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SESAME: A Beacon of Light in the Middle East

Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME) is a third-generation light source operated as an intergovernmental organization in Jordan. It is the only major scientific research facility in the world to be powered entirely by renewable energy. Inaugurated in 2017, it has been producing world class science since 2018. Such a facility does not come into being overnight. SESAME is the result of decades of sustained effort and a shared belief that science can play an important role in stimulating international collaboration. This is the story of SESAME, an overview of the laboratory today, and a look to the future as it moves toward realizing its full potential. From the start, SESAME has relied on the unremitting support of its members, currently Cyprus, Egypt, Iran, Israel, Jordan, Pakistan,[1] Palestine, and Türkiye, as well as backing from countries and institutions around the world[2] who have the status of observer.

The SESAME Story

The need for an international synchrotron light source in the Middle East was recognized by eminent scientists such as the Pakistani Nobel Laureate Professor Abdus Salam as early as the 1980s. The potential for such a facility was also recognized by CERN and the Middle East Scientific Cooperation (MESC) group, headed by Italian theoretical physicist Sergio Fubini. MESC's efforts began to take root in 1995 with the organization of a meeting in the Egyptian Red Sea resort of Dahab, at which Egyptian and Israeli officials took an official stand in support of Arab–Israeli cooperation in science.

Two years later, when the BESSY I facility in Berlin was scheduled to be decommissioned, a proposal was put forward for it to be used as the basis of a new light source in the Middle East. The German government agreed, provided that the cost of dismantling and transport could be covered.

This set in motion a chain of events that led to a meeting at the United Nations Educational, Scientific and Cultural Organization (UNESCO)'s Paris headquarters in 1999, at which an interim SESAME Council was established. Soon after, Jordan was selected to host the new facility following a competition with five other countries from the region. Jordan provided the land, as well as funds for the construction of a building to house the new laboratory.

In May 2002, the executive board of UNESCO unanimously approved the establishment of SESAME under the auspices of UNESCO, which is the repository of SESAME's statutes. The center formally came into existence in April 2004 when sufficient members had informed the director-general of UNESCO of their decision to join.

In the same year, the idea of rebuilding and upgrading BESSY I was abandoned in favor of building a completely new 2.5 GeV main storage ring with straight sections that could accommodate insertion devices, thereby making SESAME a world-class third-generation light source. Under this plan, some of the BESSY I components would be repurposed as an injector for the new ring. A groundbreaking ceremony was held in January 2003 in the presence of HM King Abdullah II of Jordan and Koïchiro Matsuura, then director-general of UNESCO, and the SESAME building was formally opened on 3 November 2008.

Funding has been a constant challenge for SESAME from the start. A major milestone was reached in March 2012, however, when Iran, Israel, Jordan, and Türkiye committed to pledge voluntary contributions of US$5 million each to SESAME's capital budget. Although Iran has not yet been able to fulfill its promise, this demonstration of commitment by the SESAME members encouraged the EU to decide in 2013 to provide an additional €5 million to CERN through the CERN-EC Support for SESAME Magnets project to design and to procure, in close collaboration with SESAME, the components of the magnetic system for the new storage ring. Similarly encouraged by the commitment of SESAME's members, Italy provided €1 million in 2014 to procure accelerating cavities.

This investment proved sufficient to bring SESAME into operation. The laboratory was formally opened at a ceremony on 16 May 2017 (appropriately enough, the International Day of Light). Over the following months, the first two beam-lines were commissioned and brought into operation. SESAME's first call for proposals attracted 55 submissions, of which 19 were allocated beam time. The first users came to SESAME in July 2018, and SESAME's first peer-reviewed paper was published in June 2019. A second call for proposals in late 2018

1. Pakistan has indicated its inclination to leave the organization.
2. SESAME's current observers are Brazil, Canada, China (People's Republic of), the European Organization for Nuclear Research (CERN), the European Union (EU), France, Germany, Greece, Italy, Japan, Kuwait, Portugal, Russian Federation, Spain, Sweden, Switzerland, the United Arab Emirates, the United Kingdom, and the United States of America.

resulted in over 100 submissions. Today, SESAME has five operational beam-lines, with a sixth one soon to be commissioned.

Over the years, both the EU and European countries have proven to be among SESAME's staunchest supporters. The EU has continued to support SESAME through its framework programs for research; Germany, Switzerland, and the United Kingdom provided the majority of the components for SESAME beam-lines, together with Italy, which also contributed funds to build a guest house and meeting facility on the SESAME campus bearing the name of Sergio Fubini, an early proponent of the initiative.

In 2018, SESAME became the first associate of the League of European Accelerator-Based Photon Sources (LEAPS), a strategic consortium of leading synchrotron and free-electron laser facilities in Europe. This association marks SESAME's integration into the global synchrotron community and strengthens collaboration with European institutions. Through LEAPS, SESAME gains access to expertise, training, and joint initiatives, ensuring its continued advancement and reinforcing its role as a bridge between Middle Eastern and European scientific networks.

A Question of Dedication, Belief, and Good Fortune

As Egyptian and Israeli delegations sat down to discuss Middle Eastern scientific cooperation under the shade of a Bedouin tent in Dahab in 1995, a minor earthquake shook the ground beneath their feet. Years later, one of the leaders of the Israeli delegation, Eliezer Rabinovici, recalled this as the first of many trials that SESAME had to overcome on the way to becoming a reality. A theoretical physicist at the Hebrew University, Professor Rabinovici rarely misses the opportunity to give credit to the many people working in the administrations of SESAME's members and supporters whose names do not appear in any official histories, but without whom the SESAME dream could never have been realized.

The history of SESAME is marked by a spirit of indefatigability, a belief that such a facility could see the light of day, and by a fair dose of good fortune. When it became clear that Jordan was the right country to host the laboratory, the president of the interim council, Herwig Schopper, went to Amman to secure a commitment from the government. Help was to come in a surprising form. After failing to obtain a meeting at the right level of government, Schopper called a former student of his, Isa Khubeis, who had gone on to become a vice-president of a Jordanian University. During dinner at Khubeis' home, two other guests appeared, one a government minister, Khaled Toukan, who would go on to become director of SESAME, the other Prince Ghazi bin Muhammad. The following day, Schopper had an audience with the king, and he left Jordan with the written agreement he sought. "I often wonder whether SESAME would have succeeded without the help of my former student Isa, and the promise of King Abdullah II, which has been more than fulfilled," he later recalled.

This was a major milestone in SESAME's development, but there were still many hurdles to overcome, from financial to meteorological. In December 2013, Amman was hit by a particularly severe snowstorm, which led to the SESAME building's roof collapsing. This made the following year's successful commissioning of the injection system, made from BESSY I components, all the more remarkable. With nothing but an open sky above, the injection system was protected from the elements by plastic sheeting that was removed for operation. When the SESAME booster synchrotron stored and accelerated a beam to its full energy of 800 MeV in September 2014, becoming the highest energy accelerator in the Middle East, it did so as the world's only open-air particle accelerator.

A Sustainable Research Facility

Today, SESAME operates under a new roof, safe from the elements. The snowstorm that brought down the original roof was an anomaly, and today Jordan's climate has been harnessed to support the laboratory. Whereas particle accelerators are big users of electricity, Jordan's sunny climate has the capacity to be a significant supplier, and a plan was hatched to build a solar power plant to furnish the laboratory's needs. In 2016, the Jordanian government agreed to provide SESAME with 5 million Jordanian dinars from funds provided by the EU to support the deployment of clean energy sources. When its solar power plant came into operation in February 2019, SESAME became the first accelerator in the world to be powered entirely by renewable energy, and it remains so to this day.

The Machine and the Beam-Lines

The SESAME accelerator chain (see Figure 1) consists of three machines, two repurposed from the donated BESSY I synchrotron, and the third a new storage ring built in collaboration between SESAME and CERN with capital funding from three members (Israel, Jordan, and Türkiye) and from the European Union's seventh framework program.

The start of the chain is the original 20 MeV microtron that supplied beams for BESSY I, and the second stage is an 800 MeV ring assembled from BESSY I components. These are situ-

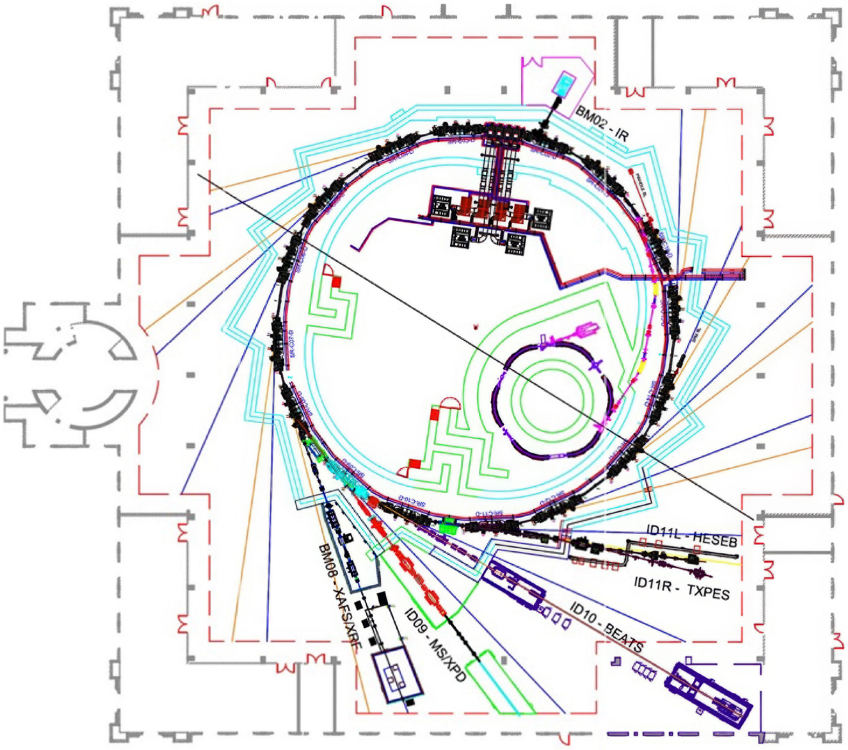

Figure 1. *SESAME layout.*

ated inside the main ring, providing beams that circulate in an anticlockwise direction.

The main ring is based on a periodic cell structure, with each cell consisting of a bending dipole magnet accompanied by focusing quadrupoles and sextupoles. The full SESAME lattice consists of 16 such cells, interspersed with straight sections that can accommodate insertion devices (see Figure 2). One of these is taken up by the machine's radio frequency acceleration system, consisting of four cavities. The SESAME main ring has an energy of 2.5 GeV and a design beam current of 400 mA. Its circumference is 133.2 meters, and its natural emittance 26 nm. rad. The machine's vacuum system maintains a very low pressure in the beam pipe of 10^{-9} mbar. Currently operating with a beam current of 300 mA, SESAME is achieving beam lifetimes of around 24 hours.

SESAME currently has five beam-lines in operation (see Figure 3), with one more soon to be commissioned and two in the design phase. It has a capacity for over 20.

The first two beam-lines, both commissioned in 2018, are the X-ray absorption fine structure/X-ray fluorescence (XAFS/XRF) spectroscopy beam-line and the infrared spectromiscroscopy (IR) beam-line. They each use one of SESAME's bending magnets as a source.

The XAFS/XRF beam-line for X-ray absorption and fluorescence studies is based on the Helmholtz Zentrum Dresden-Rossendorf beam-line, originally installed at the ESRF and donated by Germany. A state-of-the art multielement detector (Advanced X-ray PIxel Detector [AXPiDe]), developed by INFN and donated to SESAME, is available at XAFS/XRF for fluorescence analysis of diluted samples. It hosted its first users on 17 July 2018, leading to SESAME's first published peer-reviewed paper. Conducted by a team from Turkey, this looked at catalytic valorization of a biomass waste material, glycerol, with a view to obtaining synthetic liquid fuels. This beam-line has been used for a broad range of topical research, including new materials for batteries, catalysts, environmental pollution,

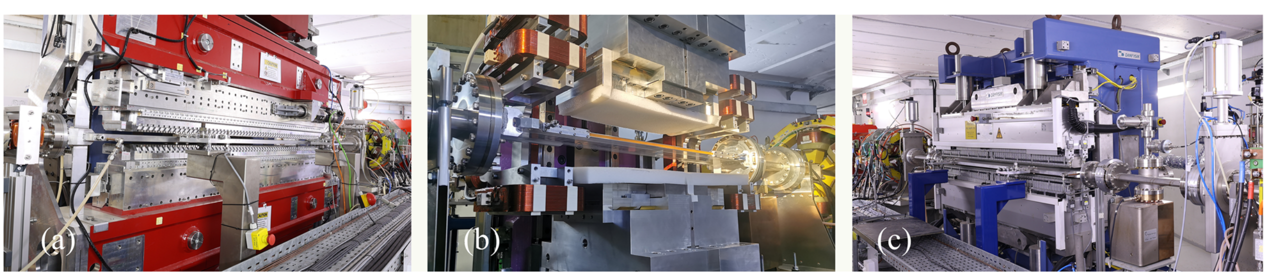

Figure 2. *The first three insertion devices installed on the SESAME storage ring. (a) the APPLE-II type undulator in section 11, (b) the 3-pole wiggler in section 10, and (c) the multipole wiggler in section 9. (Photo credits: a and c: Giorgio Precali; b: SESAME).*

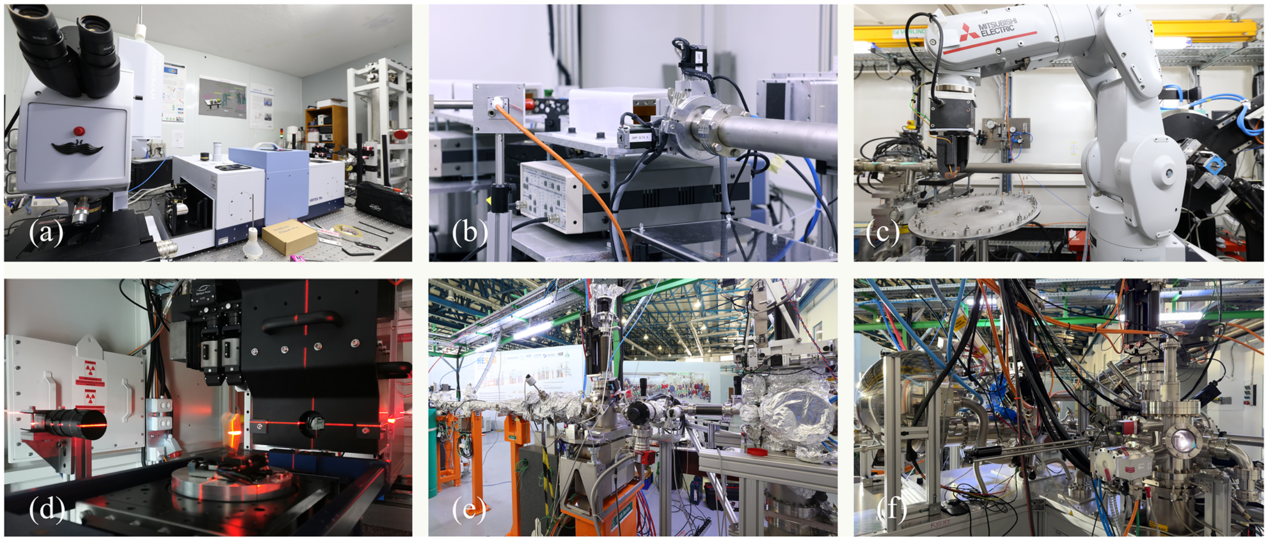

Figure 3. *Experimental setups at SESAME. (a) The IR microscope and the spectrometer at the BM02-IR beam-line; (b) the ionization chambers and the AXPiDe at the BM08-XAFS/XRF beam-line; (c) the sample changer and the powder diffractometer at the ID09-MS/XPD beam-line; (d) the sample stage and the detection setup at the ID10-BEATS beam-line; (e) the last focusing mirror and experimental chamber at the ID11L-HESEB beam-line; (6) the experimental station at the ID11R-TXPES beam-line—TXPES beam transportation components are expected in SESAME in spring 2025. (Photo credits: a, b, c, e: Giorgio Precali; d, f: SESAME).*

reporting scientific results in high-impact journals.

The BM02-IR microspectroscopy beam-line was built in cooperation with SOLEIL and hosts an IR microscope and spectrometer transferred to SESAME by INFN CHNet, Italy. It hosted its first users on 4 November 2018. It has carried out research in fields as diverse as medical research and cultural heritage. To cite just one, a study of ancient human teeth to investigate the uptake of copper from the time at which humans in the fertile crescent first took up metal working, has allowed the impact of such metals on the health of our ancestors to be investigated, with lessons to be learned for the modern age.

The Materials Science/X-Ray Powder Diffraction (ID09-MS/XPD) beam-line started hosting users on 17 December 2020. It uses a Pilatus 300K detector donated by the DECTRIS company mounted on a diffractometer donated by the Diamond Light Source, which also donated the new monochromator of the XAFS/XRF beam-line. This beam-line, along with the multipole wiggler that serves as its source, was donated by the Swiss Paul Scherrer Institute.

The BEAmline for Tomography at SESAME (ID10-BEATS), funded by the EU, along with the three-pole wiggler that serves as its source, hosted its first users on 11 February 2024. It enhances capabilities in microtomography, offering various operation modes and significant photon flux density for a broad spectrum of applications. A notable proof of principle experiment recently conducted by BEATS has shown that it will be possible literally to read ancient documents such as papyri that are too fragile to be unrolled.

The HElmholtz-SEsame Beamline (ID11L-HESEB), funded by five Helmholtz institutes, hosted its first users on 12 February. It provides soft X-ray analysis techniques to understand the atoms' electronic structure and chemical environment.

SESAME's next beam-line, the Turkish soft X-ray PhotoElectron Spectroscopy (TXPES) beam-line, will be the first to be constructed by a SESAME member. TXPES is funded and operated by a national consortium, ensuring dedicated access for its contributors. Scheduled for commissioning in 2025, part of the beam time will be reserved exclusively for users from Türkiye, reflecting its national investment and scientific priorities.

In parallel with the beam-lines, SESAME has developed the information technology (IT) infrastructure that ensures the efficient operation, data management, and accessibility of experimental results. As SESAME continues to expand its capabilities, such resilient, scalable, and secure IT infrastructure remains essential for enabling groundbreaking scientific discoveries across diverse disciplines.

A Very Versatile Scientific Infrastructure

SESAME has firmly established itself as a vital part of the global research landscape and is an invaluable asset providing a unique interdisciplinary research environment in the region to the user community with access to multiple high-level analytical techniques. The laboratory is widely expected to become a leading research facility on cultural heritage. SESAME scientists have a wealth of material to investigate from the laboratory's host region—the cradle of civilisation, spanning from the Fertile Crescent to the Indus Valley. Experiments have already shown their worth in the analysis of ancient human remains, as well as in the analysis of ancient artefacts and documents, enabling researchers to identify their provenance with pinpoint accuracy [1,2]. Future experiments will allow us to read the messages written on fragile scrolls, which have hitherto been inaccessible.

Cultural heritage, however, is just one area of research where SESAME is contributing. It has already made significant contributions to catalyst research, which is a major global activity, as catalysts are required for the synthesis of more than 80% of manufactured products, contributing to about 30–40% of the global Gross Domestic Product. A recent example of this is research contributing to the development of new catalysts that can replace expensive platinum-based materials for electrochemical fuel cells that offer a promising route to generating energy for the future.

Work performed at SESAME on the elucidation of the relationship between the structure of alternative catalysts and their function has led to several high-impact publications (e.g., Refs. [3–6]). In the fields of materials science and materials chemistry, continued development of battery technology is an area of research of the highest importance where research at SESAME has included studying so-called green synthesis coupled to the high specific capacity and rate capability of γ-Fe_2O_3/reduced graphene oxide nanocomposite as a potential anode material for sustainable Na-ion batteries [7]; improved performance in Li-ion cathode materials by doping with other elements [8] and [9]; investigation of the effect of Ni doping in $Na_{0.67}Mn_{0.5-x}Ni_xFe_{0.43}Ti_{0.07}O_2$ Na-ion cathode materials to understand the local geometry of the optimized cathode materials, in operando [10]. In the context of immediate societal benefits, a recent study identified magnetite as the main Fe-phase in the polluted topsoil adjacent to a steel factory near central Jordan so that remedial measures can be put in place [11].

Synchrotron-based techniques also help examine biological molecules, supporting drug development and medical diagnostics. Research at SESAME has contributed, for example, to exploring the properties of novel materials used in health applications and helping to understand better inflammatory breast cancer progression [1,12].

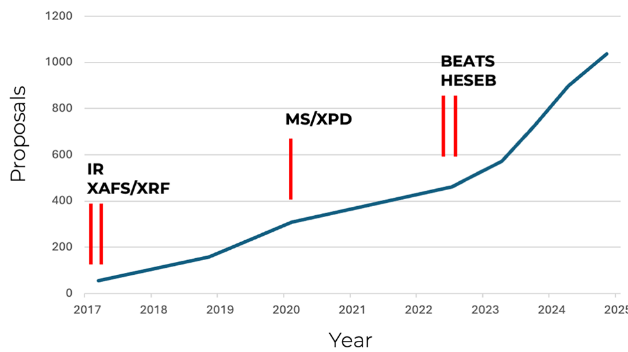

Figure 4. *The evolution of the experimental proposals received since the first call, which was closed in February 2017. The red vertical lines mark the dates when the different beam-lines were opened to users.*

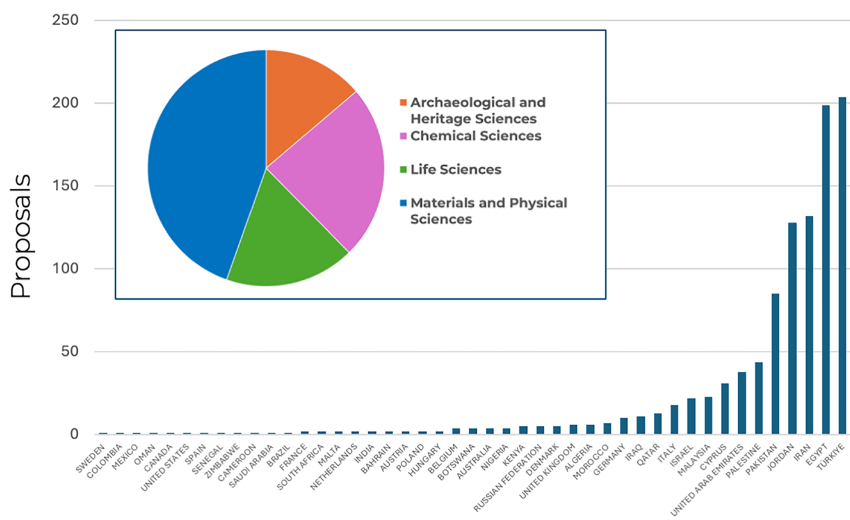

Figure 5. *Geographical distribution of SESAME beam time proposals. The inset shows how the proposals are distributed among different fields.*

Scientific demand for SESAME has been steadily increasing (see Figures 4 and 5) since the first call for proposals in 2016, which attracted 55 proposals. Initially the call for new proposals was once a year. This has now been increased to twice a year in line with most synchrotron centers around the world. Over the last eight years, including the COVID-affected years, 1,038 proposals have been received from 45 countries, with an average of around 150 proposals every six months in the recent rounds. These proposals are reviewed by the SESAME Peer Review Committee, which is made up of four subpanels of international experts representing key scientific areas, namely (1) chemical sciences, (2) materials and physical sciences, (3) life sciences, and (4) archaeological and cultural heritage. "The review process is rigorous like any other synchrotron centre and generally is able to award experimental time to 50–60% of the projects submitted," said Samar Hasnain, chair of SESAME's Programme Review Committee and professor of molecular biophysics at the University of Liverpool, United Kingdom:

> The quality of these approved projects is very high and of international standards. This is reflected in the high quality of international research publications resulting from the usage of SESAME. The number of publications has also increased, with a total number of publications reaching 133 as of 12 March 2025. These are clear evidence for SESAME's growing importance on the world stage contributing to scientific advances at the highest level (S. Hasnain, personal communication, March 3, 2025).

In addition to the scientific output (see Figure 6), SESAME and its expert staff, with the help of experienced users, have been engaged in capacity building that is resulting in a greater number of scientists trained in synchrotron radiation techniques. This is reflected in continuous improvement in the quality of proposals that are coming through to be assessed by the peer review committee.

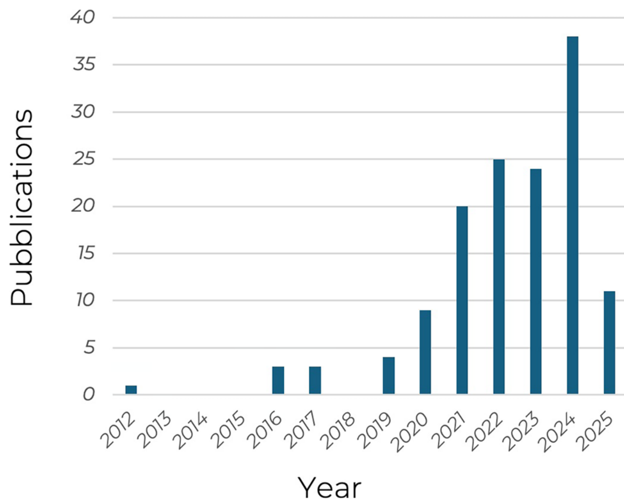

Figure 6. *SESAME publications over the years.*

SESAME's Expanding Role in Africa

Through the years of its construction, SESAME staff and future users benefited from extensive training, coming, for example, through the EU's OPEN SESAME project and the United Kingdom's Newton program. These provided vital expertise in synchrotron operation, beam-line instrumentation, research techniques, and science administration. Today, SESAME is transitioning from being a recipient of training to becoming a training center for the region and for Africa, reflecting the center's growing maturity as an international center of research excellence.

The EU-funded SUNSTONE project, which started in 2024 and will continue until the end of 2027, marks a significant step in this direction. Building on SESAME's expertise and in partnership with European and regional institutions, SUNSTONE ensures that regional as well as African researchers gain access to state-of-the-art synchrotron techniques, fostering cross-border collaborations and scientific advancement.

The possibility of establishing an African beam-line within the facility is being explored. A dedicated task force is looking at the feasibility of this, with the aim of providing African scientists with dedicated beam time and also fostering the growth of a synchrotron user community in Africa. If this goal is realized, it will play a significant role in integrating the African continent more deeply into the global synchrotron research community.

Conclusion

This laboratory profile has focused on the origins of SESAME and its science, but SESAME is more than just another synchrotron light source. It is also an excellent example for environmental sustainability because it is entirely powered by solar energy (see Figure 7). But first and foremost, it is a beacon of hope in a troubled region, and a tangible example of a different reality for the Middle East—a reality in which the people of the region work together for the common good, and for that of humanity as a whole.

Figure 7. *SESAME's solar plant. Photo credit: Noemi Caraban Gonzalez, CERN.*

Among the many strands that led to the establishment of SESAME is one that began in the CERN cafeteria, in a meeting between theoretical physicists Sergio Fubini and Eliezer Rabinovici. The story goes that the two of them were discussing the Middle East, and one pointed out to the other that the laboratory in which they were sitting, a world leader in its field, was established in the aftermath of World War II, not only as a center for scientific excellence in Europe, but also as a place where the formerly warring countries could work together for peaceful ends. If it worked in Europe, could the CERN model also work in the Middle East? So far, SESAME has proven that it can bring excellent science to the region. The second objective remains elusive, but there's no doubt that SESAME is a beacon of hope.

Acknowledgments

The performance and ongoing advancements of SESAME are largely attributable to the steadfast commitment and experience of its personnel, whose efforts guarantee the facility's smooth and effective operation. Their unwavering dedication has been essential in establishing SESAME as a premier scientific institution in the region. We express our sincere appreciation to the SESAME members for their ongoing support, and to the Observers, whose varied contributions are emphasized throughout this text. The solar plant is in particular essential to ensure the laboratory's sustainability both environmentally as well as economically.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

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