sck cen

Highlights 2019

The thousands of dimensions of tomorrow

In tune with society

According to our mission SCK CEN works on issues that are important to society, today and in the future: safety and efficiency of nuclear installations, production of and research into medical radioisotopes, protection of mankind and the environment against ionizing radiation, and sustainable development. In this way we contribute to a viable society, for ourselves and for the generations to come.

Highlights 2019

The thousands of dimensions of tomorrow

Whether it is about the development of better cancer treatments, the safety of nuclear reactors, radioactivity measurements, particle accelerators or nuclear fusion,
SCK CEN contributes to the future of our society through its scientific research.

"The future is full of possibilities"

An interview with Eric van Walle, Director General of SCK CEN

2019 was defined by the call for a better future. We organised climate marches, helped refugees and beat the record for 'De Warmste Week' – the VRT's annual charity campaign. How does SCK CEN fit into this scenario?

"We have been looking to the future since the 1950s. Our research centre was originally created in order to develop nuclear energy in Belgium, but we rapidly increased our knowledge and experience in various nuclear fields. We always concentrate on forward-looking applications of the atom and its nucleus. We wanted to use one of the universe's smallest constituent elements to make the biggest possible difference for society."

Your new motto is "Exploring a better future". Why did you choose those words?

"This slogan came to mind a few years ago when we looked at future visions for our research centre. How does the world see us? What do people think about what we do here? How can we make a more visible commitment towards society? For us, the answer to this question was clear. Our work has more societal benefits than anyone, including us, realises and everyone needs to know about this. Societal relevance has been and remains the guiding principle behind all our projects. In fact, scientific advances show that we are in a position to do more for people who are faced with a cancer diagnosis. For this reason, we want to continue investing in solutions that make our world more sustainable by using nuclear science. We therefore have the ambition of ensuring that nuclear knowledge increases and continues to increase for all future generations."

That's a fine promise, but will SCK CEN be able to keep it?

"I can confirm this to you, just as we proved it again in 2019. Just consider our BR2 research reactor. Last year, we made all the necessary preparations in order to increase the number of operating days from 160 to 210 in 2020. Demand for medical radioisotopes and doped silicon is increasing and we are pleased to help ensure that they are available. In 2019, we also launched the production of terbium-161, an emerging tool among the therapeutic radioisotopes."

"It was also all hands on deck in the field of structural materials last year. We provided solutions for the safe operation of existing and future nuclear power stations and approved structural materials for the international thermonuclear experimental reactor (ITER). In order to approve structural materials for the MYRRHA research infrastructure, we spent a record number of hours on corrosion tests. As a result, we are bringing MYRRHA closer to its goal of helping optimise the radioactive waste policy.

The additional working days spent on the BR2 research reactor immediately paid off. Commercial electricity production by fusion will only be possible in 2100 at the earliest. Is one "future" different from the other?

"Good science simply takes time. It takes time to reflect, allow ideas to mature and test them frequently. Nothing can be left to chance. Sometimes we have to adjust a concept and repeat the qualification tests that have already been done. Not all the solutions that we're working on will be deliverable tomorrow. The future is full of possibilities."

Take a look at this annual report and learn about thousands of future possibilities.

Tomorrow

2021 / 2026

2027 / 2050

Tomorrow

SCK CEN has invested massively in physical security

More than ever before, the medical sector can rely on BR2

Tomorrow

Detect, delay, neutralise

SCK CEN has invested massively in physical security

Vibration detectors, smart cameras, air lock doors with single person entry, access controls, trained security staff and a rapid intervention force. SCK CEN has significantly increased physical security over the last five years. In 2019, the research centre received official recognition from the Federal Agency for Nuclear Control. “These new measures make SCK CEN one of the most secure sites in the country,” says security manager Benny Carlé.

Five years ago, De Lijn passengers were still surprised when their bus drove past the BR2 research reactor on the Boeretang. One year later, the Boeretang was permanently closed to through traffic and De Lijn was no longer allowed to use it. The inhabitants of Mol and Dessel had to change their usual routes. This closure of the Boeretang was part of a series of security measures implemented by SCK CEN with the aim of protecting nuclear sites.

A first wave of security measures began after the 9/11 attacks, followed by a second wave after the terrorist attacks in Paris and Brussels. “The 9/11 attacks certainly opened our eyes,” recalls Benny Carlé, security manager at SCK CEN. “It was only when the terrorist threat became imminent that the idea emerged: there is a need to establish a comprehensive regulatory framework.” Under diplomatic pressure from the USA, this framework was anchored at an international level. On 17 October 2011, a royal decree on the physical protection of nuclear materials and nuclear installations was published in the Belgian State Journal. Other countries are putting similar systems into place.

Increased security

In 2006, SCK CEN had already deployed an additional security system for the BR2 research reactor. These developments were then monitored and evaluated by the U.S. Embassy. “The royal decree of 17 October 2011 focuses on concentric zones and calls for a defence-in-depth system. Whereas, in the past, we used to consider the BR2 reactor building as a whole, we now monitor each layer of security separately,” explains the security manager. “We analyse the route that intruders might use. Which is the shortest route? Where are the weak spots along this route? What if a person enters a building? When will we detect this? Which barriers have we put into place in order to slow down intruders? And how does an response team act in order to neutralise the situation?”

Detect, delay, respond. Detecting, delaying and responding to threats: these three keywords must therefore describe how the research centre defends itself against a range of realistic threat scenarios. “The government gives us different threat scenarios that we be prepared for. In the preparations, we must always take into account a possible insider threat: an employee who uses his authorised access to damage the company,” explains Carlé.

Official FANC recognition

SCK CEN introduced a range of security measures in order to cope with potential threat scenarios. This includes vibration detectors, smart cameras, air lock doors with single person entry, extensive access controls, trained security staff and an intervention force. Last year, the research centre received official recognition from the Federal Agency for Nuclear Control (FANC) for its efforts. “This was preceded by a strict audit. FANC came to visit us and meticulously checked every description in our accreditation file”, explains Carlé. “In Belgium, only five other organisations have been given this recognition.”

Security is paramount in the minds of our employees. Everyone plays their part and we are pleased.

Benny Carlé

A thousand eyes

Is it enough to install cameras and have security guards patrolling the site? No, the motto of the security sector is “continuous practice”. “The security guards can detect suspicious movements on the camera images, but they also have to be able to give appropriate instructions so that the response team can take action. The security service, army and police must therefore be perfectly in step with one another”, he continues. “In order to master these skills, they have to be practised at least 100 times. For this reason, SCK CEN organises 21 table-top exercises every week (in other words, theoretical exercises) and at least 4 exercises with action in the field. In the meantime, our security teams have been training for several years. FANC also keeps up its surveillance and will schedule regular inspections. The official bodies are not alone in contributing to the success of the security concept. Security is paramount in the minds of our employees. Through them we have 1000 pairs of vigilant eyes that contribute to surveillance. Everyone plays their part and we are pleased,” concludes Carlé.

Cybercrime: a thriving business

Cybercrime is on the rise. The worldwide turnover from online crime is equal to the turnover from drug trafficking. In response, SCK CEN is working on an advanced and highly secure ICT infrastructure. “Dividing the network into sub-zones, partitioning these zones with barriers, providing efficient detection methods… Over the last few years, we have paid special attention to all of this and will continue to do so in years to come. Cybercrime does not remain static: attacks are becoming increasingly complex and our challenges are growing,” concludes Carlé.

Safeguarding knowledge, materials and data

Nuclear institutions around the world are working hard to make their sites more secure, both physically and digitally. SCK CEN is no exception to this, partly on account of the changed international context. In 2020, we can rightly be proud of the result achieved, for which we received official recognition from FANC. However, this official recognition is not the end of our efforts. We will continue to modernise our security to keep pace with new challenges.

— Peter Baeten
Deputy Director General

Morgen

More than ever before, the medical sector can rely on BR2

SCK CEN increases availability of the research reactor from 160 to 210 days

The number of cancer patients continues to increase year by year, which means that the need for medical radioisotopes is also growing. "A continuous supply is crucial," says Steven Van Dyck, director of the reactor at SCK CEN. In order to guarantee this supply, SCK CEN has decided to increase the number of operating days for the BR2 research reactor from 160 to 210 per year.

In 2016, the scientific and medical world was relieved when the BR2 research reactor was successfully restarted after a complete overhaul. The BR2 was ready for at least another decade of ambitious projects. "Thanks to this full refurbishment, we are technically able to achieve even greater efficiency," it was described after the completion. SCK CEN immediately put these words into action. In 2019, the research centre made all the necessary preparations in order to increase the number of operating days from 160 to 210. The motivation? The growing international demand for radioisotopes for medical imaging and the treatment of cancer.

A race against the clock

"There are only a handful of medical radioisotope producers in the world. The OSIRIS reactor in France closed its doors at the end of 2015, followed by NRU in Canada in late 2016. There are now only six producers that are left to cover the worldwide demand. And this demand is increasing year by year. This underscores the need for our BR2 research reactor to be available," explains Steven Van Dyck, director of the reactor. "In addition, we cannot build up stocks, as is the case for hypodermic needle production lines, for example. It's a race against the clock to get medical radioisotopes to the patient in time. A continuous supply is crucial."

Change of focus

Medical radioisotopes currently account for two thirds of the irradiation channels at BR2. It was different in the past. “Previously, the emphasis was placed on research focusing on materials, whereas medical radioisotopes were a by-product,” explains Van Dyck.

Is this the end of the line for all other applications? “No,” says Van Dyck emphatically. “The BR2 research reactor is multi-purpose. It is a versatile and flexible installation that can combine several tasks at the same time. We can use the reactor to produce medical and industrial radioisotopes, while at the same time, we can produce high-quality (doped silicon) semi-conductors, and conduct research on materials. In 2019, for example, we successfully completed a multi-year irradiation campaign. By doing this, we brought ITER, the international fusion test reactor at the French research centre in Cadarache, one step closer to its goal of demonstrating the technical and scientific feasibility of nuclear fusion [see p. 46].”

“At the same time, demand for these types of irradiations will only increase in the future. Especially now, since in 2018 the curtain fell on the Halden research reactor in Norway after over 60 years of good and loyal service. This reactor was used for experimental research on fuel and materials.”

Anyone can provide a supply that lasts five years. The new diesel generators must also continue to function after operation. We are preparing for the future.

Karel Sebrechts

With this increased availability, SCK CEN is already making a vital contribution to this continuous supply, but the research centre has made an extra effort by increasing its irradiation capacity. "We have equipped an additional reactor channel for the production of diagnostic radioisotopes and doubled our production capacity for therapeutic radioisotopes," explains Van Dyck.

Which radioisotopes are rolling off the proverbial production line? "The majority are reserved for the production of molybdenum-99, the most important diagnostic radioisotope. Every year, almost seven million examinations can take place thanks to these radioisotopes produced in Belgium. We also produce radioisotopes for the development of targeted cancer treatments. Take lutecium-177, for example. This radioisotope is promising for the treatment of prostate cancer, which is responsible for 90,000 deaths per year in Europe. Or one of the terbium isotopes, which is also known at CERN MEDICIS as the "Swiss Army Knife" of nuclear medicine [see p. 29]."

More jobs

In order to be able to offer the scheduled number of operating days, SCK CEN increased the number of operating cycles of the reactor and extended their duration. Van Dyck: "We now operate for 4-5 weeks at a time, whereas we were previously accustomed to operating periods lasting three weeks. In order to ensure that this operation is successful, we recruited 25 employees. These employees are given in-depth training on how to complete each task perfectly. They have to be in perfect harmony with each other."

Due to the new operating regime, the shutdown time, the period when the reactor is not running, is shorter. This has an impact on the planning of inspections, for example. "Everything is meticulously planned so that all the statutory audits and regular maintenance can be conducted. We attach great importance to these checks. Safety is, and will remain, a top priority."

The emergency system is divided into two trains. If one train breaks down, we have another in place as a backup: an emergency solution for an emergency solution.

Bob Derboven

Left: Karel Sebrechts who initiated the building project.
Right: project engineer Bob Derboven.

The three Y's of BR2

Familiarity, availability and reliability. BR2 is a major supplier of medical radioisotopes all over the world. From 2020, the reactor will be more available than ever before. In order to increase its reliability, SCK CEN has replaced the emergency generators. The emergency generators keep the BR2 power grids running in the event of a power failure. "If this type of power failure occurs, the reactor will shut down unexpectedly. An unscheduled shutdown causes us to lose two operating days. This amounts to 1% on an annual basis," explains Karel Sebrechts who initiated the construction project. "When you know that 7 million medical examinations take place every year thanks to molybdenum-99 produced in Belgium, then it is clear that an unscheduled shutdown would affect quite a few patients. The old diesel emergency generators had been in service for over 50 years. We could no longer trust them blindly, so it was time to replace them."

In the old system, three flywheels were continuously turning at 1000 revolutions per minute. The wheels were mechanically linked to diesel generators. As soon as the grid failed, they would start the diesel generators. Project engineer Bob Derboven: "In the new design, we have disconnected both of them. Six intelligent wheels idle in a vacuum at 10,000 revolutions per minute. The flywheels absorb a voltage drop, while the diesel generators, in parallel, start-up electrically. After they start-up, they take over the work of the flywheels. The emergency system is also divided into two trains. If one train breaks down, we have another one in place as a backup. You could call it an emergency solution for an emergency solution." SCK CEN has constructed a new building to house the emergency generators.

Ready for the future

The project leaders have also developed a safety net for a wide range of incidents. What if a fire is reported? Or if an earthquake causes the site to shake? Bob Derboven, project engineer: "The building is designed to resist earthquakes. In addition, it is divided into different zones. This means that we can keep a fire "sealed off" in a room. In this way, the other rooms remain intact and we can guarantee the operational reliability of BR2."

Modularity is at the heart of the entire concept. Karel Sebrechts: "Anyone can provide a system that will last five years. The time horizon is not clear for BR2. BR2 will currently be operated until 2026, but we have submitted a safety dossier to extend this period to 2036. There will also need to be emergency response groups for certain functions, regardless of operation. It is therefore important that we can easily extend our modules and replace parts. Our vision for the future goes beyond operation - this is what makes this installation unique. We are preparing for the future."

BR2 as a hub for social relevance

I like to call BR2 an important hub for our social relevance. The numerous ways in which our research reactor is used to irradiate materials with neutrons illustrate this clearly, but nowhere as directly as in its role as an indispensable supplier of medical radioisotopes. During each operating cycle, we provide the necessary raw materials for the diagnosis of cancer in at least 1 million patients and for the therapeutic treatment of more than 3,000 cancer patients. The social relevance of BR2, and by extension, all research lines of our national nuclear research institute, is something we Belgians can be proud of.

— Sven Van den Berghe
Nuclear Materials Science

2021 / 2026

New technology measures radiation doses without a dosimeter

SCK CEN disassembles the installation that significantly reduced the footprint of BR3's decommissioning

Terbium-161: an emerging radioisotope in the fight against cancer

2021 / 2026

New technology measures radiation doses without a dosimeter

Using cameras and computers to accurately measure radiation for doctors

People who work in operating theatres are exposed to a small amount of ionising radiation. In order to prevent health risks, dosimeters monitor individual radiation doses. However, these meters are not very accurate. SCK CEN, in partnership with six international partners, has developed a revolutionary technology, in order to calculate radiation doses more precisely using a camera and specialised software. This technology has great potential, according to the PODIUM project (Personal Online Dosimetry Using Computational Methods).

An interventional radiologist numbs the patient's skin, pierces the groin artery and inserts a catheter into the blood vessel. The catheter has to be pushed to the area that he wishes to examine, before he injects a contrast agent. During this procedure, he takes x-rays of the blood vessels.

Most patients do not think about it, but their doctors are also exposed to ionising radiation. The radiation dose experienced by the doctor depends on his actions. For example, does he bend over the patient slightly when taking x-rays or does he hold his hands over them? This may increase the accumulated radiation dose. A conventional dosimeter measures the quantity of radiation inside the device. A camera and motion sensors make it possible to determine the radiation dose in each part of the body.

Specialised software

In partnership with six international partners, SCK CEN has developed a revolutionary technology in order to calculate the individual radiation dose experienced by a doctor. This is done by a camera and adapted software. The camera – together with motion sensors – closely monitors all the actions of the interventional radiologist and records every movement of his body. The software combines this data with the output from the x-ray machine being used, which enables it to calculate the radiation dose received. “The software takes into account the radiation field of the source and the distance between the radiologist and the patient”, explains SCK CEN scientist Pasquale Lombardo. “What energy level is the radiation? At which angle are certain parts of the body irradiated? It all makes a difference.”

Personalised dosimetry

The software used in the new technology was developed using simulations with dummies. This took place at St. James's Hospital in Ireland and the Malmö University Hospital in Sweden. The scientists placed anatomical torsos close to an x-ray machine. “We placed dosimeters inside the torsos in order to record exposure to radiation for the entire body,” explains Lombardo. “We collected the same measurements with and without personal protective equipment. For example, which dose would we measure in the different organs if the torso wore a lead apron? This is crucial information. We also used torsos of different sizes: male and female, big and small… This should make personalised dosimetry possible in the future.

More tests required

The technology seems to outperform the current physical dosimeters. Should we stop using them? “We need to walk before we can run”, says project coordinator Filip Vanhavere, with tempered expectations. “Physical dosimeters do indeed have limitations. For example, they only have one single measurement point for the whole body. As

> We used cameras for personalised dosimetry. This approach is unique and an international innovation.
>
> Filip Vanhavere

a result, they provide little information about the different organs. The measurement results are only available after a few weeks, with an uncertainty factor of 2 for measurement accuracy. Our software is able to overcome these limitations, but the technology is still in its infancy. It needs to be further developed and tested.”

The consortium partners plan to develop a prototype in 2021, before launching it in 2023 and marketing it in 2025. At the same time, they want to test it in other contexts, beyond interventional radiology and cardiology. Last year, the scientists already installed a test configuration in workplaces with neutrons.

Male and female, big and small… Our new technology enables specially tailored dosimetry.

Pasquale Lombardo

Innovative approach

The new technology is part of the regulatory principle known as ALARA (“As Low As Reasonably Achievable”). This principle stipulates that a radiation dose must always be kept as low as possible. Other scientists from all over the world have also used cameras with motion sensors to monitor the ALARA principle. As soon as a person comes too close to a radiation source, a warning appears. But the PODIUM project is taking things further.

Vanhavere: “We use cameras for personalised dosimetry. This approach is unique and an international innovation. In addition, computers are becoming faster and faster. This development is important, as we calculate the organ doses based on “Monte-Carlo” simulations. A Monte-Carlo simulation is a computer-controlled technique, which simulates a physical process not once but many times. In our research, this physical process involves emitting radiation particles.”

“In a Monte-Carlo simulation, we release millions of radiation particles from the x-ray machine”, explains Lombardo. “Each radiation particle has a different energy or flies in a different direction. We follow all of them on their different paths and calculate the radiation dose that they ultimately deposit in the different organs. Every time the doctor moves, we repeat the same simulation. This requires powerful and therefore fast computers, but it also produces very accurate data. The more powerful computers become and as the quality of images from the camera continue to improve, the more we can further refine our technology.”

Seven partners pulling together

Seven partners joined forces to make the innovative PODIUM project a success: SCK CEN (Belgium), Universitat Politècnica de Cataluyna - UPC (Spain), Helmholtz Zentrum Munich (Germany), Lund University (Sweden), Public Health England (Great Britain), Greek Atomic Energy Commission (Greece) and St. James's Hospital Ireland (Ireland). “Monitoring individual radiation doses is crucial for effective radiation protection. Our goal is to continue our research and improve our current measuring techniques”, says Filip Vanhavere.

The PODIUM project is funded by the Euratom 2014-2018 Research and Training Programme. It forms part of the H2020 CONCERT project, a European programme integrating European and national radiation protection research.

Surfing along on the wave of the fourth industrial revolution

The fourth industrial revolution merges the physical, digital and biological worlds. Also the world of radiation protection basic science is improved with advanced technological developments, artificial intelligence, machine learning, and big data. They are used for increased protection of humans and their environment in the context of medical applications, advanced impact studies, space missions… Innovative and rigorous, an indispensable link in a multidisciplinary network.

— Hildegarde Vandenhove
Environment, Health and Safety

2021/2026

After 20 years MEDOC is over, but this is not the end

After 20 years of service, SCK CEN disassembles the installation that significantly reduced the footprint of BR3's decommissioning

After 20 years, SCK CEN took its MEDOC installation out of service. In that installation, the decommissioning experts of SCK CEN cleaned metal reactor parts by chemically scraping off the contaminated surface layer. This significantly reduced the footprint of the decommissioning of the BR3 reactor. Now, the research centre is expanding that success story with a promising method for the final processing of secondary waste.

With the Nuclear Power Phase-Out Act of 2003, the federal government decided to gradually shut down nuclear power plants. Upon closure, a new, major challenge awaits us: the nuclear power plant must be decommissioned. The aim is to restore the site to its original state, so that it can be given a new purpose. “Every decommissioning project has one golden rule: reduce the amount of radioactive waste to the bare minimum in a cost-effective way”, says Kurt Van den Dungen, decommissioning expert at SCK CEN.

How can we reduce the amount of radioactive waste? During the dismantling of the BR3 reactor, SCK CEN developed techniques to help specialists succeed. One of those techniques is MEDOC. “MEDOC stands for metal decontamination by oxidation with cerium. As the name suggests, we immerse metal reactor parts in an acidic cerium bath at an elevated temperature. The cerium dissolves the contaminated surface layer via a chemical process, so that the metal is free of radioactivity. After treatment, the materials can be disposed of as scrap and recycled in the steel industry”, explains Van den Dungen. SCK CEN refined an existing process that literature studies identified as promising, and developed an installation to decontaminate the contaminated parts of the BR3 pressurized water reactor.

The installation was commissioned in 1999 and blew out 20 candles last year. Van den Dungen: “After more than 20 years of loyal service, we decided to shut down the installation. Several factors have influenced that decision. On the one hand, the phase of decommissioning, in which we had to treat a large part of the metal reactor components, has been completed. On the other hand, the installation was located within the BR3 building, which itself is also part of a decommissioning project. The installation is currently being expertly dismantled and paths are being explored to give the installation a second life.”

Valorising sophisticated technology

The dismantling experts achieved a remarkable result with the MEDOC installation. Van den Dungen: “In all, we treated over 100 tonnes of metal in the MEDOC plant. Ninety percent of it could be free-released and thus be given a new purpose. Ten percent went to the neigh-

We have achieved a remarkable result with the MEDOC installation. This creates prospects for the future.

Kurt Van den Dungen

bouring company Belgoprocess, a subsidiary of the National Agency for Radioactive Waste and Enriched Fissile Materials (ONDRAF/NIRAS), which manages radioactive waste in Belgium." With this technique, SCK CEN has thus been able to drastically reduce the amount of radioactive waste. "We have achieved a remarkable result with the MEDOC installation. This creates prospects for the future."

"We would like to valorise our knowledge and experience, but first we have to find a final solution for secondary waste", says Van den Dungen. With secondary waste, he refers to the chemical solution in which the metal parts were decontaminated. Fellow scientist Elie Valcke: "This decontamination solution is radioactive and must also be treated and given a final destination. We are currently examining this in collaboration with ENGIE, which showed an interest in using MEDOC for the decommissioning of its nuclear power plants." This project is part of a cooperation agreement between ENGIE-Electrabel and SCK CEN to ensure techniques and activities in the areas of operation and decommissioning of nuclear power plants are kept up-to-date.

The treatment of the secondary waste consists of two steps: a pre-treatment step and a conditioning step. In the pre-treatment step, the researchers neutralise the acidic, radioactive solution, let the radioactive sludge sink down to the bottom, and then separate the sludge to wash out the soluble sulphates. In the conditioning step, they mix the remaining radioactive sludge with a cement-based immobilisation matrix. "The conditioned waste must meet a set of acceptance criteria imposed by ONDRAF/NIRAS. How does the freshly prepared cement behave in the short term? How much heat does it generate? How long does it take for the cement to cure? How stable is the conditioned waste in long-term storage at cold or high temperatures and humidity? What if the conditioned waste comes into contact with water?", Valcke explains.

"We want to avoid at all costs that an alkali-silica reaction occurs, which would result in gel formation. An alkali-silica reaction is a reaction in which sulphates cause the cement swell. However, there are types of cement that can withstand low concentrations of sulphate, including the type of cement that we have formulated and tested. That's why we filter out as many sulphates as possible in advance."

Years of testing

Patience is a virtue. The researchers at SCK CEN are also experiencing this in this project. "It takes years to extensively test our self-formulated

cement composition", emphasises Valcke. "During the chemical reaction between the cement and water, heat is released, the so-called heat of hydration, which can cause the temperature of curing mortar to rise. The heat of hydration depends, among other things, on the cement composition and fineness. Too high a temperature during the production process can lead to cracking after cooling. The first results are promising: the cement does not become too hot during the production process, it cures sufficiently quickly, it can withstand robustness tests... The fact that we were able to achieve such results is thanks to excellent teamwork. In a next phase, we will test with radioactive material. We are looking at what effect that outliers from the average composition of the decontamination solution have. Several components can influence the stability of the end product. The cement formula must be able to cope with that."

> The chemical solution remaining after treatment must also be treated and given a final destination. We are currently examining this in collaboration with ENGIE.

Elie Valcke

2021/2026

Terbium-161: an emerging radioisotope in the fight against cancer

SCK CEN has taken the next step in the production chain for the first time

A higher local dose allows for an increased therapeutic effect. Terbium-161 appears to be one of the radioisotopes of the future, but is this really the case? In order to answer this question, SCK CEN began producing terbium-161 on a small scale. "We performed all the stages of the production chain for a radiopharmaceutical product: from the preparation of irradiation targets to the radioactive labelling of biomolecules. This is a major first for SCK CEN!" say the radiochemists involved.

"It has a half-life of just under seven days and decays by emitting a beta particle with a maximum energy of approximately 0.5 MeV. Suitable low energy gamma rays are also emitted for imaging. While this could be a description of the therapeutic radioisotope lutetium-177, the isotope we are producing also emits low-energy conversion and Auger electrons."

The radioisotope described here is terbium-161. "A new emerging talent among therapeutic radioisotopes," says Andrew Burgoyne, radiochemist at SCK CEN. "Therapeutic radioisotopes are a vital link for targeted cancer treatments. In this type of treatment, a carrier molecule transfers a radioisotope very precisely to the cancer cells. Once the carrier molecule has attached or embedded

In future years, we will extend the process to include other promising radioisotopes.

Bernard Ponsard

Availability of terbium-161 is limited. This slows down research and development.

Michiel Van de Voorde

itself in the cell, the radioisotope can irradiate the cancer cell. The cancer cells are damaged, causing them to die and the tumour itself eventually shrinks."

Treating cancer cells locally

Targeted cancer treatments have existed for a while. What makes terbium-161 so special? "Auger electrons," replies fellow radiochemist Michiel Van de Voorde. "When terbium-161 decays, the isotope emits, on average, two low-energy Auger electrons per beta particle. Once ejected, the Auger electrons – like alpha particles – do not travel far. This means that a higher dose can accumulate per injection and the cancer cell is treated very locally. In addition, damage to healthy tissues is kept to a minimum. We are therefore hoping for an even greater therapeutic effect than with lutetium-177."

In order to prove this therapeutic effect, a great deal of pre-clinical research is still required. "However, the availability of terbium-161 is currently limited, which slows down research and development," says Van de Voorde. We are working to increase the availability, as SCK CEN itself began small-scale production in 2019. "The more available terbium-161 becomes, the more studies can be conducted and the more rapidly the radioisotope will reach the patient," explains Bernard Ponsard, reactor physicist and radioisotopes stakeholder manager.

From production to pre-clinical studies

In the past, SCK CEN was only concerned with the first phase of medical radioisotope production: target irradiation. "We are now taking another step in the production chain. This is a major first for the SCK CEN," says Burgoyne. "After irradiation in the BR2 research reactor, the capsules are transported to a radiochemical laboratory on another part of the site in Mol. In this laboratory, we isolate pure terbium-161 by separating the isotope from gadolinium and dysprosium using a

chemical process. We implemented and optimised this separation technique in-house."

Moving up a gear

Irradiations at the BR2 research reactor began last year. "In each cycle, we reserved irradiation positions for the production of research quantities of terbium-161. In the first cycle, we irradiated two capsules for two days. Afterwards, we systematically increased our capacities: two capsules became four, two days of irradiation turned into ten," explains Ponsard. In future years, SCK CEN wishes to have the process GMP (Good Manufacturing Practice) certified, set up high-end production (as part of the NURA project, see box) and extend the process to include other promising radioisotopes. "Lutetium-177, tungsten-188 / rhenium-188 and samarium-153 are the first in line," explains Van de Voorde. For this purpose, the radiochemists will begin to use a new specialised radiochemical laboratory in 2020.

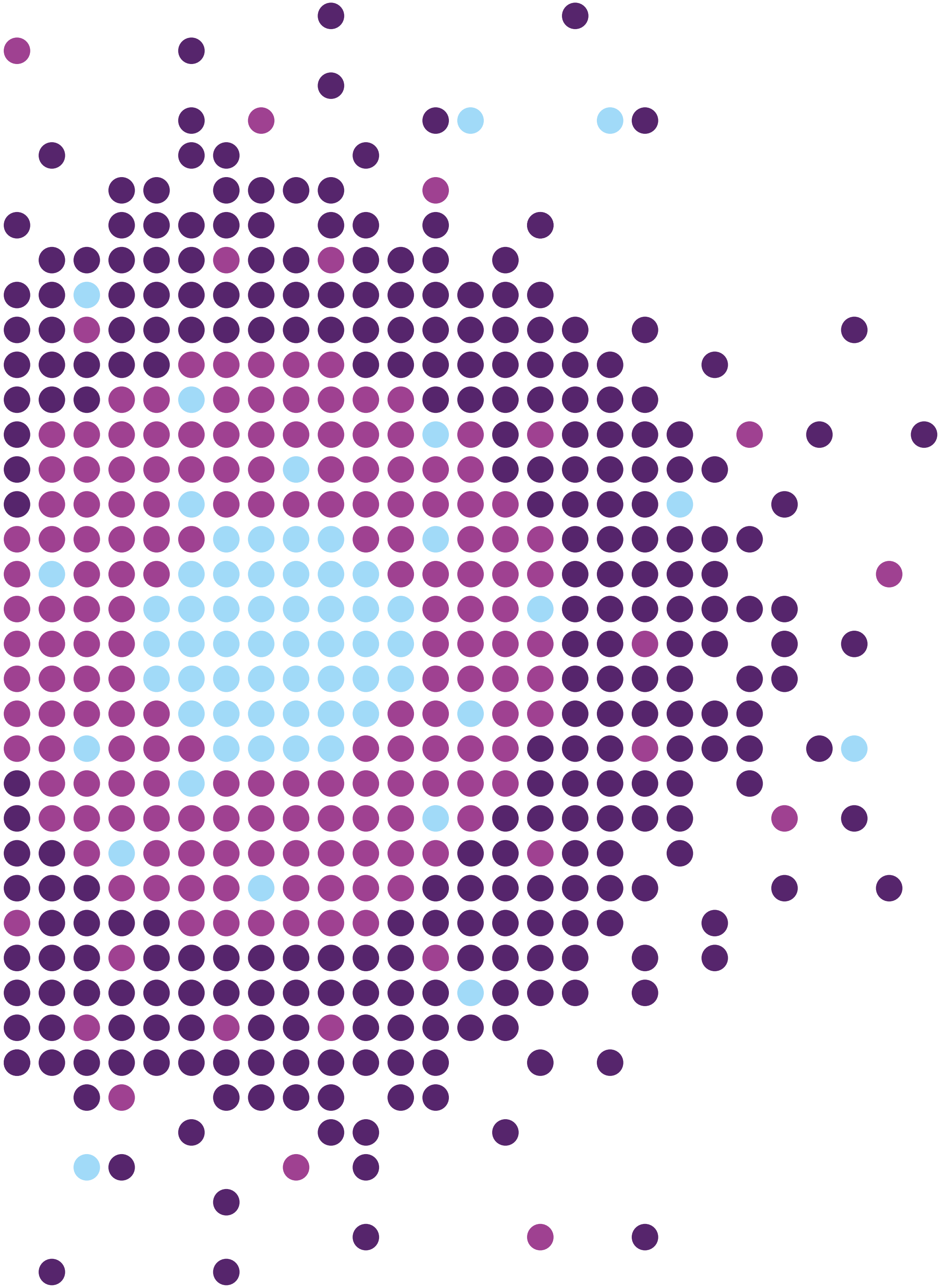
The Terbium Brothers

Terbium-161 can also be used as part of a cocktail with similar terbium isotopes. Terbium-155 could reveal pathological processes in SPECT scans. Doctors could administer terbium-152 during PET scans (positron emission tomography) in order to detect malignant tumours and metastases. Or they could closely monitor the development of cancer treatment. "For the actual cancer therapy, we hope to be able to use terbium-149 in the future for alpha therapy on the one hand, and terbium-161 for beta therapy on the other. Terbium is therefore perfectly suited for diagnostic and therapeutic purposes. In short, it is a theranostic radioisotope par excellence," adds Burgoyne. Why did SCK CEN opt to produce terbium-161 and not one of the other terbium isotopes? "We can produce terbium-161 in our BR2 research reactor. In order to produce terbium isotopes other than terbium-161, you do not need neutrons, but protons," explains Bernard Ponsard. This installation is still under construction [see page 34].

> We have implemented and optimised an in-house separation technique in order to isolate pure terbium-161.
>
> Andrew Burgoyne

The NURA project: radiopharmaceuticals for the treatment of cancer

The NURA project is conducting pioneering research into radiopharmaceutical products for the treatment of various types of cancer. This research is taking place in partnership with clinical and industrial partners. The KU Leuven is one of the partners, with which SCK CEN scientists will conduct the first pre-clinical studies for terbium-161. They have already linked terbium-161 to a carrier molecule and are now evaluating the effect of this radiopharmaceutical product. Additionally, a number of international collaborations are already underway.



2027 / 2050

New generation of medical radioisotopes in the making

Successful corrosion tests on materials for MYRRHA

How to prepare for increasingly long space voyages

Nuclear fusion: the sun in a box

2027

SCK CEN produces radioisotopes

The oven – ISOL@MYRRHA's "target container" – passes its first integrity test

Engineers at SCK CEN have built ISOL@ MYRRHA's target container – a type of oven that can reach 2400°C. In this "oven", SCK CEN will produce radioisotopes for medical applications and basic research from 2027 onwards. The research centre has already successfully completed its first integrity test. "The temperature gauge functioned well – it was an incredible feeling," said Lucia Popescu, one of the driving forces behind the project.

In 2019, when nuclear physicist Lucia Popescu and her fellow engineers, after long preparations, connected the ISOL@MYRRHA target container to the energy supply, it immediately turned orange-red. The oven – with a diameter of only 4 cm – easily reached a temperature in excess of 2000°C. “We were all looking forward to this moment. The fact that it managed to reach the target temperature without any problems is an incredible feeling,” says Popescu.

Target container

What is the target container for? According to Popescu, “SCK CEN is currently working intensively on building MYRRHA, the world’s first particle accelerator-driven research reactor. The construction of MYRRHA will consist of several phases. During phase 1, we will build MINERVA, the particle accelerator that can reach an energy level of 100 mega-electron volts (MeV). In a subsequent phase, we will increase the energy level to 600 MeV. This energy is needed to complete all the planned tasks in the MYRRHA research reactor, especially the transmutation demonstration. The research reactor itself will be built in the third and final phase, which will take until 2036.”

The proton beam is diverted at an energy level of 100 MeV. Five percent is sent to an ISOL installation (Isotope Separation On-Line) at the Proton Target Facility (PTF). This 5% shoots through the target discs in the ISOL@MYRRHA target container. “The targets are approximately the same size as a coin, barely 1 millimetre thick and made from a porous material,” explains Popescu. “Due to the energy deposited by the proton beam, the temperature in the target container rises to approx. 2000°C. This enables the radioisotopes to evaporate from the targets. The magic therefore

SCK CEN and TRIUMF join forces

SCK CEN and the Canadian research institute TRIUMF are joining forces. The two partners have agreed to share multi-disciplinary expertise and infrastructures. They immediately put their words into action, as TRIUMF has shared the ARIEL design with SCK CEN. ARIEL stands for *Advanced Rare Isotope Laboratory* and is the flagship of TRIUMF.

Other challenges

With the new ISOL installation, TRIUMF aims to produce rare radioisotopes. The ISOL@MYRRHA design will resemble that of ARIEL. "Except for the target assembly design," emphasises Lucia Popescu. "In MYRRHA, the proton beam is directed on the target with an energy level of 100 MeV, while the ARIEL proton beam is only 500 MeV. This results in very different challenges. Once the radioisotopes have evaporated, the effect is the same." The cooperation agreement was signed in 2019 by Eric van Walle, Director General of SCK CEN, and Jonathan Bagger, director of TRIUMF.

happens at the heart of the PTF. This enables us to begin developing theranostic radioisotopes – radioisotopes which are intended for therapeutic treatment or diagnostic research. The target container itself is located in a water-cooled vacuum chamber.

Once the radioisotopes have escaped from the disks, they start to wander. They collide with everything until they find a small opening in the target container. Popescu: "This is the so-called transfer tube, which transfers the isotopes to an ioniser. Then they are accelerated in an electric field and then separated by a magnetic field based on mass. The latter is very important. For example, a substance such as actinium-225 has a half-life of 10 days, while actinium-227 has a half-life of over 20 years. It is therefore crucial to select the right mass. The isotopes are collected at the end of their journey."

Uniform temperature profile

First of all, the isotopes must be able to reach the transfer tube. A uniform temperature profile plays a decisive role in this respect. "Some radioisotopes are anything but volatile and need a temperature of 2000°C in order to evaporate," explains Lucia Popescu. "If the target container wall is colder in any place and a radioisotope collides with it, it may attach itself to the wall. This would cause us to lose many radioisotopes. That of course is not the intention. That is why we strive to obtain a uniform temperature profile."

The proton beam heats the targets by depositing energy. Subsequently, the target discs radiate heat onto the target container. By placing the disks at a specific distance from each other, we can guarantee a uniform temperature profile.
If the particle accelerator is switched off or the proton beam is interrupted, we maintain the temperature by using an electrical current. Thus, the target container serves as an "oven" that vaporises radioisotopes. It is this last method of heating that we have tested in our oven, which was manufactured in house."

Material testing

In 2019, the "oven" was tested for the first time by heating it electrically. The target temperature was reached, the vacuum was maintained and cooling took place without any problems. Next year, our scientists will check whether it is possible to guarantee a uniform temperature profile. They are also analysing how the material in the target container reacts under extreme conditions. "High temperatures, thermal shocks, a vacuum environment… All these factors are likely to affect the integrity of the material. For example, the material may melt, clogging up the porosity and trapping the radioisotopes in the disks. Or cracks may develop in the target container, in which radioisotopes could be lost. We are looking forward to completing construction," concludes Popescu.

MYRRHA's injector produces its first protons

The particle accelerator is under construction at the Centre de Ressources Cyclotron (CRC) in Louvain-la-Neuve. The configuration at Louvain-la-Neuve is limited to 5.9 MeV. This low-energy part – the injector – is extremely important for the behaviour of the proton beam during acceleration. In fact, the injector determines the reliability of the accelerator. For this reason, SCK CEN pays great attention to conducting detailed tests of it.

Bringing components together

"All the parts were tested individually. In March 2019, it was time for the next phase, which involved getting all the components working simultaneously," says physicist and particle accelerator specialist Dirk Vandeplassche. This phase rapidly proved successful, as the first protons came out of the ion source without any problems. Vandeplassche explains that "the ion source provides protons that continuously increase in energy. First, in the radio frequency quadrupole (RFQ) and then through a series of magnets and cavities. This acceleration requires a certain amount of power. This power is supplied by powerful amplifiers. Our amplifiers were designed and built by the Belgian company IBA." The scientists have analysed the first protons and prepared for them to be injected into the RFQ. Proton beam injection is scheduled for 2020.

Relocation to Mol

Once the low energy part is fully ready, the energy level of the particle accelerator will gradually increase. "At an early stage, we will build MINERVA, the particle accelerator with an energy level of up to 100 MeV in order to start developing innovative medical radioisotopes and to perform materials research. In the second phase, we aim to reach an energy level of up to 600 MeV. Before this is possible, the particle accelerator must be moved to Mol. All the preparations are progressing well for the building, in which MINERVA will be installed," concludes Vandeplassche.

Science and technology as communicating vessels

Scientific progress is the driving force behind technological development. Technological development in turn creates new research opportunities and thus stimulates science. Both aspects cannot interact as communicating vessels without researchers acting as a connecting factor. Researchers from different disciplines joining forces. A working environment where they can exchange their ideas is at the heart of it. We therefore try to safeguard our interdisciplinary environment in order to achieve our ambitious objectives.

— Marc Schyns
Advanced Nuclear Systems

2036

SCK CEN beats the world record

20,000 hours of corrosion tests: 7,000 hours more than the former world record holder

Around 2036, SCK CEN aims to complete construction of the innovative research infrastructure called MYRRHA, which will be unique worldwide. Preparations are well under way and the search for materials plays a key role in this process. “During the corrosion tests, our structural materials broke all the records. Everything indicates that they can withstand the required time that they need to remain in the reactor core without any issues,” say the scientists.

A complex system of shiny tubes dominates the technology hall of SCK CEN, where a wide variety of experiments are conducted for the planned innovative research infrastructure known as MYRRHA. This imposing network of pipes is the world's most powerful lead-bismuth corrosion cycle. The installation – which has been aptly christened CRAFT – continuously pumps 400 litres of lead-bismuth through the pipes at a rate of two metres per second. It is used to confirm the corrosion resistance of the structural materials selected for MYRRHA in liquid lead-bismuth.

According to Erich Stergar, the SCK CEN scientist who coordinates research on structural materials: "Lead-bismuth is a liquid metal, which we will use to cool the core of MYRRHA. We have to be sure that our selected structural materials can easily cope with the extreme conditions of the research reactor. The CRAFT installation is an essential tool that is needed to determine admissible corrosion in the components, such as the fuel elements, heat exchanger tubes, reactor vessel and other parts."

World record

In 2019, SCK CEN scientists conducted a large-scale corrosion experiment. The stainless steel shell, that will hold the fuel, spent over 20,000 hours in the hot lead-bismuth at 400°C. "This enabled us to set a new world record," says Stergar. The former record holder, the Karlsruhe Institute of Technology in Germany, managed a total of 13,000 hours. Are the materials corrosion-resistant? "Absolutely," he says.

However, the conditions for this experiment were more extreme than in the final infrastructure. The temperature in the MYRRHA reactor vessel fluctuates between 220°C and 400°C. Engineer Rafaël Fernandez who helped design MYRRHA explains: "We measure temperatures locally, which reach 400°C in the fuel elements. The liquid lead-bismuth passes through it in order to cool the core. When the lead-bismuth flows into the core, it has a temperature of 220°C, but when it leaves the core the average temperature is 306°C."

> Are the materials corrosion-resistant? Absolutely!
>
> Erich Stergar

Worst case scenario

MYRRHA's components will therefore not be continuously exposed to 400°C, although this was the case with the large-scale corrosion experiment. "The higher the temperature, the more corrosion increases," explains Fernandez. In MYRRHA, the fuel elements remain in the reactor core for eighteen cycles, but they only have to withstand a temperature of 400°C during two cycles. "This experiment lasted 20,000 hours or 9.3 cycles. We have therefore considered the worst case scenario," he adds.

These temperature variations are the subject of further research. In 2020, the SCK CEN scientists will simulate real conditions in MYRRHA and therefore immerse the structural materials in the lead-bismuth at different temperatures. "The goal is to qualify the base material," explains Stergar.

Thus, the scientists have only tackled one new obstacle. "Of course, MYRRHA will not consist purely of base materials. The base materials are welded together or assembled so that they can still move. How do these components react to the extreme conditions? How resistant are they to corrosion? Can we replace them easily? We want to find answers to all these questions during the next stages of our research," concludes the scientist.

A touch of oxygen makes material breathe

How exactly does corrosion occur? The stainless steel shell that will hold the fuel is an alloy of iron, chrome, nickel and carbon. The lead-bismuth that flows by the outside of the tube, eats away at the nickel – and, to a lesser extent, the chrome – in the steel. This changes the thickness of the shell, which becomes thinner. "The shell is the first physical barrier for the uranium fuel and therefore must not disintegrate," explains the scientist Stergar. In order to prevent this, the scientists add a "thimble" of oxygen. "When stainless steel comes into contact with water, a layer forms in order to protect the steel. In the case of liquid lead-bismuth, we only need to add a little oxygen in order to obtain this same protective layer. However, the concentration must be limited: just enough to create this protective layer, but not enough to oxidise the lead-bismuth. This would prevent the core from cooling." The scientists aim for a target value of 10 to 7% by weight in the liquid lead-bismuth, which is equivalent to approx. 1 gram of oxygen for 1,000 tonnes of lead-bismuth. The MYRRHA reactor vessel will be filled with 7,600 tonnes of lead-bismuth. A thimble of oxygen should therefore suffice.

> The higher the temperature, the more corrosion increases. We have therefore studied the worst case scenario.
>
> Rafaël Fernandez

His Majesty the King visited SCK CEN

His Majesty the King paid a working visit to SCK CEN in Mol on 26 June 2019. The visit followed the government's 2018 decision to build MYRRHA, which is the first of its kind in the world, in Belgium. "This unique new research infrastructure will attract young and dynamic scientists from all over the world," says Hamid Aït Abderrahim, Deputy Director General of SCK CEN and MYRRHA project leader. The construction of MYRRHA has advanced well thanks to the government's decision. His Majesty the King was able to see this on his working visit.

Turning dreams into action

'Exploring a better tomorrow' is our new tagline. It perfectly reflects our mission: to develop innovative applications for society. Scientific ingenuity is necessary to come up with innovative ideas, but only with strict project management do we turn that idea into a success story. What do we want to achieve? What are the milestones of the project? When are we supposed to deliver them? We continue to ask ourselves these questions so that we can continue to work together efficiently. With our eyes on the agreed deadline and our focus on society.

— **Adrian Fabich**
MINERVA Design & Build

2040

How to prepare for increasingly long space voyages

SCK CEN sends bacteria and rotifers into space

Last year, the International Space Station had special guests on board: tiny organisms measuring 1 micrometre to 1 millimetre in size. They are invisible to the naked eye. However, despite their small size, they might provide an answer to many different problems in space. Will they open up a gateway to Mars in 2040?

Millions of kilometres separate us from the planet Mars. Yet it is not the material distance that is blocking the way to this coveted red planet. The obstacles facing a long manned space voyage are factors, such as weightlessness, cosmic rays and a limited supply of water and food. Among other things, prolonged weightlessness and cosmic radiation affect vision, while also making the bones fragile and increasing the risk of cancer. In addition, a voyage to Mars and back, which takes 2.5 - 3 years, would be impossible without an independent water and food supply. It should also be remembered that you would have to carry approx. 25 tonnes of food and drink per passenger and today's space vessels are not equipped do this. Every kilo transported is worth its weight in gold, which means that quantities have to be limited.

Fortunately, space exploration does not stand still for one second. Scientists are working on solutions and technologies aimed at overcoming these obstacles. After all, the mysteries that we can unravel on Mars and other planets have incalculable value, including for life on earth. They boost our scientific knowledge, which leads to crucial innovations. SCK CEN also supports these innovative studies. In 2019, it conducted two experiments in space with (inter) national partners: one with bacteria and the other with tiny rotifers.

Bacteria as a "raw material" for agriculture on the moon

Before setting foot on Mars, the NASA space agency plans to send people to the moon in 2024, where it plans to establish a permanent base. At a distance of approx. 385,000 kilometres, our nearest neighbour in space could act as a springboard to Mars. "Inhabitants of the future Moon Village, such as astronauts, will not be able to return to Earth for supplies for a certain period. They will

> We have gained an overview of the possibilities of obtaining nutrients by mining planetary surfaces. We can use these nutrients as raw materials to produce food in space.
>
> Rob Van Houdt

have to produce their own water, food and oxygen on the spot", explains Natalie Leys, microbiologist at SCK CEN. But how? Will it be possible to sow, plant and harvest crops on the moon?

In order to answer this question, scientists from SCK CEN, the Deutsches Zentrum für Luft- und Raumfahrt and the University of Edinburgh sent bacteria and basaltic rocks into space last year. "Basalt is a volcanic rock, which is also found on the moon", explains SCK CEN scientist Rob Van Houdt who is coordinating the project. "We were checking whether bacteria attaches itself to this type of lunar rock and whether it develops. Are they able to release the necessary nutritive elements (nutrients) from the lunar rock under the influence of microgravity and space radiation, in order to transform the rock into a more "fertile" soil? We could then use these nutrients as raw materials to produce food. And this would make agriculture possible in space."

Less dependent on the earth's resources

The partners collected three types of bacteria from the rock: *Sphingomonas desiccabilis, Cupriavidus metallidurans and Bacillus subtilis*. Van Houdt: "In order to make the soil fertile, we need to know which bacterium is the most appropriate. Which bacterium would be the best raw material? The first bacterium released more nutrients, while the second produced the same quantity and the third produced less."

It is too early to dig up the surface of the moon and plant vegetables, but the results point towards a better understanding of *biomining*. In other words, we have gained an overview of the possibilities of obtaining nutrients by mining planetary surfaces. This makes it possible for us to improve these processes and, ultimately, become less dependent on the earth's precious raw materials", adds Van Houdt.

Rotifers – suited to life in space

In the autumn, six months after the experimental flight with bacteria, UNamur and SCK CEN sent a cargo of rotifers from the Kennedy Space Center in Florida to the ISS. The rotifers survive in an airless space and are more resistant to high doses of radiation and even dehydration. This is remarkable, as their cell structure resembles that

> This research can play a part in developing ways of increasing astronauts' resistance to radiation.
>
> Sarah Baatout

of human beings", explains Sarah Baatout, radiobiologist at the SCK CEN. By means of this space experiment, the research partners wish to identify the underlying causes. The advantage is that "this information can play a part in developing ways of increasing astronauts' resistance to radiation during future space voyages."

The rotifers have been circling the Earth for two weeks, which meant that they were exposed to the effects of space. After a successful flight, the scientists examined the rotifers in terms of reproduction, gene expression and genome structure. According to Boris Hespeels, biologist at UNamur, "genetic expression tells the cells that they are producing proteins. This is necessary, for example, in order to repair damage caused to the DNA. By studying this gene expression in detail, we can see which processes take place in the rotifers and therefore which mechanisms protect against the extreme space environment. We then checked their genomes to determine whether the damaged DNA had been correctly repaired. A badly repaired genome can lead to infertility and anomalies in the progeny even after death."

Focusing on the progeny

UNamur and SCK CEN have also kept rotifers on Earth and treated them in the same way. Karin Van Doninck, biologist at UNamur: "By comparing the status of the rotifers that travelled into space with that of rotifers on Earth, we can study the impact of extreme space conditions on the exposed rotifers. How does their progeny behave, for example? Because they clone themselves and therefore reproduce asexually, they also copy any errors that appear when the DNA is repaired."

> The research will also be useful on Earth. For example, it could help protect cancer patients against the negative effects of radiation exposure during their treatment.
>
> Bjorn Baselet

The rotifers were able to repair their DNA without any problems under the influence of cosmic rays. Subsequent research will have to show how they manage to do this. These discoveries pave the way for more extensive space exploration, but this research will also be useful on Earth. Radiobiologist Bjorn Baselet from SCK CEN says that "our results may lead, for example, to measures aimed at a more effective protection for cancer patients or occupational workers who are exposed to the negative effects of radiation during their treatment."

Without human intervention

Rotifers are microscopic (200 micrometres - 1 millimetre). They live in lakes and rivers, on mosses, damp soils, tree trunks, rocks and leaf debris. Some species, such as the bdelloid rotifer, reproduce asexually. In other words, the females clone themselves. The rotifer owes its name to the lashes that form a crown around its mouth and can rotate at lightning speed like a wheel. As a result, water flows into its mouth, with which the rotifer filters its food. UNamur and SCK CEN have sent the rotifer *Bdelloidea Adineta vaga* into space. A new flight is planned for autumn 2020 and 2023.

2050

Nuclear fusion: the sun in a box

SCK CEN is testing structural materials for a nuclear fusion reactor

For two years, SCK CEN has been testing structural materials for ITER (international thermonuclear experimental reactor) at its BR2 research reactor. The materials have been exposed to a high neutron flux at up to 1200°C. In 2019, the irradiation campaign was completed and the fusion test reactor at the French research centre at Cadarache moved closer to its goal of demonstrating the technical and scientific feasibility of nuclear fusion. "Never before in the history of SCK CEN have we achieved such extreme conditions," explains project coordinator, Dmitry Terentyev.

The Sun on Earth. A Star in a Jar. Many different nicknames are used when referring to nuclear fusion, the technique that imitates how energy is generated by the sun. In practical terms, it involves the collision of two atomic hydrogen nuclei which fuse together to form a heavier atomic nucleus (helium). Nuclear fusion could provide an almost unlimited quantity of energy without any greenhouse gas emissions. This is good news when it comes to combating climate change. This technique would also produce far less long-lived radioactive waste than “conventional” nuclear energy.

It will probably take a while longer for a working nuclear fusion installation. At the French research centre at Cadarache, SCK CEN is working with an international team of scientists on the ITER international fusion test reactor. The ITER project aims to demonstrate the scientific and technical feasibility of nuclear fusion as a usable energy source for the future. In 2050, ITER will be replaced by DEMO, a prototype industrial nuclear fusion reactor. That prototype should demonstrate the feasibility for commercial production of electricity.

Radiation-resistant materials

The technical and practical challenges of nuclear fusion are significant. One of the most complex points of operation is the effect of radiation on the equipment, robotics and structural materials of a reactor. In this context, last year, scientists at SCK CEN completed a multi-year irradiation campaign at the BR2 research reactor.

“During the campaign, we qualified the materials that will be used in the fusion reactor. This included materials for the “first wall”, which is directly exposed to the plasma”, explains nuclear fusion expert Dmitry Terentyev. “For two years, we have exposed the materials to a high neutron flux at up to 1200°C. In order to imitate the fusion conditions as closely as possible, we developed the HTHF (High Temperature High Flux) irradiation device. Never before in the history of SCK CEN have we tested structural materials under such extreme conditions. As part of the next stage, the scientists will map the thermal, mechanical and micro-mechanical properties of the irradiated materials. In order to achieve this, SCK CEN is working with research institutes from Germany, Italy, Switzerland and Greece.

Choosing a supplier

For the irradiation campaign, the structural materials remained in the BR2 research reactor for two years. “This was the minimum length of time needed to imitate the full life cycle of materials in ITER,” says Terentyev. “We mainly studied the possibilities of tungsten, steel and copper. The tungsten in ITER has to provide shielding for the divertor, which is the component that removes heat and cinders from the fusion reactor so that the plasma is not contaminated. The temperatures will be at their highest in the divertor. The outer shell of the divertor is water-cooled and made from tungsten. The inner pipe, through which the water passes, is made from copper. The steel has to support the copper and tungsten structure.”

The material of the divertor is made of tungsten, steel and copper.

> For two years, we have simulated the effects of nuclear fusion on structural materials. Never before have we achieved such extreme conditions.
>
> Dmitry Terentyev

The base materials for the fusion test reactor have already been selected. SCK CEN is now assessing materials provided by different suppliers. “How the tungsten, steel or copper reacts with the radiation can vary from one supplier to another,” explains Terentyev. “It depends, for example, on the composition of the material, the production process and the installations used. During 2020 and 2021, SCK CEN will analyse any damage and the ageing process of the irradiated materials.”

Higher TRL level

Completing the irradiation campaign is another step towards the realization of ITER. “We are increasing the TRL level again”, says Dmitry Terentyev proudly. TRL stands for Technology Readiness Level and refers to the level of development for new technologies. The scale consists of 9 levels - from level 1 (research) to level 9 (introduction on the market). “We are currently at level 4 for tungsten and level 5 for steel. For copper, unexpected material embrittlement occurred. We will therefore have to adjust the design in order to progress to the next TRL level.” The ITER nuclear fusion is a part of the EUROfusion project, a H2020 partnership between Euratom, European Union countries, as well as, Switzerland and Ukraine. For the next stage of the research, SCK CEN, in collaboration with international partners, is developing a new irradiation device in order to test the structural materials used in ITER fuel cells. Therefore, SCK CEN will continue to expand its irradiation capacities at the BR2 research reactor in order to meet the needs of nuclear fusion research.

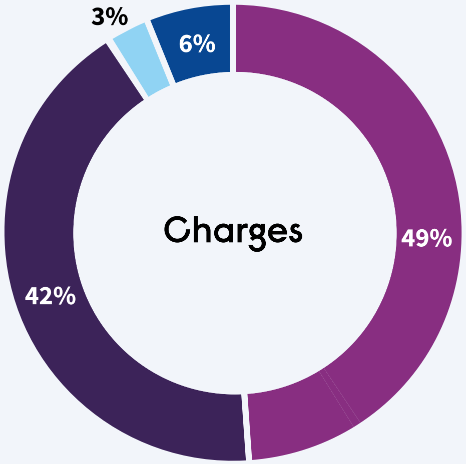
A world-class knowledge centre

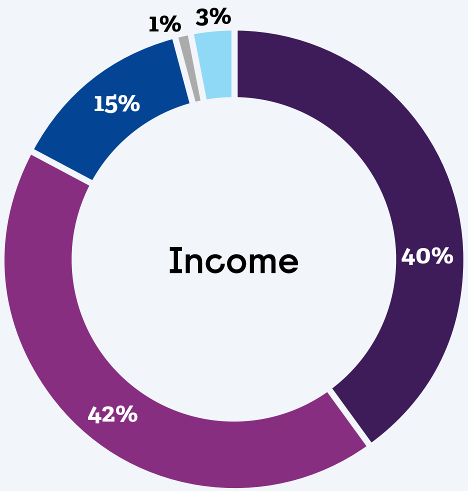
Compare large-scale projects such as MYRRHA or ITER with the climb of Mount Everest. The summit is the ultimate goal, but the direct path to it is much too steep. That's why we take the alternative, somewhat longer route: one with several approach roads so that we can involve young scientists and celebrate intermediate successes. This creates team spirit and motivation.

— Hamid Aït Abderrahim
Deputy Director General and Director of MYRRHA

Key Figures

Budget

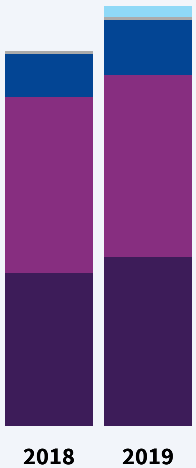




Budget evaluation

Charges (in kEUR)

	2018	2019
Personnel costs	82,686	90,221
Purchases, services	64,434	78,253
Provisions	5,762	6,138
Depreciation	9,726	11,201
TOTAL	**162,608**	**185,813**



Income (in kEUR)

	2018	2019
Turnover	66,256	73,473
Subsidies from government, grants	76,897	76,723
Other	18,745	26,528
Financial income	1,196	1,093
Extraordinary income	156	4,792
TOTAL	**163,250**	**182,609**

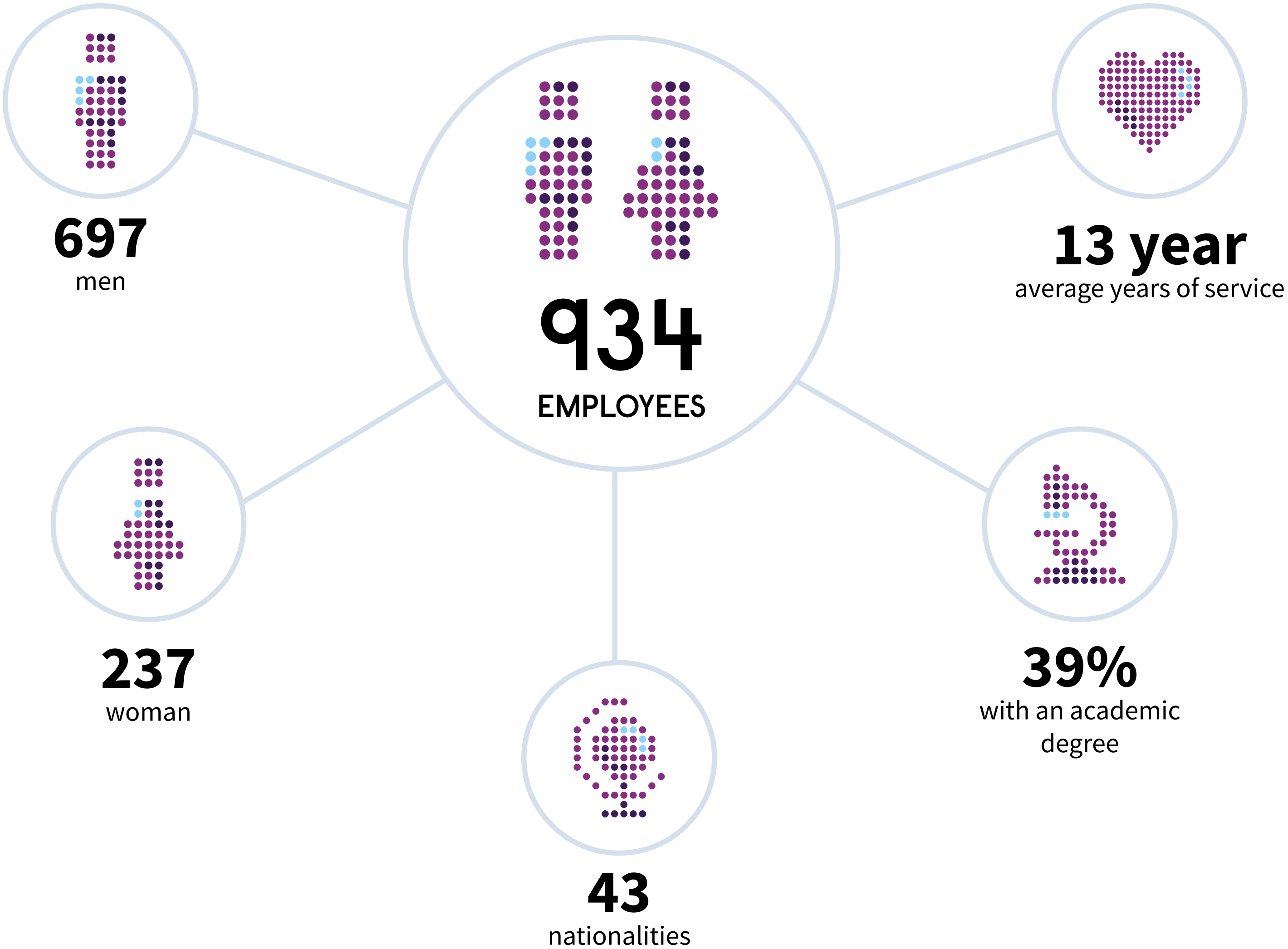
Active in 59 countries
(highlighted in purple)

Featured by innovation

A company can only really innovate if it is able to realise its plans. I am proud to say that SCK CEN is such an innovator. The ambitious plans we have made in recent years are becoming a reality step-by-step. This can be seen on the field, but is also reflected in our figures. SCK CEN is growing: more employees, more income. At the same time, innovation is about skilfully balancing between science, organisation and budget management. We want to continue to show our innovative strength without losing grip. More than ever, we count on every employee to make our plans come true and to remain a healthy organisation.

— **Kathleen Overmeer**
Corporate Services and Administration

Personnel



Publications

679
scientific publications & presentations

Training and research

72
PhD students

35% from Belgium
65% from abroad

27
PhD started

130
Training for third parties

1956 participants

Promoting through networking

In 2006, Flanders had 34,706 full-time workers in the Research and Development (R&D) sector. In 2018, this figure had reached 53,933 workers which is an increase of 55%. Flanders – and by extension Belgium as a whole – is very much focused on research and innovation. “We hold all the cards to create an impact for society with all our potential. Strategically, SCK CEN wants to compete in this regard”, explains Pascal De Langhe, director of Business Development & Support. “We bridge the gap between researchers and various actors on the market: from nuclear energy to the industrial and medical sector, which increasingly needs our attention. To do so, we start a dialogue, we set up networked collaborations, we create consortia and get financial support where necessary. As a knowledge institute, we make sure that the knowledge acquired is protected.”



65 years of experience in nuclear science and technology

As a research centre dealing with peaceful applications of radioactivity, SCK CEN is an indispensable part of our society. We perform forward-looking research and develop sustainable technology. In addition, we organise training courses, we offer specialist services and we act as a consultancy. With more than 850 employees, SCK CEN is one of the largest research centres in Belgium.

Throughout all of our work, there are three research topics that receive particular attention:

- Safety of nuclear installations
- Development of nuclear medicine
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