SESAME

Synchrotron-light for Experimental Science and Applications in the Middle East

Benefits Derived from Membership in SESAME and Obligations of the Members

I. What is SESAME?

SESAME is a major intergovernmental science facility in Allan, Jordan, that was formally opened by H.M. King Abdullah II of Jordan on 16 May 2017. It is the first synchrotron light source in the Middle East, and also the region's first true international centre of excellence. It was created under the auspices of UNESCO, but is an independent intergovernmental organization. It is modelled on CERN (although it has very different scientific aims).

The heart of SESAME is a 2.5 GeV synchrotron light source (133m in circumference).

SESAME is:

- Fostering scientific and technological excellence in the Middle East and neighbouring regions by starting to enable world-class research in subjects ranging from medicine and biology, through materials science, physics and chemistry to healthcare, the environment and archaeology,
- Building bridges between neighbouring countries and fostering mutual understanding and tolerance through international cooperation, and
- Helping to prevent and reverse the brain drain that is holding back science education and research in the region.

The Members of SESAME are currently Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, Palestine and Turkey. SESAME is actively seeking new Members both from across the Middle East and neighbouring countries and elsewhere. The Observers are Brazil, Canada, China, France, Germany, Greece, Italy, Japan, Kuwait, Portugal, Russia, Spain, Switzerland, Sweden, the UK, the USA, as well as CERN and the European Union.

As will be testified by the Associate status LEAPS (League of European Accelerator-Based Photon Sources) has granted to SESAME, the international scientific community has full confidence in the success of the Centre and its role as a centre of excellence. SESAME is the first Associate of LEAPS.

SESAME is the world's first large accelerator complex to be fully powered by renewable energy, thus making it the world's first carbon neutral accelerator laboratory. This makes SESAME economically, as well as environmentally sustainable. It has recently signed the UN's Climate Neutral Now pledge.

A synchrotron light source is an accelerator-based facility that uses electromagnetic radiation emitted by circulating electron beams to study a range of properties of matter. It is equipped with beamlines that focus the light on samples that scientists wish to study. Each beamline can support several experiments in series and in parallel. Synchrotron light sources have become an essential tool in a very wide range of applied and basic sciences. There are some 60 light sources in the world, including a few in developing countries, but until SESAME there was none in the Middle East and neighbouring countries

II. Governance of SESAME

SESAME is 'owned' by its Members which have full control over its development, exploitation and financial matters.

Through the Council, which is the governing body of SESAME, the Members participate in decisions on:

- the Centre's policy in scientific, technical and administrative matters;
- the Centre's financial regulations and staff rules;
- the establishment of staff posts at the Centre;
- the installation, operation and upgrading of the Centre's facilities;
- the scientific programme of the Centre;
- the training programme of the Centre;
- the election of the President and two co-Vice Presidents of the Council, and the appointment of the Directors of the laboratory, and chairpersons and members of the Council's advisory committees;
- all financial issues, including adoption of the yearly budget, review and approval of expenditures, etc.

III. Returns for investment in SESAME

SESAME groups the efforts of a number of countries, is located on land provided by the Jordanian Authorities in a building they funded, and has benefited from important external contributions in cash and in kind, as well as from scientific expertise. It therefore offers an extraordinarily cost-effective way to access excellent wide-ranging research opportunities.

SESAME is bringing scientific excellence to the Middle East and neighbouring countries thereby permitting science institutes in the region to stand as equal partners with laboratories in the scientifically more advanced countries. The possibility for scientists to carry out experiments at SESAME while remaining based in national universities and research institutes is helping to prevent or reverse the brain drain that is holding back science education and research in the region.

The extensive SESAME training programme has been playing an important role in strengthening scientific and technical capacity in the SESAME region ever since the inception of SESAME. Moreover, since 2014 scientists from the Members have been able to carry out research with the FTIR (Fourier Transform Infrared) microscope that was then producing science at SESAME with a conventional IR source - this microscope is now coupled to synchrotron infrared radiation. However, it is only since 2018 when the first two beamlines at SESAME came on stream that the Members started to derive the full benefits of membership in earnest. These benefits are spelled out in detail in Section VII below. Briefly they include:

- Access to wide-ranging research opportunities to execute national priority projects;

- Opportunities to collaborate with scientists from the other SESAME Members and beyond, including scientists from Europe, the USA and other countries who are involved in experiments at SESAME;
- Experience in up-to-date experimental techniques, which will open up opportunities for collaboration at other synchrotron-light sources around the world;
- Valuable experience for any countries that may in due course wish to build their own light source;
- On-going opportunities for training through workshops, Users' meetings, visits to other light sources, etc. that SESAME organises;
- A voice in the governance of SESAME, including in the choice of future beamlines and the scientific strategy behind the programme;
- Opportunities for appointments at SESAME;
- Opportunities to obtain SESAME contracts, which is an effective way to transfer technical capabilities;
- Raising the standard of research and education in the SESAME Members' national universities and institutes by exposure to international standards through collaboration and international peer review as has been the case in the national universities and institutes of Members of other international organisations (for example, CERN); and
- Easier access to SESAME for users granted beam time there, thanks to the Seat Agreement between SESAME and Jordan that facilitates the delivery of entry visas to Jordan, than could be the case to synchrotron light sources located in some countries for which an entry visa may be more difficult to obtain.

IV. SESAME's Accelerators

Particle acceleration at SESAME starts with the Microtron (the injector) that produces electrons and accelerates them to 20 MeV. These electrons are then transferred to the Booster where they are accelerated from their initial energy of 20 MeV to 800 MeV. From the Booster, electrons are passed through a transfer line to the Storage Ring that on each fill keeps an electron beam of 270 mA (eventually to be 400 mA) at 2.5 GeV circulating for many hours. Bending magnets on the Storage Ring force the electrons to change trajectory as they circulate, causing them to emit synchrotron light. This light is transmitted to beamlines that focus the light on samples that scientists wish to study.

SESAME's Microtron is that of BESSY I that was donated to SESAME by Germany. It has been greatly refurbished and upgraded and has allowed the SESAME laboratory to come into operation. It is planned to soon replace it by a new LINAC.

SESAME's 2.5 GeV Storage Ring is completely new. It was built from scratch with European Union funding (€5 million) for construction of the key magnetic system for the Storage Ring, and also part of the power supplies. This project, which was led and coordinated by CERN with support from SESAME, put CERN's expertise at the service of SESAME, while the ALBA light source in Barcelona played an important role in magnet testing. Three key contracts were placed in SESAME Members (Cyprus, Israel and Pakistan), with the rest placed in Europe, and CERN received in-kind support from three SESAME Members (Iran, Pakistan and Turkey), which facilitated valuable knowledge transfer.

V. Science at SESAME

Two of SESAME's beamlines are now in operation, and the Centre's full scientific programme, which is now beginning, will span fields ranging from medicine and biology, through materials science, physics and chemistry to healthcare, the environment, agriculture and archaeology. In June 2019, the first scientific paper presenting results using data obtained at one of SESAME's beamlines - the X-ray absorption fine structure/X-ray fluorescence (XAFS/XRF) spectroscopy beamline - was published in Applied Catalysis B: Environmental. (*S: Bac et al. Applied Catalysis B: Environmental, 259, 2019, 117808)*.

The laboratory will be exploited in up to 20 or more experiments operating simultaneously on independent beamlines, which will focus the synchrotron light on samples of materials. In the first phase, there will be seven beamlines. These beamlines, which have been selected on the basis of requests from scientists in the region, are the following:

- XAFS/XRF (X-ray Absorption Fine Structure/X-ray Fluorescence) spectroscopy beamline;
- IR (Infrared) spectromicroscopy beamline;
- MS (Materials Science) beamline;
- MX (Macromolecular Crystallography) beamline;
- BEATS (BEAmline for Tomography at SESAME) beamline;
- HESEB (HElmholtz-SEsame) beamline for soft X-rays; and
- SAXS/WAXS (Small Angle and Wide Angle X-ray Scattering) beamline.

The XASF/XRF beamline started receiving users on 17 July 2018 and the IR beamline did so on 4 November. The MS beamline is expected to come on stream in 2019, and construction of the already-designed MX beamline will start immediately the required funds are secured. Planning for the BEATS and HESEB beamlines has started and they are both expected to come into operation in 2022. Full funding for the BEATS beamline and a substantial part of the funding for the HESEB beamline needed to bring both into operation is assured. Plans for the seventh beamline are yet to start.

The **XAFS/XRF beamline** is based on the donated Helmholtz Zentrum Dresden-Rossendorf beamline, originally installed at the European Synchrotron Radiation Facility in Grenoble (France), which has been adapted to the characteristics of SESAME. It is optimized for X-ray spectroscopic studies in all fields of science including *in situ* studies of functional materials. It can be used in materials and environmental science, in designing new materials and improving catalysts (e.g. for the petrochemical industries), and to identify the chemical composition of fossils and valuable paintings in a non-invasive manner. It is equipped with an advanced state-of-the-art silicon detector (funded by Italy) that has a sensitivity that is at least 50 times higher than of any detector currently available.

The **IR beamline** is a completely new beamline. It was designed and built in collaboration with the French light source, SOLEIL. It allows the application of infrared microspectroscopy and imaging in a wide range of fields, including surface and materials science (e.g. characterization of new nano-materials for solar cell fabrication and for drug delivery mechanisms), biochemistry, archaeology, geology, cell biology, biomedical diagnostics and environmental science (e.g. air and water pollution).

The **MS beamline** is based on components donated by the Swiss Paul Scherrer Institute (PSI), with modifications to match the characteristics of the SESAME Storage Ring. It will be the first

SESAME beamline equipped with an insertion device (a wiggler, also donated by PSI) which enhances the brightness of the synchrotron light, reducing the time needed to make measurements, and making it possible to follow fast processes. A powerful PILATUS 300K area detector, donated by DECTRIS (Switzerland), will provide the fast read-out time that is required to investigate the evolution of nano-scale structures and materials in extreme conditions of heating and cooling under gas flows. The MS beamline will be used in applications of the powder diffraction technique in materials science. It will provide a powerful tool for studying microcrystalline or disordered/amorphous material on the atomic scale, evolution of nano-scale structures and materials in extreme conditions of pressure and temperature, and for developing and characterising new smart materials.

The **MX beamline** will be a completely new beamline. It will be a state-of-the-art MX beamline, based on an in vacuum undulator, and will have robotic sample handling and utilize a high-performance photon counting detector. It will be used to elucidate the mechanisms of proteins and nucleic acids at molecular level and provide guidelines for developing new drugs and therapies. It is envisaged that in the early stages there will be strong collaborations with recombinant protein production and crystallization laboratories in the region. Protein crystallography studies at synchrotrons have contributed to the award of five Nobel prizes, the first in 1997 and the latest in 2012.

The **BEATS beamline** will also be a completely new beamline. The source is still under study, but already it seems more than probable that it will be a three-pole wiggler, or a similar source to be installed on a short straight section of the SESAME Storage Ring giving the best combination of flux and coherence in the energy range from ~7 keV to ~40keV. In order to preserve these characteristics of the source, a Double Multilayer Monochromator (DMM) will be built and the sample stage will be at a long distance (~50m) from the source. Although this will require some modifications to the SESAME building, the advantages in terms of spacial resolution will be enormous, allowing BEATS to image submicron details of the samples under investigation. This beamline will have important applications in archaeology and cultural heritage, which is particularly relevant given how rich the region is in archaeological sites and artefacts, but also in health and biomedicine, geology (i.e. geological rock samples relevant for oil/gas/water exploration, reservoir engineering, mining, etc.) and materials and nano science and engineering. Construction of the beamline is being funded by the European Union through its Horizon 2020 programme and the beamline is being developed by a consortium of leading research facilities in the Middle East (SESAME and The Cyprus Institute), well established European synchrotron radiation facilities and high-energy laboratories (DESY,[1] ELETTRA, ESRF, INFN and PSI) with decades-long experience in synchrotron radiation research and technology, and more recently founded synchrotron laboratories (ALBA-CELLS[2] and SOLARIS). Not many synchrotron light facilities have a tomography beamline, which in many ways will make SESAME's beamline unique.

The **HESEB beamline** will be a state-of-the art beamline in the soft X-ray energy range (between ~70 - ~1800eV). Soft X-ray spectroscopy is a collective name for a wide range of techniques with which the electronic structure of atoms, molecular bonds and chemical characteristics of materials can be investigated. It has applications in the fields of health

1 DESY (Deutsches Elektronen-Synchrotron), Elettra (Elettra-Sincrotrone Trieste S.C.p.A., ESRF (European Synchrotron Radiation Facility), INFN (Instituto Nazionale di Fisica Nucleare) and PSI (Paul Scherrer Institute)

2 ALBA-CELLS (Consorci per a la Construcció Equipament i Explotació del Laboratori de Llum de Sincrotró)

sciences, photonics, advanced materials, environmental sciences, nanostructures, petrochemistry and energy. The optical, mechanical and vacuum components of the beamline, as well as the related infrastructures, will be completely new. They will be constructed by five research centres of the Helmholtz Association of German Research Centres (DESY, FZJ,[3] HZB, HZDR and KIT) under the leadership of DESY. The source will be a fully refurbished EPU (Elliptically Polarized Undulator) of the APPLE II (Advanced Planar Polarized Light Emitter) type, previously installed at HZB. SESAME has a crucial role in assuring the compatibility of the components provided by the Helmholtz partner with the layout of SESAME, as well as assuring that the needed modifications to the existing infrastructure (e.g. of the vacuum chamber) are made in order to assure their smooth installation. Moreover, it will provide all the necessary support for the installation and alignment of the beamline. The Helmholtz Association is funding most of the construction of the beamline.

VI. Users

The users of SESAME are based in universities and research institutes principally, though not exclusively, in the region, thereby permitting networking with scientists both in and beyond the Middle East and neighbouring countries. They visit the laboratory periodically to carry out experiments, generally in collaboration, where they are exposed to the highest scientific standards. There are now 593 users registered on SESAME's database. The potential user community, which continues to grow rapidly, is being fostered by a series of Users' Meetings and by excellent training opportunities (supported by the IAEA, the European Union, various governments, many of the world's synchrotron laboratories, and foundations and small charities) which are already bringing significant benefits to the region.

A first call for beam time on the XAFS/XRF and IR beamlines issued in 2017 resulted in 55 proposals, and 103 proposals were received in response to a second call in September 2019, pointing to the clear need for a synchrotron light source in the region. In both cases, the applications were from the Members of SESAME and beyond.

All proposals are reviewed by SESAME's Proposal Review Committee (PRC), an international advisory body responsible for evaluating the scientific and technological merit of proposals and determining their priority using criteria based on IUPAP's (International Union of Pure and Applied Physics) Recommendations for the Use of Major Physics Users Facilities.

Beam time for the first call for applications was granted for twenty-eight proposals, while for the second call beam time was granted for fifty-seven proposals.

At the date of 31 March 2019, there had already been 26 measurement runs carried out at the two beamlines. They ranged from topics such as novel materials for batteries; the possible use of herbs for treating Alzheimer's Disease; ancient human remains from the Eastern Mediterranean and the Near East; and ancient manuscripts from the Quran.

Users visiting SESAME for their experiments are being accommodated at the temporary Guest House on the SESAME campus. Construction of the permanent 48-bedroom Guest House, also on the SESAME campus, has been completed and the ground floor (cafeteria and more formal dining room), as well as 5 bedrooms on the first floor (1 double room, 3 single rooms and 1 room for a disabled person) have been furnished. In September 2019, this Guest House will be

---

3 FZJ (Forschungszentrum Jülich), HZB (Helmholtz-Zentrum Berlin), HZDR (Helmholtz-Zentrum Dresden-Rossendorf) and KIT (Karlsruher Institut für Technologie)

inaugurated and will start to accommodate users in conjunction with the temporary Guest House. As more of the bedrooms are furnished more of the visiting users will be accommodated in the permanent Guest House until they are all accommodated there and the temporary Guest House is phased out to be transformed into an administrative building. There is a conference room on the ground floor of the permanent Guest House and in periods when they are not needed by SESAME, the conference room and Guest House will provide a venue for regional meetings on other topics (such as agriculture, water resources and pollution) in secure and easily accessible surroundings, furthering SESAME's mission as a focal point for regional cooperation.

VII. Opportunities for national institutions and scientists and engineers from the SESAME Members

1. Scientific and Technical Activities

Scientists from the Members of SESAME have full access, free-of-charge, to the facilities in the laboratory, including existing beamlines and instruments as outlined in the SESAME User Policy (http://www.sesame.org.jo/sesame_2018/for-users/user-guide/sesame-user-policy). They are able to propose to design and conduct experiments according to their specific interests/needs, without being limited to what is offered under routine operational conditions at synchrotron radiation user facilities elsewhere.

SESAME provides its Members a unique environment for training in a field that is at the frontiers of science. Young scientists are not only able to benefit from the training fellowships provided through SESAME, but they also have greater opportunities for hands-on training through more generous beam time allocations than would be available elsewhere. Furthermore, through international cooperation enabled by SESAME, scientists and technicians from the Members of the Centre will be brought to world-level standards and will become equal partners in the world scientific community.

National universities of the Members also stand to benefit. The international synchrotron radiation community's enthusiastic response to SESAME opens the way for international collaborations and student exchanges, which will help to enlarge local pools of know-how. Moreover, since most of the experiments will be carried out in international collaborations by scientists from universities in the Members of SESAME and beyond, this will enable universities to compare their standards with those of internationally-renowned universities which, in turn, will contribute to raise the level of their competence. Universities will also benefit from various spin-offs. For example, with the help of SESAME, the infrastructure of internet connections will be developed to enable the intensive exchange of electronic messages and scientific data produced by the SESAME beamlines. Furthermore, local high-technology capacity, in areas such as ultrahigh vacuum, high-specification electromagnet production, electronics and IT infrastructures, is being developed to support experiments conducted at SESAME, and also preliminary or complementary experiments that SESAME users may wish to conduct in their home country. One example is the EU-funded LinkSCEEM project which has not only helped to define the computing needs of SESAME, but has also provided a user base for the supercomputing facility at The Cyprus Institute which has made the project more competitive at an international level.

In the same way that the intense scientific activity of CERN in Switzerland led to the creation of other European scientific organisations, e.g. EMBL (European Molecular

Biology Laboratory) in Germany, SESAME's activity may in the long term lay the seed for the establishment of other collaborative laboratories in the region, which in turn will bring greater prosperity to the participating countries and innovative openings for their scientists and engineers.

2. Training

Scientists and engineers from the SESAME Members are able to benefit from SESAME's large training programme. To date, some US$5.5 million have been invested in training (almost all provided by outside supporters). The training programme has three main elements:

(a) Users' meetings that provide a forum for formulating SESAME's scientific strategy, and are fostering the formation of international collaborations which will carry out experiments at SESAME. So far, sixteen users' meetings have been held and more are being organised (for details see http://www.sesame.org.jo/sesame_2018/sesames/events). At each there is an average of 120 participants. Regular funding for these meetings is generally provided by the American, British, French, German, Italian and European physical societies, the American, French and German chemical societies, the German Mathematical Society and the International Union of Pure and Applied Physics (IUPAP).

(b) Workshops and schools of which SESAME has organized some 21 in the Middle East and elsewhere. These meetings have attracted some 900 scientists and engineers. The workshops focus on specific topics, while the schools provide basic training for *inter alia* carrying out experiments at synchrotrons, machine commissioning, instrumentation, safety, science administration and management, and public outreach. Support for these activities is forthcoming amongst others from the European Union (EU), which is providing €2M through the Open SESAME project (http://www.opensesame-h2020.eu/en/), the International Atomic Energy Agency (IAEA), and the Abdus Salam International Centre for Theoretical Physics (ICTP).

(c) Individual training through visits to leading laboratories around the world. Approximately 136 young scientists and engineers from the SESAME Members have been recipients of fellowships that allowed them to spend periods of up to two-three years receiving training, or working at synchrotron radiation facilities and other centres (mostly in SESAME Observer countries) in Europe, the USA, Asia and Latin America. These fellowships are being financed by sponsors such as the IAEA, which has already provided more than €1.3 million for SESAME's training programme, the UK Department for Business, Energy and Industrial Strategy (BEIS) through the Rutherford Fund which has provided some GBP1.2M, the EU, ICTP, synchrotron laboratories in different parts of the world, foundations and small charities.

It should be pointed out that the engineers who received training in European laboratories on how to install and later operate a synchrotron radiation source in the early years of the SESAME project received this tuition thanks to the SESAME training programme and the generosity of their European hosts. A number of the engineers are now staff members of SESAME. A similar mechanism was subsequently established for scientists to learn how to install and operate beamlines, and how to carry out tests using synchrotron radiation techniques.

How much a Member benefits from SESAME's training programme depends on how active a Member is in proposing candidates. This training is not only useful for the exploitation of SESAME, but also has benefits for the Members' universities, and even industry - some of the people trained by SESAME have moved to high-tech jobs in the Member countries.

VIII. Staff at SESAME and Contracts for Equipment/Services

Although no definite quotas are foreseen, applicants from the Members are given priority when international staff are hired at SESAME.

Moreover, for contracts placed by SESAME preference is given to national companies from the Members (provided their bids are not more than 8% higher than any bids from non-Members), and they have been awarded a number of contracts for components of the SESAME machine. Such contracts are not only interesting from a financial point of view, but in many cases are important tools for technology transfer. The flow of contracts is expected to continue as further beamlines are built, other facilities are added, and (in due course) SESAME is upgraded, as happens periodically at all light sources.

As in the case of the training programme, the number of nationals a Member has serving on the staff of SESAME and the number of contracts awarded to a Member's national companies depends on how active a Member is in proposing candidates and submitting offers in response to calls for tenders.

IX. Obligations of the SESAME Members

1. Intellectual and Other Obligations

The SESAME Members are to ensure that they are represented on the Council of SESAME by persons having the required experience and authority. Each Member may have up to two delegates on the Council. Ideally, one should be a scientist and the second a person entrusted with decision-making powers. They may be accompanied to Council meetings by up to two advisers.

The delegates to the Council should make known the Council decisions to their respective national authorities. They should be pro-active in responding to the Council's calls for representation on its advisory committees, candidates for training and vacant SESAME staff posts, bids for components that are to be purchased for the SESAME beamlines, etc. They should bring SESAME's activities to the attention of their national scientific institutions and universities so that their country may benefit to the full from the opportunities offered by SESAME.

2. Financial Obligations

The operational costs of SESAME (staff costs, materials for operating the machine, running the Centre……) are covered by the Members of the Centre, and the total yearly budget is distributed among them based on a system inspired from the principles of the

UN scales. The total yearly budget and its distribution among the various Members are presented to the Council every year and require unanimous approval by the Council.

In 2019, the yearly budget of SESAME is US$5,288,613.20. It should stay the same for several years thanks to the solar power plant that is now in place – as in the case of all accelerators, SESAME's machine is greedy in energy, and without the solar power plant, its operational budget would be double that which it is. It is hoped that eventually the number of Members will increase to more than a dozen with the consequence that the contribution of any single Member will be rather modest.

X. Capital investment

Israel, Jordan and Turkey have each provided US$5 million as a voluntary contribution towards SESAME's capital investment.

Although contributions to the capital budget are not obligatory, it is hoped that current (and future) Members will provide such funding for construction of future beamlines, further development of SESAME's infrastructure, and the periodic upgrading of SESAME facilities.

XI. Further Information About SESAME

A visit of the SESAME Centre may be organized on request.

More information about SESAME is available on http://www.sesame.org.jo/sesame_2018/

Contact: Clarissa Formosa Gauci cfg@sesame.org.jo

June 2019