highlights

2015

SCK•CEN

STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

“ 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, solutions for the disposal of radioactive waste, 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 te come.

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DEAR READER

2015 was a challenging year for SCK•CEN: reconciling reduced funding with a high level of investment and costs, whilst at the same time still guaranteeing meaningful research, proved to be no easy task.

The radical refurbishment of the BR2 research reactor, a highlight in this brochure, immediately gave rise to a financial low point: we shut down our most important installation for 18 months, with the inevitable lower revenues and high investment costs. But the result is really something: in July 2016, BR2 will shine again like never before! With the reactor being operational for up to eight cycles per year, SCK•CEN will be able to respond even more flexibly to the wishes of its customers.

An example of BR2's world class capabilities is the solution-oriented applied research we conducted for the Doel 3 and Tihange 2 reactors. You can read how we used our unique infrastructure and expertise to make a thorough analysis of the integrity of the reactor vessels. You will note that BR2 has been performing at the top level for decades. Our ambitions are at least as high for its successor, the new research facility MYRRHA. The course is set for the coming years, with the first hurdle being the construction of the accelerator.

We scored even more good points: *Magics instruments,* a new KU Leuven and SCK•CEN spin-off, is the perfect illustration of how great ideas can turn into valuable applications. Thanks to the right guidance, two young scientists succeeded in developing chips that have up to a thousand times greater resistance to radiation. Valorisation, a lovely word; and we are putting it into practice. Our expertise reaches further still: we support national and international authorities in the field of nuclear emergency planning and work together to reduce potential chemical, biological, radiological and nuclear risks. An instructive exchange of knowledge and experience.

Top of the class is the *SCK•CEN Academy for Nuclear Science & Technology.* Barely three years after its formation, the number of participants on our training courses has almost doubled and we have passed the landmark of the hundredth PhD diploma. Undoubtedly a success story and a guarantee for the future. Science and technology make young people dream and stimulate them to realize their ambitions. We at SCK•CEN are more than ever convinced of this; giving people opportunities to grow and put their talents to the best possible use for innovative and ground-breaking research is our most valuable investment.

I wish you an enjoyable read.

Eric van Walle
Director-General


content

01

Valorize expertise

“Lower own income and higher investments”

A challenging combination during a period of transition

A research centre that exists since 1952 must constantly evolve and remain faithful to the work of the pioneers, the founders of SCK•CEN big world premieres. This means investing in scientific development, security and infrastructure. In recent years SCK•CEN built up reserves in order to partially cover these investments. Negotiations with the government have also created renewed confidence for the coming years because, after a 2015 in which federal government funding was greatly reduced due to general cutbacks, SCK•CEN has now received a financial commitment for the next two years as part of a four-year plan. 2015 and 2016 are clearly transitional years in the life of SCK•CEN.

Interview with **Christian Legrain**, Secretary-General

> “SCK•CEN’s strengths are our creativity and the flexibility of our employees.”

What do the research centre’s financial balance sheets look like during recent years?

Christian Legrain: They look very positive! The years 2013 and 2014 were exceptional as regards our own income. SCK•CEN supplemented its government grant with higher sales than in previous years. This evolution enabled us to build up financial reserves and make the investments needed to ensure that in the future all our infrastructure is state-of-the-art.

What exactly were the main sources of SCK·CEN’s own income?

Christian Legrain: In addition to our own developments, there were two outstanding major projects in which we were asked to take part. Our employees carried out extensive research for Doel 3 and Tihange 2, a topic that regularly appeared in the media. We were able to irradiate materials with our high-performance BR2 research reactor. Thanks to the expertise of our staff and the flexibilities of our BR2 reactor and ‘hot labs’, we succeeded in predicting the behaviour of both reactor vessels for the coming decades (see page 52). It is clear that, with our expertise, we can make a valuable contribution to answering such nuclear questions. The efforts of our employees in this area generated substantial additional income for SCK•CEN.

We also conducted a major project for the development of a new radioisotope for palliative care (see page 14). This went very well for a couple of years but in 2015 it came to an end, even though a major pharmaceutical company showed interest in continuing it. This project generated exceptional income for three years, but in the future this will not be the case anymore. All the same, this proves once more that SCK•CEN, with its knowledge of irradiation technology and radiochemistry, can make a significant contribution to the pharmaceutical world. This does not mean that subsequent years are going to be equally exceptional. Yet another reason, thanks to federal government funding, to ring-fence approximately half of our resources.

You say that the financial reserves that have been built up will now come in useful. What investments do you have planned?

Christian Legrain: The trend towards rising incomes will not continue automatically, and therefore I consider 2015 and 2016 to be transitional years. These years will see a combination of lower sales and higher investment costs. The main reasons for this are the shutdown of our BR2 research reactor – for more than 18 months (see page 44) – and a series of upcoming investments. The total cost price for the ‘refurbishment’ of BR2 is 30 million euros, excluding our personnel costs. Added to this are the investments in site security and the stress test. After more than sixty years’ service we have completely replaced the high voltage substation at SCK•CEN, and if you come to our site you will immediately see that there is a lot of work going on (see pages 78-83). Amongst other things, our water tower has been refurbished and construction of an entirely new building has started.

How does the federal government view the future of the research centre? Have any agreements been reached on this?

Christian Legrain: It was indeed necessary to enter into dialogue with the Belgian government. Actually, the federal government had not included the development of the new multifunctional MYRRHA research reactor in its 2015 budget, which meant 20 million euros less than expected for us. The costs and investments in this programme were financed fully by SCK•CEN itself. But in October 2015, thanks to constructive dialogue, we were able to obtain a clear vision from the government about the entire SCK•CEN in the period 2016 up to and including 2019, as well as a separate two-year grant for MYRRHA.

What precisely does this vision mean?

Christian Legrain: There is an undertaking on three levels. In the first place, our public funding will be maintained in order to partly cover our personnel and other costs. Secondly, there will be a special grant for MYRRHA: 20 million euros for 2016 and 20 million euros for 2017. Thirdly, a separate budget has been allocated for our site security and for the stress test.

> *"Thanks to constructive dialogue, we were able to obtain a clear vision from the federal government."*

You mention a separate budget. Do security and the stress test require so much investment?

Christian Legrain: Site security, a justified preventive measure against the danger of terrorism, will cost altogether some 30 million euros over a period of five to six years. The stress tests, a result of the measures following the Fukushima incident, will cost 11 million euros. SCK•CEN also has to comply with such a stress test, because this applies not only to Belgium's nuclear power plants, but also to research centres.

Are you optimistic about the future?

Christian Legrain: The world is changing faster and faster, and our ability to adapt is of essential importance. We have laid down our policy for the future in our strategic plan and built in the flexibility we need to be able to respond rapidly to the opportunities that the market may offer us. We have strengthened our support services in recent years, in partciular to develop the commercial potential of our expertise. Moreover, we have created two spin-offs in a period of just two years (see page 11). Of course, we are taking care to ensure that our management tools can best meet the challenges of tomorrow as well as monitoring our activities. But our strengths lie particularly in our creativity in the broadest sense and the flexibility of our employees. Yes, I view the future very positively, on condition that we keep working hard in order to maintain a high level of quality in terms of research, innovation and valorisation.

Magics Instruments: from project to product

Microelectronics a thousand times more radiation resistant

SCK•CEN regularly offers doctoral students radiation facilities for their research. This also happened in the case of a thesis about radiation-resistant microelectronics. The work focused on designing circuits or chips that have to be highly resistant to radiation. This was so successful that the idea arose of actually creating products with this project, which is why Magics Instruments was set up.

The seeds of the research lay with SCK•CEN, where there was a demand for making continuous measurements under an intense radiation field, such as in the ITER fusion reactor and in the MYRRHA research reactor. This resulted in circuits being designed at the department of Electrical Engineering (ESAT) at the Catholic University of Leuven. SCK•CEN not only made the irradiation facilities of the BR2 reactor available, but also shared its extensive knowledge about the effects of radiation on materials. The installations required to test these chips at extreme gamma radiation doses were designed by researchers at ESAT and realised in cooperation with Ludo Vermeeren and Wouter de Cock from the *Instrumentation and Control Research* unit at SCK•CEN.

Wouter De Cock, Instrumentation and Control Research
Vincent Massaut, Business Development & Support

Paul De Keyser and **Stefan Tormans,**
Business Development & Support

One thousand times more resistant

SCK•CEN Business Development Advisor Paul De Keyser has been following the project closely: “The units of quantity of absorbed ionising radiation are rads and grays. The current state-of-the-art radiation-resistant chips can usually deal with 10,000 grays, which is sufficient, for example, for space missions. But research has shown that doses of 5 million grays and more are possible. With our innovative approach we have actually developed a chip that offers a thousand times more resistance than the current components for space missions. This result was achieved thanks to ten years of research and attention to all sorts of measures that make microelectronics highly resistant to radiation.”

New application areas

Such an impressive improvement in radiation resistance opens the way to completely new application areas under conditions of either high-level or prolonged radiation. Paul De Keyser: “The dismantling of old nuclear power plants or nuclear research reactors, a discipline in which SCK•CEN already has great expertise, springs to mind. There are also potential applications related to storage of radioactive waste. Interventions in the case of accidents, such as in Fukushima where SCK•CEN has already deployed its knowledge, are more acute. The initial radiation levels there were extremely high, and then you need robots that can cope with this. A high degree of radiation resistance is also an advantage for measurement systems inside or in the vicinity of fission and fusion reactors, for example in the case of safety upgrades.”

Scientists become entrepreneurs

The development of a chip with high radiation resistance offers commercial prospects. For this reason, various parties put their heads together: developers, professors at ESAT, KU Leuven, LRD (KU Leuven Research & Development), Gemma Frisius Fund and SCK•CEN. The cooperation resulted in a limited liability company under the name of *Magics Instruments.*

> *"It is our ambition to market products as soon as possible, so that Magics Instruments can keep growing."*

Stefan Tormans, SCK•CEN's senior lawyer, was closely involved in setting up the company: "With so many different parties and interests, it was necessary to reach a balanced agreement. Some parties contributed cash, others intellectual property. We started by drawing up a term sheet: a concise summary of the main agreements. This was followed by a whole series of concrete documents and detailed agreements, such as a shareholder's agreement including, among other things, the distribution of shares, the articles of association of the new company, management agreements and a technology transfer agreement."

The intensive incorporation process lasted nine months and resulted in a file with hundreds of pages. Stefan Tormans: "After the Board of Governors gave the green light, we went to the notary on 28 October. The limited liability company Magics Instruments came into being. The creation of this spin-off is just a first step. The developers now need to evolve further from scientists into entrepreneurs."

Commercial growth

Magics Instruments is currently occupied with contract research projects mainly. Paul De Keyser explains: "This will result in a small number of prototype circuits. Such projects only have a limited potential to increase sales. For this reason, the ambition is to commercialise products as soon as possible, so that the company can actually keep growing. Magics Instruments also wants to climb up the value chain and develop from selling electronic components to selling integrated measurement modules."

In the medium term, Magics Instruments seeks to grow further by launching total solutions for specific nuclear applications, for example for dismantling and waste management. "SCK•CEN wants to make a full contribution to this. Vincent Massaut, our Deputy Director of Business Development & Support is a member of the Board of Governors of Magics Instruments. His wide experience of dismantling nuclear installations, including the BR3 research reactor, and his activities in fusion research, where such sensors will be useful, could be very valuable. He and other staff at the research centre will deploy their professional knowledge and their worldwide network in order to make Magics Instruments a success story."

A valuable radioisotope for cancer treatment

ACPIL, a challenging project with strict conditions

A company in the medical sector was looking for actinium-227 in order to develop a highly promising medicine. The decay process of this radioisotope results in radium-223, which is very useful in the prevention and treatment of cancer. SCK•CEN had its own stock of actinium and offered its services. Frédéric Jutier and Patrick Lycke from the Radiochemistry expert group were closely involved in this important project, which was given the name of 'ACPIL'.

Frédéric Jutier,
Radiochemistry

In the late 1960's SCK•CEN produced actinium-227 (Ac-227), the most stable radioactive isotope of actinium. Ac-227 has favourable nuclear properties meaning it can be used as a heat source in outer space. Frédéric Jutier outlines the context: "Various countries had extensive space programmes at that time. Since Ac-227 was deemed to be a good radioactive source for providing spacecraft with energy, SCK•CEN produced this by irradiating the raw material radium-226 (Ra-226) in the BR2 reactor. Back then, this was derived from pure radium obtained from the mining company Union Minière, today called Umicore. Even then Belgium was playing a role in the development of space applications. Unfortunately, the costs of production and further technological development of a heat source based on Ac-227 were too high, as a result of which SCK•CEN stopped production in 1976."

A small but active stock

After the project was stopped, the research centre continued to retain a limited stock of purified Ac-227. “The quantity was very small in terms of weight”, says Patrick Lycke. “You couldn’t even see the actinium with the naked eye. But it did display a significant amount of radioactivity. This stock of Ac-227 was stored here for several decades, until the time when a request came out of the blue. The fact that SCK•CEN had Ac-227 available attracted the attention of a medical company.”

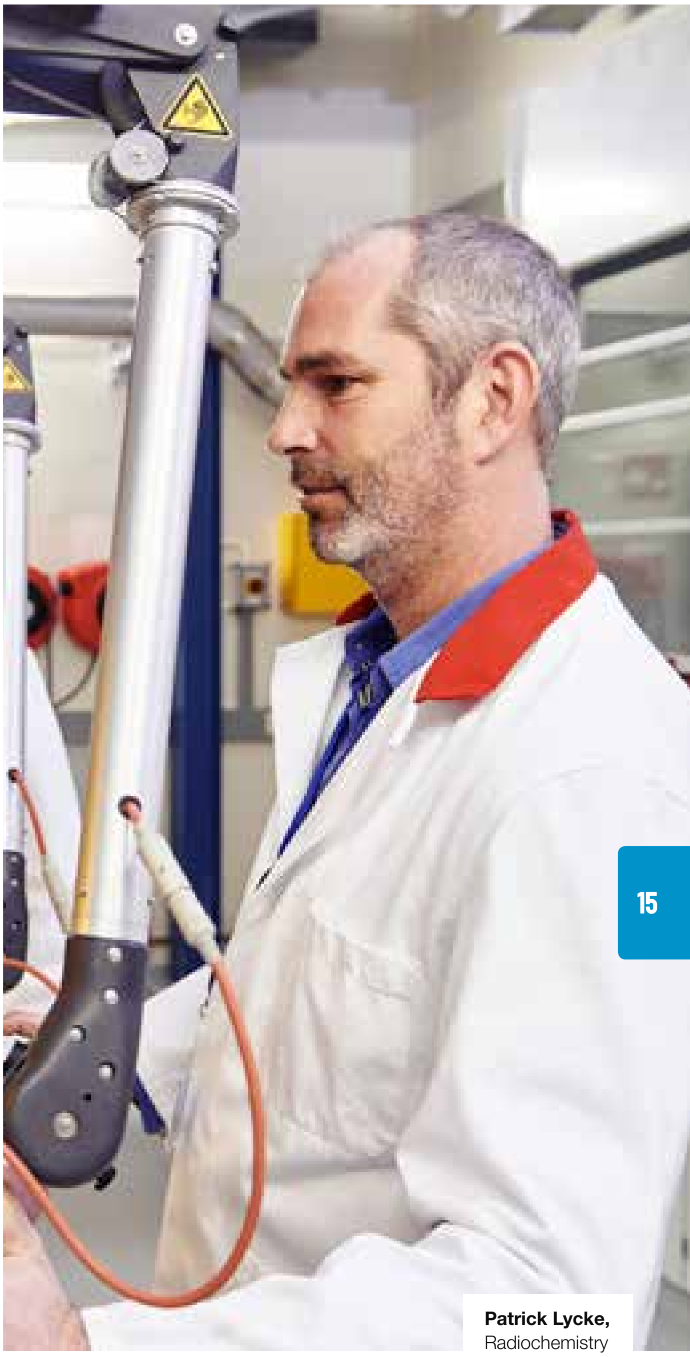
This company has a great deal of know-how in the field of cancer treatment using radium-223 (Ra-223). Frédéric Jutier explains this: “Both the elements radium and calcium are group II metals and have comparable chemical properties and affinities. Because of this, radium can be absorbed into the human body in the same way as calcium, and becomes concentrated in the bone tissue. The company developed a method using the radionuclide Ra-223 to selectively destroy bone metastases in patients with castration-resistant prostate cancer.”

The radioactive isotope Ra-223 has a very specific effect, says Frédéric Jutier: “The decay of Ra-223 results in the emission of alpha particles with energies between 5 and 6 MeV. The alpha particles emitted have a high linear energy transfer: they lose a lot of energy to the substance they pass through, so their range is limited. This is precisely what makes it possible to destroy cancer cells and at the same time to minimise the damage to healthy tissue around the metastasis.”

Highly concentrated

How is Ra-223 actually obtained? Frédéric Jutier explains: “This happens via the decay process of Ac-227. The supply of Ac-227 was therefore of crucial importance for our customer in order to evaluate the medicine by means of clinical tests.”

“The Ac-227 sources from SCK•CEN were too radioactive to transport and process at the medical company itself”, according to Patrick Lycke. “No suitable transport container was available and our customer did not have a facility where it could process such highly radioactive Ac-227. For these reasons we started the *ACtinium reconditioning PILot* (ACPIL) project at SCK•CEN in 2009 in order to divide the Ac-227 sources into smaller portions.”



Patrick Lycke,
Radiochemistry

“Our customer set the bar particularly high. We are looking forward to another challenge like that!”

The sources were first taken to a new hot-cell, a shielded environment for remote handling of highly radioactive sources. Patrick Lycke had to work with the utmost care: "This type of source is packed inside a small bolt – you could hardly see the Ac-227. We dissolved the Ac-227 in an acidic medium and then divided the solution up into twenty small capsules. This operation involved a lot of money. If we let one droplet fall, then we'd lost as much as a luxury car costs! This is why the entire dissolution process was recorded on camera."

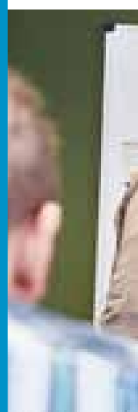
Everything worked perfectly: "We divided it up neatly in twenty leak-proof capsules, which we then put into a suitable transport container two at a time. They were then transported under strict security. Our customer could handle the quantity in one container and can now, due to the gradual decay of the radioactivity, use and re-use the Ac-227 for many years for radio-therapeutic applications."

Prospects of new projects?

With the ACPIL project, SCK•CEN complied with its obligation as an establishment of public utility to supply a medical company with a raw material that is absolutely necessary for the development and clinical testing of a highly promising medicine. Frédéric Jutier and Patrick Lycke look back with satisfaction at the interdisciplinary cooperation: "It was great to work together with various groups within SCK•CEN: we could rely on our colleagues for, amongst other things, radiochemical analyses, safety studies and technical support. Our customer set the bar very high with stringent requirements and a strict time limit. We are looking forward to another challenge like that!"

350-METRE LONG TUBULAR DUCTING

There was yet another impressive accomplishment. The inert radioactive gas radon-219 (Rn-219) was released during the processing of the Ac-227 sources. Fortunately this isotope has a very short half-life, namely 4 seconds, so that the Rn-219 has decayed after less than one minute. However, all the radon had to have completely decayed before it was disappeared via the flue of the hot-cell ventilation. The solution was to build a Radon Delay System (RDS) inside two leak-proof shipping containers stacked on top of each other: an almost endless system of pipes and filters. This included, amongst other things, a delay loop of 350 metres plastic tubing designed to slow down the emission of Rn-219 and to allow complete decay of the radioactivity. Additional filters would trap the so-called daughter products of the Rn-219. The system was installed in between the hot-cell and the main ventilation flue. Everything worked perfectly: no significant radioactivity was measured in the flue.



IAEA recognises educational efforts

A three-year long collaboration with the SCK•CEN Academy

The efforts made by SCK•CEN to share its knowledge with the world are highly valued. It is not by chance that in 2015 the International Atomic Energy Agency (IAEA) signed a Practical Arrangement with SCK•CEN to cooperate in the areas of education and training of students and nuclear professionals.

The aim of the Academy is to maintain and increase nuclear knowledge, skills and competences by means of education and training. It offers opportunities to Bachelor and Master, PhD and post-doctoral students, and provides continuous training to professionals who have to deal directly or indirectly with ionising radiation in their daily work.

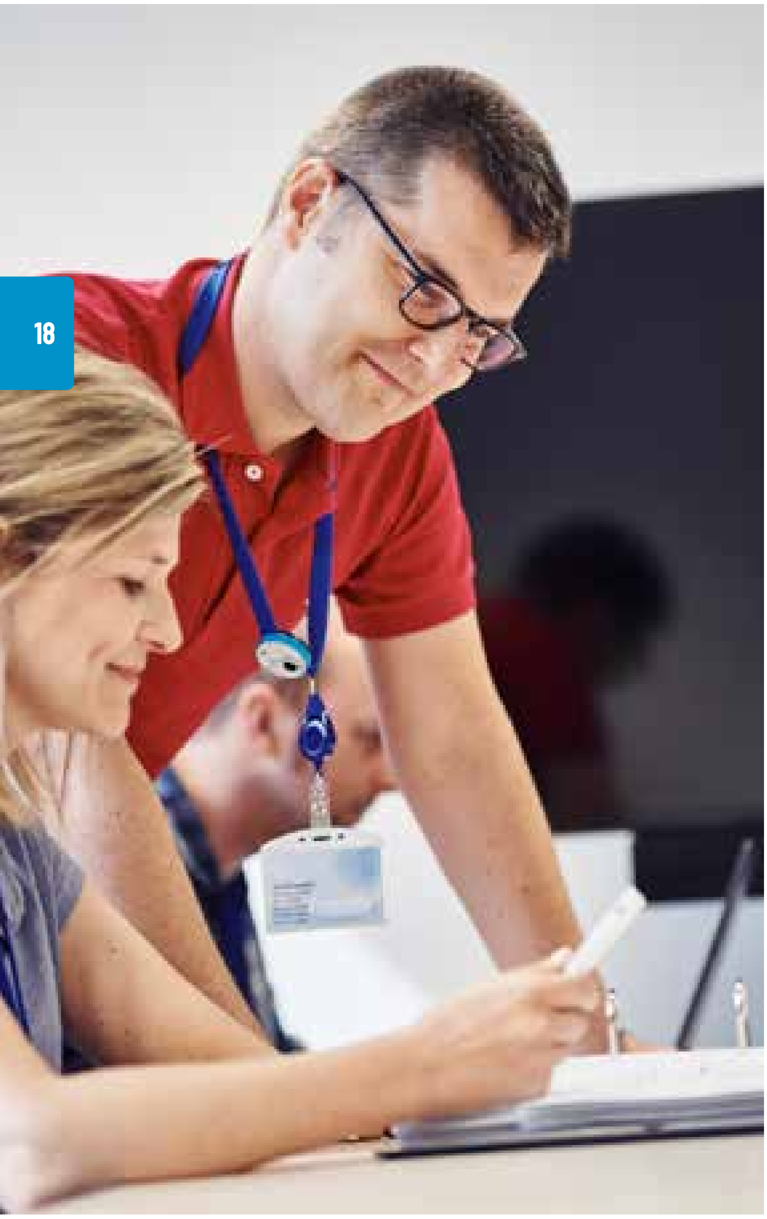
Experts from SCK•CEN regularly share their scientific and technological knowledge with other parties, both in Belgium and internationally. Many emerging countries starting out with nuclear applications call on the services of our specialists. All these training activities are centralised in the SCK•CEN *Academy for Nuclear Science and Technology.*

Larger network

The activities of the SCK•CEN Academy attracted the attention of the International Atomic Energy Agency (IAEA). This resulted in a Practical Arrangement, an agreement with the IAEA, which was signed at an international congress in Vienna. The purpose is to expand the participation of SCK•CEN in IAEA research and training projects in a structured manner.

Eric van Walle, Director-General of SCK•CEN and **Mikhail Chudakov**, IAEA Deputy Director-General and head of the Department of Nuclear Energy, sign the agreement.

> *This agreement with the IAEA is an official recognition of our in-house expertise.*



For SCK•CEN this Practical Arrangement is an official recognition of its in-house expertise. The agreement also provides additional contacts with countries and businesses that could result in cooperation in the area of consultancy, training and scientific research.

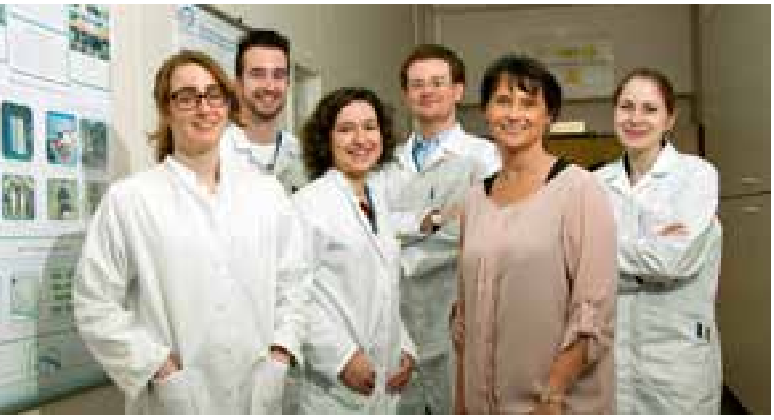
Concrete projects

In practice, the SCK•CEN Academy for Nuclear Science and Technology has the responsibility to coordinate and realise various activities. Our specialists will participate in expert missions to evaluate requests from countries applying for IAEA support and they will contribute to projects on nuclear knowledge management, education and training. In addition, there will be a greater exchange and dissemination of knowledge and information with countries that have recently started to use nuclear power or which will do so in future.

Meanwhile, the SCK•CEN Academy is continuing with ongoing collaborative links with the IAEA. Examples of these are participation in a steering committee on education and training in radiation protection, transportation and waste safety.

Motivating pupils

A new initiative is a *Coordinated Research Project* (CRP) to introduce promising young pupils to STEM-related topics (science, technology, engineering and mathematics). The SCK•CEN Academy for Nuclear Science and Technology was already active in this area and will now have the chance to exchange experiences with a number of IAEA members.



HUNDREDTH DOCTORAL STUDENT

Since 1992 SCK•CEN has built up a close collaboration with universities to provide doctoral students the opportunity to perform their research in its nuclear installations and laboratories. In the early period, some five to eight students came to us every year. After 2006 the numbers shot up, with the research centre welcoming between 12 and 20 new PhD students each year, with a peak of 21 in 2015.

This continuous flow of doctoral students resulted in the hundredth doctoral diploma under this collaborative scheme with SCK•CEN. This was celebrated on 21 December 2015 with a meeting for all doctoral students and their promoters and mentors. At the same event, SCK•CEN launched its alumni network, which seeks to bring together everyone who has been at the research centre for a few weeks, months or years, in order to facilitate networking within this group. In the future this target group will become more involved in the research activities.

Youngsters

are the future

One hundred doctorates successfully defended! A milestone in the history of SCK•CEN and a symbol of the rejuvenation of the past two decades. New ideas, motivated tutors and supervisors, different cultures, many projects – such dynamism! The interest that schools, universities, students and trainees have in our work, provides fresh blood and is the guarantee of our future.

Frank Hardeman

Deputy Director-General

Belgium's largest nuclear emergency exercise

The result of two years' preparation

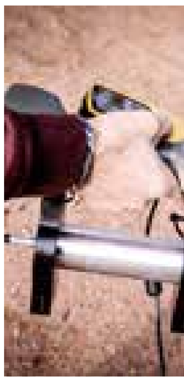
How can you test procedures that are laid down in emergency and intervention plans? By actually applying them in practice. A large-scale emergency exercise simulating a nuclear incident was therefore held on 29 and 30 October near Mol and Dessel. The authorities, Belgoprocess and SCK•CEN had prepared everything intensively.

SCK•CEN has to conduct a nuclear emergency exercise every two years. Philippe Antoine, who coordinated the operation for the research centre, provides an overview of the two-day exercise.

Communication test

"The most demanding part of the exercise came on the first day. The exercise was coordinated by the Government Coordination and Crisis Centre (CGCCR) in Brussels, in consultation with the integrated provincial coordination committee. This committee, which includes representatives of the emergency services and the municipalities, met at the crisis centre in Dessel. A nuclear emergency plan differs greatly from plans for accidents in other industrial sectors. For this reason, coordination is in the hands of the federal authorities. Information was transmitted to the government crisis centre in Brussels from the Emergency Plan Room at SCK•CEN. This was an ideal opportunity to test communication via the new video conferencing system – with very positive results. Everything was thoroughly evaluated afterwards."

A large group of students from the *Heilig Graf Instituut* in Turnhout and the *Artesis Hogeschool* in Antwerp also took part in this exercise. They simulated reactions from the population and the media via a closed social media platform.



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Mobilising all employees

Employees at the research centre site were actually involved in the exercise: "Personnel who have a role in the emergency planning organisation were mobilised via the so-called 'Site Emergency' alarm. In addition, there was a 'General Emergency' alarm in which the sirens on the site were sounded. All employees had to assemble inside the building where they were at the time and were not permitted to leave it: an ideal test of the communication between the Emergency Plan Room and the various buildings. In order not to alarm the population unnecessarily, the Ministry of the Interior's siren network was set to silent."

Evaluating the situation

The Evaluation Cell and the Measurement Cell within the CGCCR were busy both days collecting and analysing radiological data. "Their job was to evaluate the technical situation and determine its impact", says Philippe Antoine. "Measurements in the neighbourhood were taken using vehicles from either SCK•CEN, Civil Defence, the National Institute for Radio Elements (IRE) or the army. We also had to take account of the wind direction in order to measure the fallout from the radioactive discharge. Lastly, we had to collect the measurement data from all of the teams and interpret them correctly." On the second day, the focus was on aftercare – returning to a normalised situation. This part of the exercise was run in the form of a workshop at the CGCCR.

Measurements from a helicopter

On the second day Johan Paridaens, member of the *Physical Control* service, took to the air in a helicopter to measure the contamination: "A lot of people ask me why this is not possible immediately after an incident. The answer is simple: you cannot take measurements if there is still radioactivity in the air, because then the helicopter would also become contaminated. You can only measure contamination once there has been fallout. The radioactivity must have been deposited on the ground. It is of course necessary to work with equipment that has a high degree of sensitivity and a short measurement time. This allows you to measure extensive areas of contamination. We employ *Aerial Gamma Spectrometry* (AGS). This technique is safe for pilots and passengers flying above a contaminated area. You can use this technique to take measurements after a nuclear incident but it is also useful system for measuring radioactivity from previous contaminations."

An Agusta helicopter was on stand-by at the Beauvechain air force base : "Thanks to an agreement between the Ministries of the Interior and of Defence, the army provides at least one helicopter for emergency planning. We flew to Mol and on the way we took real measurements at a historically contaminated site where we inspected the area from a height of 100 metres. In just a few seconds our detectors are able to collect sufficient statistical data in order to quantify the contamination. The results were identical to the measurements I had taken on foot a while ago at the site."

MEASUREMENT TEAM EXPANDED

SCK·CEN has its own measurement team, which can be called on to carry out on-the-spot measurements after nuclear incidents. Six or seven people are needed during an intervention: at least two to take samples, two to prepare the samples and two to carry out the measurements. The team was expanded in 2015. Twenty potential operators applied following a call for candidates. They received theoretical and practical training in, among other things, measurement tools, personal protection equipment and communication. Then they went out and about as assistant operators along with an experienced colleague.

02

Push boundaries

“Smart radiation measurements after incidents”

Electronic components and mobile phones as dosimeters

When there is a radiological incident, people in the surrounding area can be exposed to significant radiation doses. It is important to know precisely how much, for example to treat victims or to reassure them. But how do you measure retrospective doses if no one has a specialised dosimeter on them? And how useful are smartphone apps for measuring radiation? Filip Vanhavere and Olivier Van Hoey give us an insight into the use of mobile phones and smartphones as incidental dosimeters and real-time detectors.


Filip Vanhavere, Dosimetry and Calibration

Which materials are suitable as incidental dosimeters? And how do you measure the radiation dose?

Filip Vanhavere: Radiation-sensitive components can serve as incidental dosimeters for retrospective measurements, so that the radiation dose can be assessed after the event. Look at a mobile or smartphone: the resistors on the electronic circuit, the back of the chip in the SIM card and the glass of the screen are highly suitable. If these components are heated or lit up after being exposed to radiation, the electrons in the material will ‘climb’ to a higher level. Afterwards they ‘decay’ to the lowest energy level and luminescent light is released. Then you can take measurements with specialised equipment. The quantity of emitted light is to a large extent proportional to the radiation dose. With this technique you can measure the radiation dose incurred over an extended period.

The more radiation, the more light

This luminescence under the influence of radiation is found not only in mobile phones or smartphones, but also in ordinary consumer articles…

Filip Vanhavere: That's right. You will find such luminescent properties to a greater or lesser extent in all kinds of electronic components, but also in dust, shoe soles, items of clothing, ceramics, sand, etc. The more radiation they have absorbed the more light is released if you heat or light them up afterwards. In recent years, we have characterised in detail various components as incidental dosimeters. Important properties for this are the minimum detectable dose, the signal decay over time, the relationship between dose and signal, the reproducibility and changes in sensitivity.

Can you measure radiation of incidental dosimeters on the spot or is this only possible at SCK•CEN?

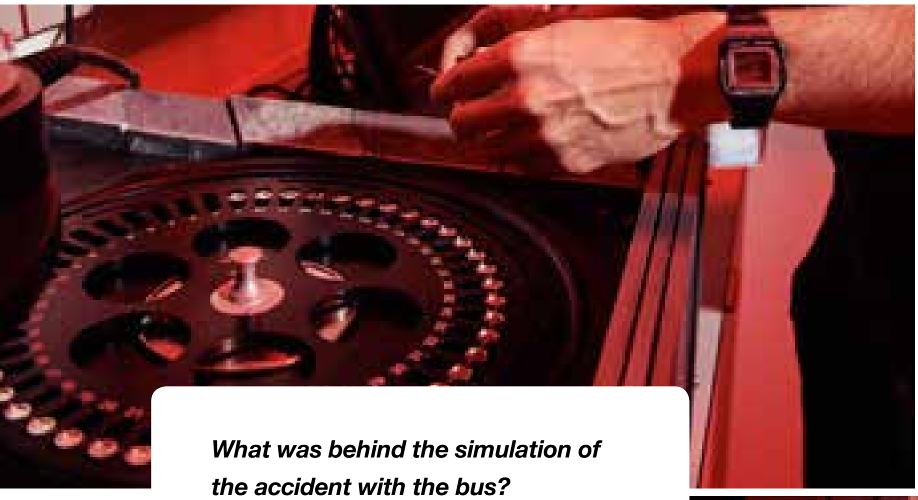
Olivier Van Hoey: Investigation based on luminescence is only possible in specialised laboratories such as the one we have here in Mol. You might therefore need to make your bank card available because we need the chip in order to measure the radiation dose. I must admit that this will involve practical problems. We could also use tooth enamel, but then you would have to give us one of your teeth. But we aren't going to do that. *(Laughs)*

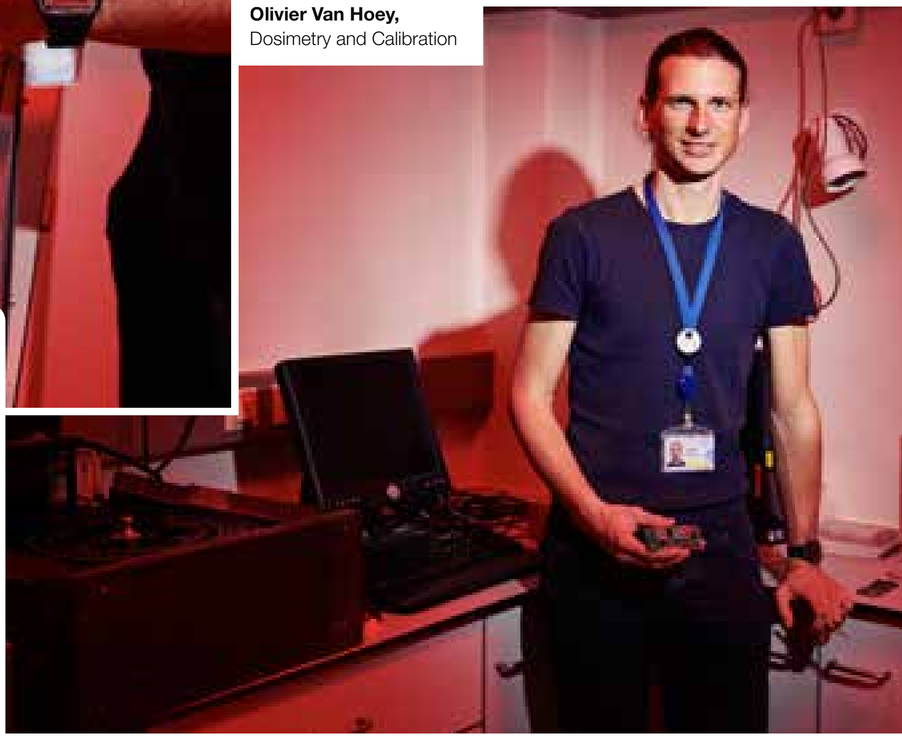
Simulation of an accident in Bolivia

There was an accident in 2002 on a passenger bus in Bolivia involving a radioactive iridium source used in pipeline inspections. You have now reconstructed this accident in cooperation with various laboratories. Why?

Filip Vanhavere: The reconstruction of this accident has been used as a realistic test case for retrospective dosimetry. The case focussed on the investigation itself: human models were equipped with both specialised and incidental dosimeters, for example mobile phones. This allowed us to compare real and incidental dosimeters. The radiation doses in various parts of the body were also simulated with a computer code based on the Monte Carlo technique.

> *"We have characterised in detail various components as incidental dosimeters."*





Olivier Van Hoey,
Dosimetry and Calibration

What was behind the simulation of the accident with the bus?

Filip Vanhavere: We determined that the resistors inside mobile phones are particularly useful for dose reconstructions. Other materials are also useful: even shoe soles and dust are useful for rough estimates. The major uncertainty in the results arose from the heterogeneity of the radiation field. So there was a difference between people who carried their mobile phone on the left and those who held it on the right. If you want an accurate overall picture of the situation, then these details are important — but people often forget such details. For this reason, you need to use as many different incidental dosimeters as possible. That way you will obtain the most complete picture possible, so you can make the most accurate dose estimate possible.

Within Eurados, the European Radiation Dosimetry Group, you work together with laboratories from many countries. Do you compare the results between these laboratories?

Olivier Van Hoey: Absolutely. This is why we participated in a Eurados inter-comparison at the end of November 2015. Various laboratories received mobile phones that had been irradiated with a dose that was unknown to the participants. The aim was to use the luminescence in the glass displays of those mobile phones to reconstruct the radiation dose. These and other investigations show that the differences detected are not that large.

Apps for measuring radiation

In the meantime, there are about a dozen apps for smartphones on the market with which you can measure radiation. They are not all equally reliable. How can you extract reliable results from such measurements?

Olivier Van Hoey: These apps measure radiation by means of the smartphone camera, which you first have to cover up with black tape. They are meant to measure radiation at a specific moment in time. For some applications it is possible to put the data online. If we were to collect the data on a map and analyse it, then we would have a good idea of the radiation level in a specific area. The individual data itself is perhaps not sufficiently exact because the measurements were taken too briefly. By combining the measurement results it is still possible to make a reasonably good estimate of the radiation level.

Wouldn't it be better that such measurements are carried out by SCK•CEN's own measurement teams?

Filip Vanhavere: Of course those teams are useful for specific and local measurements, but they are too few in number to carry out a full measurement in the case of an accident over a large area, such as all of Belgium. Imagine instead that you have a network of people making measurements over the entire country, then you can ask them to measure for 10 minutes with their mobile phone and you can collect and process all the data in just half a day. In this way, ordinary people can be of great service.

Sharing knowledge to reduce risks

Towards a safer CBRN situation in countries surrounding the European Union

How can we in Europe and beyond reduce the chemical, biological, radiological and nuclear (CBRN) risks and manage the consequences of any incidents? The European Commission posed this question in terms of its security and peace policy. SCK•CEN is also contributing to this awareness-raising project inside and outside the European Union.

The European Commission created the *Instrument contributing to Stability and Peace* (IcSP) in order to strengthen stability and peace both within the European Union and more widely in the world. Support from the IcSP includes that given to the *CBRN Centres of Excellence,* an initiative to prevent CBRN incidents or to reduce their consequences. Several SCK•CEN scientists are involved in these European projects on nuclear security and emergency planning. We talked to Klaas van der Meer, Carlos Rojas Palma and Matej Gedeon.

Carlos Rojas Palma,
Crisis Management and Decision Support

Handbook, procedures and courses

Governments and businesses in many countries need knowledge about how to deal with the consequences of CBRN incidents. “That is why we compiled a handbook on dealing with radioactive sources in terrorism cases,” says Carlos Rojas Palma. “We also summarised crisis management procedures based on comprehensive CBRN knowledge. This handbook brings together technical and operational information for a wide target group – from the European Commission, through businesses to end users.”

This is not limited to just compiling handbooks and procedures. Carlos: “We want to provide a course to the police, emergency services and intervention teams throughout the 28 member states of the European Union. This will be done in cooperation with the Federal Agency for Nuclear Control, the multidisciplinary Campus Vesta training centre for professional safety training courses, the University Hospital of Ghent and the Federal Public Health Service, from whom we received great acclaim for the content of our course. There is a lot of interest in this initiative.”

Klaas Van der Meer,
Society and Policy Support

Lebanon, North Africa and Eastern Europe

Klaas van der Meer talks about some international projects: “SCK•CEN drew up a national CBRN response plan for Lebanon. There are now detailed standard operating procedures (SOPs) available and a list of materials needed for first aid intervention. At the request of Lebanese officials, we also performed a dispersal calculation in case of an accident at the Israeli Dimonah reactor.”

SCK•CEN did similar work in Africa for the Moroccan Civil Defence service, but the team plays a particularly important educational role in East and Central Africa: “There is a serious lack of knowledge within first aid organisations about how they should respond to chemical and

A basis for better legislation

SCK•CEN also works together with international partners in the context of the CBRN Centres of Excellence in order to make Europe’s external borders more stable and less vulnerable to CBRN incidents. Klaas van der Meer: “Many countries have very weak legislation when it comes to CBRN. We can indicate how they can amend their laws to better combat improper use of CBRN materials and to prosecute criminal and irresponsible use of these substances.”

On a more practical level, SCK•CEN specialists train employees of first aid organisations to respond better, more rapidly and more effectively to CBRN incidents. “We teach people how to protect themselves, how to measure radiation and the best ways to respond to an incident. Our knowledge is welcome, because there are often strong parallels between the approach to nuclear incidents and, for example, the approach to chemical incidents.”

“We teach people how to protect themselves, how to measure radiation and the best ways to respond to an incident.”

radiological incidents. The population is often not well-informed either. For this reason, we organise awareness campaigns close to chemical factories, because people often do not realise that fleeing is not necessarily the best response during a CBRN incident.”

SCK•CEN is also leading a major project in the Balkans and the Black Sea area. Matej Gedeon explains this: “We are helping to improve the legislation and procedures in various countries. We will also hold exercises in order to train multidisciplinary teams. We have the necessary experience: in 2015 we organised a field exercise in Mol, dealing with radiological risks, for a dozen emergency responders from different countries, including from Slovenia, Romania and Estonia. We conduct simulations during such training courses and investigate how team members respond to an incident, we let them test equipment and show them how they can best communicate. There is now less CBRN terrorism in Eastern European countries than in the past, but we are increasingly confronted with incidents related to derelict factories or abandoned hospitals.”

Work to be done

The European Commission has outlined a plan for CBRN projects up to 2020. During the next two years, our specialists will provide a large number of training courses and we will organise concrete exercises: “Various first aid organisations will be equipped with modern first aid materials. In this way, we hope to contribute to a safer CBRN situation in countries surrounding the European Union.”

Response

to social challenges outside the nuclear sector

SCK•CEN has built up international recognition in radiation protection, medical applications, dismantling of installations, waste and disposal, and all this with a unique integration of social and human sciences. We also put our expertise to use in social challenges outside the nuclear arena: emergency plan preparation and training in the context of CBRN risks, research into the ageing of concrete, projects to make deep space travel possible, studies relating to geothermal heat. We are active in all kinds of areas and always put the importance to society centre stage.

Hildegarde Vandenhove

Environment, Health and Safety Institute Director

Successful dismantling of sodium installations

More space for new applications

At the start of the 1970's, researchers at SCK•CEN designed a number of experimental circuits for testing the behaviour of sodium as the coolant for fast reactors. These installations were shut down for good after ten years and have been preserved ever since under an inert atmosphere, until that is, the Decontamination and Clean-up Processes unit was given the task of dismantling them. This was a step into the unknown with a potentially dangerous chemical element.

“The thorough preparation and the intense cooperation between various services inside and outside the research centre meant the project could be carried out safely, smoothly, and on schedule.”

Before dismantling

After dismantling

The cleaning and dismantling of all the infrastructure used for experiments with sodium had to not only create space, but also to remove an environmental and safety hazard in the form of the 8 tonnes of sodium present on the SCK•CEN site. Besides sodium, the inventory also contained NaK, an alloy of sodium and potassium which is liquid at room temperature and even more reactive than sodium.

All the sodium installations were housed in the Technology building: individual items, small installations, a pilot circuit (ASL1) and a semi-industrial cicuit (Na-3), all of which had become ‘contaminated’ with non-radioactive sodium or NaK during their operational periods. When sodium comes into contact with water, or moist air, this can lead to explosively dangerous situations. Both loops were therefore placed under argon atmospheres, so that the sodium remained permanently screened off from the air. The team also worked as much as possible under inert conditions during the clean-up and dismantling operations.

Searching for knowledge

Since SCK•CEN had stopped experimention with sodium back in the early 1980's, the team members lacked practical knowledge about both dismantling installations and working with sodium. Therefore they first undertook training at the French *École du sodium* (sodium school). They could also call on the services of a retired project engineer who had been involved in the design and operation of the installation. He explained the blueprints and logbooks.

By using, amongst other things, endscopy and radiography, the team was able to describe the condition, quantity and topography of the sodium and NaK residues, resulting in a more detailed and accurate inventory. They researched dismantling techniques and cleaning processes, taking into account the properties of sodium and NaK. Tests carried out in a custom-built pilot installation showed that the water vapour-nitrogen (WVN) process and carbonatation were the most suitable cleaning techniques. WVN is a controlled reaction of metallic sodium with superheated steam. In the case of the carbonatation process, carbon dioxide is also brought into contact with the sodium in addition to the steam. This process is simpler to control than the WVN process, but it is slower and, partly due to the higher temperatures required, cannot always be applied.

A three part project

The first part of the project consisted of dismantling, packing up and disposing of the Na and NaK present in individual items, small installations and the ASL1 pilot circuit. This involved about sixty reservoirs and filling and distillation installations for a total of 900 litres of sodium and 100 litres of NaK.

Then it was the semi-industrial circuit's turn: a large eight-storey installation, with four basement levels, including a filling tank, a dump tank, pipework, heat exchangers and more than 7,000 litres of sodium. Sodium melts at approximately 98 °C. As a test case, 500 litres of sodium were first melted inside the filling tank: heated to more than 120 °C in order to transfer it as a liquid into specially designed waste containers. Then the sodium remaining in the horizontal piping of the Na-3 installation was melted and transferred under low pressure to the dump tank, after which the 7,000 litres could be removed from the dump tank into waste containers.

The final step was to dismantle the loop itself which consisted of, amongst other components, a pump, a cold trap, a furnace, two heat exchangers, test sections, pipes, valves and the dump tank underneath. The team removed the protective structure surrounding the Na-3 loop in order to systematically cut up the components and to manipulate them with the help of the overhead crane. A large part of the circuit was cleaned on the spot, after first cutting it up, and removed as scrap metal.

The WVN process was used at the end of phases two and three to remove the residual sodium on the walls of the filling tank and the dump tank. After a necessary extra manual intervention, both tanks were rinsed with water and removed as scrap metal.

The project ran for a period of five years and was completed in 2015. SCK•CEN called on the services and expertise of a French company, *Métaux Spéciaux* (MSSA), for the actual implementation and removal and further processing of all sodium and sodium-contaminated components. The thorough preparation and the intense cooperation between various services inside and outside the research centre meant the project could be carried out safely, smoothly, and on schedule. This created space for new applications inside the Technology building.

Experience for two other projects

There are at least two related projects in the pipeline, for which the gained experience could be useful. There is still another pilot installation inside the building used for testing lithium, also an alkali metal, as coolant. In the near future SCK•CEN intends to dismantle this installation in a professional manner, even if the 100-200 litres of lithium are not actually radioactively contaminated. In addition, there are residues elsewhere on the BR2 site from experiments with radioactive sodium or NaK. Thanks to a new treatment cell it will be possible to safely remove those residues.

What is the expiry date on concrete and cement?

Research on materials for waste disposal and other applications

If you want to store radioactive waste for hundreds or thousands of years, are concrete and cement sufficiently reliable in the long term? As construction and barrier materials, they play a considerable role in preventing radioactive waste coming into contact with people and the environment. But how well do they actually succeed in this? Thanks to two doctoral research projects, SCK•CEN has built up considerable expertise on cement-containing materials. Various agencies are already making use of our knowledge.

Many studies have already been carried out on the weathering of cement and concrete for the construction industry. These studies tend to deal only with periods of upto hundred years, because the research is centred on structures such as bridges and buildings which only need to last for a limited time. Such studies,

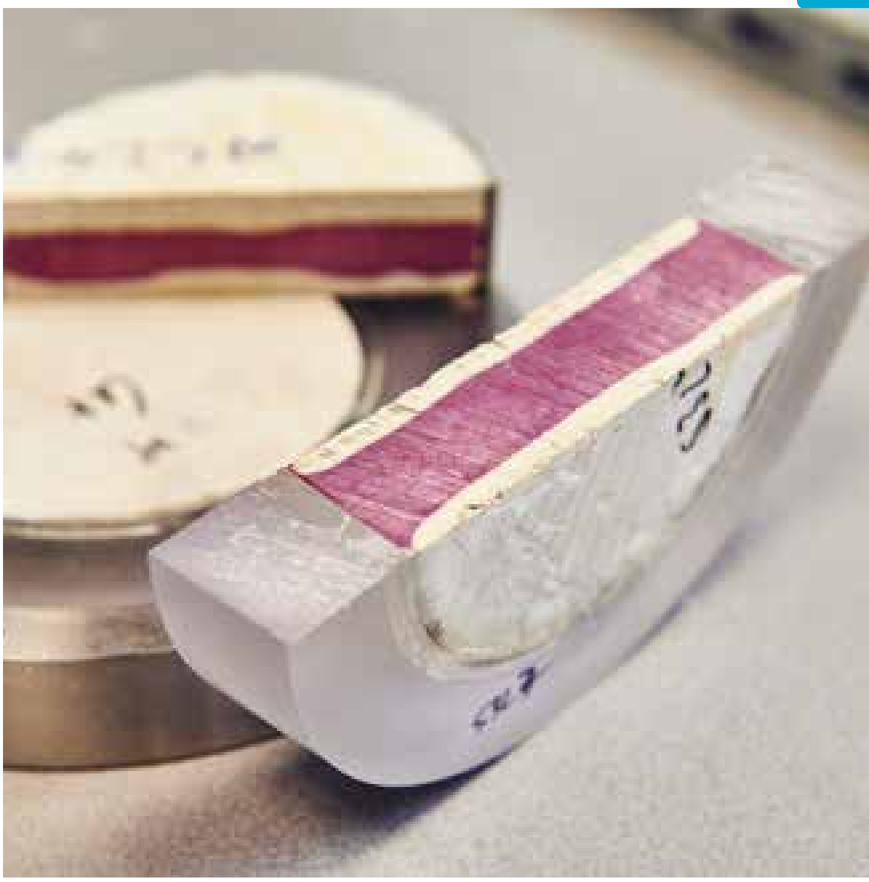
> *The collaboration with the universities served to improve even further the quality of the research.*

therefore, are of little relevance to the disposal of radioactive waste. In fact, for the geological disposal of medium- and high-level radioactive waste and the surface disposal of low-level waste much longer periods of time are taken into account. And then other factors, such as changes in diffusion, porosity or permeability due to weathering over very long time periods, become more important. And what is the impact of these, in terms of safety, over a period of hundreds or thousands of years?

Collaborative research with universities

To answer the question, the *Performance Assesments* and *R&D Disposal* units started up a research project in 2011 to study the most important processes affecting the long-term durability of cement-containing materials. These have a naturally very high (alkaline) pH value, but, due to contact with the environment, the pH falls and the structure and composition of the cement-containing material change accordingly. The scientists investigated in particular those properties that regulate the flow of water and the movement of dissolved substances, including radionuclides, through the porous structure. The project was run in collaboration with two world renowned research groups in the field of concrete research: *Labo Magnel* at the University of Ghent and *Microlab* at the Technical University of Delft.

SCK•CEN employees had already developed similar experimental techniques for the study of clay; now two doctoral students were given the chance to look at concrete. Phung Quoc Tri used accelerated weathering processes to simulate long-term weathering, in order to measure the effect of this on the properties of the concrete. Ravi Patel developed a numerical model in order to model these processes at the micro-scale. The collaboration with the universities only served to improve even further the quality of the research carried out



Effects of weathering processes

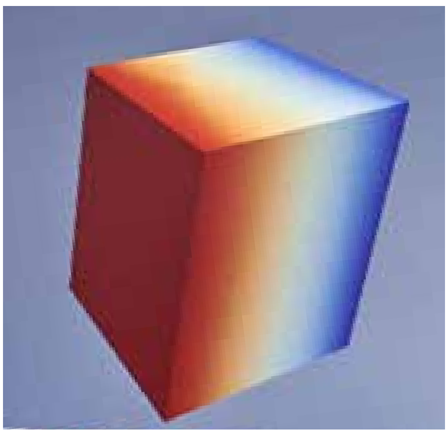
The first experimental research examined the effect of weathering processes on the microstructure of concrete: what are the effects on water permeability and diffusion transport properties? Doctoral student Phung Quoc Tri developed and refined various innovative experimental techniques dealing with accelerated weathering, water permeability and diffusion of dissolved gases.

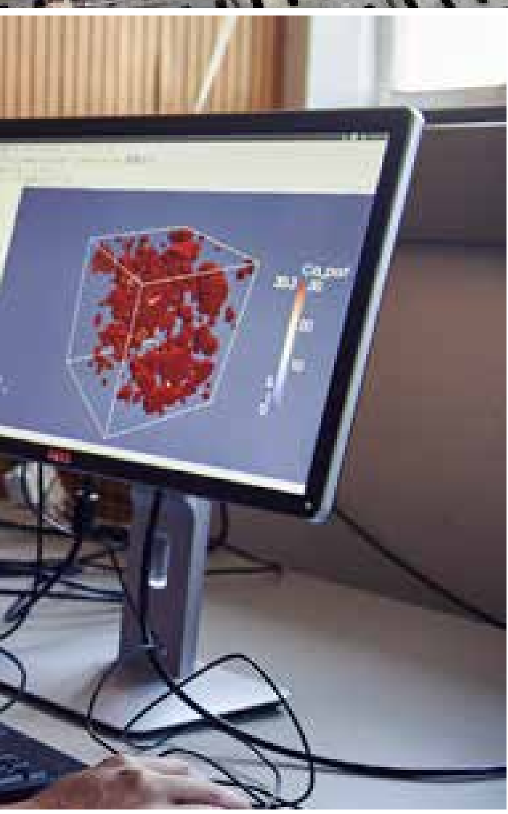
With his experimental research he succeeded in describing how cement-containing materials weather under the influence of carbonatation (conversion of cement minerals into calcite) and decalcification (leaching of calcium). Both these weathering processes are relevant for waste storage. He also investigated how the weathering of the materials can be linked to their transport properties, which, amongst other factors, determine how radionuclides are transported.

Long-term model

The second researcher, Ravi Patel, succeeded in developing a model to determine the transport properties of cement materials based on microstructural information. He was faced with the challenge of developing mathematical models that would reproduce the weathering processes and their effects on transport properties at the microscale. The ultimate purpose of his research was to predict the long-term behaviour of the materials. He added a number of new elements to the 'lattice Boltzmann formalism', which is a way of simulating transport processes in a microstructure. The most important innovation is the possibility to link the transport model to a geochemical model.

In practical terms a simulation runs as follows: starting from information about the microstructure of cement-bearing materials (pore size, connectivity of pores, distribution of cement minerals), the researchers simulate transport properties. If this transport model can be linked to a geochemical model that simulates weathering, it is possible to predict the evolution of the microstructure, the chemistry and the transport properties over very long time periods. The predictions from the simulations can be tested against experimental observations.





Resulting contracts

The success of both these doctoral studies has led to research and development contracts, including with the European Commission, the National Agency for Radioactive Waste and enriched Fissile Material (NIRAS) and ENGIE.

For the European Commission and NIRAS, SCK•CEN will study the effects on transport properties when Boom Clay and concrete are brought into contact with each other. Components in Boom Clay cause weathering of the concrete whilst, in return, components released from the concrete cause chemical changes in Boom Clay.

For ENGIE, the researchers want to learn how microfissures accelerate carbonatation and how carbonatation in turn changes the microstructure and the transport properties of fissures.

New doctoral projects

The two research projects will be extended with a study into the effect of aggregates on the weathering of cement-bearing materials. In addition, the experts will use visualisation techniques such as X-ray tomography to investigate how gas transport occurs in these materials. There will also be an experimental study into the interaction between cement constituents and nuclear waste. The emphasis here will be on the precipitation of expansive minerals and its effect on transport and mechanical properties.

SCK•CEN will expand its experimental installations and modelling capabilities even further for both the ENGIE project and the study into the effect of aggregates.

SCK•CEN explores the missing link between experiments and theory

Nuclear fuel laboratory for advanced experimental research

During the last 25 years nuclear fuel research at SCK•CEN was focused primarily on in-reactor behaviour and less on front-end research. This changed recently thanks to the construction of a brand-new nuclear fuel laboratory. In the course of 2015 the laboratory received its final licence to be able to work with all forms of uranium and thorium – in liquid, powder and pellet forms. The experiments are highly complementary to the research performed at the BR2 reactor.

Since its inception, SCK•CEN has carried out applied as well as fundamental research on fuel for nuclear reactors. Extensive research on fuel continued upto 25 years ago by which time this activity had matured to an industrial level and could be handed over entirely to Belgonucleaire.

A place for experiments on solids

In recent years, SCK•CEN has invested mainly in post-irradiation research into new nuclear fuels for BR2, as well as making progress in theoretical research on both current and future nuclear fuels. However, the possibility of carrying out experiments on solid phase materials was missing from this overall picture. Thanks to the financing from the nuclear industry and from Europe, the possibility finally arose to set up a new laboratory for advanced experimental research on solid phase materials.

A team of experts carry out both fundamental and applied research in this new laboratory. Thanks to their work, SCK•CEN is in a position to bridge the gap between theoretical research and the practical realisation thereof. It is now possible to carry out detailed research on nuclear fuels at the laboratory scale.

“Research becomes faster, more thorough and more complete thanks to the closer relationship between theory, experiments and industrial and societal questions.”

What does it actually involve?

The experiments carried out in a nuclear fuels laboratory result in both in-reactor experiments and complementary research. One example of the latter is research into the oxidising behaviour of uranium. The data resulting from the laboratory research is subsequently tested using theoretical models for numerous different extreme conditions. If such a model is capable of predicting what takes place in normal and exceptional conditions, then it will contribute significantly to reactor research.

This fundamental experimental research seeks to explain the features of uranium and thorium compounds that are applicable to all phases of the nuclear fuel cycle: production, in-reactor behaviour and used fission material.

Empirical research, often very valuable, was carried out in the past but sometimes too little attention was paid to the underlying mechanisms. As a result, the researchers continued to work on a research path that afterwards did not turn out to be successful. The link between experimental and theoretical research was also often missing. The new laboratory fills this gap: thanks to closer relationship between theory, experiment, and industrial and societal questions, it is possible to respond much more quickly. The research becomes faster, more thorough and more complete.

Construction of the new laboratory started in 2010 thanks to a co-investment from the nuclear industry via AREVA. The financing was completed by funding from the seventh European framework programme MAXSIMA of 2013 and SCK•CEN's own resources. In the meantime, the *Fuel Materials* expert group built up the infrastructure step by step in close cooperation with the *Health Physics* unit. The final licence was issued in 2015; the nuclear fuel laboratory can now work with uranium and thorium in liquid, powder and pellet forms.

Highly promising

The first results are highly promising: in 2015, in the context of two doctoral studies, the grid constant of uranium dioxide was calculated ten times more accurately than was previously possible and new phases were discovered in thorium-gadolinium oxide compounds.

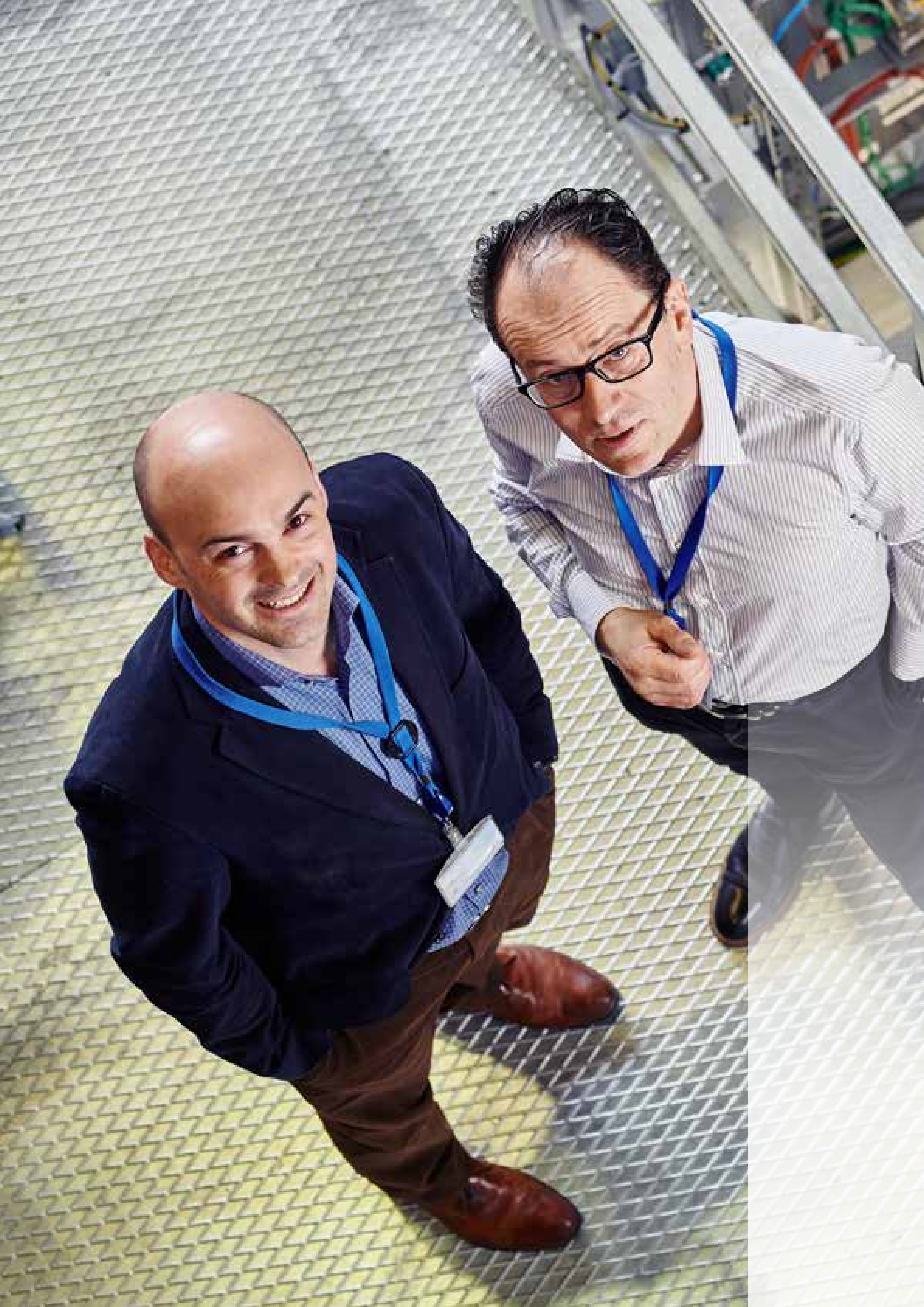
Furthermore, model compounds were created that simulate the behaviour of spent nuclear fuels over several hundred thousand years. These model compounds will be useful in studies that NIRAS, the National Agency for Radioactive Waste and enriched Fissile Material, requires in order to investigate the safety of disposal options for spent nuclear fuels.

In 2016, the laboratory experts will produce nuclear fuel rods in order to carry out safety studies for the MYRRHA reactor. These studies take place as part of a European collaborative project (MAXSIMA). The purpose of the project is to investigate in detail the interaction between the nuclear fuel and the tubing.

Fully booked up

SCK•CEN only uses the services of other laboratories for very specific research on nuclear fuels. What is more, both businesses and research institutions are very interested in the new nuclear fuel laboratory: the diary for 2016 is completely full and 2017 is already heavily booked up by external partners. The research centre works closely with them in order to provide well founded scientific feedback about the practical application of the research conducted.

One of the current research topics is the demand for nuclear fuels that produce less waste and are based on thorium. SCK•CEN has long carried out research into the in-reactor behaviour of thorium-based fuels, but one of the greatest problems remaining is the difficulty of producing this nuclear fuel. In collaboration with industrial partners, a master's thesis and a doctoral thesis are on-going with the aim of making a breakthrough in this area. The new nuclear fuel laboratory is immediately contributing to SCK•CEN's ambition of continuing to play a leading role in the world of nuclear science.

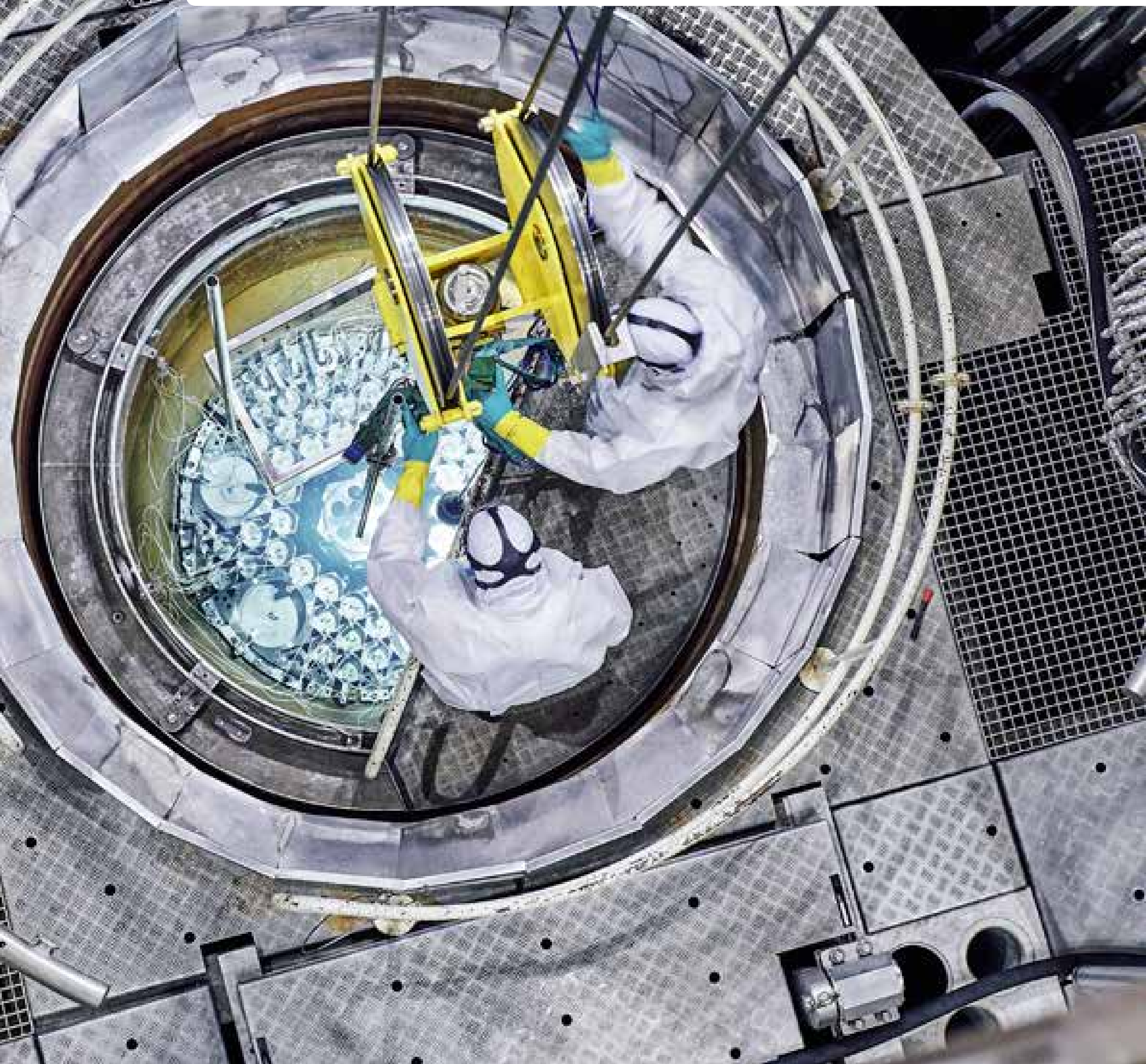


03

Develop and innovate

“BR2 receives a sixteen-month makeover”

Essential in support of public health and safety research



In February 2015, SCK•CEN shut down its BR2 research reactor for a 'refurbishment' lasting sixteen months. Everything has to be ready in July 2016, in particular to produce radioisotopes again for the medical sector. The most significant part of the refurbishment is the replacement of the matrix, the internal structure of the reactor vessel, which is not an easy task due to its complex construction. Steven Van Dyck, the BR2 reactor manager, and Paul Leysen, head of the Nuclear Systems Design group, offer an insight into the progress of the work.

Paul Leysen, Nuclear Systems Design
Steven Van Dyck, BR2

A strict planning has been set up for the refurbishment of the BR2 reactor. The reactor has to function again in 2016. Why is the schedule so strict?

Steven Van Dyck: Internally, almost all of SCK•CEN's services are directly or indirectly affected by the refurbishment. To the outside world, BR2 is the essential global supplier of radioisotopes. This is not just an idle boast! There are only six reactors in the world that export isotopes. Many countries have to import them. At the end of 2015, the French reactor, Osiris — which represented 20 per cent of global production — stopped producing radioisotopes and at the end of 2016, there will be no more routine production at the Canadian NRU reactor. There is no direct replacement for either of these.

Paul Leysen: The buyers are a limited number of medical firms which process isotopes into radiopharmacological products for hospitals. Supplying these companies is essential in order to support public health and the medical sector. When BR2 restarts in July 2016, the sector will heave a sigh of relief.

How did you plan all the necessary work in concrete terms?

Steven Van Dyck: We had already set up a weekly schedule some years ago. Above all, the work in and immediately next to the reactor is critical: the replacement of the matrix, the inspection of the reactor vessel and the removal of the neutron tubes. This is all finished now. In the spring of 2016, we will load the new matrix channels and we build up the reactor again step by step. We report every month to the safety authorities – the Federal Agency for Nuclear Control (FANC) and its technical subsidiary Bel V – and we hold follow-up meetings with their inspectors. We communicate clearly about all the changes and modernisations that we are carrying out for verification purposes. In this way, we can avoid still having to obtain a large number of approvals at the end of this process. Now we have every phase approved.

So neutron tubes were removed from the reactor. What was the point of that?

Paul Leysen: In order to carry out certain tests, in the past, the neutron tubes were placed next to the reactor core: these are hollow tubes which lead the neutrons from the reactor core to experiments outside the reactor dock. We have removed the ten neutron tubes because we do not plan to carry out any more irradiation programmes. A French company has designed an automated means of mechanically cutting these off remotely, because the reactor core is radioactive. This milling machine is capable of correcting itself from its own position in order to shave off the neutron tubes and flatten these. We counted on October and November to remove them, but we finished in two weeks, thanks to excellent preparation and also because the radiation level was many times less in practice than what we had anticipated during the preparation.

Certain sections have been removed, but a lot of components have been replaced particularly in and around the reactor.

Steven Van Dyck: In fact, we have revised one of the four large pumps in the primary circuit. The water in this circuit flows through the reactor and cools the nuclear fuel. It is therefore essential that the pumps work well. For this reason, we also bought a reserve pump to use if one of the other pumps were to show a defect in the future. In this way, we can guarantee the availability of the pumps for the cooling of the reactor core in the longer term. In the secondary circuit, the large pipes which run under the road to the cooling towers have been replaced. The discharge from the reactor dock, which under normal circumstances is filled with water, was also modernised. And there were a lot of upgrades to the electrical, instrumentation and nuclear ventilation systems.

Paul Leysen: We replaced all of the underground pipes. Most of them had been in use for fifty years. The structure of the cooling towers was upgraded and all of the mechanical components were replaced. All the underground cables, distribution boards, transformers and the electrical emergency power grid were checked and modernised where needed. These are often preventive replacements, but this also makes the installations more reliable and easier to maintain using current techniques. Many internal employees and external partners were active at various sites.

Because of its complex structure, replacing the matrix was the biggest challenge in this operation. Also, the calculations of the matrix were not entirely correct in the previous two refurbishments. Why did this happen?

Paul Leysen: BR2 is sixty years old. In the old days, the drawings were on paper, all calculations were done manually and the dimensions were transferred manually to the drawings. Moreover, we did not know whether what resided in the reactor corresponded exactly to the reports and the drawings. So we started from nothing in 2012, using the most general hyperboloid mathematical formula. You should be aware that draughtsmen used to make human errors. After the calculation, they may have put the wrong result on the drawing. A ‘transcription error’ is impossible in computer-aided design (CAD), because the data comes directly from the calculation model. If you manufacture everything precisely in the way you have designed it and you take account of the tolerances in your calculation, then it has to fit. We verified a number of drawings from the past using the CAD model. Everything matched and we resolved the calculation errors from the old drawings.

> *When BR2 restarts in July 2016, the medical sector will heave a sigh of relief.*

SCK•CEN had to make an appeal to external partners in order to produce the new matrix. How did you deal with this?

Paul Leysen: We first compiled a short specifications manual and then we visited the interested companies to see whether they were capable of creating the matrix. We selected three candidates for the steel parts and one American company for the beryllium. The contracts were awarded mid-2013 and the production took approximately eighteen months.

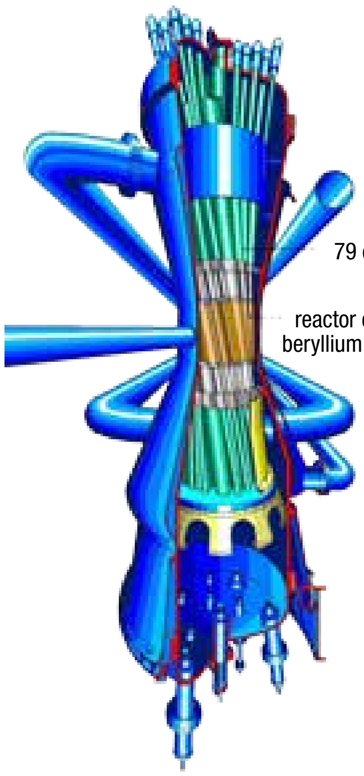
Steven Van Dyck: That seems a long time, but the production is hugely complicated. We monitored the production process strictly in order to overcome all of the problems together with the manufacturers. The components, which are all separate items, were delivered to Mol in 2015. All the channels were assembled here and placed in a test vessel.

But that wasn't that easy?

Paul Leysen: No, but it went a lot more smoothly than we expected. We first compiled a picking list per channel and thoroughly checked this. Each channel consists of five large and twenty or thirty small parts, and it is essential that every part is clearly known in every detail. Then we started on the assembly. There are three channel sizes: the small channels have an internal diameter of 50 mm, the medium ones 80 mm and the largest 200 mm. The latter makes BR2 unique. This is the only test reactor in the world in which you can place such large test rigs. And we have five of these large channels!

THE BR2 MATRIX

The central section of the BR2 reactor consists of a beryllium matrix, composed of hexagonal channels containing the nuclear fuel elements, the control and regulating rods and various irradiation devices. This matrix forms the heart of the reactor. Although the capacity and the volume (approximately 1 m³) of the core are 30 times smaller, BR2 produces a neutron density that is 500 times greater than in a power reactor.



Steven Van Dyck: We expected to assemble the channels in the course of 2015, from the end of January to November, but we had already finished everything by August. We had planned on one per day for the assembly of the small and medium channels, and one week for the large ones. We met every Monday with reactor and project managers, designers, mechanics, reactor operators, industrial safety specialists and physical controllers and inspectors. Every non-conformity was reported. As soon as all of the channels were ready, Bel V came to inspect the result and to validate the conformity with the specifications.

Paul Leysen: Then the time came to mount everything in the test vessel, a life-size model of the reactor vessel. If it fits here, then it also has to fit in the actual BR2 vessel. Eventually, we were able to install all of the channels, without errors. This is impressive when you consider that the tolerances are only tenths of a millimetre. The placement of the final channel was tense, but it fitted!

In the meanwhile, extension pieces have been developed to attach the channels in the reactor. We have reserved two months for this installation in 2016, but it may go faster, because we only needed two weeks for the test rig. What is more, the sequences have been repeated and we made video recordings of all the movements. These will come in useful later.

When will BR2 be operationally ready?

Steven Van Dyck: We will take measurements and put the lid on the reactor in spring. After that, we will test everything in cold and hot conditions to see whether all of the systems are in order. We will then ask FANC for permission to load nuclear fuel and we will start from zero power to critical operation. Lastly, we will load all the experiments and irradiation installations. We should be ready for the first operational cycle during the second or third week of July 2016.

UNITED FORCES

Although, at first sight, nearly all the refurbishment is conducted on the BR2 site – both literally and figuratively – this is really a joint project involving all of SCK•CEN. From the planning, design and technical detailing up to the administration and purchasing, a multitude of services and people within and outside SCK•CEN have worked on this project, which will also shape our research centre in the near future.

The BR2 licence is reviewed every ten years. If the reactor restarts in 2016, does that mean that 2026 is the end date?

Steven Van Dyck: Legally speaking, there is no end date. Therefore, the next ten-year period does not have to be the last. That is why we are looking now at which components need to be modernised or serviced. We often opt for new components that have a lifespan exceeding ten years. What is more, SCK•CEN's strategy is intended to have a large irradiation installation permanently available.

Paul Leysen: The case of the reactor vessels in the Doel 3 and Tihange 2 reactors has demonstrated that BR2 has significant added value, not only for our research centre, but also for the entire country. Without BR2, it would not have been possible to demonstrate that the impact of the microcracks that were detected is so small that further operation of the power plants is justifiable.

Steven Van Dyck: For this reason, we are already looking at the period between 2026 and 2036. Also for the parts that we are not replacing now – for example the reactor vessel – we already have a campaign running to evaluate the current and future conditions. We certainly intend to continue this programme until 2036.

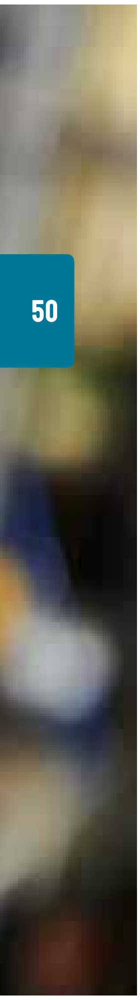
Renewing

to the core

Nuclear knowledge and technology at SCK•CEN are unaffected by wear and tear. The third refurbishment in its fifty-year existence keeps our BR2 reactor in peak condition. Thirty years after the initial production of radioisotopes in BR2, these substances are now being successfully and extremely effectively employed in cancer treatment. And also, thirty years after the invention of MOX fuel, we are now using this technology to develop thorium-based nuclear fuels that produce less waste. Continue to innovate, that is our mission.

Leo Sannen

Nuclear Materials Sciences Institute Director



Goodbye CALLISTO, hello ReCall

New flexible set-up for BR2

The refurbishment of BR2 offers SCK•CEN the ideal opportunity to take a close look at the irradiation set-ups in the reactor. For example, CALLISTO achieved great results for more than twenty years in fuel and materials research. But it became clear that this concept was not flexible enough for modern use. Consequently, SCK•CEN decided to uncouple the material and fuel experiments. One of the first new installations is ReCall, developed for the irradiation of reactor vessel material.

Each new set-up will do a part of what CALLISTO was able to do. In ReCall, the researchers will still be able to irradiate standard samples of reactor materials for Charpy impact tests under the conditions of a pressurised water reactor, but in smaller quantities. The flexibility of the system is the major advantage.

Movable installation

CALLISTO was a rig that was permanently inside the BR2 reactor. SCK•CEN wishes to incorporate more flexibility in the future. That is why ReCall, which stands for *Replacement of CALLISTO*, will be a movable installation with which it will still be possible to maintain a constant temperature of approximately 300 °C.

The heating takes place within the casing tube in an irradiation channel, even if the reactor is out of service. For this reason, ReCall will include both heating elements as well as thermal insulation, with a smaller housing for samples as a result. The number of standard Charpy samples has been reduced from 100 to 20. It was a real challenge for the designers of ReCall to figure out a feasible layout for such a limited space, which is under high pressure.

In practical terms: similar irradiations such as those required for research of the Doel 3 and Tihange 2 reactors can be performed perfectly in ReCall (see page 58). The only difference is that in ReCall, fewer samples can be irradiated simultaneously.

> *“In ReCall, we will be able to perform irradiations such as those required for the Doel 3 and Tihange 2 reactors.”*

Assembly and testing

The designers played it safe. The design has been validated by the safety committee and there will now be a detailed development phase. Accurate models for the actual geometry need to be developed to check how the set-up will respond under all possible operational circumstances.

Production will start as soon as the developers are convinced that all the features of the ReCall design can guarantee safe operation. Following delivery of the ordered parts, the first test assembly will take place outside the reactor with a thorough test programme. This will consist of the verification of the dimensions, pressure and leak tests and research into potential operational transients in a test run outside the reactor. If all the tests are satisfactory, then SCK•CEN will submit a construction file to the Federal Agency for Nuclear Control (FANC) in order to apply for an irradiation licence.

Commissioning end of 2016

As soon as FANC grants the licence, the design team will transfer ReCall to the colleagues at BR2. They will reassemble ReCall, install it in the reactor and test it again before BR2 starts up. The final commissioning is scheduled for the end of 2016.

Investigation into the integrity of Doel 3 & Tihange 2 vessel walls

Unique expertise to determine material behaviour correctly

The microcracks in the vessel wall of the Doel 3 and Tihange 2 nuclear reactors have regularly been in the media in recent years. The operator called upon SCK•CEN expertise to assess whether the situation was serious or not. In 2015, our researchers carried out several irradiations and hundreds of tests and evaluations in order to make a reliable assessment of the material behaviour.

In 2012, during a scheduled inspection, the Doel 3 reactor was investigated on so-called 'underclad defects'. These are small cracks between the inner cladding of the reactor vessel and the outer vessel steel. No cracks were discovered in the cladded lining of the reactor vessel near the wall itself. However, the inspection revealed a large number of quasi-laminar error indications, called 'hydrogen flakes', in the lower and upper vessel ring of the Doel 3 reactor pressure vessel.

Meanwhile, the Tihange 2 reactor pressure vessel was also investigated, because this closely resembles Doel 3 and was constructed by the same manufacturer around the same time. The same indications were also found here: hydrogen flakes that had formed at an early stage during the manufacture of the steel parts. There was too much hydrogen present when the molten steel cooled down and

hardened and the temperature was not kept at a determined level long enough in order to eliminate the hydrogen flakes. This resulted in the formation of hydrogen flakes in the steel, a known phenomenon in the steel industry occurring in macrosegregation areas.

Technically, macrosegregation means certain parts of the material contain a concentrated quantity of impurities and alloy elements. When the reactor vessel was constructed, these impurities were flattened into cracks. If too much hydrogen is present during the cooling down it will form a thin film that leads to microcracks with an average length of 12-16 mm and the thickness of a cigarette paper. These microcracks show a laminar tendency: they run parallel to the curve of the reactor vessel wall.

Request for more clarity

The Doel 3 and Tihange 2 operator took the logical decision not to start the reactors as long as there was no clarity on the actual and future integrity of the reactor vessel structure. This happened under the supervision of FANC, the Federal Agency for Nuclear Control.

In order to investigate the hydrogen flake-containing material, substitute flake material similar to the Doel 3 and Tihange 2 material was used. AREVA supplied the first substitute flake-containing forging named VB-395. SCK•CEN performed more than 500 tests on different non irradiated materials, focusing on the effect of the macrosegregation and the hydrogen flakes on the material resistance. In light of the known influence of radiation on materials, no significant effect on the mechanical properties of the vessels was determined. An additional safety margin was applied. Following a thorough analysis and evaluation by panels of international experts and safety authorities, FANC granted permission in May 2013 to run two reactors for one cycle of approximately one year, on condition that the results were verified on the irradiated material.

Unexpected results

SCK•CEN therefore received the order to carry out further research with a new irradiation campaign in the BR2 research reactor and to analyse thoroughly the result of related tests. The aim was to study experimentally the real effect of irradiation on macrosegregation and on hydrogen flakes, and not to rely only on other experiences.

The researchers were astounded by the results after the material was irradiated: the embrittlement was far greater than expected. The operator was notified of this observation, who decided to shut down Doel 3 and Tihange 2 again on safety grounds and to order more irradiation and test programmes in order to understand this anomaly.

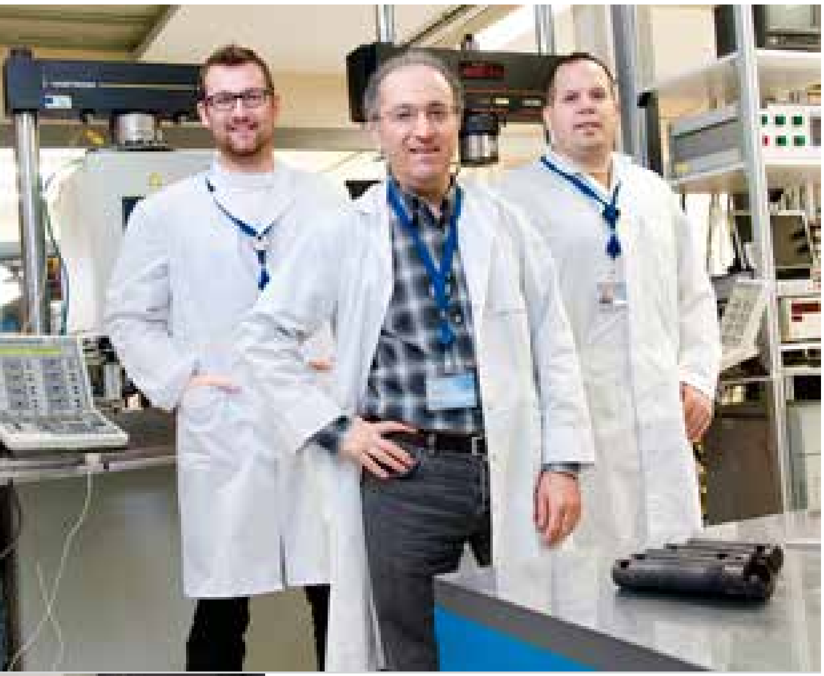
Describing and comparing properties

Was this extra unexpected material embrittlement inherent to VB-395 or not? To find this out, SCK•CEN was in the meantime able to investigate various vessel materials and similar materials with flakes. This item, under the name of KS-02, was supplied by MPA from Germany. The characteristics of VB-395, KS-02 and other materials were extensively identified, in both non-irradiated and irradiated conditions. The purpose was to describe and compare the specific data on the evolution of properties of all materials.

The materials were irradiated in the BR2 reactor to different fluences, from low to high, to investigate whether the hydrogen flakes could have affected the embrittlement and to determine the system of the degradation. No fewer than 1,000 mechanical

tests were thus performed – including more than 500 on irradiated materials – for the integrity study of the reactor vessel. Specially created samples with a crevice or crack in a specific macrosegregated area were tested in order to determine the toughness in the vicinity of a hydrogen flake. Furthermore, large samples with a large number of hydrogen flakes were tested with good results in order to verify the conservative approach to the previous tests and integrity calculations. Lastly, four series of irradiation tests were carried out in BR2 in order to investigate the radiation effects on a variety of samples and materials.

Four irradiation campaigns were performed in BR2 in order to investigate the irradiation effects on different samples and materials. The overall investigation made it clear that the embrittlement in the VB-395 was inherent to the VB-395 material and did not occur in KS-02 flake material or Doel 3 and Tihange 2.



“We applied very modern tests and thorough evaluation procedures in order to determine the material behaviour under irradiation accurately and reliably.”

Interpretation of the results

SCK•CEN applied very modern and validated tests and thorough evaluation procedures in order to determine the material behaviour under irradiation accurately and reliably. The results were investigated using up-to-date interpretation tools and analysed further in order to support the structural integrity calculations for the reactor vessel. The test results and their analyses were presented to FANC and an international review board which supports FANC. The purpose of the review board is to assess and to guarantee the quality and relevance of these investigations in order to be able to assess the safe operation of both reactors. As an additional measure, the research by FANC was also submitted to an independent laboratory, *Oak Ridge National Laboratory* in the United States, that applied its own methodology to confirm the integrity analysis.

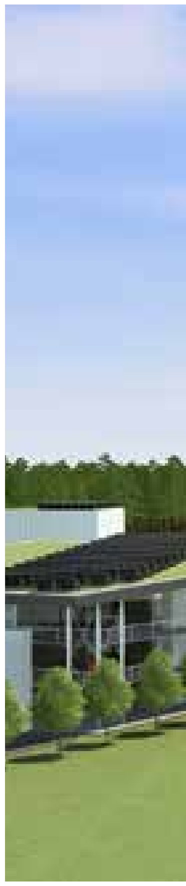
The conclusion was that the integrity of the Doel 3 and Tihange 2 reactor vessels was within the required safety standards and that the presence of hydrogen flakes did not impair the safe operation of the reactors. As a result, FANC concluded in November 2015 that there were no longer any reasons not to restart the Doel 3 and Tihange 2 reactors.

MYRRHA,
safer and cleaner technology

SCK•CEN is working actively on the design and construction of a new multifunctional irradiation facility: the *Multi-purpose hYbrid Research Reactor for High-tech Applications,* also known as MYRRHA. This successor to the BR2 reactor will be the first prototype in the world of a particle accelerator driven nuclear reactor. MYRRHA operates with fast neutrons, and cooling is done using a liquid metal: a mixture of lead and bismuth. We refer to it as a subcritical reactor because the core does not contain enough fissile material to maintain the chain reaction spontaneously. It must be continuously fed by an external neutron source, i.e. the particle accelerator. This is the reason why the reactor is coupled to a particle accelerator. It is a technology that is safe and easy to control. When the accelerator is switched off, the chain reaction stops within literally a fraction of a second, and the reactor is stopped.

The fast neutrons ensure that the fuel in the reactor is used more efficiently, and, as a result, there is less residual radioactive waste. Moreover, MYRRHA should demonstrate that it is technically feasible to change the most radiotoxic elements of long-lived waste by transmutation. This fission of long-lived elements into products that are radiotoxic for a considerably shorter period of time ensures a further reduction in the quantity and the life span of the waste. This reduces the storage time required from hundreds of thousands of years to a few hundred years.

In addition to research into transmutation, SCK•CEN will deploy MYRRHA for a wide range of applications, including material testing for current and future reactors, nuclear fusion technology and the development of new nuclear fuels. In addition, there is also the production of medical radioisotopes. In general agreement with the MYRRHA Ad Hoc Group, SCK•CEN established an implementation plan in 2015. As of 2024 SCK•CEN will put into operation the first step of MYRRHA: a 100 MeV particle accelerator (see page 58).



Financing

The total cost of the MYRRHA project is estimated at 1,500 MEUR (2014). In 2010, the Belgian government decided to support the project for five years and to grant a 60 MEUR global budget for further research and development. The government also specified that Belgium, being the host state, would bear 40 percent of the total cost for the complete realisation of MYRRHA. On the basis of the evaluation report for the period 2010-2014, the government decided in 2015 to provide SCK•CEN with exceptional funding of 40 MEUR for MYRRHA for the period 2016-2017.

2015

After a year of evaluation comes government support

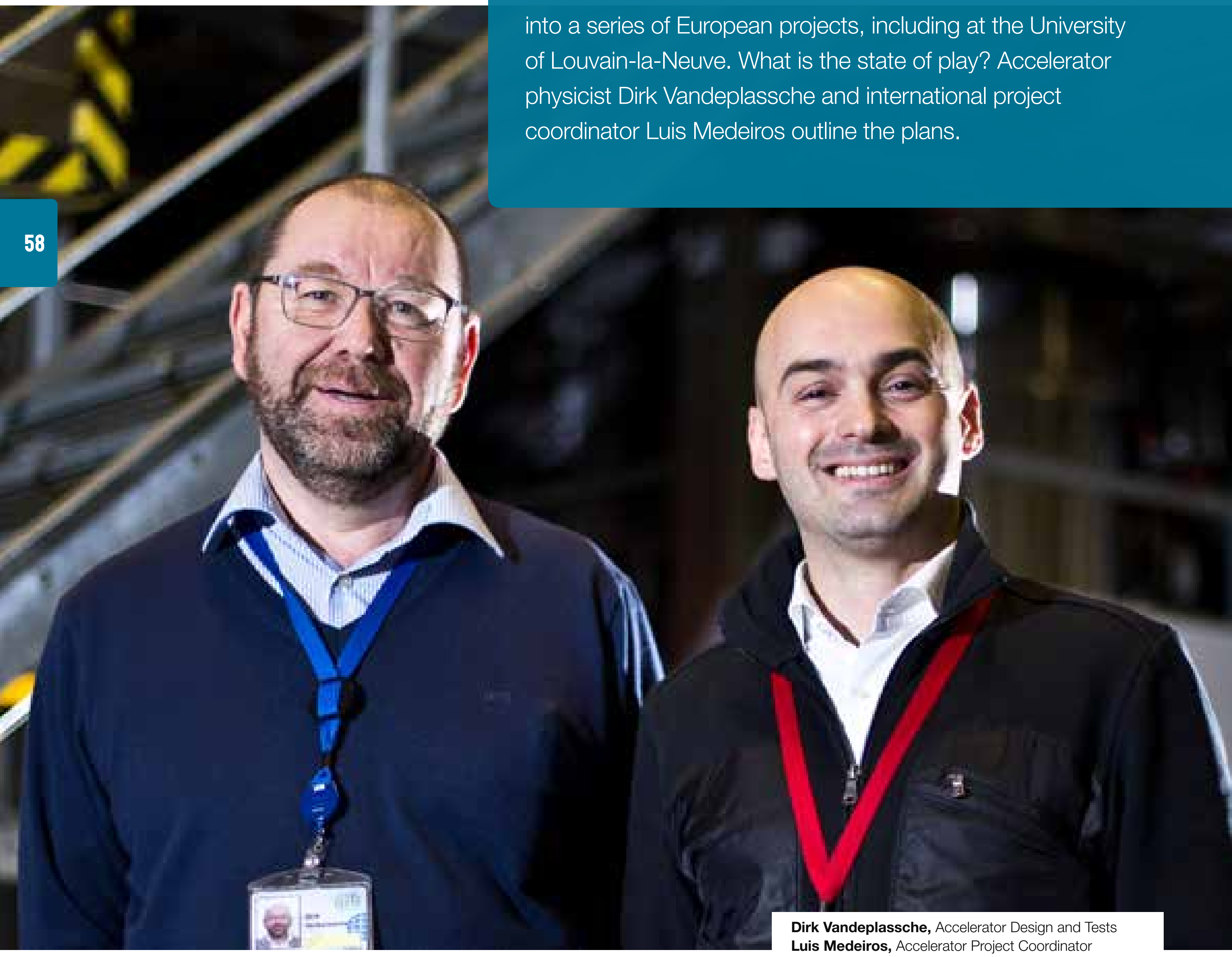
The support of the Belgian government has been critical in the past. We are delighted that the federal authorities have promised their support and financing for the next two years. We are also expecting much of the High Representative who will be appointed by the government to facilitate the foundation of the international consortium around MYRRHA and to deliver the financial support of the European Investment Bank.

Hamid Aït Abderrahim
MYRRHA Director

"A super-reliable particle accelerator for MYRRHA"

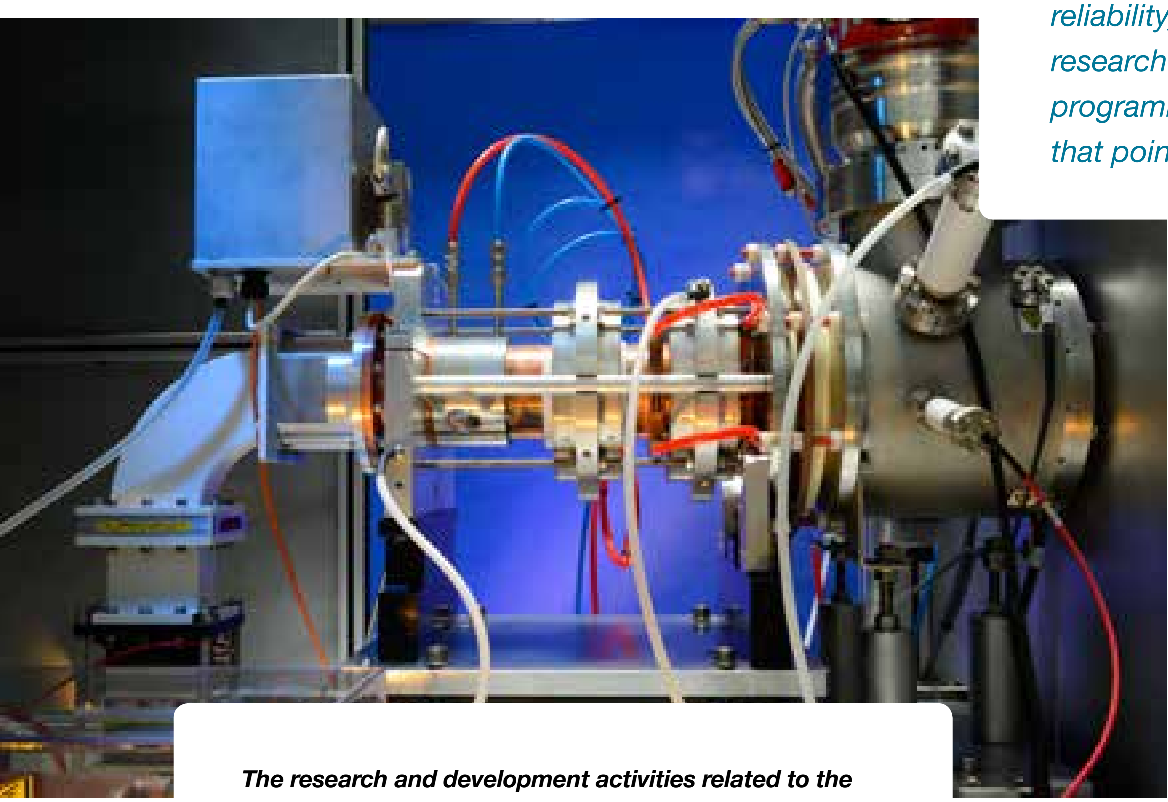
Research and development at European level

The future research reactor, MYRRHA, is an ADS or 'Accelerator Driven System'. The special feature in this installation is the particle accelerator – a crucial component. The development and construction of the MYRRHA accelerator is clustered into a series of European projects, including at the University of Louvain-la-Neuve. What is the state of play? Accelerator physicist Dirk Vandeplassche and international project coordinator Luis Medeiros outline the plans.



Dirk Vandeplassche, Accelerator Design and Tests
Luis Medeiros, Accelerator Project Coordinator

> *"The biggest challenge of the accelerator is its reliability, and the entire research and development programme is focused on that point."*



The research and development activities related to the MYRRHA accelerator are split up into various European projects. Why the choice for European research?

Dirk Vandeplassche: Today at SCK•CEN, we have a small team of four employees dealing with accelerators. In the future, we will be extending it and the team will concentrate mainly on the coordination and management of the accelerator programme. The actual research is conducted in an almost exclusively European joint venture. In other words, we coordinate and give direction, while our various partners carry out the experimental programme specifically at a scientific level. This is a win-win situation for all parties.

What is the specific role of the team in the eventual construction of MYRRHA?

Luis Medeiros: The MYRRHA project consists essentially of a subcritical reactor core which is fed by an external source of neutrons. This source is formed by a spallation target on which an intense proton beam is focused. Our team concentrates specifically on the development and construction of the particle accelerator which produces this proton beam.

Dirk Vandeplassche: In the future, when we start on the actual construction of the accelerator, the close collaboration means we will know which party to call on for the construction of which components.

You've opted for a superconducting linac or linear particle accelerator with a high reliability. Why?

Dirk Vandeplassche: In the core of the MYRRHA reactor, we want to produce neutrons by using protons. An effective reaction for achieving this is spallation, and you can achieve that with energy of a few hundred mega-electron volts (MeV) up to 1.5 giga-electron volts (GeV). Energy of 600 MeV is perfectly feasible from various machines, but for MYRRHA, the proton beam at the time of delivery in the core has to reach a capacity of 2.4 megawatts. That's quite a lot, so you only have a choice between a cyclotron and a linac. With a cyclotron, you are already close to the limit with 600 MeV, and that is partly why a linac gives us much greater reliability.

Luis Medeiros: The reliability parameters are of a technical and operational nature. If something goes wrong with the proton beam in an ADS, the reactor stops at once. In a traditional reactor, that's called a scram, an emergency stop. After that, it can take several hours to start up again. That is precisely why you have to be sure that the accelerator is working properly. The main challenge of the MYRRHA accelerator is its reliability, and the entire research and development programme is concentrating on that point. Firstly, we have to characterise the proton beam as accurately as possible for the low-energy side of the accelerator (0 to 15 MeV). That is essential, because the quality of that beam guarantees the successful acceleration throughout the entire structure – no less than 300 metres in total.

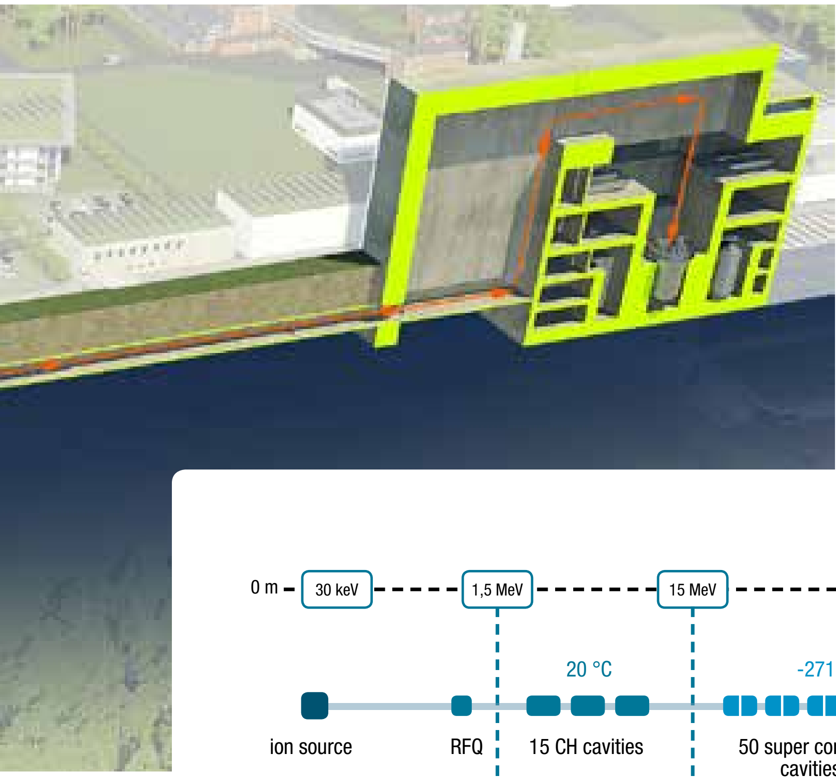
The beam tests are in progress in the current MYRTE project, aren't they?

Luis Medeiros: That's right. In the MYRTE project, there is provision for actually constructing a limited number of components on the low-energy side of the accelerator – the Radio Frequency Quadrupole or RFQ and its high-power RF amplifier – and testing them with a beam. For the initial part of the accelerator (the ion source and the low-energy beam transport), SCK•CEN is working together with the University of Louvain-la-Neuve (UCL) in the RFQ@UCL project. We're conducting that research in close partnership with the *Laboratoire de Physique Subatomique & de Cosmologie* in Grenoble, and the test set-up there is now ready. The same team from Grenoble has also developed the GENEPI-3C accelerator for SCK•CEN's GUINEVERE project. We have a lot of contact with them. In 2017, the set-up is coming to Louvain-la-Neuve, where the university researchers will use it for extensive beam tests.

Dirk Vandeplassche: Another point requiring a lot of attention is the technology which will be applied to generate the RF power. It is now possible to construct effective and reliable amplifiers using modern high-power transistors. The construction of a prototype will be done at the IBA company in Louvain-la-Neuve.

How important is the accelerator control in the entire development?

Dirk Vandeplassche: A control system is necessary for an extra reliable accelerator. This has played a big part from the very beginning and it will be even more important in the course of the development process. The control system is extremely complex and integrates everything: each real element has a virtual component. And so, you have to consider the system as the brains which keep an eye on everything and help to guarantee reliability in that way.

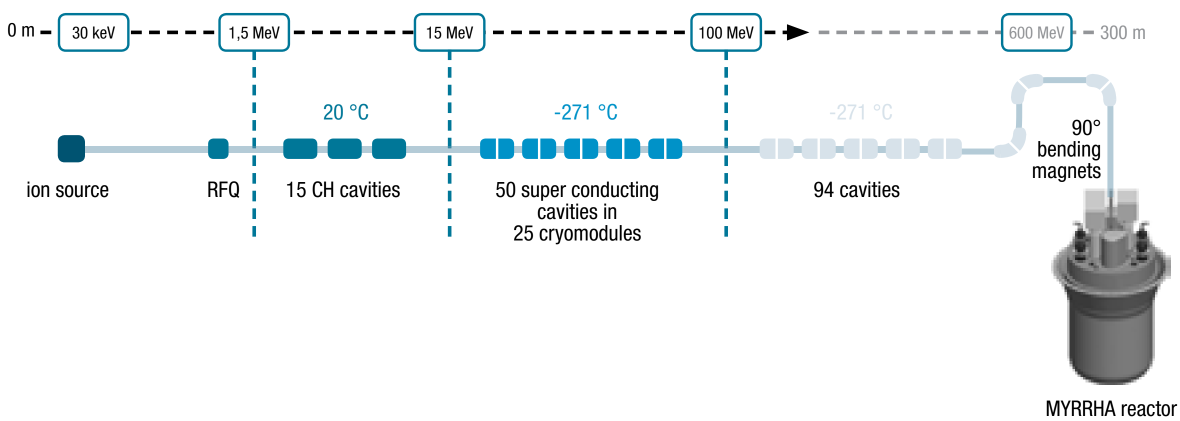


Which projects are in the pipeline in the near future?

Dirk Vandeplassche: The proton beam, which is delivered by the RFQ at the end of the low-energy side of the accelerator, has energy of 1.5 MeV. To provide more acceleration, we'll be using so-called CH cavities to rise to 6 MeV and then to 15 MeV. Once they are constructed, these components will be added to the test set-up in Louvain-la-Neuve and, in turn, tested extensively.

Luis Medeiros: The next phase is the development of the first superconducting part of the accelerator. The fact is that from 15 MeV, we're making the switchover to superconducting cavities which will operate at a temperature of 2 Kelvin (-271 °C). That is why we have to complete a prototype cryostat fitted with two such cavities. 25 of these modules, which we need to reach 100 MeV, will later form the first superconducting part of the accelerator.

MYRRHA accelerator



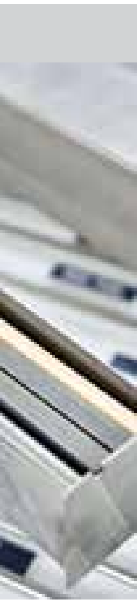
Towards a core that increasingly resembles MYRRHA

FREYA researchers introduce MOX simulant

The five-year European FREYA research project coordinated by SCK•CEN started in 2011. The project encompasses a series of physical tests to support the design and the licensing of the core of accelerator driven systems such as MYRRHA. The researchers are getting closer and closer to the intended reality. Thus, in 2015, they introduced aluminium oxide into the VENUS-F fast reactor to simulate the oxide in the fuel for MYRRHA.

New composition of nuclear fuel elements

Work package 3 took place in VENUS-F between February and October 2015. Various core configurations were loaded in order to investigate the critical core of MYRRHA. In the first place, an entirely new composition of nuclear fuel elements was selected and mounted for all the cores in this work package. These will be used until the end of the project. The fundamental difference is the use of aluminium oxide in the form of Al_2O_3 rods which simulate the oxygen of the oxide inside the MYRRHA nuclear fuel.



FREYA stands for *Fast Reactor Experiments for hYbrid Applications*. It is a project in the seventh European framework programme. The first technical work package concerned the development and validation of a method for measuring subcriticality online for an accelerator driven system or ADS. In the following work package, a core of the VENUS-F fast reactor was charged in order to be as representative as possible of the lead-cooled fast reactor (LFR). Work packages 3 and 4 were directed at a more detailed simulation of the MYRRHA core for the design and acquisition of licences.

> *The fundamental difference is the use of aluminium oxide to simulate the oxygen in the MYRRHA nuclear fuel.*

Tests using bismuth as a coolant

The final work package in FREYA is devoted to researching the reactivity monitoring in the VENUS-F sub-critical MYRRHA-type core. This is the same core as the critical CC8 core, but without the four central nuclear fuel assemblies, because of the vertical line of the GENEPI-3C accelerator that is linked again to the reactor.

Following completion of FREYA in March 2016, the installations will be used for experiments in the already running European Horizon 2020 MYRTE project (MYRRHA Research and Transmutation Endeavour). The activity in work package 5 of MYRTE is called *Experiments in support of the MYRRHA design evolution.* Specific to this is that the nuclear fuel assemblies of the VENUS-F reactor will now also contain bismuth. This allows the researchers to simulate the lead-bismuth in MYRRHA effectively.

Increasingly detailed simulations

These new nuclear fuel assemblies were first used in order to simulate the MYRRHA core without any perturbation. The second (CC7) and the third (CC8) configurations in VENUS-F simulate step by step the real MYRRHA core with perturbations. More precisely, this concerns the beryllium oxide (BeO) reflector and the in-pile sections (IPS) for the production of the radioactive isotope molybdenum, which is essential for the medical sector. The BeO reflector in MYRRHA was successfully simulated in the CC7 VENUS-F core with graphite. Futhermore, the IPS were simulated in the CC8 core with a composition similar to the real IPS in MYRRHA. However, the water provided for in the MYRRHA design was replaced with polyethylene in VENUS-F.

1 gram of oxygen per 1,000 tonnes of lead and bismuth

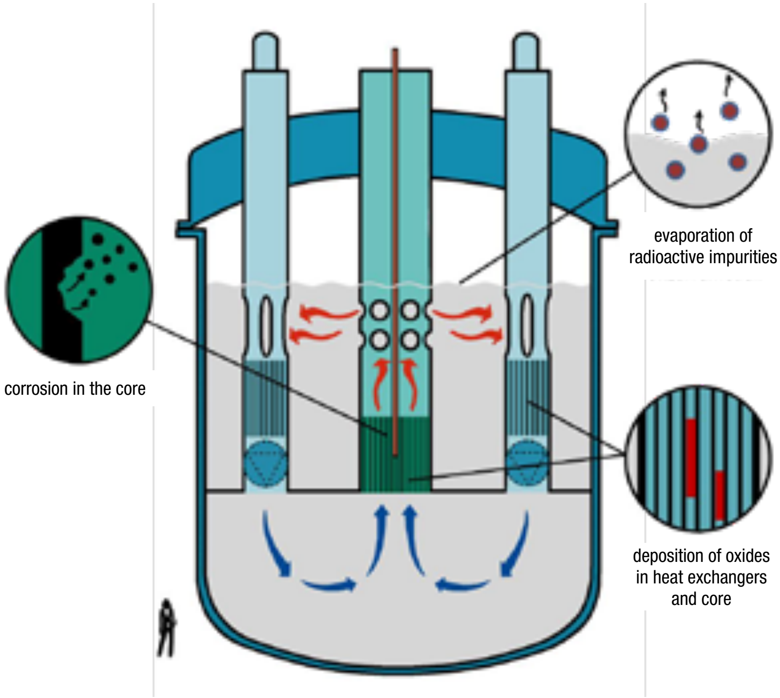
Extremely accurate sensors for safe operation of MYRRHA

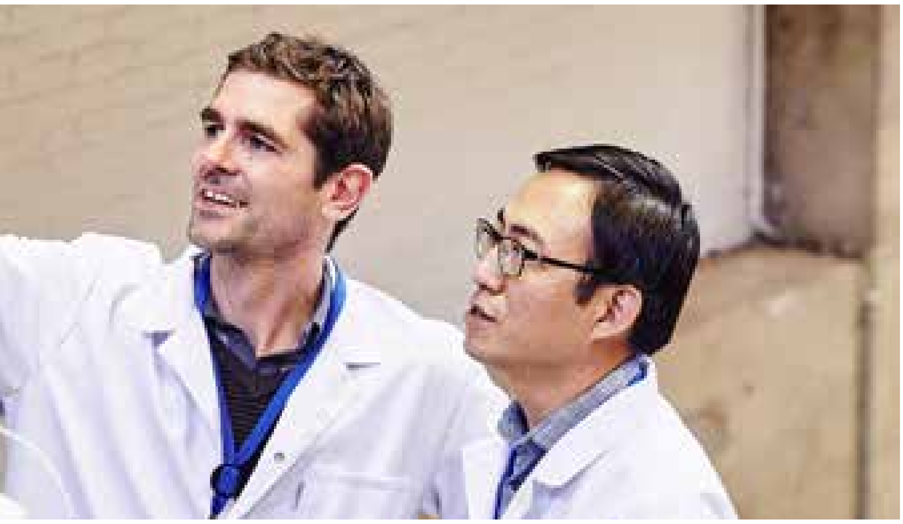
Liquid lead-bismuth eutectic (LBE) will be used as a coolant in the future MYRRHA research reactor. For this reason, SCK•CEN researchers are studying the behaviour of LBE. The objective is to arrive at precise safety calculations required to obtain licences. This requires the development of very accurate and reliable systems for the measurement and control of the oxygen concentration in the LBE for the reactor.

LBE contains a very small quantity of dissolved oxygen. Yet oxygen is the crucial element for chemical processes in LBE. Even a small concentration may affect the functioning and safety of an LBE-cooled reactor such as MYRRHA. If the oxygen concentration is too high, then there will be a reaction with the lead in the coolant liquid. This reaction creates solid lead oxide which then starts to precipitate. These solid parts can cause blockages in the reactor core or heat exchangers.

Corrosion is another problem. If the oxygen concentration is too low, corrosion will speed up. Corrosion needs to be reduced as much as possible in order to keep the steel housing around the fuel intact and to prevent the release of fission products into the LBE.

What is more, oxygen is the most important partner in reactions with impurities in LBE. For example, take iron and chromium, which are released in LBE in the process of corrosion. They react with oxygen and form solid particles, resulting in a risk of blockage. Oxygen reactions, in turn, strongly affect the chemical behaviour of radioactive impurities such as vaporisation and deposition on surfaces that come into contact with the LBE. All these processes could greatly affect safety.





Careful monitoring of oxygen concentration

It is therefore essential to carefully monitor the oxygen concentration in LBE: the researchers of the *Conditioning and Chemistry Programme* are seeking to achieve a target value of 10^{-7} weight per cent of oxygen in LBE, which is equivalent to approximately 1 gram of oxygen per 1,000 tonnes of lead and bismuth. The MYRRHA reactor, which contains several thousand tonnes of LBE, will only contain a couple of grams of oxygen. Even if the oxygen is present in very low concentrations, accurate monitoring is still necessary in order to guarantee the safety of the reactor.

There are various systems around the world for measuring oxygen in LBE. A lot of laboratories use gas, a relatively simple method. Another method is to dissolve lead oxide in a controlled manner, a technique originally developed in the Soviet Union.

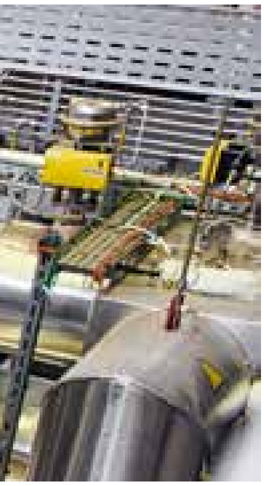
In these systems, the precision of the usual oxygen sensors is unsatisfactory under 350 °C. SCK•CEN has now succeeded in reducing the temperature limit for sensors to 150 °C. The minimum temperature in MYRRHA will be approximately 200 °C, so there is a margin. The result of this is a new family of oxygen sensors and associated technologies that are suitable for MYRRHA conditions. In the meanwhile researchers from Japan, Romania and China have already acquired the new oxygen sensors.

Electrochemical pumping of oxygen

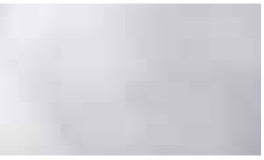
In addition to sensors, tools are needed to add or remove very small quantities of oxygen to LBE in a controlled and reliable manner. That is why SCK•CEN has developed a unique new technique under the name of EPO: *Electrochemical Pumping of Oxygen.* The researchers apply EPO to the experimental MEXICO loop, but MYRRHA is 1,000 times larger. In order to achieve a system in MYRRHA that will result in the same performance, the efficiency of EPO will need to be coordinated even more precisely for large LBE installations.

Detecting impurities

Until now, out of all the impurities in LBE, it was only possible to measure oxygen online with a large degree of sensitivity. It would be ideal also to have specific sensors for other impurities. The development of such sensors is not simple and would require a great deal of development time and money. Luckily, the researchers discovered that they can also follow up other significant impurities such as iron by measuring the oxygen. Thanks to this insight, they recently successfully detected impurities in LBE with an unheard-of level of detail.



> *Researchers from Japan, Romania and China have already bought our new oxygen sensors.*



Unravelling fundamental processes

The *Conditioning and Chemistry Programme* unit is planning more projects. The team seeks to better understand fundamental chemical processes which cause the formation and deposit of solid particles as a result of reactions with oxygen. Work is also being done on detailed 3D simulations of chemical processes with oxygen in MYRRHA in order to predict how and where the oxygen concentration in the reactor differs from the intended concentration. The knowledge that is required about LBE also offers possibilities for applications and commercial use outside the nuclear industry, for example in batteries and solar power. These are highly promising applications, but they are not core activities of SCK•CEN.

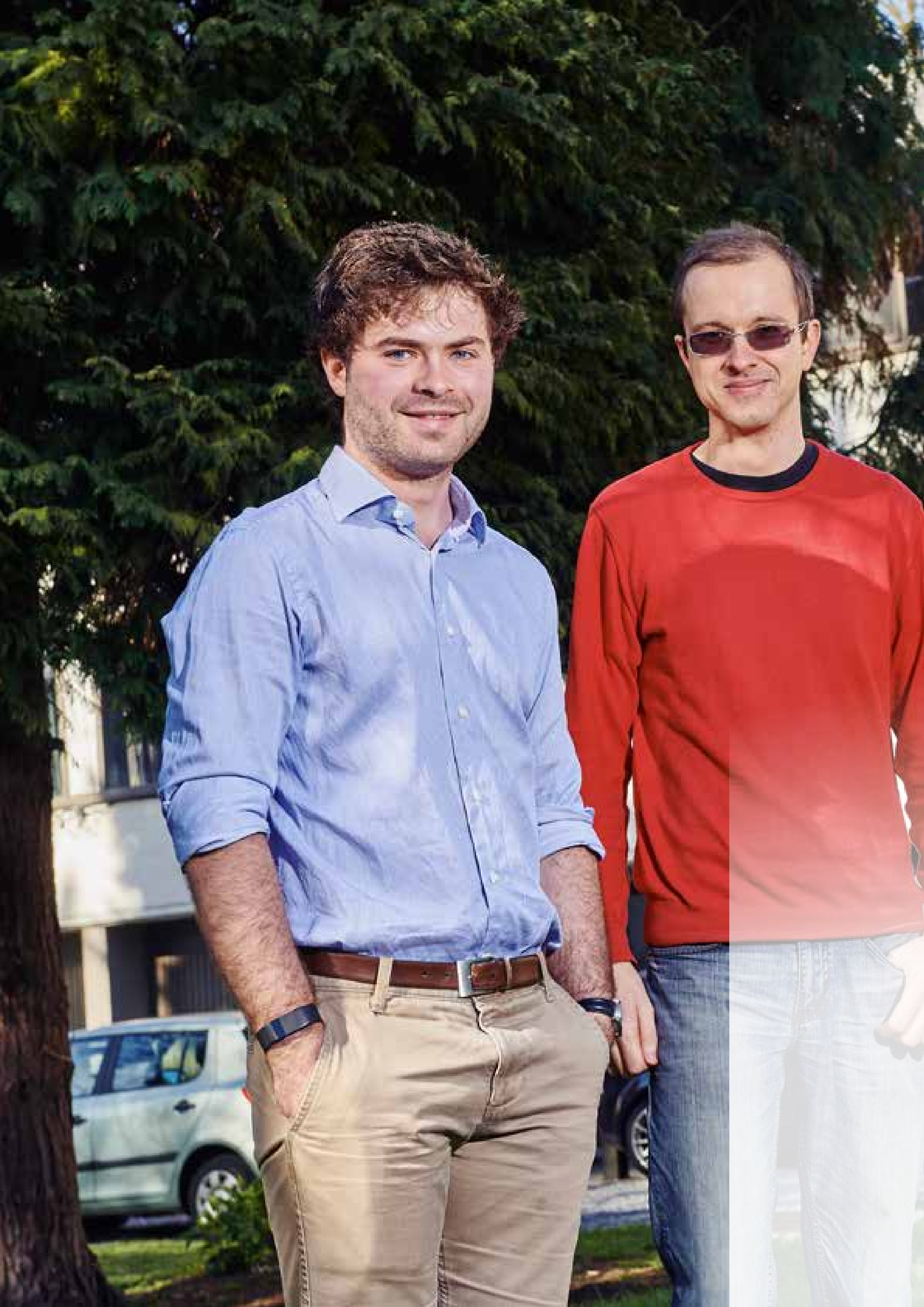
Innovating

is in our genes

SCK•CEN can build on a rich history of groundbreaking research and unique technological achievements. We now put this extensive knowledge and expertise to full use in developing sustainable solutions for today's social issues. Continuous innovation and a flexible response to the challenges of the future are the keys to our success.

Peter Baeten

Advanced Nuclear Systems Institute Director



04

Optimize talents and resources

Paper belongs to the past; the present and future are digital. That's why SCK•CEN has started to digitise the old publications in its library. At the same time, ROMa was built – a brand-new platform for scientific output. This rich database can already be consulted by our own employees; researchers at other institutions and the general public will gain access in the future. Knowledge Manager, Danielle Couvreur, gives us a guided tour of her digital city.

Danielle Couvreur, Knowledge Management

“The future is digital and maximally connected”

New platform for registering and managing scientific output

For some time, you have been busy digitising scientific publications in the SCK•CEN library and removing books with outdated content. Why is that?

Danielle Couvreur: By modernising the library, we wish to make available our catalogue and electronic documents to employees via our internal Knowledge Centre portal. They will gain access to a number of services, allowing them to consult articles, papers and research information. We were also informed at the end of 2014 that the library might move – which requires lengthy preparations. This was the right time to rationalise our book collection. We organised a book fair in December 2015, which generated a lot of interest among our colleagues.

How are you going to deal with this digitisation?

Danielle Couvreur: We started digitisation in 2015 and will continue this process through 2016. It will take several years to complete the digitisation of our old scientific publications. In the context of archiving, we have issued instructions to an external partner to scan all of our paper information. Nothing will be lost; we will make all publications available as searchable documents. All our digital files will be stored in centralised form in *Alexandria*, our document management system. The required confidentiality is built into every publication.

We also switched over to the *Brocade* library software in 2014. With this, our users can search for a publication a lot more quickly. Links between Alexandria and Brocade make it possible to search for documents and read the entire text. Everything is neatly listed by title, authors, type of publication, related events, etc. If need be, we correct the data.

> *“Thanks to the new information platform, we can share our knowledge with researchers in other centres and with the general public.”*

You have now also digitised publications written by SCK•CEN employees. Will these only be internally accessible, or are you going to make this knowledge more widely available?

Danielle Couvreur: The majority of our publications can be consulted internally. The new application, *ROMa* (Research Output Management), enables our researchers to register and find their scientific publications more easily.

But we live in a connected world. It is for the common good to share our knowledge, both with researchers in other centres and with the general public. For this reason, we are developing an application on our public Science Platform website that offers easy access to our publications. This Institutional Repository will not only contain scientific works, but also certain public projects, for example at European level. Searching, thematic tracing and exporting will be possible. This allows us to be mentioned in other repositories and thus our reputation will grow.

How are such publications evaluated? Are there any changes?

Danielle Couvreur: There are two major changes in the evaluation of our scientific publications. We now assign a score to the publication itself and no longer to the first author credited. We have also looked at the structure of the scores again, in order to place more emphasis on the quality and less on the quantity.

What were the challenges in the IT area, with regard to both digitisation of all publications and the creation of ROMa?

Danielle Couvreur: We are talking here about two projects that run in parallel: scanning the documents and the implementation of ROMa. The latter required the integration of three earlier databases compiled over a period of more than sixty years. There were major differences in structure, organisation and personnel. The exchange of information between ROMa and the HR, SAP, Brocade and Alexandria databases was a big task. We not only created new workflows for the validation in Alexandria and ROMa, but also coordinated the two technologies with each other in order to ensure a uniform presentation on the public Science Platform website.

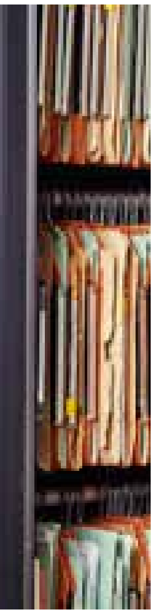
Our team comprised library staff, IT people and employees who helped us to set up processes, rules and guidelines. Thanks to our close cooperation, we created an efficient information platform with ROMa which will be able to receive necessary upgrades in the future.

People are the power of our research centre

Use talents optimally and offer a future

People are the real power of our organisation. They make projects work and together create the expertise that SCK•CEN offers the world. For such a group of employees, one has to administer the present and maximise future potential. This is a job that the Human Resources Management (HRM) department leads with enthusiasm.

750 ELECTRONIC PERSONNEL FILES DIGITISED



Everyone who works for SCK•CEN receives his own personnel file, which will store a number of documents: curriculum vitae, application letter, employment contract, degrees, references, etc. Foreign workers have additional documents such as a visa, a host worker's agreement and residence documents. Altogether, this adds up to a large pile of paper, in particular because documents have to be retained up to ten years after the employee leaves service.

Saving paper, space and costs

A few years ago, the HR department was still looking for new archival solutions for paper personnel files. HR Business Partner, Annik Stessens, realised that the solution was to be found elsewhere: "Digitising the personnel files has a lot more advantages. An electronic archive is fully searchable and one can identify the data quickly. What's more, we save paper, space and costs."

Digital and safe

To achieve this, it was necessary to scan all the personnel files. Annik Stessens: "We handed over this job to a specialised company. But first, everyone at HR management made a contribution by putting the documents in all existing personnel files into the same structure and sequence. All the active files have now been scanned and stored in a safe location as a digital file."

Access to personal file

All new files are now created electronically, but occasionally there are still paper documents. "We scan these immediately and insert them into *Alexandria*, the SCK•CEN document management system", says Annik Stessens. "Alexandria facilitates making the documents quickly available to employees."

Annik Stessens, HR Business Partner

CAREER DEVELOPMENT INTERVIEWS OFFER TALENT A FUTURE

Discovering and discussing talents helps employees make choices about jobs, tasks and assignments where they can use their talents. If an organisation places emphasis on things at which people are good, employee involvement and satisfaction also increases. SCK•CEN aims to do this through career development interviews.

ADDED VALUE FOR THREE PARTIES

Employee

A career is an essential part of the lives of our employees. They work from the time when they leave the classroom until they retire. It is interesting that they themselves can contribute to designing their careers and that they can do what they are good at. Employees can discover and achieve this by talking about it with their manager.

Manager

"What is happening in my team and what talent is there in the team?" If managers are aware of this, they can plan tasks better and share them out among their employees.

Organisation

The organisation acquires an understanding of the talent and expectations of its employees. By using that human capital judiciously, the organisation increases everyone's involvement in the long term. The more employees do what they do well and enjoy doing, the more energy there is in our organisation.

Appreciation is the basis

"During a career development interview, we want to find a balance between ambition, talent and possibilities," say HR Business Partners, Véronique Verbruggen and Nele Bruers. "Our aim is to allow employees to do more of what they like and what they are good at, always within the possibilities of the team and the organisation. This is key for placing talent at the centre of a career development interview. We expect the employee to take charge of the meeting and personally look for available opportunities. We expect managers to approach the meeting from the perspective of an appreciative inquiry: the starting point is not what is going wrong or what is missing, but what people can do and what stimulates them."

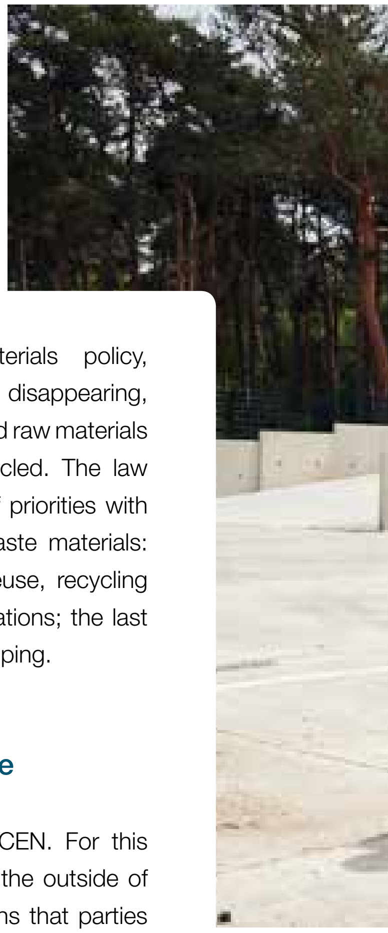
Open atmosphere

"The main thing is talking in an open atmosphere; this applies to every organisation and every industry." HR Management knows that from experience. "The meetings are not compulsory, but are something that every employee is entitled to. Therefore, there is no fixed time, because the moment that a career development interview is useful differs for everyone. In any case, the employee and the manager can start with a manual full of tips, tricks and useful questions to shape the future together."

Nele Bruers, Véronique verbruggen, HR Business Partners

New recycling facility for non-nuclear waste

Neat and ready for collection



Until recently, SCK•CEN had no central location for the collection of non-nuclear waste by external waste partners. In 2015, SCK•CEN completed the construction of its own recycling park. Waste management runs more efficiently now and according to strict rules which exceed statutory requirements. Thanks to thorough selective collection, costs are falling and more waste can be recycled.

In contemporary materials policy, the idea of 'waste' is disappearing, because useful scrapped raw materials can be reused or recycled. The law imposes a sequence of priorities with regard to managing waste materials: prevention first, then reuse, recycling and other useful applications; the last stage is removal or dumping.

The new recycling park is the culmination of a process of changes in the management of non-nuclear waste. The *Management of Waste and Liabilities* unit was designated as the central service to collect waste from our site, store it temporarily in the recycling park and arrange to have it collected by the external waste partners with whom SCK•CEN has a contract. This 'single point of contact' is, organisationally speaking, a radical break with the past, when various services each processed a part of the waste.

Attention to safety, protection and the environment

There are strict security requirements at SCK•CEN. For this reason, the new recycling park was laid out on the outside of the site and has a separate entrance. This means that parties who collect containers and loads do not drive over the site. When collectors leave the recycling park, detectors perform a final safety check for the presence of radioactive materials. SCK•CEN also gave thought to the surroundings: regional plants have been placed around the recycling park and a bee hotel has been installed.

“We have taken a major step forward in dealing with waste materials efficiently and in an environmentally friendly way.”

Maximum selective collection

SCK•CEN selectively collects more than twenty different waste types: not only waste comparable to domestic waste, but also hazardous medical waste, construction and demolition waste, metal and wood waste, electronic devices, oils, and so on. In addition, hazardous waste is further sorted according to the hazard properties.

Maximum selective collection promotes recycling potential and reduces processing costs. The better the sorting at source, the cheaper it is to have waste collected and processed. The proceeds from a number of waste flows and the thorough management of packaging waste are also economically useful.

There has been an awareness-raising campaign in order to update all employees on the new waste policy. Thus, SCK•CEN took a major step forward in 2015 in order to deal with waste materials efficiently and in an environmentally friendly way.

Soil and energy management go hand in hand

Research and decontamination result in clean soil

The common distant heating system at SCK•CEN and VITO runs on natural gas and heats a large number of buildings. A few buildings on the site however, are still using oil for heating. Unfortunately, the heating oil tanks contaminated the soil in the past. SCK•CEN is now restoring the quality of the soil, taking preventive measures and, where possible, simultaneously improving energy consumption and air quality.

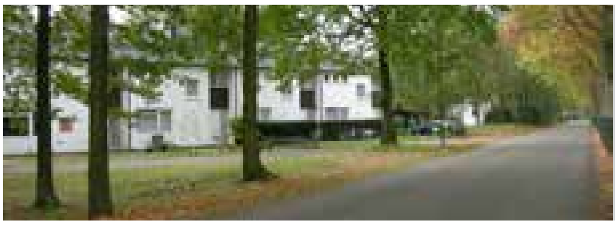
Exploratory soil surveys revealed soil contamination at a number of SCK•CEN sites. The contamination was demarcated horizontally and vertically in descriptive soil surveys, so as to establish the size of the contaminated zones. This was followed by setting up and carrying out decontamination projects to clean the soil. Decontamination was required in four zones: the residential quarter, the BR2 site, the BR3 site and a small zone in Mol-Donk.

The residential quarter

Soil contamination has been found in the residential quarter around various domestic heating oil tanks. Following a survey by experts, contractors decontaminated the contaminated zones in 2014. The contaminated soil was removed for biological cleaning and reuse. New double skin heating oil tanks with permanent leak detection were installed in accordance with current legislation. The operation was carried out whilst ensuring the stability of the houses, and in consultation with the residents.

BR2 site

The refurbishment of the BR2 research reactor in 2015 was an ideal moment to deal with the fuel oil contamination at the ventilation building: old tanks were cleaned and removed, contaminated soil was excavated and replaced with clean soil. The old boiler installation was replaced with a combination-plant, which runs mainly on natural gas and only makes limited use of oil. This project restores soil quality, reduces the risk of soil contamination in the future and improves both energy efficiency and air emissions.



"Experts keep a close eye on the situation according to a strict aftercare track."

BR3 site

BR3 is a relatively remote site which is being fully decommissioned. There is a contaminated zone directly next to and beneath the building. Old tanks were cleaned and rendered inert. New tanks that complied with the strictest requirements were installed. The final decontamination has been planned in consultation with the Public Waste Agency of Flanders (OVAM) and is scheduled to take place during the final phase of the BR3 decommissioning, foreseen for between 2020 and 2030.

Experts keep a close eye on the situation in the three projects following a strict aftercare programme.

Mol-Donk zone

It will be the turn of a smaller plot of land at the Lichtstraat in Mol in 2016 and 2017: an old measurement station for environmental monitoring located within existing asbestos contamination in Mol-Donk. In the context of a larger local decontamination project, the asbestos will be covered with insulation foil and a new protective mantle.

Diesel fuel for emergency generators

There are also diesel fuel storage tanks for the emergency generators on the research centre site. In order to limit the risk of soil contamination, obsolete tanks will be systematically replaced with new ones. Account will be taken in this regard of the preconditions of the stress test that SCK•CEN has undergone. The authorities require a minimal degree of autonomy for emergency generators. This is decisive for the volume of the new tanks.

Attention

to safety and the environment

Running our research centre in a safe, environmentally friendly and energy-conscious way requires constant attention. We pursue an integrated approach for both the new-build installations and the existing infrastructures. Matching the needs in the field of safety, security and the environment to optimum effect is part of our social responsibility. We regard this as a priority in all our activities.

Fernand Vermeersch

Head of the Internal Service for Prevention and Protection at Work

Water tower gets a facelift

Renovation and improved infrastructure

If you visit SCK•CEN, you can't miss it: there is a massive water tower on the site. It distributes water from the drinking water company Pidpa to SCK•CEN and VITO. Because the tower was in a bad condition, it needed urgent renovation. Tinne Withofs and Kris Iven monitored the project closely.

Tinne Withofs, Kris Iven, Buildings

The water tower was constructed in the mid-1950s. It ensures that there is sufficient pressure in the drinking water mains on the site and also serves as a physical separation between the public water supply and the SCK•CEN supply. This separation is compulsory according to Pidpa rules. It is a multifunctional tower, says Kris Iven: "The water tower not only functions as a distribution point for the drinking water at the site, but the content of the tank also serves as a buffer for fire extinguishing water. It holds a total of 400 m^3."

A study by AIB Vinçotte showed that the tower was in bad condition due to concrete rot, although there was no problem with the stability. Tinne Withofs makes it clear: "It was necessary to take action to guarantee that the water tower would function for at least another ten years."

Concrete repair

Following a call for tenders, SCK•CEN awarded the contract to the Renotec firm in Geel. Before the work started, the 46-metre tall tower was entirely encased in scaffolding.

The concrete had rotted in various places on the outside, as Tinne Withofs explains: "The coating had to come off, loose concrete was removed and then the reinforcement was checked. During the repair work, the reinforcement was dealt with first, then the repair mortar, a levelling layer and a coating were applied."

“It was necessary to take action to guarantee that the water tower would function for at least another decade.”

The specialists also repaired the concrete on the inside of the water tank and the underground reservoir. A special coating on the concrete keeps everything safe for drinking water.

Improved infrastructure

A lot of adjustments were made to the technical infrastructure. Kris Iven: “New vertical pipes were installed and the panels in the pipework ducting were replaced. The roof of the technical room and the water tank was replaced. Fall protection was also essential, so that maintenance on the roofs can be done more safely.”

This was also the ideal time to install new steps to the roof and to replace the access doors and windows in the plant room, which was also thoroughly updated. A number of old installations that were no longer in use were removed, creating more space in the cellar and under the water tank.

No direct water supply in the immediate future

The renovation work took from mid-August until the end of 2015, the last phase being the renovation of the buffer reservoir. The water tower will last for a while longer now.

The need for the water tower may disappear though, if the water company Pidpa can supply water directly. Tinne Withofs is realistic: “However, this would only be possible after ten years. Not only is it necessary to replace the drinking and extinguisher water mains, but it will be necessary to make adjustments to the drinking water distribution in all of the buildings. This is certainly a long-term project.”

Beating heart gets second life

High-voltage substation completely refurbished

The high-voltage substation at SCK•CEN had been in service since 1958 and was situated in one of the oldest buildings on the site. After almost sixty years, refurbishment was a matter of urgency, guaranteeing continued safety and operational reliability, but with one important condition: there was to be no interruption of the power supply during the refurbishment.

“Electricity is essential for the operation of SCK•CEN, but it has been taken for granted for ages,” say Valentin Vandebosch and Hans Van der Veken. They are members of the *Electricity* team charged with giving a second life to the research centre’s quietly beating heart. “We worked on this from December 2014 to October 2015. From time to time, we found signs of ageing in the 33 substation cells and felt it was time to switch over to a new high-tech vacuum installation. This should give us greater flexibility and redundancy; you will be unaware of anything in the event of maintenance or interventions on the electricity grid.”

Every mistake can be fatal

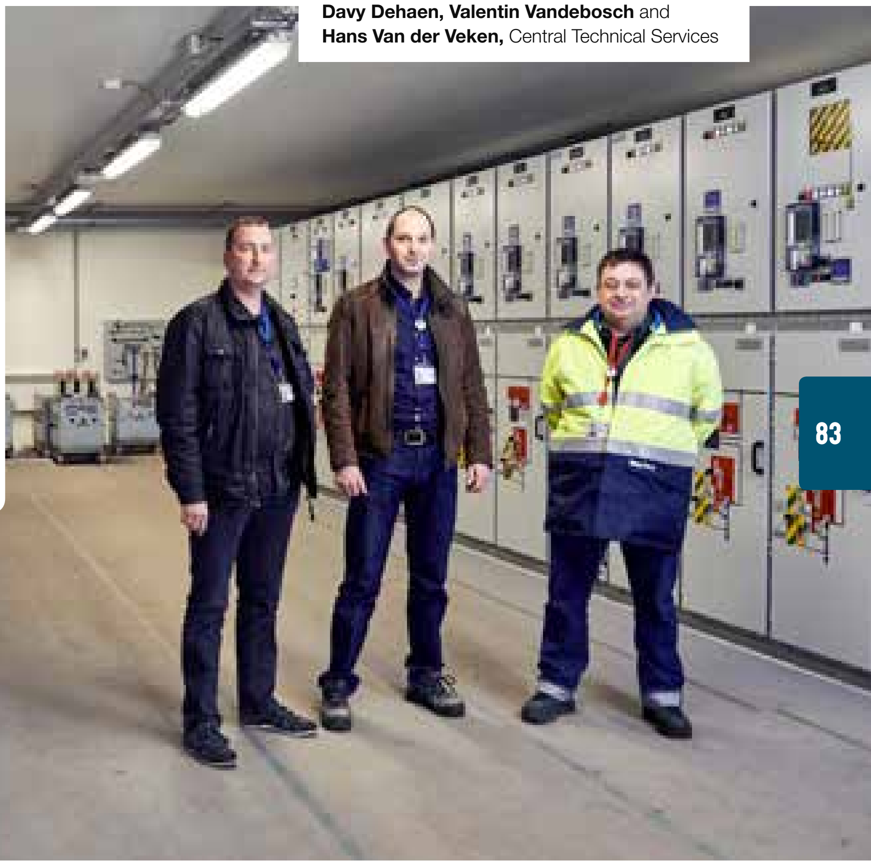
The first and most challenging step was the full refurbishment of the main substation (SS1). According to Valentin Vandebosch it was a complex operation: “Every mistake can be fatal, not only for the installation, but also for the people working on it and the operation of the company. That means testing intensively and following up every change or imperfection – in the end, more than 3,200 switching operations have been carried out. We also had to take account of all the new standards, laws and stress test requirements. Only in limited areas, such as the residential quarter, we did carry out any interruptions during the day, all according to the plan.”

Everything renewed

A great many aspects came into play in the refurbishment of SS1. Hans Van der Veken sums them up: “Not just the refurbishment of the 10 kV installation itself, but also the auxiliary supply installation, the fire compartmentalisation, the lightning protection and the fire alarm system. And, of course, everything to do with ICT, lighting and heating. The building has been refurbished from top to bottom. Did you know that structurally we only left the walls and the roof in place?”

From now on, the maintenance of SS1 will be far easier. Valentin Vandebosch: “We can use an application to analyse the condition and the energy flows. You do need some knowledge of this, as SS1 supplies another three substations. Automated recording of consumption and billing for each building is now also possible.”

> *“The new high-tech vacuum installation gives us greater flexibility and redundancy.”*



Davy Dehaen, Valentin Vandebosch and **Hans Van der Veken,** Central Technical Services

Work is far from complete

The project is not yet at an end, because work is still required on the other three substations: “In 2016, SS2 must be ready for the restart of the BR2 reactor. This conversion will also take place without the works being apparent. SS3 and SS4 are jobs for 2017. In any event, the beating heart of SCK•CEN can go on for another thirty years.”

Key figures for 2015

As indicated in the *2014 Highlights*, SCK•CEN ended the 2015 financial year with a big loss, amounting to 23.7 MEUR compared to a profit of 11.3 MEUR in 2014. The main reason for these weaker results is the cut in federal funding by 25.8 MEUR. Excluding this, the loss is in line with expectations on account of the refurbishment of the BR2 reactor, which has led to additional expenditure and a loss of revenue. The exceptional income is offset by exceptional depreciation and consequently has no impact on the 2015 result.

After two outstanding years, turnover has fallen back to its 2012 level. In other income, the share relating to the reduction in withholding tax for scientists continues to rise (6.0 MEUR).

The federal authorities accounted for 37% of the financing of our expenditure in 2015.

The total costs of SCK•CEN in 2015 were 125.1 MEUR. Staff costs came to 73.4 MEUR of this, or 59% of the total; reduction of the employer's social security contributions has had a positive impact on this expenditure. Compared with 2014, the increase amounts to 2.8%. Following the increases of previous years, there has been a slight fall, of 5, to 731 members of staff at year end 2015. Expressed in full-time equivalents, this remained at the 2014 level with 691 units.

'Purchases and services', accounting for 37% of the total costs, fell by 18 MEUR. The greater part of this fall relates to the Technical Liabilities programme.

After two years of high additions to the reserves, there was a net reversal, or use of 5.6 MEUR, in 2015; this is a difference of 18 MEUR, compared to 2014. Provisions represent 57% of the balance sheet liabilities at year end 2015 and mainly cover future expenditure for dismantling and waste processing.

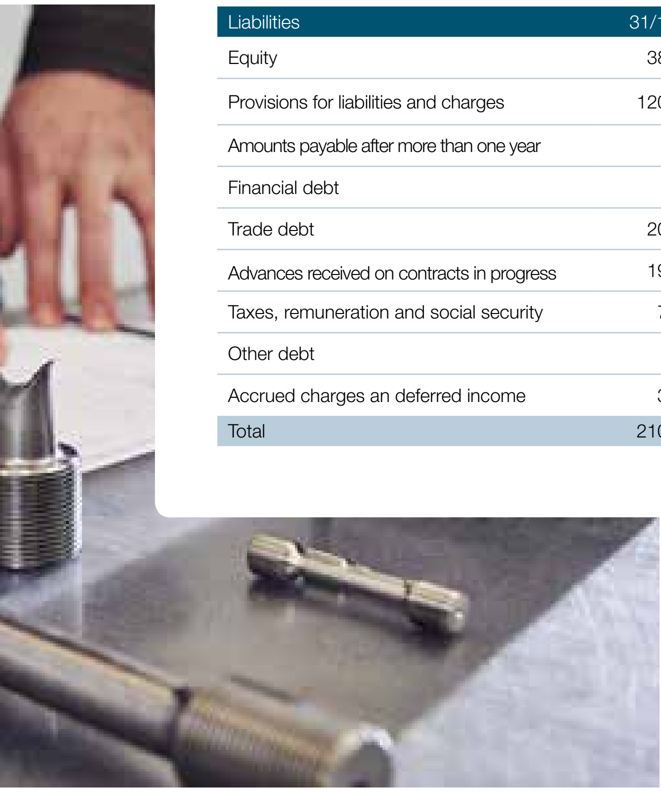
Social balance sheet for 2015
Number of employees as on 31 december 2015

	Fulltime	Parttime
Under a Contract of Employment for an indefinite duration	581	85
Under a Contract of Employment for a definite duration	63	2
Males	512	46
Females	132	41
Employees joining service	68	1
Employees leaving service	65	9
Average number of employees	638	97
Total	644	87

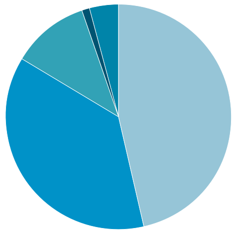
Comparative balance sheets (in kEUR)

Assets	31/12/15	31/12/14
Intangible fixed assets	5,653	5,590
Tangible fixed assets	49,201	42,660
Financial fixed assets	6,467	6,196
Receivables for more than one year	585	385
Stocks, work in progress	26,870	42,777
Receivables within one year	32,333	28,758
Current investments	400	4,956
Cash at bank and in hand	88,226	105,896
Deferred charges and accrued income	576	2,932
Total	210,311	240,150

Liabilities	31/12/15	31/12/14
Equity	38,540	61,922
Provisions for liabilities and charges	120,331	125,978
Amounts payable after more than one year	0	0
Financial debt	0	0
Trade debt	20,296	24,552
Advances received on contracts in progress	19,983	17,437
Taxes, remuneration and social security	7,892	7,932
Other debt	8	8
Accrued charges an deferred income	3,261	2,321
Total	210,311	240,150

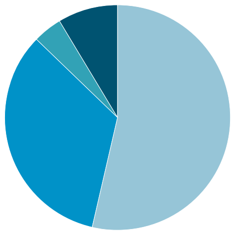


Income 2015 (in kEUR)



Turnover	47,101
Subsidies from government, grants	37,792
Other	11,231
Financial income	1,341
Extraordinary income	3,947
Total	**101,412**

Charges 2015 (in kEUR)



Personnel costs	73,456
Purchases, Services	45,804
Provisions	-5,648
Depreciation	11,462
Total	**125,074**
Transfer to Allocated Funds	0
Net result	**-23,662**

Cash fell by 22.2 MEUR to 88.6 MEUR at year end 2015 and came to 42% of the balance sheet total. The fall would have been greater without the reduction of the working capital by 13.9 MEUR.

As a result of the loss in 2015, the share of equity capital compared to the balance sheet total has fallen from 25.8% in 2014 to 18.3% at year end 2015.

The investment expenditure in 2015 came to 18.3 MEUR. In 2015, the refurbishment of the BR2 reactor was the biggest item in this regard. The restart of BR2 is scheduled for July 2016. With an eye to the future, there will be further investment in the renovation of buildings, the physical separation from the Flemish Institution for Technological Research (VITO) and the security of the site. The federal authorities anticipate separate financing of these additional security investments in the next few years.

2015 in a nutshell

January

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09/01
MYRRHA included in European Commission 'Junker' investment plan for 1.5 billion euros

12/01
Belgian scientists use new technology in search for elementary particles

March

20/03
After 40 years of research, a policy decision on geological disposal of high-level and/or long-lived waste becomes possible

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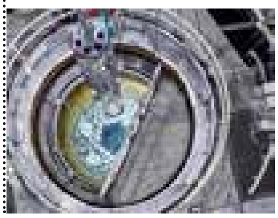
25/03
Start of the major maintenance and renovation operation of BR2



April

03/04
Frank Hardeman is appointed Deputy Director-General of SCK•CEN

23/04
Belgian schools participate in a live video call with an astronaut in the international space station

May

15/05
SCK•CEN contributes to improving the effectiveness of worldwide nuclear explosion monitoring

June

22/06
Hans Vanmarcke is the new Vice-Chairman of the United Nations UNSCEAR Committee

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Chinese Vice Prime Minister, Liu Yandong, visits SCK•CEN

14/09
Minister Marghem praises SCK•CEN's expertise at International Atomic Energy Agency

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15/09
Algeria boosts expertise in nuclear technology through collaboration between COMENA and SCK•CEN

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Flemish Minister-President Geert Bourgeois discovers research for new medical treatments

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SCK•CEN and the Ministry of Defense use a helicopter with measurement equipment during nuclear emergency exercise


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11/10
The federal Council of Ministers decides to include MYRRHA in the governmental agreement for the period 2016-2017

FOR MORE NEWS PLEASE CONSULT OUR WEBSITE

December

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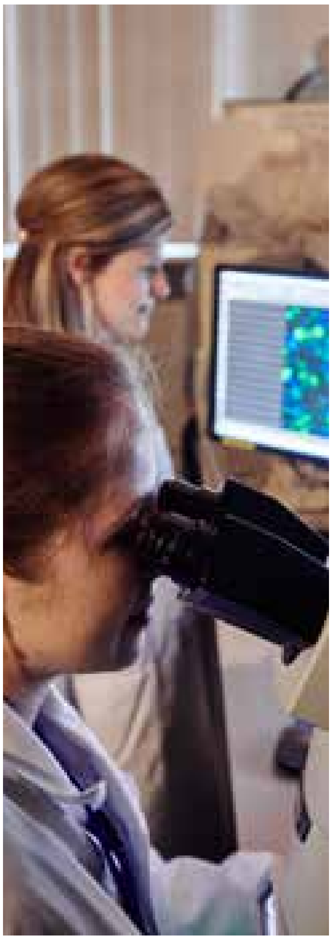
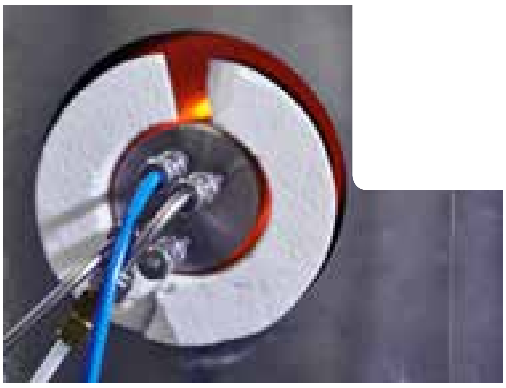
The SCK•CEN Academy more than doubles its students in 3 years





SCK•CEN

STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

2015
highlights

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SCK•CEN
Belgian Nuclear Research Centre

60 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 750 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
- Well-thought-out management of radioactive waste
- Human and environmental protection against ionizing radiation

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