Next Step Offers New Possibilities

It is widely felt that generating support for new synchrotron radiation facilities needs the opportunities to be discussed by experts and by potential new users. The experimental possibilities which will derive from future high-intensity light sources and the directions of advances in their construction were reviewed at a recent workshop (Giessbach, 10-12 October) that considered the scientific potential of the proposed Swiss Light Source (SLS). Initiated and chaired by K.A. Müller (Zurich University), the meeting attracted 100 participants including many leading experts, among them the Directors of five existing synchrotron radiation facilities in Berkeley, Daresbury, Hamburg, Lund, and Stanford.

Proposed European synchrotron light sources

	Photons keV	Energy GeV	Current mA	Emittance nm.rad	Circumference m	Straight sections m
SLS	0.01 - 50	2.1 / 1.5	4000	3.2 / 1.6	252	17 / 6
SOLEIL	0.01 - 20	2.15	300	16	200	6
			60*	35		
SLC	1 - 20	2.5	200	25	250	4
SINBAD	0.005 - 0.2	0.7	300	10	100	15
DIAMOND	0.1 - 50	3.0	300	20	300	3

SLS: Swiss Light Source (PSI); optimized for maximum brightness below 1 keV.
SOLEIL: (LURE, Orsay); to replace LURE; many insertion devices; *: in 6 bunches.
SLC: Synchrotron Laboratory of Catalonia (Barcelona): high flux/medium brilliance.
SINBAD: (Daresbury Lab); to replace SRS; low energy/high brilliance.
DIAMOND: (Daresbury Lab); to replace SRS; medium energy.

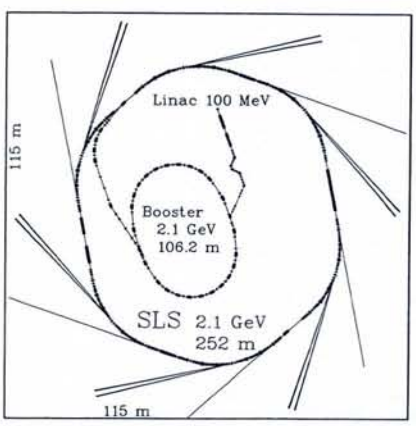
Several regional and national synchrotron light sources complementary to the European Synchrotron Radiation Facility and to each other are being proposed (see table). In the case of the Swiss Light Source (SLS), it was agreed during a first informal meeting in 1991 that the highest priority be given to a machine providing high-quality light sources with hopefully unprecedented performance. Within the anticipated financial constraints, the quality of the available light was favoured over the maximum number of available beam ports. It was also believed that the design should be sufficiently flexibile for future developments. Following these general guidelines, a design philosophy emerged which formed the basis of a study carried out by the Paul Scherrer Institute (PSI), Villigen. Helped by valuable support from an international advisory board of machine experts, it comprised an extended investigation of possible designs. The machine concept and the design underwent critical reviewing and received high marks in an evaluation by 12 international experts in the autumn of 1993.

Two Main Advantages

The scientific presentations at the workshop made it clear that the exceptionally wide **energy range** of available photons is one of the major merits of sources such as the SLS in serving instruments for numerous applications ranging from low-energy spectroscopy,

Approaching the Theoretical Limit

Synchrotron radiation quality in terms of brightness is mainly limited by the quality of the electron beam, *i.e.*, a low beam emittance is required. The SLS design was thus optimized to provide the lowest possible beam emittance for a ring of given size, the latter essentially being dictated by the chosen cost limit. As is well established, a high quality of radiation at low frequencies is best achieved using undulators as insertion devices in straight sections of the ring. Incorporating such devices thus requires optimization of the number of sections and their length. Extending the available spectrum is possible using the ring's bends as sources of photons.

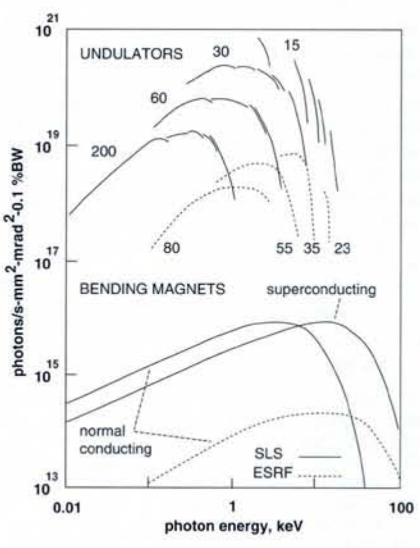


Layout of the Swiss Light Source showing the linac, booster, and storage ring. Also shown are single beam lines from insertion-device sources and twin beam-lines from six superconducting bending-magnet sources.

The detailed considerations led to a storage ring (see figure) that can be operated in two modes with electron energies of 1.5 and 2.1 GeV. The low-energy mode allows for an emittance of 1.6 nm.rad — a value that has never been achieved before in a machine of comparable cost and size. The 2.1 GeV mode offers unprecedented beam brightness and photon energies (see figure) stemming from the insertion of small-period undulators and the extension of the available photon spectrum to higher energies from bending magnet sources based on a very small beam size and superconducting magnets.

A characteristic feature of the design is the presence of two relatively long (17 m) straight sections. One of them is planned to be equipped with a fixed gap, 12 m long, electromagnetic undulator with a period of 200 mm. This device is capable of providing a diffraction limited (maximum theoretically achievable limit) source of photons with energies up to 100 eV. Achieving this maximum brightness also implies full coherence of the radiation — clearly a novelty with high potential for future experimental possibilities. Operation is possible both in linearly and circularly polarized modes. The second straight section is thought to be indispensable for implementing future developments in various aspects of source design.

Apart from fulfilling the most important prerequisite of touching new limits in radiation production, the present design also offers great flexibility owing to the possibility of several operating modes, an on-axis injection option, ideal matching to the insertion devices, and top-up injection to provide an almost constant photon intensity. This last feature will be invaluable as it permits an essentially time-independent heat load on optical elements, favourable for high stability and high resolution instruments.



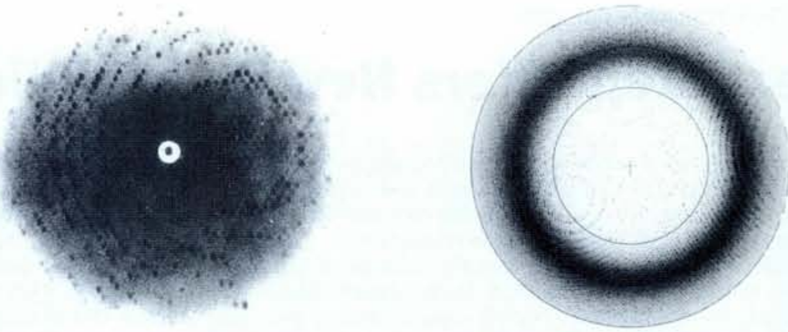
The design brightness for typical insertion devices (labelled by their periods in mm) and dipole magnet sources at the SLS, calculated assuming an electron energy of 2.1 GeV, a beam current of 400 mA and an emittance coupling of 10%. Also plotted are curves for representative sources at the ESRF, Grenoble, for operation at 6 Gev and 100 mA. The ESRF is currently operating routinely at 160 mA and 200 mA is planned for early 1995, which means that the brilliance for the bending magnets and undulators should be increased by factors of 1.6 and 2.0, repectively (brilliance being proportional to the current).

spectromicroscopy, photo-electron microscopy and holography, to crystallography, biology, medicine, and three-dimensional microstructure fabrication.

Much of the discussion concentrated on the expected benefits of **high brightness**, which is identical to spectral brilliance, *i.e.*, to the number of photons per time and unit area into a unit solid angle for a given frequency or wavelength interval. An obvious advantage is the possibility of achieving high fluxes on small samples. This, in general, means a very good signal-to-noise ratio with the result that extremely short measuring or exposure times are sufficient for obtaining the desired data. This feature ensures that measurements may be done under stable conditions, although controlling possible radiation damage must be seriously considered. Short measuring times allow one to study the effect of varying experimental conditions such as the specimen temperature or applied pressure very quickly.

Other possibilities include the time-resolved observation of the folding of proteins and of cellular dynamics by monitoring the flow of fluorescent chemicals (hence the great potential for high-brilliance synchrotron radiation sources in biology, biochemistry and medicine). High flux on small samples also clearly favours measurements on exotic materials that are not available in large quantities, of matter under very high pressure, and the identification and subsequent spectroscopic investigation of components in nanoscale structures.

Precautions will in general have to be taken to limit radiation damage or excessive heating of specimens. High-intensity sources may also saturate existing detectors so their availability will encourage the development of detector technology. High brightness must also be accompanied by exceptional beamline optics in order to preserve the phase space up to the sample positions. Problems of this type are best solved if the layout of the sources and the planning of experiments are done in cooperation at an early stage.



The X-ray Laue pattern (on the left) of hemoglobin (6.45×10^4 K Daltons) as obtained with a sealed-tube X-ray source (courtesy of M. Perutz, Cambridge), compared with the pattern for a bovine enterovirus (> 10^7 Daltons) obtained using synchrotron radiation at the Daresbury facility (courtesy of D. Stuart, Oxford).

Two Examples

The advantage of high photon fluxes is well illustrated by comparing diffraction patterns of complicated structures obtained employing conventional X-ray sources and synchrotron radiation (see figure). The drastic enhancement of well-resolved information obtained using modern instrumentation is truly impressive.

Another important example concerns the surface-sensitive method of photo-electron spectroscopy. Using a conventional rotating anode source to record a valence-band spectrum of a solid, typically using a scan of 10 eV with a resolution of 0.3 eV and good statistics, needs a few hours. This poses severe contamination problems for many materials. However, the same spectrum may be obtained from a bending-magnet source in a few minutes. Undulator sources deliver yet another factor of 10^5-times more radiation intensity, implying that the same energy range of electronic states may be scanned within a fraction of a second to produce spectra with a much improved energy resolution from a significantly smaller spot on the sample. One can, in fact, obtain two-dimensional photo-electron "images" with a resolution that may reach 100-200 Å. Additional information can be obtained by monitoring the spin dependence of the emission, where the inherently low efficiency of detection methods makes high-intensity sources particularly useful.

The workshop concluded that the SLS project is timely as it would ensure world-wide leadership for the foreseeable future in photon production at energies between 10 eV and 3 keV, complementary to other, powerful sources operating at even higher energies. It would also make a respectable contribution to the large and still growing international community of scientists from many different disciplines who use synchrotron light sources.

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Teachers in National Physical Societies

Summary of a survey carried out by the Forum for Education (questionnaire sent in January 1994; 16 countries replied formally)

Society	Div	Union	Orgs	Conf	Gen	Act	Govt	Advice	Comp	Exch	Teach bu	Soc bu	Links	Prizes	Int
A 1230 / NR / 100	y	y	y / - / - / -	-	y / 1	c	advice	curricula	- / y / y	- / -	4 / 30	i / 4 / 12	c / -	y	y
B 400 / 5 / 100	y	y	y / - / - / -	-	sat / 1	-	-	-	- / y / -	- / -	- / -	- / 12 / 16	- / c; lab visits / -	-	-
CH 1430 / NR / 100	-	-	y / - / - / -	-	- / 0.5	-	-	n	- / - / -	- / -	- / -	- / - / -	c / -	-	-
CR 190 / 60 / 100	y	y	- / y / - / -	-	-	sem	plan	-	- / y / -	- / -	- / -	col / ? / ?	c / -	-	-
E 3000 / <1 / 100	y	?	- / - / - / -	?	- / 2	?	?	?	y / - / -	- / -	- / -	i;a / 4 / 80	- / -	?	?
EE 230 / 7 / 100	comm	-	y / y / - / -	-	y / 1	-	-	-	- / y / -	- / -	- / -	- / - / -	c / -	-	-
F 2480 / <1 / <100	comm	-	y / y / - / -	-	y / 2	-	-	teaching	y / - / -	- / -	- / -	i / 5 / 36	staff / -	-	-
FIN 1000 / 20 / 100	y	-	y / y / y / y	-	y / 1	c	-	-	- / - / -	- / -	- / -	a / 4 / 100	dep; c / -	-	-
G 27050 / 2 / 100	y	y	y / y / - / y	1	- / 1	s	-	-	- / y / -	- / -	- / -	i / 10 / 110	c / -	-	y
H 1490 / 43 / 100	y (2)	-	- / - / - / -	-	- / 3	-	react	-	y / y / y	y / -	12 / ?	col / 12 / 40	- / s	-	-
I 1350 / 2 / 100	comm	y	y / - / y / -	-	y / 1	sem	react	curricula	- / - / -	- / -	- / -	i / 4 / 80	c / y	y	-
N 850 / 30 / 100	y	y	y / - / - / -	3	y / 1	-	-	-	- / y / y	- / -	- / -	si / 4 / 20	c / -	-	-
NL 3600 / 5 / 100	comm	-	y / y / - / -	1	- / 1	sem; c	-	-	y / y / -	- / -	- / -	a / 26 / 12	c; dep; lect; tut / -	grants	y
P 1700 / 67 / 100	y	-	- / - / - / -	-	sat / 2	sem	-	-	- / y / -	- / y	- / -	a / 4 / 80	EU / -	-	-
PL 1800 / 13 / 25	y	-	y / - / - / -	?	- / 2	?	?	?	- / y / -	- / -	6 / 20	a / 6 / 100	- / -	?	?
R 1200 / 4 / 100	y	-	- / - / - / -	-	y / 2	sem	-	ed reform	y / y / -	- / -	- / -	0.1 / 4 / 30	- / -	-	-
S 1050 / 25 / 100	y	y	y / - / - / -	?	y / 2	-	y		- / y / -	- / -	- / -	i / 4 / 30	res; c; lect / -	-	y
SL 260 / 50 / 100	y	-	y / y / - / -	-	y / 1	lect	-	teaching	y / - / -	- / -	- / -	i / 6 / 20	c / -	-	-
UK 18500 / 10 / 100	y	y	y / y / - / y	1	- / 1	c	react	various	y / y / -	- / -	6 / 40	a;i / 12 / 80	- / -	y	-

Society: nat. soc. (NS) membership / % teachers (**NR** = not recorded) / % of fee
Div: organized as a Division (**comm** = national committee only)
Union: teachers' union exists
Orgs: other teacher organizations exit / collaborate / joint members / joint activities
Conf: annual teachers conference (frequency in years)
Gen: annual (or similar) general conference involving education / frequency in years
Act: other activities organized for teachers (**c**ourses; **s**chools; **s**eminars; **l**ectures)
Govt: advise government
Anal: survey, analysis, etc. carried out (subject/s)
Comp: national competition / Physics Olympiad participation / training courses for Olympiad
Exch: exchange teachers between conferences / between countries
Teach bull: teachers bulletin published: no. issues p.a. / pages per issue
Soc bull: society bulletin published: contents relevant to teachers (**a**rticles; **i**nformation; **s**pecial **i**ssues; **col**oumn; %) / no. issues p.a. / pages per issue
Links: teachers with universities (**c**ourses, university **staff** teach; special univ. **dep**artments; teachers act as **tut**ors; **res**ource **c**entre; **lec**tures for teachers / teachers with institutes (**s**cholarships)
Prizes: prizes, grants, etc. awarded to teachers
Int: participation in international bodies (IUPAP, Int. Baccalaureate, EU, OECD, *etc.*)