THE MYRRHA POST

edition 1

Less and shorter-lived radiotoxicity for high level nuclear waste

SCK•CEN is working actively on the design and construction of a new multifunctional irradiation facility: the Multi-purpose hYbrid Research Reactor for High-tech Applications, also known as MYRRHA. This successor to the BR2 reactor will be the first prototype in the world of a particle accelerator driven nuclear reactor.

MYRRHA operates with fast neutrons, and cooling is done using a liquid metal: a mixture of lead and bismuth. We refer to it as a subcritical reactor because the core does not contain enough fissile material to maintain the chain reaction spontaneously. It must be continuously fed by an external neutron source, i.e. the particle accelerator. This is the reason why the reactor is coupled to a particle accelerator. It is a technology that is safe and easy to control. When the accelerator is switched off, the chain reaction stops within literally a fraction of a second, and the reactor is stopped

Many applications

The fast neutrons ensure that the fuel in the reactor is used more efficiently, and, as a result, there is less residual radioactive waste. Moreover, MYRRHA should demonstrate that it is technically feasible to change the most radiotoxic elements into long-lived waste by transmutation. This fission of long-lived elements into products that are radiotoxic for a considerably shorter period of time ensures a further reduction in the quantity and the life span of the waste. This reduces the storage time required from hundreds of thousands of years to a few hundred years. In addition to research into transmutation, SCK•CEN will deploy MYRRHA for a wide range of applications, including material testing for current and future reactors, nuclear fusion technology and the development of new nuclear fuels. In addition, there is also the production of medical radioisotopes. In general agreement with the MYRRHA Ad Hoc Group, SCK•CEN established an implementation plan in 2015. As of 2024 SCK•CEN will put into operation the first step of MYRRHA: a 100 MeV particle accelerator.

Support from the Belgian government

"*The total cost of the MYRRHA project is estimated at 1,500 MEUR*", says Hamid Aït Abderrahim, Project Director. "*In 2010, the Belgian government decided to support the project for 5 years and to grant a 60 MEUR global budget for further research and development. The government also specified that Belgium, being the host state, would bear 40 percent of the total cost for the complete realization of MYRRHA. On the basis of the evaluation report for the period 2010-2014, the government decided in 2015 to provide SCK•CEN with exceptional funding of 40 MEUR for MYRRHA for the period 2016-2017.*"

MYRRHA will be built on the SCK•CEN site in Mol, Belgium. This research facility will be an international pole of attraction for organisations and scientists that are involved in research in nuclear reactors and particle accelerators, which will enable new collaborations and innovations. MYRRHA will also enable Belgium to continue its pioneering tradition in peaceful nuclear applications for the next 50 years.

EDITORIAL

As Chairman of the MYRRHA Ad Hoc Group, what I found challenging and interesting in the MYRRHA project are twofold: the necessity to think out of the box and to continuously challenge your knowledge on advanced nuclear systems and the level of innovation and multidisciplinarity such as bringing accelerator and reactor communities that seldom shares the same challenges to understand the challenges of each other community to reach their common objective.

On 20th of May 2016, I'm joining a workshop organized at Belgian Ambassador residence in Stockholm where we are looking to foster a collaboration between Belgium and Sweden thanks to their innovative projects MYRRHA and ESS-ERIC and the new European hub for Back-end of the Nuclear Fuel Cycle studies project in Sweden.

Alberto Fernandez Fernandez
Chairman of the MYRRHA Ad Hoc Group
Head of Nuclear Applications Department
at FPS Economy & Energy

Research and development at European level

The future research reactor, MYRRHA, is an ADS or "Accelerator Driven System". The special feature in this installation is the particle accelerator – a crucial component. The development and construction of the MYRRHA accelerator is clustered into a series of European projects, including at the University of Louvain-la-Neuve (UCL).

The research and development activities related to the MYRRHA accelerator are split up into various European projects. "Today *at SCK•CEN, we have a small team of four employees dealing with accelerators*", says accelerator physicist Dirk Vandeplassche. "*In the future, we will be extending that team and the team will concentrate mainly on the coordination and management of the accelerator programme, but the actual research is conducted in an almost exclusively European joint venture. In other words, we coordinate and give direction, while our various partners carry out the experimental programme specifically at a scientific level. This is a win-win situation for all parties.*"

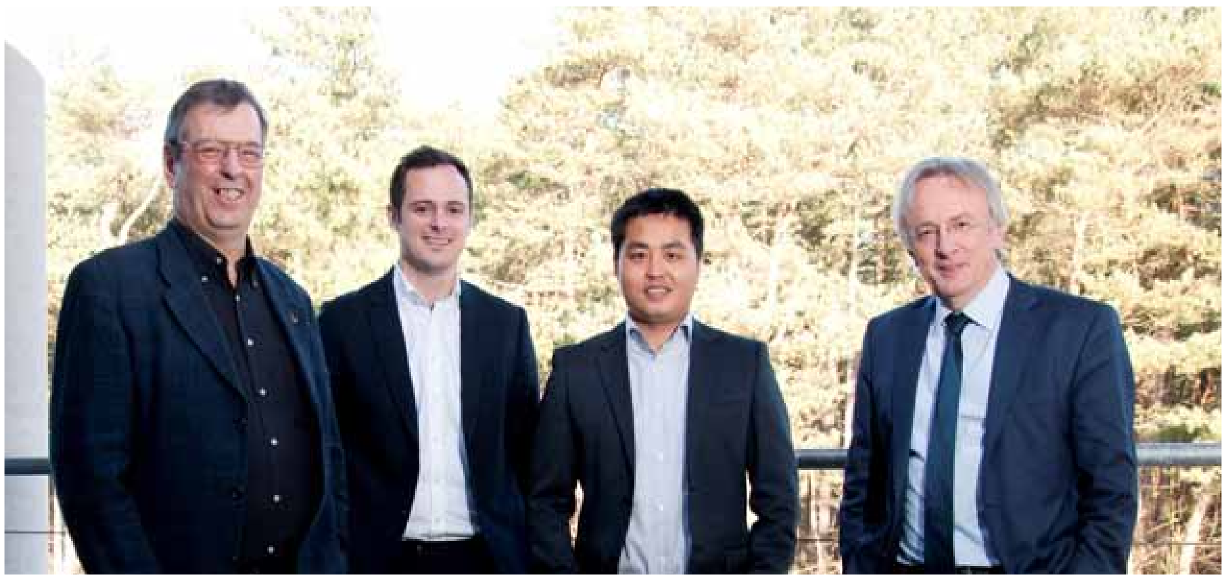
For the initial part of the accelerator, SCK•CEN is working together with the University of Louvain-la-Neuve (UCL). "*We're conducting that research in close partnership with the Laboratoire de Physique Subatomique & de Cosmologie in Grenoble, and the test set-up there is now ready*", explains Luis Medeiros, international project coordinator. "*In 2017, the set-up is coming to Louvain-la-Neuve, where the university researchers will use it for extensive beam tests.*"

Read more p.3

From pioneering research to spin-off

MAGICS Instruments makes electronics operate in radioactive environments

MAGICS Instruments was formed in late October 2015 as a spin-off company of KU Leuven and SCK•CEN and continues to build on seven years of research in both institutions. MAGICS Instruments has developed advanced technology to ensure that electronic devices can still function under exceptionally strong radiation.



Exposure to radiation reduces the lifespan of electronics. MAGICS Instruments has developed chips which are highly resistant to radioactive radiation and other electromagnetic radiation of over 1 Mega Gray. MAGICS Instruments chips continue to function reliably in high radiation environments up to a thousand times longer. The pioneering technology from MAGICS Instruments also offers unprecedented opportunities for the use of electronics for interventions during nuclear accidents, nuclear reactor inspections, dismantling of old nuclear power plants, disposal of radioactive waste, space travel missions, and new nuclear developments such as nuclear fusion or the MYRRHA research reactor.

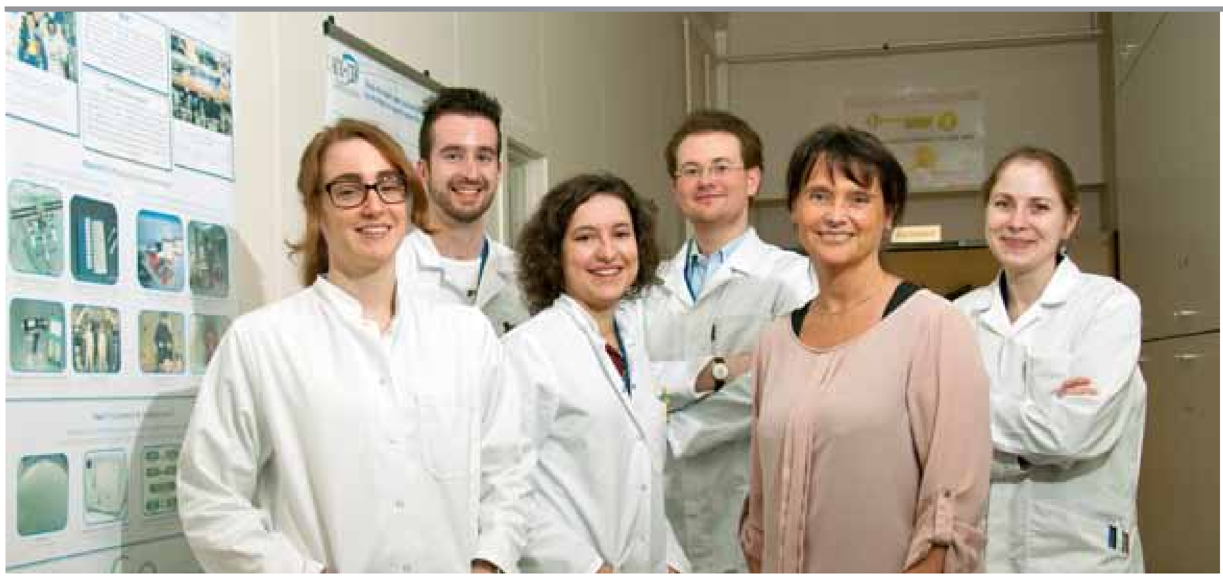
> "Excellent ideas which can benefit society often have their origins in scientific research."
>
> **Eric van Walle**
> Director-General

Commercial future

"*MAGICS Instruments is the missing link between the semi-conductor industry and the nuclear industry*", says joint founder Jens Verbeeck, CEO of MAGICS Instruments. '*Our technology has proved itself on several occasions during assignments from nuclear companies and opens the door to a whole range of electronic applications in nuclear environments. Our chips make it possible to deploy robots and inspection tools in nuclear power plants to carry out operations which involve risk to people's lives. In case of nuclear disasters such as in Fukushima, our technology also offers tremendous added value.*"

Support for entrepreneurs

Since 2008, the founders of MAGICS Instruments, Jens Verbeeck and Ying Cao, have built up their knowledge, especially for the development of the MYRRHA reactor. The founders of the spin-off and researchers from SCK•CEN have developed the drafts for testing the chips with extremely high doses of gamma radiation. SCK•CEN made the radiation facilities of reactor BR2 available and also granted access to its extensive knowledge of the effects of radiation on materials. Eric van Walle, SCK•CEN Director-General: "*We regularly offer doctorate students facilities for the research which they do. Excellent ideas which can benefit society often have their origins in scientific research. An excellent idea or product isn't enough on its own. There's also a need for a locomotive. Scientists who themselves believe enthusiastically that an idea is commercially viable.*"



Inspiration for the younger generation

They are between 25 and 35 years old, and all of them chose to get involved in nuclear research. They all have the same motivation: to push the limits of knowledge even further and find solutions to the major technological and societal challenges of tomorrow.

By way of a response to ever increasing demand, SCK•CEN set up the Academy for Nuclear Science and Technology in 2012 to provide a much wider and diversified range of training courses. Three years on, student numbers have almost doubled and the 100th PhD was surpassed this year. The Belgian research centre is continuing its task of knowledge transmission to produce future generations of experts and maintain high-quality research in our country.

MYRRHA provides solution

"*The unique facilities and a large number of areas of research here provide me with solid experience to address the challenges faced by the sector*", says Alessandro Marino. "*Abandonment of nuclear systems in certain countries will require expertise in dismantling them. The MYRRHA project also provides solutions for the two major problems of nuclear waste management and production of radioisotopes*".

> Nuclear technology like MYRRHA can bring about a large number of applications to move many domains forward.

Of the 104 PhDs that completed their studies, almost half secured employment with SCK•CEN to pursue some promising research. Nor does the other half take long to find jobs in a large number of sectors. Other students, such as Ying Cao, chose to put their experiences into practice and set up their own company. During his PhD, he was involved in the design of a laser detection and ranging system for the MYRHHA reactor. The young researcher has developed extensive knowledge of radiation effects on integrated circuits and components. "*After my PhD, SCK•CEN helped me develop and market my project*", says Ying. "*Nuclear technology like MYRRHA can bring about a large number of applications to move many domains forward - medicine, space technology or waste management. All these developments that are vital to society require an undertaking on the part of several generations of researchers.*"

Towards a core that increasingly resembles MYRRHA

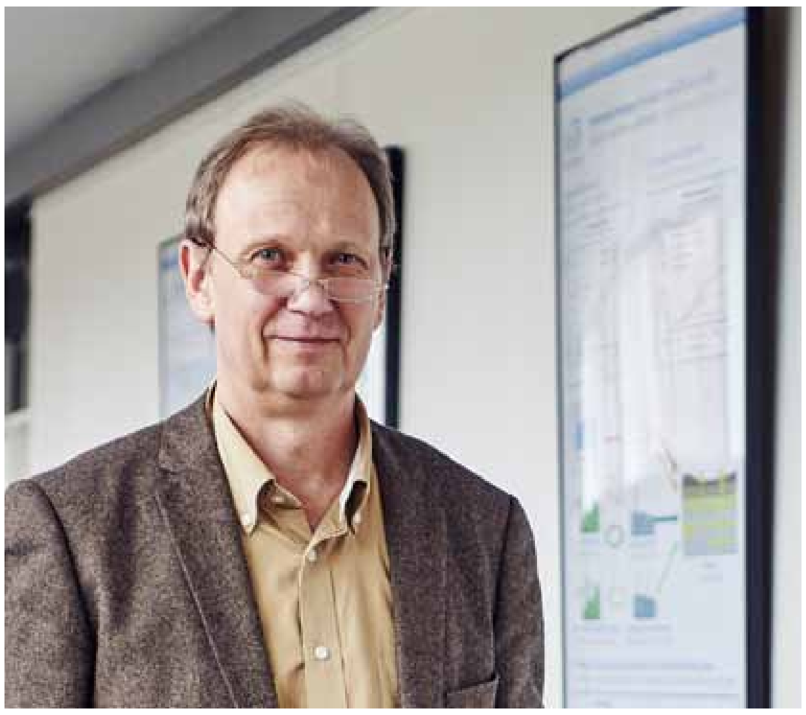
The five-year European FREYA research project coordinated by SCK•CEN started in 2011. The project encompasses a series of physical tests to support the design and the licensing of the core of accelerator driven systems such as MYRRHA. The researchers are getting closer and closer to the intended reality.

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

New composition of nuclear fuel elements

Work package 3 took place in VENUS-F between February and October 2015. Various core configurations were loaded in order to investigate the critical core of MYRRHA. In the first place, an entirely new composition of nuclear fuel elements was selected and mounted for all the cores in this work package. These will be used until the end of the project. The fundamental difference is the use of aluminium oxide in the form of Al2O3 rods which simulate the oxygen of the oxide inside the MYRRHA nuclear fuel.

> "The fundamental difference is the use of aluminium oxide in the form of Al_2O_3 rods which simulate the oxygen in the MYRRHA nuclear fuel."
>
> **Anatoly Kochetkov**



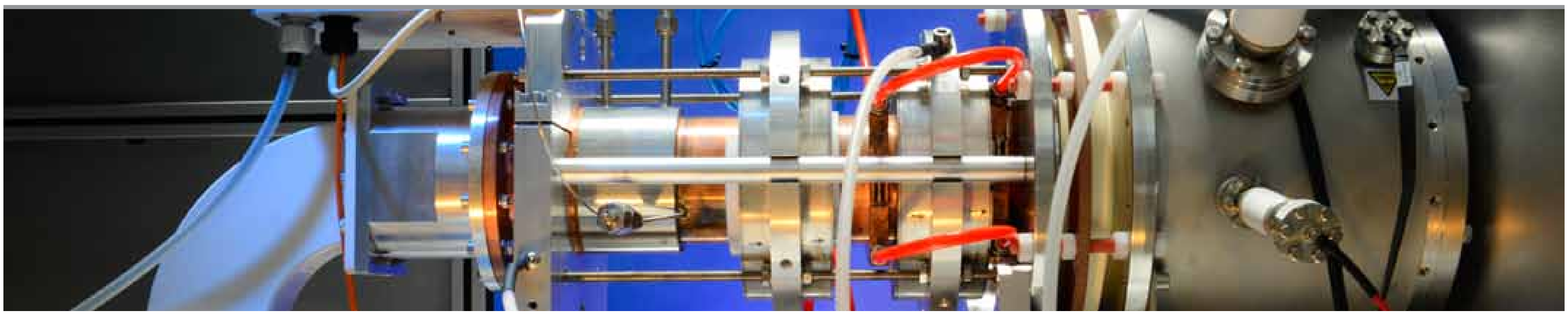
Increasingly detailed simulations

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

Tests using bismuth as a coolant

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

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



A super-reliable particle accelerator for MYRRHA

The future research reactor, MYRRHA, is an ADS or "Accelerator Driven System". The special feature in this installation is the particle accelerator – a crucial component. What is the state of play?, Accelerator physicist Dirk Vandeplassche and international project coordinator Luis Medeiros Roma outline the plans.

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

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

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

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

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

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

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

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

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

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

How important is the accelerator control in the entire development?

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

Which projects are in the pipeline in the near future?

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

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

Extremely accurate sensors for safe operation of MYRRHA

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

Liquid lead-bismuth eutectic (LBE) will be used as a coolant in the future MYRRHA research reactor. SCK•CEN researchers are studying the behaviour of LBE. The objective is to arrive at precise safety calculations required to obtain licences.

LBE contains a very small quantity of dissolved oxygen. Yet oxygen is the crucial element for chemical processes in LBE. Even a small concentration may affect the functioning and safety of an LBE-cooled reactor such as MYRRHA. If the oxygen concentration is too high, then there will be a reaction with the lead in the coolant liquid. This reaction creates solid lead oxide which then starts to precipitate. These solid parts can cause blockages in the reactor core or heat exchangers.
Corrosion is another problem. If the oxygen concentration is too low, corrosion will speed up. Corrosion needs to be reduced as much as possible in order to keep the steel housing around the fuel intact and to prevent the release of fission products into the LBE.
What is more, oxygen is the most important partner in reactions with impurities in LBE. For example, take iron and chromium, which are released in LBE in the process of corrosion. They react with oxygen and form solid particles, resulting in a risk of blockage. Oxygen reactions, in turn, strongly affect the chemical behaviour of radioactive impurities such as vaporisation and deposition on surfaces that come into cvontact with the LBE. All these processes could greatly affect safety.

Careful monitoring of oxygen concentration
It is therefore essential to carefully monitor the oxygen concentration in LBE: the researchers of the *Conditioning and Chemistry Programme* are seeking to achieve a target value of 10^{-7} weight per cent of oxygen in LBE, which is equivalent to approximately 1 gram of oxygen per 1,000 tonnes of lead and bismuth. The MYRRHA reactor, which contains several thousand tonnes of LBE, will only contain a couple of grams of oxygen. Even if the oxygen is present in very low concentrations, accurate monitoring is still necessary in order to guarantee the safety of the reactor.
There are various systems around the world for measuring oxygen in LBE. A lot of laboratories use gas, a relatively simple method. Another method is to dissolve lead oxide in a controlled manner, a technique originally developed in the Soviet Union.
In these systems, the precision of the usual oxygen sensors is unsatisfactory under 350 °C. SCK•CEN has now succeeded in reducing the temperature limit for sensors to 150 °C. The minimum temperature in MYRRHA will be approximately 200 °C, so there is a margin. The result of this is a new family of oxygen sensors and associated technologies that are suitable for MYRRHA conditions. In the meanwhile researchers from Japan, Romania and China have already acquired the new oxygen sensors.

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

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

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

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

Innovating is in our genes

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

Peter Baeten
Advanced Nuclear Systems Institute Manager

A worldwide project

Today, 150 engineers, scientists, technicians and administrative assistants - SCK•CEN employees and external experts alike – have contributed to developing our MYRRHA project. Our collaborators come from no less than 27 different countries. Moreover, we are collaborating with a number of Belgian partners such as the von Karman Institute, the Université Catholique de Louvain, KU Leuven, Ghent university, the Free University of Brussels, and more than 30 European institutions, thanks to research programmes of the European Commission.

Hamid Aït Abderrahim
MYRRHA project director

Curiosity keeps you young

We are the biggest federal research centre in Belgium. The fact that we have funding for MYRRHA means we have the necessary political support and backing. Nuclear research is something that calls for a vision over at least 50 years; fortunately we have people here in Belgium who have that vision and can defend it.

Derrick Gosselin
Chairman of the board of governors

AROUND THE WORLD

Kaunas University of Technology (KTU) has awarded the title of honorary doctor to Hamid Aït Abderrahim, Director of the MYRRHA project. This honorary distinction is a recognition of this efforts since 2001 in the field of ultrasonic visualisation applied in MYRRHA.

The Belgian Nuclear Research Centre has the special honour of welcoming Chinese Vice Prime Minister, Liu Yandong and the Belgian Secretary of State for Science Policy, Elke Sleurs. "*We consider this visit a special privilege and a confirmation of the international reputatiton of our research and infrastructure*", says Eric van Walle, Director-General.

The Belgian Minister of Energy, Marie Christine Marghem, paid a visit to the GUINEVERE project, an operational scale model of MYRRHA. "*I am convinced that we will continue to be in the forefront of developments in innovative nuclear applications. Today, more than ever, Belgium is determined to keep the lead in this area.*"

Publication notes

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