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SESAME, a third generation synchrotron light source for the Middle East region

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Abstract

Developed under the auspices of UNESCO, SESAME is being established as an autonomous international research centre in the Middle East/Mediterranean region. It will have as its centrepiece a 2.5 GeV third Generation synchrotron light source with 13 straight sections for insertion devices and an emittance of 26.6 nm-rad. It will provide intense radiation from the IR to hard X-rays to a community that is expected to exceed 1000 users a few years after the start of operation in 2008.

Keywords: Synchrotron radiation; UNESCO; Light Source; Middle East

1. Introduction and overview

From its inception in 1997 SESAME (*S*ynchrotron-light for *E*xperimental *S*cience and *A*pplications in the *M*iddle *E*ast; www.sesame.org.jo) has had a steady evolution in scope and design due to increasing interest by scientists and governments both within and outside the Middle East/Mediterranean region. The project aims to promote science and technology in the Middle East, while reducing tensions in the region by improving understanding among peoples of diverse backgrounds through peaceful scientific cooperation.

When it starts operation, now expected in 2007–8, SESAME will be an advanced centre for training as well as research. Experienced scientists now working abroad will be attracted to return to their region to pursue their research at SESAME, and graduate students and young researchers will no longer have to go abroad for advanced training. Scientists, engineers and technicians trained at SESAME, including those trained in various accelerator technologies (ultra-high vacuum, control and feedback systems, high power radio frequency, precision survey and alignment, etc.) will find employment in a variety of domains in industry, hospitals, universities and other sectors. They will also contribute to the development of new enterprises and a knowledge-based economy.

This report describes the present plans for a third generation 2.5 GeV synchrotron light source facility to support a scientific program which includes structural molecular biology, molecular environmental science, surface and interface science, X-ray imaging, archaeological microanalysis, material characterization, and medical applications.

In this introduction we review the origins and development of this unusual project which is now in construction in Allan Jordan, about 30 km northwest of Amman (Fig. 1) as a cooperative venture by presently nine Members (mostly governments) from the Middle

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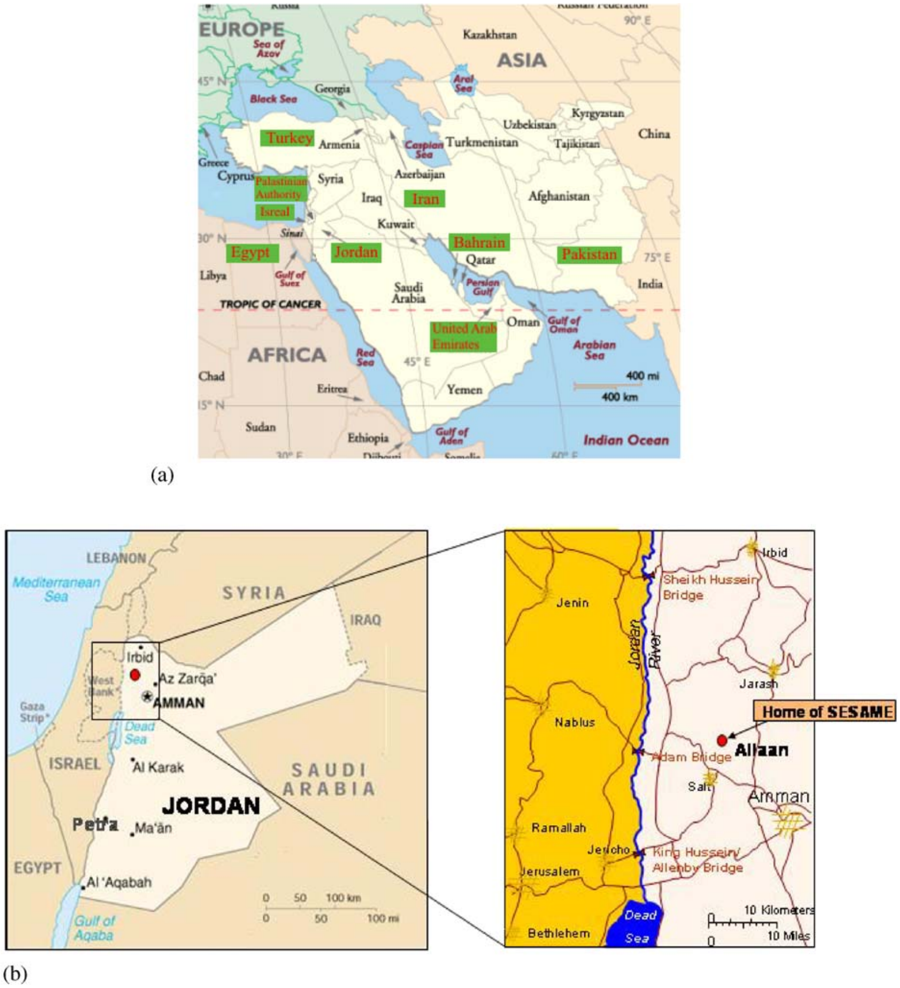

Fig. 1. (a) Map of the Middle East region showing the 9 Members of SESAME. (b) Detailed maps showing the location of SESAME in Allaan Jordan.

East/Mediterranean region of a permanent SESAME Council. Seven of the original 12 Members of an Interim Council proposed sites and Jordan was chosen to host the international project. One of the major conditions for this choice was that every scientist of the world must have access to the centre. The site and the building to house the facility are provided by Jordan. Construction of the building (Fig. 2) began in August 2003.

Although funds must still be identified and detailed designs must be completed, SESAME is well-underway. An accelerator group is being formed in Jordan from among 18 Middle East scientists and engineers who have completed 2 years of training at European synchrotron radiation laboratories. The project now has an Acting Director-General, a Technical Director, and an Administrative Director (see the web site) and several staff members. A search is underway for a Scientific Director.

1.1. Origins

SESAME started with a suggestion in September 1997 that the 0.8 GeV BESSY I second generation storage ring and injector system, after its decommissioning due to the start up of the 1.7 GeV BESSY II third generation facility, be offered by Germany as a gift to start a new international research centre in the Middle East.

BESSY I began 17 years of extremely productive scientific operation in Berlin in 1982. During its last few years of operation BESSY I served 130 user groups, with a total of about 700 users, per year working on about 180 projects using more than 30 experimental stations which could operate simultaneously. Users came from Germany and 12 other European countries. It ceased operation only because of the start up of BESSY II, since both facilities were in Berlin. The BESSY I facility stopped operation in December 1999

Fig. 2. The 80 × 80 m SESAME building in construction starting in August 2003.

and all components of the ring and injector were shipped to Jordan in June 2002.

The design of BESSY I (Bernstorff et al., 1987) was optimized to provide VUV/soft X-ray radiation from the bending magnets (critical energy 0.64 keV and hence high flux out to about four times this energy or about 2.5 keV) to compliment the higher photon energy capabilities available to German scientists at DESY/Hasylab and elsewhere. As the first facility for the Middle East, it was important that the spectral range of SESAME extend to X-rays of at least 15-20 keV so that important areas of research requiring hard X-rays, such as structural molecular biology and molecular environmental science, could be well served.

1.2. First design of SESAME

Led by G.-A. Voss of DESY, studies began in November 1997 on ways to upgrade the BESSY I storage ring so that it could be used as the centrepiece for SESAME; particularly to extend its spectral range to about 20 keV. The initial concept was presented by Voss at an April 1998 meeting in Uppsala Sweden of the Executive Committee of the CERN-based Middle East Scientific Collaboration (MESC) group. The project was subsequently described in more detail in a 73 page, January 1999 Conceptual Design Report by 26 scientists, mostly from BESSY, and in the 113 page October 1999 Green Book proposal by 57 scientists, including 18 from the Middle East (Voss et al., 2001).

The initial concept was to make extensive use of the BESSY I equipment, upgrading it to 1 GeV and increasing the circumference from 62 to 101 m, so that four insertion devices could be accommodated rather than two in BESSY I. The lattice would be modified with low-beta straight sections to reduce the electron beam transverse source size (one sigma horizontal/vertical values in the wiggler of 0.44/0.02 mm) and to facilitate the use of 7.5 T multipole superconducting wigglers (critical energy 5 keV), thus providing high flux and high flux density extending to about 20 keV. The emittance was 50 nm-rad, a factor of 2 lower than the natural emittance due to the damping effect of two high-field wigglers. The VUV/soft X-ray spectral range would be served by the bending magnets (critical energy 1 keV) and undulators. Performance comparisons showed that this ring was competitive with the best of the second generation light sources around the world, including those with electron energies up to 3 GeV. However the design allowed for a limited number of hard X-ray stations from the superconducting wigglers, perhaps only about six.

1.3. UNESCO interest

The project gained momentum when Federico Major, then Director-General of UNESCO, invited Middle East region governments to learn about the project at a consultative meeting at UNESCO headquarters in Paris in June 1999. The project received enthusiastic endorsement, leading to the formation of an Interim Council with 12 Middle East Members and with four advisory committees (Technical, Scientific, Training, and Finance) reporting to this Council.

SESAME has benefited greatly by continuous strong support by UNESCO, which has played the role of an umbrella organization under which the project could develop, notwithstanding the tensions in the Middle East. In May 2002 the Executive Board of UNESCO, mandated by the General Conference, unanimously approved the establishment of SESAME under its auspices, calling SESAME a model project for other regions and a "quintessential UNESCO project combining capacity building with vital peace-building through science".

1.4. Identifying and serving the SESAME scientific community

During 2000–2 five scientific workshops and schools, primarily in the areas of structural molecular biology and materials science, were held in the Middle East region. Reports on these are on the SESAME web site. Funds for these activities, and other activities such as committee meetings and the controlled dismantling of BESSY I, were provided by UNESCO, Members of the Interim Council, the International Atomic Energy Agency (IAEA), the International Centre for Theoretical Physics (ICTP), the Japan Society for the Promotion of Science (JSPS), the US Department of Energy and the US State Department.

With the growing size of the potential Middle East region user community, and with input from future users at these workshops and schools, it became clear that it would be very desirable to have more hard X-ray beam lines than could be provided on the superconducting wigglers in the 1 GeV design. This was particularly emphasized at the first SESAME Users' meeting (http://conference.kek.jp/JASS02/).

This led to the development of a 2 GeV design (the White Book; see the SESAME web site) by the SESAME Technical Director and scientists and engineers from the Middle East who were working in accelerator technology at European synchrotron radiation laboratories for periods of up to 2 years. These visits were financed mainly by SESAME but also with some support by these laboratories (Anka, Daresbury, DESY, Elettra, ESRF, Lure, Maxlab, and the Swiss Light Source). Although this 2 GeV storage ring would use few of the BESSY I storage ring components, full use would be made of the BESSY I 0.8 GeV injector system.

1.5. Design of the 2 GeV ring

The 2 GeV ring (Einfeld et al., 2002; CAARI) had a circumference of 117 m, an emittance of 17 nm-rad, and 16 straight sections, 13 of which were available for wiggler and undulator insertion devices with lengths up to 2.75 m. Hard X-rays, as well as VUV/soft X-rays, would be available from the bending magnets (critical energy 3.7 keV). Multipole wigglers and undulators would further extend capabilities. For example, 2.2 T permanent magnet multipole wigglers would provide a spectrum with a critical energy of 5.8 keV and high flux out to about 23 keV. Small-gap undulators would provide high-brightness photon beams up to about 8–10 keV.

1.6. Formal establishment of SESAME and new advisory committees

In June 2002 the Director-General of UNESCO, Koïchiro Matsuura, invited the Members of SESAME and other governments from the Middle East to join a permanent SESAME Council by accepting governing statutes that had been drafted by the Interim Council. When at least six governments accept these statutes and join the Council, SESAME would become a formal reality; an independent research facility under the auspices of UNESCO. On January 5, 2003, at the ninth meeting of the SESAME Interim Council (see the SESAME web site for reports of these meetings) and at the January 6, 2003 groundbreaking ceremony, Matsuura announced that the required six governments had joined, so that SESAME was formally launched.

The ground breaking ceremony, presided over by King Abdullah II of Jordan and attended by dignitaries from many countries and international organizations, marked the beginning of the 80×80 m building designed by engineers at Al-Balqa' Applied University in Jordan with the assistance of engineers at the Karlsruhe Research Center and based on the design of the building for the 2.5 GeV Anka ring in Karlsruhe.

The first meeting of the permanent SESAME Council took place in Amman on January 6, 2003. As of September 2003 nine Members have joined the SESAME Council. These are Bahrain, Egypt, Israel, Iran, Jordan, Pakistan, the Palestinian Authority, Turkey, and the United Arab Emirates. More are expected to join. Among other responsibilities, Council Members provide the annual operations budget. Capital funds for the ring, beam lines, and essential user-support laboratories are being sought from the EU, Japan, the US and other sources.

With the establishment of SESAME, four new Advisory Committees were also formed. A Scientific Committee and Beam Lines Committee are developing the scientific program and proposal for the first set of beam lines. A Training Committee is continuing the development of programs to train both accelerator scientists and users. A Technical Committee provides advice to the Council and Technical Director and critical reviews of technical plans. Members and Chairs of these new committees include many scientists from the Middle East region. See the web site for names and affiliations.

1.7. Review by the European Union

During 2002 the European Union was asked to provide funds for the upgrading of the BESSY I equipment and construction of the 2 GeV storage ring. A panel formed by the EU reviewed the plans and strongly endorsed the project, while recommending that the electron energy be increased to be more in line with the 2.5–3 GeV new ring projects recently completed in Switzerland and now in construction in Australia, Canada, France, the UK and the US. A primary motivation for this higher electron energy is to extend the range of high-brightness undulator beams to about 15 keV. Such an extension of spectral range would, in particular, enable SESAME to meet the strong demand at facilities around the world for undulator beams at 12 keV, the K-absorption edge of selenium, for protein crystallography studies.

As of September 2003, the EU expressed its willingness to consider a contribution to the financing of SESAME provided a revised proposal is considered to be technically and scientifically adequate. Such a proposal has been prepared for review and funding by the EU. It includes the latest 2.5 GeV design (see Sections 1.8 and 2 below) and a description of the initial complement of beam lines, scientific program, and user community.

1.8. The 2.5 GeV design—constraints and solutions

While electron energy higher than 2 GeV is clearly desirable, such a ring would have to fit within the 80×80 m building now in construction while maintaining reasonable space for insertion devices in straight sections and beam lines. These constraints led to a modification of the 2 GeV White Book design to reach 2.5 GeV in a ring with a circumference of 124 m (the Yellow Book and Einfeld et al., 2003a; PAC). The main features of the White Book design (e.g., 13 straight sections for 2.75 m long insertion devices and beam line lengths of about 30 m) were maintained. The higher energy was reached by extending the length of each of the 16 bending magnets in the 2 GeV White Book design from 1.9 to 2.3 m. To provide space for these longer magnets the initial 2.5 GeV design did not include a family of quadrupoles (so-called QD family, see Section 2) for adjusting the vertical focusing of the electron beam and the vertical tune of the machine. Instead the vertical focusing was provided by gradients in the bending magnets, which were also equipped with pole face windings. Analysis showed that the pole face windings could provide for about a 5% adjustment of the vertical tune.

Further study (see Section 2) has led to a refinement of the above design in which the QD family is included so that there is greater operational flexibility. This will facilitate commissioning and could be important for future modifications, such as the possible inclusion of very high field superconducting devices, which change the vertical tune. To accommodate the additional quadrupoles the circumference is increased to 128.4 m.

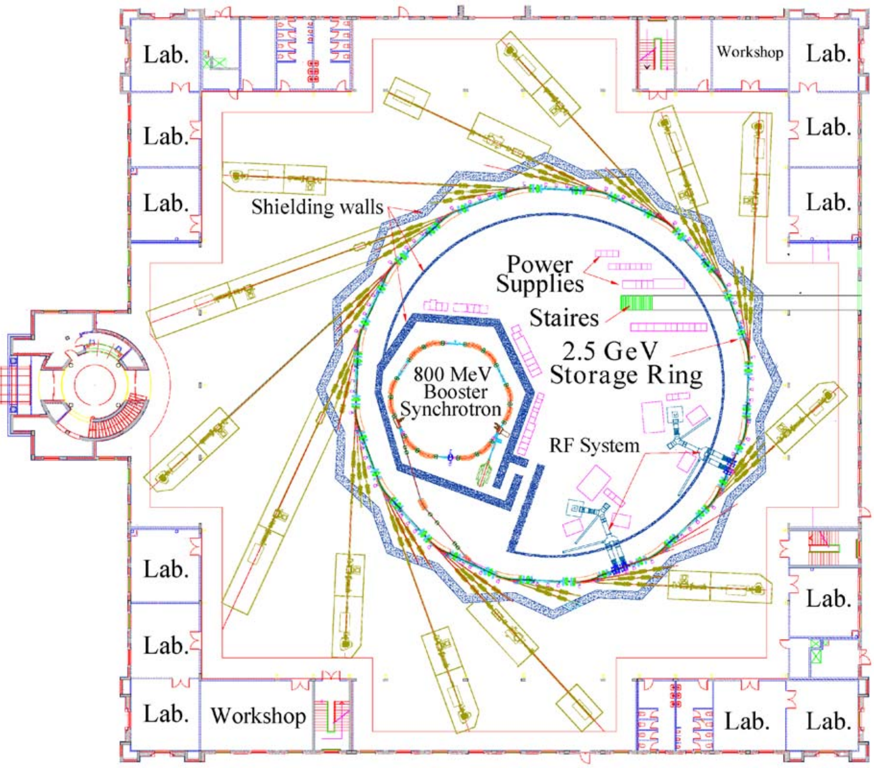

Fig. 3. Layout of the storage ring in the eccentric location showing beam lines from the 13 insertion device locations. In addition, beam lines can be brought out from each of the 16 bending magnets.

The larger circumference is possible while maintaining straight section and most beam line lengths by moving the ring 6 m off the centre of the building (Fig. 3). This shortens a few of the beam lines, but increases the length of others. The three straight sections which would have served the shortest beam lines are used for RF cavities and injection equipment rather than for insertion devices.

2. Detailed design of the facility and performance

The ground floor of the building contains the storage ring, beam lines, workshops and laboratories. The experimental area has a space of 60×60 m (with crane coverage) with an extension at each side of 7.5×30 m. The 13 beam lines from insertion device locations have lengths as follows: 2 at 22 m, 1 at 26 m, 3 at 29 m, 2 at 31 m, 3 at 33 m, 2 at 35 m. The enlarged ring could accommodate a future full-energy injector inside the ring so that "top-up" operation could be used. Offices for staff and users, plus other rooms (library, seminar and meeting rooms, control room, etc.) are located in the first floor (Einfeld et al., 2003b; SRI).

The lattice, a "TME-Optic" (Ropert, 1996), gives the smallest emittance and the highest percentage of the circumference for insertion devices with up to 2.75 m length. The symmetry is 8, with $2 \times 22.5°$ bending magnets in each unit cell (Figs. 4 and 5). The focusing in the horizontal direction is performed with only two families of quadrupoles (QF); the main part of the vertical focusing is done by the gradient in the bending magnets with flexible tuning by a small quadrupole (QD).

Another feature of this rather simple lattice is the excellent beam dynamics properties; in particular a very

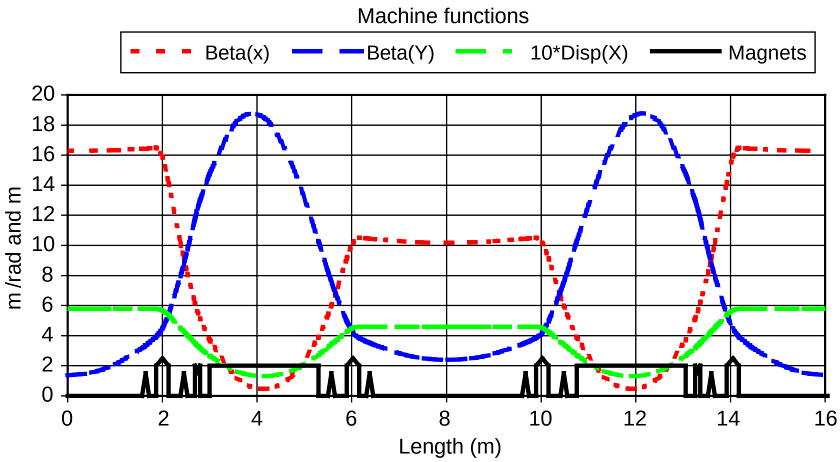

Fig. 4. Machine functions within the unit cell of SESAME.

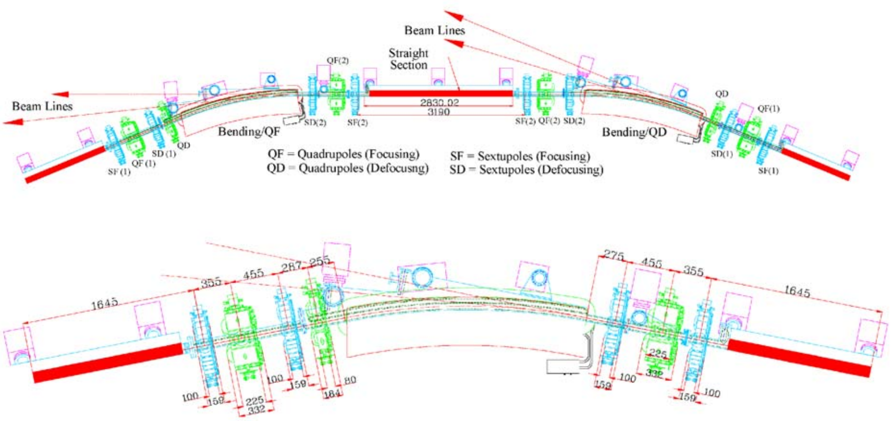

Fig. 5. The arrangement of the magnets within the unit cell.

large dynamic aperture (± 80 mm for the 3% energy acceptance of the lattice). This results in a good beam lifetime.

The natural emittance is 26.6 nm-rad, leading to beam cross-sections in the straight sections as low as $\sigma(x) = 700\,\mu$m, $\sigma(y) = 35\,\mu$m, with 2% coupling. With lumped absorbers and installation of 32,000 l/s of pumping speed, it should be possible to reach an average pressure of 10^{-9} mbar after conditioning, leading to a lifetime of ~ 15 h. The main parameters of SESAME are summarized in Table 1. The flux and the brightness of the emitted radiation of a 400 mA stored beam from the different sources are presented in Fig. 6.

3. Scientific programme, proposals, and beam lines

SESAME will exploit the wide range of applications possible at a multi-GeV third generation synchrotron radiation source. It will encourage interdisciplinary research and establish an environment for collaborations as well as individual development. It will help to accelerate research and development relevant to problems and concerns in the region that need urgent attention. Examples include biomedical applications in the field of pathogen characterization and specific drug development, monitoring mineral nutritional value of crops, investigating tolerance of plants to different pollutants, environmental monitoring including soil quality and salinity, characterization of minerals, and microanalysis of material at archaeological sites.

Scientific directions for SESAME, hence, include structural molecular biology and biomedical applications, molecular environmental science, surface and interface science, material science and archaeological microanalysis (cultural heritage). These areas are reflected in the large number projects that have been submitted by the user community. As can be seen in Table 2, as of September 2003 a total of 56 research proposals have been received, five of which are collaborations between scientists from two countries from the region. Each of these fields has significant communities within the SESAME Members so that a critical mass will be achieved by bringing these communities together in the utilization of a common world class regional research centre. In this way SESAME will enable scientists from the region to make significant scientific contribution on the world scientific stage. Based on these proposals, plus input from the various workshops and Users' meeting, a first set of beam lines have been proposed jointly by the Scientific

Table 1
The main parameters of SESAME

Energy	2.5 GeV
Maximum beam current	400 mA
Bending flux density	1.425 T
Emittance (horizontal)	26.4 nm-rad
Length of insertion devices	2.75 m
Beam cross-section in straight sections	$700 \times 35\,\mu\text{m} \times \mu\text{m}$
Available straight sections	13
Circumference	128.4 m
Electron energy spread	0.1%

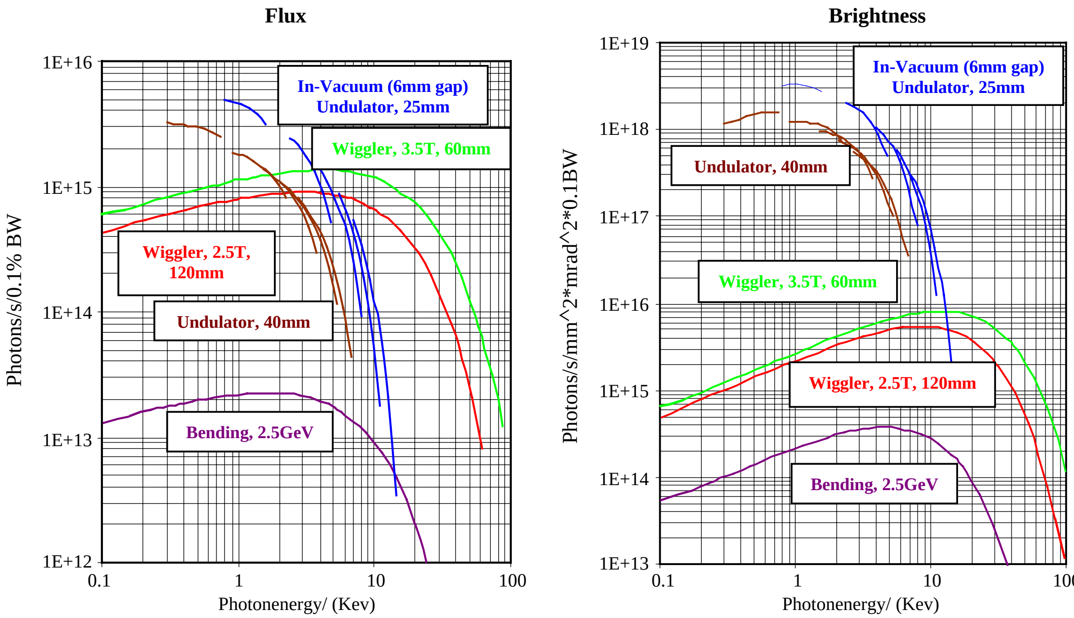

Fig. 6. Radiation characteristics of bending magnets, wigglers and undulators.

Table 2
Proposals submitted to SESAME as of September 2003

Originated from	Research area/ beamline	Number of proposals
Egypt	A/b and e	2
Israel	B/b, e,c,f	11
Jordan	A,B,C/a,b,c,d,e,f	16
Oman	A/a, d, c	4
Palestinian authority	A,B/b,d,e	3
Saudi Arabia	A/d,e	2
Turkey	A,B,D/a,b,c,d,e	5
United Arab Emirates	A/d,e	4
Canada	A/e	2
Greece	B/b,c	6
USA	B/b	1
Total		56

A: Material science, B: Structural molecular biology, C: Environmental science, D: Archaeological sciences. a: Photoabsorption/photoemission spectroscopy, b: MAD protein crystallography, c: Small/wide angle solution X-ray scattering, d: Powder diffraction, e: X-ray absorption fine structure and X-ray fluorescence spectroscopy, f: infra-red spectroscopy

Table 3
Proposed first set of SESAME beam lines

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

Committee and Beam Lines Committee. These are given in Table 3.

Acknowledgements

Significant contributions to SESAME have been made by very many, including Members of the Interim Council and Permanent Council, Advisory Committees, UNESCO staff, accelerator trainees and their hosts at European synchrotron radiation laboratories, staff at synchrotron radiation laboratories around the world who have contributed to workshops and schools, staff from the Budker Institute of Nuclear Physics and the Yerevan Physics Institute who carried out the dismantling of BESSY I, and others. We are indebted to Eshraq Al-Dmour for her excellent assistance in preparing this manuscript. We particularly acknowledge the early contributions of G.-A. Voss without which there would be no project today.

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