highlights

2016

SCK•CEN

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

2016

“ 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.

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

2016 highlights

DEAR READER

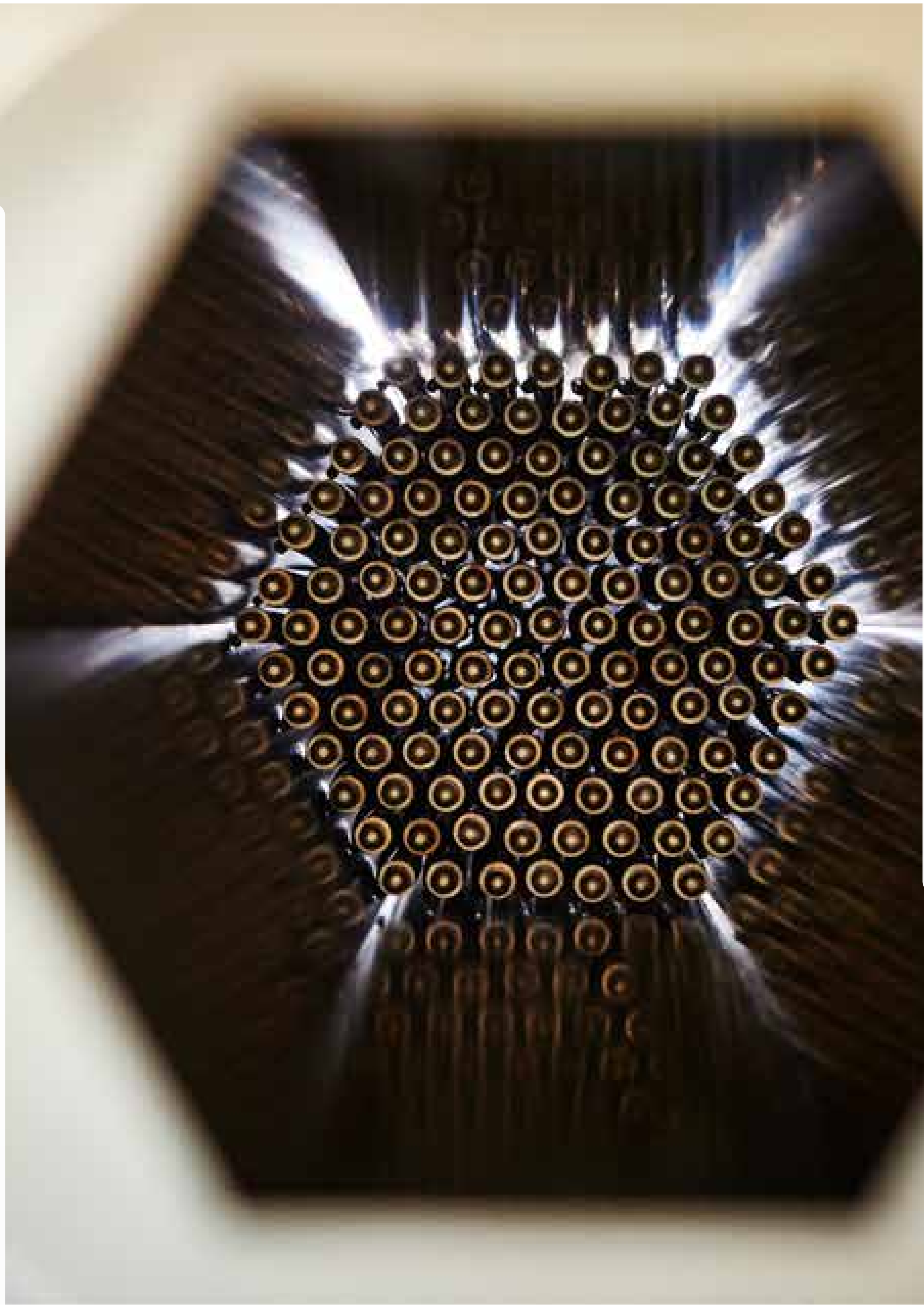
The years go by and times change: 2015 was filled with all sorts of challenges, while 2016 proved to be even more tumultuous, with a series of unplanned actions on top of our planned projects. The consequences of the tragic terrorist attack in Brussels led to us accelerating the implementation of our security plan and strengthening our security services, whilst quickly establishing close and effective collaboration with the military personnel deployed on our site.

These circumstances were unexpected; however, they have not prevented us from completing all of our ambitious projects, as you will see in this annual report.

Our new strategic plan reshaped the future of our research centre. More than ever, we wanted to focus our efforts on the key areas in which, thanks to our scientists, our expertise and our unique infrastructures, we are able to create real added value for our society.

The thorough refurbishment and modernisation of our BR2 research reactor was a complete success. It was restarted as planned, celebrated by the scientific and medical community at an academic session attended by Her Royal Highness Princess Astrid. At BR2, we will redouble our efforts to produce new medical radioisotopes that are even more effective in fighting cancer. Nuclear medicine is the cornerstone of our strategic plan and is the common thread that ties together the development of many disciplines within SCK•CEN. And did you know that old sources of thorium could prove to be rare and precious assets in the development of new cancer treatments? Discover the advances made by our researchers in the field of *Targeted Alpha Therapy* in this edition.

The MYRRHA project is also making progress with its new phased implementation plan. The first stage in the schedule of this multipurpose research facility is the construction of the accelerator and of experimental stations for the production of radioisotopes and research into materials. This 2016 edition will also reveal the helping hand we received from Archimedes in the design of the MYRRHA reactor, together with the discovery of particularly innovative and promising building materials for 4th generation reactors.



Water is a vital and essential resource, not only for our planet, but for our scientists too. Water plays a crucial role in our research into geological disposal in a deep clay formation, at a depth of around 225 metres. As it does on the surface, where the water that you drink every day is scrupulously monitored in our laboratories.

At international level, our research centre distinguished itself once again in 2016, through the numerous accolades for its young researchers and the top-level positions entrusted to its experts, in particular within the prestigious UN scientific committee UNSCEAR.

Lastly, how can the long-duration space travel applications developed in the Campine be landing in Africa? You will be 'Inspired' to read it!

Eric van Walle
Director-General
of SCK•CEN

content

01
The future is now

02
A boost for MYRRHA

03
Technology geared towards innovation

04
Contributing to great social challenges

05
Key figures

01 The future is now

Clear vision of the future

New strategic plan for SCK•CEN

‘We cannot predict the future. But we can be prepared for it.’ Frank Hardeman, Deputy Director-General, explains why SCK•CEN updated its strategy. ‘It’s not a break with the past, but it does mark a shift in focus. Our strategic plan forms a balanced vision that supports future decisions about research, installations and employees.’

Everything at SCK•CEN used to revolve around nuclear power. But that’s no longer the case, Frank Hardeman explains: ‘Research, the provision of services and the accumulation of knowledge related to the safe application of nuclear power remains a cornerstone of our work. But the world is changing. As a result of the ageing population and a greater focus on health, we are increasingly involved in medical developments. We are also a leading knowledge centre for nuclear waste management and decommissioning aspects.’

High-performance infrastructure

SCK•CEN can only provide its expertise if the infrastructure performs effectively: ‘For that reason, we’ve just finished refurbishing reactor BR2 and we’re now carefully preparing MYRRHA. Innovation is important. Other installations are also important: the post-irradiation research in the Laboratory for High and Medium Activity (LHMA), the HADES underground laboratory, the future campus for medical nuclear research and about a dozen smaller installations.’

“As a result of the ageing population and a focus on health, we are increasingly involved in medical developments.”

“Our young and international workforce is buzzing with energy.”

‘Sharing knowledge, both nationally and internationally, is something SCK•CEN has always been big on’, Frank Hardeman explains. ‘We want to structure our knowledge activities – acquiring, maintaining and distributing knowledge – even more within our organisation via our Learning Centre and our Academy. Our Human Resources department will contribute by further developing the competence management of our staff.’

Modern context

At the same time, SCK•CEN wants to maintain constructive relationships with the scientific world, security authorities, government and industrial partners, both in Belgium and further afield: ‘We are working towards structural partnerships with leading countries globally that may wish to use our infrastructure or expertise that they don’t have.’

People enjoy working at SCK•CEN. Frank Hardeman points out: ‘Staff turnover is low. But we want to offer our employees a modern context, financial security and opportunities for development. For that reason, we intend to improve their soft skills, give middle management more responsibility, fully develop the integrated management system, and so on.’

Frank Hardeman comments: ‘The balance between commercial applications and pure science will form a common thread through our decisions. We support our employees in engaging in research and development as an activity that results in income for SCK•CEN. But we remain a balanced institute and explicitly maintain the scientific components of our activities.’

‘In 2017, we’re putting our strategic plan to music’, Frank Hardeman explains. ‘We’re devising an action plan and setting up a follow-up tool. This is the perfect moment to make things concrete. Our young and international workforce is buzzing with energy. You will be hearing more from SCK•CEN. Much more, and often too!’

Looking boldly to the future in uncertain times

What role does SCK•CEN play in our society?

Or does SCK•CEN still have a role to play in our society? It does, and more so than ever, Secretary-General Christian Legrain explains. The research centre needs to gain even greater stature as a beacon of objectivity and innovative scientific research.

These days, the energy issue isn't always viewed with due consideration for the facts. In Western Europe, the tone is certainly set by ideologists and gurus. What is the role of SCK•CEN in this era?

Christian Legrain: 'I think it's crucial that we remain serious. We need to reliably support our activities. This means research, acting as an expertise centre, substantiating facts, providing figures, articulating complex science in a comprehensible manner... in short, practising science in a mature manner. SCK•CEN always carries out thorough research and wants to provide an objective view on everything related to nuclear energy. Never biased, always responsible. This is important in a society that's spinning out of control due to the wealth of information that we're inundated with from the internet and social media. It's crucial that the role of the expert remains central in fields such as energy and healthcare, in which nuclear technology undoubtedly has a key role to fulfil.

> *"SCK•CEN always carries out thorough research and wants to provide an objective view on everything related to nuclear energy. Never biased, always responsible."*

Terrorism, as well as anti-terrorism measures, influence how SCK•CEN operates. What are your thoughts on this?

Unfortunately the world has changed, and we need to learn to live with this new situation. I find the security measures necessary, but we need to remain approachable, because we have a social responsibility. The 'borders' aren't there to protect us, but to protect the citizens – so that they can't fall victim to an act of terrorism on our site.

How does SCK•CEN make sure its employees remain highly committed?

We're doing more and more in the field of human resources. We've provided training sessions in people management, for example. And a pathway has been established for 135 more experienced colleagues so that they can pass on their knowledge and expertise to younger employees. This creates prospects for young people, a resource we also tap into via our Academy. We motivate young people to study sciences, we present projects for competitions – our Inspiration project is a good example of the numerous initiatives that we have undertaken – and we take part in events for students such as the Creativity Marathon. Science is engaging and relates to various aspects of our society. Through all these efforts, we aim to attract young people to work at SCK•CEN.

It will certainly be important to communicate intensively then...

Of course. It doesn't help that SCK•CEN is hidden away in the quiet Kempen region. We may well be better known outside of Belgium than in Belgium itself. For that reason, we want to continue acting as an independent scientific expert in the media and to motivate people to choose sciences, especially those with which we are involved at SCK•CEN. Just look at MYRRHA, an exceptional project that is so sophisticated that we will amaze the whole world.'

Greater site security implemented quickly

International incidents increase controls

Security at SCK•CEN has been tightened significantly in 2016. You can't avoid the presence of armed soldiers on the site, the controls have been tightened at the main entrance and the respective entrances to the secured zones, and the Boeretang has been closed off to through-traffic. However, these aren't the only modifications.

The plan had been to divide the campus into one area for SCK•CEN and one area for VITO. 'As a result of the increased need for security, we sped up this process,' explain Benny Carlé and Jan Veraghtert, who are coordinating the operations. 'This reinforcement of security measures is part of an international evolution. And of course, there are international guidelines for nuclear sites that have also been adopted by Belgian legislation. You can see the physical security measures, but intensive work is also being carried out on improved cyber security by internal employees and external specialists.'

At various locations, access security has been stepped up. Benny Carlé and Jan Veraghtert explain: 'We changed the traffic situation on the Boeretang so that it once again became a private road for the Boeretang industrial area, we have had a new fence built in order to protect the site and we have considerably updated and extended the security infrastructure of the internal perimeters and secured zones.'

In order to ensure that everything went according to plan, we organised an information campaign for the entire workforce: 'We held a series of training sessions in order to improve the security awareness of our employees and to make them familiar with the new security initiatives. An Information Security Officer has been appointed, and a second information campaign will also be held with regard to protecting confidential information.'

Jan Veraghtert and **Benny Carlé**, responsible for security works

More responsibilities for security staff

A number of new responsibilities have been assigned to the security office: 'Our security staff have been given extra operational tasks, including access control with metal detection, X-ray scanners and explosives detection. We expanded the team two years ago to include female security staff, so that searches can be carried out on females. These are extremely competent security staff who have in the meantime become well-integrated.'

In addition to the security staff, permanent military staff are also present on the SCK•CEN site: 'They form a type of mini barracks, with their own accommodation and vehicles on site. The military also train here on site.'

There were no incidents in 2016: 'A suspicious package – a false alarm - was discovered, nothing else. Every now and then a driver causes trouble because he's no longer allowed to drive along the Boeretang. These incidents as well as the overall progress of the security policy are reported in 'Nuclear Security Summits'.'

Planned upgrades

Various upgrades to security within the secured zones on campus have been planned for 2017. We are also planning the construction of a new main entrance on the southern side of the site.

Security policy, both in terms of physical protection as well as on the ICT side, will be monitored by a newly established Security Risk Committee. This committee will be responsible for handling threat analysis, identifying potential risks and suggesting structural improvements.

Security

Attention to security

SCK•CEN's management is fully aware of how important it is to operate every facility in a safe, secure and environmentally friendly way. In view of the growing security requirements, efforts have been stepped up over the past year as part of our integrated approach to risk management.

Fernand Vermeersch
Head of the Internal Service for Prevention and Protection at Work

Reactor BR2 has a big future ahead

The scientific and medical worlds are breathing a sigh of relief. After a thorough service lasting 16 months, the Belgian Reactor 2 (BR2) was successfully restarted in July 2016. The research reactor is ready for at least another decade, with ambitious perspectives in sight.

Interview with
Sven Van den Berghe, Reactor Stakeholder Manager BR2 and
Steven Van Dyck, Reactor Manager BR2

Steven Van Dyck: 'It wasn't just a service. Many internal mechanisms were updated, all underground pipes and cables were replaced, the ventilation ducts were reinforced and the beryllium matrix on the inner side is also brand new. We carried out all anticipated interventions and BR2 was restarted right on the scheduled date, 19 July 2016.'
Sven Van den Berghe: 'This kind of timing is unique in the nuclear world, where unfortunately you often have to deal with significant delays. Precision remains a hallmark of BR2: we provide quality in a safe way and in the shortest time possible. Even when BR2 was being built, it was delivered with only six months' delay after four years. As scientists and technologists, we're always cautious with our communication. But this refurbishment was a success.'

How long can BR2 now run for?
Steven Van Dyck: 'We've submitted a dossier for the ten-year safety review. That gives BR2 the prospect of another ten years. But we're looking further ahead, because in a following step we want to prepare the period from 2026 to 2036.'

"7 million patients in the world yearly get a diagnostic research thanks to the Belgian radioisotope production."

BR2 dates back to 1962. Is your vision for the future realistic?
Steven Van Dyck: 'We've replaced components that were already fifty years old. They're now brand new and can last for ten, if not many more, years. We inspected the reactor vessel itself with the greatest precision. What did we find? No signs of wear whatsoever. If we view the material data and extrapolate this into the future, we already know that the reactor vessel can last until the year 2036 without any issues. Of course, further studies are needed in order to verify that, but we have time.'

For which objectives does SCK•CEN want to turn on BR2?
Steven Van Dyck: 'At this time, there aren't many places in the world where isotopes are being produced. This highlights how necessary it is that BR2 be reliable. We need to guarantee sufficient production. Doctors all over the world are counting on us. The BR2 routinely produces around a quarter of annual requirements for the most important medical isotope, molybdenum-99. When the reactor is operational, it can cover two thirds of the weekly global demand. 7 million patients in the world yearly get a diagnostic research thanks to the Belgian radioisotope production.

Sven Van den Berghe: 'Our reactor is operational 40 to 50 per cent of the time, but it is just as important that we keep it in tip-top shape the rest of the time; that's something we're very strict about. With the new matrix and the new components of the reactor, we're technically able to achieve a higher level of efficiency. The production of isotopes is a continual and repetitive activity through which our reactor makes a major contribution to society. Besides the core production of molybdenum-99 for the diagnosis and treatment of cancer, we also carry out isotope irradiation for the development of products – new therapies or combinations thereof – or for other applications of existing products. This type of qualification process from development to routine production can take years. The isotope market is extremely dynamic. Supply and demand fluctuate and new applications are constantly emerging.'

Steven Van Dyck: 'In the three cycles that were provided for 2016, 6 tests were carried out to produce isotopes that we hadn't previously supplied or to validate known isotope production for new applications and clients.'

However, isotope production isn't the only objective…

Sven Van den Berghe: 'The reactor is, and will remain, available for a range of applications. The specifications for the design of the BR2 stated: 'a reactor with the greatest overall usefulness'. That's exactly what we got. BR2 is a versatile and flexible irradiation machine that is able to do many different jobs at the same time.'

Steven Van Dyck: 'Besides the production of isotopes, BR2 also functions as a materials testing reactor. At this time, research reactors are hardly being built anywhere in the world, but there is need for research. This is only possible in a high-performance research reactor. That's why BR2 is so successful.'

SCK•CEN wants to provide scientists and companies with the opportunity to use BR2 in a structural manner. That's possible thanks to the new concept of BREASY (BR2 Reactor Experimental Access and Scientific Yield). What exactly does this involve?

Sven van den Berghe: 'With BREASY, we are making the capacity of BR2 available to scientists all over the world so that they can carry out experiments. In concrete terms, we are inviting institutes and even countries to engage in a capacity participation in BR2. They purchase some of our neutrons, thereby buying part of the research reactor as it were. We also want to make part of our capacity available to the academic world. We call it our 'user facility'. We used to work on an ad hoc basis with PhD students who were carrying out research or research projects with external partners.'

"With BREASY, we are making the capacity of BR2 available to scientists all over the world so that they can carry out experiments."

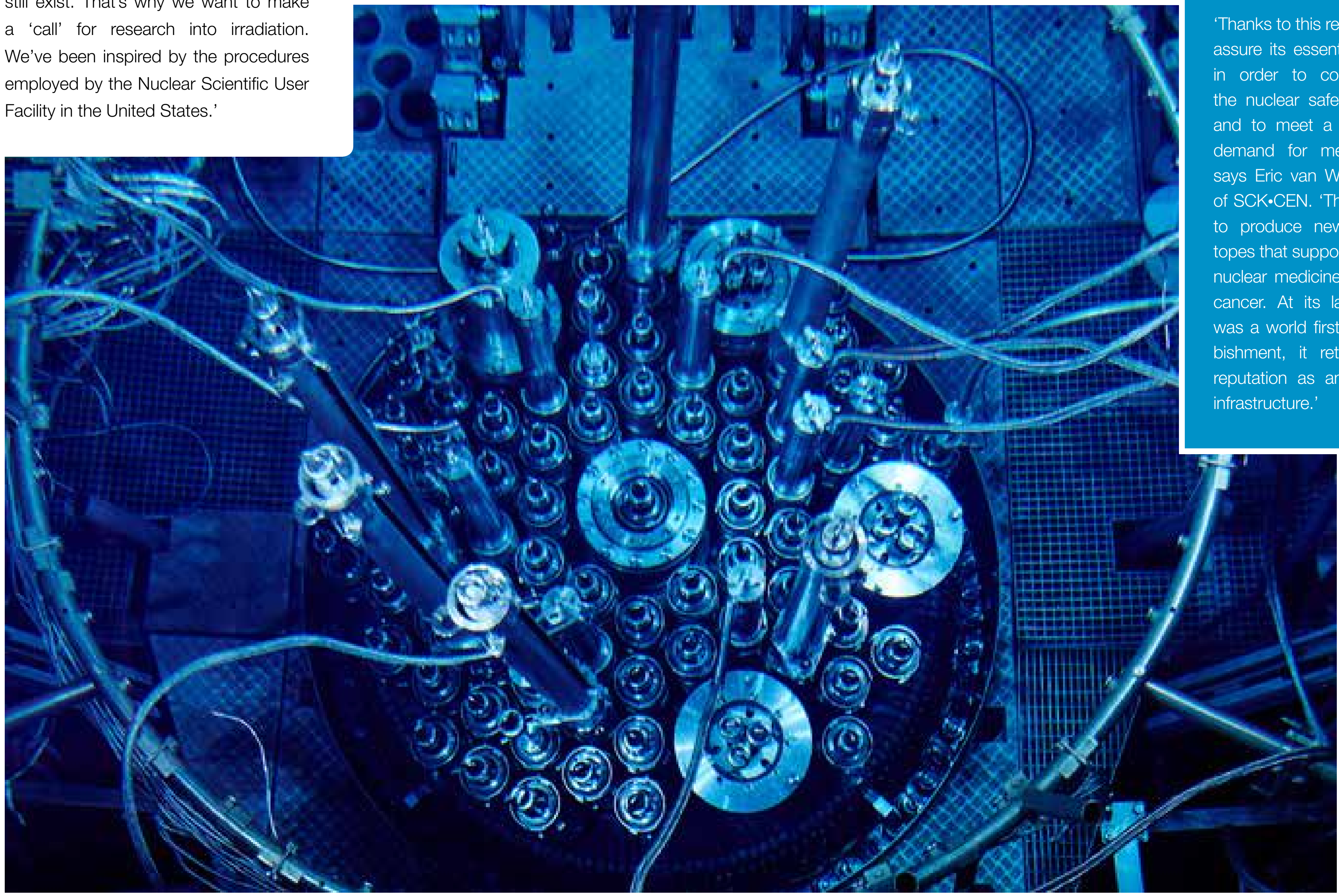
What's the difference?

Sven Van den Berghe: 'We are now moving towards a more structural partnership: a community of users who enter into a permanent relationship with us. They will retain access to our infrastructure, so that their research can develop. For us, as the operator, this provides continuity in terms of levels of usage. Various European universities used to have research reactors on their campuses, but that's no longer the case. The departments of nuclear engineering still exist. That's why we want to make a 'call' for research into irradiation. We've been inspired by the procedures employed by the Nuclear Scientific User Facility in the United States.'

ACADEMIC SESSION ATTENDED BY HRH PRINCESS ASTRID

On Friday 28 October 2016, SCK•CEN in Mol organised an academic session in the presence of Her Royal Highness Princess Astrid to celebrate the successful start-up of its BR2 research reactor after a 16-month refurbishment.

'Thanks to this refurbishment, BR2 can assure its essential role in technology in order to continue to guarantee the nuclear safety of power reactors and to meet a growing international demand for medical radioisotopes,' says Eric van Walle, Director General of SCK•CEN. 'The reactor is also able to produce new types of radioisotopes that support the advancement of nuclear medicine in the battle against cancer. At its launch in 1961, BR2 was a world first; thanks to this refurbishment, it retains its international reputation as an advanced research infrastructure.'



02

A boost for MYRRHA

MYRRHA switches to phased development

150 engineers, scientists, technicians and administrative assistants from 27 different countries are working on MYRRHA, the Multi-purpose Hybrid Research Reactor for High-tech Applications. What stage is the financing and development of this successor to BR2 at? Project Director Hamid Aït Abderrahim takes stock of the situation.

In 2009, investment in MYRRHA was estimated at 960 million euros. What are the figures today?

Hamid Aït Abderrahim: 'The slow but steady inflation of the euro caused the figure to increase by 112 million euros. In 2011, the nuclear accident in Fukushima also happened. As a result, although our project was still only on paper at that stage, additional security requirements were imposed on us by the Federal Agency for Nuclear Control, FANC. This resulted in almost 150 million euros of additional investments. Finally, the design of MYRRHA evolved, and that brought with it an additional cost of 250 million euros. Together, this meant a total figure of 1.6 billion euros. That was at the end of 2014, and we are still on track to reach that amount today.'

Is MYRRHA still a profitable project to carry out?

In 2015, we looked into this question together with external experts. The answer was unanimously positive. The portfolio of the analyses remains valid and necessary.

And what about the planning?

The Board of Directors asked us to examine closely the implementation strategy of the MYRRHA project. A step-by-step strategy must enable risks to be reduced and investments to be spread out.

What does this strategy involve?

We are dividing our work into three phases, of which phase 1 is currently the most concrete. In this phase, we plan to build the accelerator to be capable of 100 MeV (Megaelectron-volts), as well as one or two research stations: one to produce radioisotopes and one to carry out material research. We are doing that in phase 1 in order to demonstrate the reliability of our accelerator. Normally, such a large accelerator stops frequently, for example 2,000 times per year. In MYRRHA, we want to reduce the number of stops lasting more than three seconds to ten per quarter. The accelerator therefore needs to be extremely reliable. That will be possible thanks to a fault-tolerant design in which cavities can take over from each other, and also to injector redundancy.

How long will the development of the accelerator take?

We will be building the 100 MeV accelerator at actual size between 2019 and 2022. After that, we will spend two years testing reliability in real life situations, which will take us to 2024. Our simulations indicate that we will achieve the desired level of reliability, now it's up to us to demonstrate that in reality. At the same time, the development of stations for the production of radioisotopes and the material research will be taking place. As a result, the research stations will prove their value from the outset.

"During construction of the whole project, almost 1,000 people will be involved over a three-year period; during operation, between 300 and 400 people will be permanently employed for MYRRHA. And all these jobs will in turn generate another three jobs indirectly."

What will happen in the following two phases?
Phase 2 serves for the further development of the accelerator up to and including 600 MeV. Phase 3 is the construction of the reactor, i.e. the complete construction and finalisation of MYRRHA. We anticipate phases 2 and 3 will cost 1.25 billion euros. By building MYRRHA over an 11-year period, we are able to spread out the investment and have more time to bring all the funding together.

Where will the finances come from?
From a range of different sources. The Belgian government has already awarded us 40 million euros for 2016-2017 in order to develop the project with the new phased process. By the end of 2017, we need to provide the government with eleven large reports so that they can make a decision for the building activities in phase 1. But there's even more. At the start of January 2015, the government decided to include MYRRHA in the list of Belgian projects for the new investment plan of the European Commission, the Juncker Plan or EFSI, for an amount of 1.5 billion euros. And in the new Horizon 2020 programme from EURATOM, more than 11 million euros will be invested in MYRRHA via the H2020 MYRTE project, 9 million of which will come from the European Commission. Furthermore, MYRRHA has been chosen by the European Investment Bank as a potential project for financing via the InnovFin programme. That could generate a loan of between 120 and 240 million euros with a redemption-free period of 10 years and a long repayment period with a low interest rate. All sorts of negotiations are under way.

By when does the investment in MYRRHA need to be repaid?
We are starting a building period of 11 years, between now and 2030. After that, MYRRHA will be used for 35 years, until 2065. The repayment itself needs to be completed within 26 years. That doesn't take account of the impact of employment. During construction, almost 1,000 people will be involved over a three-year period; during operation, between 300 and 400 people will be permanently employed for MYRRHA. And all these jobs will in turn generate another three jobs indirectly.

What income will MYRRHA generate?
The world is awaiting new techniques for the management of radioactive waste. If we are able to develop and patent this, this will create opportunities. MYRRHA is also important for the building of future lead-cooled GEN IV reactors and SMRs (small modular reactors). Our expertise in terms of developing a new type of reactor that can use the same core for ten years without having to reload, with a lower production of waste and improved safety... that's something we can all make use of.

What does collaboration with other countries look like now?
We are currently in discussions with a number of countries regarding their participation in MYRRHA. We are preparing a cooperation agreement with the French CNRS (*Centre national de la recherche scientifique*), Sweden is prepared to participate, Japan is going to decide about its possible participation and the German government is again examining a cooperation report. More news will be revealed in the course of 2017!

Archimedes gives a boost to MYRRHA

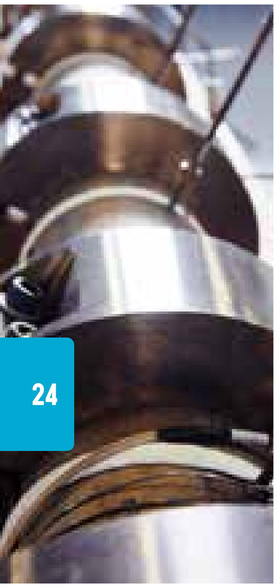
A closer look at fuel bundles and control rods

Our scientists are using the lead-bismuth loop COMPLOT to investigate the thermal hydraulic and hydrodynamic behaviour of full scale reactor components intended for MYRRHA. They have focused on pressure drops in nuclear fuel assemblies and have also built and tested a prototype control rod.

The pressure drops in the fuel bundle determine the flow rate of the coolant through the reactor core. It is important to know whether there is always a sufficient flow rate of the coolant, especially when the reactor stops suddenly. This must then be able to remove the heat from the fuel in a passive way, that is to say without interfering with the pumps.

In COMPLOT, researchers Katrien Van Tichelen and Graham Kennedy investigated these pressure drops: 'We demonstrated that the data that we use for the reactor design for pressure drops in the fuel bundle are sufficiently precise.' Other environmental factors have an influence: 'The temperature changes the characteristics of the coolant and the material of the bundle. As a result, the walls of the bundle may become rougher, for example, resulting in an additional loss of pressure.'

In the near future, they want to conduct further research on the behaviour of the fuel bundle: 'How strong, for example, are the vibrations of the fuel rods that result from the flow of the coolant? We will also investigate whether the pressure drops vary over time if additional phenomena were to manifest themselves.'



Thanks to Archimedes

A second research study in COMPLOT focused on the control rods: 'They form a complex component that is almost 10 metres long, with the same size, geometry and weight in the experiment as in MYRRHA. We are trying to demonstrate that it is possible to put them in the reactor core in less than one second. That's important for safety, because it must be possible to stop the reactor quickly. It is a big challenge to position the slender structure precisely so that it doesn't end up getting jammed or distorted when in motion.'

Moving the control rods takes place in lead-bismuth, a heavy liquid metal. That makes the conditions different to those of a traditional reactor, Katrien and Graham explain: 'In traditional reactors, the control rods go down thanks to gravity. In this case, the liquid is so heavy that standard materials continue to float in it.'

The solution? 'We place the control rods under the reactor core. If we release them, they move upwards. These proof-of-principle tests are unique within their field. For the first time, use is being made of Archimedes' principle for the insertion of control rods. And it's paying off.'

Following the demonstration of the principle, research is shifting to the behaviour of the control rods during repeated insertion. They need to last at least one reactor cycle of three months: 'We assume this will be longer, because we have made a very conservative estimate of the durability.'

The testing of other components is planned for the future. 'The majority of our time will be spent adjusting COMPLOT for testing the thermal hydraulic behaviour of the MYRRHA heat exchanger tubes. We want to supply proven basic information to our designers so that they can use this in the following design revision.'

"For the first time, use is being made of Archimedes' principle for the insertion of control rods. And it's paying off!"

Innovation

Unique experimental facilities are essential

SCK•CEN uses advanced and complex mathematical models in developing innovative nuclear systems. These models are validated through targeted experiments in specific experimental set-ups. This exclusive array of experimental facilities enhances the international character of SCK•CEN and adds to its unique allure.

Peter Baeten
Advanced Nuclear Systems Institute Director

Unique corrosion cycle for MYRRHA

Clear insight via correlations

Are you planning to use a heavy liquid metal as the coolant in a nuclear reactor? If so, remember that corrosion can occur with certain materials. That's not good for the temperature and durability of the components. For that reason, it's necessary to carefully examine the effects of corrosion when designing an installation such as MYRRHA. But how can you demonstrate that the materials will survive when MYRRHA doesn't even exist yet?

MYRRHA is a research installation that will contain fourth-generation nuclear reactor technology. The materials pose a difficulty for the development of MYRRHA. They need to be able to endure harsh conditions, such as high temperature, strong radiation and a corrosive environment.

High temperatures

Different conditions will apply in future reactors compared to traditional reactors. The temperature in MYRRHA can reach up to 400°C, for example; in fourth-generation nuclear reactors with liquid lead as coolant, temperatures can even reach up to 600°C. What is the corrosion resistance of the selected materials if they then come into contact with the coolant, liquid lead-bismuth metal?

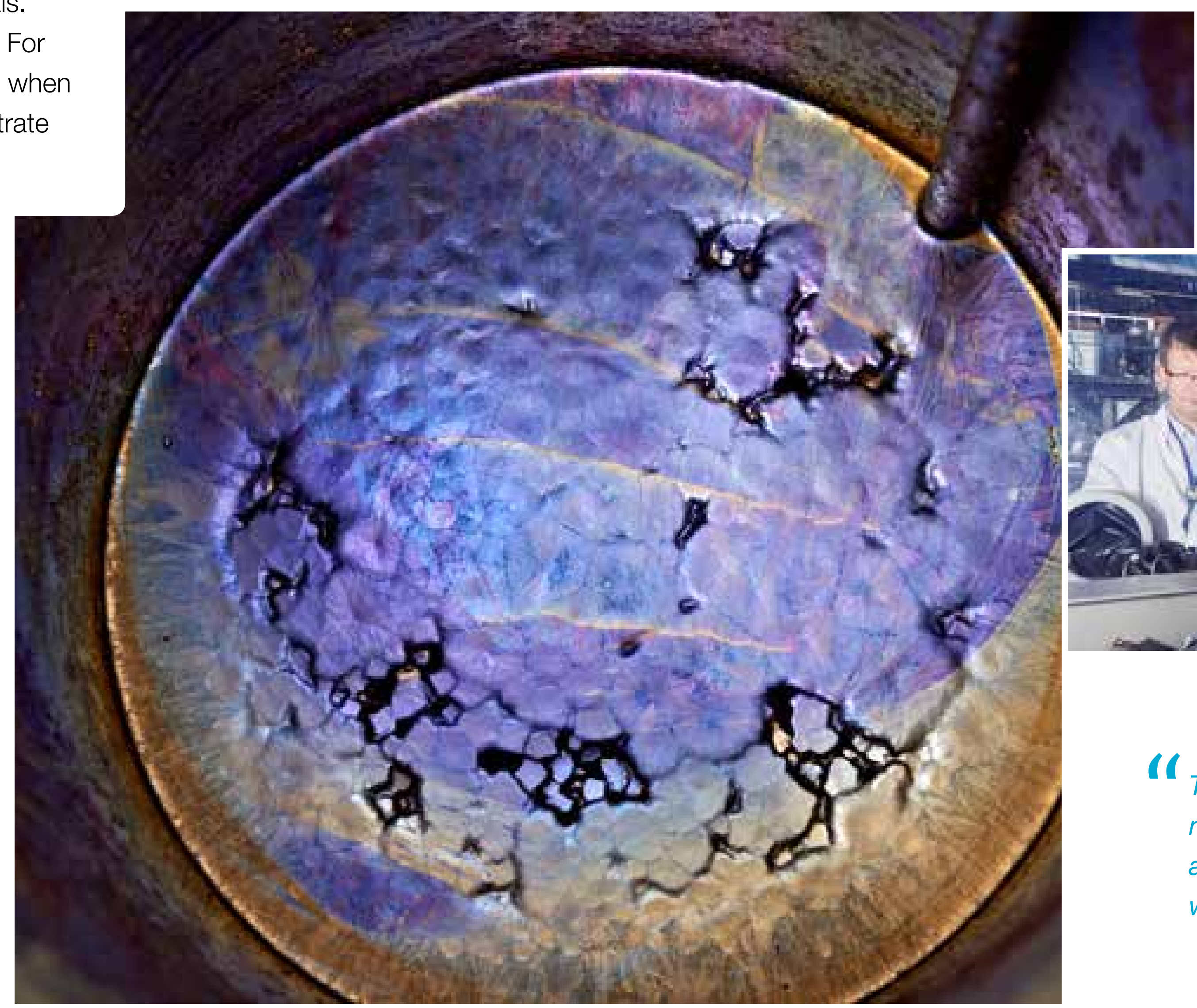
This is being investigated as part of the material programme for MYRRHA. The aim is to select and verify the candidate materials selected for structural and functional components of the primary circuit in MYRRHA.

The tests for this research are taking place in an environment that simulates real corrosion conditions. A realistic approach to researching corrosion in circumstances that are representative for MYRRHA would require much more expensive and sophisticated configurations, which would then have to run for many years in parallel.

Unique corrosion cycle

For that reason, the researchers at SCK•CEN developed a method that gives a clear insight into corrosion thanks to the principle of correlation: the possible interaction between two series of observations. The researchers didn't just use a number of small test set-ups, they also built a large corrosion cycle, which is unique in its field. This is necessary in order to prove that the correlations calculated from the small set-ups are conservative enough.

By analysing and comparing the test results, the researchers find solutions to counter the effects of corrosion. The calculations form a useful tool for the MYRRHA designers to define limitations, estimate operating parameters and to validate the permitted corrosion in components such as fuel elements, heat exchanger tubes, the reactor vessel etc.



Examining corrosion mechanisms

Right now the researchers are checking whether the correlations are able to predict corrosion damage accurately by comparing every experimental result obtained with the predictions. At this point, the predictive ability of the observed correlations has been very positive.

They are also examining corrosion mechanisms, by using modern techniques to describe the microstructure and microchemistry, as well as various types of electron microscopy. This insight into mechanisms is necessary in order to substantiate the correlations. Finally, the researchers also want to improve and update the correlations developed, especially for the welds in materials.

> *"The researchers didn't just use a number of small test set-ups, they also built a large corrosion cycle, which is unique in its field."*

Structural materials for Gen-IV reactors

Promising collaboration between SCK•CEN and KU Leuven

A pump impeller is used in the MYRRHA reactor. This is a rotating pump component, the role of which is to move the coolant Lead Bismuth Eutectic (LBE). With traditional structural materials such as stainless steel, there is a risk of erosion and dissolution. In order to prevent the pump impeller becoming a stumbling block for the reactor, SCK•CEN and KU Leuven have joined forces. Innovative structural materials based on MAX phases are the result.

Which materials retain their shape and characteristics if they come into contact with fast-flowing heavy liquid metals (HLM) such as LBE and lead? Thomas Lapauw, a PhD student at KU Leuven, is researching the potential of MAX phases: 'This class of ternary carbides and nitrides exhibits a unique combination of features: some have the characteristics of ceramics and others have the characteristics of metals.'

Superior resistance

MAX phases are robust. They have a superior resistance against corrosion if they come into contact with liquid metals and are characterised by a high damage tolerance. As a result, MAX phases have a high potential for use in HLM-cooled nuclear systems. Konstantza Lambrinou from SCK•CEN is supervising the research and is extremely enthusiastic about MAX phases: 'You can use them to produce components with a complex geometry. Even if the durability of high-performance MAX phases doesn't suffice when exposed to fast-flowing HLMs, it is possible to form durable phases such as binary carbides and nitrides on the impeller surface.'

MAX phases are also relevant for pump impellers in fourth-generation lead-cooled fast reactors (Gen-IV LFRs). The impeller must be reliable in MYRRHA at temperatures up to 270°C, but with LFRs the temperature increases to 480°C. Of course, this requires thorough investigation. Thomas Lapauw explains how he is approaching this: 'First of all, I prepare MAX phase-based monoliths and their composites, for example cermets (composite material made of ceramic parts in a metal matrix), by means of powder metallurgy. After that, I carry out a micro-structural characterisation of the materials produced and I assess the strength and fracture toughness. Finally, I evaluate the resistance against corrosion and erosion in liquid metals.'

MAX phases form a material with which it is possible to make complex shapes. Conventional milling can also work perfectly.

Discovery of new MAX phases

What is the highlight of this project? Konstantza Lambrinou leaves us in no doubt: 'The powder metallurgical synthesis of MAX phase materials that are difficult to make. Thomas discovered promising new MAX phases, such as Zr_2AlC, Zr_3AlC_2, Hf_2AlC and Hf_3AlC_2, ideal for applications in HLM-cooled systems and high-temperature applications. It is logical that SCK•CEN and KU Leuven have submitted a joint patent application.'

Cermets for even better performance

Is it possible to produce cermets on the basis of MAX phases? This is a question that will be answered in the near future. These composites are able to maintain the benefits of these ternary carbides and improve the fracture toughness. Thomas Lapauw has prepared a first generation of these materials in order to evaluate their mechanical characteristics.

03

Technology geared towards innovation

First of a kind for BR2

Fusion requires high-neutron-flux irradiation at 1200˚C

Two decades into the future seems a long way off. But at Cadarache in the South of France, the test fusion reactor ITER is currently being built. This is the last step before the construction of the industrial fusion reactor DEMO, which should be ready by about 2044. As a research centre, SCK•CEN is also doing its bit: for the European programme EUROfusion, high-flux irradiation will take place in BR2 at 1200°C. Such extreme conditions have never before been achieved in the history of SCK•CEN.

The ITER reactor, which will be arriving at Cadarache in France within a few decades, is the first step towards demonstrating both the technical and the commercial benefits of nuclear fusion. Research teams are currently developing and specifying the materials that will be contained in the fusion reactor, including those for the 'first wall', which will be directly exposed to the plasma.

The selection of basic materials for use in ITER has now been completed. Tungsten will be used as the armour material for the divertor – a component that maintains a maximum heat load in order to achieve the most stable discharge of the plasma. The end-of-life dose received by the divertor material in ITER will not exceed 1 dpa (displacement per atom).

Research into new materials now needs to be developed to ensure that commercial fusion facilities can be operated safely – specifically DEMO, the industrial fusion prototype that will be the successor to ITER. The accumulated dose will be at least a factor of 10 or 20 higher. This nuclear fusion research is being carried out as part of the EUROfusion project, a H2020 partnership between Euratom and a consortium of various European Union member states, Switzerland and Ukraine.

"The first irradiation campaign above 1000°C in BR2 will be a real challenge and will provide new opportunities for the development of high-temperature materials for both nuclear fusion and nuclear fission."

Irradiation campaign in BR2

At SCK•CEN, the initial data is being screened and selected for irradiation conditions 'after ITER'. In 2017, the researchers are due to start a new irradiation campaign in the research reactor BR2 in order to select innovative tungsten-based materials. It is possible to mimic fusion conditions in BR2 thanks to its core flexibility, the high flux and the wealth of in-house expertise available. By increasing the neutron flux and the irradiation temperature, the researchers create neutrons that are similar to those in a fusion environment. However, the end-of-life conditions require a long uninterrupted period of irradiation of at least five years.

New irradiation equipment

The project will run for about three years and has a total budget of 2.5 million euros, half of which will be used for irradiation, and one-third for post-irradiation experiments (PIE). The project also includes the development of new irradiation equipment, the High Temperature High Flux (HTHF) (see box).

In this machine, high-neutron-flux irradiation will be carried out at 1200°C under active temperature and environmental control, a first in the history of experiments conducted at SCK•CEN. After irradiation, the researchers will systematically document the thermal, mechanical and micromechanical properties of the irradiated materials in SCK•CEN's Laboratory for High and Medium Activity (LHMA).

The materials to be irradiated are tungsten-based alloys, designed for the first wall and the armour. The researchers use nano-engineering to achieve the best results under fusion conditions. Their aim with the irradiation campaigns is to investigate whether the performance of the production materials will be maintained after exposure to neutrons or whether these neutrons will throw a spanner in the works.

> *"The project also comprises the development of a new irradiation device, the so-called High Temperature High Flux (HTHF)."*

Step by step

The project itself consists of three parts with various post-irradiation tests and is proceeding in collaboration with the research centres FZJ and KIT (Germany) and Demokritos (Greece). There is good reason to share the project among different centres. One single laboratory does not have all the requisite materials, expertise and knowledge in-house. Furthermore, it is a race against time, because the schedule for establishing the DEMO design is really tight, even though the plant is not due to be completed until 2044.

GRAPHITE KEEPS IT COOL

HTHF is the name of the housing in which the TUNER project (TUngsten NEutron irRadiation) will carry out specific irradiation. This specific housing will be used to investigate the effect of the combination of high temperature (800°C) and high flux (1 dpa in tungsten) on materials and their properties.

The advantages of graphite

Graphite was chosen because it has a low neutron-absorption capacity and good thermal conduction properties. Furthermore, due to its low specific gravity, graphite warms up less of its own accord. In this way, the researchers make sure that the temperature does not increase too much. Initially, the design followed a few more general criteria; at a later stage, it was tailored to the client's specific criteria. Designer Gitte Borghmans had to work in an extremely detailed manner: 'There are 26 cases, hanging one after the other like small carriages. Each case is only 30 mm high.'

Six cycles in BR2

The HTHF equipment has now been designed and construction will go ahead in early 2017, so that irradiation can commence before the 2017 summer holidays. As a result of the required 'high flux', HTHF will remain in the BR2 reactor over six cycles, which is approximately a year. The LHMA laboratory will analyse the irradiated samples in 2018.

The BR2 campaign is going to be a real challenge and will reveal whether BR2 is able to provide extreme irradiation conditions for new materials. After successfully demonstrating the HTHF performance, the next stage in the research consists of a sub-miniaturisation programme: the smaller the volumes, the lower or cheaper the irradiation conditions that need to be met. Small sample volumes also mean quick deactivation, inexpensive transport and, generally, fast PIE feedback. In the future, the use of miniaturisation will grow significantly, which will be the next big challenge for the Fusion Materials Programme.

Technology

Sustainability is not a buzzword

Thanks to its refurbishment and unique set-up, BR2 is still one of the best test reactors and will continue to be for generations to come. BR2 is also a very reliable source of medical radioisotopes, accounting for as much as two-thirds of global production. The further development of new and promising medical radioisotopes for cancer treatment shows that our nuclear research is and will always be characterised by sustainability.

Leo Sannen
Nuclear Materials Sciences Institute Director

How does heat affect pore water composition in the Boom Clay?

Research 225 metres underground

Is the Boom Clay suitable for underground disposal of radioactive waste? This question is currently the subject of intensive research. One project is investigating the extent to which the heat emitted by radioactive waste – simulated by the PRACLAY Heater test – influences the composition of pore water, which can, in turn, influence the behaviour of radionuclides. The experiments are being carried out in the HADES laboratory, 225 metres below ground level.

Scientists around the world consider deep underground disposal in geologically stable strata to be the most appropriate way to manage highly radioactive waste in the long term. In Belgium, the research programme is focusing on deep clay formations such as the Boom Clay. Before disposal in clay can become a practical reality, however, the behaviour of the clay and the impact of possible disruptions must be thoroughly investigated. SCK•CEN started this research in Belgium almost 40 years ago.

Research into the impact of heat on the composition of pore water takes place in the underground HADES laboratory, as part of the PRACLAY Heater test. This test enables researchers to investigate how the Boom Clay behaves thermally, hydromechanically and chemically when it is heated as a result of contact with highly radioactive waste.

Researchers **Mieke De Craen** and **Miroslav Honty** in the underground laboratory HADES

Research into thermal load

The aim of one of the experimental set-ups is to study the chemical changes that occur as a result of the clay warming up. The research will continue over a period of 10 years. What does it actually involve?

Researchers Mieke De Craen and Miroslav Honty take us 225 metres deep underground: ‘We analyse the pore water and the gases dissolved in it at regular intervals in the laboratory. To do this, we drill a hole in the clay and insert a piezometer. This is a type of metal tube with filters that collect the water at various points. That water is conveyed to the experimental set-up in the underground laboratory via thin pipes. Under normal circumstances, the pore water at this depth has a temperature of 16°C, but as a result of the heating phase of the PRACLAY Heater test, the temperature at the filters is currently around 55°C. This can disturb the chemical equilibrium and that’s exactly what we want to study. The experimental set-up enables us to measure a number of specific parameters and to sample the pore water and the gases dissolved in it separately. The samples are then sent to the above-ground laboratory for further analysis.’

> *“The temperature and pore water pressure measurements in the clay confirm the calculations that the researchers made in advance on the basis of small-scale heating experiments.”*

PRACLAY HEATER TEST

The PRACLAY Heater test is taking place in a 45-metre long side gallery of HADES, the unique research laboratory that is managed by EIG EURIDICE, a partnership between SCK•CEN and ONDRAF/NIRAS (the Belgian Agency for Radioactive Waste and Enriched Fissile Materials).

The heating phase commenced in 2014 for a period of 10 years. In August 2015, the target temperature of 80°C was reached at the interface between the concrete gallery wall and the clay. The temperature and pore water pressure measurements that have so far been carried out in the clay confirm the calculations made by the researchers in advance on the basis of the results of earlier small-scale heating experiments. This confirmation, on a scale that is representative of an actual waste repository, is one of the most important aims of the experiment. In addition, the PRACLAY Heater test also provides the opportunity to assess the geochemical changes in the clay, the stability of the concrete lining and the reliability of the measuring instruments at elevated temperature.

Comparing results with predictions

Heating causes chemical reactions that affect the pore water. The researchers want to determine the extent to which this happens and whether it has an impact on the behaviour of radionuclides. Mieke De Craen and Miroslav Honty again: ‘We have a large database of pore water data at a naturally occurring temperature of 16°C. And we also have geochemical models for predicting the composition of pore water at increased temperatures. But until now, we haven’t had the opportunity to test their validity using experimental data.’

This is now possible on a large scale thanks to the HADES heating experiment. The researchers will determine the pore water composition and compare the results with their predictions: ‘Thanks to the new data, we’ll be able to study the situation in detail at elevated temperatures. A study is also currently under way in close collaboration with the Microbiology group. They are going to assess the possible presence and activity of micro-organisms in pore water in the Boom Clay subject to thermal stress.’

U_3O_7: the missing piece of the puzzle

A better understanding of the uranium dioxide oxidation process

Uranium dioxide (UO_2) is the most commonly used nuclear fuel. When exposed to air or water, UO_2 oxidises to U_3O_8. During this oxidation reaction, the material swells by at least a third, and with very fine powders this process can take place very quickly. Scientists have spent more than seventy years studying the complex structures that are formed during the oxidation of UO_2 to U_3O_8, but an important intermediate phase, namely U_3O_7, has remained unexplained until now. Gregory Leinders changed all that with his PhD research.

Uranium powders and cylindrical fuel pellets always oxidise if they come into contact with air. This can have drastic consequences for both the production of nuclear fuel and the storage of spent fuel. During the oxidation reaction, a considerable amount of heat is released, as a result of which there is a risk of auto-ignition of very fine powders. This generates a number of safety risks, because fire is to be avoided at all costs in a production process.

And that's not all. When the oxidation reaction goes to completion, the higher and more stable oxide U_3O_8 is formed. This oxide cannot be used for the production of nuclear fuel. During the crystallographic transition to U_3O_8, the volume increases by as much as 36 per cent. This can cause storage containers to crack, during not only the production process, but also the processing and storage of the spent fuel.

Contradictory information

Together with his colleagues from the Fuel Materials group, Gregory Leinders investigated how oxygen interacts with UO_2 powders: 'I looked at the way in which and how quickly oxidation occurs. The conditions were based on those in the production of nuclear fuel and the storage of UO_2 powders and fuel pellets. Specifically, a maximum oxygen concentration equal to that in the air and temperatures of up to around 250°C.'

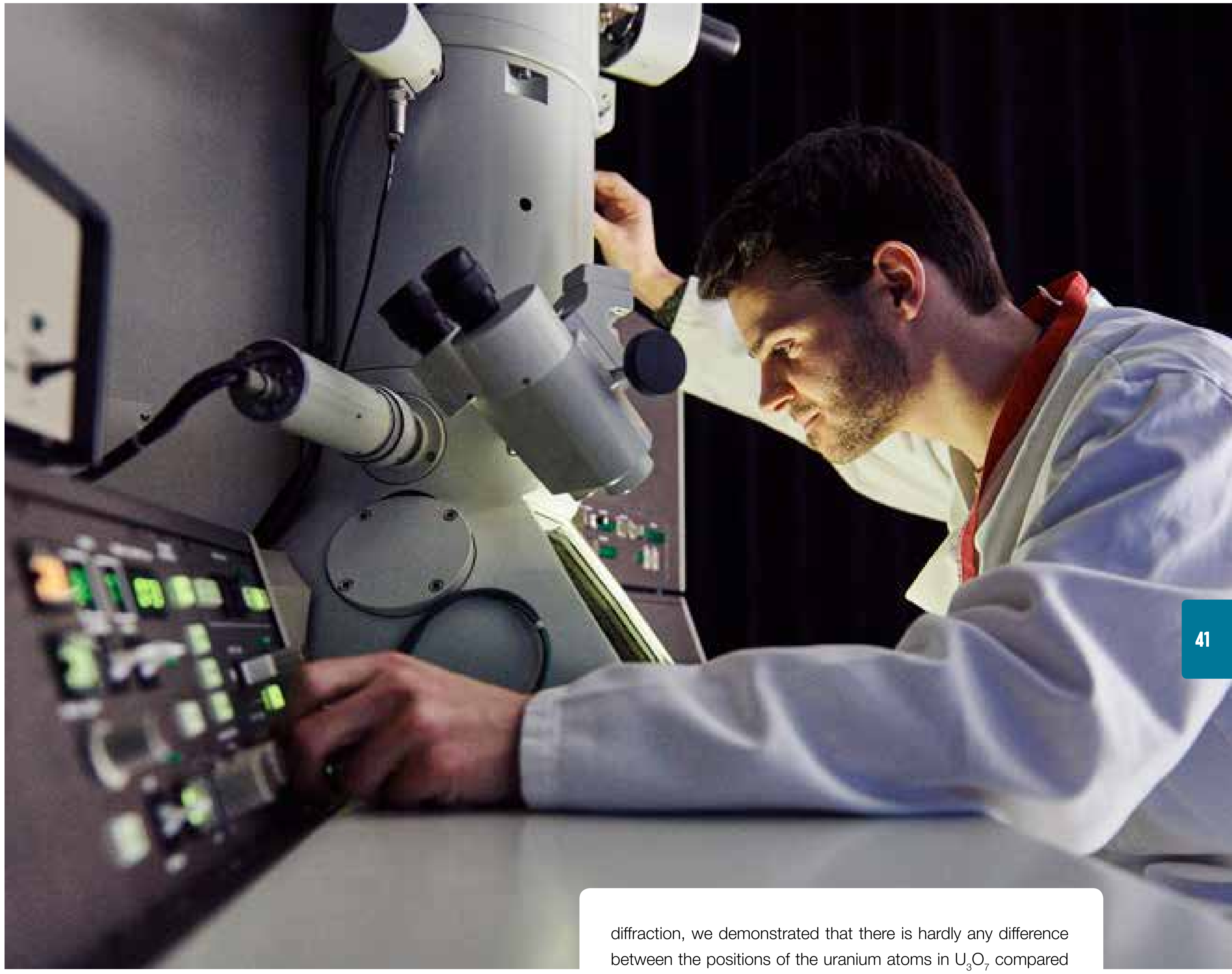
Before U_3O_8 is formed in these conditions, the intermediate uranium oxide U_3O_7 is created. Gregory Leinders: 'Although we've known about this oxide for seventy years, we didn't understand its complex crystal structure. The data was sometimes even contradictory. My colleagues and I managed to develop a consistent model for this structure, based on new experimental results.'

Periodic arrangement

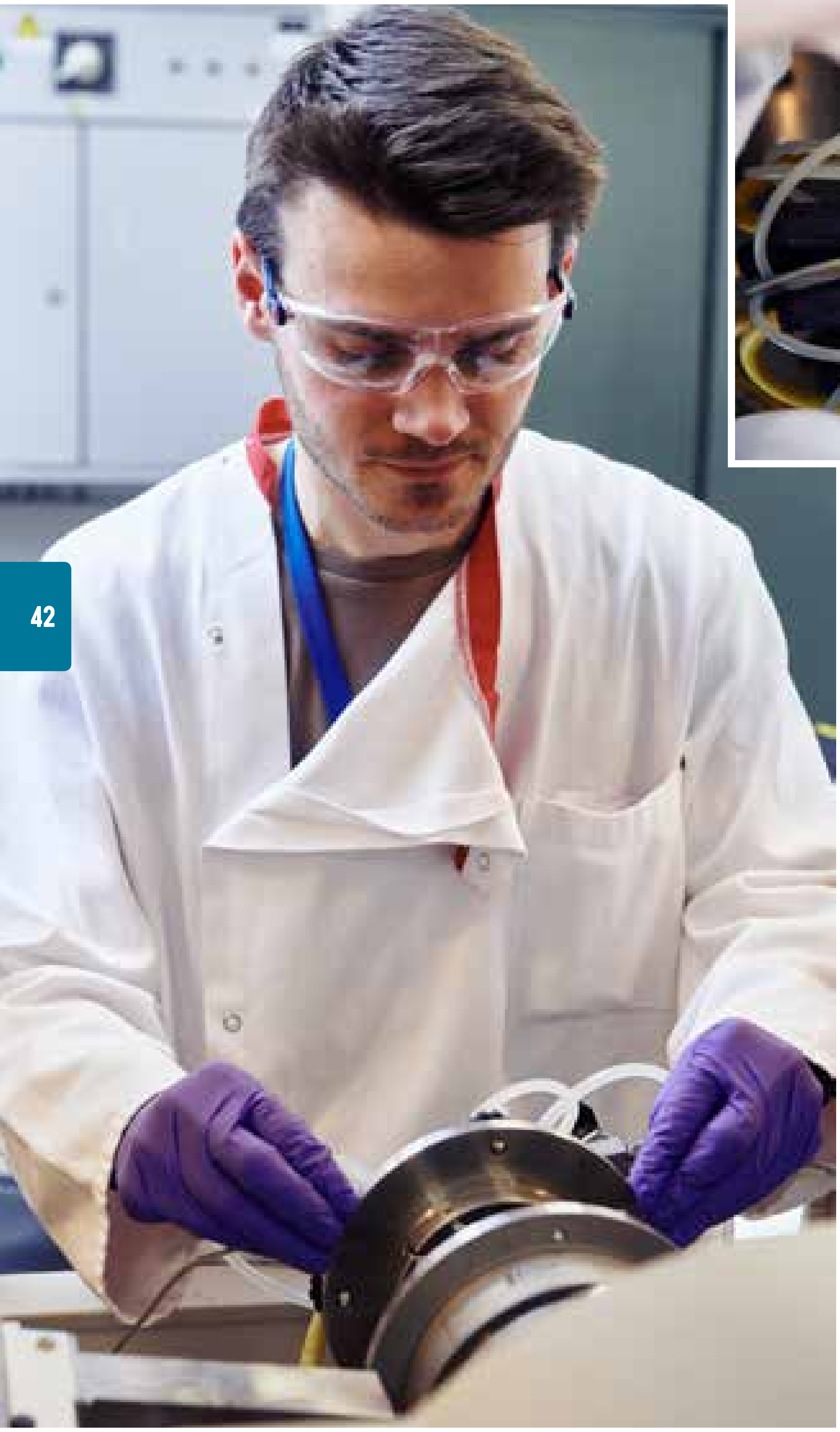
After polycrystalline U_3O_7 powders were produced in the SCK•CEN labs, researchers used X-ray diffraction and electron diffraction for the structural analysis: 'We do that using a beam of X-rays and a beam of electrons, so that a scattering process takes place that is sensitive to the position of the atoms in the structure. The result is an interference pattern, and that's what we measure. Diffractograms like this provide us with information about the position of atoms and the distance between them, and also about the symmetry of the crystal structure.'

The use of the two diffraction techniques made it possible to determine the structure properly: 'Using X-ray diffraction, we demonstrated that there is hardly any difference between the positions of the uranium atoms in U_3O_7 compared with UO_2, while electron diffraction enabled us to determine the clustering of the additional oxygen atoms. On average, the structure closely resembles that of UO_2, but additional anions are grouped into cuboctahedral oxygen clusters, which results in a long periodic arrangement. The crystal lattice can subsequently be described as an enlarged primitive cell that contains 15 fluorite-type subcells.'

Scientists have been racking their brains for over 70 years to solve this problem. SCK•CEN researchers have finally found a consistent model for for the complex crystal structure of U_3O_7.



“We finally developed a consistent model for the complex crystal structure of U_3O_7.”



Towards a quantitative interpretation

Having determined the U_3O_7 crystal structure, SCK•CEN has discovered an essential missing piece of the puzzle of the oxidation mechanism of UO_2. But more work is needed: ‘The primitive cell in itself still requires more detailed research. In a follow-up study, we want to figure out additional structural information using state-of-the-art techniques. These include synchrotron X-ray absorption spectroscopy (XAS), in order to establish the valence state of the uranium atoms. Another option is precession electron diffraction to further refine the crystal structure – this is a more advanced technique that can be used to determine and interpret intensities in an electron diffractogram quantitatively. All of these results should contribute to a greater understanding of the way in which the important end product of oxidation is formed: U_3O_8.’

New opportunities in cancer treatment

Valuable capsules with thorium for Targeted Alpha Therapy

The past can hold valuable treasures for the future. In the 1970s, SCK•CEN produced sources of thorium and is currently one of the rare research institutes in the world to possess thorium-229, a scarce and promising radioisotope. Today, the new SERAPHIM project is picking up where they left off: thorium can make a useful contribution to cancer treatment.

Thorium-229 (Th-229) is a valuable radioisotope, used in atomic clocks, for example. But that’s not all: the daughter isotopes actinium-225 (Ac-225) and bismuth-213 (Bi-213) have a great deal of potential for cancer treatments. That sounds encouraging, but there is one problem: the global quantity of Th-229 is extremely limited. SCK•CEN has succeeded in demonstrating that there are relevant quantities of Th-229 in the historical sources of thorium, creating the opportunity to initiate R&D into radiopharmaceuticals. Researchers are specifically interested in the decay product Ac-225, both for direct applications and for the creation of a generator for Bi-213.

Targeted alpha therapy

Ac-225 and Bi-213 can be coupled to specific antibodies. An antibody is a type of carrier molecule to which a short-lived radioactive particle can be attached. The antibody coupled to Ac-225 or Bi-213 subsequently moves inside the body and binds specifically to a cancer cell like a key in a lock, and during radioactive decay of Ac-225 and Bi-213, alpha particles are released that destroy the cancer cell. This is the principle of targeted alpha therapy (TAT).

One of the few

SCK•CEN is one of the few research institutions in the world that is in possession of Th-229 as a source for Ac-225 and Bi-213. During research into the historical sources of thorium, the available quantity of Th-229 was established using a non-destructive measurement method based on gamma spectrometry and mathematical modelling. The qualitative method applied had the advantage that the hermetic seal on the historical capsules remained intact and that the purity of the valuable product was not compromised. The knowledge and experience of the Dismantling, Decontamination & Waste expert group was crucial when it came to determining the test set-up and interpreting the results. The thorium – just 1 milligram! – was contained inside capsules that needed to be opened with great care in a subsequent phase.

“SCK•CEN is one of the few research institutions in the world that is in possession of Th-229, a precious radioisotope.”

“Through our preclinical research, we want to convince the medical community of the huge benefits of targeted alpha therapy. This insight may open the door to large-scale isotope production for SCK•CEN. It’s very promising!”

Mission accomplished

The capsule was successfully opened in December 2016. Work immediately commenced in the form of the SERAPHIM project (Separation of thorium-229 from historical sources for the production of radioisotopes for targeted alpha immunotherapy). First of all, the radiological content is being processed to separate out Th-229. After that, the aim is to produce an Ac-225/Bi-213 generator, from which Bi-213 will be extracted for the development of Bi-213-coupled antibodies for the treatment of ovarian and breast cancer. This is being carried out as part of the PhD research of Yana Dekempeneer, which involves a successful collaboration between the Radiochemistry expert group and the Vrije Universiteit Brussel.

Thomas Cardinaels, head of the project, firmly believes that these alpha isotopes have a great future ahead: ‘Through our preclinical research, we want to convince the medical community of the huge benefits of targeted alpha therapy. This insight may open the door to large-scale isotope production for SCK•CEN. It’s very promising!’

04

Contributing to great social challenges

“I could never have dreamed of becoming chairman”

Hans Vanmarcke at the helm of UNSCEAR

In 1996, he became a member of the Belgian delegation of scientists. He never missed a single meeting in Vienna. The Ministry of Foreign Affairs appointed him as head of the Belgian delegation in 2008. In 2015, he became vice-chairman. And in 2016, the 27 participating countries elected him as chairman. This was all at UNSCEAR, the United Nations Scientific Committee on the Effects of Atomic Radiation. His name? Hans Vanmarcke, radiation protection expert at SCK•CEN.

1955. At the height of the Cold War, the USA and the USSR were fully engaged in above-ground nuclear testing. Large quantities of radioactive material were released into the atmosphere and both superpowers were contaminating the world with radioactive waste. An organisation was needed to determine the consequences of the radioactive fallout in a neutral manner.

The General Assembly of the United Nations established UNSCEAR (the United Nations Scientific Committee on the Effects of Atomic Radiation) and gave it a mandate to assess the global levels of exposure to nuclear radiation and to investigate the resulting health effects. This exposure was the result of not only the arms race, but also the development of nuclear power, the extraction of raw materials, the growth of medical applications and natural exposure.

Elevated status

There is an important difference between how UNSCEAR operates and how organisations such as the IAEA (International Atomic Energy Agency) and the WHO (World Health Organisation) operate, Chairman of UNSCEAR Hans Vanmarcke explains: ‘Those organisations have a permanent base, where many staff members are employed. UNSCEAR is completely different. We just have a small secretariat in Vienna. The input comes from the countries that take part.’ But for every disadvantage there’s an advantage: ‘UNSCEAR has an important status because we report directly to the United Nations General Assembly.’

Reaching a consensus

The reports from UNSCEAR provide the United Nations and governments around the world with a scientific basis for evaluating radiation risks and taking safety precautions. Hans Vanmarcke emphasises UNSCEAR’s neutrality: ‘We try to reach a scientific consensus that serves as a basis for the legislation on protection against radiation across the globe. UNSCEAR’s task as a scientific committee is to process research results and to report on how things stand. An example? We are researching the presence of radon in homes: what are the concentrations and what is the likelihood that people develop lung cancer as a result?’

In addition, UNSCEAR also communicates directly with the public about exposure to ionising radiation and the effects of it: ‘One example is the accessible brochure “Radiation: effects and sources” that we have compiled and that is being published by UNEP (the United Nations Environment Programme). The work involved in translating this into many languages shouldn’t be underestimated.’

Belgium playing its part

Hans Vanmarcke has been a member of the Belgian delegation since 1996. 'It's a huge privilege and a real honour to chair this United Nations committee and to represent Belgium. I have invested a great deal of my time in UNSCEAR over the years and many colleagues from SCK•CEN have worked on UNSCEAR reports in that time. My chairmanship contributes to our renown and prestige. But this privilege does not only go to our research centre. That's why I'm also involving other Belgian organisations.'

The chairmanship of Hans Vanmarcke also has consequences for the Belgian embassy in Austria: 'Belgium now has to take the lead in UNSCEAR-related diplomatic activities at the United Nations. I am leading the scientific part, and the ambassador is taking charge of diplomacy.'

Currently, 27 countries are members of UNSCEAR: 'One diplomatically sensitive subject in 2017 is the question of whether to expand the committee with new member states. It's important to point out that becoming a member isn't a gift, it's a responsibility. As a country, you are given a task to make a difference to the world, and that's only possible if you appoint motivated scientists.'

A dream come true

During Hans Vanmarcke's term of office, UNSCEAR will focus specifically on producing various long-awaited reports: the health consequences of exposure to radon in the home, the biological mechanisms of exposure to low radiation doses, the epidemiological studies into the occurrence of radiation-related cancer and the occurrence of 'secondary' cancers following radiotherapy.

'It is of fundamental importance for us to pursue our research into the effects of ionising radiation on human health, especially the consequences of low radiation doses. It's essential that we provide the UN General Assembly, the scientific community and the general public with valid, scientific information.'

All this is tremendously hard work, as Hans Vanmarcke is all too aware. 'But it's also the icing on the cake as far as my career is concerned. After two years as chairman, I'll be able to serve as past president for another two years. I never dreamed that I'd lead an international organisation like this.'

> *"As a country, you are given a task to make a difference to the world, and that's only possible if you appoint motivated scientists."*

VALUABLE REPORTS

Since its foundation, UNSCEAR has published reports on twenty very important investigations. These reports are accepted as the standard all over the world and are used as a reference by the scientific community. Here are just a few examples:

- The effects of ionising radiation on animals and plants;
- Epidemiological studies into the link between cancer and exposure to radiation;
- Effects of exposure to radon in homes and workplaces;
- Health effects of exposure to radiation in children;
- Overview of global exposure to radiation (Fukushima, Chernobyl, health, etc.);
- Radiation exposure from electricity generation arising from different generating technologies.

More info: http://www.unscear.org

What impact does radiotherapy have on our health?

For better diagnostic and therapeutic treatments

Exposure to ionising radiation can have negative health effects. At SCK•CEN, researchers are investigating when these effects occur and how they can be prevented. This is important for the medical sector, which is increasingly making use of this useful and effective technology for diagnostic and therapeutic treatments.

In 1945, the Japanese cities of Hiroshima and Nagasaki were the targets of atomic bomb attacks. Children who were exposed to sufficiently high doses of radiation as foetuses between week 8 and 25 exhibited clear signs of delayed mental development at the age of 12. The size of their brains was also smaller.

Statistical data was collected, but no mechanistic studies were carried out. For that reason, scientists at SCK•CEN have, for a number of years, been studying the consequences of exposure to ionising radiation during the foetal or early post-natal stage. More specifically, they are investigating the effect of exposure on the development and later functionality of the brain, neurodegeneration and ageing processes, including the incidence of early onset Alzheimer's disease.

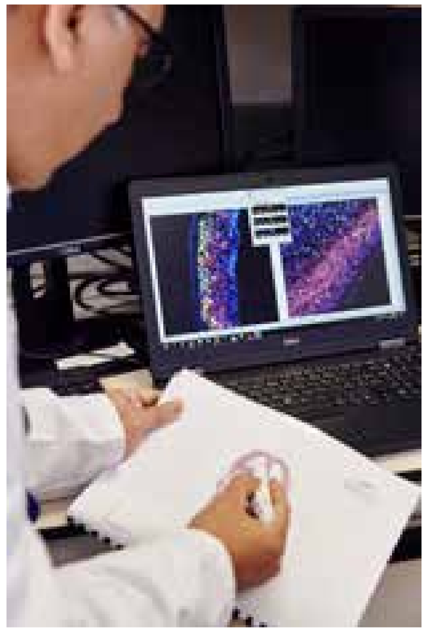
The researchers are also testing how it might be possible to protect children against the negative effects of radiation exposure, either before or immediately after birth.

The studies are making use of SCK•CEN's animal facility, where the researchers are looking at how ionising radiation influences the brains and behaviour of mice. The effects can be determined in a much shorter space of time than with people. Work is also being carried out on a genetic mouse model that is susceptible to the development of Alzheimer's disease.

Clarification of link between exposure of foetus to radiation and defects as an adult

The conclusions are clear: during the early stages when the organs are developing, sufficiently high doses of ionising radiation can lead to deformities, such as microphthalmus (disorder of the eye) and anencephaly (incomplete development of the skull). At the start of the period in which new nerve cells are being formed, radiation causes lasting developmental disorders and functional and structural changes in the brain, resulting in behavioural problems.

At the moment, the researchers are investigating the underlying mechanisms of these disorders and the related biomarkers. In the future, these could be used to identify people who may be susceptible to certain diseases as a result of exposure to radiation. The intention is also to test ways of providing better protection of healthy tissue when exposed to radiation.



More sensitive methods

At the same time, research is also under way into the effects of prenatal exposure to radiation on the development of the brain of mouse embryos, specifically defects in the neural tube (precursor to the central nervous system) and the development of microcephaly (small size of the brain). The researchers are trying to identify the molecular mechanisms of these defects and are investigating whether administering folic acid or inhibitors of the p53 tumour suppressor gene can prevent the mechanisms.

They have found out that the p53 gene, which regulates the expression of many other genes, plays a key role in the mechanism of reduced growth of the brain after exposure to radiation, which is also seen in people infected with the Zika virus. Although p53 is the most widely studied gene in medical and biological science due to its role in the development of many cancers, SCK•CEN has discovered a number of new target genes of p53, which may be important for a number of fields of research.

Thanks to more sensitive methods of measuring both the size of the brain and cognitive functions, the scientists were able to demonstrate that prenatal exposure to nuclear radiation can have negative effects at lower doses than previously suspected. However, these doses can still be deemed relatively high in the context of medical diagnostics.

> *The intention is to better protect healthy tissue during radiotherapy, thereby contributing to an improved quality of life for the patients.*

Identification of biomarkers

Ionising radiation also has an effect on the cardiovascular system, often only after one or two decades. This has also been observed in the survivors of the Japanese atomic bomb explosions in WWII. Problems related to cardiovascular diseases can also occur as a result of radiotherapy treatment for breast cancer. When the symptoms present themselves, the disease is often already at an advanced stage. For that reason, it is necessary on the one hand to identify biomarkers that indicate an issue at an early stage, and on the other hand to intervene in order to prevent the problems developing further.

Based on research into the underlying cellular and molecular mechanisms of radiation-induced cardiovascular conditions, SCK•CEN scientists are gaining a better understanding of the potential health risks for people who are exposed to ionising radiation. Specific attention is being devoted to the development of atherosclerosis. The researchers are attempting to contribute to the formulation of improved guidelines for cardiovascular radioprotection. They also want to identify the agents that are able to limit the harmful effects of ionising radiation if they are administered just before, during or after the treatment.

The research is being carried out with in-vitro cell cultures from endothelial cells, the cells that line blood vessels and are in direct contact with the blood. Endothelial cells are important in order for the vascular system to function normally. If they become damaged, cardiovascular diseases may result. In this experiment, mice are also exposed to ionising radiation and blood samples from cancer patients who have been treated with radiotherapy are analysed.

The researchers have now discovered that a low acute dose of X-ray radiation can cause DNA damage and cell death. The results of the DNA damage indicated a non-linear relationship with relatively more DNA damage at lower doses.

Chronic exposure to radiation at a low dose rate can lead to a profile of cell stress and infection in the first instance, which further results in premature cell ageing. The researchers are also revealing the mechanisms behind the delayed-onset effects of ionising radiation. Furthermore, they now want to study intercellular communication: how do cells in a radiation area communicate with other cells, and how can this intercellular communication be prevented?

Expertise

Social relevance is key to us

SCK•CEN is using its scientific and technical expertise to find solutions and answers to social issues. Is our drinking water safe? What are the potential risks of using ionising radiation for diagnostic and therapeutic purposes? SCK•CEN builds bridges. We ask people for more information about their values and expectations and then start a dialogue on the risks of using ionising radiation. We offer our expertise to developing countries. We are strongly engaged with society.

Hildegarde Vandenhove
Environment, Health and Safety
Institute Director

Key role in radioactivity measurements for Drinking Water Directive

New measurement techniques refined and validated

Michel Bruggeman and Freddy Verrezen

Over the next few years, a large number of water sources will be subject to radioactivity monitoring. This comes in the wake of a recent European Directive. But how do you determine the various radionuclides and parameters in drinking water? To this end, researchers from SCK•CEN have selected, refined and validated nuclear measurement techniques.

Radiological monitoring of drinking water is nothing new. The Low-level Radioactivity Measurements (LRM) expert group has been analysing drinking water for many years, primarily via gross alpha and beta measurements. They do this for a number of major soft drink producers.

New recommended values

The research has gained great momentum in recent years as a result of the implementation of new European legislation in Belgium. LRM researcher Michel Bruggeman explains: 'In 2013, the new European Directive 2013/51/EURATOM laid down recommended values for the monitoring of radioactivity in both drinking water and water that is used for the preparation of food or that comes into contact with food. The new legislation also defined the nuclide-specific recommended values that you need to bear in mind in detailed monitoring.'

What is the result of all of this? Michel goes on: 'Both drinking water producers and food companies that make use of water that comes into contact with food need to have their various sources of water monitored. Of course, everything depends on how each individual member state interprets the Directive. For us, the differences in national legislation present an additional challenge.'

His colleague Freddy Verrezen considers the scope of the monitoring: 'It's not just about water that may be contaminated by radioactivity as a result of human activities; it's mainly about the concentrations of radioactivity that are the result of natural radioactivity. Groundwater comes into contact with rocks underground that are naturally radioactive to some extent. As a result, it always contains radionuclides from the natural series of uranium, thorium and potassium.'

Quick, sensitive and affordable

'The Federal Agency for Nuclear Control (FANC) organises the monitoring of drinking water on the basis of a decision tree: first of all, screening is carried out (overall measurements and the quantification of two key nuclides) and – depending on the results of this screening – more detailed analyses are then performed in order to determine the presence of more radionuclides. For the basic screening for radioactivity, we've purchased additional proportional meters that we use to measure the gross alpha and beta activity.'

Radionuclides of importance can be divided into two groups. One group is characterised by natural radioactivity, whereas the other is the result of human activity. Michel Bruggeman: 'We've mainly focused on the first group and have established new measurement techniques for Ra-226, Ra-228, Rn-222 and Pb-210.'

The LRM researchers therefore faced the challenge of developing new measurement techniques for nuclide-specific analyses of water that would produce results relatively quickly and cost-effectively. But it is not just the speed of the technique that is important, as Freddy Verrezen explains: 'It also needs to be reliable and comply with the sensitivity requirements of the Directive.'

"Sometimes the success of a method is found in the small things that you need to discover during your research."

Not the best, but the most suitable

Researcher Mirela Vasile coordinated the development of the measurement techniques for monitoring purposes. Use was made, for instance, of filter membranes in order to filter certain elements out of the water and then measure them selectively. This type of membrane technology provides a quick way of removing certain elements from the water, but the full method must also be balanced: 'It took us several months to be able to guarantee the stability of the measurement with a RAD disk™. This is selective for radium and can therefore be used to determine Ra-226 and Ra-228. After filtering the water, you can simply measure the membrane using liquid scintillation spectroscopy or gamma spectroscopy. You do need to know the appropriate after-treatments of the membrane and the start time of the measurement in order to be able to carry out reliable measurements.'

A team fit for the future

There are not many laboratories in Belgium that can perform all necessary analyses of the radioactivity of drinking water samples. The number of samples which will have to be analysed in the next few years is still hard to predict but the LRM expert group prepared to undertake a large number of these tests over the coming years. 'We anticipated the demand by expanding the measurement capacity of the screening. We've bought additional meters and developed techniques with short throughput times. We've been working hard in the field of client acquisition too. Together with our business department, we've been seeking partnerships with other water analysis laboratories that are only able to carry out chemical or biological testing. We're waiting with bated breath...'

You do science with and for people

PISA builds a bridge between science and society

In the 1990s, SCK•CEN launched the 'Programme for Integration of Social Aspects into nuclear research' (PISA). In the nuclear sector, this programme has expanded to become the driving force for addressing social science and humanities issues in the nuclear debate at a European level. SCK•CEN is playing a leading role in this integration, now more so than ever. Interview with Catrinel Turcanu and Tanja Perko from the Nuclear Science & Technology Studies Group.

Why do social science and humanities need to find a place in a field that is primarily about exact sciences?

Catrinel Turcanu: 'These days, you can no longer work in the field of nuclear science without engaging with society. You do science with and for people. This means that you take account of the standards, values and opinions of all stakeholders – and not just researchers, industry and the government, but everyone in our society. SCK•CEN's PISA programme certainly enjoys an international reputation for its pioneering role in this. We have acquired a great deal of expertise on the integration of social science and humanities, specifically with regard to the research into the risks of ionising radiation.'

Are exact scientists happy about this?

Tanja Perko: 'We're taking exact scientists out of their comfort zone. But we aren't being disruptive; we're generating new solutions. Because only together can we practise effective and complete science. More interaction is required; you need to cross the boundaries between different disciplines: social and technical aspects cannot be separated from each other.'

> *It's infectious, because there are now a growing number of initiatives to integrate social and ethical aspects into nuclear research at an international level.*

'The fact that we hold a mirror up to scientists can be annoying... but this can also be useful. At SCK•CEN, we'd built up the necessary support within fifteen years and were able to go public. It's infectious, because there are now a growing number of initiatives to integrate social and ethical aspects into nuclear research at an international level.'

After the nuclear accident at Fukushima in 2011, the European Commission concluded that action needed to be taken with regard to communication about ionising radiation. The result was the EAGLE project...

Tanja Perko: 'How do you enlighten people about the risks and advantages of ionising radiation? How can they be in a position to make informed decisions? What should they do in the event of an incident? In EAGLE, we systematically documented national and international data, instruments and methods, looked into education, information and communication requirements and identified the potential for coordination at European level. EAGLE was also a step towards a communication ideal: to bring everyone together so they can learn from each other – the nuclear sector, the users of ionising radiation, the government, mass and social media, informed citizens, and so on.'

What is the tangible end result of EAGLE?

Tanja Perko: 'A series of recommendations about how to achieve a communication process in which the citizen plays a central role – always in the context of the risks of ionising radiation. From nuclear producers to journalists, everyone can use the recommendations. They are being published in a booklet for RICOMET 2017.'

Catrinel Turcanu: 'RICOMET is an international conference about risk perception, communication and ethics of exposure to ionising radiation. It's yet another initiative from SCK•CEN! In 2015 and 2016, RICOMET was the number one place to exchange views about scientific research, communication, risk perception and ethics – always at an international level and in the field of nuclear applications, natural radioactivity and radiological protection. One study for example dealt with citizen science in Japan after the accident at Fukushima. Immediately after the disaster, citizens in Japan took control by measuring radioactivity in the environment with Geiger counters and publishing the collected data online. This type of citizen science is a response to a public need to share reliable information about nuclear radiation. We can learn lessons from this for the future.'

Organising a conference is one thing, but how do you keep interest and the debate alive?

Tanja Perko: 'First of all, there's our network. We keep that active via a European platform for social science and humanities in research into ionising radiation. Besides that, we want to develop an environment for responsible research and innovation in the field of ionising radiation. It is important that we continue to encourage self-reflection among technical communities. We want to be a source of inspirational ideas for social science research in various areas. Of course, we will always align our research with social values, requirements and expectations. We would also like to create a public science centre in order to enhance media relations and to communicate intensively with the public.'

It all started off with PISA. How do you want to give your efforts more impact in the future?

Catrinel Turcanu: 'Greater integration is necessary for that. The impact of social science and humanities was addressed in the European OPERRA and CONCERT projects. But that process is too fragmented. That's why, in collaboration with our international partners in Europe, we've proposed developing a strategic agenda for social science and humanities in radiological protection research, within the CONCERT HORIZON 2020 project. We want to break down the barriers between the various disciplines that are involved with ionising radiation, but also the barriers between academic science and society. The aim of all this is to be able to better respond to the demands of the general public and to involve the policy-makers in the process. It's not only communication that needs to be addressed; other social and ethical aspects are extremely important too. You can't isolate these issues. As a pioneer in the integration of all of these aspects, SCK•CEN continues to play its part, now more than ever.'

Inspiration fuels space research in Congo

Combating malnutrition with Spirulina, the green protein source

In Congo, around 43% of all children under the age of 5 suffer from chronic malnutrition. The result is a high infant mortality rate. This prompted researchers from SCK•CEN to start working in Congo on the cultivation of spirulina, a type of algae rich in vitamins and minerals that are essential for combating chronic malnutrition in children. This Inspiration project is the first in a series and signals our research centre's ambition to contribute towards a balanced and sustainable world.

'Traditionally, SCK•CEN has supported a range of small projects. Each organisation received a small amount of money from us. More and more often, however, we found ourselves wondering: what are we actually supporting, what is the result of it, what is our aim?' Eric van Walle, Director-General of SCK•CEN, outlines how the Inspiration project came about: 'We had the idea of focusing on one social project and getting our own staff involved in it. This is how we first came into contact with Entrepreneurs for Entrepreneurs, an organisation that motivates companies in developed countries to enter into sustainable partnerships with developing countries. We felt the concept was an interesting one, so we made an appeal to our employees.'

Researcher Felice Mastroleo stepped up: 'Management asked if we had an idea that could be applied in Africa. Together with a few colleagues, we presented "Inspiration", or INtroduction of SPIRulina in equatorial Africa To Improve lOcal Nutrition. Our aim was to start growing spirulina algae in Congo in order to combat chronic malnutrition in children.'

From space to Congo

Where does the knowledge about spirulina come from? 'From our work for the ESA space project', Felice explains. 'As part of that, MELiSSA was developed, a recycling system for long-term space missions. The aim is to produce drinking water, food and oxygen for the astronauts. In that system, plants and bacteria carry out the recycling process. One of the bacteria is spirulina, which is actually a cyanobacterium that can be seen as something between a bacterium and a plant. Spirulina grows as quickly as a plant and produces oxygen. In our research, we're investigating whether spirulina is resistant to the effect of outer space – and especially ionising radiation – and to the effect of micro-gravity.'

Out of all the proposals, SCK•CEN's management chose the Inspiration project. But the researchers were not given carte blanche, as Eric explains: 'The first task was to establish good contacts in Africa. We didn't simply want to send people over there. We also entered into a commitment with them: they would be able to work on the project for a number of working hours, but would have to spend just as much free time on it.'

> *"Inspiration highlights what the DNA of our research centre consists of. In at least half of our activities, we try to develop solutions to major societal challenges."*

Felice set about establishing contacts: 'First of all with Louvain Coopération, an organisation of the Université catholique de Louvain (UCL) in Louvain-la-Neuve, where a project was under way for Burundi. But due to the civil war, we were forced to find an alternative. That's how we ended up at the NGO Congodorpen, an organisation that focuses on various aspects of agriculture and medicine in Congo. They have set up an agricultural centre in the Congolese village of Mooto. The people there produce palm oil, coffee and cocoa and also farm fish.'

From Mol to Mooto

The leap from research in molecular biology to the large-scale cultivation of spirulina is a considerable one. With his colleagues, Felice built an open basin with a capacity of 1,000 litres of water: 'We did that in our research building in Mol. In order to simulate the tropical climate, the temperature was a constant 30°C. The light was as natural as possible. The test with the basin lasted eight months. My thanks go to the many colleagues that volunteered their time to regularly stir the spirulina basin. They also helped raise money at an event where people were able to try waffles, pasta and chervil soup that had been fortified with spirulina.'

In summer 2016, Felice and his colleague Ben Vos left for the village of Mooto in Congo: 'First of all, we started the preculture of the spirulina and built the basin. The challenge in growing spirulina was getting the composition of the nutrients right, although spirulina doesn't need many. We'd brought nutrients with us from our lab, except for nitrates, which you're not allowed to transport by air. Once we were there, we went on the hunt for a good source of nitrates to add.'

Pure water, healthy spirulina

The biggest challenge was finding pure water: 'Analysis of various sources found large quantities of nitrites and heavy metals. The least contaminated source was the furthest from the village. But we made the people use that water. Spirulina is very nutritious, but acts like a sponge for heavy metals. Pure water is needed for healthy spirulina.'

The spirulina grew according to plan. The residents of Mooto were able to eat it immediately: 'You pour the crop through a filter. This collects the spirulina cells. You can then eat the spirulina straight away with a spoon. Unfortunately, however, you can't store it in that state, which is why we've developed a method to dry it. This means that the local population can add it to their food. Spirulina has a neutral taste, but is high in protein compared with cassava, their daily staple.'

In Mooto, Felice did even more than setting up the cultivation of spirulina: 'We demonstrated how people can incorporate spirulina into the cultivation of pondu, a spinach-like vegetable. We introduced spirulina to researchers from colleges and universities, so that they can pass this knowledge on in their courses. And we showed a doctor from the local hospital the things he needs to pay attention to if he wants to give spirulina to patients.'

Proven commitment

The Inspiration project attracted the attention of the press and had the honour of being nominated for the Entrepreneurs for Entrepreneurs award. 'This project highlights what the DNA of our research centre consists of. In at least half of our activities, we try to develop solutions to major societal challenges. This clearly shows what we are doing at a social level. Sustainability is also crucial to us, hence why we want to send our researchers on the field to pass on their knowledge and enable local people to assume responsibility for their own health. How could it have been done better than with a public health project?'

TROPHY FOR MOST SUSTAINABLE ENTREPRENEUR

Our project "Inspiration" was one of the finalists for the Trophy Most Sustainable Entrepreneur, awarded by the organisation Entrepreneurs for Entrepreneurs. The event rewards the work of Belgian companies that stimulate sustainable entrepreneurship and economic growth in developing countries. SCK•CEN was praised for its work in the Congo by Alexander de Croo, Deputy Prime Minister and Minister of Development Co-operation.

Key figures

05

768 EMPLOYEES

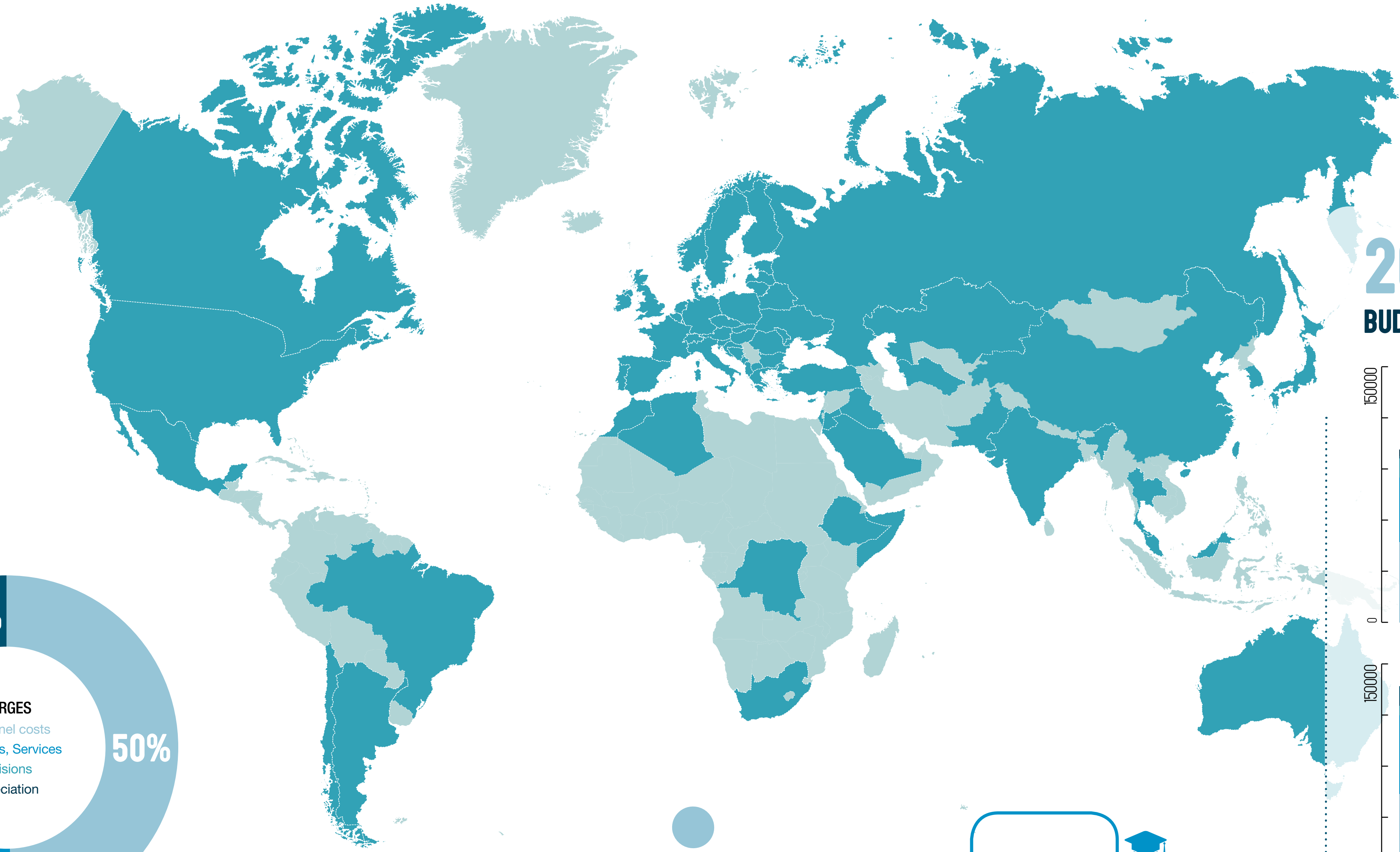
184 ♀ 584 ♂

35% WITH AN ACADEMIC DEGREE

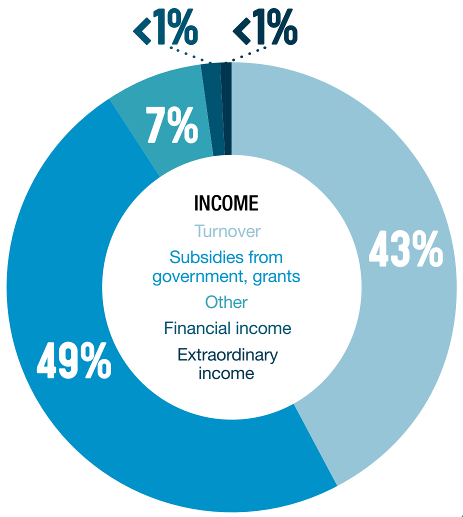
73 PHD STUDENTS

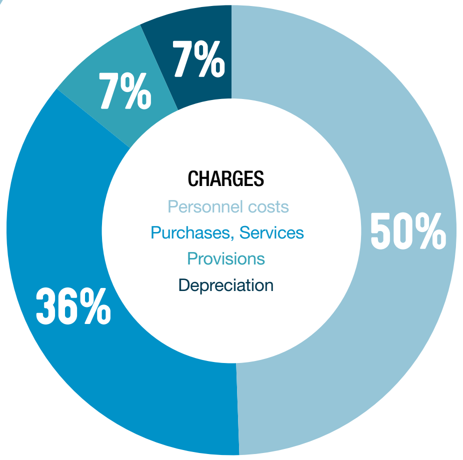
41 NATIONALITIES

ACTIVE IN **57** COUNTRIES



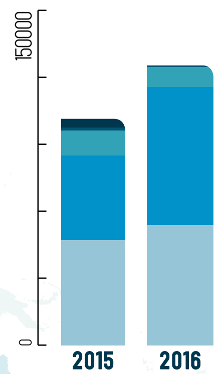
2016



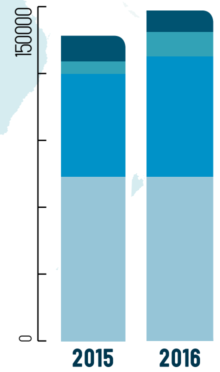


2015-2016

BUDGET EVALUATION (kEUR)

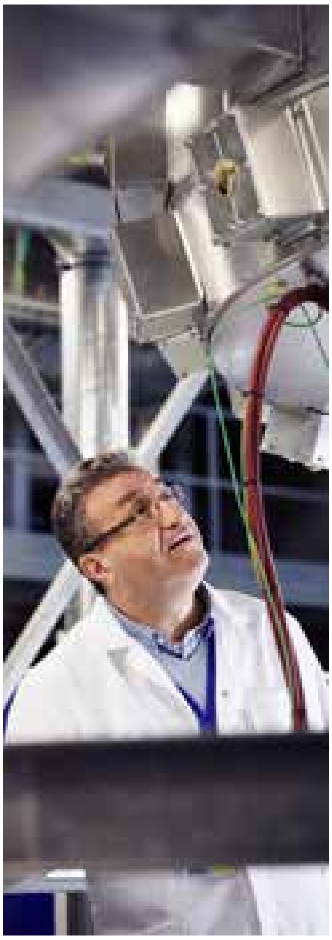


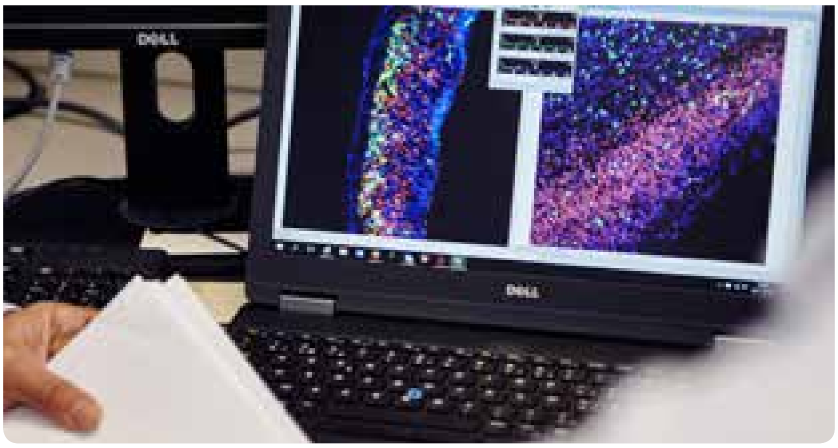
INCOME	2015	2016
Turnover	47101	53772
Subsidies from government, grants	37792	61754
Other	11231	8988
Financial income	1341	856
Extraordinary income	3947	13
Total	101412	125383



CHARGES	2015	2016
Personnel costs	73456	73277
Purchases, Services	45804	53851
Provisions	-5648	10904
Depreciation	11462	9650
Total	125074	147681

994 SCIENTIFIC PUBLICATIONS & PRESENTATIONS





SCK•CEN

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

2016
highlights

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

Laboratories
Boeretang 200
BE-2400 MOL

Registered office
Avenue Herrmann-Debroux 40
BE-1160 BRUSSELS

Publisher
Eric van Walle
Director-General

Editing
Erik Dams, erikdams.com
Communication expert group

Photography
Klaas De Buysser
klaasdebuysser.be
SCK•CEN photo collection

Form
Annelies Van Calster
Danielle Knot
leftlane.be

Printing
Albe De Coker
Hoboken

SCK•CEN

Belgian Nuclear Research Centre

65 years of experience in nuclear science and technology

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

www.sckcen.be

@SCKCEN

Albe De Coker Antwerpen 1877
CO_2 neutral print
Certificate Number 10506-1602-1001
www.climatepartner.com

FSC® www.fsc.org
MIX
Paper from responsible sources
FSC® C019064