highlights

2011

SCK•CEN

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

“In tune with society”

According to our mission SCK•CEN works on issues that are important to society, today and in the future: safety and efficiency of nuclear installations, solutions for the disposal of radioactive waste, protection of mankind and the environment against ionising radiation, and sustainable development. In this way we contribute to a viable society, for ourselves and for the generations te come.

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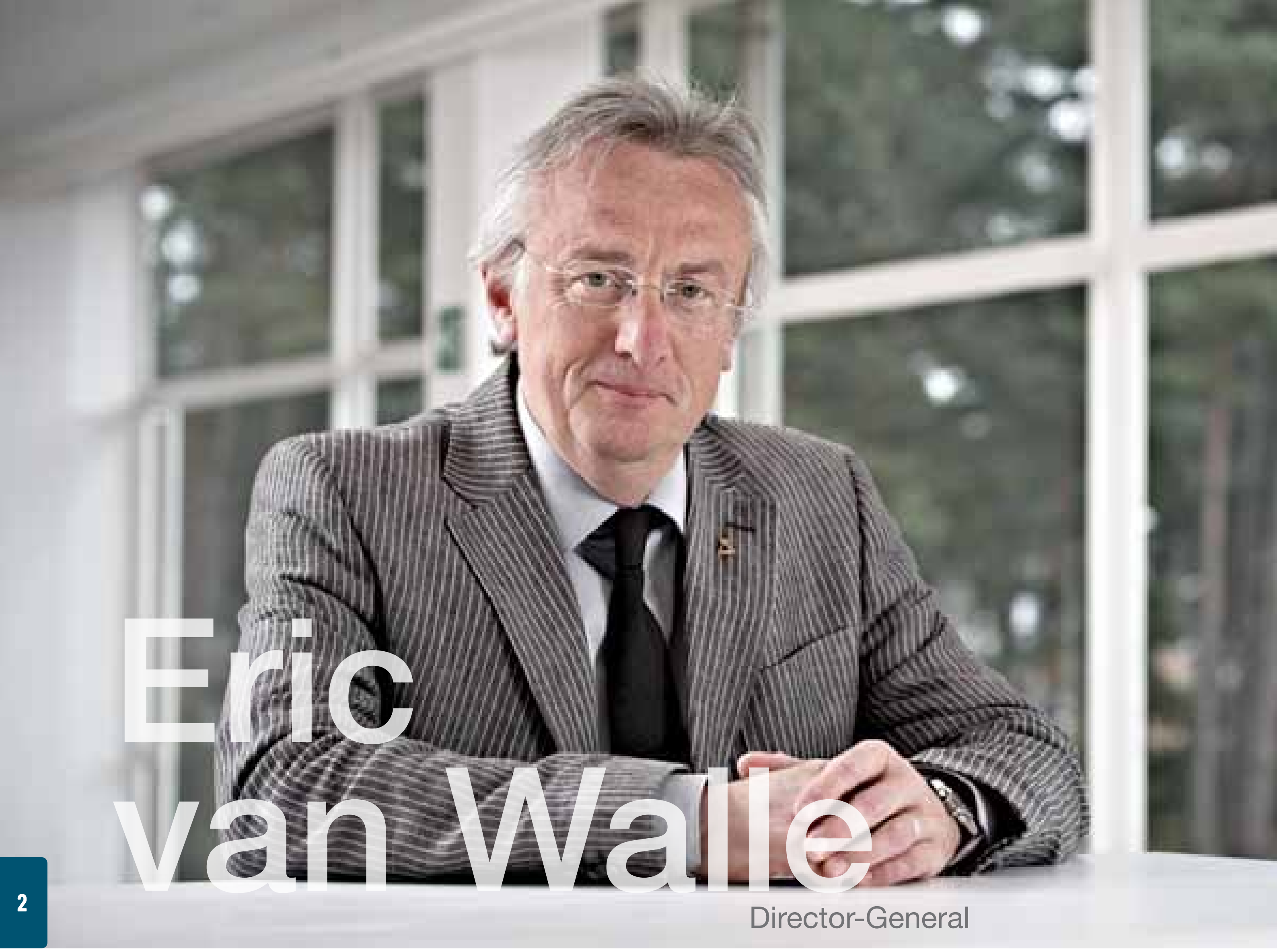


Director-General

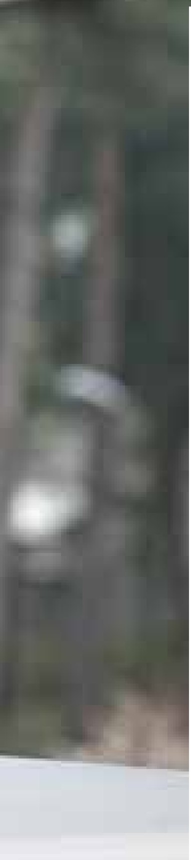
Dear reader

In this brochure, you will discover quite a few highlights that have been achieved by the Belgian Nuclear Research Centre in 2011. Reality, however, forces us to begin these '2011 highlights' with a disaster. The forces of nature that ravaged the northeast of Japan and caused the accident at the Fukushima Dai-ichi nuclear power plant in March shocked the world, and cast a dark shadow over the year 2011.

As an organisation which works closely together with our colleagues in Japan, SCK•CEN felt very involved in these events. It quickly became clear that we would also become closely involved in the consequences of Fukushima. Almost immediately, journalists from all over the world bombarded us with questions in their search for correct information and interpretation. In light of our mission, which is to provide information, we have answered these questions to the best of our abilities. The government also called upon the services of SCK•CEN, in particular with regard to measuring travellers returning from Japan. Moreover, the intensity and frequency of the usual analyses were increased greatly in order to assess any impact in Belgium.

SCK•CEN also made its expertise available on the accident site itself. This involved, in particular, mapping the contamination of the sea water and predicting its evolution, as well as supplying effective alternatives for soil remediation.

Another consequence of Fukushima has been the introduction of stress tests, to which SCK•CEN installations are also subjected. Since mid-2011, a number of work groups have been focussing on a thorough analysis of the existing safety features. Imagine the huge deployment of people and resources required in order to ensure timely reporting to the Federal Agency for Nuclear Control. It is still too soon to draw conclusions, but I look forward



> *"2011 was an eventful year. But we have succeeded once again in taking a number of major steps forward."*

with confidence to the results and their assessment. Safety is the first priority in the nuclear world at all times, and SCK•CEN is no exception to this. Our aim here is to improve continuously the safety of our employees and the environment, which is one of the foundations of our safety culture.

Fukushima has made us all think. This applies in particular to our employees. After an event like this, we invariably scrutinise the existing procedures and techniques. The design of our future MYRRHA reactor was also analysed critically once again. A number of supplementary provisions were put in place, but the final conclusion is that our designers and engineers had already made the correct, innovative choices years ago, as a result of which our installation can withstand a succession of extreme events.

But – let there be no doubt – 2011 also had plenty of highlights. One of those was even an absolute world first. In the autumn, for the first time ever, a particle accelerator was connected to a reactor with a full lead core as part of the GUINEVERE project. This successful world premiere therefore paves the way for the authorisation procedure for MYRRHA.

In expectation of MYRRHA, reactor BR2 remains one of the most powerful research reactors worldwide and an indispensable instrument both for research and, for example, for the production of medical radioisotopes. Continuing to ensure this supply whilst converting to low-enriched uranium as fuel, a commitment that was made in the context of the non-proliferation treaty, represents a major technological challenge. A number of important steps were taken in 2011 in order to make this possible.

The application of ionising radiation in medicine is becoming increasingly important. More and more lives can be saved thanks to early diagnosis with the help of medical imaging or successful radiotherapy. This evolution also confirms the increasing relevance of research into the effects of low radiation doses. As an example, SCK•CEN has been studying the effects of radiation on the brain for quite some time. As a result of this experience, as well as the presence of suitable infrastructure, the Belgian Nuclear Research Centre is now coordinating a new, ambitious European project in this field. The study should lead to a better understanding and the further optimisation of the doses to which patients are exposed, particularly embryos in uterus.

In terms of staff, SCK•CEN has again grown significantly in 2011. Due to the strengthening of the MYRRHA team in particular, the Centre now employs a staff of 700. In order to provide all our colleagues with a comfortable place to work, an extensive renovation project is underway. The renovation of the side wings of building BR1 was finished in 2011. The offices and laboratories underwent radical renovation, while still respecting the valuable architecture dating back to the fifties. Maximum use was made of energy-efficient technology and materials during the renovation, resulting in a four-fold reduction in energy consumption.

2011 was an eventful year which required special efforts from all our staff. But it gives me great pleasure to point out to you that we have succeeded once again in taking a number of major steps towards the realisation of our mission, which is the development of sustainable solutions for challenges from the past, the present and the future.

Enjoy your reading.

Eric van Walle
Director-General


content


Speedglas

01

Safety as the top priority

Safety and prevention in the wake of Fukushima

Stress tests in full preparation

In the aftermath of the accident at the Fukushima Dai-ichi nuclear power plant, Europe decided to subject all European nuclear facilities to stress tests. Belgium has expanded these resistance tests to include all class 1 installations. This also includes several SCK•CEN facilities.

Following the requirements for nuclear power plants, the Federal Agency for Nuclear Control (FANC) also published specifications for the stress tests for other nuclear installations in June 2011. These are also imposed on SCK•CEN, and are very similar to the requirements for nuclear power plants. The ultimate aim of stress testing is to explore how the various safety functions of an installation behave under exceptional circumstances, and, in particular, under a combination of several extreme events. The dramatic accident in Fukushima was actually the result of three consecutive events: an earthquake, a tsunami and the breakdown of the power supply and the emergency generators. In addition, Belgium also imposed an analysis of the safety systems against threats caused by people, the so-called man-made events, such as a plane crash or a cyber-attack.

More than a mere technical issue

A multidisciplinary steering group was formed within SCK•CEN for the implementation of the stress tests. Their first task was to map out those SCK•CEN installations that are subject to the stress tests. It soon became clear that this involved a significant part of the Centre. Several work groups started a thorough analysis of the existing safety systems. The tests will investigate the initiating events or start events that could have an impact on the installations. The focus is primarily on the prevention of certain

SAFETY ANALYSES ARE NOTHING NEW

This is the first time that SCK•CEN installations have been subjected to stress tests. But thorough safety evaluations are far from new. SCK•CEN is, in fact, by law subject to a safety review every 10 years. As part of this, the safety provisions in the various plants are examined and improved on a virtually permanent basis. The issues that were included in the previous audit will be completed by the end of 2012. In the meantime, preparations for the next 10-yearly revision have already started.

Fernand Vermeersch

Head of the Internal Service for Prevention and Protection at Work (ISPPW)

> “Even if no stress tests had been imposed on SCK•CEN, we would have still examined closely what happened in Fukushima, and whether the safety systems of our own installations would be able to deal with a similar disaster. Drawing lessons from incidents and events in order to continuously improve safety is a basic element of our safety approach.”

consequences. In a second component of the task, it is assumed that something has gone wrong. In such an event, it is especially important to examine how any consequences could be limited as far and as effectively as possible.

The work groups incorporate virtually all the disciplines that are active at SCK•CEN. All know-how regarding the properties of the reactors is present at the technical level, as well as know-how regarding the utilities and the stability of buildings. Adequate understanding of the work organisation and the communication within the various installations is also important, both during normal operation and in exceptional circumstances.

NUCLEAR EMERGENCY PLAN TESTED

SCK•CEN's nuclear emergency plan was tested on 15 December 2011. The scenario of the exercise was based on a leak in reactor BR2, and an almost simultaneous incident at Belgoprocess, the neighbouring radioactive-waste processing company. The federal, provincial and municipal emergency plans were tested during the drill, together with the internal emergency plan procedures in place at SCK•CEN and Belgoprocess. The overall evaluation of the emergency plan drill involving all departments and authorities was completed in the spring of 2012. SCK•CEN has assessed the internal response and organisation as positive.

What if … ?

SCK•CEN submitted a progress report to FANC on 15 December 2011. This report described the methodology that the Belgian Nuclear Research Centre will follow in the implementation of the stress tests. FANC approved the progress report with some minor adjustments. The actual analyses had already been started in the meantime. The impact of all initiating events on the various installations is being studied since September 2011. This includes extremely serious earthquakes, floods and other extreme weather conditions, man-made events, forest fire, toxic gases and explosions. The studies are not limited to purely technical analyses. The response in an emergency situation is also critically examined. The accident in Fukushima provides important new insights in this context that will serve as a basis to evaluate the current emergency plan procedures, and to enhance them where necessary.

External consultants have been involved for some studies, but the major part of the analyses is carried out by internal SCK•CEN departments. This means, of course, a substantial effort in terms of both human resources and budget. The stress tests are implemented in close cooperation with the safety authorities (FANC and Bel V), and the analysis is running according to schedule. SCK•CEN will submit the final stress test report to FANC on 30 June 2012 at the latest.

Prevention and safety management

Healthy employment in a safe environment

In 2011, the Internal Service for Prevention and Protection at Work (ISPPW) placed the spotlight on the topics of prevention and safety. In the context of global safety management, ISPPW carries out audits on installations and working conditions, makes recommendations, and ensures that these are implemented. Another task is to raise the staff's awareness of various occupational risks, and the provision of solutions to avoid these risks.

In April 2011, the spotlight was on ISPPW itself during a 'meet & greet' session in which SCK•CEN staff were introduced to the various ISPPW activities. The units Health Physics; Industrial Safety and Environment; Security, Guarding and Access Control; Nuclear Safety and Internal Medical Surveillance introduced themselves during an attractive exhibition. The visitors also received handy tips, for example, regarding working on computers. In order to bring the prevention message to mind every day, mouse pads with the emergency numbers and alarm signals printed on them were distributed.

There is no doubt that the meet & greet has contributed to a greater awareness of the functions and tasks of ISPPW. This was, in fact, one of the major objectives of the internal Safety Culture action plan.

ALARA in practice

Safety comes first in the case of extensive renovations in highly active installations

ALARA is the recurring theme for all operations in the nuclear sector. The acronym for As Low As Reasonably Achievable provides an indication of how radiation risks should be handled. They must remain as low as possible at any time. In 2011, a number of special projects were launched at SCK•CEN, in which ALARA forced engineers and researchers to push the limits. Not infrequently, this requires a significant dose of insight and creativity.

HOT-CELL M2

ALARA and efficient approach go hand-in-hand

Hot-cell M2 is a 3 by 3 metre bunker with a height of 5 metres. The walls are about one metre thick, and are made of concrete and lead. The cell dates back to 1977, and was used for destructive tests on nuclear fuel and on highly radioactive elements from the reactor core and the primary circuit of nuclear power plants. It contains historical and non-standardised waste. High alpha, beta and gamma values have been measured inside. The cell also exhibits a number of mechanical faults. Several airlocks are blocked. The hot-cell must be fully operational again in a few years' time, because it will play a key role in the verification and qualification of components and materials for nuclear power plants and MYRRHA.

Safety through creativity

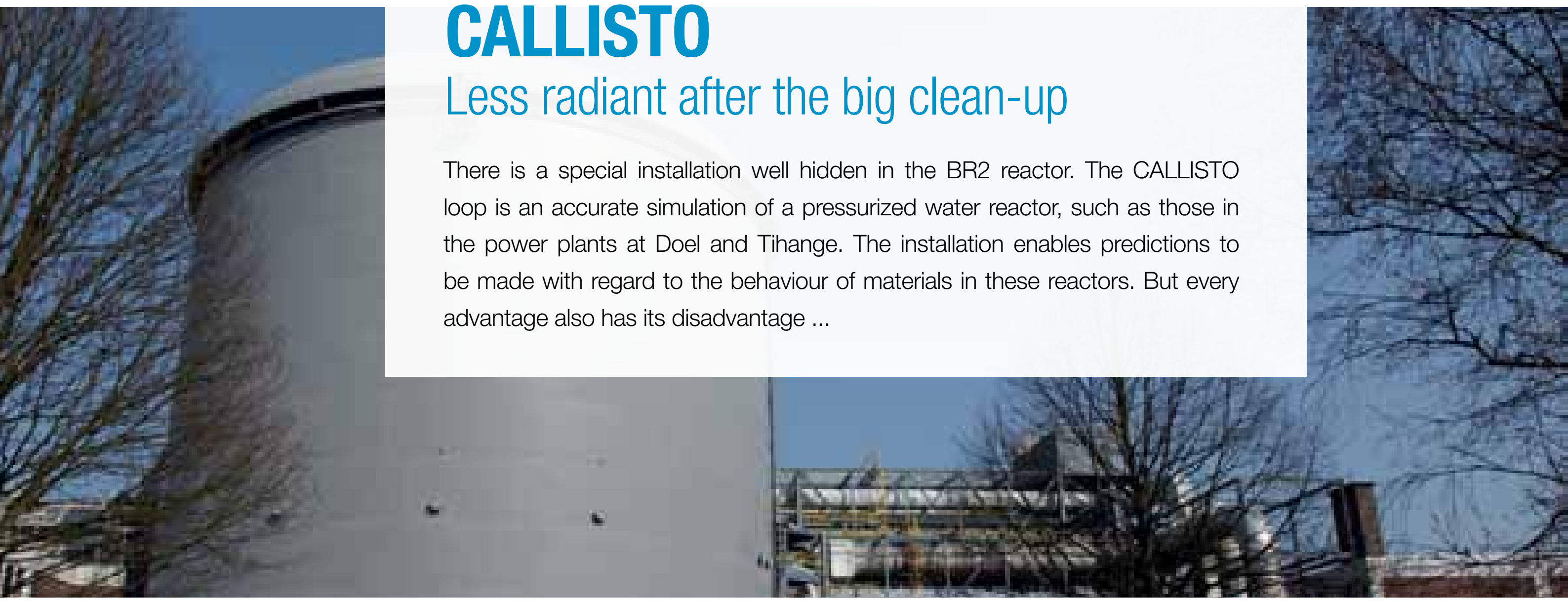
For this operation, a multidisciplinary team was set up consisting of specialists from the Decommissioning and Decontamination unit, the Laboratory for High and Medium Activity and the Health Physics department. The SCK•CEN team has been reinforced with colleagues from Belgoprocess who have extensive experience in working with telemanipulators. Due to the high activity in the cell, it is currently not accessible to operators. After thorough measurement of the radiation, initial repairs to the cell were launched in early 2011. Initially, there was limited access of about 18 cm to bring equipment inside. The creativity of the team was seriously put to the test here. They needed to develop a range of equipment, such as drilling equipment that could be fully dismantled, and folding saw blade holders, each of which had to be assembled in a stable manner inside the cell. In this way the team has succeeded in repairing the main access airlock and the ventilation. The first high-level waste could also gradually be disposed of. Telemanipulators were used to remotely saw larger pieces, such as a lathe and a milling machine, into smaller pieces for later disposal.

ALARA, anytime and anywhere

Every operation is always carefully planned in advance and described in detail, including the necessary safety measures. Alternative solutions are also studied for each action. Furthermore, each manipulation is practiced during so-called cold tests without nuclear material. In the context of the ALARA principle, interventions are limited to the minimum, and this includes intervention by operators. This applies to all stages: the cutting, the transfer to a waste drum and disposal. The shielding of the staff and the dose per operation is calculated with Visiplan, a software package that has been developed by SCK•CEN. In addition, several cameras have been set up around the hot-cell with the aim of monitoring and optimising the safety of the operations.

From a safe distance

One of the main choices was to work by remote control as much as possible. Thanks to the use of manipulators and a bridge, the basket for the removal of the waste no longer needs to be filled manually. Maintenance-free mechanical grippers were designed and produced in order to make this possible. The top of the cell has been modified to ensure the safe removal of waste. The waste is hoisted from the cell in baskets, and is placed in drums through secure airlocks. The system is designed to ensure that hardly any manipulations are required during the transfer, thereby reducing the risks. Remote real-time monitoring of the exposure dose has been planned for a later project phase, when the radiation in the cell has been somewhat reduced due to the removal of waste. In addition, wireless telecommunication has been foreseen between the operators and the person who coordinates the operation from the outside, which represents quite a challenge in a Faraday cage. The target is to have the cell fully operational again by 2016.



CALLISTO

Less radiant after the big clean-up

There is a special installation well hidden in the BR2 reactor. The CALLISTO loop is an accurate simulation of a pressurized water reactor, such as those in the power plants at Doel and Tihange. The installation enables predictions to be made with regard to the behaviour of materials in these reactors. But every advantage also has its disadvantage ...

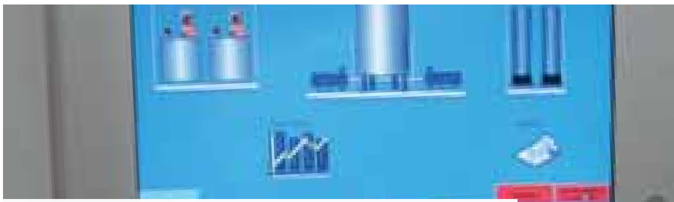
CALLISTO consists of three channels that are used to carry out experiments, such as testing fuels or materials. These experiments take place at 300 °C and 150 bar, exactly the same conditions that exist in a pressurized water reactor or PWR. Due to the perfect similarity, the same corrosion products found in a normal PWR are also produced in CALLISTO. These circulate along, and finally precipitate in the entire piping system, where they form a thin oxide layer. When passing through the reactor core, some of these corrosion products, such as cobalt, are activated before they precipitate, and a lot of radioactivity builds up in the circuit over the years. This causes additional radiation in the immediate surroundings.

Twice as fast, also in terms of contamination

An additional problem is that CALLISTO actually simulates the conditions in a pressurized water reactor a little too well. The neutron flux in BR2 is much higher, and more activation products are therefore produced. This means that 10 years' operation of the CALLISTO loop results in the same radioactivity level as 20 years' operation of a normal PWR. Since the effective commissioning in the early '90s, the dose rate around the various components has continued to increase, and, consequently, the same is true for the collective dose for people who work on the loop. After the previous 10-yearly safety review, it was decided that the exposure of the staff had to be reduced.

The most difficult option

There were three options. The first was to install additional shielding around the components. But, the staff would also be exposed to high doses during the installation and, in addition, placing so much lead would make it quite difficult to access certain components. The second option consisted of reducing exposure of the staff by reducing their access time to CALLISTO. In view of the cramped working environment and the mandatory maintenance tasks, this option was unrealistic. According to the ALARA principle, only one solution remained: to reduce the contamination by selectively removing the oxide layer together with the precipitated activated corrosion products by means of chemical decontamination. A similar chemical process is also used in industrial PWRs. Due to the unique characteristics of CALLISTO and the small scale involved, SCK•CEN experts could



carry out this operation themselves. In fact, they already have the unique experience of the decommissioning and associated decontamination of the BR3 reactor to their credit.

Dissolving, circulating and concentrating

The chemical process ensures the selective removal of the oxide layer without affecting the underlying metal. The oxide layer was thoroughly studied in 2006, so clear information regarding its thickness (in microns) and composition was available. The contamination levels were also mapped. It was therefore possible to calculate how much iron, nickel and chromium (the major corrosion products) had to be chemically dissolved to ensure an efficient decontamination. The chemical process itself is based on the cyclic use of permanganate and oxalic acid at high temperatures. The dissolved corrosion products are retained in the solution as long as possible, and are circulated through an ion exchange unit. The resins of the ion exchanger retain the dissolved corrosion products, including the radioactivity, and are disposed of as concentrated, solid radioactive waste.

In the context of ALARA, numerous simulations were carried out in order to determine how much shielding was required around these resin columns. A system was designed for the removal of the resins such that the content of the tall resin columns could be transferred to a waste drum without the need for complex, dose-intensive operations. The removal of the waste to Belgoprocess was also prepared thoroughly in the design phase. After the feasibility study and the design and preparation of the required working procedures, the installation was thoroughly tested in June and July 2011, and the training of the operators was started. Following this, the decontamination unit was connected to CALLISTO, and the required density and functional tests were carried out. The Federal Agency for Nuclear Control gave the green light for the operation in early September. The actual cleaning process took place during one week in October, involving three shifts of three people working around the clock, supported by radiation monitoring and permanent staff.

Cleaner, but above all safer

After the successful implementation of three decontamination cycles, the dose rate dropped significantly, with an average of a factor 2 to 2.5 lower. A total of 3 to 4 micrometres of the oxide layer was dissolved and disposed of with the resins. The amount of radiation removed in this way fully meets the specified objectives. ALARA rarely allows the simplest solution to be chosen, but, thanks to thorough preparation and careful implementation of this clean-up operation, the dosage for the staff involved is now considerably lower.

Ground-breaking research

into the optimum protection of people and environment

02

Frank Hardeman

Institute Manager
Environment,
Health and Safety

"A disaster like the tsunami in Japan and the events that took place around Fukushima are a humbling experience for us as human beings, but events like this should above all prompt us to do better in the future in order to avoid similar failures. Within SCK•CEN, we must continue to ensure that the required knowledge and resources are retained in order to be able to reliably support the population, the government and industry if an accident occurs anywhere in the world."

Fukushima and the role of SCK•CEN

Expertise at the service of the population and government

The moment the nuclear power plant of Fukushima Dai-ichi became world news, SCK•CEN was flooded with questions from everywhere. The government was looking for answers also.

When it appeared that the situation in and around the stricken nuclear power plant was very serious indeed, a voluntary repatriation of Belgian citizens was organised from Belgium. SCK•CEN was asked to check the returning people, on a voluntary basis, for any internal or external contamination.

As the information that reached us from Japan was initially quite limited, the government decided to set up a measurement campaign at the Military Hospital in Neder-Over-Heembeek. The Belgian Nuclear Research Centre and the Federal Agency for Nuclear Control (FANC) therefore joined forces. For one week, everyone who returned from Japan could be examined voluntarily by dosimetry specialists. 14 people had their thyroids checked for possible traces of radioactive iodine. No trace of radioactivity was found in anyone. After a week, the measurement campaign was continued at SCK•CEN in Mol. In the months that followed, another 10 or so thyroid examinations were carried out. About 30 people underwent a full body measurement in the unique installation at the whole body counting department. Inside a fully shielded room, no contamination could go undetected during these measurements. A number of media representatives who had stayed in the vicinity of the affected area, for example, were examined during this period. Traces of radioactivity that could be clearly linked to their stay in the region were found in a limited number of people. The measured values were so low, however, that they had no effect whatsoever on their health.

Additional measurements in Belgium

The Belgian Nuclear Research Centre fulfils a specific role within federal emergency planning. The Belgian emergency plan was not announced after the accident in Fukushima, but the government did request that a certain number of actions be carried out. FANC has a surveillance programme in which radioactivity is measured in the air, in food, in the soil and in the water, which is carried mainly by SCK•CEN. In the months following the accident, the Low-level Radioactivity Measurements expert group carried out a wide range of additional measurements. Traces of radioactive iodine and caesium were detected after the radioactive cloud from Japan crossed over our country. The levels measured were so extremely low that one can be certain that in Belgium there were no effects on people or the environment. In addition, at the request of the Federal Agency for the Safety of the Food Chain (FASFC), SCK•CEN examined samples of foodstuffs that were imported from Japan.

The Low-level Radioactivity Measurements expert group analysed seaweed and sea fish samples at the request of Greenpeace. These were collected during a Rainbow Warrior mission in the coastal waters off Fukushima in May 2011. The food limit for radioactive iodine and caesium was exceeded in a large number of these samples.

The Crisis Management and Decision Support unit at SCK•CEN has distribution and dose models available in order to chart the contamination and exposure levels of the affected area. These model calculations could also be checked against the actual measured spread of radioactivity. This enables us to update these models for the future. This unit also studies the response of the Japanese government in terms of evacuation and other crisis measures.

An alternative solution for the contaminated soil

SCK•CEN experts are also studying the situation on site. The Biosphere Impact Studies unit has built up a lot of expertise in the field of the behaviour of radionuclides in the environment and in remediation techniques, particularly in the context of the far-reaching investigation into the Chernobyl accident. After the accident in Fukushima, SCK•CEN offered this expertise to Japanese colleagues.

The soil in the region around the nuclear power plant contains caesium-137 and caesium-134. Caesium-134 has a half-life of 2 years, and will have little or no impact after 10 years. Caesium-137 with a half-life of 30 years, however, does require a decisive approach for a long period of time. In Japan, the focus is now on the excavation and decontamination of the soil. SCK•CEN experts see potential virtue in other techniques. Excavation and removal create a considerable amount of waste. There are counter-measures that prevent this waste problem from occurring. Depending on the type of soil and the level of contamination, deep ploughing could be a solution, or fertilizing the soil with potassium which generally reduces the absorption of caesium

by plants. Another option is to grow crops that absorb very little caesium. Should the concentration of caesium in food crops still be too high, then it is still possible to grow crops that are used for their fibres or energy production rather than crops for food consumption. SCK•CEN experts are ready to share these insights with their Japanese colleagues. But whether this approach will be followed depends strongly on how the government and the population perceive these countermeasures.

Together with KU Leuven, the Biosphere Impact Studies unit developed a training programme for five Japanese researchers in the characterisation of Japanese soils in terms of plant sensitivity to caesium uptake. In addition, SCK•CEN is also offering a Japanese student the opportunity to study in Belgium for a PhD on the sensitivity of Japanese soils in terms of the transfer of caesium into food crops. Both initiatives are running in cooperation with KU Leuven, and, in part, are made possible thanks to the support of the Flemish government.

Support to the United Nations

SCK•CEN is involved closely in the extensive study of the radiation levels in and around Fukushima and its effects. This research is being carried out by a large team of researchers commissioned by UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation). Experts in various disciplines are carrying out this research in cooperation with the Japanese authorities. SCK•CEN is making an important contribution to the study of the impact on the marine ecosystem. Because radioactive water was discharged into the sea over a long period of time, a great deal of importance is being placed on the study of the sea water. Once a clear picture of the contamination levels is available, it will be possible to estimate the impact on the fauna and flora in the short and longer term. Based on the initial findings, it cannot be excluded that there might be an impact on certain organisms with regard to reproduction. It is necessary to verify this, however, through observation and follow-up.

In the meantime, the contamination has spread. Shortly after the accident, elevated levels were measured in the sea, but after one month, most of the short-lived radionuclides had disappeared, and it was mainly caesium and iodine that remained. An additional problem is that other, non-radioactive, pollution also ended up in the sea as a result of the earthquake and the tsunami. This pollution is a complex mix of different substances, and this makes it difficult to accurately assess any effects. A lot of expertise on dynamic models for the absorption of radionuclides in marine fauna and flora is available within SCK•CEN. These models are now of great value, because they enable us to make reliable predictions. In the course of 2013, a full report will be presented to the General Assembly of the United Nations.

Aid to Japan

Interview with
Jordi Vives i Batlle (left),
marine radio-ecologist**,**
Hildegarde Vandenhove (middle),
Deputy Institute Manager Environment, Health and Safety and Head of Biosphere Impact Studies,
Johan Camps (right),
Head of Crisis Management and Policy Support

Even though Japan has not asked directly for assistance from the Belgian Nuclear Research Centre in the course of 2011, the accident in the nuclear power plant of Fukushima has had a strong impact on the work of dozens of researchers and other staff members of SCK•CEN. For Hildegarde Vandenhove, Jordi Vives i Batlle and Johan Camps, Fukushima will continue to be a major study subject for many years to come.

What was your first reaction when you heard the news?

Jordi Vives i Batlle: I knew immediately that it would have a major impact on my job as a marine radio-ecologist, because it was probably one of the worst accidents involving discharges into the sea. And that turned out to be true. In the case of Chernobyl, there were no direct discharges into the sea. But, in Fukushima, the wind blew mainly in the direction of the ocean, and this makes it, in effect, the first nuclear accident with significant discharges at sea.

Hildegarde Vandenhove: If they had asked me to provide help on site at that time, I would have done so. Radiation can be measured, and the radiation dose one is exposed to can therefore be monitored. My only fear was the earthquakes, and whether the condition of the reactors was stable enough. But we have the expertise, and we were concerned about the people and the scientists in Japan.

> *“Fukushima is a case from which many lessons will be learned in terms of emergency planning.”*

Did you travel to Japan in the end?

Hildegarde Vandenhove: Indeed. I was invited for workshops on the lessons to be learnt from Chernobyl, and on contamination of the environment and remediation possibilities. I visited Chernobyl six years after the accident, in the case of Fukushima, my visit was only six months after the accident. You’re there to measure the diffusion of the radioactivity, but you’re also confronted with the concerns of the people. My feeling as a scientist was that, given the extent of contamination, there were other options available for remediation instead of excavating and storing the contaminated layer of soil. But is the population ready for the consumption of food crops from the affected region, even if the caesium concentrations are below the food standard? An alternative is to opt for non-food crops, for example bio energy crops, or fibre crops. Thanks to certain processing systems, there would be little or no contamination at all in the finished products. But the aversion to contamination is high, and the question therefore remains: will the population use these products at all? People don’t want milk with contamination levels below the food limit, they want milk without caesium. That’s one of the things that was the most striking. As experts, we look at a situation from the principle of acceptable risks, and we might think that their approach is not ideal. But imagine if we would experience something like this here in Belgium. How would we react if we had the choice between potatoes without caesium, or potatoes with a little caesium?

Will Fukushima provide many new insights in the short or in the long run?

Hildegarde Vandenhove: Yes, indeed, an immense amount of information has been generated from this that can be used for future studies. The problem is that Japan is far away, and that they keep their borders reasonably closed. Otherwise we would be involved even more.

Johan Camps: Fukushima is also a case from which many lessons will be learned in terms of emergency planning. One of the key insights is that the nuclear emergency plan must also be able to operate after a severe natural disaster. In the event of an accident, the main issue is to carry out measurements as soon as possible in order to monitor the cloud, and to determine the exposure of the local residents and the contamination of the environment. But this requires instruments, and often also electricity. In Fukushima, there was no power supply anymore, and a number of resources were therefore simply not available at the time the radioactivity escaped from the plant. Are the available resources still adequate and deployable if a nuclear accident results from a major natural disaster? This key question is the starting point for what one could call the stress test for the emergency plan.

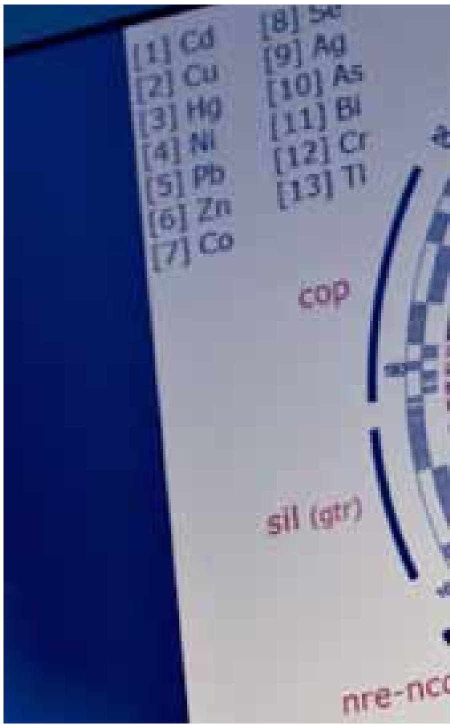
Jordi Vives i Batlle: We always learn from accidents in the past. We can use this knowledge to help us better prepare for new emergencies, even if we hope that this will never be necessary.

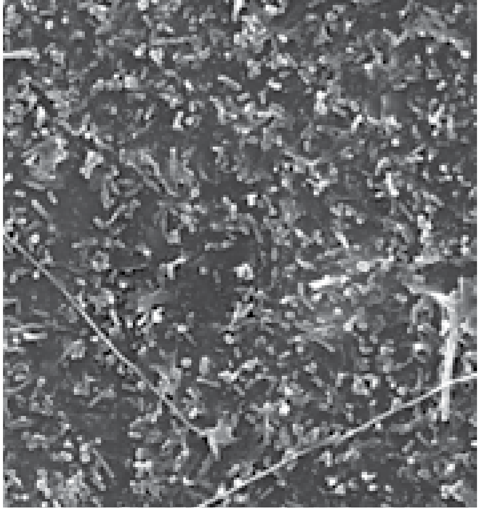
Bioinformatics is taking off

New technology for rapid analysis of genetic material

Genetic building blocks are investigated in numerous research projects into the impact of ionising radiation on living organisms. This means the investigation of their deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). A large proportion of DNA is transcribed into messenger RNA, which serves to create proteins. This process is known as gene expression and can be followed experimentally. The study of gene expression provides a great deal of data. Due to this mass of data, molecular biology must rely on highly advanced informatics systems.

As DNA and RNA studies are important for numerous research projects, SCK•CEN has developed considerable expertise in bioinformatics. For some time, molecular biology has been using microarrays to measure gene expression on a large scale, more specifically involving many thousands of genes in parallel. A microarray consists of a glass slide to which RNA can be attached in a gene-specific manner. This attached RNA is marked with dyes to enable the measurement of the quantity of bound RNA, which provides an indication of the extent to which a protein is created.



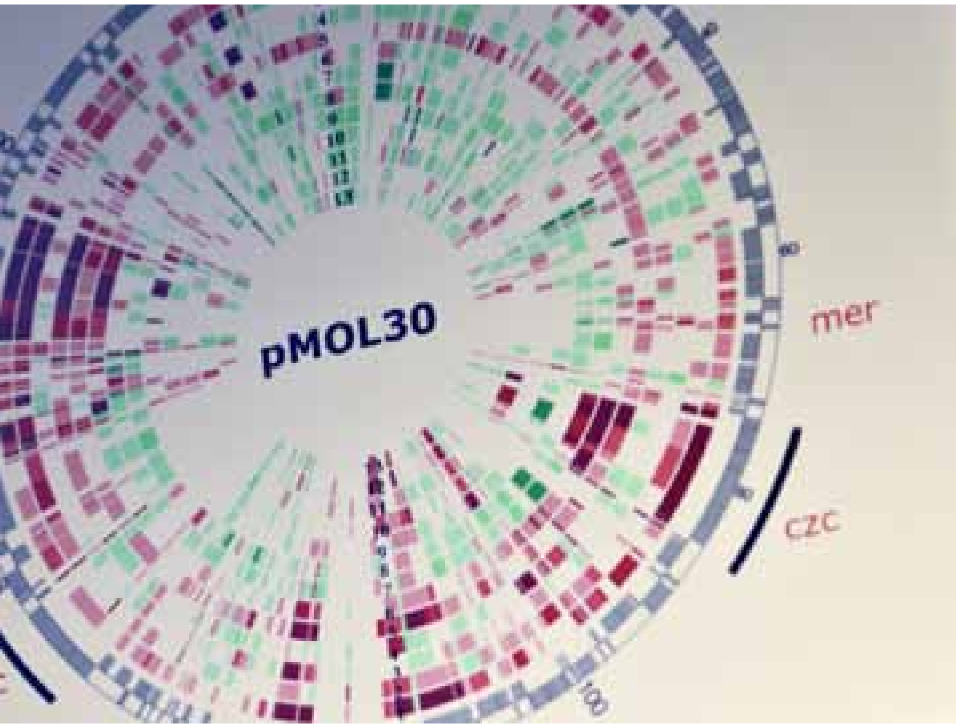


From one year to one week

In 2011, SCK•CEN bioinformaticians used a new technology to increase significantly the speed with which DNA is determined. Whereas an international consortium required a full year and tens of millions of dollars for the sequencing of a bacterial genome in 1995, the current technology is able to unravel completely the same genome in only a few hours or days, using a single machine, and for a fraction of the price. Even in the case of the human genome which is several thousand times larger than that of a bacterium, 90% of the sequence can be established within one week.

Guides through a mass of data

The new sequencing technology produces gigabytes of data, however. In order to accurately analyse this huge quantity of data, advanced bioinformatic methods are essential. SCK•CEN also makes use of these new techniques, primarily for research into the resistance of bacteria to certain metals, and in space research. The analysis of this data provides important clues as to the possible function of genes and proteins.



BACTERIA IN BOOM CLAY IMPART THEIR SECRETS

The advantages of the sequencing technique can be used to their full potential in a study that is being conducted as part of research into the disposal of radioactive waste in the Boom clay layer. Until recently, it was only possible to isolate the bacteria from a soil sample and cultivate them separately in the laboratory. Following this, the DNA of the various bacteria could be determined. Unfortunately, not all bacteria from soil samples can be cultivated in a laboratory.

Thanks to sequencing, it is now possible to analyse the entire bacterial population present in the clay layer. This is important in order to assess the possible impact of bacterial action, for example with regard to the long-term disposal of high-level radioactive material underground. The aim is to establish whether the bacterial populations could cause gases or acids to be formed during geological disposal. SCK•CEN is working together with colleagues from the international Mont Terri project in Switzerland, where similar research is being carried out.

What is the effect of low radiation doses on the brain?

SCK•CEN coordinates international CEREBRAD project

For 30 years, SCK•CEN has been making an important contribution to the study of the impact of ionising radiation on the brain. The start of the European research project CEREBRAD represents a further major step towards obtaining clarity about the impact of low radiation doses on the brain.

More than 60 years of research

The effects of high radiation doses have been described in detail on the basis of epidemiological data collected from the victims of nuclear accidents and from the atomic bombings of Hiroshima and Nagasaki, more than 65 years ago. A model which can predict reliably the impact of high radiation doses was developed on the basis of this data. There is a need for more and better information with regard to low radiation doses however. Below a certain value, insufficient measurement data is available to be able to make reliable predictions. This relates to low doses of 0.1 Sievert and below. For higher doses, there is indisputable evidence of the occurrence of cancer effects. In addition to this, exposure to ionising radiation can cause other diseases, more specifically cardiovascular and cerebrovascular disorders, but can also result in the formation of cataracts on the eyes, for example. Some of these effects occurred in residents of Hiroshima and Nagasaki, and in the vicinity of Chernobyl, as late as 20 to 30 years after the exposure.

Clear evidence is essential

Comprehensive understanding of the effects of low-dose radiation is not only important for those who are exposed in exceptional circumstances, such as a nuclear accident, or for astronauts in space. The main reason is undoubtedly the continuous increase in the number of medical examinations involving X-rays or other types of radiation. There is, for example, no conclusive evidence yet as to whether or not a CT scan might have an effect on pregnant women or young children. In Belgium, we are exposed to a 2 mSv (milliSievert) dose every year as a result of the natural radioactivity around us. Due to

medical examinations, this exposure is increased, on average, by a further 2 mSv. Clear evidence of the potential impact of such low radiation doses is therefore essential.

Initial research into the effect of ionising radiation on the human brain started more than 65 years ago, after the bombing of Hiroshima and Nagasaki. An increase in mental retardation was observed at the time in children who were exposed to radiation in utero during a certain period of their development. In order to prove this hypothesis, SCK•CEN and other research centres have conducted research on mice that were exposed to radiation during gestation. From behavioural testing after birth, in which the memory and learning ability of the mice was measured, it appeared that exactly the same effects occurred as in children. The hypothesis is thereby confirmed.

A research project with three pillars

SCK•CEN has been studying the impact of ionising radiation on the brain for more than 30 years. With the launch of CEREBRAD (Cognitive and Cerebrovascular Effects Induced by Low Dose Ionizing Radiation), this research received a new impetus in October 2011. Eleven research institutes and universities are participating in this ambitious European project, which is incorporated into the 7th Framework Programme.

CEREBRAD comprises three pillars. First and foremost, the aim is to reinforce the statistical value of the epidemiological data that was obtained from Hiroshima and Nagasaki. For this purpose, data was collected from patients who underwent radiotherapy during which the brain was exposed to relatively low-dose radiation. The behaviour of these people and their cognitive functions are studied in-depth during the project. In addition, monitoring of a sample of residents from Chernobyl who were born soon after the accident and who were all exposed to radiation either in utero or during the first year of life, is taking place. With this data, researchers hope to gain more insight into mental retardation or cognitive effects in people caused by radiation.

The second pillar relates to animal testing involving the prenatal and postnatal exposure of mice. They are exposed to radiation on day 12 of gestation and on day 10 after birth. The effects on the animals are then studied. A considerable proportion of the research consists of behavioural studies. The aim is to simulate a similar external exposure on the basis of the information collected from the residents of Hiroshima and Nagasaki. This is possible through radiation with X-rays or gamma rays. For Chernobyl, a similar simulation is carried out for the internal contamination caused by caesium.

In addition to these effects, the research project focuses on the impact of radiotherapy in mice. The blood circulation in the brain and the oxygen level in the blood are examined in this context. In the meantime, medical imaging using magnetic resonance at 3, 10 and 40 weeks after birth has provided early data that could demonstrate that the cerebral cortex, an important part of the brain, is smaller in animals that were exposed to radiation.

The last pillar of CEREBRAD is the search for the ultimate mechanisms behind established radiation effects. This challenge includes a detailed analysis of the cellular and molecular processes involved. This knowledge could serve as a basis for the formulation of recommendations to regulators with regard to exposure limits, for example the optimal and maximum doses for radiotherapy.

Interview with **Rafi Benotmane,** Coordinator CEREBRAD project and responsible of neurobiology in the Radiobiology unit

CEREBRAD

CEREBRAD is an international research project in which SCK•CEN is taking the lead. According to coordinator Rafi Benotmane, this is only possible thanks to the many years of experience with studies into radiation effects on the brain.

Rafi Benotmane: We started these in the '80s at the Belgian Nuclear Research Centre. In the meantime, a lot of knowledge has been built up in this field, and new technologies have been implemented in the area of genomics and bioinformatics. This is also the reason why SCK•CEN coordinates this project. We are leading the research into the impact of radiation on the brain. Few institutes have the same expertise in this field that we have.

Eight researchers are working on CEREBRAD within SCK•CEN. What is the focus of this European project?

Rafi Benotmane: We focus on the animal studies, for which we will mainly use our X-ray facility. The imaging and behavioural studies will be carried out together with our colleagues from KU Leuven. One key advantage is that SCK•CEN has the know-how and the infrastructure to examine the effects at the level of the DNA. We will be taking care of all the genetic research with our genomic platform. We will use this to carry out the gene expression of our own samples and those of other research groups. The measurement of the exact radiation dose will also take place in Mol. Just as for people, we are also lacking substantiated proof of low-dose effects in animals. We therefore collaborate with the dosimetry service at SCK•CEN to do the same as for people, for example, with regard to radiotherapy. In this area, we know exactly the dose to which certain organs have been exposed. Until recently, we didn't have the expertise to also measure this in animals. Thanks to our dosimetry colleagues, we can now calculate exactly the dose that the brain of the mouse foetus effectively receives. This is very important, because our only reference is the total external dose, but that is not the same as the effective exposure dose. In most studies that we have carried out so far, we have worked with 1 Sievert. This is, in fact, a relatively high dose, but we do not know how much the embryo has actually received. Perhaps only one third is absorbed. This

is what we are emphasising in the study, because we are now able to determine what dose is really absorbed.

What are you hoping to find?

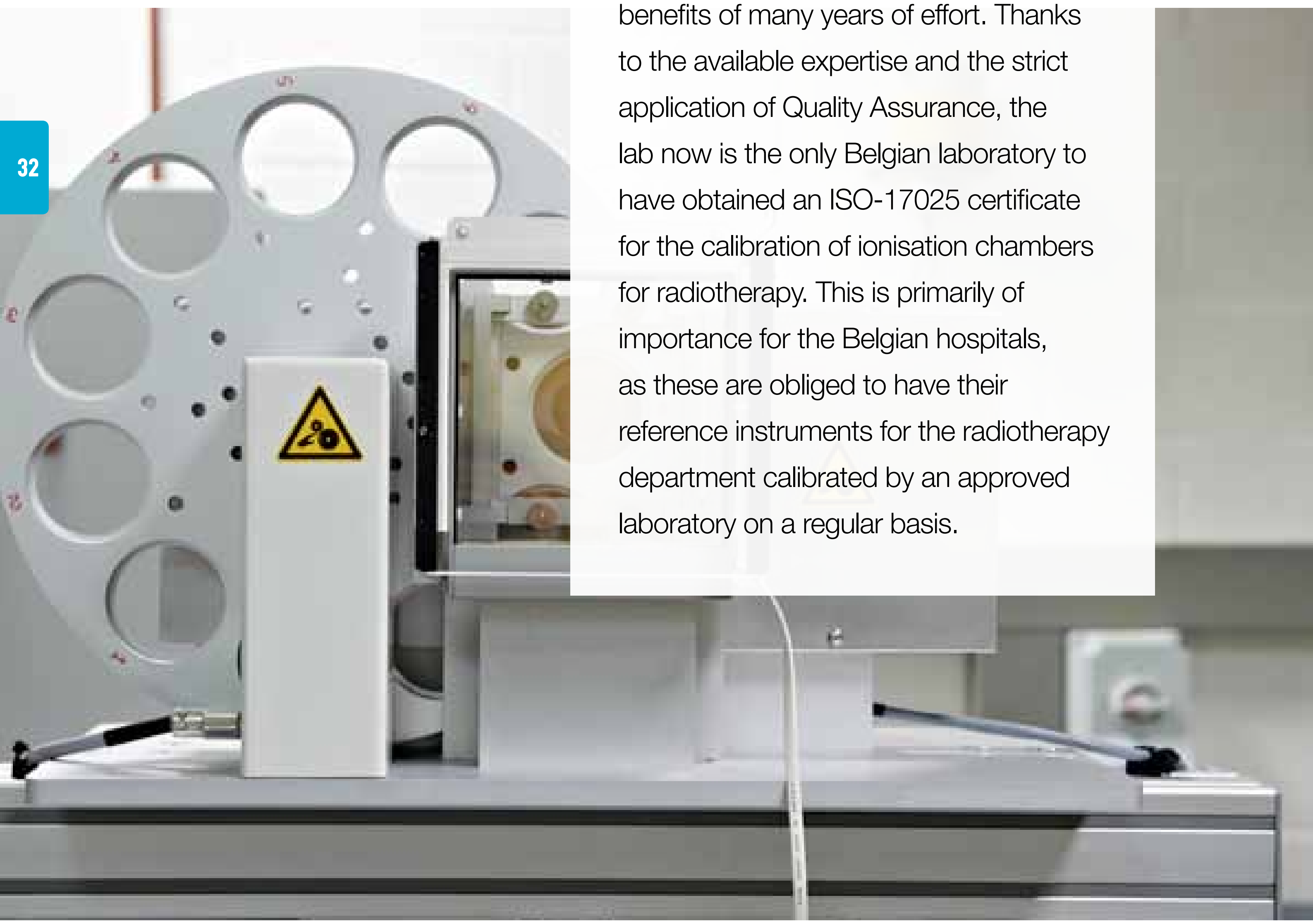
Rafi Benotmane: If we determine the effects at low radiation doses, I would hope to learn to understand the underlying mechanisms. This knowledge will enable us to make recommendations to the regulators regarding exposure limits, for example with regard to the optimal doses for radiotherapy. If there are no low-dose effects, that's even better. But there is always a certain level of caution where we are saying 'be careful'.

What we are also missing is the individual sensitivity. Even if we do have information implying that there is no low-dose effect, some individuals may just be more sensitive than others. We must be careful, and keep the radiation levels as low as possible according to 'ALARA', the universal rule in the field of radiation protection. Radiation must be As Low As Reasonably Achievable. We also need to inform the regulatory bodies regarding the threshold values where certain effects occur. The results of the research project are therefore likely to lead to new rules regarding dose limits. In particular, we are also aiming to protect the foetus in the uterus as well as young children. We know that the radiation sensitivity in this sub-population is three times higher than in adults, resulting in certain effects being more pronounced. But it is, of course, not possible to create rules for each type of population. The best is therefore to reduce the doses in general. 'As low as reasonably achievable' remains the watchword.

ISO-17025 certificate for radiotherapy calibrations

Accurate calibrations for Belgian hospitals

In 2011, the SCK•CEN Laboratory for Nuclear Calibrations was able to reap the benefits of many years of effort. Thanks to the available expertise and the strict application of Quality Assurance, the lab now is the only Belgian laboratory to have obtained an ISO-17025 certificate for the calibration of ionisation chambers for radiotherapy. This is primarily of importance for the Belgian hospitals, as these are obliged to have their reference instruments for the radiotherapy department calibrated by an approved laboratory on a regular basis.



SCK•CEN offers this service in cooperation with Ghent University (UGent) and under the supervision of the Federal Agency for Nuclear Control (FANC). In 2008, the Belgian Nuclear Research Centre acquired an important part of the activities of the UGent laboratory for standard dosimetry. Since then, a programme has been established to optimise the service provided to Belgian hospitals. Patients that require radiotherapy are exposed to a sizable dose of radiation. It is therefore of the utmost importance that the administered dose is exactly monitored. The success of the treatment depends largely on the accuracy of the exposure and of the prescribed dose. It is therefore essential that the device that is used provides correct measurements.

Recognised expertise

In order to be able to measure the administered doses, ionisation chambers are used as measurement instruments in hospitals. These ionisation chambers must be calibrated on a regular basis in order to ensure the accuracy of the measurements. This must be carried out by a certified calibration laboratory. In 2011, SCK•CEN was the only institute in Belgium to obtain the coveted ISO-17025 certificate from the Belgian Accreditation Body (BELAC) for the calibration of ionisation chambers for radiotherapy.

Reliable instruments

From now on, Belgian hospitals no longer need to go abroad for the mandatory regular calibration of their reference instruments for radiotherapy. The laboratory in Ghent has a source that generates a well-characterised radiation beam, for which the dose rate is very precisely known. The ionisation chamber provided by the hospital for calibration is placed in this radiation beam. The measured dose rate is then compared with the known reference dose rate. In the ideal case, there is no deviation. The hospital instrument is calibrated in this way to ensure its reliability.

Historic waste in bitumen

Suitable for underground disposal?

This question has been occupying the Waste and Disposal expert group for some time now. Preparations for a series of large-scale tests started in 2011. The research, which has been on-going for many years, will take several decades more to complete. But there are good reasons for this.

Bituminised waste is a mixture of bitumen with liquid waste packed in steel drums. In this case, this relates to radioactive waste originating from the reprocessing of spent fuel elements from the former Eurochemic in Dessel. Large quantities of intermediate-level waste were stored there in tanks, with a view to reprocessing. Bitumen is what remains after the distillation of coke, and can best be compared to asphalt. The technique was applied mainly from the late ’70s until the first half of the ‘80s. The drums are stored in bunkers at Belgoprocess, which, after the closure of the plant, took care of Eurochemic’s installations and waste. Due to the half-lives and the nature of the radionuclides, geological disposal is the most appropriate solution for this waste. But before being eligible for this, this type of waste must be approved by the National Agency for Radioactive Waste and Enriched Fissile Materials (ONDRAF/NIRAS). The Belgian Nuclear Research Centre is carrying out the necessary research in this context.

The first tests

As early as the ’80s, SCK•CEN was conducting initial tests regarding the so-called leaching behaviour of bitumen. Bitumen is a material that is impervious to water, and also to gas to a certain extent. It was assumed that this would be ideal for repelling water. The mixture of bitumen and waste contains a large quantity of salt, however, with concentrations of 20% to 30% by weight. A major property of these salts, and sodium nitrate ($NaNO_3$) in particular, is that they absorb water, much like cooking salt in fact. The result is that bitumen will swell if there is water in the vicinity. And if there is no room to swell,

pressure will be exerted on the drum. Moreover, the sodium nitrate will also gradually leach into the clay.

Contact with water is inevitable in the case of geological disposition in clay. If the bitumen comes into contact with water, pressure will build up and, if this pressure becomes too high, cracks will appear in the layer of clay. Theoretically, radioactivity could spread along these cracks relatively quickly. This must, of course, be prevented. On the basis of the current know-how, a crack is not immediately considered to be a major problem. Boom clay is a plastic clay and, if any cracks occur, they are repaired by the pressure of the clay itself. Nevertheless, the Waste and Disposal expert group is aiming to better understand and chart these phenomena, in order to predict via models what the potential pressure build-up could be for a particular disposal concept. For example, as part of defining how many drums could be stored in an underground gallery.

Steven Smets, Wim Verwimp and Elie Valcke, R&D Waste Packages

Bubbles without risk?

Another phenomenon that SCK•CEN experts are investigating closely is a major formation of gas. Hydrocarbon molecules, of which bitumen is composed, form hydrogen under irradiation. In the event of geological disposal, this hydrogen cannot escape. But it can dissolve partially in clay water. As soon as saturation is reached, however, small hydrogen bubbles arise and will eventually converge to form larger bubbles. There is no immediate danger of explosion due to the absence of oxygen, but, as the pressure in the gas bubble increases, the likelihood increases that cracks could appear in the clay layer as an escape route for the gas. The combination of both events, i.e. the swelling of drums as a result of the absorption of water and the stress caused by the build-up of pressure due to the formation of gas, could indeed be a problem. The impact of both phenomena is currently being studied.

Test set-ups simulate phenomena underground

In recent years, significant progress was made in the understanding of the swelling, water absorption and salt leaching processes, both qualitatively and quantitatively. One way in which this is achieved is through test set-ups in which the material is brought into contact with a solution that is similar to that which the material would be exposed to in a layer of clay. Different instruments measure the swelling. Levers and weights create a specific pressure, and the swelling is then studied as a

function of time. The composition of the solution is also varied in order to study its effects. This type of test is referred to as a chemo-hydraulic mechanical model. The pressure that is applied goes up to 44 bar, which corresponds to the total pressure at the depth of a potential disposal site in clay.

The distribution of large quantities of salts (sodium nitrate $NaNO_3$) in the clay requires additional research. Clay has a number of favourable properties for the disposal of radioactive waste. One of these is that radionuclides spread less quickly in clay. Research in which the presence of bacteria is omitted has demonstrated that the sodium nitrate has little or no negative impact on this favourable property. It is, however, conceivable that bacteria could have an influence on these processes. This is being investigated further.

Preparations for a series of large-scale tests in this field started in 2011. In order to monitor the long-term evolution, research into the waste bitumen is likely to run for another 30 to 40 years. Rather than concentrating all efforts on short-term effects, the spreading of this research effort over time has the advantage that the expertise that is accumulated in this field is preserved, and will be passed on to future generations of researchers.

03

Innovative reactor systems

Particle accelerator and reactor coupled successfully

GUINEVERE presents a new world-first for SCK•CEN

GUINEVERE shone brightly in 2011. The project involves the coupling of a particle accelerator (GENEPI-3C) with the rebuilt SCK•CEN research reactor VENUS-F. GUINEVERE is the very first demonstration model of a reactor with a full lead core that is powered by a particle accelerator operating in continuous and pulsed mode.

The reactor became critical for the first time in January 2011. This was the first time that a fast neutron reactor has been operated at SCK•CEN. The renewed VENUS-F reactor has a lead core while over the past 40 years a water-moderated reactor had been in operation.

Critical without any problems

The first step of the commissioning was implemented without any problems. The reactor was very stable and easy to control in the critical mode. An experimental programme was carried out in the spring of 2011 to characterise the core. Experts measured various parameters, such as the maximum neutron flux in the reactor, the flux distribution (the distribution of the neutrons as a function of the location), the reactor temperature and the behaviour of the reactor in the event of changes to the core or modifications to the power supply. These tests were incorporated in the commissioning phase, during which it had to be demonstrated that the installation operates as described. In case of the GUINEVERE project, the commissioning consists of three phases: the non-nuclear tests without fuel, the critical phase with fuel and then the subcritical phase. The installation must succeed in all three components. The tests in the critical phase were completed by the end of April 2011. In August, the green light was obtained from the safety authorities to start up the last and subcritical phase.

The last straight run to a world first

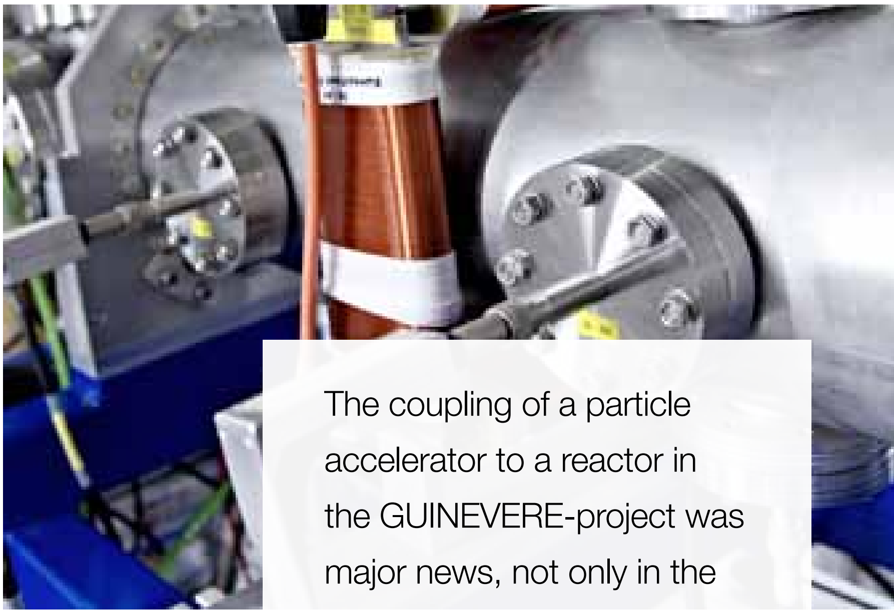
In essence, the subcritical phase is the coupling of the particle accelerator GENEPI-3C to the VENUS-F reactor. The core of the reactor was first modified to fit the vertical beamline of the accelerator into the reactor. Several fuel assemblies were removed for this purpose. The accelerator had already been extensively tested before the critical phase, albeit without fuel in the reactor. Additional tests were carried out before the coupling in order to perform the required reference measurements on the loaded reactor. The moment of truth then arrived on 10 October 2011. The accelerator was started for the very first time, creating a source of neutrons in the subcritical core. When the control rods of the reactor were then set to the reference level, the coupling was a fact. For the very first time, a subcritical reactor with a full lead core was powered by a continuous particle accelerator.

GUINEVERE

GUINEVERE (Generator of Uninterrupted Intense NEutrons at the lead VEnus Reactor) is a demonstration model of a system that is powered by a particle accelerator, also called an Accelerator Driven System (ADS). The rebuilt SCK•CEN VENUS-F reactor is coupled to the GENEPI-3C particle accelerator that was constructed by the French National Centre for Scientific Research (Centre National de la Recherche Scientifique, CNRS). The French Atomic Energy and Alternative Energy Commission (Commissariat à l'Energie Atomique et aux Energies Alternatives, CEA) has supported the development of the concept and the infrastructure, and has provided the fuel. About 10 other European laboratories and the European Commission were also involved in the project.

The official inauguration of GUINEVERE took place at SCK•CEN in Mol in March 2010. During the first year, the particle accelerator, the ventilation systems and the various supporting systems of the plant were thoroughly tested. In February 2011, the reactor was started up in the classical critical mode for a comprehensive series of characterisation tests. Then, in October 2011, the actual coupling between the accelerator and the VENUS-F reactor was carried out, whereby the system became subcritical.

GUINEVERE is a test installation with limited capacity that has been designed to support the MYRRHA project. The plant is of key importance, as it enables us to adjust the operation and control of future subcritical reactors, such as MYRRHA. This type of reactor is particularly safe because the reactor component of an ADS depends on the particle accelerator for its operation. As soon as this is switched off, the reactor stops immediately.



The coupling of a particle accelerator to a reactor in the GUINEVERE-project was major news, not only in the Belgian and French media. This world-first instantly went around the globe through specialised information channels. But why is it that this world premiere was achieved with GUINEVERE, and what is the significance of this success for the development of future Accelerator Driven Systems (ADS)?

The value of a world premiere

Interview with Peter Baeten, Institute Manager Advanced Nuclear Systems

Peter Baeten: GUINEVERE is very important in the context of the ADS story. Several countries are currently working on systems that are driven by a particle accelerator, but no-one has a high power ADS. This is the purpose of MYRRHA. The step that precedes this is a scale model. Small Accelerator Driven Systems have been developed in the past. As such, that's nothing special. We also used to have an ADS at SCK•CEN. But these systems cannot be compared to a large ADS.

Why were these existing systems not adequate?

Peter Baeten: We needed an ADS that is relevant for the MYRRHA authorisation. Many small ADS systems are not very useful for the authorisation procedure of a full-scale ADS. For the licensing, you need something that is representative, and this involves two aspects. On the one hand, computer calculation codes must be validated under representative conditions in order to be able to define the safety margins correctly. On the other hand, you need a reliable method to measure the subcriticality of the reactor, and that has never been done in a systematic manner before. The first step was made with MUSE, an FP5 project in the French research centre of Cadarache, where the GENEPI accelerator was coupled with the MASURCA reactor. The experiment provided plenty of

FREYA

SCK•CEN has worked very closely together with the French National Centre for Scientific Research (Centre National de la Recherche Scientifique, CNRS) in the realisation of the GUINEVERE project. Both parties are also working together closely for the continuation of the project. A new European research project with the name FREYA was launched in March 2011. FREYA (Fast Reactor Experiments for hYbrid Applications) is the experimental programme that is carried out with the VENUS-F reactor and the GENEPI-3C particle accelerator from the GUINEVERE project. In the coming four years, FREYA will provide new data that is of major importance for the development of Accelerator Driven Systems.

Due to the characterisation of the reactor core that consists of lead and uranium, the neutron codes that will be used for MYRRHA can be tested experimentally for the first time. These codes provide a picture of the neutron distribution in the reactor, which is essential data for the control and safe operation of the system.

The impact of the position of the neutron source will also be examined as part of the FREYA project. A tritium target is positioned at the end of the accelerator. This is the point where the neutrons that will feed the reactor are produced. In MYRRHA, the target is liquid, and the position is therefore variable. The FREYA project offers the opportunity to examine whether or not such fluctuations have an impact on the operation of the reactor.

information, but simply not enough. The conclusion that was drawn from MUSE was that a system such as GUINEVERE is needed if you really want to carry out experiments that provide relevant results for an authorisation procedure.

Why is it that this world first was achieved with GUINEVERE?

Peter Baeten: There are many couplings of something with a reactor worldwide. But these are of no value in the context of an authorisation process for a full-scale ADS. They are academic experiments, suitable for students to carry out measurements. Our objective was to collect information for the validation of computer calculation codes and a validated method for measuring subcriticality. For this purpose you require an installation that allows you to carry out the same experiments that you will carry out at a later stage with MYRRHA under acceptable, representative conditions. Otherwise, the safety authorities will say something like: “How far can this be extrapolated?”. And then we get stuck.

We needed an accelerator that works as it would in a full ADS. The accelerator in MUSE was a pulsed version. An accelerator that is used in a high-performance ADS will never be a pulsed accelerator; because it requires a continuous beam. Secondly, the core of the scale model must also be representative. This means a fast reactor core with the material of an industrial ADS; i.e., either lead or lead-bismuth, but not sodium or water. These two conditions must be fulfilled if we want to review the standard techniques we already studied in MUSE. We can now demonstrate this for the first time with GUINEVERE. And that’s what makes it effectively a world first that will enable the construction of a high-performance ADS. In other words, our baby MYRRHA with zero capacity is a crucial step for the authorisation process of the final version at full scale.

Interview with
Hamid Aït Abderrahim,
MYRRHA Director

MYRRHA in 2011

“ Because of the MYRRHA project, I meet many colleagues from all over the world. We regularly host foreign delegations at SCK•CEN also. And I can honestly say that people keep looking at us with admiration. I’m often told that we are doing extraordinary work with our team of 700 people, which is quite a modest workforce from an international perspective. This can only be achieved with very dedicated and highly motivated staff. ”

MYRRHA in an eventful year

Innovative research facility convinces the world

The accident in the Fukushima Dai-ichi nuclear power plant also had an impact on the MYRRHA project. From the very first design of the system, the focus was on the maximum exclusion of any risk. After the events in Japan, the MYRRHA team again spent several months on the revision of the existing design.

We reviewed whether any adaptations to the safety systems or other important components should be incorporated. It was also yet to be seen whether Fukushima would have an influence on the composition of the international consortium that is to finance and manage MYRRHA.

Hamid Aït Abderrahim: The events of 11 March were so unlikely. Nobody had expected anything like it. The first reaction in the MYRRHA team was to examine what happened, and to see what lessons could be drawn from this for our design. But, of course, we also needed to know what the possible impact on the progress of the project could be. In March and April, the people involved in MYRRHA, and particularly the Management Team, were closely involved in the study that SCK•CEN carried out with regard to the accident in Fukushima and its consequences. We then took a close look at whether an accident like this could be possible in MYRRHA. What if the power supply breaks down? Could the core also melt? This scenario has already been foreseen in the design, but, in the light of the accident, we returned to the drawing board and checked yet again that the figures were really correct. And we were right, because the core of MYRRHA will not melt, even if we lose all active cooling systems. Therefore, the worst that happened at Fukushima could not happen here. Naturally we have also studied other aspects in further detail. There are new recommendations with regard to the impact of extreme earthquakes, and these are, of course, incorporated in the design.

In addition, it's now a matter of waiting for the choices that Europe will make regarding the financing of research into fourth generation reactors in the context of the Strategic Energy Technology Plan (SET-plan). It is possible that the financial support for MYRRHA from this source may be reduced. On the other hand, MYRRHA is also a research facility, and that's where we maintain our strong position, as we are on the priority list of large research infrastructures of the European Strategic Forum for Research Infrastructures (ESFRI).

Will the decision made by Germany to phase out nuclear power have any consequences for the MYRRHA project?

Hamid Aït Abderrahim: That remains to be seen. We have always believed that Germany could be one of the major

> *“2012 will be another exciting year for the MYRRHA team.”*

partners in MYRRHA. After the news that Germany had opted for phasing out nuclear power, it was difficult to assess the impact that this decision would have on their interest in MYRRHA. Germany is still interested, and very specifically in the possibilities of MYRRHA for the transmutation of high-level, long-lived radioactive waste, a process by which the radiotoxicity of the remaining waste is significantly reduced, as well as the required storage time. Research into this scenario, i.e. relating to the optimisation of the final disposal, remains topical, even for countries that are considering or have already planned the phasing out of nuclear power.

How far are you with the formation of the international consortium for MYRRHA?

Hamid Aït Abderrahim: In 2011, we set ourselves the target of reducing the 40 or so potential countries we had listed for negotiations to a shortlist of countries with which we really believed we could enter into an agreement. We used two criteria in this context. We only considered those countries who would be able to join the consortium at very short notice, and parties who would be able to make a very significant contribution. We went through this exercise, and we now have a shortlist of 13 countries, mainly in Europe and Asia.

We have also identified a limited number of scenarios for the MYRRHA consortium, with the corresponding key factors for success. Furthermore, we have determined how the best possible synergy for each scenario could be reached between the represented interests of the partners and the strategic objectives of SCK•CEN and Belgium. For SCK•CEN, the deployment of MYRRHA as a multifunctional research infrastructure for innovative applications is of crucial importance. For Belgium, Flanders and Wallonia, it is crucial that continuous investment is made in innovation,

PARTNERSHIP AGREEMENT WITH UCL

The Belgian Nuclear Research Centre and the Université catholique de Louvain (Catholic University of Louvain, UCL) have signed a partnership agreement with a view to the development and testing of the first section of the particle accelerator of MYRRHA. With its Centre de Recherche du Cyclotron (CRC), UCL has extensive experience and competence in the field of accelerator technology. The university will make a building available to SCK•CEN that is highly suitable for starting the construction of the first section of the MYRRHA accelerator in 2012. This consists of the injector with proton source. Here, the particles will be ionised and transformed into an ion beam. A radio frequency quadrupole (RFQ) will then ensure the acceleration of the ion beam.

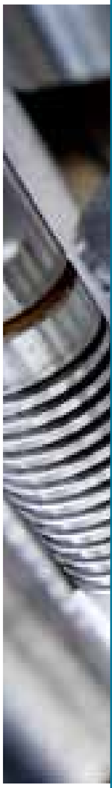
The cooperation with the Université catholique de Louvain provides significant synergies. For UCL, it is particularly interesting to valorise its own expertise in the field of particle accelerators, and to further develop their existing knowledge in this field, while SCK•CEN will not be required to build a new hall, and will be able to rely on the technical support of the Centre de Recherche du Cyclotron.

UCL
Université catholique de Louvain

and that we support the knowledge economy. MYRRHA will, of course, also be deployed for the production of medical radioisotopes and for the irradiation of silicon for use in wind turbines, hybrid vehicles and the like.

What is the target date for the composition of the MYRRHA consortium?

Hamid Aït Abderrahim: Our agreement with the government states that we should have partners that, together, should cover at least 40% of the investment for 2014. It is, however, clear that the economic situation in the Western world and the impact of Fukushima on major investments in the nuclear sector, even in the area of research, has not made the search for partners any easier. We remain optimistic, however, and will further strengthen the existing contacts. Yes, 2012 will be another exciting year for the MYRRHA team.



MYRRHA

In full, MYRRHA is short for Multi-purpose hYbrid Research Reactor for High-tech Applications. This successor to the BR2 reactor represents a particularly innovative research infrastructure. MYRRHA operates with fast neutrons, and cooling takes place with liquid metal: a mixture of lead and bismuth. MYRRHA is the very first prototype of a nuclear reactor worldwide that is driven by a particle accelerator. We are referring to a subcritical reactor: the core does not contain enough fissile material to maintain the chain reaction spontaneously. It must be continuously fed by an external neutron source. This is the reason why the reactor is coupled to a particle accelerator. It is a technology that is particularly safe and easy to control. When the accelerator is switched off, the chain reaction stops literally within a fraction of a second, and the reactor stops.

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

In addition to research into transmutation, SCK•CEN will deploy MYRRHA for a wide range of applications, including material testing for current and future reactors, nuclear fusion technology and the development of innovative nuclear fuels. In addition, there is also the production of medical radioisotopes that are essential for the diagnosis and treatment of cancer, and the irradiation of silicon for electronics, which is used in wind turbines and hybrid vehicles, among other applications. SCK•CEN aims to put MYRRHA into use in 2023. The total cost has been estimated at € 960 million (2009).

MYRRHA takes shape

Fukushima confirms the choices for the design

2011 was a decisive year for MYRRHA's Central Design Team (CDT). CDT is a European project set up for the design of this multifunctional research facility, in which a number of international partners each concentrate on a part of the high-level design. In this phase, major decisions are made with regard to the design that will later be developed further by an engineering office.

In the course of 2011, the team has been reinforced with engineers who will be responsible for the implementation of the complete MYRRHA infrastructure, with the exception of the nuclear component. They are experts in civil engineering, architecture, process engineering, instrumentation and control, electricity, piping and heating, and ventilation and air-conditioning (HVAC). In 2011, a start was made with the selection of the engineering office that will further elaborate the various components of the construction project.

A new design for the heart of MYRRHA

2011 also turned out to be a crucial year for the designers of the core of MYRRHA; this is called the primary system in the jargon. It is the nuclear part of the installation. The design of the primary system was subjected to several major technical revisions in the course of 2011. Revision 1.2 was presented in June. The European partners now use this modified design for the safety analyses of the system. The final mechanical revision was completed by the end of 2011. This means that a coherent design of the complete nuclear part in which all components are completely or to a large extent drawn in is now available.

One of the key challenges that were encountered was the design of the diaphragm; a very large, complex structure in the reactor vessel that separates the hot zone from the cold zone. Despite intensive development efforts on the diaphragm, it turned out to be necessary to lower the maximum temperature of the lead-bismuth cooling agent. Extensive research into the feasibility of this type of large, complex structure was also carried out in 2011.

The designers have also developed a skirt for MYRRHA: the baffle. This system ensures that any fuel element that comes loose remains within this skirt. The fuel can only land within a restricted zone, and is always within reach of the robot arm MYRRHA is equipped with especially for this type of operation.

In addition, a core restraint system has been introduced that is able to block the reactor core in the reactor vessel. In MYRRHA, the fuel assemblies will have a lower density than the lead-bismuth cooling agent, so that they will float. The fuel is situated above in a grid. In the event of a serious earthquake, however, the entire vessel could be shaking, and the assemblies could possibly come closer together than foreseen. In order to avoid them touching each other, the designers have developed a blocking mechanism, i.e. a system that blocks the fuel assemblies, in order to exclude any possible risk.

The neutronic design of the reactor core has also been further optimised. A slight adjustment of the fuel configuration has been opted for with respect to the previous version of MYRRHA. Initially, the calculation of the neutron distribution was only based on fresh fuel (the so-called beginning-of-life core). This calculation provided a first indication of the system performance. An estimate was then made for cores containing a mix of new and old assemblies. Thanks to further development of the ALEPH computer code, it is now possible to calculate an equilibrium cycle so that a transfer system for the fuel assemblies in the core can be analyzed.

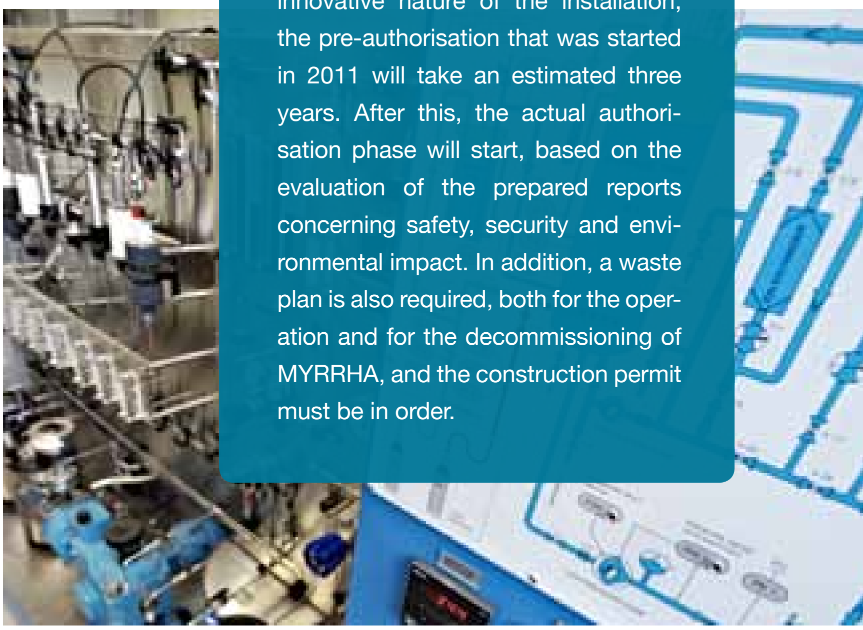
The non-nuclear part is also taking shape

In 2011, all non-nuclear systems were defined (secondary and tertiary cooling systems, ventilation, hot-cells, etc.) and developed conceptually. This provided a picture of the complete installation for the first time. All systems have been described in specifications, on the basis of which the external engineering office will start working at the beginning of 2013.

READY FOR THE AUTHORISATION

Together with the design, the safety criteria for MYRRHA have also evolved in 2011. The accident in Fukushima also inevitably had an impact on the timing and the approach of the authorisation process. In addition to the specific legal requirements that are in place with regard to obtaining a license for this type of nuclear facility, the Federal Agency for Nuclear Control (FANC) has introduced a pre-authorisation procedure. Well before the required safety and other reports were prepared, the FANC experts had already received extensive information regarding the key components of MYRRHA in the course of 2011. The exchange of information at this stage, together with technical support from the Scientific Council of FANC, brought a number of issues to the surface. The impact of these issues in terms of safety has yet to be studied. In the end, this will lead to a modified design whose compliance with the objectives and requirements of FANC must then be demonstrated.

MYRRHA incorporates technological innovations with multiple applications in which the use of existing techniques and materials goes hand-in-hand with research and development. Due to the innovative nature of the installation, the pre-authorisation that was started in 2011 will take an estimated three years. After this, the actual authorisation phase will start, based on the evaluation of the prepared reports concerning safety, security and environmental impact. In addition, a waste plan is also required, both for the operation and for the decommissioning of MYRRHA, and the construction permit must be in order.



Safety provided by Mother Nature

Interview with
Paul Leysen, Head of Nuclear Systems Design,
Rafaël Fernandez, Head of Primary System Design
en **Gert Van den Eynde**, Head of Nuclear Systems Physics

The accident in the Fukushima Dai-ichi nuclear power plant was not without consequences for the MYRRHA design team. Several experts have been deployed to carry out the stress tests, to which the Belgian Nuclear Research Centre was also subjected. On the other hand, the accident in Japan has confirmed that the MYRRHA designers made the right decisions years ago.

When the news about Fukushima became known, we knew immediately what we could expect.

Paul Leysen: When the news about Fukushima became known, we knew immediately what we could expect. Within the MYRRHA project, a number of people started working temporarily on studies within the context of the stress tests. The civil engineer and the architect participated in the research into the stability of a number of buildings at SCK•CEN. Our electricity expert was another team member who spent a lot of time on these resistance tests. In general, Fukushima has resulted in FANC setting higher safety requirements for the construction of new facilities such as MYRRHA. Resistance against earthquakes must be increased, for example, and that implies that the walls should be thicker or contain more steel reinforcement. But Fukushima has also shown us that our starting point was correct. Our basic philosophy was that the entire cooling system of the reactor should operate passively. In the event of an emergency, it should be able to put itself in a safe mode without human intervention, or without an external energy source. This principle, which was incorporated in the MYRRHA concept from the beginning, has now been highlighted as a prerequisite by FANC.

Rafaël Fernandez: We don't need electricity or external intervention. The physics of Mother Nature ensures that the reactor cools down. That's the essence. We have planned four redundant circuits for the cooling. If you should lose part of a system because of a plane crash, you still have three cooling circuits left. They are independent, and you only need one. And if the last system also breaks down, we still have an additional cooling system that works with natural ambient air circulation. The complete MYRRHA design has been conceived in such a way that no electricity, emergency diesels or human intervention is required. That was precisely the major problem in Fukushima. Because of the tsunami, all the emergency systems were disabled, and the people were unable to take any action, such as starting up emergency diesels.

This means that, in a sense, the accident in Fukushima was also a confirmation of the choices that were made for the MYRRHA design?

Rafaël Fernandez: Absolutely. What happened in Fukushima has confirmed that we have come up with a very good cooling system. At the time there was, in fact, no obligation on us at all to have redundant and passive cooling. But, after the accident, FANC asked us: "What if anything like what happened in Fukushima was to happen over here; an earthquake or another external phenomenon with such an extreme impact?". We then showed them our design, and they responded positively to the fact that we had calculated this in from the outset.

This was therefore already included in the design years ago?

Paul Leysen: That was indeed the case for the primary system, the nuclear reactor component. But we hadn't yet estimated what it would take to extrapolate this to the non-nuclear component of the installation. This was studied extensively in 2011, together with the European partners. We have now found a solution that is – again – unique in the world: MYRRHA will be the first nuclear installation in which all essential systems are passive.

Has the accident in Fukushima affected the MYRRHA project in any other ways?

Gert Van den Eynde: Early in 2011, we had already started with the analysis of the consequences of potential serious accidents. The events in Fukushima have propelled this research into a maelstrom. A major accident in a nuclear power plant means that the reactor core is severely deformed or damaged. It is then assumed that the installation is lost, but it must, of course, be ensured that any impact on people and the environment is limited to a minimum. We have launched a major research project with experts from the Karlsruhe Institute of Technology (KIT) in Germany. They have developed the SIMMER computation code for reactors such as MYRRHA. This is one of the major reference codes used to predict the impact of serious accidents. One of our staff members has been trained on site, and we develop the models and analyse the results together. This had already been planned, but these analyses started earlier following the events in Fukushima.

New technology tested in practice

How do moving parts behave in lead-bismuth?

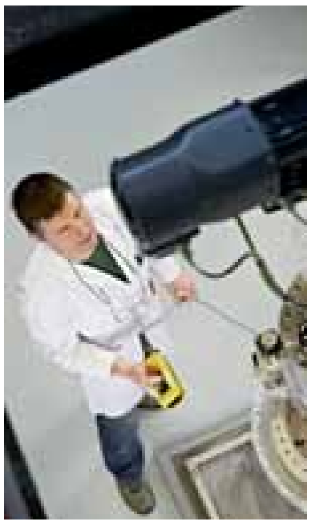
Even though the foundation stone for MYRRHA hasn't been laid yet, engineers and researchers at SCK•CEN are already very busy with physical testing in test rigs. Several systems were put into use for this purpose in 2011.

One of the most remarkable of these test set-ups is RHAPTER (Remote HAndling Proof of principle TEst Rig). With this installation, it is possible to test the behaviour of moving parts in lead-bismuth, the liquid metal that will serve as cooling agent in MYRRHA.

RHAPTER has been in operation since September 2011. It is a test vessel filled with 50 litres of lead-bismuth and a large range of measuring instruments. The vessel contains two vertical shafts, a fast one and a slow one. Different components that need to be tested are fitted to these shafts. In an initial phase, the ball bearings for MYRRHA's robot arm were tested first, but the design of the test rig enables the testing of virtually all crucial parts, such as gears, springs, etc. They rotate in RHAPTER with a specific load, and the wear and tear can be measured accurately.

Authentic empirical research

The behaviour of moving parts in lead-bismuth has never been thoroughly tested before. In industry, bringing components such

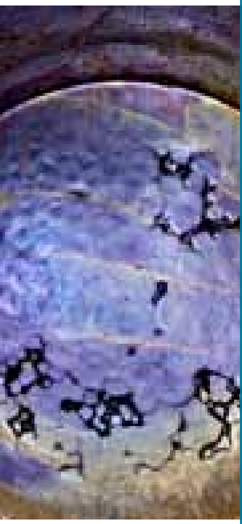


as the bearings of a pump in contact with lead is usually avoided, because too little is known about the behaviour of these moving parts. But this cannot be avoided in the case of MYRRHA. The strategy is to use as many existing components as possible, and to then establish how they react in lead-bismuth through experiments in RHAPTER.

The liquid metal confronts the engineers with some extraordinary challenges. To start with, it is impossible to lubricate parts, and lead-bismuth itself also has no lubricating effect because it is too fluid. Corrosion is another problem. In principle, the tested materials are not very susceptible to corrosion, on the condition that the oxygen concentration in the lead-bismuth is kept within certain limits. But, to be safe rather than sorry, the corrosive effect of lead-bismuth is also studied.

WHAT IS LEAD-BISMUTH?

Lead-bismuth is the liquid metal that serves as cooling agent in MYRRHA. First and foremost, lead-bismuth is not syrupy. On the contrary, it is even more fluid than water. Pure lead-bismuth is opaque, and looks like a mirror - albeit rather a heavy one. One litre of the mixture has a mass of no less than 10 kilo. Because it is literally as heavy as lead, steel, for example, will not sink in a vessel of lead-bismuth, but will float. Another interesting aspect is the phenomenon of oxidation. The mirroring effect is, in fact, very transient. As soon as any oxygen comes near it, the surface will immediately become matt through oxidation. A thick skin of non-liquid lead oxides will eventually be formed. These small particles are extremely hard, and could cause a lot of damage to the moving parts of an installation. Lead-bismuth has a melting temperature that is well below that of lead and bismuth separately. The relatively low melt temperature has a positive impact on the service life of the mechanical components and the materials that are used. Lead-bismuth is primarily used in electronics, and will soon also be used for cooling down innovative reactors.



The entire test programme will run until beyond 2014, but whether the tested parts could be used at all should be quite clear before that time. The first phase involves the determination of the best design and the best choice of material for these MYRRHA components. Afterwards, durability tests will be conducted to study the reliability of the components and to determine how this may still be improved.

New test rigs follow each other in rapid succession

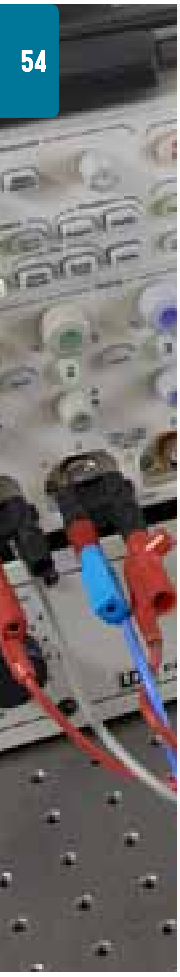
HELIOS 3 was also constructed in 2011. This is a melting and conditioning installation that ensures the provision of pure lead-bismuth with the correct oxygen content to minimise the corrosive effect.

Other projects are currently still on the drawing board. LILIPUTTER was a small circuit to determine the behaviour of a screw pump in lead-bismuth; this loop will be used for filter testing in the future. E-SCAPE will be a MYRRHA scale model that allows the characterisation of the flow of the cooling agent. Electrical heating elements will simulate the heat of the fuel. COMPLOT is another circuit that represents one of MYRRHA's nuclear fuel ducts at full size. CRAFT examines the corrosion of materials in lead-bismuth, and MEXICO explores the mass transport of oxygen in a lead-bismuth loop.

Predictions for the more advanced

The search for the ideal materials for fusion reactors

Generating energy on Earth according to the same principles as in the Sun is a very attractive idea. Research into nuclear fusion has been on-going for several decades already and, with ITER, an international project team in Cadarache (France) has started the construction of the first experimental fusion reactor. But plenty of challenges remain for scientists and engineers alike. The Structural Materials expert group at SCK•CEN is now looking into one of them.

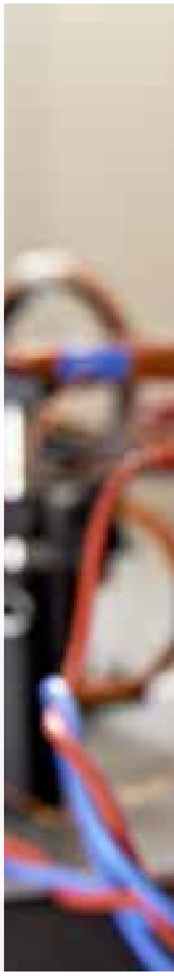


The selection of suitable materials for fusion reactors is no easy task. In a fusion reactor, the reactor vessel must be able to withstand extremely high temperatures, from 600 up to even 1,000 °C. The neutron flux is also many times higher than in a traditional fission reactor, where nuclear fission provides the source of energy. An additional problem is that these extreme conditions cannot be simulated in a fission reactor. But even if the conditions may not be the same, experiments with materials are still possible. In order to draw sensible conclusions from the results, computational models are then developed. Current research focuses on the extrapolation of existing experimental data and methods for the characterisation of materials.

Simulation is not an option

Certain types of ferritic steel are currently being studied as the structural materials of fusion reactors. Tungsten may be considered for the material that comes into contact with the red-hot plasma. This coating material inside the reactor vessel forms a first barrier. It should ensure that the plasma remains enclosed inside. The material must have excellent heat properties, but that is not the only criterion. When it is removed from the reactor during decommissioning, it will be contaminated with radioactive tritium, among other substances. It should therefore not shatter like glass on the slightest shock. The structural materials for the construction of fusion reactors therefore have to be sufficiently plastic. If they break, this should happen in a controlled manner. In other words, there is a need for materials with highly predictable mechanical properties.

In order to develop reliable models that are able to predict the behaviour of these materials accurately, data is collected at different levels: both the changes at an atomic scale and the mechanical effects that are visible with the naked eye should be covered.



Primarily, the aim is to understand how irradiation causes damage at the atomic level. For this reason, material that was irradiated in reactor BR2 is examined under an electron microscope and compared with identical material that has not been irradiated. Any changes that have occurred under these specific conditions can be derived from this. The materials are then submitted to various mechanical tests. The results are related to the changes in the material that result from the irradiation. If the models can then finally provide an adequate explanation for this experimental data, they are reliable. The ultimate target is to determine whether or not the material complies with the requirements.

Were the choices that were made confirmed in practice?

The materials for the international experimental nuclear fusion reactor ITER, a project in which also SCK•CEN participates, have been selected in the meantime. Yet ITER remains very interesting for the researchers who are working on models. When ITER is launched, flows of data concerning the materials used will come in. It will be a valuable practical test for the models that are now being made, because it will then be possible to assess their validity on the basis of actual measurement data. In the meantime, the Structural Materials Modelling and Microstructure unit within SCK•CEN is carrying out research with a view to the next major nuclear fusion project: the DEMO reactor. DEMO is intended to demonstrate that it is effectively possible to produce electricity by nuclear fusion. The studies that SCK•CEN is currently carrying out may provide a significant contribution to the optimisation of the existing fusion materials and the development of new types.

04

BR2: motor for sustainable innovation

Less waste thanks to new types of fuel

Thorium-plutonium fuel ready for the ultimate test

For some time now, Europe has been supporting research into innovative technologies that minimise the production of radioactive waste from the generation of electricity in nuclear power plants. This relates primarily to light water reactors, or LWRs. This is the most common type of nuclear power plants in Europe.

In 2005, SCK•CEN initiated the European LWR-DEPUTY project (Light Water Reactor fuels for DEep burning of PU in Thermal sYstems). The Belgian Nuclear Research Centre coordinated the research programme in which about a dozen research institutes and industrial partners participated. This was, in fact, a continuation of the earlier European OMICO project (2000-2006), which had yielded some good results, in particular with regard to a new nuclear fuel based on thorium and plutonium. This new fuel was developed, irradiated and investigated partially. Unfortunately, due to its long duration, the lengthy post-irradiation examination that is crucial before a new type of fuel could ever be introduced into the reactor of a nuclear power plant could not be performed within the timeframe of the first project. A continuation of this promising research was therefore more than desirable. SCK•CEN has been able to play a pioneering role in this, thanks to its expertise in the field of fuel materials and the physicochemical and radiochemical analysis of such materials. The tests and analyses were carried out mainly in the BR2 research reactor, the Laboratory for High and Medium Activity and the laboratories for Radiochemical Analysis.

Evolving or 'out-of-the-box' thinking?

The researchers took two paths within the LWR-DEPUTY project. On the one hand, they started to explore very innovative materials, such as metal ceramic fuels, also known as cermets. Several types were developed and tested in BR2. The initial results are encouraging, but substantiated conclusions will only be available in a few years' time, once these nuclear fuels have been irradiated for much longer.

The focus, however, was on completing the study of the thorium-plutonium fuel that was launched at the beginning of this century. Its behaviour under irradiation in a reactor is promising, and the fuel is very similar to plutonium-uranium oxide, better known as MOX. A major difference, however, is that fuel consisting of thorium and plutonium will enable a higher net reduction of the plutonium production. This is because thorium-232 does not lead to the production of the higher actinides (plutonium, americium and curium). These elements are considered as highly problematic for humans and for the environment because of their high radiotoxicity and the fact that they are long-lived.

Leo Sannen

Institute Manager Nuclear Materials Science

> “Thanks to the worldwide valued quality of our research reactor and the corresponding laboratories, we can take the lead in answering the societal questions with regard to safe reactors, an adequate management of nuclear waste and the security of supply of medical radioisotopes.”

Thorium-plutonium one step closer to being used as a new type of fuel

The thorium-plutonium fuel is not considered to be the ultimate alternative, but rather a transitional solution. It might be used for perhaps 20 years to enable the gradual transition from reactors that operate on the basis of uranium fission towards actual thorium reactors.

The LWR-DEPUTY project continued the thread of the previous research with a comprehensive analysis of the thermo-mechanical properties of the nuclear fuel. This study made it possible to build up reliable data sets that enable a correct understanding of the behaviour of the experimental fuel. Non-destructive and physicochemical analyses provide a good picture of the changes that have occurred during the irradiation, while destructive radiochemical analysis provides accurate identification and quantification of the isotopes that were incinerated and built up. This knowledge is essential for all steps of the process and is especially important from a safety point of view. This is because some of the actinides that are produced with the new fuel types require specific protective measures.

The next best solution

One option in our search to reduce the production of waste products, which is inextricably linked to the generation of electricity in nuclear power plants, is to develop better solutions that can be applied to today's nuclear facilities. Amongst international researchers, however, this pragmatic approach is considered to be the second-best solution. Backing a new generation of reactors, such as MYRRHA, for example, is another option. There is no doubt that new reactor concepts and the latest technological developments offer better opportunities for reducing the production of nuclear waste.

There is a two-fold reason why the LWR-DEPUTY project focused on the non-optimal option. On the one hand, we cannot yet predict with 100% certainty that the innovative approach towards new reactor types will live up to the very high expectations. And, on the other, their introduction on an industrial scale could easily take another 40 years. Seen in this light, it is certainly wise to also explore the next best option.

Ready for the ultimate test

LWR-DEPUTY was completed at the end of September 2011. Thanks to the very successful cooperation with all partners involved, the study represents a major milestone in the introduction of a new, low-waste nuclear fuel. With respect to the thorium-plutonium fuel, the analyses resulted in the development of a data set that enables us to make the required safety calculations for the ultimate step, i.e. the irradiation of the fuel in a full-scale nuclear reactor. In other words, no longer in the BR2 research reactor, but in the reactor of a nuclear power plant.

Research into out-of-the-box fuels also yielded good results. Further research into these very innovative fuel types is required, but the results of the initial irradiations in the BR2 reactor certainly demonstrate that they have potential.

Low-enriched uranium as fuel for research reactors

Cadmium wires serve as neutron absorbers

Stimulated by the United States, global efforts have been made for several decades now to reduce the use of highly enriched uranium in civilian applications in order to curb the proliferation of nuclear weapons. Much research has already been carried out into the conversion of highly enriched uranium (HEU) to nuclear fuel based on low-enriched uranium (LEU), especially in the case of research reactors.

A significant number of research reactors have made this conversion successfully in recent years. For a number of reactors with special properties – and this includes the SCK•CEN high-performance reactor BR2 – an optimal fuel type based on LEU still needs to be developed however. The Belgian Nuclear Research Centre is one of the pioneers in this research, in which it is working closely together with American and French partners. The specific focus for BR2 is the extent to which neutrons can be absorbed. This is decisive for the efficiency of the fuel as well as safety. In 2011, a fuel element with a new type of neutron absorber was therefore submitted to an ultimate test in the BR2 reactor.

Steven Van Dyck

BR2 reactor manager

A new absorber

The fuel for the BR2 reactor currently consists of a mixture of highly enriched uranium and aluminium containing small concentrations of samarium and boron. If low-enriched uranium is used with aluminium, there is no place for samarium and boron. A possible alternative is a configuration in which cadmium wires serve as neutron absorbers. In order to investigate this option, a new fuel element has been developed in which cadmium wires have been fitted in the areas between the fuel plates and the carriers. The aim is to determine whether the fuel in the reactor is burning at least as safely and efficiently as traditional fuels.

The new composition was tested in the BR2 reactor in combination with the current nuclear fuel based on highly enriched uranium. The irradiation of the fuel elements with cadmium wires throughout the complete life cycle demonstrated that the neutron absorption corresponded to the theoretical predictions. No degradation of the structure of the absorbing wires nor any undesired deposits of the material in the cooling water were observed.

Safe and efficient

The fuel element tested has a slightly different shape compared to the existing elements. In the second part of the study, an assessment was made as to whether this minor physical adjustment was compatible with the properties of the primary coolant of the BR2 reactor, and in particular with the flow rate of this coolant through the fuel elements. Investigation of these hydraulic properties demonstrated that there is no significant difference from the standard elements.

Due to the irradiation campaign of the fuel elements with cadmium wires in combination with HEU fuel, characteristics such as neutron absorption and control of the reaction have now been thoroughly studied and proven. The efficiency of the fuel consumption and the safety has thereby been demonstrated. The composition of the low-enriched fuel, on the other hand, has not yet been finalised. Several experiments are in progress in order to define the most suitable type. The development of this LEU fuel represents a major challenge, but expectations are that the gradual conversion of the fuel for BR2 from HEU to LEU could start before the end of the decade.

Producing radioisotopes from low-enriched uranium

A vital conversion

Highly enriched uranium (HEU) must not only make way for low-enriched uranium (LEU) when it comes to fuel for research reactors. The same conversion is planned for the production of radioisotopes for medical applications. SCK•CEN experts and several partners are currently working on solutions to make this possible in the BR2 reactor. Unfortunately, they cannot take advantage of the efforts made by colleagues who are perfecting the new LEU fuel.

A radioisotope target may look very similar to a fuel plate for a reactor, but it is used in an entirely different manner. A fuel plate produces neutrons over many cycles, whilest a radioisotope target remains in a reactor for no more than 150 hours undergoing fission. The target is then removed and processed as quickly as possible at the manufacturer's site, such as the National Institute for Radio Elements (IRE) in Fleurus (Belgium) or Covidien in The Netherlands, in order to retrieve the actual medical radioisotopes. These radio-isotopes are fission products of uranium, in this case, primarily molybdenum-99.

Until now, the materials used in the manufacturing of radioisotope targets were quite similar to those of highly enriched uranium fuel plates. Unfortunately, the new low-enriched fuel types developed for research reactors are not suitable as models for radioisotope targets because they are not compatible with the further processing of the radioisotopes. Intensive research and development work is essential in order to convert the targets from highly enriched to low-enriched uranium without incurring losses in the production. IRE and other manufacturers of medical radio-isotopes have therefore opted to break this conversion down into at least two phases.

The pragmatic approach

During the first phase, the existing radioisotope target is adjusted as far as possible, without altering the composition. The target is a thin slide with a thickness of a few millimetres that consists of a layer of uranium-containing pellets embedded in a pure aluminium binder. By using more fuel pellets, and thereby increasing the density, the target can still contain the required quantity of uranium-235, without needing to use highly enriched uranium. This will change the geometry of the targets however.

The programme for the qualification of this LEU target was launched in 2011. The first task will be to produce new slides. It is expected that these will increase slightly in thickness, and that the irradiation infrastructure in the BR2 reactor will therefore need to be modified. Moreover, safety tests are necessary to establish whether the modified irradiation devices comply with all the established criteria.

While the manufacturers of radioisotope targets are concentrating on research relating to the production of customised slides, SCK•CEN is making the preparations for the first qualification experiments in BR2. The actual irradiation of the LEU targets will start in the course of 2013. The post-irradiation research will be concluded with a qualification report, on the basis of which the manufacturers will be able to produce the customised targets, and the safety authorities can grant their approval for routine use.

Continuity is of vital importance

While the qualification of the new LEU targets is in progress, production can continue with highly enriched uranium. An interruption could, in fact, have a major impact on the availability of radioisotopes. This is a consequence of the limited number of reactors that can produce molybdenum-99, and its limited shelf-life; after discharge from the reactor, every three days half of the produced molybdenum-99 disappears by radioactive decay. Molybdenum-99 is the ‘parent-isotope’ of technetium-99, the radioisotope that is used in 80% of all radio-diagnoses using medical imaging. Ultimately, it’s not about materials, but about human lives. Therefore the challenge is great. The conversion process will be gradual in order to guarantee supply without interruption or loss of quality. In a first step, a composition has been opted for that is only slightly different from the current targets. This also ensures that the systems for further processing at the manufacturers’ sites will not require modification.

The optimal option

Phase two started in 2011, at almost the same time as the first phase. We are looking a lot further ahead in this second phase. The challenge consists of optimising the production of medical radioisotopes and reducing the waste that is generated during the production process. The first option that we are currently developing in order to enable the conversion from high to low-enriched uranium is not optimal in terms of productivity and waste reduction.

Phase two includes the development of an entirely new type of target with a modified composition. By using another uranium compound as fuel pellets, the conversion from HEU to LEU could go hand in hand with a significant increase in efficiency. This type of modification would involve a number of significant changes to the (chemical) processes used to isolate the molybdenum-99 and to process it further for medical applications. This will, of course, require more research and development from the manufacturers, such as IRE, but the result would mean a significant increase in production efficiency, and a reduction of waste. As this option contains more unknowns, however, the development and the testing will require a few years more than the modification of the existing targets.

Realistic experiments support safety

Testing of reactor materials in extreme conditions

How do you know how the materials that have been used for the construction of our nuclear power plants will behave after years of exposure to radiation and other environmental factors? One option is to subject similar materials to accelerated irradiation in a research reactor and to test them afterwards. SCK•CEN has many years of experience in this field with the CALLISTO loop in the BR2 research reactor. But there is also another method; i.e. a true simulation of the conditions of a nuclear power plant in which the material originating from the reactor itself is exposed to normal and to extreme loads.

Mathematical models are used to establish what damage could occur in a specific material and when. The experimental data that is required to create such a model is the result of long series of tests in a test environment.

SCK•CEN has two experimental test rigs for carrying out corrosion testing on materials from nuclear power plants, one for non-radioactive material, and an almost identical set-up in a large hot-cell. This is a shielded area used for remotely controlled investigation of highly radioactive material. Only a handful of comparable installations can be found worldwide. Accurately simulating the specific operational conditions of a nuclear power plant also requires a great deal of technical expertise.

Understanding and predicting

In this way, SCK•CEN studies the corrosion resistance of the materials that are present in the nuclear power plants of Doel and Tihange. The focus of the research is on stress corrosion. This is a form of corrosion where damage may be caused to materials as the result of the combined effects of stress and a specific environment, in this case cooling water.

Unique study objects from nuclear power plants

An example of metal reactor parts that are susceptible to stress corrosion is the so-called baffle bolt. These stainless-steel plate bolts can become brittle as a result of radiation damage, and this could lead to cracks underneath the bolt head, which is the most heavily loaded point. In order to test this pro-actively, a number of bolts were removed from the nuclear power plant in Doel and taken to SCK•CEN for further examination. In practice, this means that experts test the stress resistance of these highly radioactive parts in a hot-cell.

A particularly interesting study object came from the nuclear power plant in Tihange. It was a tube that was originally situated inside the reactor core. It served as a guide tube for a sensor that measures the reactor power output on the basis of the neutron flux in the core. Due to its location in the reactor core, this tube had been exposed to high levels of radiation, and therefore provides an indication of the maximum radiation damage to materials in a reactor. For corrosion researchers, this study material is not only extremely interesting, but also very complex due to the high radioactivity. This is where the unique hot-cell expertise of SCK•CEN comes into play again.

There is another completely different category of materials that are prone to stress corrosion. Many stainless steel pipes are welded to the carbon steel reactor vessel. The welds are made with nickel alloys. Research has demonstrated that these welded seams might be susceptible to stress corrosion over the long term. SCK•CEN has a unique piece of material available for thoroughly studying material ageing in this context: a piece of welded tube from a Spanish nuclear power plant that was never put into operation. Small sections are cut from the welded seam for testing in the test set-up. The nickel weld provides very useful information on the susceptibility to stress corrosion.

Extreme stress testing

The simplest test consists of putting a piece of material under tension, and then waiting until damage occurs. This time-to-failure-test demonstrates how long the material can withstand different load conditions. Damage occurs quicker at higher loads. By lowering the load down to a level where the part no longer suffers damage, the so-called limit load can be determined. As soon as the limit load has been determined, it can be compared to the stress to which the material is exposed in the nuclear reactor. As long as these values are below the limit load, including a generous safety margin, the integrity is guaranteed. It goes without saying that this limit load must be a very reliable value. For this reason, the quality of the test set-up is of crucial importance.

By the end of 2012, an extensive matrix will be available with the results of tests that were carried out at various loads. Based on this, reliable models will be created with the aim of predicting the behaviour of the materials. The next step is then to repeat the tests while varying the loads during the test, which will provide an even more realistic picture of the material degradation. Material research is improving over the years, but it is not unique in this …

DIFFERENT, YET THE SAME

The test rig simulates the primary cooling circuit of a nuclear reactor. SCK•CEN has succeeded in reproducing exactly the same conditions by using an autoclave, kept under pressure by means of a water circuit, as a miniature version of a reactor vessel. Very hot water (~ 320 °C) at high pressure (~ 150 bar) flows through the circuit. The composition of the water is exactly the same as in the primary cooling circuits of the nuclear power plants of Doel and Tihange. The water chemistry is very specific. In order to prevent oxygen corrosion, the water does not contain oxygen, but does contain lithium to adjust the acidity and boron to control the reactivity in the core. Hydrogen is also added in order to reduce the corrosion caused by water. The installation is equipped with an on-line measuring system for the continuous monitoring of the acidity of the water, the quantities of dissolved oxygen and hydrogen, and, for the control of the purity, the electrical conductivity.

05

2011: a year of renewal and expansion

Secretary-General

Christian Legrain

“2011 was a pivotal year in terms of Human Resources Management. Around 50 new employees were recruited, primarily for MYRRHA. Not only is this an exceptional number of people, but the high proportion of foreigners who were recruited also represented a major challenge for our Human Resources department. But we succeeded in adapting to this strong internationalisation within a very short period of time, and we are now not only able to support the new colleagues, but also their families upon their arrival in Belgium. And this is just the beginning. SCK•CEN now boasts a total of 37 different nationalities. This not only creates some challenges, but also offers very exciting opportunities which we will ensure are developed further.”

Thorough renovations and new building plans

Sustainable renewal respects authentic architecture

2011 was a year of big projects for the Central Technical Services at SCK•CEN. Both the renovation of the BR1 building and the renewal of a major discharge pipe for waste water to Belgoprocess were large construction sites that demanded several months of work. And there are even larger challenges ahead.

New wings for the BR1 building

SCK•CEN started the renovation of the south and north wing of the BR1 building in 2010. Besides the BR1 reactor, this building also houses several laboratories and a significant part of the administration. The north wing was completed in March 2011. The renovation of the south wing was started soon after. This represented a major challenge for the technical services, as this wing also accommodates the VENUS reactor and the particle accelerator from the GUINEVERE project. This installation had to remain operational while the work was in progress, without compromising safety in any way. Amongst other aspects, this meant that the supply of electricity and water could not be interrupted. Additionally, the building contains two laboratories in which activities could not be stopped. It was a major challenge for the engineers and technicians not to disrupt operations whilst the entire building was being stripped, the outer walls partially demolished, the joinery removed, and simultaneously renewing the heating, water and electrical systems.

Like most buildings on the SCK•CEN site, the BR1 building is almost 60 years old. Apart from the usual maintenance, only minor repairs have been carried out during the previous decades. Moreover, some of the rooms have changed usage over the years; some of the offices having been rearranged as laboratories, or the other way round. Therefore, an extensive renovation was becoming inevitable, not least because the infrastructure no longer met current standards in terms of comfort and energy consumption.

As part of the renovation of the wings, the single-glazed windows were replaced by windows having a high insulation value, and the roof was also insulated to modern standards. Together with some other changes, including lighting control by motion detectors and automatic blinds, this has resulted in an impressive reduction in energy consumption. An energy level of 95 kWh/m^2 has been achieved in the new sections. Before the renovation, the energy level amounted to some 350-400 kWh/m^2. Energy consumption is therefore about four times lower.

An important aesthetic challenge was to preserve the typical character of the buildings. Even with the sometimes quite radical renovations, such as the wings of the BR1 building, the aim was always, wherever possible, to respect the original design by the architect Jacques Wybauw. Similar building bricks were therefore used for the outer walls, and the typical lay-out of the windows and the raking coping of the roof were retained.

The work on the south wing was completed by the end of 2011. The renovated part was put into service early in 2012.

A modern animal building

SCK•CEN has more special construction plans. The study for the construction of an animal building was completed in 2011. This animal building will house the mice that are used for research into the effects of radiation, for the CEREBRAD project for example (see p. 30). The Research Centre is currently using the facilities of VITO, but, as this animal building will shut down in the near future, SCK•CEN will require its own infrastructure in 2013. For the design of this special building, the Central Technical Services have called upon the experience of Janssen Pharmaceutica, and have appointed a specialised engineering office.

The animal building will have a surface area of 450 m^2. For biological safety, the infrastructure must be pathogen-free as far as possible, in order to minimise the proliferation of microbes, viruses, etc. Among other aspects, this means that all walls must be completely washable and that it must be possible to disinfect all material brought into the building. Other special requirements for the animal building relate to the ventilation and access control.

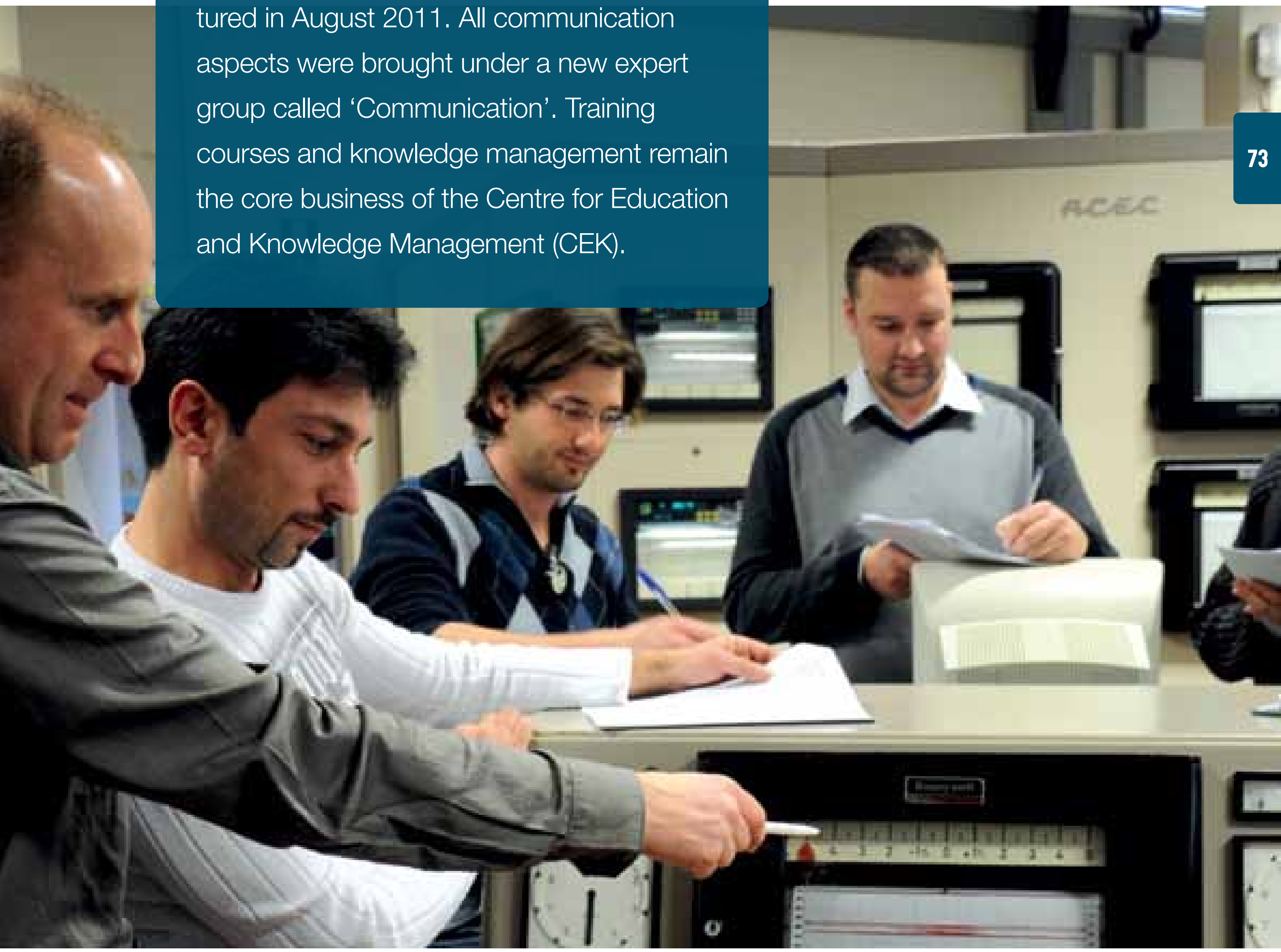
1 kilometre of new piping

In recent months, visitors to SCK•CEN couldn't miss it. Work on the waste water pipe from SCK•CEN to the nearby Belgoprocess site has been in progress since mid-2011, both along the access road and on the site itself. This is for the waste water from the Laboratories for High and Medium Activity and the BR2 reactor. The water is stored in tanks, and is pumped to Belgoprocess at regular intervals, where it is conditioned and processed. The existing pipe will be completely replaced by a new, double-walled pipe. This required digging a trench with a depth of 3 metres and a width of 5 metres over a total length of 1 kilometre. The new pipe is equipped with a highly sensitive leak detection system that reacts immediately as soon as even one drop of water leaks from the inner wall. This system also indicates automatically where the leak has occurred. In addition, the partition walls will be subject to overpressure, ensuring that any possible leak can be detected immediately as a result of the drop in air pressure in the partition wall. Pits with additional detection equipment will be installed every 60 metres. Water will flow to Belgoprocess through the new pipe for the first time in mid-2012.

Knowledge and communication

Even more attention to education

The expert group Communication, Education and Knowledge Management was restructured in August 2011. All communication aspects were brought under a new expert group called ‘Communication’. Training courses and knowledge management remain the core business of the Centre for Education and Knowledge Management (CEK).



One of the main focus areas within the CEK expert group is the Learning Centre. This group exercises an umbrella function for the whole of SCK•CEN with respect to the development policy for both in-house staff and external employees, and manages the overall organisation of training courses. The aim is to retain and increase the knowledge and skills of all staff, with a view to optimising performance and well-being in the workplace.

The Learning Centre is responsible for all steps involved in the organisation of training courses: this includes collating and analysing the needs, identifying the providers, contacting lecturers/facilitators, registrations, the practical organisation and monitoring of attendance lists, up to the follow-up and analysis of feedback and efficiency of the training programmes.

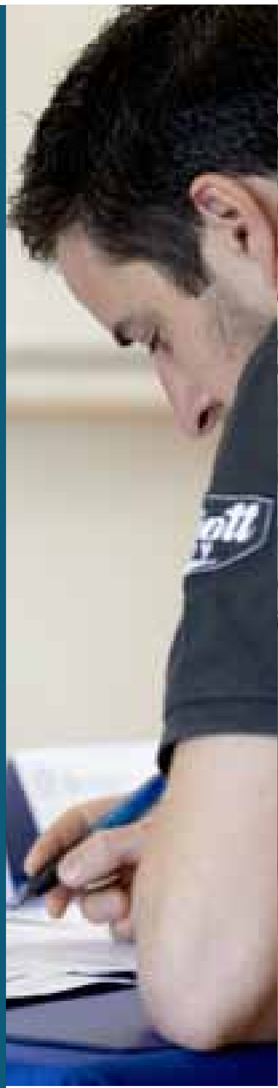
The training programmes at SCK•CEN focus on four major subjects: safety and security, technical and scientific subjects, personal and management skills and information regarding the SCK•CEN working environment. A customized database was set up with the help of Microsoft Dynamics CRM in order to manage the extensive and dynamic training courses. Through an intranet application developed in-house, every staff member can submit requests, register, provide feedback and follow-up his/her personal development file.

In addition to the Learning Centre, CEK is also responsible for knowledge and document management through the Alexandria project, and for the coordination of all training programmes that SCK•CEN offers to third parties. In this sense, 2011 was a significant preparation year for the launch of the SCK•CEN Academy for Nuclear Science and Technology.

NEED FOR INFORMATION

As soon as it became clear that the Fukushima Dai-ichi nuclear power plant was threatened, SCK•CEN was flooded with questions from just about everywhere. Journalists from the most diverse media were looking for clear and objective information. The press coverage was very international, and included requests for interviews from TV stations in the USA and Russia. SCK•CEN counted a total of 165 media contacts relating to Fukushima, and our experts in reactor technology and radiation protection were invited to give their interpretations of the situation in 45 news broadcasts and other programmes on radio and TV. SCK•CEN experts were also well represented in the written press, with articles published in 65 national and international papers and magazines.

In order to respond quickly and accurately to this flood of questions, a special media cell was established to keep close tabs on all developments. At the request of the press, SCK•CEN also arranged for several demonstrations of measurement equipment and of its specially-equipped intervention vehicle. Providing interpretations of topics that fall within SCK•CEN areas of expertise is part of our mission. We were therefore very flexible in responding to the questions from the media, and this was clearly appreciated.



“Assume that a serious nuclear accident occurred in Belgium. How would we handle this? Is there a chance that something can blow over to us from Japan? Do we have the same nuclear power plants as in Fukushima? What is radioactivity actually?”

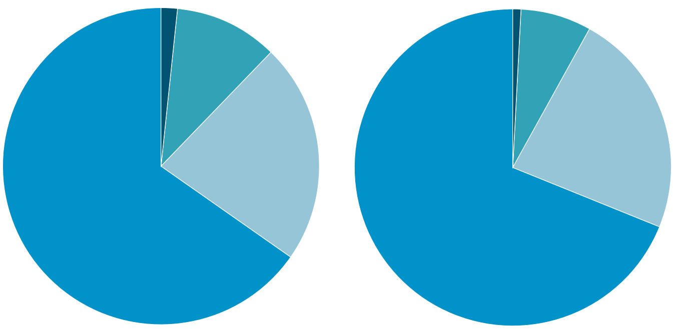
The expert group Communication was established on 1 August 2011. The new group has been brought under the auspices of the General Management. The main objectives of the group include increasing the visibility of SCK•CEN and strengthening know-how with regard to the corporate mission and activities.

The new expert group Communication: Ellen Van Roey, Inge van Aert, Cindy Verachtert, Roel Dillen, Jan Ruts, Anne Verledens, Dirk Wouters.

Scientific output

Graphs 2010 and 2011

Sharing and dissemination of scientific knowledge is one of the core tasks of SCK•CEN. For this reason, researchers present the work they are doing at numerous international conferences. In addition, many publications appear in magazines and other media.



2010 2011

	2010	2011
Books	12	7
Articles in (conference) proceedings	68	46
Journals	143	148
Presentations	418	440

2011 in a few words

JANUARY

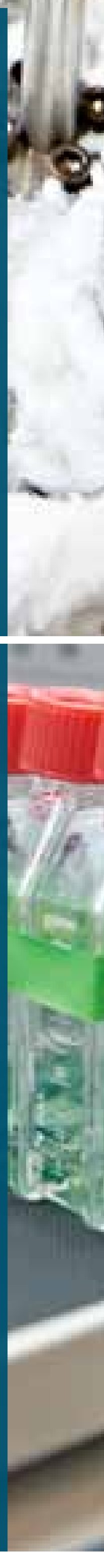
SCK•CEN and the Von Karman Institute sign collaboration agreement as part of MYRRHA project

On Monday 10 January, with the Prime Minister of Belgium Yves Leterme, the Federal Minister in charge of Energy Paul Magnette and the Federal Minister in charge of Science Policy Sabine Laruelle in attendance, the Von Karman Institute (VKI) and the Belgian Nuclear Research Centre signed a Memorandum of Understanding (MoU) for experiments with techniques and components to be used as part of the MYRRHA project. VKI, a federal research centre, will create an experimental infrastructure for simulating and validating the run-off of coolant fluid from the MYRRHA research reactor.

MARCH

New brochure 'Chernobyl - 25 years later' presented

On 26 April 2011, it was exactly 25 years since the accident in Chernobyl took place. Researchers at SCK•CEN have packed a quarter-century of research relating to the worst nuclear accident in history into a concise and very readable brochure. 'Chernobyl - 25 years later' is also available online on www.sckcen.be.



JUNE

SCK•CEN shares its expertise in a new European alliance for radio-ecological research

The Belgian Nuclear Research Centre is one of the eight research institutes that integrate their radio-ecological research into the newly-established European Radio-ecology Alliance. The partners will define the needs and priorities for joint research for the coming 15 years. They will arrange activities at a European level in order to make the best possible use of the research resources, to organise joint radio-ecological training courses and to ensure that the obtained knowledge is retained.

OCTOBER

SCK•CEN and FANC present new insights into the health impact of prenatal and early postnatal radiation

Prenatal or early postnatal radiation exposure is necessary for some treatments. This is sometimes not without consequences: It could result in death, growth retardation and birth defects, mental retardation, leukaemia or cancer. The first childhood years are also a period of increased radiation sensitivity. This has been demonstrated by the marked increase in thyroid cancer in people who were exposed to high levels of radioactive iodine in their childhood after the accident in the Chernobyl nuclear power plant. A thorough study of this type of risk is therefore essential. This research is being carried out by the Belgian Nuclear Research Centre, among other institutions. On 7 October, SCK•CEN and the Federal Agency for Nuclear Control (FANC) organised a symposium to make these new insights more widely known.

DECEMBER

SCK•CEN obtains access to the largest market for neutron doped silicon

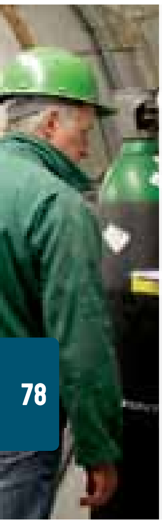
SCK•CEN has signed a key agreement with respect to the irradiation of silicon during a princely mission in China. One of the largest companies operating in this market has signed a three-year contract with SCK•CEN for the doping of silicon. Irradiation-doped silicon is the ideal semiconductor for applications with high electrical loads. It is mainly used in wind turbines and solar power systems. Hybrid vehicles and high-speed locomotives also contain essential electronic components on the basis of this type of doped silicon. SCK•CEN is currently responsible for 20% of the world production, and the trend is upwards.

SCK•CEN hands over a stress test progress report to FANC

Within the framework of the realization of the stress tests, the Belgian Nuclear Research Centre handed over a progress report on this subject to the Federal Agency for Nuclear Control on December 15, 2011. This document provides a detailed overview of the procedures proposed by SCK•CEN. These procedures are in conformity with European and Belgian guidelines. The due date for SCK•CEN to hand over the final report to the national safety authorities is June 30, 2012.

Core numbers

In financial terms, the results of the fiscal year remained balanced



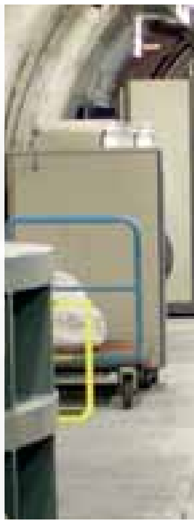
The total costs of SCK•CEN amounted to € 108.4 million in 2011. Personnel costs amount to 58% of this figure. The increase in personnel costs is mainly due to recruitment for MYRRHA. The workforce remained relatively constant until mid-2010, after which the number increased from 640 to 690 by the end of 2011, or to 654 full-time equivalents. The operating resources and depreciations are 3% and 6% respectively.

Financing 48% of these costs was covered by the federal government. Revenues from contracts for scientific research or specialised services amounted to 42%, whereas this figure was 49% in 2010. Compared to the previous year, the decline in own revenue is attributable to the operation of the BR2 reactor; the usual five cycles being carried out in 2011, in contrast to the six cycles in 2010.

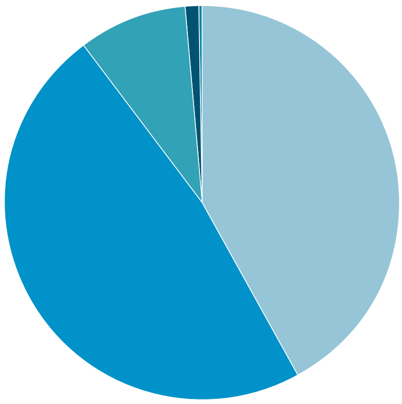
The financial resources declined by € 6.3 million, which is the result of the lower cash flow (result plus depreciations) and of the net increase of € 8.1 million in operating capital (short-term assets and liabilities). Equity of € 49.1 million amounts to 28% of the balance sheet total.

As in the previous years, investments remain significant (€ 8.7 million). The major investment projects that SCK•CEN is aiming to realise are MYRRHA, the systematic renovation of the buildings over the next 10 years, the renewal of reactor BR2, the safeguarding of the site and the physical separation from the Flemish Institute for Technological Research (VITO).

Safety was given an additional official dimension in 2011. The Royal Decrees for the safeguarding of nuclear installations were approved in October. Among other aspects, a review of the division between SCK•CEN and VITO must be carried out within a period of 36 to 42 months, and a clear physical separation between both institutes should be established with two completely separate entrances to the technical areas.



Income 2011
(in thousands of Euros)



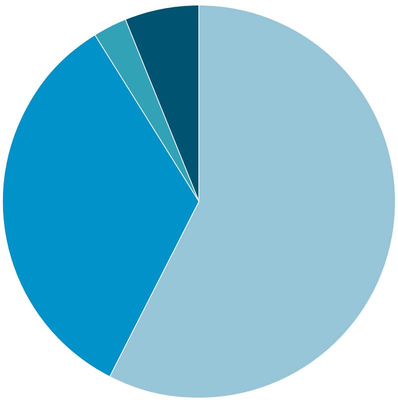
Turnover	45 683
Subsidies from government, grants	52 137
Other	9 604
Financial income	1 340
Extraordinary income	132
Total	**108 896**

Comparative balance sheets
(in thousands of Euros)

Assets	31/12/11	31/12/10
Intangible fixed assets	3 631	2 562
Tangible fixed assets	29 333	28 478
Financial fixed assets	6 182	5 860
Stocks, work in progress	20 074	18 462
Amounts receivable within one year	30 332	24 893
Current investments	78 277	84 233
Cash at bank and in hand	4 372	4 689
Deferred charges and accrued income	3 090	1 387
Total	175 291	170 564

Liabilities	31/12/11	31/12/10
Equity	49 100	48 098
Provisions for liabilities and charges	91 392	88 319
Amounts payable after more than one year	0	0
Financial debt	0	0
Trade debt	11 123	11 534
Advances received on contracts in progress	16 692	12 022
Taxes, remuneration and social security	6 905	8 711
Other debt	29	38
Accrued charges and deferred income	50	1 842
Total	175 291	170 564

Charges 2011
(in thousands of Euros)



Personnel costs	62 403
Purchases, Services	36 550
Provisions	3 073
Depreciation	6 418
Total	**108 444**
Transfer to Allocated Funds	0
Net result	**452**

Summary of the social balance sheet for 2011
Number of employees as on 31 december 2011

	Full time	Part-time
Under a Contract of Employment for an indefinite duration	559	77
Males	494	45
Females	117	37
Number of employees joining service	99	1
Number of employees leaving service	53	10
Average number of employees	597	78
Total	611	79

The final word

In 2011, the Board of Directors of SCK•CEN – with the support of the Scientific Council and the Financial Committee – focussed on the following topics in particular:

- Scientific quality and strategy
- Sound financial management
- Reliability of the installations
- Safety of the staff, the public and the environment
- Protection of the installations against external threats
- Flexible and efficient management of the human resources
- Representation in national and international forums and institutions
- Cooperation with national and international universities and research centres
- Industrial services and services with a social aim, in particular the production of medical radioisotopes
- Objective communication
- Internal and external training and development
- Support with regard to political decision-making
- Corporate governance
- MYRRHA and other priority projects

The Board of Directors is pleased that SCK•CEN is increasingly recognised as a world-class nuclear research centre, at the service of both the Belgian and the international community.

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 State Secretary in charge of Energy.

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SCK•CEN

Belgian Nuclear Research Centre

60 years of experience in nuclear science and technology

As a research centre dealing with peaceful applications of radioactivity, SCK•CEN is an indispensable part of our society. We perform forward-looking research and develop sustainable technology. In addition, we organise training courses, we offer specialist services and we act as a consultancy. With more than 700 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:

- The safety of nuclear installations
- Well-thought-out management of radioactive waste
- Human and environmental protection against ionising radiation

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