SYNCHROTRON LIGHT FOR EXPERIMENTAL SCIENCE
AND APPLICATIONS IN THE MIDDLE EAST

SESAME

An international centre for research and advanced technology under the auspices of UNESCO

- Seeing better with synchrotron light
- The SESAME synchrotron light source
- Advanced training, another string to SESAME's bow
- New opportunities
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Photo: Royal photographer, Jordan

At the groundbreaking ceremony for SESAME at Al-Balqa' Applied University (Jordan) on 6 January 2003, UNESCO Director-General Koïchiro Matsuura unveils the commemorative plaque together with HM King Abdullah II of Jordan, who has just laid the cornerstone for the future SESAME building.

AN INTERNATIONAL CENTRE FOR RESEARCH AND ADVANCED TECHNOLOGY under the auspices of **UNESCO**

Koïchiro Matsuura,

Director-General of UNESCO

Ever since taking the helm at UNESCO in November 1999, I have made it a policy to ensure that the goals of a culture of peace are actively supported through projects which enable people the world over who share common interests in education, sciences, culture, information and communication to come together. In this way, people gain a better understanding of one another, promote tolerance and, ultimately, enhance the chances of peace.

In SESAME, I see all of that. That's why I promised that UNESCO would do all it could to bring this innovative, exciting project to fruition. With the 188 countries which make up UNESCO having enthusiastically endorsed SESAME at the Organization's General Conference in the autumn of 2001, it was a logical progression for the Executive Board to place SESAME under the auspices of UNESCO the following May.

It is UNESCO's hope that SESAME will prove to be as successful as the centre on which it is modelled, the European Organization for Nuclear Research (CERN) in Geneva, Switzerland. From the outset, UNESCO has been an active player in establishing SESAME. Now that the centre is an entity in its own right, it may always count upon UNESCO's counsel and partnership.

Herwig Schopper,

President, SESAME Council

The word SESAME may be interpreted in different ways but the most attractive meaning is that of a 'door opener'. Indeed, it is hoped that the new centre will open many doors. By becoming a world-class laboratory, SESAME will provide facilities for basic research and many applications and thereby promote science and technology in the region.

Another main objective will be the extensive training of scientists, engineers and technicians who might later find employment in a variety of domains in industry, hospitals, universities and other sectors. SESAME will thus contribute to the development of new enterprises and, in the long run, to reducing unemployment.

Last but not least, I confidently hope that SESAME will meet with success similar to that of CERN by fostering better mutual understanding and tolerance between people from different traditions, political systems and creeds, thus becoming an excellent tool for peace building – a tool which the region now needs more than ever. Many were sceptical about the vision behind such a project in a region and at a time when enormous tensions dominate. However, we all hope and are convinced that SESAME, in the safe cradle of Jordan, will grow and bloom, and that it will outlive the present difficult times, a light for human hopes.

SEEING BETTER WITH SYNCHROTRON LIGHT

In everyday life as in advanced scientific research, we learn by 'seeing' things using light. Advanced sources of light (like the laser and synchrotrons) are a prime factor in promoting scientific and technological progress. Little over 50 years ago, in 1947, synchrotron radiation light was observed from the General Electric 70 MeV synchrotron in the USA. The extraordinary power of synchrotron light, which ranges from X-rays to infra-red, has become an essential scientific infrastructure.

Synchrotron light sources have, until recently, been built exclusively in the developed world. Owing to their wide impact across the scientific spectrum with quite often 'near-market' benefits, many of the emerging economies, including Brazil, India, Republic of Korea, Singapore, Taiwan and Thailand have recently built their own sources. There are now more than 50 operating synchrotron sources around the world; a further 10 are under construction and 13 are at the planning stage, involving 23 countries. The worldwide user community for synchrotron radiation is estimated to be in excess of 20,000. Even taking into account the new sources under development, the rapid growth of the user community and ever-increasing range of applications are outpacing the available supply of synchrotron light for the foreseeable future.

Nobel Prizes based on discoveries through X-ray work

Physics

1901	Wilhelm Röntgen
1914	Max von Laue
1915	Sir William Henry Bragg and Sir William Lawrence Bragg
1917	Charles Barkla
1924	Karl Manne Siegbahn
1927	Arthur Compton
1981	Kai Siegbahn

Chemistry

1936	Peter Debye
1962	Max Perutz and Sir John Kendrew
1964	Dorothy Hodgkin
1976	William Lipscomb
1985	Herbert Hauptman and Jerome Karle
1988	Johann Deisenhofer, Robert Huber and Hartmut Michel
1997	Paul D. Boyer and John E. Walker

Physiology or Medicine

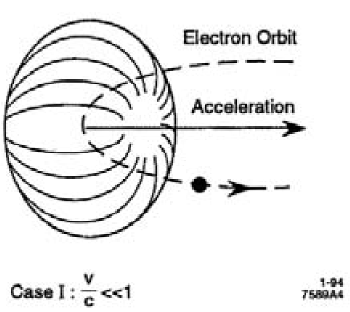
1946	Hermann Joseph Muller
1962	Francis Crick, James Watson and Maurice Wilkins
1979	Alan M. Cormack and Sir Godfrey N. Hounsfield

How is synchrotron radiation produced?

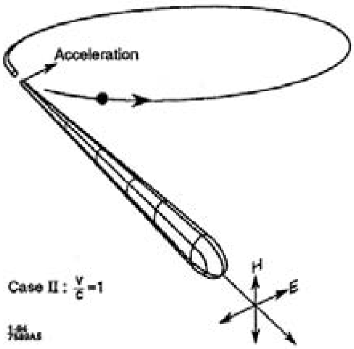
In a synchrotron, bunches of charged particles – electrons – circulate at nearly the speed of light for several hours inside a long ring-shaped tube under vacuum. As magnets in the ring force the electrons to bend, they emit 'synchrotron light', the wavelength of which can range from infra-red radiation to X-rays. The emitted light is collected by different 'beamlines' (optical systems) connected to the ring; thus, many experiments can be run simultaneously.

- When electrons are accelerated (e.g. linear acceleration in a radio transmitter antenna), they emit electromagnetic radiation (e.g. radio waves) in a rather non-directional pattern

- Electrons in circular motion are also undergoing acceleration but this is centripetal rather than linear



At low electron velocity (non-relativistic case), the radiation is emitted in a non-directional pattern

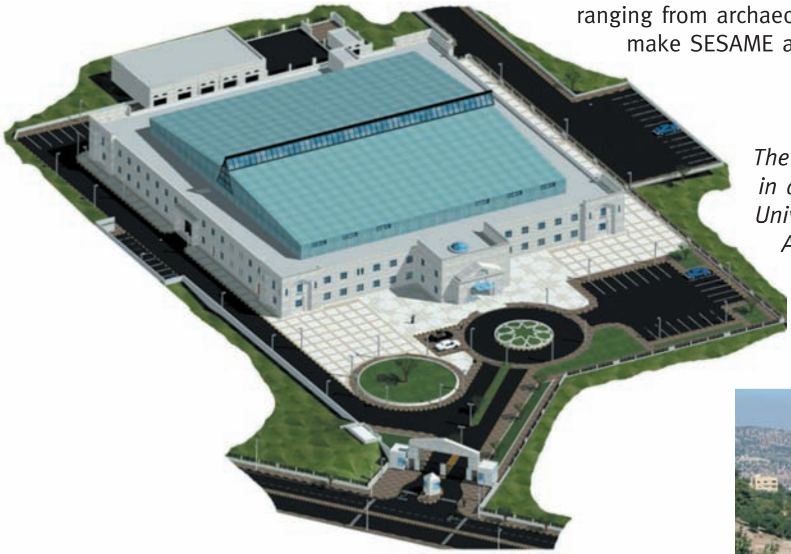


When the electron velocity approaches the velocity of light, the emission pattern is folded sharply forward. In addition, the radiated power goes up dramatically

THE SESAME SYNCHROTRON LIGHT SOURCE

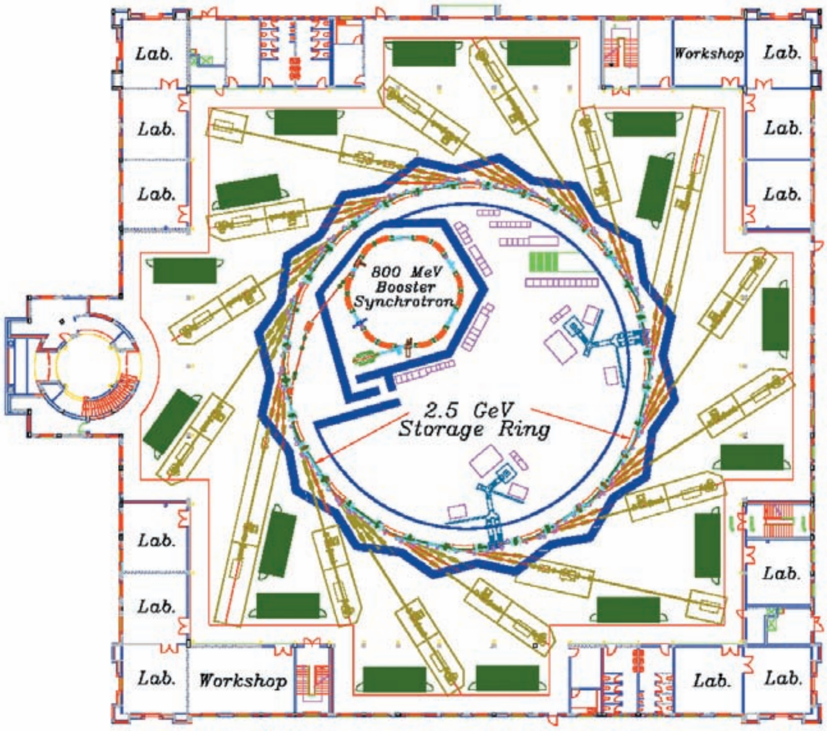
Triggered by the gift from Germany of the 0.8 GeV BESSY I storage ring and injector system, the SESAME project is destined to become a major centre of excellence. Recently, the parameters of SESAME were optimized and a final design energy of 2.5 GeV and circumference of ~133 m were selected. Its performances will be equivalent to the modern synchrotron, the so-called 'third generation' sources which are defined as synchrotrons where the main light sources are undulators and wigglers and light beams are highly collimated.

SESAME is expected to begin operations at the end of 2009 with six beamlines, their number being expected to rise to 20 by 2013. Several hundred scientists from the region and other parts of the world are expected to use these beamlines, which will cover disciplines ranging from archaeology to the biological and medical sciences. This will make SESAME a unique multidisciplinary centre in the Middle East.



The synchrotron light source is to be housed in a building built at Al-Balqa' Applied University (Jordan), some 30 km northwest of Amman. Financed by Jordan, the building has been designed by civil engineers from Al-Balqa' Applied University.

Construction of the SESAME building began in July 2003 and is expected be completed in June 2006 (photo shows progress in construction as at August 2005).



Experimental floor layout: In addition to the synchrotron and beamlines, the SESAME building will house support laboratories for visiting scientists.

ADVANCED TRAINING, another string to SESAME´s bow

SESAME will provide essential infrastructure for the scientific and technological development of the Middle East. Experienced scientists will be attracted by the prospect of returning ‘home’ to their region to pursue their research interests at SESAME and graduate students and young researchers will no longer have to go abroad for advanced training.

Once SESAME has been established as a physical entity, a highly trained scientific and technical staff will ensure that both experienced and inexperienced users of the centre are successful in their experiments. This ‘user-facility’ approach has proved its effectiveness in opening this advanced technology to thousands of users from many disciplines, including biology, chemistry, geology, materials science, medicine and physics, in most synchrotron radiation sources worldwide. As an interdisciplinary centre, SESAME will provide a stimulating environment for international co-operation.

The process of training Middle Eastern scientists in the uses of synchrotron radiation and both scientists and engineers in the relevant accelerator technology is well under way. From 1999 to 2004, more than 300 scientists and engineers from the region participated in thirteen SESAME workshops and schools in the Middle East, and elsewhere, on applications in biology, materials science and other fields, as well as on accelerator technology.

Approximately 35 of these men and women have spent periods of up to two years working at synchrotron radiation facilities in Europe, the USA and Asia. The majority of these facilities are situated in countries that are Observers to the SESAME Council. These facilities offer scientists from the Middle East the opportunity to use their own light sources while SESAME is under construction, thereby providing them with first-hand experience and further swelling the ranks of Middle Eastern scientists with experience in using synchrotron radiation sources. European, American and Japanese centres are also contributing valuable assistance and advice in designing, constructing and utilizing SESAME.

At the first SESAME users meeting on 26–27 October 2002, the drawing-up of the initial beamlines was begun. Their layout has since been considered in further users meetings and the type of experiments to be carried out with them has been examined.

A research centre modelled on CERN

A CERN-inspired international laboratory, SESAME is much more than an advanced scientific facility. Past experience of synchrotron light centres from different parts of the world shows the substantial and practical benefits for the host region:

- The region’s best scientists and technologists are motivated to stay in the region or return if they have emigrated;
- The members’ brightest young talent is attracted to scientific higher education and thus contributes to the development of a knowledge-based economy;
- By stimulating the regional economy, synchrotron centres create jobs well beyond those of the centres' own staff. They create business for local and regional operators in the areas of travel, accommodation, restaurants, logistics and technical support needs;
- Frequently, enterprises involved in research and development acquire additional know-how, thus enhancing their competitiveness and scope;
- New synchrotron-based technologies like structural genomics, materials science and microanalysis can lead to spin-off enterprises;
- Mutual understanding between people from different traditions, religions, races and political systems will be fostered.

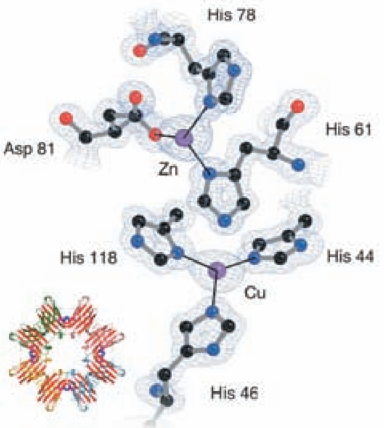
NEW OPPORTUNITIES

● Exploring biological structures

Synchrotron light explores the microscopic world in many different ways and with unprecedented effectiveness. One area that stands out for its present explosive growth is X-ray protein crystallography.

Synchrotron-based crystallography techniques locate the positions of thousands of atoms in huge biological molecules, most notably proteins. The structure of a whole ribosome can be determined at the atomic level.

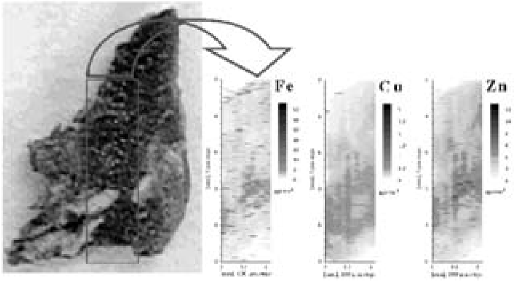
This type of information is crucially important for understanding how biological systems function. The knowledge of the sequence of many genomes (including the human genome and that of several pathogens) has provided a new scientific opportunity, namely that of translating genome sequences into large numbers of structures via high throughput structure determination methods. Such a challenge can only be met using synchrotron methods where crystallographic data on a protein can be collected in a few hours. Knowledge of structures is of strategic importance for healthcare in terms of reducing the cost of drug discovery and increasing drug effectiveness.



The structure of the active site of SOD1, a human enzyme, mutations to which are known to cause motor neuron disease. To the left of the active site, the structure of one of the disease-causing mutants which is helping to understand how the disease is caused.

Why does a lobster change colour when cooked?

The slate-blue colour of the lobster is due to the interactions of a pigment (astaxanthin) with its binding protein crustacyanin. Upon cooking, crustacyanin is denatured and the pigment is released, regaining its red-orange colour. The use of tunable X-rays from a synchrotron source allowed determination of the structure of the complex and provided an insight into the processes involved.



The elemental composition of cancerous lung tissue can be compared with that of healthy tissue by X-ray fluorescence mapping measurements on a synchrotron source. In the figure, an optical micrograph of lung tissue is shown together with specific maps showing iron, copper and zinc distributions in the boxed area of the tissue.

● Materials science

Materials science has seen dramatic growth with the advent of advanced manufacturing methods and the ability to probe the structures of these materials while they are being made. Properties of materials can be controlled by a variety of factors including reaction rates and temperature.

In a recent success story, new intermediate phases for magnetic domains have been determined in time-resolved powder diffraction experiments using synchrotron light.

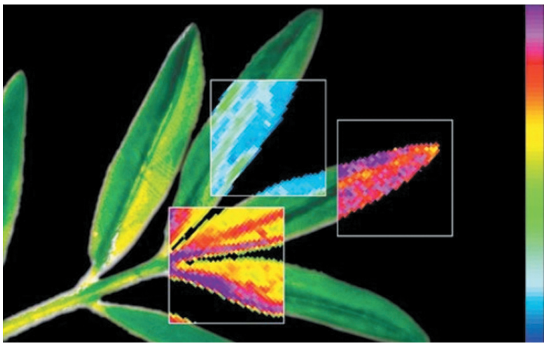
Techniques originally developed for materials science have recently found their uses in archaeology with remarkable results. This is due mainly to the high intensity and tunability of X-rays from a synchrotron source. Several techniques can be applied at micron resolution.

Above: Egyptian vase, 7th century A.D. (left) and Iraqi polychrome, ca 10th century A.D.
A recent study combining XAFS, X-ray fluorescence and diffraction has revealed the physico-chemical processes involved in the production of Islamic lustre ware and the transfer of this technology to medieval Spain and Italy.

● Studying the behaviour of atmospheric pollutants

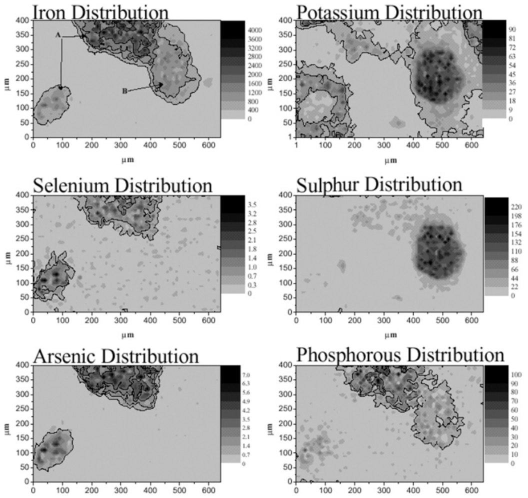
Molecular behaviour of atmospheric pollutants can be understood by using intense ultraviolet light from SESAME. For example, the interaction of ultraviolet radiation with sulphur dioxide (i.e. understanding its photo-fragmentation) is important both from an environmental and a planetary science point of view.

X-rays illuminate selenium in plants



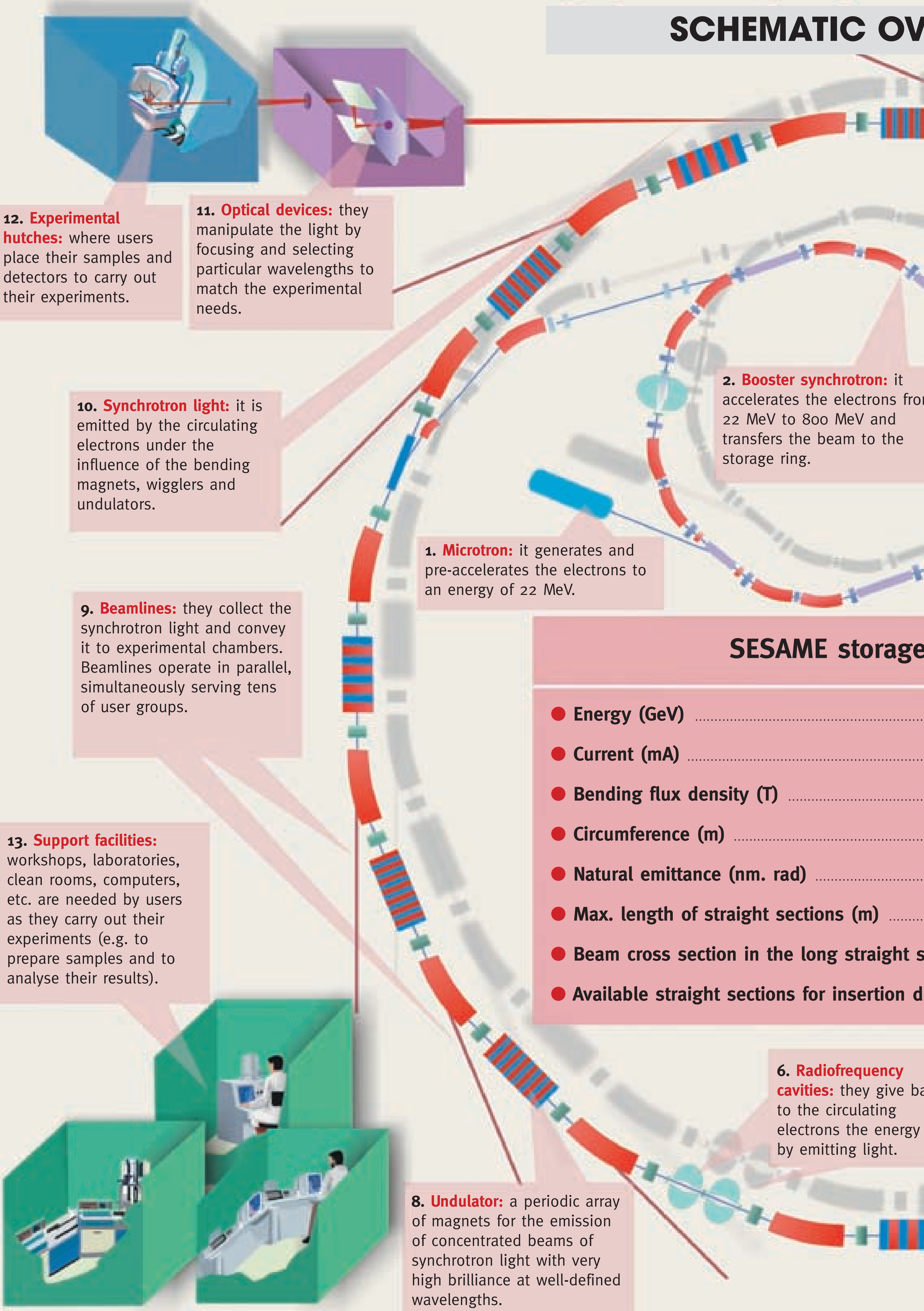
Synchrotron X-rays are used to study how plants absorb and transform toxic materials and guide development of new strategies for environmental remediation. Biotransformation of selenium in Astragalus bisulcatus *(locoweed) is studied using synchrotron X-rays. Spatial locations and absolute concentrations of different selenium chemical species can be studied to understand how plants absorb and transform toxic materials.*

Analysing soil quality



Availability of nutrients and toxic elements control soil quality. Distribution of materials in soil sections can be determined using synchrotron-based X-ray fluorescence microprobes and X-ray absorption spectroscopy.

SCHEMATIC OV



12. Experimental hutches: where users place their samples and detectors to carry out their experiments.

11. Optical devices: they manipulate the light by focusing and selecting particular wavelengths to match the experimental needs.

2. Booster synchrotron: it accelerates the electrons fro
22 MeV to 800 MeV and transfers the beam to the storage ring.

10. Synchrotron light: it is emitted by the circulating electrons under the influence of the bending magnets, wigglers and undulators.

1. Microtron: it generates and pre-accelerates the electrons to an energy of 22 MeV.

9. Beamlines: they collect the synchrotron light and convey it to experimental chambers. Beamlines operate in parallel, simultaneously serving tens of user groups.

SESAME storage

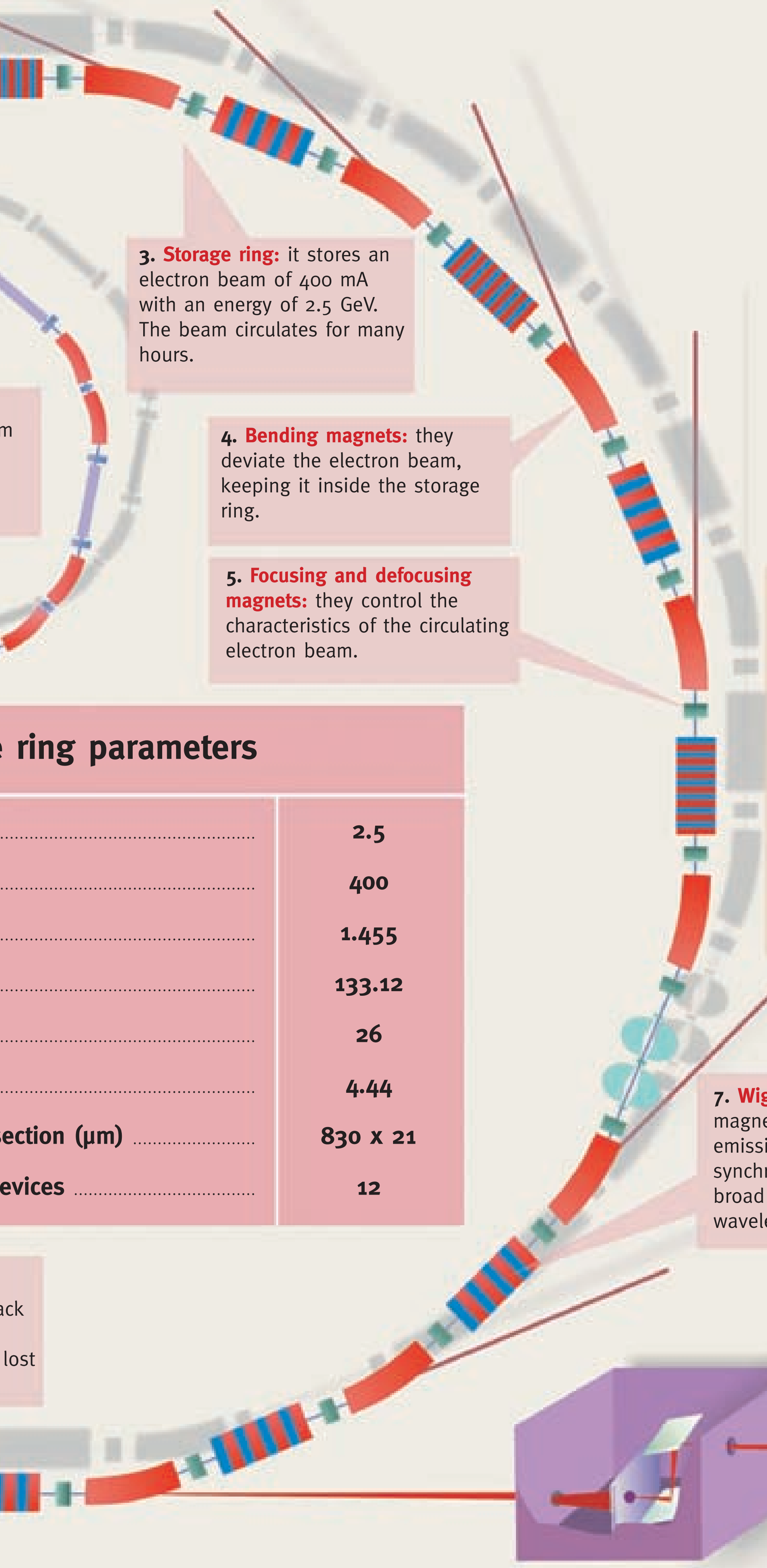
- Energy (GeV) ....
- Current (mA) ....
- Bending flux density (T) ....
- Circumference (m) ....
- Natural emittance (nm. rad) ....
- Max. length of straight sections (m) ....
- Beam cross section in the long straight s
- Available straight sections for insertion d

13. Support facilities: workshops, laboratories, clean rooms, computers, etc. are needed by users as they carry out their experiments (e.g. to prepare samples and to analyse their results).

6. Radiofrequency cavities: they give ba
to the circulating electrons the energy
by emitting light.

8. Undulator: a periodic array of magnets for the emission of concentrated beams of synchrotron light with very high brilliance at well-defined wavelengths.

ERVIEW OF SESAME



3. Storage ring: it stores an electron beam of 400 mA with an energy of 2.5 GeV. The beam circulates for many hours.

4. Bending magnets: they deviate the electron beam, keeping it inside the storage ring.

5. Focusing and defocusing magnets: they control the characteristics of the circulating electron beam.

m

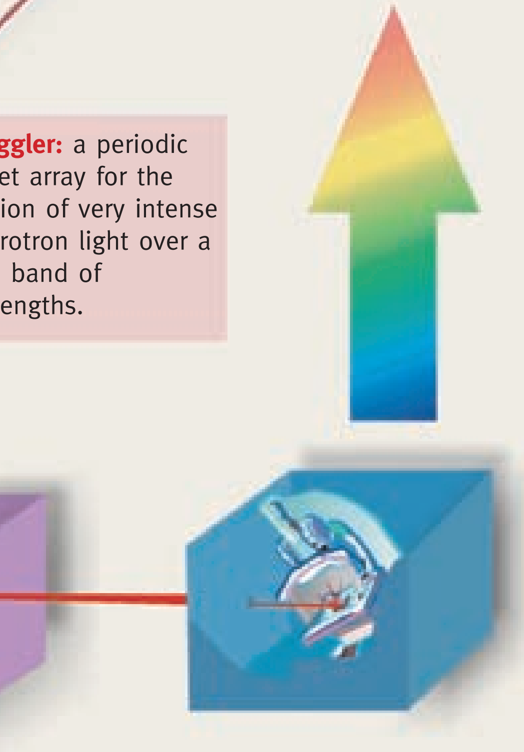
ring parameters

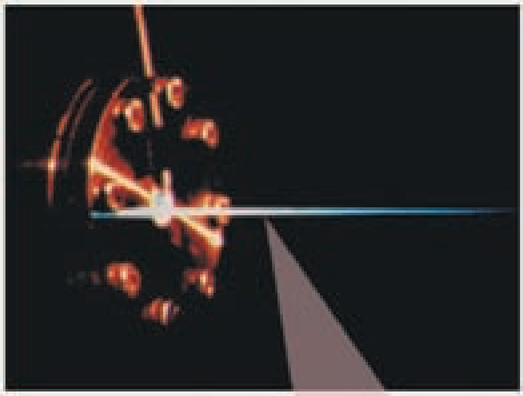
	2.5
	400
	1.455
	133.12
	26
	4.44
ection (μm)	830 x 21
evices	12

ack

lost

7. Wiggler: a periodic magnet array for the emission of very intense synchrotron light over a broad band of wavelengths.





14. Synchrotron light: X-rays causing a visible air fluorescence as an intense X-ray beam emerges from a beryllium window at the end of a beamline.

Photo of X-ray beam, courtesy of Paul Horowitz, Harvard University, USA

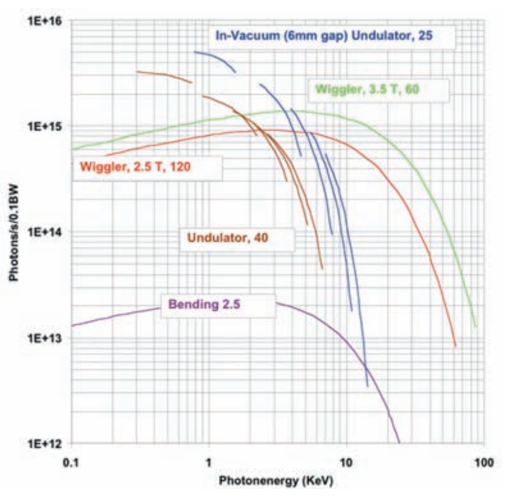
Synchrotron light is useful for a wide range of applications including spectroscopy, microscopy, crystallography and other structural techniques, radiology, industrial fabrication and many other experimental approaches.

SESAME FLUX AND BRILLIANCE
A CLOSER LOOK FOR SCIENTISTS

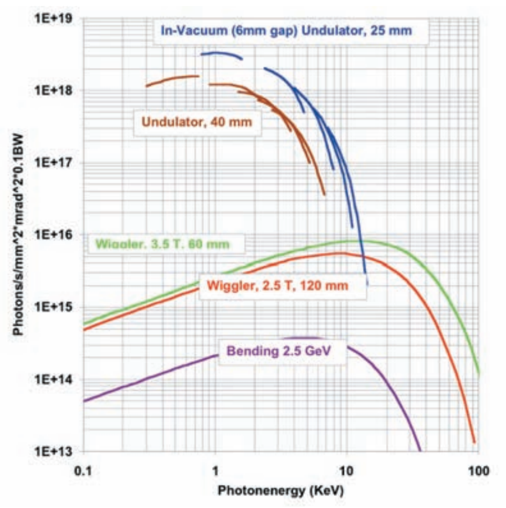
Parameters describing the quality of a synchrotron source are the flux, brilliance (a measure of the concentration of the radiation), spectral range, as well as the number and length, of insertion devices. The spectral range of the radiation is determined by the square of the energy of the stored electrons. With an electron energy of 2.5 GeV, SESAME will provide the spectral ranges, as well as the number and length, of insertion devices. The radiation originates in the bending magnets and in the wiggler and undulator insertion devices located in the straight sections between bending magnets. In-vacuum undulators in SESAME will provide high brilliance reaching the K-edge of selenium (12 keV) for Multi-wavelength Anomalous Dispersion (MAD) phasing, a powerful technique for protein structure determination. The flux (the amount of light delivered to an experimental sample) is proportional to the energy of the stored electrons, the current in the storage ring and the acceptance angle of the beamline. With a stored current of 400 mA, SESAME bending magnets and multipole wigglers will provide very high photon flux over a wide spectral range from the infra-red to X-rays of 60 keV and beyond. The number of insertion devices depends on the number of straight sections in the ring. The SESAME design provides for 13 straight sections for wiggler and undulator insertion devices covering nearly 40% of the circumference. These characteristics make SESAME very competitive with other ‘third generation’ world-class synchrotron light sources.

The fluxes of radiation from the different sources such as bending magnets, wigglers and undulators on SESAME are given in the figure on the left below. As at other synchrotron light sources, the flux of the wiggler radiation is up to 2 orders of magnitude higher than that from the bending magnets. The flux from the undulator, at lower photon energies, is higher than that from the wiggler, whereas it is vice versa for higher energies.

As at other synchrotron light sources, the brilliance of the wiggler radiation is up to 2 orders of magnitude higher than that from a bending magnet. Brilliance of the radiation from undulators is the highest but, as shown in the figure on the right below, only with a restricted spectrum range. With an In-Vacuum undulator at SESAME (2.5 GeV), the important Selenium K-edge, which is crucial for protein crystallography experiments, can be reached.



Flux of the radiation from different sources such as bending magnets, wigglers and undulators on SESAME. The numbers in mm in the boxes are the corresponding period length.



Brilliance of the radiation from different sources such as bending magnets, wigglers and undulators on SESAME. The numbers in mm in the boxes are the corresponding period length.

SESAME beamlines at start-up

Number	Description of beamline	Energy range
1	MAD protein crystallography (undulator)	7.5–15 keV
2	Small angle X-ray scattering (undulator or wiggler)	5.0–15 keV
3	Spectroscopy of gases and solids (undulator)	0.05–2 keV
4	XAFS	3–5 keV
5	Powder diffraction	3–25 keV
6	Infrared spectroscopy	0.01–1 eV

THE SESAME STORY

The idea of an international synchrotron light source in the Middle East was first proposed in 1997 by Herman Winick of the Stanford Linear Accelerator Center (Stanford University, USA) and Gustaf-Adolf Voss of the German Electron Synchrotron (Deutsches Elektronen Synchrotron) during a workshop organized by the CERN-based Middle East Scientific Co-operation group headed by Sergio Fubini. Germany had just decided to decommission its facility, BESSY I, since a newer one was being built in Berlin. At the request of Sergio Fubini and Herwig Schopper, the German government agreed to donate the components to SESAME, provided the dismantling was taken care of by the latter.

The plan was brought to the attention of Federico Mayor, then Director-General of UNESCO, who called a meeting at the Organization's Headquarters in Paris in July 1999 of delegates from the Middle East and other regions. The outcome of the meeting was the launching of the project and the setting-up of an International Interim Council under the Chairmanship of Herwig Schopper. Jordan, which has been selected to host the centre, is providing the land as well as funds for the construction of the building. The groundbreaking ceremony was held in January 2003 and construction work began the following July. The component parts of BESSY I have been shipped from Germany to Jordan.

In May 2002, the Executive Board of UNESCO unanimously approved the establishment of the centre under the auspices of the Organization. UNESCO is the depository of the SESAME Statutes. In April 2004, the Centre's creation was formally sealed following an exchange of correspondence between Koïchiro Matsuura, Director-General of UNESCO, and UNESCO's Member States.

At the first meeting of the permanent Council – replacing the International Interim Council – that took place after the Centre's formal creation, the statutes of the Centre were ratified and the President (Herwig Schopper from Germany) and two Vice-Presidents (Khaled Toukan from Jordan and Dincer Ülkü from Turkey) of SESAME were elected. Following Khaled Toukan's nomination as Director of the Centre in June 2005 the two Vice-Presidents are now Fawzi Abdel Kader Elrefai from Egypt and Dincer Ülkü from Turkey.

The SESAME members

THE SESAME COUNCIL

The permanent Council governs the SESAME center. The current Members are Bahrain, Egypt, Israel, Jordan, Pakistan, the Palestinian Authority and Turkey. The Observers are Germany, Greece, Italy, Kuwait, Russian Federation, Sweden, U.K. and USA.

In addition, the following countries have been deeply involved in the Interim Council and are in the process of confirming their status in the permanent Council: Cyprus, France, Iran, Japan and the United Arab Emirates. Other countries interested in joining the centre are invited to do so by notifying the President of the Council.

Herwig Schopper (Germany), President: *Herwig.Schopper@cern.ch*
Maciej Nalecz (UNESCO), Secretary: *m.nalecz@unesco.org*

Bahrain: new delegate being nominated; **Egypt:** Aly Islam M. Aly; Fawzi Abdel Kader Elrefai; **Israel:** Moshe Paz Pasternak; Eliezer Rabinovici; **Jordan:** Ziad Kodah; Abdul-Halim Wriekat; **Pakistan:** Masud Ahmad; Sheikh Riazuddin; **Palestinian Authority:** Said A. Assaf; Salman M. Salman; **Turkey:** Okay Çakiroğlu; Dincer Ülkü.

THE SESAME COMMITTEES

The SESAME Council is advised by four committees: the Beamlines Committee for the conceptual design of some of the phase one beamlines; the Scientific Committee for the planning of the overall scientific management of the programme; the Technical Committee for the design and upgrading of the SESAME machine; and the Training Committee for the training of personnel and users. The composition of the Council and of its committees is the best illustration of the international character and level of the project – and a guarantee of its success.

Staff numbers are being consolidated with the appointment of Technical, Scientific and Administrative Directors. Since 2001, young technical experts from the region have been receiving training in synchrotron radiation laboratories in Europe and the USA. A number of them have already been transferred to the site.

Beamlines Committee

Samar Hasnain (UK/Pakistan), Chair
Joan Bordas (Spain); Nasser Hamdan (Jordan/Palestinian Authority); Engin Ozdas (Turkey); Joel L. Sussman (Israel); Soichi Wakatsuki (Japan); Herman Winick (USA)

Scientific Committee

Zehra Sayers (Turkey), Chair
Adel El Nadi (Egypt); Jean-Patrick Connerade (France/UK); Abdeslam Hoummada (Morocco); Sami Mahmood (Jordan); Pierre J. Rizkallah (Lebanon/UK); Irit Sagi (Israel); Metaxia Vlassi (Greece)

Technical Committee

Albin F. Wrulich (Germany), Chair
Fawzi Ibrahim Ali Asfour (Egypt); Carlo J. Bocchetta (Italy); Mikael Eriksson (Sweden); Mohammad Hadi Hadizadeh Yazdi (Iran); Amor Nadji (Algeria/France); Salman M. Salman (Palestinian Authority); Ernst Weihreter (Germany)

Training Committee

Reza Mansouri (Iran), Chair
Javad Rahighi (Iran), Vice Chair
Shoaib Ahmad (Pakistan); Massimo Altarelli (Italy); Said A. Assaf (Palestinian Authority); Tomador El-Khalafawy (Egypt); Isa Khubeis (Jordan); Shin-ichi Kurokawa (Japan); one vacancy

THE SESAME DIRECTORATE

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