Science Beyond Boundaries – SESAME and International Collaboration

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Abstract. SESAME is a 2.5 GeV third-generation light source, which is coming into operation in Jordan. It will foster science and technology in the Middle East and neighbouring countries (from biology and medical sciences through materials science, chemistry, and physics to archaeology), as well as cooperation among the scientists from diverse countries across the region who will visit SESAME periodically to carry out experiments.

Keywords. Synchrotron light. International collaboration. Science for peace.

1 Introduction

SESAME (Synchrotron-light for Experimental Science and Applications in the Middle East) is a large scientific facility, just coming into operation in Jordan, which will enable research in many fields, and foster cooperation across political, religious and cultural divides. There is nothing remarkable about SESAME as a scientific facility, except that of over 50 synchrotron light sources in the world, it is the only one in the Middle East. The list of Members that belong to SESAME, which is an intergovernmental organisation, is however very remarkable. They are Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, the Palestinian Authority and Turkey. The list of SESAME Observers (Brazil, Canada, China, EU, France, Germany, Greece, Italy, Japan, Kuwait, Portugal, Russian Federation, Spain, Sweden, Switzerland, the UK, and the USA), whose role will be explained later, is a manifestation of world-wide support for SESAME.

SESAME has faced many difficulties, almost all financial, but it is now starting to work, and the experimental programme is about to begin, albeit on a limited scale, with minimal supporting infrastructure. For over a decade, SESAME's vigorous training programme has been building scientific capacity in the region and nurturing a community of scientists who will visit the facility in order to carry out research.

I will begin this talk by saying something about CERN, on which SESAME is modelled conceptually, although the scale and scientific aims of the two organisations are completely different. I will then go on to introduce SESAME and synchrotron radiation, describe the origins of the project and how it is funded and how it was built, outline some of the science that will be enabled by SESAME, discuss SESAME's training programme, and finally describe some of the challenges the project has faced and its future prospects.

2 ‘Science for Peace’ – CERN and SESAME

CERN and SESAME were both created under the umbrella of UNESCO, which uses the strapline ‘science for peace’. CERN was conceived in the late 1940s, with two aims: to enable the construction of expensive facilities beyond the means of any individual European country, and to foster collaboration between countries that had very recently been in conflict. European physicists (of whom Edoardo Amaldi was one) realised that the large, expensive accelerators being built in the USA would soon take over from cosmic rays as a source of high-energy particles whose collisions they wished to study, and that they could only afford to build competitive facilities by collaborating. They joined forces with some far-sighted science administrators and diplomats who were developing the idea of establishing a collaborative project to help rebuild collaboration and trust in Europe following the war.

SESAME was conceived in the late 1990s with the same aims, the major differences being that some of the Members are currently in conflict, and the scientific goals of SESAME and CERN are very different. CERN has built bridges between peoples in many ways. For example:

- It was the first intergovernmental organisation that Germany joined after the war.
- The first post-war meetings between German and Israeli scientists took place at CERN.
- Collaboration between CERN and Russia continued through the Cold War, and was a model for later USA-Russia collaboration.
- In the late 1970s, when China was closed, scientific contacts between Europe and China were pioneered in work at DESY (in Hamburg) and later at CERN, in collaborations led by Nobel Laureate Sam Ting from MIT with the backing of Deng Xiaoping.
- In 1985, when USSR-USA arms negotiations in Geneva were stalled, the US delegation asked the Director General of CERN to arrange a dinner at CERN for Russian and American scientific advisors - which facilitated a subsequent breakthrough.
- CERN had an open-door policy for scientists from East European countries during the cold war, which allowed them quickly to join CERN (as an expression of their European identity) following the fall of the Berlin wall.

CERN has found that, although they are often initially mutually suspicious, scientists and engineers with very different political and religious views and cultures who work together develop technical respect. This then leads to greater understanding and tolerance of their respective views. Today over 12,000 scientists carry out research at CERN (some 7,300 from the 21 Member States, the rest from 81 other countries, among which the largest contingents come from the Observers – India, Japan, Russia and the USA). The collaborative work these (mainly young) scientists carry out at CERN undoubtedly creates better understanding. This is also happening at SESAME.

3 Introduction to SESAME and Synchrotron Light Sources

SESAME is a third-generation light source, a device which (pending an explanation below) can be thought of as an extremely bright flashlight which illuminates samples of materials that scientists study using very powerful microscopes. SESAME will foster science and technology in the Middle East and neighbouring countries (from biology and medical sciences through materials science, chemistry, and physics to archaeology), as well as cooperation across political, religious and cultural divides.

International collaboration is the obvious way for countries with relatively small scientific communities and/or limited science budgets to build synchrotron light sources. The breadth of the scientific programme they can support makes them ideal facilities for building scientific capacity, which is SESAME's primary goal. SESAME will be a user facility: scientists will typically go to the Centre two or three times a year for a few days to carry out experiments, often in collaboration with scientists from other institutions/countries, with the support of SESAME's small permanent staff.

Synchrotron light sources accelerate bunches of electrons that then circulate for many hours in an evacuated beam-pipe with a diameter of a few centimetres which forms a (almost) circular ring (with a circumference of 133 m in the case of SESAME). The electromagnetic field surrounding the electrons is unable to respond instantaneously when the electrons are steered around the ring by the magnets that surround the beam pipe. Some of the energy in the field keeps going, producing a tangential cone of synchrotron radiation. As the electrons' energy increases, the cone of radiation narrows, and the radiated power goes up dramatically. In third-generation sources such as SESAME, devices inserted in straight sections of the accelerator (called wigglers or undulators) put magnetic 'bumps in the road' – radiation shaken off as the electrons traverse successive bumps adds up to make a much more intense beam of synchrotron light.

Devices called beamlines, positioned at various points around the accelerator, select synchrotron light with particular wavelengths and focus it on samples of materials that scientists wish to study, which are surrounded by sophisticated detectors that are used to analyse what happens.

4 Early History of SESAME

Eminent scientists such as the Pakistani Nobel Laureate Abdus Salam recognised the need for an international synchrotron light source in the Middle East some 35 years ago. The CERN and Middle-East based Middle East Scientific Cooperation (MESC) group, headed by Sergio Fubini, also felt this need. MESC's efforts to promote regional cooperation in science, and also solidarity and peace, started in 1995 with the organisation in Dahab (Egypt) of a meeting at which the then Minister of Higher Education of Egypt, Venice Gouda, and Eliezer

Rabinovici (MESC and Hebrew University, Israel) took an official stand in support of Arab-Israeli cooperation.

In 1997, Herman Winick (SLAC National Accelerator Laboratory, USA) and the Gustav-Adolf Voss (Deutsches Elektronen Synchrotron, Germany) suggested building a light source in the Middle East using components of the soon to be decommissioned BESSY I facility in Berlin. This brilliant proposal fell on fertile ground when it was presented and pursued during workshops in Italy and Sweden organised by MESC (which adopted the proposal) and others. Fubini and Herwig Schopper (a former Director-General of CERN) persuaded the German Government to donate the components of BESSY 1 to SESAME, provided funding to transport the equipment (which was eventually mainly provided by UNESCO) could be found.

Schopper brought this plan to the attention of Federico Mayor, then Director-General of UNESCO, who convened a meeting of delegates from the Middle East and other regions at the Organization's Headquarters in Paris in June 1999. The meeting resulted in the launching of the project and establishment of an international Interim Council with Schopper as Chair. Jordan was subsequently selected to host SESAME in a competition with five other countries from the region. The Government of Jordan provided the land, as well as funds for the construction of the building. In May 2002, the Executive Board of UNESCO unanimously approved the establishment of the Centre under the auspices of UNESCO, which is the depository of SESAME's Statutes. The Centre formally came into existence in April 2004 when the required number of Members had informed the Director-General of UNESCO of their decision to join.

Meanwhile, in 2002 questions were raised about the wisdom of re-building and upgrading BESSY 1. It was formally abandoned in 2004 in favour of building a completely new 2.5 GeV main storage ring, with straight sections that can accommodate insertion devices (wigglers and undulators), thereby making SESAME a competitive third-generation light source, while retaining the BESSY 1 microtron and booster synchrotron, which provide the first two stages of acceleration. A ground-breaking ceremony was held in January 2003 in the presence of HM King Abdullah II of Jordan and Koïchiro Matsuura, then Director-General of UNESCO. The SESAME building was formally opened on 3 November 2008 in a ceremony held under the auspices of HM King Abdullah II, with the participation of HRH Prince Ghazi Ben Mohammed of Jordan and Koïchiro Matsuura, then Director General of UNESCO, representatives of the SESAME Members and other distinguished guests.

Following the opening of the building in November 2008, I took over from Herwig Schopper as President of the Council. Before agreeing to this, I visited SESAME where I was impressed by the commitment of Khaled Toukan, the Director of SESAME (who was then also Jordan's Minister of Education; he is now the Chairman of the Jordan Atomic Energy Commission, having meanwhile been the Energy Minister). I was also deeply impressed by the enthusiasm of the young people who, having been trained as accelerator specialists in Europe, with Fellowships arranged by SESAME, had returned to the Middle East to build SESAME (the training programme is described in section 7). I was further impressed by a remark made by Eliezer Rabinovici, when he visited the UK to persuade me to take on the role of President, that “As a string theorist, I work on parallel universes. I was always curious about what a parallel universe was like, and now I know. I'm living in one when I go to SESAME meetings working hand in hand with our neighbours on a common goal, bringing advanced knowledge to our region.”

5 The Construction Phase

5.1 Planning and Funding

When I took over as President, SESAME had a large empty building and a design for the accelerator, but there was no plan for building the facility as there were no funds to do so. I decided that anyway SESAME needed a Strategic Plan, which of necessity would be based on the obviously false assumption that the necessary funding would become available when needed, and that there was a need to review earlier costings. This plan (which the SESAME Council endorsed in November 2009) has been followed subsequently, albeit nothing like as rapidly as hoped, and with numerous items postponed, because the necessary capital funding was not available.

The Members of SESAME make annual contributions, which cover operational costs (manpower, consumables, electricity,…). However, when SESAME was set up, no provision was made for the Members to cover the initial capital costs since the plan then was simply to upgrade and rebuild the old Berlin Synchrotron, while Jordan had agreed to provide the land and fund the building. When the decision to build a completely new (2.5 GeV) main storage ring was taken, it was hoped that the European Union, which the SESAME Council had hoped would fund the upgrade, would provide the much larger capital funding that was needed to build and equip the new main ring. However, the 2009 Strategic Plan revealed that (as I had suspected) construction would cost much more than previously assumed, and it became clear that it would not be possible to obtain all the funding from outside without first obtaining a substantial part from the Members.

A breakthrough came in early 2012 when Israel volunteered to contribute $5 million provided four other Members did the same. I convened a meeting of Members who were willing to consider contributing, which was attended by representatives of Iran, Israel, Jordan and Turkey. Until shortly before the meeting, it was hoped Egypt would send a representative but the country was then in a state of turmoil and a change in the government intervened. The four countries that did attend agreed to contribute $5 million each, while hoping that Egypt or others would join them later (meanwhile the Royal Court of Jordan had made a significant cash contribution, and Jordan’s Scientific Research Support Fund is currently supporting construction of a beamline as described in section 6). In the event, Iran has not yet been able to pay its voluntary capital contribution, or since 2011 its annual contributions, due to sanctions. Unfortunately, partly because of frequent changes of government, Egypt has so far not fulfilled its expressed wish to make a capital contribution (this is the only example of a direct effect on SESAME of the Arab Spring).

Following this breakthrough, the European Commission (which had already provided funds to SESAME though its collaboration agreement with Jordan) agreed to provide CERN with

€5 million to lead the procurement of the magnet system for the main ring, in collaboration with SESAME. CERN's contribution was hugely beneficial, and working with CERN's experts provided wonderful training experience for SESAME staff. The voluntary support from the Members also encouraged Italy to provide €1 million in 2014, which was used to procure accelerating cavities; this was followed by further Italian contributions, so far amounting to a total of €3.35 million of which the most recent part is being used to build a hostel for SESAME users.

This funding, together with the Members' annual contributions to the operational budget and donations of equipment that had become surplus to requirements by a number of synchrotron laboratories[1], were sufficient to bring SESAME into operation. I hope that the additional capital funding that will be needed in the future, for purposes indicated in section 9, will come from the annual contributions as well as from external supporters. This should be made possible by the construction of a solar power plant (see section 8) which will reduce the enormous burden of paying for power that would otherwise have fallen on the Members. Many have tiny science budgets and have sometimes struggled to pay their annual contributions, although I hope that they will find it easier once SESAME is producing results.

5.2 Construction and Opening

Construction began with the installation of the massive concrete shielding walls that surround SESAME's accelerators, and fill much of the experimental hall, using funds from the Royal Court of Jordan. By November 2013, the ex-BESY 1 mictrotron, a relatively small device that provides the first stage of acceleration (through 22 MeV), had been refurbished, brought into operation, and installed in its final position. Installation of the refurbished BESSY 1 booster synchrotron, which accelerates the electron bunches up to 800 MeV, was well underway, but in December 2013 disaster struck when an unprecedented snowstorm (it even snowed in Cairo for the first time in 112 years) produced an accumulation of slush on the roof, which collapsed.

While time was spent debating who was responsible, and who would pay for a replacement roof, the SESAME staff – working under open skies – valiantly got on with the job, and in September 2014 a beam was stored in the booster and accelerated to 800 MeV, making the booster the then highest energy accelerator in the Middle East. By the time the new roof was fully in place, in March 2015, the first of 16 'cells' of the magnet system which is at the heart of SESAME's main ring had been built, using EU funding, and assembled for testing at CERN.

Thereafter installation of the components of the main ring and associated systems proceeded relatively smoothly, and was essentially complete by late 2016. On 11 January 2017, a beam was transferred from the booster and circulated in the main storage ring for the first time. By late April, the accelerating system was fully installed and a beam (albeit with a very modest current) was accelerated to the design energy of 2.5 GeV.

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[1] For a list of external contributors to SESAME see www.sesame.org.jo/sesame/images/News/SESAME-Opening/Souvenir_Booklet.pdf.

During 2016 we planned a major opening ceremony for May 2017, on the assumption that the machine would be working by then. On 16 May, His Majesty King Abdullah II of Jordan duly declared SESAME open, in the presence of the Directors General of CERN, IAEA and UNESCO, the European Commissioner for Research, Science and Innovation, senior representatives of the SESAME Members and Observers, visitors from round the world, and of course the SESAME staff and their spouses. Following a meeting of the Council the next day, I handed over as President to Rolf Heuer, another former Director General of CERN.

I had hoped that by the time of the opening, the first experiments would have begun, but installation of the initial beamlines (which are described in the next section) took longer than anticipated, although the scientific programme is now about to start. Since the full energy was reached in April, there have been some problems with the reliability of the machine. Just before this conference, however, a 40 mA beam was accelerated to 2.5 GeV (much less than the ultimate/design current of 400 mA, but enough to allow experiments to begin) and stored for three hours (the current then fell to 20 mA, which was stored for another three hours). Light was sent down the first beamline for the first time shortly after the Amaldi Conference.

6 Science at SESAME

Synchrotron light sources are equipped with 'beamlines' which focus the light on samples that scientists wish to study. Each beamline can support several experiments in series and in parallel. Initially, SESAME will have just two beamlines, which are described below: an X-Ray Absorption Fine Structure/X-Ray Fluorescence (XAFS/XRF) spectroscopy beamline, which is currently being commissioned, and an Infrared (IR) spectroscopy beamline, which is expected to come into operation around the end of this year. A Materials Science (MS) beamline (for studying disordered/amorphous material on the atomic scale and the evolution of nano-scale structures and materials in extreme conditions of pressure and temperature) is expected to come into operation in 2018. It is based on high quality components that were donated by the Swiss Light Source, which also donated a wiggler which will be associated with this beamline. A Macromolecular Crystallography (MX) beamline (which, combined with a protein expression/crystallization facility for structural molecular biology, will be used to elucidating the mechanisms of proteins at the atomic level and providing guidelines for developing new drugs) should become operational in 2019. The MX beamline is a new beamline constructed in part with funds provided by Jordan's Scientific Research Support Fund. In Phase 1, three more beamlines will be built once funding is available: it currently seems likely that the European Union will fund one of them.

The XAFS/XRF beamline, which is based on components of a beamline previously in use at the European Synchrotron Radiation Facility, will be equipped with an advanced detector, generously contributed by Italy, that will have a sensitivity at least 50 times higher than existing detectors and an unprecedented dynamic range. This beamline will have applications in basic materials science, life sciences, and environmental science on the nano-and micro-metre scale. Some research undertaken by scientists from the region at synchrotrons in Europe is expected to continue at SESAME. Examples with regional relevance include a study of absorption and mobility of heavy metals in soils in the vicinity of the Jordan and

Yarmouk rivers, tracking air and soil pollution in some Arab regions, and studies of metal storage and balance in wheat (which uncovered the origin of the efficacy of zinc-based fertilisers, and of the deleterious effects of cadmium in the soil).

Topics that can be studied at the IR beamline, which is a new beamline constructed in collaboration with the Soleil Synchrotron, include surface and materials science, biochemistry, microanalysis, archaeology, geology, cell biology, biomedical diagnostics, and environmental science. In 2014, SESAME purchased a Fourier Transform Infrared microscope which (pending the availability of a very much more intense beam generated by SESAME) has been used with a thermal source of infrared radiation. The first experiments included a study of breast cancer by Fatemeh Elmi (from the University of Mazandaran in Iran), and a study of the effect of a medicinal oil (now published, with Randa Mansour, a PhD student in the Faculty of Pharmacy, University of Jordan, as first author). Further medical work at SESAME is expected to include investigation of a hepatitis C genotype that is prevalent in the Middle East.

SESAME put out a call for proposals to carry out experiments at the XAFS/XRF and IR beamlines in early 2017. Fifty-five were received, demonstrating a clear need for SESAME.

7 SESAME’s Training Programme

The process of training scientists and engineers from the region in the use of synchrotron radiation and relevant accelerator technology began soon after SESAME came into existence. Support for training has been received from Brazil, Canada, China, France, Germany, Italy, Japan, Portugal, Spain, Sweden, Switzerland, UK, USA, EU, IAEA, ICTP, and UNESCO (see the link in footnote 1 for a list of the organisations that have helped SESAME). To date, SESAME has organised some 30 workshops and schools in the Middle East and elsewhere. These meetings, which have attracted some 750 scientists and engineers, have focussed on applications of synchrotron radiation in biology, materials science and other fields, as well as on informatics (in six meetings organised with the Cyprus Institute in the framework of the EU-funded LinkSCEEM project) and accelerator technology.

In addition, the training programme has allowed approximately 105 young men and women to spend periods of up to two years working at synchrotron radiation facilities and other centres (mostly in Observer countries) in Europe, the USA, Asia and Latin America. This has provided them with first-hand experience and further swollen the ranks of Middle Eastern scientists with experience in using synchrotron radiation sources. In addition to offering training opportunities, scientists from the world’s synchrotron laboratories have generously provided invaluable advice as visitors and as members of SESAME’s Advisory Committees, while representatives of the Observers have shared their wisdom with the Council.

On-going support for training, from the IAEA and others, will be further strengthened by the OPEN SESAME project, funded by the European Union. Its three key objectives are to: train SESAME staff in storage ring and beamline instrumentation technology, research techniques and administration for optimal use of a modern light source facility; build-up human capacity in the Middle East and neighbouring regions to make optimal use of SESAME’s infrastructure; train SESAME staff and its user community in public outreach and corporate communications; and to support SESAME and its stakeholders in building awareness and demonstrating its socio-economic impact to assure longer-term success.

8 Powering SESAME

When fully operational (5000 hours/year) SESAME will consume 10 GWh/year of electrical power, which (at the price of $375/MWh which the laboratory is currently paying) would lead to an annual bill of $3.75 million. This would roughly double the annual budget, which many of the Members are already struggling to pay. Contemplating this prospect, it became clear that construction of a Solar Power Plant (SPP) would be necessary to ensure the sustainability of the project. The conditions near Amman are favourable, a suitable site was made available by the Jordan Atomic Energy Commission, and agreement was reached with the grid to provide SESAME (when needed) with the same amount of power that SESAME's SPP will feed into the grid.

SESAME was thinking of a build, operate, transfer contract for the SPP, when the Government of Jordan generously agreed to transfer to SESAME part of funds provided by the EU (for carbon emissions reduction in neighbourhood countries) for the construction of the SPP. Consequently, power will be almost free when the SPP comes into operation in mid-2018. This will not only put SESAME on a sustainable basis, but will make it the world's first accelerator powered entirely by renewable energy.

9 Conclusions and Outlook

SESAME has overcome many challenges. Most were financial, although some (such as the perennial question of the name under which Palestinians participate) were political, and one (the collapse of the roof) was natural. Construction has taken longer than hoped because of lack of funding (the Strategic Plan adopted in 2009 asserted that SESAME could be in operation in 2014 with three beamlines if sufficient funds became available when needed). However, the design energy has now been reached, experiments are about to begin at the first two beamlines, and - in parallel with construction - the training programme has strengthened scientific and technical capacity in the region. Meanwhile construction of the Solar Power Plant will prevent the budget rising to an unaffordable level, thereby putting SESAME on a sustainable basis, and provide an example for accelerators elsewhere.

In addition to dealing with on-going problems generated by the political situation in the region, such as travel restrictions which have made it impossible for most of the Members to host Council meetings, SESAME faces three immediate challenges. The first is to find the funding needed to complete the proposed suite of seven 'Phase 1' beamlines (as stated in section 6, it currently looks as if the EU may fund one of them), and (perhaps more urgently) provide additional supporting infrastructure, including laboratories and properly equipped workshops. The second is to find a means for Iran to pay, which has been impossible since sanctions began. The third is to attract new Members, which SESAME has always sought in order to spread the benefits more widely. The political complexion of SESAME, coupled with scepticism that SESAME would ever work, has made it difficult to attract new Members, but with SESAME in operation, and potentially large rises in annual contributions now capped by the construction of the SPP, the situation has changed, and the time has come for vigorous efforts to increase the number of Members.

In the not too distant future, SESAME will have to be equipped with a 2.5 GeV injector in order to remain competitive with other light sources, where full energy injection is becoming increasingly common. Such injectors allow the beam current, which would otherwise decay with time, to be topped up so that the intensity of the synchrotron light remains constant in time, allowing experiments to be performed more rapidly (and making the whole system easier to operate as the conditions remain constant). This will be an expensive undertaking, for which (as agreed at the last Council meeting that I chaired) SESAME needs to begin planning now.

SESAME also needs to find funds to build a conference centre. When SESAME is not in operation, and the conference centre and guest house (which is now being built, funded by Italy; there is already a small temporary guest house which will be able to accommodate the relatively small number of initial SESAME users meanwhile) are not in use, they can be used to house international meetings on other topics of regional interest (related to agriculture, water, archaeology, etc.) in secure easily accessible surroundings, in a country that is open to visitors from across the region. It is my dream that this will lead to the creation of other regional collaborations and facilities, just as CERN led to the creation of other joint European scientific centres.

Meanwhile SESAME is building scientific and technical capacity in the region, and will soon be producing results, some of immediate regional impact for the environment and health. It is already a working example of Arab-Israeli-Iranian-Turkish-Cypriot-Pakistani collaboration. Senior scientists and administrators from the region are working together to govern SESAME through the Council, with input from scientists from around the world through its Advisory Committees. Young and senior scientists from the region who have been collaborating in preparing the scientific programme (at Users' Meetings and Workshops) will soon be collaborating in experiments at SESAME.

On several occasions since I became involved, the future of the project was in doubt, but we soldiered on and the construction of SESAME has been a victory of optimism over scepticism and realism. I would like to leave the last word to some scientists who will use SESAME, which they expressed in a short 2012 BBC film that can be seen at http://www.bbc.co.uk/news/science-environment-20447422, and in contributions to a (now in other ways out-of-date) brochure http://mag.digitalpc.co.uk/fvx/iop/esrf/sesamepeople (further information about SESAME can be found at www.sesame.org.jo). Their enthusiasm makes me confident that the future of SESAME is secure.