional technical reviews that may be required will be conducted by ad hoc panels. At present, there is close contact between the FAC and the ROC during the construction phase, in particular over issues regarding both the feasibility of beamline design and the effects of beamlines on the performance of the synchrotron.

The Beamline Development Cycle

Developing a new beamline at the CLS follows the process initially outlined in a document approved by the BPAC in late 1999. A formal document describing in depth the beamline development cycle is being prepared and will be available on the CLS web site after approval by the Board of CLSI. Together with Table 4·1, the following paragraphs summarize the major stages of the beamline development cycle. Review and approval processes occur at each major stage of beamline development.

Facility Advisory Committee*

Alex McAuley (Chair)	University of Victoria
Daryl Crozier	Simon Fraser University
Bruce Gaulin	McMaster University
Stewart McIntyre	University of Western Ontario
Piero Pianetta	SSRL, Stanford University
George Sawatzky	University of British Columbia
Dale Sayers	North Carolina State University
Edwin Westbrook	APS, Argonne National Laboratory

* FAC members as of December 31, 2001. Gordon Brown (Stanford) and Howard Padmore (Berkeley) were FAC members from 1999–2000.

Review Oversight Committee

John Tse (Chair)	National Research Council Canada
Ercan Alp	APS, Argonne National Laboratory
Walter F. Davidson	National Research Council Canada
Mikael Eriksson	MAX lab, Lund University ,Sweden
Steve Hulbert	NSLS, Brookhaven National Laboratory
Alan Jackson	Lawrence Berkeley National Laboratory
Paul Schmor	TRIUMF
Gwyn P. Williams	Thomas Jefferson National Accelerator Facility (Jefferson Lab)

Letter of intent

The first step in the beamline development process is the formation of a group of researchers called a Beamline Team (BT); these people will provide the scientific justification for the beamline and will be its active supporters and users. Once this group is formed, the CLS Beamline Manager should be contacted to provide support and guidance in the writing of a Letter of Intent (LOI) to the CLS Executive Director. This LOI is reviewed by BPAC, which advises the director on any areas of potential concern regarding duplication, feasibility, and so on.

Proposal and Conceptual Design

An accepted LOI results in an invitation from CLSI to proceed with a conceptual design (CD) proposal. This document outlines the scientific goals, identifies the committed and potential users, and provides sufficient detail to judge the technical feasibility of the beamline. The proposal is then considered at a subsequent meeting of the FAC. CLS resources (including CLSI personnel) are available to assist in the generation of this proposal. The technical aspects of this proposal become the basis of the formal conceptual design. After a beamline proposal is recommended by the FAC, the proposal document becomes a Conceptual Design Report (CDR).

Preliminary Design

After formal approval by the CLSI Board, the beamline enters a multistage development process. In consultation with the BT, CLSI personnel (usually a CLS Beamline Developer) are assigned to the project. An important member of the beamline team, the Beamline Developer is responsible both for developing the beamline and for meeting the scientific requirements that were expressed in the CDR.

Detailed Design

In this phase, detailed engineering design is performed to support either a build-to-print or a design-build contract. Technical and safety reviews of major individual items are carried out prior to issuing requests for bids and tendering contracts.

Tendering and Construction

Once contracts have been awarded, the beamline development scientist is responsible for tracking vendor compliance with regard to technical performance and adherence to schedule.

Commissioning

When each sub-assembly is ready for performance evaluation, a pre-defined testing program is carried out. After all the components are installed and aligned, the final commissioning phase begins. Commissioning is considered complete when the beamline and its associated source and front-end components have met all safety requirements and have demonstrated the performance specified in the initial conceptual design report.

Table 4·1 Stages in beamline development at the CLS

Stage	Documents	Contact	Review Process	Consequences
Letter of Intent (LOI)	Main document: LOI, which identifies the Beamline Team (BT), its scientific goals, and beamline performance requirements.	CLS Executive Director	BPAC review	i) LOI revision, or ii) Submission of a full proposal
Conceptual Design (CD)	*Main document:* Conceptual Design Report (CDR), which describes the optical layout that could satisfy the scientific goals and the performance requirements (written by the CLSI Beamline Developer in conjunction with the BT). *Ancillary documents:* estimated budget and schedule.	CLS Executive Director	1) FAC review (peer review) 2) CLSI Board review (final decision)	i) Rejection, or ii) Recommendations for changes and resubmission, or iii) Approval (Note: funding is authorized in a separate process.)
Preliminary Design (PD)	*Main document:* Preliminary Design Report (PDR), which provides the basis for engineering the beamline (by refining the CDR, describing in detail the optical properties, and including detailed performance specifications for each major system and subsystem). *Ancillary documents:* an updated budget and schedule; safety, operations and commissioning reports; layout and elevation drawings; and the procurement strategy.	Beamline Manager	1) Internal review 2) External review 3) CLSI Board review	Permission to proceed (at each review, modifications may be recommended.)
Detailed Design (DD)	*Main document:* Detailed Design Report (DDR), written by the CLS beamline developer together with engineering experts procured by CLSI. *Ancillary documents:* updates to all documents from the PD stage, detailed design drawings; and a commissioning plan for submission to CLSI.	Beamline Manager	1) Internal review 2) External review	Permission to proceed (at each review, modifications may be recommended.)
Tendering and Construction	*Main documents:* continually updated drawings and commissioning plans. *Ancillary documents:* updates to all DD documents, as required, and "as built" engineering drawings.	Beamline Manager	1) Internal review 2) Periodic reviews of technologies in key areas	Permission to proceed
Commissioning	*Main document:* Commissioning Report (results of the performance tests).	Beamline Manager	Internal review	Permission to operate
Operation	*Main document:* Beamline Operations Manual. *Ancillary documents:* updates to all prior documents.	CLS Executive Director	1) Internal reviews 2) Safety reviews	Capabilities for BT, fee-for-service, and independent investigator research programs

Operation

Details of the proposed interactions between beamline teams and the CLSI during the commissioning and operating phases are currently being worked out. A document approved by the CLSI Board, *Principles and Process for Beamline Development and Operation,* describes general principles for the beamlines funded by the CLS project. This document can be obtained by contacting the CLS Users' Office.

Initial Beamlines at the CLS

The CLS proposal submitted to the CFI in 1998 was developed through a series of workshops and discussion groups sponsored by the Canadian Institute for Synchrotron Radiation (CISR), along with extensive interaction with the Saskatchewan Accelerator Laboratory staff. The proposal visualized the storage ring and twelve major beamlines with fifteen attendant endstations as generally defined by the community in 1995. When project funding was awarded in 1999, the principal funding agency, the Canada Foundation for Innovation (CFI) recommended that operation of at least six beamlines would be regarded as completion of the CLS Project. However, considerable time had passed since this definition of the project, so the CLS Beamline Planning Advisory Committee determined that a new round of public consultation was advisable. A broadly based invitation to participate was issued through the CISR: the community was invited to form beamline teams and submit LOIs. The FAC was formed to evaluate the proposals and to provide scientific guidance to the CLS.

Fourteen letters of intent were received. The BPAC recommended that duplications should be avoided and that ten projects should be invited to create full beamline proposals (two proposals were merged). The CLS Facility Advisory Committee considered these ten proposals, and recommended seven for immediate scientific approval by the CLS. The FAC requested that the three deferred proposals return for reconsideration after revision. Two of these proposals have since received scientific approval from the FAC. The third has not yet been reconsidered. As of December 31, 2001, the FAC has recommended the scientific approval of ten beamlines at the CLS.

Seven beamlines (plus a facility diagnostic beamline) are presently proceeding within the budgetary envelope of the CLS Project; these are listed in Table 1·3 in Chapter 1. These seven beamlines were selected with the participation of the FAC and the BPAC. They were subsequently approved by the University of Saskatchewan President's Committee, which oversees the overall construction process, and also by the CLSI Board.

In the following sections, various beamlines that have been proposed and approved for installation at the CLS are described in approximate order of increasing photon energy—first bending magnet (BM) lines and then Insertion Device (ID) lines.

Bending Magnet Beamlines

Facility diagnostic beamline

This beamline (2B1.2) will use visible light from a bending magnet source. It will initially provide light to a fast gated CCD camera to aid in facility commissioning. Ultimately, some of the visible light from this source will be switched to a streak camera as well. A simple pinhole camera is anticipated to operate with X-ray photons and to provide continuous measurement of the storage ring phase space ellipse parameters. The facility diagnostic beamline is mounted on a source point that is not suitable for development of a regular beamline.

Infrared spectroscopy beamlines

There are three IR beamlines proposed for the Canadian Light Source, of which two are approved in the CLS project. A far IR beamline (1B1.1) is designed for high-resolution studies of gas phase systems. A mid-IR spectromicroscopy (2B1.1) beamline is anticipated to have a large component of biological and industrial applications. All of the IR beamlines will share similar light collection and transmission optics; they will diverge significantly in optical requirements only at the experimental endstations.

Double crystal monochromator (DCM) beamline

The DCM beamline is intended for experiments in "tender X-ray spectroscopy". It has been approved, is under design, and has been allocated a bending magnet source point (11B1.1).

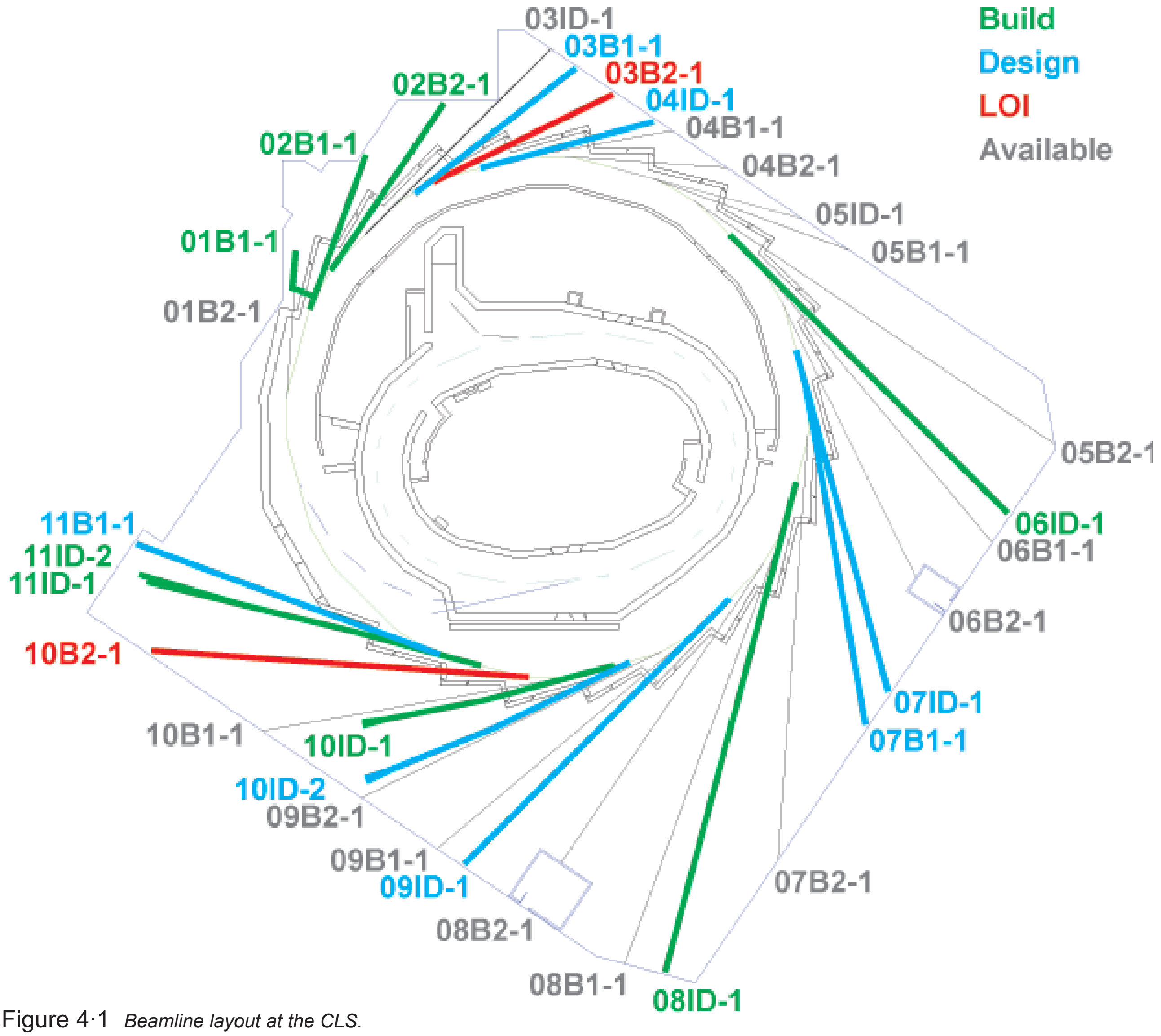

Figure 4·1 *Beamline layout at the CLS.*

Table 4·2 Current proposed allocation of photon ports at the CLS

Beamline	Length (m)	Port Type	Port Allocation	Beamline Status
01ID.1/2	—	—	Not available (injection)	—
01B1.1	short	BM	High Resolution Far IR	Design
01B2.1	short	BM	Not allocated	Expansion
02ID.2	20.5	ID	Not available (reserved for second RF)	—
02B1.1	short	BM	Mid-Infrared Spectromicroscopy	Design
02B1.2	19.1	BM	Facility Diagnostic (visible optics and streak camera)	Design
02B2.1	21.4	BM	Facility Diagnostic (X-ray pinhole)	Design
03ID.1/2	27.4	ID	Not allocated	Expansion
03B1.1	23.5	BM	Mid-Infrared Spectromicroscopy	Design
03B2.1	21.2	BM	Nanotechnology Centre	LOI
04ID.1	19.1	Wiggler	Biomedical Imaging	Design
04ID.2	19.1			
04B1.1	15.9	BM	Not allocated	Future
04B2.1	16.9	BM	Not allocated	Future
05ID.1	20.4	ID	Not allocated	Expansion
05ID.2	20.4	ID	Not allocated	Expansion
05B1.1	21.6	BM	Not allocated	Future
05B2.1	45.5	BM	Not allocated	Future
06ID.1	41.5	SC Wiggler	XAFS	Design
06ID.2	41.5			
06B1.1	37.9	BM	Not allocated	Future
06B2.1	31.9	BM	Not allocated	Future
07ID.1	37.4	SC ID	Powder X-ray Diffraction	Design
07ID.2	37.4	ID	Not allocated	Future
07B1.1	35.8	BM	Small Molecule X-ray Diffraction	Design
07B2.1	44.5	BM	Not allocated	Future
08ID.1	53.1	SGU	Canadian Macromolecular Crystallography Facility #1	Design
08ID.2	53.1	SGU	Canadian Macromolecular Crystallography Facility #2	Design
08B1.1	48.9	BM	Not allocated	Future
08B2.1	37.7	BM	Not allocated	Future
09ID.1	39.4	SC ID	Hard X-ray Microprobe	Design
09ID.2	39.4	ID	Not allocated	Future
09B1.1	35.7	BM	Not allocated	Future
09B2.1	34.9	BM	Not allocated	Future
10ID.1	34.7	EPU	Soft X-ray Spectromicroscopy	Design
10ID.2	34.7	EPU	Tentatively allocated to X-ray Emission Spectroscopy	Design
10B1.1	32.9	BM	Not allocated	Future
10B2.1	40.4	BM	VESPERS (simultaneous XRF and XRD)	LOI
11ID.1	39.3	Undulator	High Resolution Spherical Grating Monochromator	Design
11ID.2	39.3	Undulator	Variable Line Spacing Plane Grating Monochromator	Design
11B1.1	34	BM	Medium Energy Double Crystal Monochromator	Design
11B2.1	short	BM	Not allocated	Future
12ID.1/2	—	—	Not available (RF)	—
12B1.1/2	short	BM	Not allocated	Future

Insertion Device Beamlines

Variable line spacing plane grating monochromator (VLS-PGM) beamline

The VLS-PGM beamline (11ID.2) is planned for operation on a linear undulator. The three gratings of this monochromator will provide good brilliance and high resolution (>10 000) over the energy range of 5.5–250 eV.

High resolution spherical grating monochromator (SGM) beamline

The SGM beamline (11ID.1) will also operate on a linear undulator. The three gratings of this monochromator will cover the energy range of 200–1900 eV. This beamline will use the grating support structure and other beamline components of the Canadian SGM beamline currently at the Synchrotron Radiation Center at the U. of Wisconsin-Madison. The CLS implementation will have a similar energy coverage but much higher brilliance. It will have two endstations: one will be a fixed endstation equipped with a high resolution hemispherical analyzer, while the other will be modular to allow the use of various endstations.

Soft X-ray spectromicroscopy beamline

An elliptically polarized undulator (EPU) will deliver arbitrarily adjustable polarized photons. A plane grating monochromator (a co-development project between the CLS and the Advanced Light Source) will provide high brightness and modest energy resolution in the energy range of 250–2000 eV. This beamline (10ID.1) will have two endstations: a fixed scanning transmission X-ray microscope (STXM), and a mobile photoemission electron microscope (PEEM). These microscopes will be used for the analysis of a wide variety of biological, environmental, and industrial materials to a spatial resolution of ~50 nm.

Macromolecular crystallography beamline

A small-gap in-vacuum undulator will be used to deliver high brilliance photon flux in the energy range of 6.5 to 18 keV. This beamline (8ID.1) is being designed in cooperation with the Advanced Photon Source, and will be similar to the SER-CAT protein crystallography beamline.

General purpose micro-XAFS beamline

A wiggler will be used to deliver high photon flux in the energy range of 5 to 40 keV. This beamline (6ID.1) will deliver stable high flux into a spot as small as approximately 10 × 10 micrometres, and will provide both microprobe and XAFS capabilities.

Powder diffraction beamline

This beamline has been approved, is under design, and has been allocated an insertion device source point (9ID.1).

5

Industrial Research by CLSI

Rob Slinger and Jeffrey Cutler
Canadian Light Source Inc.

A significant amount of research has been completed to develop an industrially responsive program at the Canadian Light Source. The program supports the vision of the Canadian Light Source Inc. (CLSI) to assist industrial research and development programs by offering synchrotron light as an effective tool for industry. To help our industrial programs expand, the CLSI has nurtured several collaborations around the globe. In particular, CLSI has worked with DARTS (Daresbury Analytical Research & Technology Service, Daresbury Laboratory, UK) and MediChem (at the Advanced Photon Source, Argonne, IL), both of which are industrially responsive fee-for-service organizations.

After its first year of activity, our program has completed eleven reports to different industries and government agencies, and has facilitated five projects at Daresbury. CLSI has also hired its first joint industry-CLSI research associate to focus on a specific problem for a client. Reports to date on fee-for-service projects are summarized in Table 5·1. These projects range from the study of advanced materials for coatings and lubricants (with the United States Air Force) to the speciation and associated geochemistry of arsenic in mill tailings (with COGEMA Resources Inc.).

Table 5·1 Industrial reports by CLSI

Report Title	Company
Sulphur Analysis for Australian Geological Survey (AGSO)	AGSO
Cerium Analysis using X-ray Absorption Spectroscopy	IFire/Westaim
Sulphur Analysis using X-ray Absorption Spectroscopy	Cominco
XANES Analysis of Various Coatings	US Air Force Research Laboratory
Chemical Speciation of Arsenic in Uranium Mine Tailings	COGEMA Resources Inc.
Chromium Speciation in Ash	NRCan Devon
Speciation of Sulphur and Carbon in Coke Samples by X-ray Absorption Spectroscopy	NRCan Devon
Sulphur Analysis using X-ray Absorption Spectroscopy	NRCan Ottawa
Iron Phosphate Analysis using X-ray Absorption Spectroscopy	Surface Science Western
Speciation of Contaminated Soils using X-ray Absorption Spectroscopy	Clifton Associates Ltd.
Petrographic and Synchrotron X-ray Analysis of Carbonaceous Material in Graphitic Pelitic Gneisses, M-Zone, Saskatchewan, Canada	Saskatchewan Research Council

Note: CLSI facilitated additional research that was carried out by DARTS at Daresbury (UK) for Alcan, COGEMA, NRCan, DNX Inc., and the University of Alberta.

Scientists with the CLSI business development and industrial liaison office have traveled to three different synchrotron light sources to accomplish these projects.

The soft X-ray beamlines at the Canadian Synchrotron Radiation Facility at the U. of Wisconsin-Madison were used to study the nature of carbon, sulphur and phosphorous in soils (U. of Saskatchewan, Clifton Associates), coke (NRCan, Devon, AB), slag (Cominco), hematite (NRCan, Ottawa), and coals (Australian Geological Survey Organization). Also studied were the nature of phosphates in catalysts (Surface Science Western) and the local environment of zirconium in silicon oxides (United States Air Force Research Laboratory).

Lori Walerius and Lavina Carter—key members of the crew that keeps CLSI organized.

Brett Moldovan (Cameco Corporation) presenting his work on X-ray absorption studies of uranium mine tailings at the Fourth CLS Users' Meeting in November of 2001.

A study by the Saskatchewan Research Council on the alteration of graphite and its association with mineralization has lead to the publication of an extended abstract and the presentation of results at an international conference in Poland.

Two hard X-ray beamlines at the Advanced Photon Source (APS) were used to study environmental geochemistry samples. The Pacific Northwest Consortium-Collaborative Access Team (PNC-CAT) and Commercial Beamline Collaborative Access Team (COM-CAT) beamlines were used for an extensive XAFS study on the speciation and mineralization of arsenic in mill tailings, in collaboration with COGEMA Resources Inc. These results were used by COGEMA in a license hearing before the Canadian Nuclear Safety Commission. COGEMA and the CLS have now cosponsored a research associate to continue working on this project (a research report is presented in later in this chapter).

The interaction between DARTS, CLSI and MediChem led to an experimental collaboration to determine the structure of Vitamin B2 by means of powder diffraction experiments at COM-CAT. Discussions are continuing to explore further areas of cooperation.

The association with DARTS is allowing us to facilitate additional experiments for various clients. Samples from five different projects were sent to Daresbury for powder diffraction (Alcan and DNX), single crystal diffraction (University of Alberta), and XAFS investigations (NRCan and COGEMA). The single crystal data obtained for the University of Alberta was especially exciting because the group at DARTS was able to collect diffraction data from a crystal only 5 micrometres in width. This was the smallest crystal for which DARTS has ever been able to collect a diffraction pattern.

The industrial collaboration program at the CLS has been growing steadily; the value of the work now completed is estimated to be in excess of $150,000. These preliminary demonstration activities were funded by CLSI, the University of Saskatchewan, Saskatchewan Economic and Cooperative Development, and Western Economic Diversification Canada.

CLSI is continuing to develop interest in several different industry sectors and organizations in the power and potential of this third-generation light source. The project opportunities are phenomenal and the potential for cutting-edge research is immense.

Ning Chen and Jeff Cutler discuss the analysis of EXAFS data on mining tailings.

Chemical speciation of arsenic in uranium mine tailings by XAFS

J. N. Cutler[1,2]*, D.-T. Jiang*[1,3] *and G. Remple*[4]
[1]Canadian Light Source Inc., Saskatoon, SK
[2]Department of Chemistry, U. of Saskatchewan
[3]Department of Physics, U. of Saskatchewan
[4]COGEMA Resources Inc., Saskatoon, SK

Introduction

In the ever-evolving world of environmental issues, it is increasingly important to understand and predict the stability and bioavailability of heavy metal contaminants such as arsenic in mine waste. Environmental regulations have become more stringent, and a mine's ability to operate a mill tailing facility is directly related to its capacity to predict the long-term stability of the waste.

Traditionally, the stability of mine waste was predicted using various thermodynamic models—normally in conjunction with powder X-ray diffraction analyses to determine material composition, and assorted wet chemistry techniques to determine total species concentrations. Recent works by Waychunas [1] and Brown [2–4] have shown that synchrotron-based techniques, such as X-ray Absorption Spectroscopy (XAS), are powerful tools for enhancing our understanding of the geochemistry of mine waste.

This work demonstrated that synchrotron-based techniques are useful for determining the mineralogy associated with the JEB Tailing Management Facility (TMF) in northern Saskatchewan. The TMF contains (or will contain) uranium mill tailings from McClean Lake, Midwest, and Cigar Lake ore bodies. These tailings are high in arsenic (up to 10%) and nickel (up to 5%) [5]. The long-term goal of the TMF is to control the release of these contaminants into the surrounding groundwater. The release of contaminants is related to (i) their long-term solubility; (ii) the solids chemistry of the tailings; and (iii) diffusion and other transport mechanisms of As and Ni. Understanding these factors and developing control strategies are the overall goals of this research.

Methods and Materials

COGEMA Resources Inc. supplied nine samples for XAS studies. Three samples were synthetic ferric arsenate ($FeAsO_4$ or scorodite) prepared by G. Demopoulos at McGill University. Two samples were crystalline ferric arsenate as determined by powder X-ray diffraction (pXRD), and a third standard was characterized by pXRD as amorphous. Along with the model compounds, six samples from various points in the mill cycle were supplied. Two neutralized raffinate samples (precipitated from liquid tailings in the laboratory) with two different iron to arsenic ratios (3.5:1 and 1.3:1) were supplied. Two samples of leach residue (which fed the tailings neutralization circuit) were supplied. Two dried tailing samples from the tailings thickener underflow (feed to the TMF) were also provided. These latter two had an arsenic concentration of about 1000 ppm; one had received no treatment and the other had undergone a gypsum dissolution procedure.

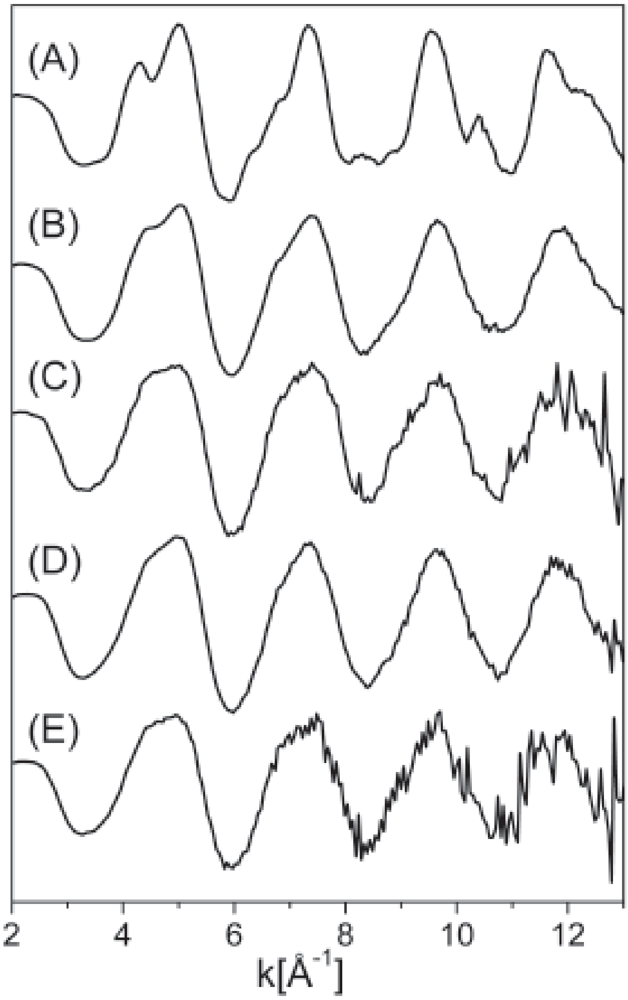

Figure 5·1 *Comparison of the k versus $k^3\chi(k)$ of (A) crystalline ferric arsenate, (B) amorphous ferric arsenate, (C) arsenate adsorbed on FeOOH, (D) neutralized raffinate (with an Fe:As ratio of 3.5:1), and (E) tailings.*

XAS spectra [6] were collected at the PNC-CAT bending magnet beamline at the Advanced Photon Source (APS), the 7.0 GeV storage ring at the Argonne National Laboratory in Chicago, IL. The As K-edge (11 867 eV) spectra were recorded using a fixed-exit double-crystal monochromator with Si (111) crystals. This configuration provided an effective energy range of 3 to 27 keV with a resolving power of about 7000. The photon energy scale for the double-crystal monochromator was referenced to the inflection point of the Au K-edge of a thin gold foil at 11 918 eV. The relative energy scale was reproducible within ±0.1 eV. All the spectra presented were the average of at least three scans.

Results

Figure 5·1 shows a plot of k versus $k^3\chi(k)$ for two synthetic ferric arsenates (crystalline and amorphous), an arsenate adsorbed on a 2-line ferrihydrite, laboratory neutralized raffinate (with an Fe:As ratio of 3.5:1), and a dried tailing sample. All the EXAFS signals shown in Figure 5·1 have a principal sine wave, which is the result of the backscattering associated with the first shell around the arsenic (As–O). The fine structure, which is evidenced by shoulders and splitting on the main wave pattern, is associated with scattering from the higher shells (in this case, As–Fe). The EXAFS of the crystalline ferric arsenate is in excellent agreement with the previous work of Foster et al. [3]. Crystalline ferric arsenate is characterized by the fine structure on the first oscillation at ~4.5 Å^{-1}, whereas the amorphous ferric arsenate shows a significantly reduced peak-to-valley magnitude in the fine structure. This change in fine structure relates to a decrease in the long-range order within the material. When the precipitated raffinate solids and tailings samples are compared with crystalline and amorphous ferric arsenates, the mill samples appear not to correspond to the more crystalline material. The first oscillation at ~4.5 Å^{-1} in the precipitated raffinate solids and tailings has a flat top, no splitting, and remains unidentified.

Figure 5·2 shows a comparison of R versus the Fourier transform magnitude of the $k^3\chi(k)$ data shown previously in Figure 5·1. The first feature at ~1.27Å (uncorrected for phase shift) is associated with the As–O single scattering. The second feature at ~2.8 Å is reflective of the local structure linked with the higher shells (As–Fe).

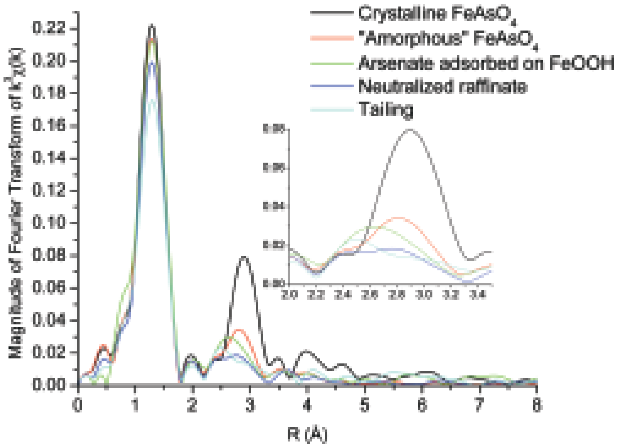

Figure 5·2 *Comparison of the Fourier transform magnitude of the As K-edge k^3-weighted EXAFS of crystalline ferric arsenate, amorphous ferric arsenate, arsenate adsorbed on FeOOH, neutralized raffinate (Fe:As of 3.5:1), and tailings.*

The intensity of scattering due to As–Fe is less for the amorphous ferric arsenate crystalline than for the crystalline form. As mentioned above, the "amorphous" sample was previously characterized as amorphous using laboratory techniques, but actually it appears to have a microcrystalline structure with a length scale too short to be observed with traditional XRD. A truly amorphous material would not show higher shell scattering, so therefore the existence of higher shells indicates the presence of some crystallinity in the material.

The arsenate adsorbed on FeOOH has a broad band centred at ~2.6 Å. The exact structure of the adsorbed arsenate is unclear from this data.

Between 2.2 Å and 3.2 Å, the curves of the raffinate and tailings appear to be composed of two bands that are linked with the local environments around the arsenates. The band at ~2.8 Å is in good agreement with that found for the amorphous ferric arsenate. The source of the second band, at shorter distance, remains unknown.

Discussion

XAFS techniques were applied to study the mineralogy of arsenic both in precipitated raffinate solids and in tailing samples from a tailings preparation circuit of a uranium milling facility. When compared to crystalline and amorphous ferric arsenates, the data shows that neither the tailings nor the raffinate were composed of a single type of material. In the raffinate solids, there is evidence of a ferric-arsenate-like phase, most probably "amorphous", and a second unknown component having a slightly shorter arsenic iron distance. Interestingly, the amounts of each component in the raffinate solids (not shown) were not related to the Fe:As ratio.

The XAFS of the tailings samples show the same two features at higher *R* distances that had been observed in the raffinate solids, although at different relative intensities. The peak at ~ 2.6 Å, which could be related to the unidentified species, was lower in intensity for the raffinate solids. Further work is required before an unambiguous assignment of the different arsenic species in the raffinate solids and tailings may be made.

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Interaction with synchrotron instrumentation suppliers at the Fourth CLS Users' Meeting (November, 2001).

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CLS Users' Office

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CLS Users' Office

The CLS Users' Office exists for the users of the Canadian Light source. Current and future users should contact this office for answers to any and all questions concerning the CLS. If the Users' Office staff cannot provide the answer, they will do their best to put the user in contact with someone who can.

CLS Workshops and Meetings

Synchrotron radiation research involves active and often close collaboration between people of various disciplines and with many different skills. It is essential that there be effective communication between all of the parties.

To facilitate this, the CLS has engaged in a variety of workshops and meetings for community outreach, accelerator design, beamline planning, insertion device planning, and scientific planning. Some of the larger activities of this type are listed in the table below.

Meetings and workshops sponsored by the CLS from 1998–2001

Title	Location	Date	Sponsors	Attendance
Biotechnology, Biopharmaceuticals and Medicine	Toronto	December, 1997	CISR, CLS Collaborative Committee	40
Mining, Minerals and the Environment	Vancouver	January, 1998	CISR, CLS Collaborative Committee	30
Materials and Manufacturing	Mississauga	February, 1998	CISR, CLS Collaborative Committee, MMO, NSERC	50
Telecommunications and Information Technology	Ottawa	February, 1998	CISR, CLS Collaborative Committee, NRC	50
First CLS Users' Meeting (Aerospace and Biotechnology)	Montreal	May, 1998	CISR, CLS Collaborative Committee,	100
Second CLS Users' Meeting	Saskatoon	November, 1999	CLS	60
Soft X-ray Spectromicroscopy Workshop	Saskatoon	November, 2000	CLS, NSERC	50
Infrared Spectroscopy and Microscopy Workshop	Saskatoon	November, 2000	CLS	50
Femtosecond X-ray Diffraction Workshop	Saskatoon	November, 2000	CLS	50
Third CLS Users' Meeting	Saskatoon	November, 2000	CLS	170
Medical Applications Workshop	Saskatoon	December, 2000	CLS	100
Earth Science Applications Workshop	Saskatoon	October, 2001	CLS, University of Saskatchewan	90
Insertion Devices Workshop	Saskatoon	November, 2001	CLS	75
Fourth CLS Users' Meeting	Saskatoon	November, 2001	CLS	210

Sandra Ribeiro, CLS User Liaison Officer, assists users in accessing CLS information and resources.

Touring the CLS facility during the Fourth Annual CLS Users' Meeting.

Lisa Croll (McMaster University) accepts a $1000 prize at the Fourth Annual CLS Users' Meeting from Ron Cavell, President of the Canadian Institute for Synchrotron Radiation (CISR). CISR awards this prize at each CLS Users' Meeting for the best poster presentation by a graduate student or postdoctoral fellow. The funds are to be used to support a further presentation by the winner at an international conference.

Banquet at the Fourth Annual CLS Users' Meeting.(November, 2001).

Canadian Light Source staff members.

The CLS in winter.