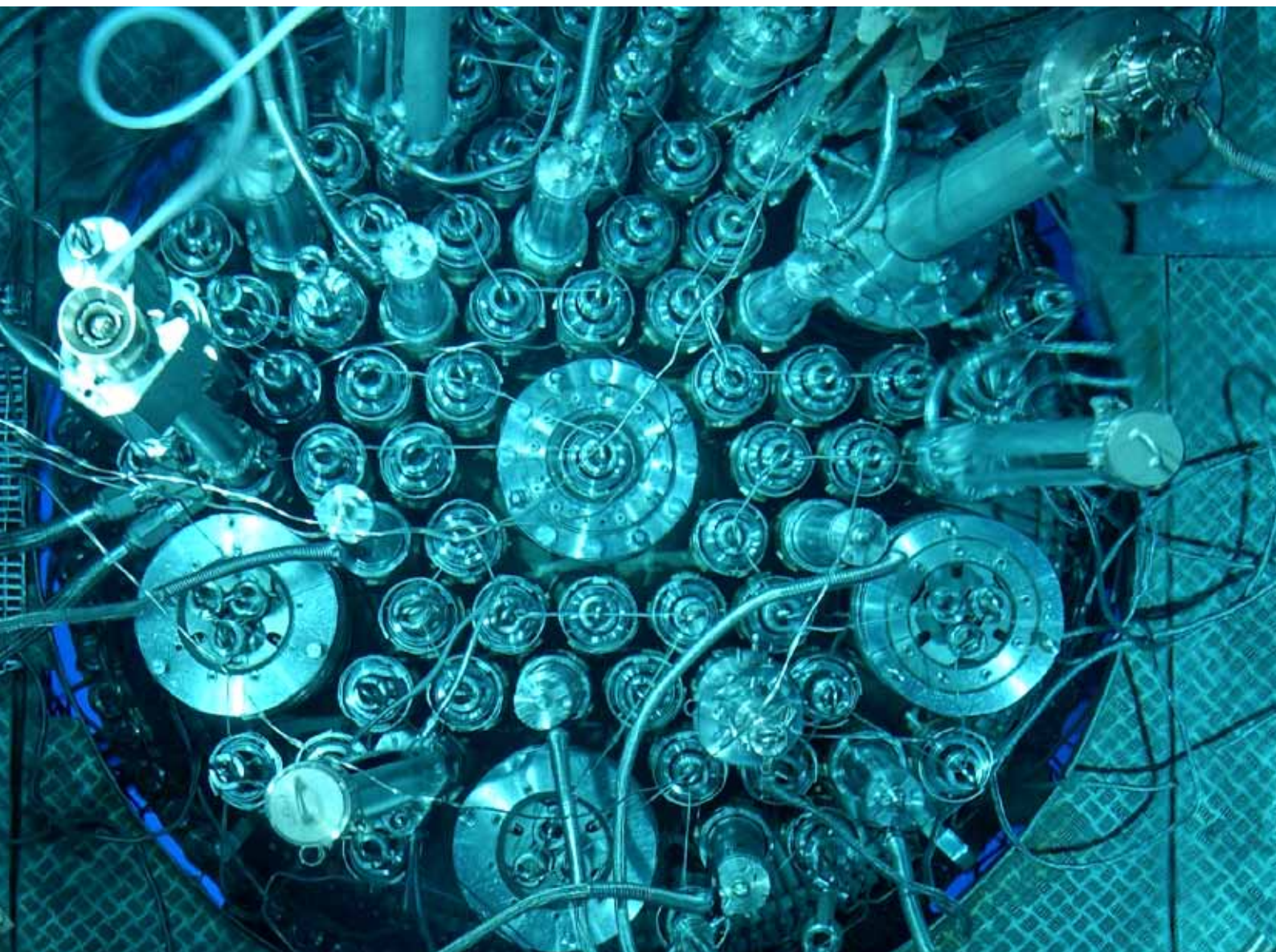


BR2

Research reactor with multiple applications



SOCKS GEN

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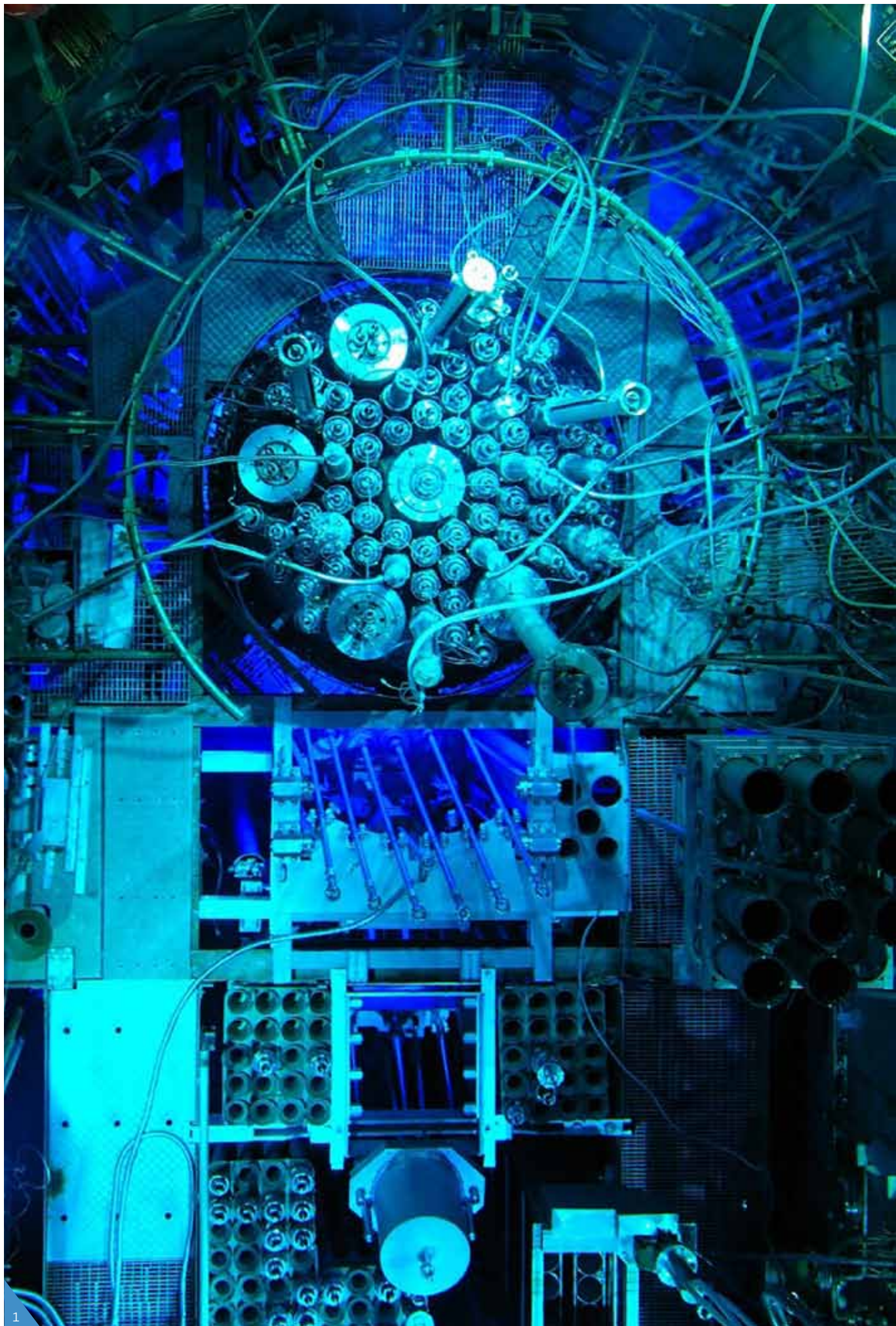
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Preface

▲ The BR2 materials testing reactor is one of the most powerful instruments for SCK•CEN. For decades, it has played an active role in our research and in the evolution of nuclear science and technology. That is why the BR2 enjoys an excellent international reputation.

Continuous modernisation of the infrastructure and the dedication of our qualified staff ensure that the BR2 is intensively used for the widest variety of purposes. Its socially relevant applications are part of our commitment to sustainable development.

The BR2 reactor is central in our research on the safety of existing nuclear power plants, the optimisation of the nuclear fuel cycle, and materials research for new reactor types and nuclear fusion.

In the BR2, we produce radioisotopes for purposes of research, diagnosis and therapy in nuclear medicine, as well as for industry and agriculture. The BR2 has also a special capability to irradiate silicon. This produces a high-quality semiconductor, a basic material for electronic components such as microchips.

Today, we are anticipating the future and are preparing ourselves for the period after the BR2. For this reason, SCK•CEN is working hard on developing MYRRHA, an innovative research facility that could replace the BR2.

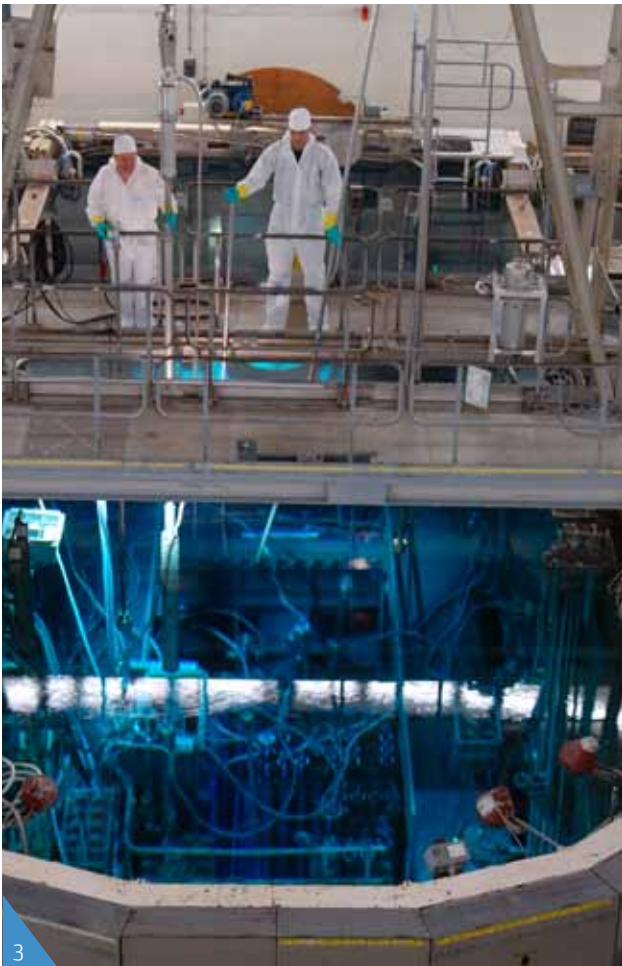
The history of the BR2 is more than a chronological ordering of events and developments. It provides us with expertise, insight, questions and answers that lead to new knowledge and challenges. I would therefore like to pay tribute to the many pioneers who achieved the full development of a technology, from the design stage to the construction and initial start-up stages. Thanks to their pioneering work, commitment, hopes and dreams, our employees are able to further develop, valorise and deploy SCK•CEN's expertise for everyone.

Happy reading.

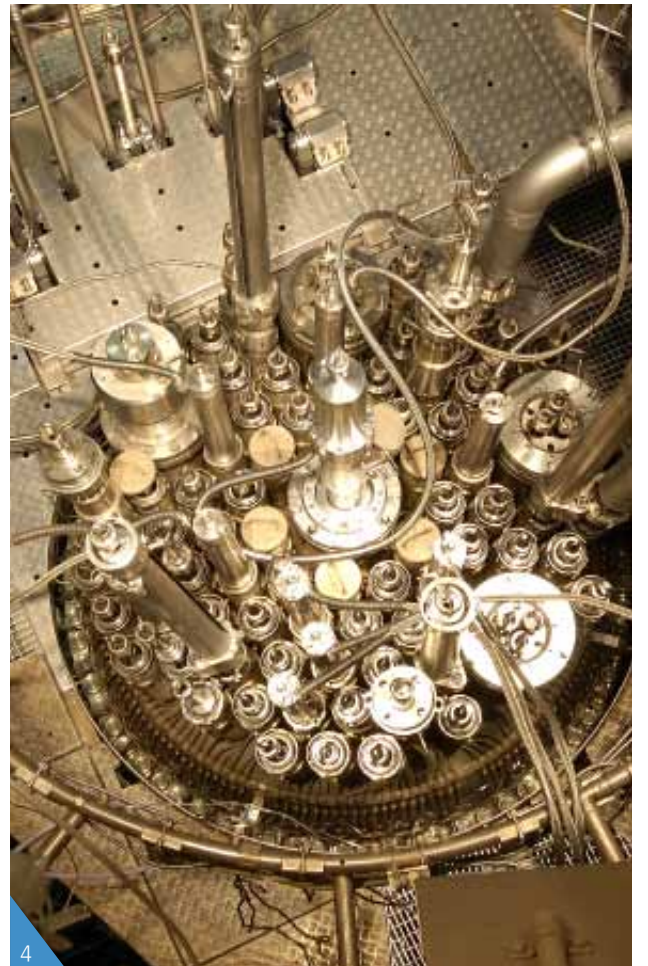
Eric van Walle
Director-General



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BR2: a powerful and flexible research reactor

▲ The BR2 or Belgian Reactor 2 is a materials testing reactor that is intensively used for diverse research purposes requiring a wide range of irradiation conditions. Neutrons released by nuclear fission are used to perform experiments, to produce radioisotopes and irradiate silicon. We perform material and nuclear fuel tests in the BR2 for various types of reactors in the world and for the European nuclear fusion programme. The reactor is not intended to generate electricity.

The BR2 differs in many ways from pressurized water reactors that are used in many nuclear power plants. The operating temperature (40 °C instead of 300 °C) and pressure (12 bar versus 155 bar) are much lower, which offers major safety advantages.

The core in the reactor vessel also looks quite different. The central part of the BR2 consists of a beryllium matrix composed of 79 hexagonal channels containing the nuclear fuel elements, the control rods and various experiments and plugs. Together they form the heart of the reactor. Although the power and volume (about 1 m³) of the core are 30 times smaller, the BR2 produces a neutron density of 20 times higher than a power reactor.

The BR2 reactor operates according to a scheme of successive irradiation cycles of three to four weeks, with interim maintenance periods

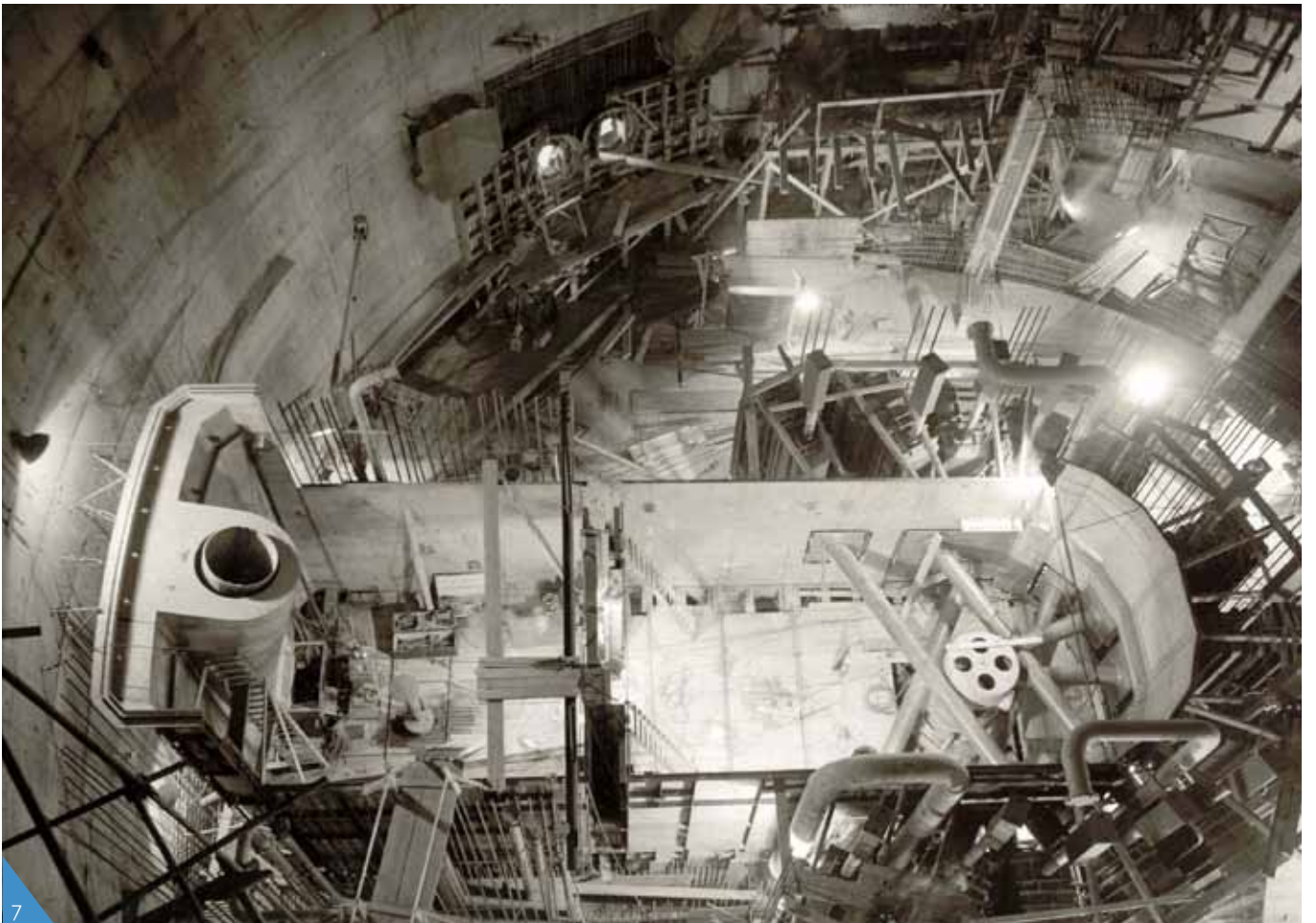
Safety comes first

The BR2 is completely submerged in water in the reactor dock. Due to the concept of the reactor, the safety system is largely passive. The nuclear fission reaction is stopped automatically if an incident occurs. After this, the nuclear fuel elements are cooled by natural circulation of the water without the need for cooling pumps. Because the reactor vessel is under water, the radiation is shielded from the environment; the water also serves as an additional buffer against radioactive releases in the unlikely event of damage occurring to the nuclear fuel.

At SCK•CEN, regular maintenance checks are an inseparable part of operating all nuclear facilities, including the BR2. Continuous innovations keep the reactor in line with the latest advances in technology.

Every ten years an inspection in connection with the review of the nuclear license by the Federal Agency for Nuclear Control (FANC) takes place. Apart from this, SCK•CEN closely tracks the condition of the various BR2 components. Thus for example, during the last decade several upgrades and improvements were implemented in fire prevention, instrumentation of the primary coolant loop, and the control rods. Also in the future, continuous investments in security measures are planned.

- 2 *The reactor building and cooling towers*
- 3 *Loading of an experiment during reactor operation*
- 4 *The reactor lid accessible during shutdown*



Milestones: the unfinished past

History is not always simple, and the history of SCK•CEN is no exception. Our chapters are written by outstanding scientists, technicians and support staff, closely associated with the development of nuclear energy. We have undergone a dramatic evolution and extraordinary growth since our inception in 1952.

As the common thread through the years, SCK•CEN has always striven to provide added value to our society. Even today, we are searching for sustainable solutions to issues that our society is facing now and shall face in the future.

The story of the BR2 reactor commenced in 1956, and the end is a long way off.

1956

In the mid-50s, SCK•CEN decided to construct a materials testing reactor (MTR). In 1956, the concept was entrusted to the U.S. study agency Nuclear Development Corporation in White Plains (New York, USA). Staff of SCK•CEN, engineers from industry, research agencies and power generation companies took part in the studies. Construction started in September of the same year.

1958

At the World Exhibition in Brussels, the Belgian Association for the Peaceful Development of the Atomic Energy organised an exhibition in the lowest sphere of the Atomium. The exhibition grouped the main Belgian and Congolese institutions that were interested in nuclear energy. SCK•CEN was also represented. As stated at the exhibition stand, the intention was to discuss the “immense opportunities arising from the splitting of the atom, and the wonderful horizons that it opens up for the welfare of mankind and for a better standard of living”. On that occasion, SCK•CEN also displayed the scale model of the BR2, of the reactor core of the BR3 (Belgian Reactor 3), and an operational cell in which radioactive iodine was produced. Visitors were also shown designs and models, along with information concerning the achievements of SCK•CEN.

1959

A full-size model of the core, BR02, was put into operation in 1959. This model made it possible to investigate how the fissile material could be loaded into the BR2 reactor in the most optimal way.

1961

SCK•CEN officially commissioned the reactor on 6th July, 1961. The then Prime Minister, the President of Euratom, the U.S. ambassador and a representative from the Ministry of Economic Affairs, attended the launch of the BR2. The reactor was further tested until the end of 1962, and in January 1963, the BR2 became fully operational.

5 Scale model displayed during the World Exhibition of 1958

6 Construction of the dome in 1959

7 Construction of the reactor dock in 1960



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The 60s

The operation of the BR2 commenced on the basis of a convention concluded in 1960 between SCK•CEN and the then European Atomic Energy Community or Euratom for short (the Joint Research Centre – JRC of today).

The BR2 reactor was recognised as a unique test reactor in Europe. As a result, SCK•CEN was able to provide other member states with scientific information concerning the qualification of nuclear fuel and materials.

The BR2 reactor was the cradle of the nuclear research programmes of the European Commission (the later “Framework Programmes”) and of many nuclear projects in the European Community countries, and later on of Japan as well.

The convention provided for an integrated cooperation, from the joint investments in the BR2, up to the joint operation. Between 1960 and 1967, the two institutions divided the investment and operating costs in the ratio of 1/3 by SCK•CEN and 2/3 by Euratom. There was a transition regime between 1968 and 1972, although many European programmes were still conducted in the BR2. A new agreement came into force between SCK•CEN and Euratom from 1973 to 1980, under which Euratom personnel were made available to SCK•CEN.

Since 1967, the BR2 was also gradually used for the development of reactor systems with gas and sodium cooling, in cooperation with Germany, the United Kingdom and France. In December 1968, SCK•CEN signed an agreement with GfK, Gesellschaft für Kernforschung mbH (Society for Nuclear Research), in Karlsruhe. Under this agreement, Belgium, Euratom, the Centres in Karlsruhe and Jülich and other German partners were able to make equal use of the BR2 reactor. This was part of the political agreements between Germany, Belgium, the Netherlands and the Grand Duchy of Luxembourg, concerning research into fast reactors. The partners repeatedly renewed the agreement.

The 70s

During a camera inspection in 1974, various cracks were discovered in the beryllium matrix in the central part of the reactor. The cracks were caused due to the breaking up of beryllium that expanded due to gas formation following neutron irradiation. SCK•CEN decided to replace the matrix, since only this would guarantee the continuation of operations. The replacement work took from January 1978 to early 1980.

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- 8 *Finishing of the ventilation building, the dome and cooling towers*
 - 9 *Installation of the reactor vessel in 1960*
 - 10 *Replacement of beryllium matrix*



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The 80s

In the 1980s work was mainly continued on fast reactor technology. The 1968 agreement between Germany, Belgium, the Netherlands, and the Grand Duchy of Luxembourg was definitively terminated in 1982. SCK•CEN continued its cooperation with the Centre in Karlsruhe up to 1989, for the development of the fast breeder reactor in Kalkar (Germany). Important tests in this context were the “Mol 7C” experiments, in which the behaviour of fuel rods in case of an accident was simulated. Cooperation on fusion research is still ongoing. In the meantime, the use of the BR2 for our own research was continued.

After the shutdown of SCK•CEN’s BR3 reactor, BR2 provided the continuity of research programmes on pressurized water reactor fuel. This was established through an intense collaboration between SCK•CEN and Belgonucleaire, resulting in the construction of the CALLISTO loop. This loop simulates pressurized water reactor conditions in BR2 and is used till present days in national and international research programmes.

The 90s

In the 1990s, SCK•CEN drew up a list of all critical systems and facilities concerning the BR2 with a view to examining them in more detail. There was a specific focus on safety, performance, aging and reliability. During this period, a programme was also started for monitoring the degradation of the reactor vessel.

Between 1995 and 1997, the BR2 was renovated for the second time. The beryllium matrix had to be rebuilt again in order to extend the operability of the reactor by several decades. The instrumentation and control rooms of the reactor were also considerably improved and modernised. SCK•CEN could restart the reactor in April 1997 within the specified time and the budget provided.

In 1999, an INSARR inspection was conducted. INSARR stands for ‘Integrated Safety Assessment of Research Reactors’. This is a service offered by the International Agency for Atomic Energy (IAEA) to Member States to check whether a research reactor is being operated according to international safety standards. After the analysis, SCK•CEN was awarded a positive report.

11 Detail of the control room

12 Assembly and inspection of the reactor prior to starting



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A reactor with multiple applications

There are various irradiation opportunities in the BR2, and orders are received from customers from around the world. Through cooperation with other research groups at SCK•CEN, irradiation experiments can be conducted from the concept stage to the post-irradiation examination on the same site. The reactor also contributes actively to the development of nuclear science and technology.

The BR2 reactor is mainly used for:

- Materials research
- Nuclear fuel research
- Production of doped silicon
- Production of radioisotopes

Materials research

Certain structural materials that are part of reactors are exposed to intense neutron irradiation, which can weaken the material. This may pose a risk to the safe operation of nuclear reactors. SCK•CEN utilises the BR2 and the LHMA laboratory (Laboratory for High and Medium Activity with specially protected cells or hot cells) for tests to reliably estimate the evolution of material properties under irradiation, and to ensure the safety of the reactor operation. Due to the BR2's high neutron flux density, the properties of materials that would otherwise occur after a lifetime in power generating reactors, can be evaluated at a greatly accelerated rate. Thereby, their behaviour can be predicted empirically decades before their theoretical life expectancy so that their 'safe lifetime' can confidently be predetermined.

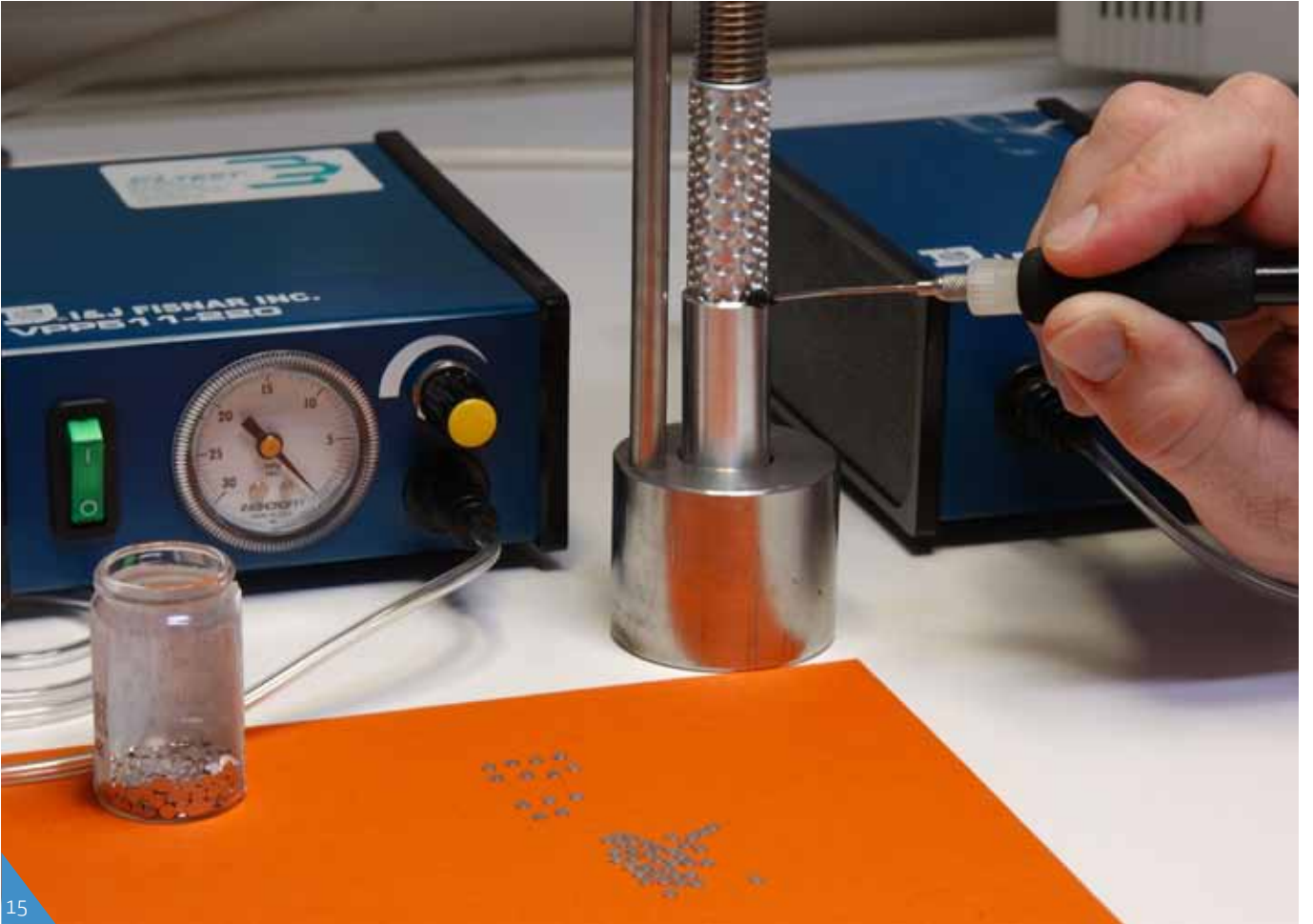
Nuclear fuel research

Due to its flexibility, the BR2 reactor is excellently suited to test nuclear fuels for various reactor types. Thus, in the past, experiments were conducted on nuclear fuel for the sodium- and gas-cooled fast reactors and the high temperature reactors.

Currently, research mainly focuses on studying the safety margins for nuclear fuel in pressurized water reactors, and to develop new nuclear fuels that generate less plutonium and other heavy radioactive isotopes. BR2 also plays a key role in the realisation of new types of nuclear fuel for existing and future research reactors.

Production of doped silicon

In the SIDONIE installation of the BR2 reactor, SCK•CEN irradiates silicon so that a high-quality semiconductor emerges. This is the basic material for electronic components such as microchips. In order to obtain semiconductors, phosphorus must be placed in the silicon material. This can be done using a chemical process, but neutron irradiation results in a much higher quality, and it also becomes possible to use larger silicon crystals. This irradiated end product, which is not itself radioactive, is called neutron-doped silicon. Among other things, it is used in advanced microelectronics applications, hybrid cars, electric locomotives, power generating wind turbines and solar panel components. Recently, SCK•CEN equipped the BR2 with an additional facility, the POSEIDON installation, that allows even larger crystals of silicon to be irradiated.



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Production of radioisotopes

It is impossible to imagine the medical world today without radioisotopes, and due to the rapid technological advances in nuclear medicine, their use is still on the rise. Worldwide, 30 to 40 million annual medical examinations and treatments are performed using radioisotopes, of which 9 million are in Europe. The radioisotope technetium-99m is used in 80 percent of these cases. However, there are many steps in the preparation of this radioisotope before it is ready for use in medical applications. The first stage in this process is the irradiation of uranium targets in a nuclear research reactor. The radioisotope molybdenum-99 is recovered and purified from these targets. This is the basis for the preparation of the radiopharmaceutical end product. Other radioisotopes again, are used in industry for inspection of welds and sterilisation of food.

Worldwide, the radioisotope molybdenum-99 is primarily produced in five research reactors, including the BR2 of SCK•CEN. With these five reactors, it is barely possible to meet the global demand. Some are occasionally shut down for maintenance or repairs. SCK•CEN has therefore decided to increase the production capacity if so required. This flexibility is necessary since it is not possible to generate stocks in view of the short life of the most widely used radioisotopes. There must therefore always be a balance between supply and demand. Increasing production capacity is being done with the consent of European partners who handle irradiated uranium targets.

The BR2 is responsible for 20 to 25 percent of the annual production of radioisotopes world-wide. This can be increased to 65 percent on a weekly basis.

Training

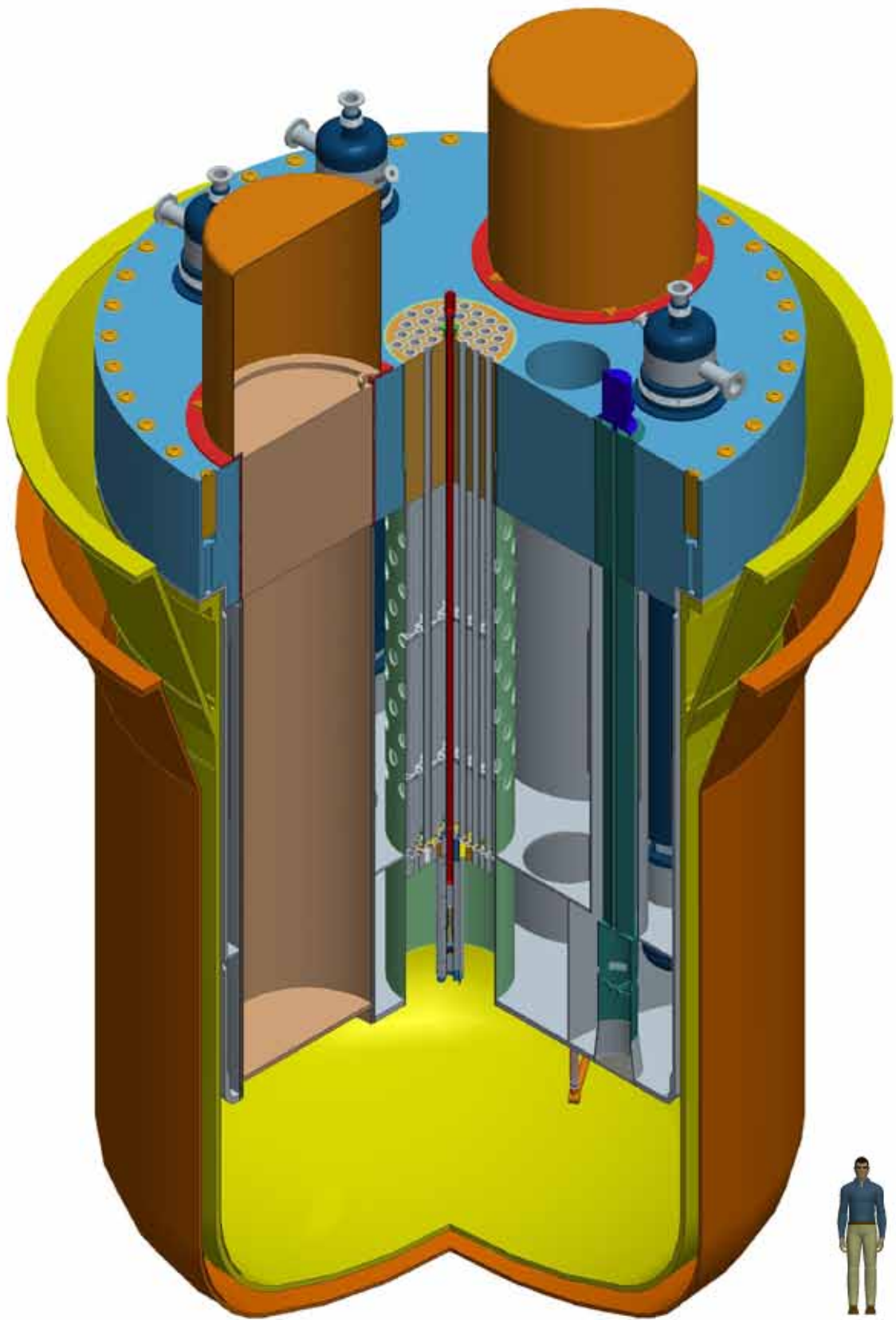
Like all collaborators of SCK•CEN, our reactor pilots and other BR2 staff follow regularly thorough theoretical and practical training, including internships in foreign research reactors. These courses optimize the skills of the employees and the general functioning in the workplace. This also contributes to the safety of the operation and the creativity of the researchers and technicians on the tests and studies.

Besides research institution, SCK•CEN is also a renowned training centre. In this context, the BR2 is an important tool: a number of Belgian and foreign PhD and Master students are studying materials, which have been irradiated in the BR2. The reactor can also be visited by university students and trainees from the nuclear and medical sectors.

Quality certificate

Since 2001, the BR2 has a quality certificate "EN ISO 9001" for the production of radioisotopes and the irradiation of silicon.

15 Preparation for the production of radioisotopes
16 POSEIDON facility for irradiation of silicon



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Collaborations & Future prospects

Collaborations

SCK•CEN carries out the irradiations in the BR2 at the request or with the help of third parties such as the European Commission, the International Agency for Atomic Energy (IAEA), Belgian and foreign nuclear power plants, manufacturers of nuclear reactors and nuclear fuel, suppliers of radioisotopes, Belgian and foreign universities.

Irradiation programmes are conducted either on the basis of trade cooperation (for example, radioisotope production, nuclear fuel qualification, etc.) or as part of joint projects, which, among others, form part of the Belgian contribution to several European research programmes. They ensure that Belgium has a visible presence on the international scene and in the development of nuclear energy, both based on nuclear fission and nuclear fusion.

Future prospects

In view of the great importance of the BR2 reactor, SCK•CEN aims to achieve continuity in the availability of a large irradiation facility on its domain in Mol. For this purpose, the operation of the BR2 is planned up to 2026, at which point it is intended to hand over the baton to the MYRRHA installation. MYRRHA is an acronym for Multi-purpose hYbrid Research Reactor for high-tech Applications.

In a European and international context, we are currently focusing on developing a future-oriented innovative research facility MYRRHA.

MYRRHA has a major benefit. This installation enables the study of how long-lived radioactive waste may be transmuted into shorter-lived waste. This will reduce the life and the amount of highly radioactive waste, thereby shortening the required period for geological disposal from several hundred thousand years to less than one thousand years.

MYRRHA will also fulfil a research function: as a fast-spectrum irradiation reactor, MYRRHA will be used to test innovative materials and nuclear fuels. The reactor is therefore an important test facility for the nuclear energy systems of the future: the reactors of the fourth-generation.

MYRRHA will also contribute to a continuous stockpiling of medical radioisotopes and the production of doped silicon. BR2 has fulfilled these two functions for many years. MYRRHA could therefore replace the BR2 in the course of time.

Before this will happen, the BR2 shall also make an important contribution to MYRRHA's development by testing the nuclear fuel and materials to be used. SCK•CEN will conduct the first tests in the BR2 reactor, in which the specific MYRRHA environment can be simulated.



Conclusion

▲ SCK•CEN combines its major assets for producing top level research namely the professionalism of its staff and its exceptional facilities, namely three operational research reactors and various specialised laboratories. It has all the fundamental research disciplines (physics, chemistry, biology, materials science, etc.).

But scientific research cannot be conducted in an ivory tower. SCK•CEN therefore encourages and cultivates maximum cooperation: with external partners, but also internally, between our own expert groups. We also provide various services to Government, industry, the scientific and medical community, and the general population.

SCK•CEN, which is a meeting point of knowledge and practice, is also an excellent training centre for our own staff, the Government, and the national and international nuclear, non-nuclear and medical sectors.

▲ Today, the BR2 reactor is and remains SCK•CEN's central research tool to study materials and nuclear fuels for use in nuclear reactors. The BR2 remains the world's leading installation in terms of performance and flexibility at the international level as well.

The importance of BR2 is manifested in the following achievements:

- Maintenance and expansion of the production of radioisotopes, with which SCK•CEN supplies over 20 percent of the world stocks.
- Contribution to the development of renewable energy applications by producing high-quality semiconductor materials.
- Contribution to the safety of nuclear power plants through the study of nuclear fuels and structural materials.
- Contribution to the development of new materials and nuclear fuels in order to develop more efficient and safer reactors for research and energy generation.

To support the development of new fourth-generation reactor types, the BR2 reactor can count on five decades of experience in which pioneering work was done in the field of reactor technology. In future, the BR2 shall therefore also contribute to the development of SCK•CEN's own new research facility MYRRHA.

▲ Safety and quality remain top priorities in the management of the BR2 reactor. SCK•CEN shall continue the efforts already undertaken to maintain and improve the safety level.

The BR2 reactor is and remains crucial to the continuity of our research activities that benefit the society in which we live at the present time and in the future.

SCK•CEN

SCK•CEN – Belgian Nuclear Research Centre
SCK•CEN is a foundation of public utility, with a legal status according to private law,
that operates under the tutorship of the Belgian Federal Minister of Energy.

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Publisher
Eric van Walle
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