2018 OYSTER Annual Report

Finishing the Cold Neutron Source Utility building

TU Delft Delft University of Technology

REACTOR INSTITUTE DELFT

Foreword

I'm pleased to present the 2018 annual report of the OYSTER programme to you.

The OYSTER programme (Optimized Yield - for Science, Technology and Education - of Radiation) has been initiated to improve and expand the RID research infrastructure. It will enable current and future educational, scientific and societal challenges in the fields of materials, health and energy to be better addressed.

Last year we finished the CNS-Utility building and installed the cooling equipment − an important milestone in the programme (see page 14). The eagerly awaited mock-up of the cold neutron source is due to arrive from South Korea early in 2019 and will be placed outside the CNS-Utility building and connected to the cryogenic system. It will be used as a test facility to verify correct functioning before the cold source is ultimately installed in the reactor pool later in 2019.

The NWO OYSTER Advisory Committee visited us a sixth time, and I'm proud of their findings. The Committee was very positive and is confident that the OYSTER programme will be successfully completed in the coming period.

For our researchers, one of the highlights was the non-invasive inspection of the original, 17th-century Antonie Van Leeuwenhoek microscope with our tomography instrument FISH (see page 28).

A lot of work went into the major upgrade of neutron reflectometer ROG. This is one of the instruments that will benefit greatly from OYSTER's neutron cold source and will contribute to addressing many scientific challenges, such as the development of hydrogen sensors and drug-delivery systems. The instrument has now been moved from the reactor hall to its new position in the experiment hall (see page 24).

I'm really looking forward to next year! This will be the year in which, after years of preparation, everything comes together. The cold neutron source will be placed in the heart of the research reactor and connected to the cooling equipment in the CNS-Utility building. The neutrons from the reactor will then be cooled with liquid hydrogen to an extremely low temperature of minus 253 degrees Celsius. RID's instruments will provide results up to a hundred times better than now. Areas for the application of research are very diverse, and range from material science, biology, chemistry, medicine and crystallography to, for instance, cultural heritage and archaeology. They include not only new generations of medical isotopes for the diagnosis and treatment of cancer and promising materials for batteries and solar cells but also, for example, self-repairing steel.

Prof. dr. Bert Wolterbeek
Director of the Reactor Institute Delft

Colophon

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Reactor Institute Delft, TU Delft

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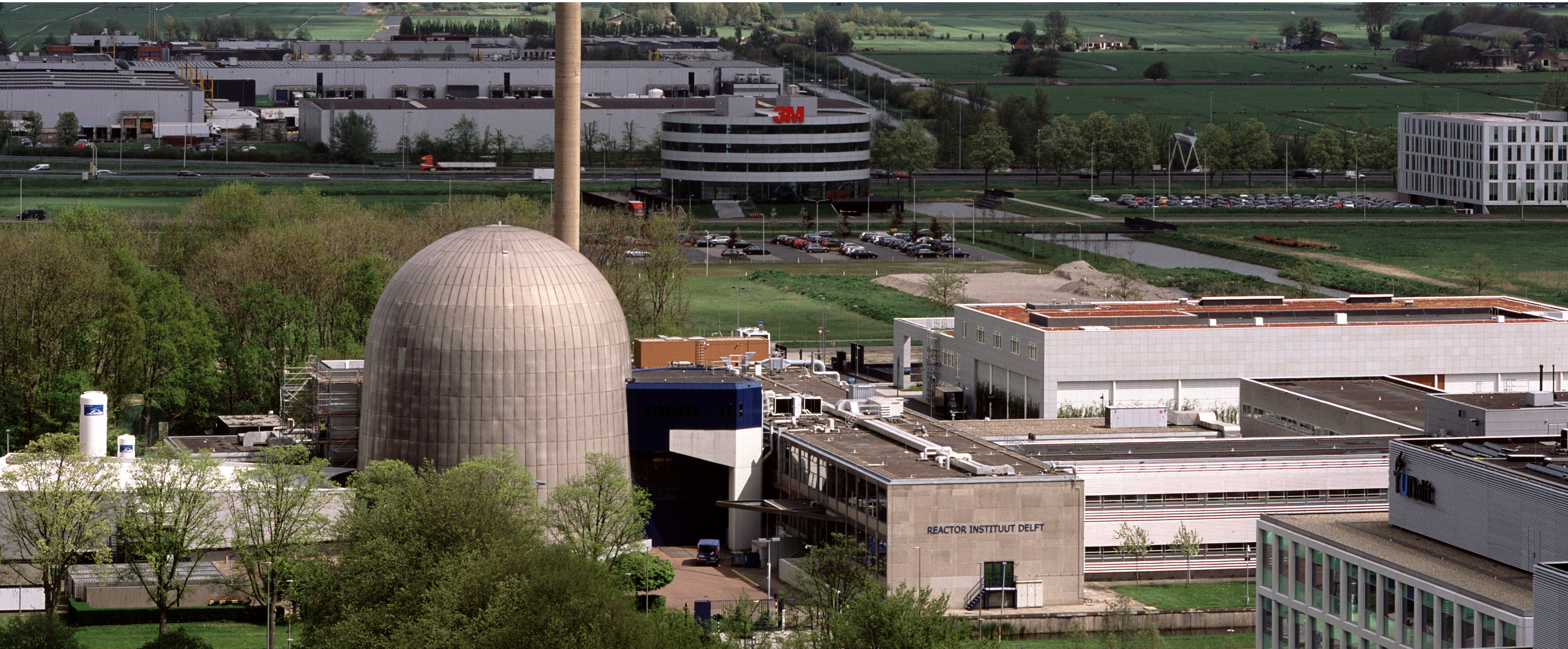
Contents

OYSTER in short

OYSTER

The Reactor Institute Delft (RID), part of Delft University of Technology (TUD), is a nuclear knowledge centre. It operates a research reactor, irradiation facilities and radiation-based research instruments. The OYSTER programme (Optimized Yield - for Science, Technology and Education - of Radiation) has been granted in 2012 to improve and expand the RID infrastructure (reactor, instruments, facilities).
This will enable current and future educational, scientific and societal questions to be better addressed.

In conjunction with the Department of Radiation, Science & Technology (RST) of the Faculty of Applied Sciences, RID accommodates resident and visiting scientists and other users from a variety of (scientific) disciplines. RID educates students, professionals and scientists, and serves as an independent source of information for society on radiation-and nuclear-related issues.



Main goals of OYSTER

RID is active in the field of neutron, positron, reactor and radiochemistry science. Here, OYSTER has five main goals:

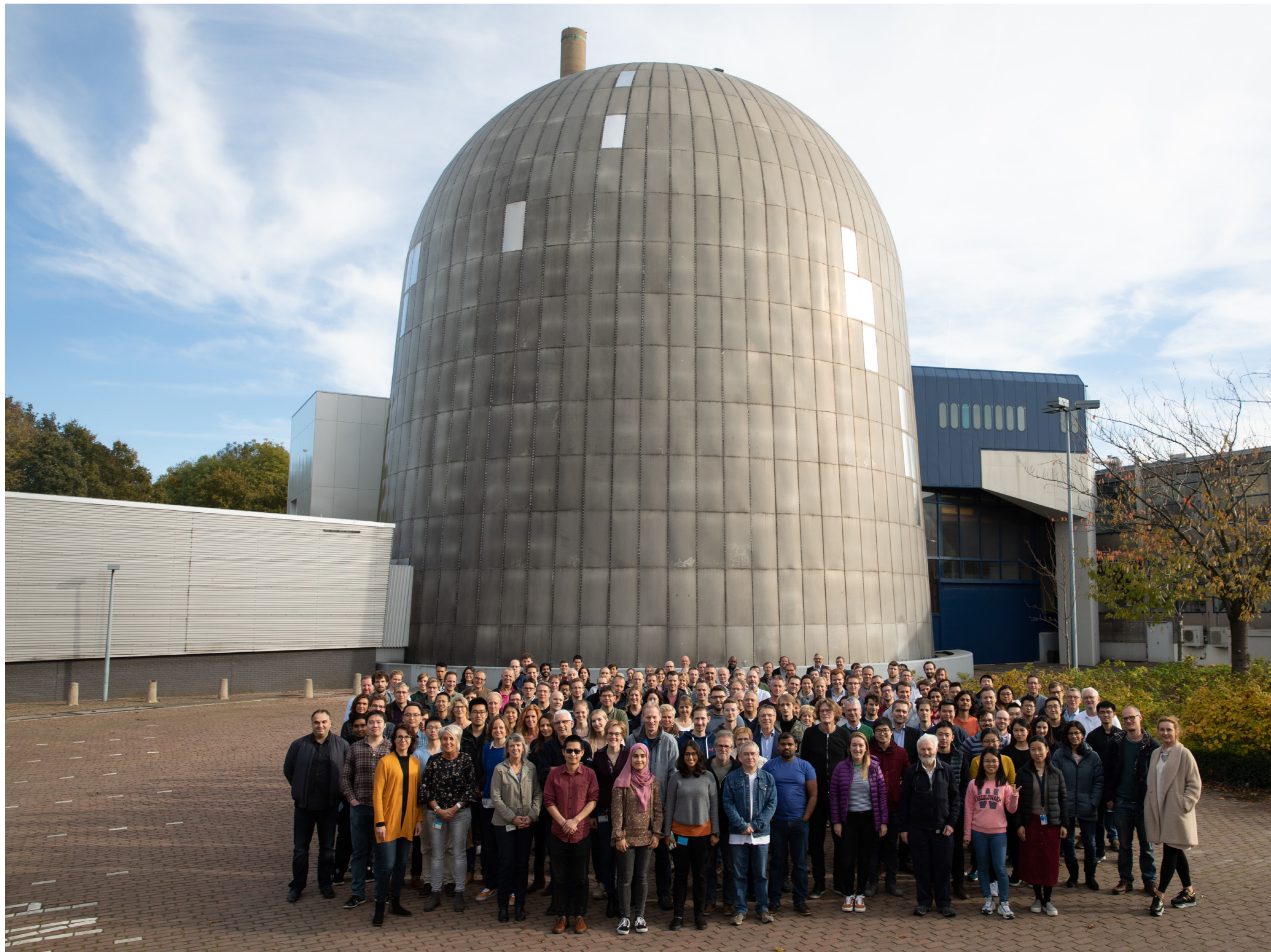
1. To strengthen RID's national coordinating role.
2. To establish RID's European role in research and training.
3. To stimulate ground-breaking innovations.
4. To create a home base for neutron scattering in the Netherlands and secure Dutch collaboration with major international neutron sources, specifically the European Spallation Source (ESS) in Lund, Sweden.
5. To sustain RID's leading role in the use and knowledge of world-class instruments, in the development of new routes for radioisotope production and Instrumental Neutron Activation Analysis (INAA).

OYSTER is an ambitious programme of technological improvements and additions to the RID infrastructure:

- The installation of a Cold Neutron Source (CNS), cooling neutrons from room temperature to -250°C, to increase the intensity of low-energy neutrons by more than an order of magnitude and improve the sensitivity of existing instruments.
- The design and construction of new research instruments.

Technological objectives of OYSTER

- The (re)design and construction of (new) irradiation facilities, to allow the development of production of radioisotopes with unprecedented purity and to boost the sensitivity and opportunities for research with isotopically enriched stable isotopes.
- The design and installation of a miniature hot-cell/decanning facility for submerged access of irradiated samples from the irradiation facilities, to allow innovative production methods of (medical) radioisotopes and studies of radiation damage effects.
- The design of irradiation facilities positioned in the tangential beam tube of the reactor, to undertake research into alternative production methods for e.g. Molybdenum-99 (99 Mo).



Participation in large international and national collaborations

OYSTER will be instrumental in securing or strengthening the role of the RID in various collaborations. For example, the Dutch contribution to the pre-construction phase of the European Spallation Source (ESS, an international collaborative facility for materials research using neutron scattering techniques) in Lund, Sweden, is partly financed through OYSTER. Scientists from Delft work together with ESS scientists in order to develop novel instrument concepts for the ESS.

RID participates in the R&D programme of Holland Proton Therapy Centre (HollandPTC), dedicated to innovative radiation treatment of cancer using proton beams. This programme is a collaboration of TUD, Leiden University Medical Centre (LUMC) and Erasmus University Medical Centre Rotterdam (Erasmus MC). Located on the RID premises, HollandPTC began patient treatments in September 2018.

OYSTER research also strengthens the role of RID in supplying innovative ideas towards the envisioned PALLAS reactor, which is to become one of the world's leading production sites for medical isotopes.

The OYSTER-initiated new irradiation facilities also enhance RID's position in the Dutch Isotope Valley (DIVA). This is an R&D collaboration set up between URENCO, RID and NRG/PALLAS towards developing, engineering and producing the best-possible medical isotopes for clinical use (both diagnosis and therapy).

Finally, OYSTER underlines the role of RID as an IAEA Collaborating Centre by demonstrating the many innovative scientific opportunities in the utilisation of a medium-sized university research reactor.

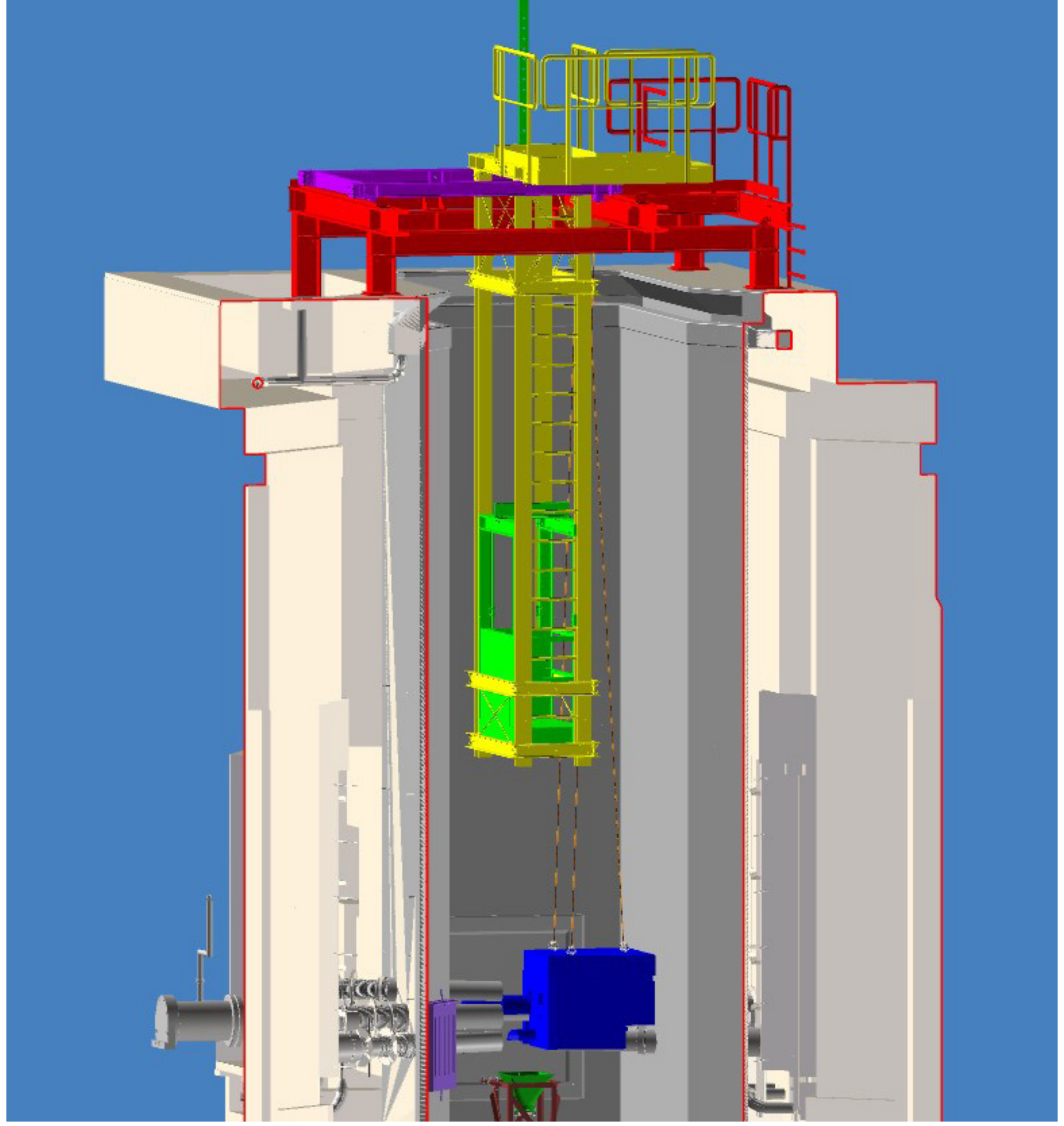


Image: The construction platform of Bilfinger Noell GmbH which will be placed on top of the reactor pool.

Reactor & Utilities

Overview

The modification of the reactor deals with the installation of Cold Neutron Source (CNS) equipment into the beam-tube pipeline between the reactor core and instrument facilities located in the instrument hall. The CNS will be installed in the reactor pool and is therefore designated as the CNS in-pool assembly (IPA). The objective of this modification is to increase the cold neutron flux in order to create better conditions for experiments connected to the neutron beam. To supply the cooling capacity for the proper functioning of the CNS, support equipment will be installed, too. Since the available equipment installation surface is limited, a completely new building structure (called CNS-Utility building) was realised next to the reactor hall. All CNS utility systems will be installed inside this building. Below we provide an overview of the status of this main part of the OYSTER project.

Reactor Modifications

Beam Tube Modifications

In order to be able to install the cold neutron source in-pool assembly (CNS-IPA), beam tubes R1 and R2 have to be modified. In June 2018, the Dutch nuclear safety authority ANVS has approved the modification proposal for this. Bilfinger Noell GmbH (BNG), who were selected by the KHC consortium as contractor for the construction works inside the pool, have started with their preparations for executing the modification activities. BNG has designed and constructed shielding elements for the remaining beam tubes, handling and construction tools such as an orbital welding device, and a construction platform which will be placed on top of the pool. Also, they have written test and handling procedures which were reviewed by the OYSTER beam tube modifications (BTM) project members. In 2019, prior to the modification activities inside the pool, all construction steps and tools will be extensively tested in a mock-up test setup in BNG's workshop. For this, the reactor pool will be reconstructed including the beam tubes.

Photo: A reconstruction of the reactor pool including the beam tubes in BNG's workshop.

Reactor Protection System

RID has a reactor protection system in place to help determine possible risks from a myriad of sensor readouts. During the OYSTER period, the current relay-based voting logics of the reactor protection system will be replaced by magnetic core voting logics. This solution was selected for its superior safety and reliability and for the lack of software needed to operate the logics. It was approved by the Dutch nuclear safety authority ANVS based on a change request and production facility audit. Detailed engineering of the new voting logics is now nearly finished and production will start in March 2019.

Reactor hall feedthroughs

To be able to make the connection between the equipment within the utilities building on the one hand and the cold neutron source on the other hand, new feedthroughs towards the reactor hall have to be made. The main prerequisite for these reactor hall feedthroughs is that they can be automatically closed off by an isolation valve located on the outside, when needed for safety reasons. Furthermore, it must be possible to verify the leak tightness of the feedthrough locally.
In the OYSTER project, these requirements will be met by installing new penetration boxes which enclose several process pipes and have electro-pneumatic isolation valves installed on the individual pipes on the outside. Electrical cables will run through a separate compartment within these feedthrough boxes and will be mounted leak-tight by using existing cables feedthrough systems. In May 2018, the modification proposal for this part of the project was sent to ANVS.

In-Pool Assembly

In 2018, the mock-up of the IPA was manufactured by Moojin on behalf of KAERI. Moojin is a South Korean manufacturer that is certified according to American Society of Mechanical Engineers (ASME) standards for the manufacturing of nuclear components. The mock-up IPA is a two-layer (hydrogen and vacuum) system that will be installed on the CNS building where the final IPA is a three-layer system (hydrogen, vacuum and gas blanket layers) that will be installed in the reactor pool. In close collaboration with RID, KAERI made several changes to the mock-up design to ensure that the mock-up could be manufactured according to the Pressure Equipment Directive (PED). The design and manufacturing processes were verified by Lloyd's Register of South Korea and India. The lessons learned during the mock-up design and fabrication will be reflected in the final IPA design and fabrication.

The experiment proposal for the installation of the IPA in the reactor pool was sent to the ANVS in July 2018. The mock-up IPA will be installed in 2019 outside the CNS-Utility building. There, it will be used as a test facility to verify the correct functioning of the thermosiphon loop of the cold neutron source. Later in 2019, the final IPA will be installed in the reactor pool, in front of the modified beam tube R2.

Realisation of the CNS-Utility building

Steel construction

The final phase of the steel construction started in January. Concrete floor plates were installed in the steel construction, additional reinforcement was added around the recesses and concrete was then poured. Due to the low winter temperature, the drying process was continuously monitored.

The timber frame parts were installed, making the building watertight. The Alucobond cladding gives the building a splash-proof finish that determines its appearance.
A cove was created for the tube posts to which the rabbit system was moved. After the rabbit system was installed, the cove was also provided with cladding. To conclude the construction phase, an additional construction was placed on the roof as a foundation for the equipment. After the civil construction phase, we proceeded with the building-related equipment, the low-voltage equipment and the wiring. This was completed in September.

Photo: The CNS-Utility building with three chillers on top, June 2018

OYSTER

Photo: the six cryo-generators in the CNS-Utility building which will be used for the cooling capacity of the Cold Neutron Source.

Equipment

The first four vessels were supplied by Kreber. Three vessels were placed on the roof in mid-summer. The “header” was delivered mid-July and placed in position. Towards the end of August, the six cryo-generators were hoisted in by means of an extra platform on the second floor and placed in position. The chillers, needed for cooling water for the cryo-generators, are also placed on the roof. The fourth Kreber vessel was then placed on the first floor. The cabinets with the Yokogawa control systems were installed and connected by Strukton Worksphere.

Outlook to 2019

This will be the year of the installation of the mock-up IPA, testing of this system for a proof of principle of the thermo-siphon system and for the heat removal system.The wall feed-throughs, beam tube modification and installation of the main IPA in the basin will have great impact on the regular cycle of reactor operations. All support utilities for the main IPA will be installed in the Reactor Hall and in and around the CNS Utility Building.

(Sub)contractors

The following executive parties are involved in the realisation of the project-related work packages.

Main contractor

CONSORTIUM KHC
Consortium of the Korea Atomic Energy Research Institute (KAERI), Hyundai Engineering and Hyundai Engineering & Construction; responsible for realising the CNS In-Pool Assembly.

Subcontractors

(involved in the fabrication/installation of materials and equipment)

ROYAL HASKONING DHV
Provides the detailed design of the building structure for the CNS Utility Building and supervises the execution

STRUKTON
Construction company for the civil works related to the CNS Utility Building structure.

DH INDUSTRIES
Main supplier of the cryogenic equipment that provides the cooling capacity for the CNS

KREBER
Main supplier of the vessels inside the CNS Utility Building

DEMACO
Main supplier of the cryogenic pipelines

YOKOGAWA
Main supplier of the control systems

STRUKTON WORKSPHERE
Main supplier of the electrical wire connections

Photo: the CNS-Utility building.

PROCESS FLOW SYSTEMS
Main supplier of interconnecting piping

MOOJIN
Supplier of the In-Pool Assembly (IPA) equipment (including CNS and the IPA mock-up)

BILFINGER NOELL GMBH
Will install the IPA equipment in the beam tube inside the reactor hall

External Expert Team

The External Expert Team (EET), which has been operational since 2014, is comprised of external specialists who assisted RID in handling various technical issues. It consisted of:

Toni Scheuer

Affiliation: Nuclear Technology Consultant at the TÜV Rheinland Group
Expertise areas: Licensing issues, and material- and component qualification
Focus within EET: Welding procedures, materials, codes & standards

Stuart Ansell

Affiliation: Neutron Scientist at the European Spallation Source (ESS) in Lund
Expertise area: Cold neutrons equipment design for research reactors
Focus within EET: Optimisation processes neutronics

Stephan Welzel

Affiliation: Chief coordinator of the reactor upgrade at the Helmholtz- Zentrum Berlin
Expertise areas: CNS process technology and operational aspects
Focus within EET: CNS process technology

Robert F. Mudde

Affiliation: Professor of Multiphase Flow, Department Chemical Engineering, TUD
Expertise area: Multiphase flows
Focus within EET: Heat and mass transfer, hydrodynamics

Robert Williams

Affiliation: Nuclear Engineer and Cold Neutron Source Team Leader at the National Institute of Standards and Technology (NIST), Gaithersburg, Maryland, (USA)
Expertise area: Cold Neutron sources, calculations and new reactor designs
Focus within EET: CNS performance calculations, operations and safety

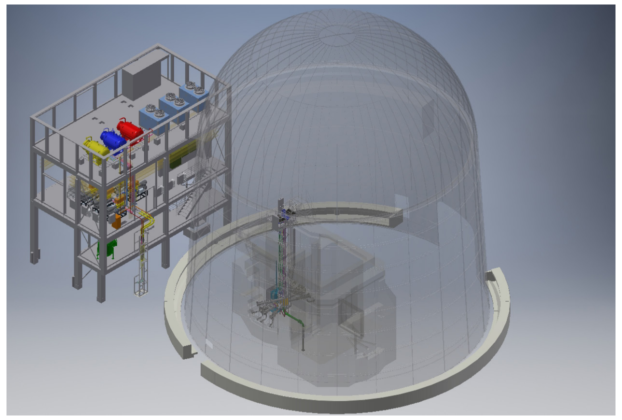
Licencing

In the context of Dutch legislation in the area of nuclear safety, RID holds a permit to operate the reactor and the various instruments. With the OYSTER programme, this permit has to be updated. The licencing procedures concern an important aspect of the project. Since 2013, RID has been working on the licencing procedures and associated review schedules with the relevant regulatory body, the Dutch Authority for Nuclear Safety and Radiation Protection (ANVS).

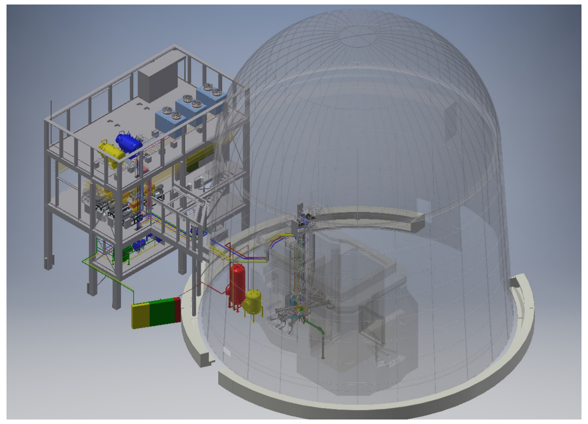
In 2017, the licence for the CNS-Utility building with its non-nuclear instruments was granted. Further on, in 2018, RID completed the licence request for the nuclear part of the OYSTER programme.

During the past year, RID and ANVS discussed updating the nuclear permit on several occasions. The formal permit modification request contained descriptions of OYSTER changes, a Safety Analysis Report (SAR) and an Environmental Impact Assessment for the modifications. The modification licence was issued on 29 January 2019 and will come into force on 15 March 2019.

In 2020, a 10-yearly safety evaluation will be carried out (10EVA), which will include drawing up a Safety Analysis Report (SAR) for the research reactor. The 10EVA and SAR will serve as the starting points for RID to apply for a full licence revision in 2021.



The CNS-Utility building at the end of 2018.



The CNS-Utility and the Cold Neutron Source at the start of 2020.

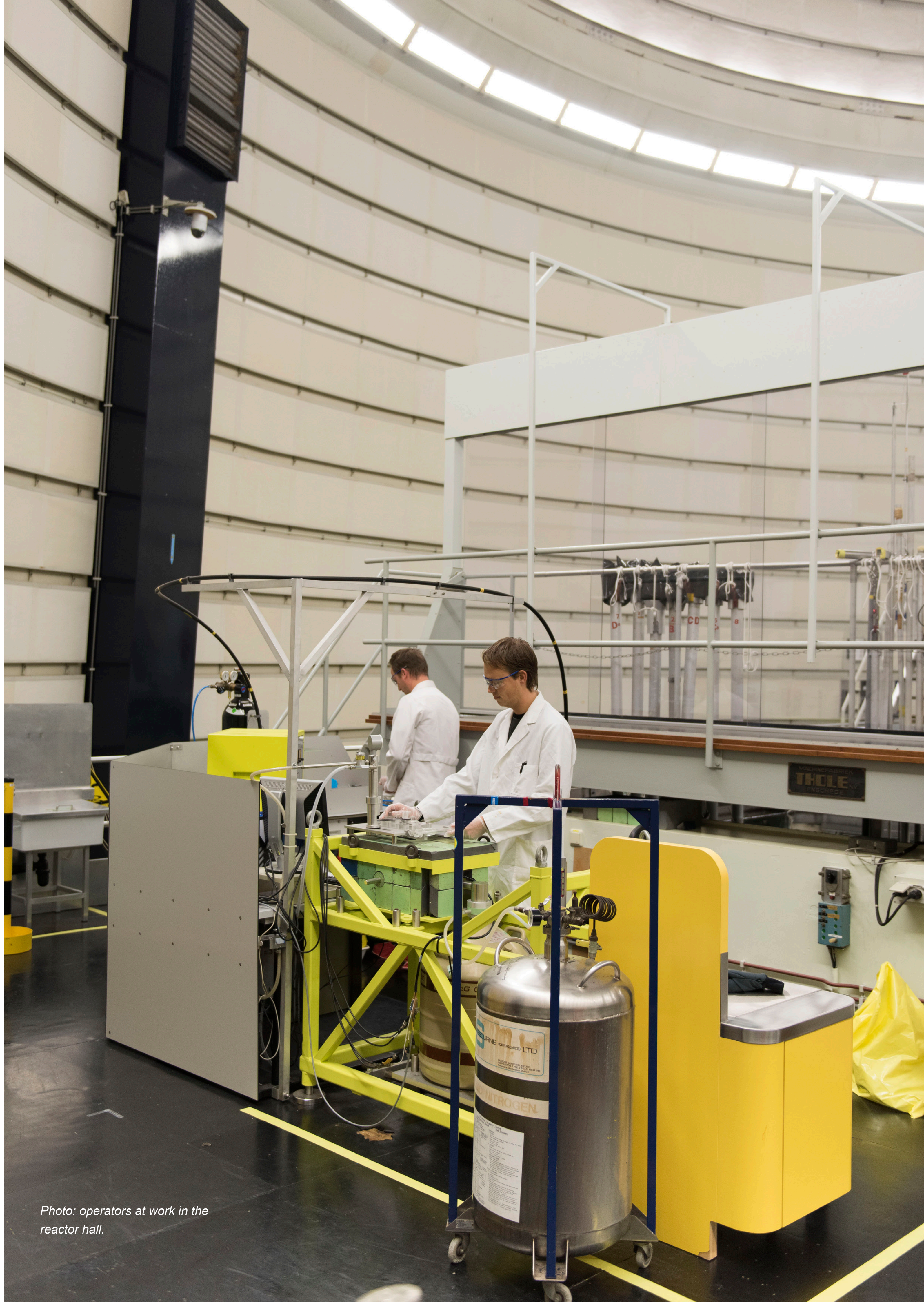


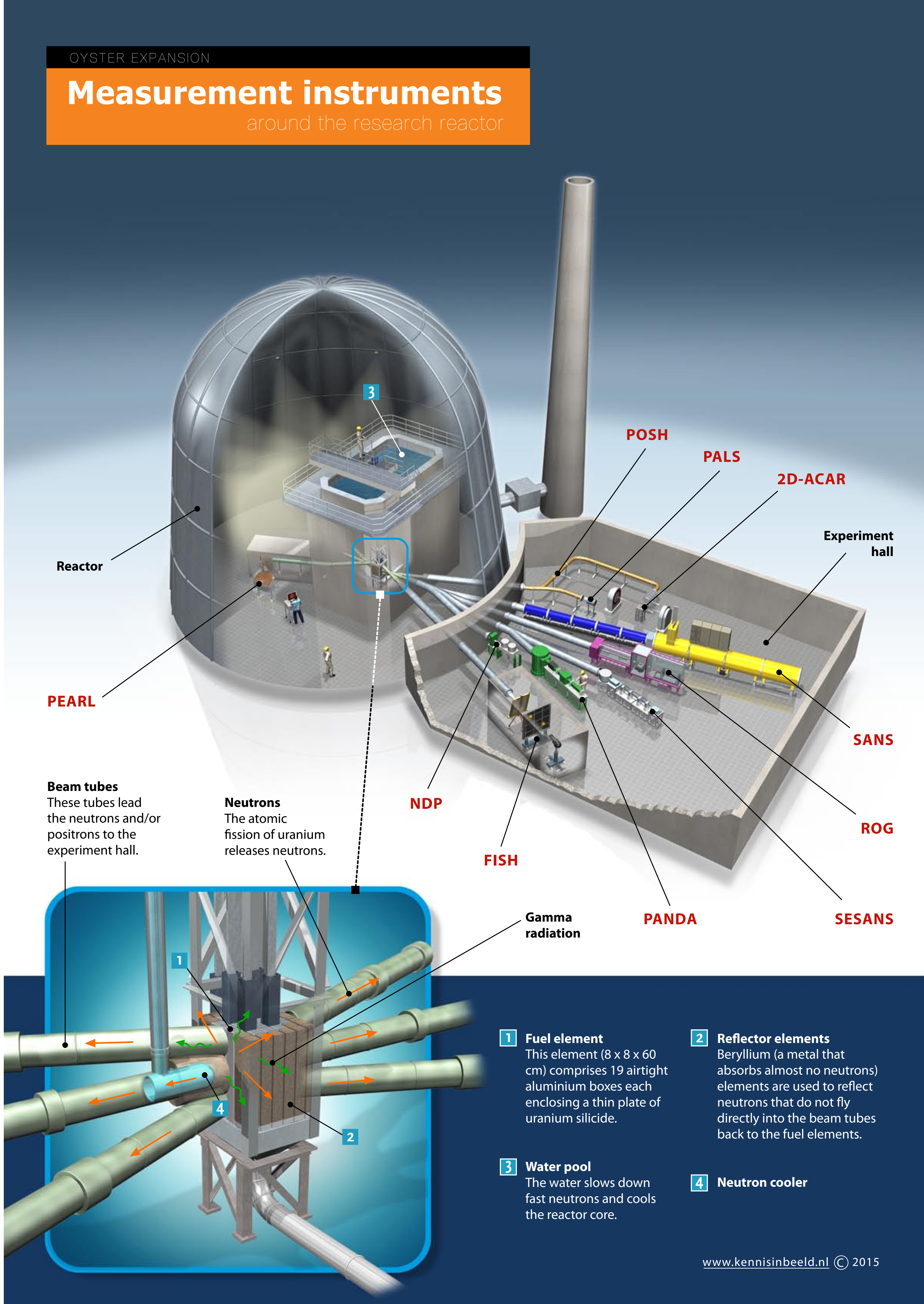
Photo: operators at work in the reactor hall.

Instruments

As part of OYSTER, RID will develop new or upgrade existing instruments that exploit the (cold) neutron and positron radiation produced by its reactor. The instruments are:

- **PEARL** – a new neutron powder diffractometer
- **ROG** – upgrade and relocation of the time-of-flight neutron reflectometer to a cold beam line
- **SANS** – a new small-angle neutron diffractometer with a dedicated cold beam line
- **NDP** – upgrade of the neutron depth profiling spectrometer
- **FISH** – a new multi-purpose neutron imaging facility
- **SESANS** – upgrade of spin-echo labelled SANS
- **Mössbauer Spectroscopy** – upgrade of the existing spectrometer

On the next pages we describe what each of the instruments does or will do, the progress achieved in 2018 and the prospects for 2019.



Energy-materials

Neutron powder diffractometry – PEARL

The PEARL neutron powder diffractometer is built mainly to determine the crystal structures of energy-materials, but its range of applications is much broader. Neutron diffraction and X-ray diffraction complement each other in the sense that neutrons are particularly sensitive to light elements and can distinguish light element in a crystal structures that contain both light and heavy atoms. As well, magnetic structures and magnetic moments in the crystal can be accurately determined. PEARL is a unique facility within the Netherlands and competitive within Europe.

Progress 2018

As part of our in-house Li-battery research, several solid state-based electrolyte and cathode materials were investigated to determine the location, occupancy and mobility of the lithium ions at the atomic scale. The magnetic structure and properties of magneto-caloric materials (which change in temperature when the applied magnetic field changes) and skyrmionics (material systems featuring complex magnetic structures called skyrmions) were probed down to 2K and the atomic mechanisms behind the decharging of hydrogen storage materials were probed non-invasively and in-situ at elevated temperatures. The complex chemistry of nuclear fuels was studied using PEARL, where we benefit from the particular sensitivity to light elements like oxygen in a stoichiometry of heavy metal oxides.

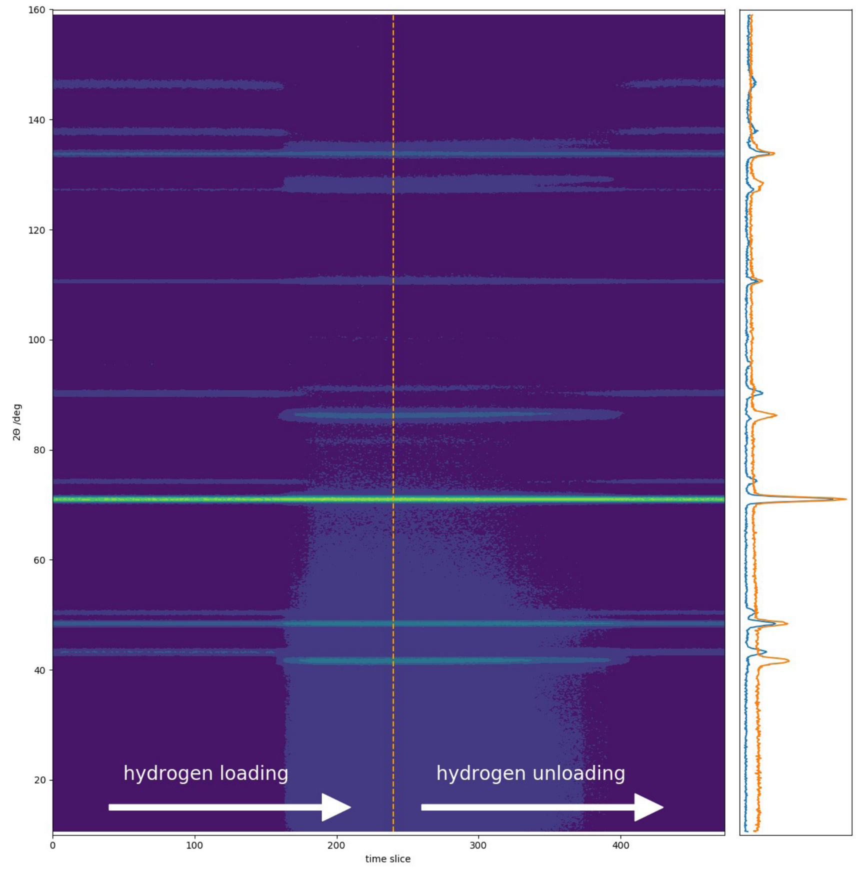


Image: Hydrogen absorption and desorption in the crystal structure of palladium. This reversible process (occuring on a minutes time scale) can be followed in-situ at the atomic length scale. The right side projection shows the diffraction pattern of the unloaded (blue) and loaded (orange) state as well as a significant increase in background, caused by the incoherent scattering of hydrogen

Instrumental developments on PEARL have been centred on expanding the temperature range for temperature-controlled experiments. We currently reach temperatures down to 1.8Kelvin for the investigation of magnetic structures and up to 800Kelvin for hydrogen storage, gas desorption materials, zeolites and metal-organic frameworks. We also performed the first in-situ and temperature-controlled hydrogen loading and unloading experiments, for which in-situ equipment was specifically designed.

Prospects 2019

In 2019, in-operandi experiments in energy materials will be performed. During the upgrade programme of the reactor, the instrument will undergo several upgrades in the mechanics, sample environment and control electronics.

Photo: the PEARL instrument.

Broad range of research: from hydrogen sensors to drug-delivery systems

Neutron reflectometer — ROG

The refractive index for neutrons depends on the chemical composition of a material. As a result, neutron reflectometry yields information about the structure and composition at surfaces and interfaces, probing depths on the nanometre scale. Applications are found in a very broad range of research, from protein adsorption at liquid-air interfaces for the stabilisation of foams, to membrane structures and hydrogen adsorption in metallic systems. ROG will contribute to many scientific challenges, such as the development of hydrogen sensors and drug-delivery systems.
As part of OYSTER, ROG's performance will be much increased due to the neutron spectrum provided by the Cold Neutron Source (CNS). To that end, the instrument is undergoing a major upgrade.

Progress 2018

- We continued to study the hydrogen-detection performance of different thin metallic films.
- We moved the instrument from its old position in the reactor hall to its new position in the experiment hall.
- We designed most of the new mechanical components, improving and optimising the performance of the instrument, adapted to the expected neutron wavelength spectrum produced by the CNS.
- We ordered new optical components, including a 20-m-long neutron guide to transport the neutrons from the CNS beam to ROG's new position in the experiment hall.
- We ordered new highly accurate rotation and translations stages.
- We adapted the software to control the 25 automated motions in a user-friendly way.

Photo below: The removal of the ROG instrument from the reactor hall to its new position in the experiment hall.

Prospects 2019

- The new neutron guide will be installed and aligned.
- All new components will be designed, produced and installed.
- Before the reactor shutdown, a reference spectrum will be measured, enabling to quantify the spectral change due to the CNS.

Chemistry, physics, biology and geology

Small-Angle Neutron Scattering instrument — SANS

The small-angle neutron scattering (SANS) technique allows the measurement of structures on length scales of a few to several hundred nanometres. SANS is a powerful technique with applications in many disciplines including chemistry, physics, biology and geology. Neutron scattering instruments are in high demand across Europe and world-wide where they can be applied to study many scientific problems ranging in areas from polymer science to magnetism.

We are commissioning a dedicated SANS instrument which will take full advantage of the increased cold neutron flux as a result of the OYSTER programme. It will be part of a complimentary suite of instruments with the reflectometer (ROG) and the SESANS instrument for large-scale structures.

Progress 2018

The instrument has been connected to a neutron beam for initial tests. The velocity selector and incident beam collimation have all been shown to work well. Work has also been done to re-commission the detector and refurbish it with the correct 3He/4He mixture.

Prospects 2019

We anticipate the first cold neutrons towards the end of the year. Once the beam is established, a calibration of the instrument will be undertaken with regular usage anticipated to commence in 2020. In parallel, the development of a dedicated sample environment and the establishment of scientific links across the TU Delft and at other universities in the Netherlands will be undertaken to take maximum advantage of this instrument and the enhanced flux that the cold source will bring.

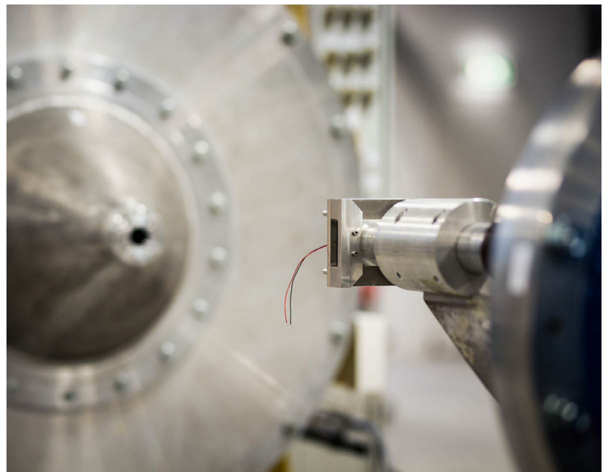
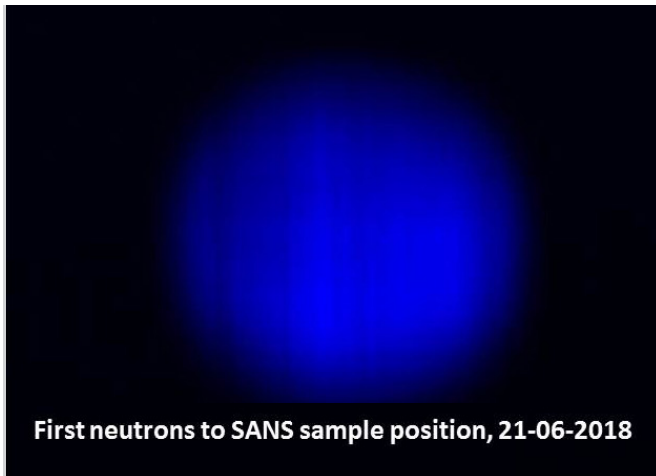


Photo left: Sample position of the SANS instrument

Photo right: Image of the beam at the sample position



Battery research

Neutron Depth Profiling — NDP

The development and use of the Neutron Depth Profiling (NDP) setup is largely focussed on Li-ion battery research, aiming at high-energy-density batteries for mobile electrical applications. NDP is a powerful technique to detect lithium, making use of the neutron capture reaction of the lithium-6 isotope yielding high-energy particles that allow us to study the position and movement of lithium atoms in any application, notably also in working batteries.

Progress 2018

Research is focussing on Li-metal plating and Si electrodes, because these represent the highest-capacity negative electrodes, unlocking the high energy density of solid-state oxygen and sulphur-based batteries. With NDP we focus on the evolution and reversibility of the Li-metal/Si layer during battery cycling, where we are able to monitor the porosity, depth distribution and plating/striping kinetics. Several electrolyte additives that should stabilize the Li-metal/Si electrodes are developed and monitored with NDP, providing insights in the lithiation and delithiation mechanism.

A large step forward was achieved for this type of operando measurements by the development of a battery-detector box. By filling this with helium at 1 atmosphere, we overcome the vacuum in the NDP chamber, yet minimizing the energy loss of the charged particles travelling from the battery to the detector. Additionally, it is assembled in the battery lab, where we can test the functioning prior to assembly in the NDP setup. Previously, the success rate for successful operando NDP measurements was between 5 and 10%; so far, it is 100%.

Progress was achieved on the 3D-imaging NDP detector, moving from 1D depth information towards 3D Li distributions in working batteries. Although the principle is shown to be feasible, the trial set-up has some shortcomings. A proposal has been submitted to continue on the development in collaboration with PSI and Nikhef.

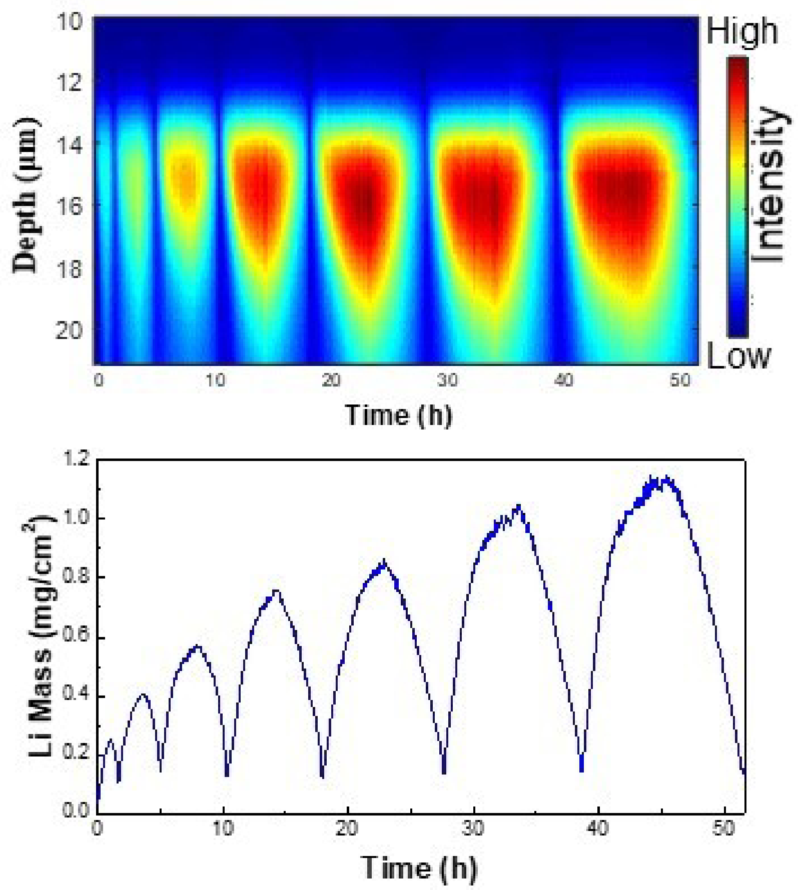


Image: Li density during 7 plating stripping cycles.
Top: *is the Cu current collector, bottom the interface with the electrolyte.*
Bottom: *Integrated Li mass, indicating the large efficiency.*

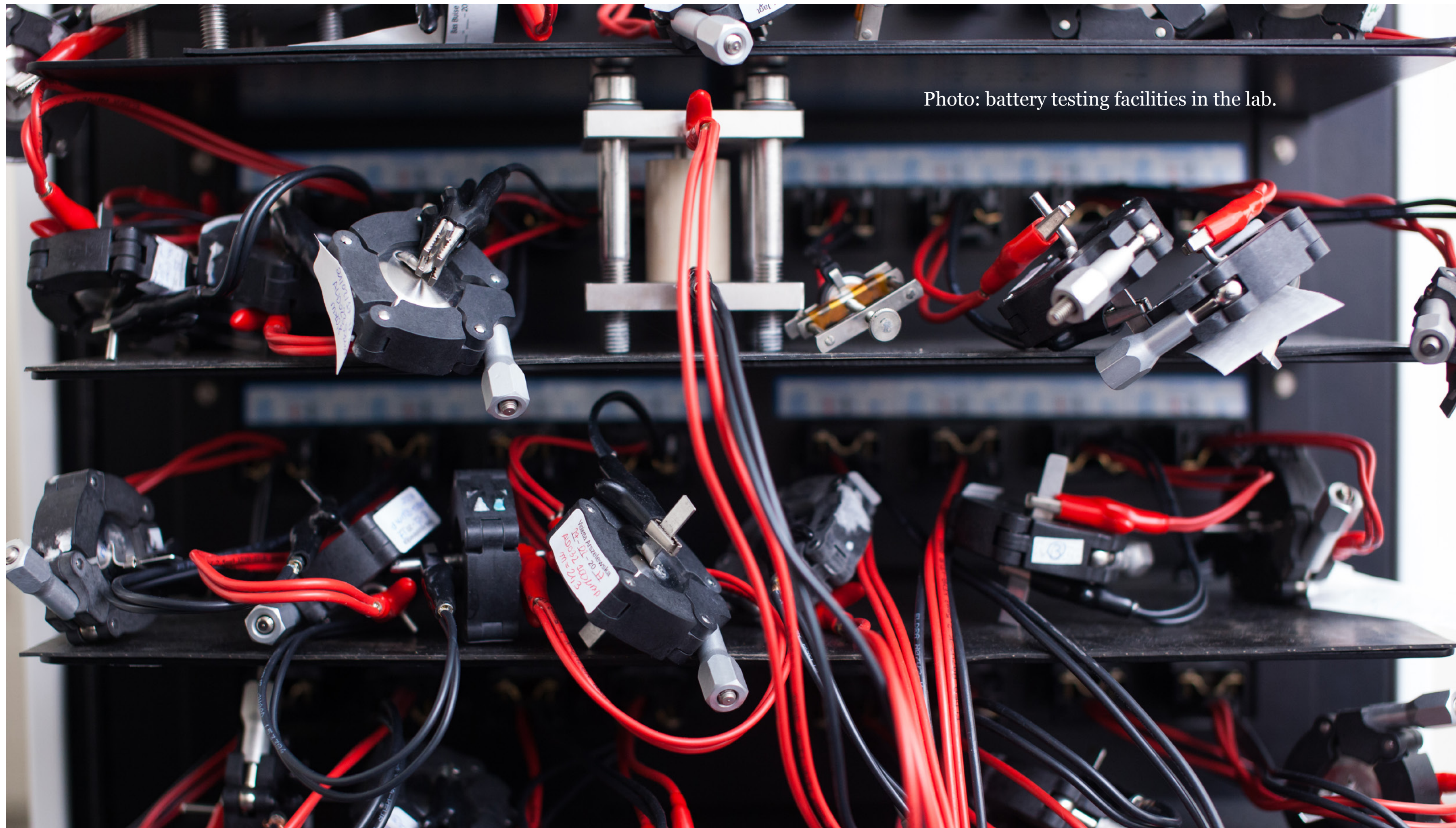


Photo: battery testing facilities in the lab.

Cultural heritage and archaeology

First Imaging Station Holland — FISH

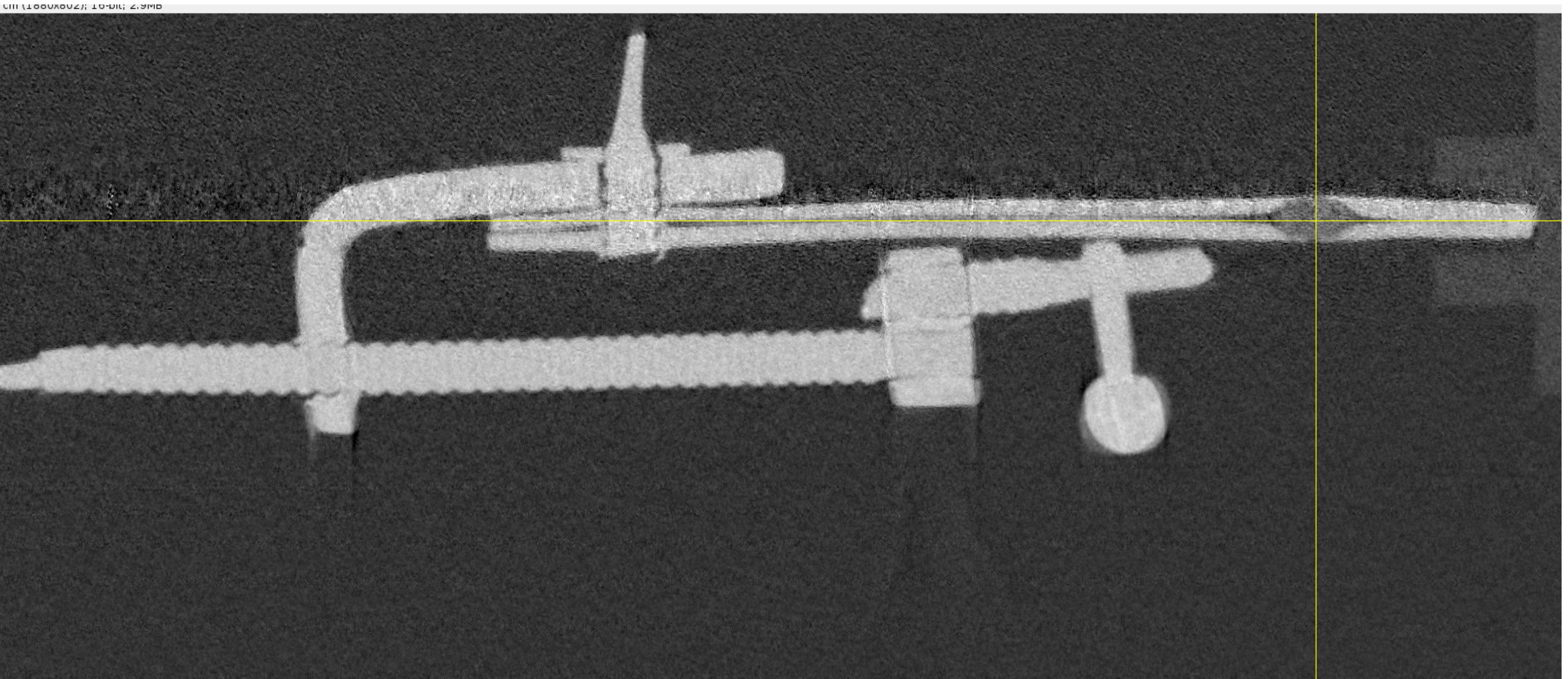
Neutron tomography enables to inspect the interior of 3D objects completely non-invasively. In many ways, this technique is similar to CT scanners in hospitals. However, the particular properties of neutrons make that dense matter like metals can be inspected, which are nearly impossible to penetrate with the X-rays used in CT scanners.

Progress 2018

In 2018, the instrument was upgraded with professional optics, improving both the spatial resolution and signal-to-noise performance. Moreover, the data acquisition and control software was completely rewritten and improved for user operation. For data treatment, professional visualization and analysis software was acquired.

The main application of FISH has been in the field of cultural heritage and archaeology. We started new collaborations with the Rijksmuseum, the National Agency for Cultural Heritage, the universities of Groningen, Nijmegen, Amsterdam (UvA) and Florence as well as with the Faculty of Civil Engineering of TUD.

Image: Tomographic slices of the Antonie van Leeuwenhoek (1632-1723) microscope (Boerhaave Rijksmuseum for Science in Leiden). The data collection for tomography is done by collecting neutron transmission images of the microscope under many different orientations of the microscope in the neutron beam. Using computed tomography (CT) reconstruction algorithms, the interior of the microscope is revealed in 3 dimensions, completely non-invasively.



"Mystery of superior Antonie van Leeuwenhoek microscope solved thanks to new technique"

A remarkable highlight of FISH was the inspection of the 17th century Van Leeuwenhoek microscope. Antonie van Leeuwenhoek (1632-1723) was a cloth trader who used lenses for the inspection of cloth fibre quality. With his skills in the fabrication of lenses, he obtained such an astonished level of optical magnification that he discovered the existence of a "micro world" (bacteria, cells, etc.) invisible to the naked eye. Although the research he performed in Delft using his superb microscopes was internationally well recognized at that time, he kept his technology on lens production secret and it took more than a century before better lenses could be produced by others.

Image: Antonie van Leeuwenhoek (1632-1723), www.rijksmuseum.nl/collectie/SK-A-957

Very few original microscopes by Van Leeuwenhoek exist today, and of these microscopes only a tiny fraction of the actual lens is visible for inspection. Together with the Boerhaave Science Museum in Leiden, we have been able to non-invasively visualize, for the very first time, the entire lens of their microscope. As this particular microscope ranked second in The Dutch Cultural Heritage Showpiece competition (Pronkstuk van Nederland) on national television, our finding on the actual lens inside the microscope generated significant media attention.

Photo: This original microscope was brought to the RID for inspection at FISH. Antonie van Leeuwenhoek would place the specimen for investigation on the tiny pin which he would then align in front of the lens (behind the centre hole in the brass plate).

Materials: food and polymers

Spin-Echo Small-angle Neutron Scattering — SESANS

Spin-Echo Small-angle Neutron Scattering is a technique that allows users to investigate structures on length scales from 20 nanometres up to about 20 micrometres, which is two orders of magnitude larger than small-angle neutron scattering (SANS). These length scales are especially relevant for many food materials such as yoghurt and cream cheese. In contrast to traditional scattering methods, SESANS data are in real space, rather than reciprocal space, which makes interpretation easier. These properties make SESANS a powerful tool for the study of structural properties of materials.

Progress 2018

- We characterised composite polymers for use in electronic shielding and new battery materials.
- We studied the effect of enzyme treatments on the wetting behaviour of cotton.
- We studied the morphology of different biopolymers to be used in medical applications.
- We used newly developed rotating sample cells to study the hydration of high concentrations of casein in water without having any problems with sedimentation or creaming.
- We improved the instrumental stability by the use of new pole shoes in the electromagnets of softer magnetic material.
- We also improved the stability and speed of measurements by a better electronic control of the magnetic fields.

Prospects 2019

In 2019, we will move the SESANS instrument from the experimental hall to the reactor. We plan to have a solid independent mounting of the foils directly on the table instead of in the magnets. This will give a better control of the orientation of the foils, which is crucial for the magnetic fine tuning of SESANS. We aim for a better stability of the setup with these changes.

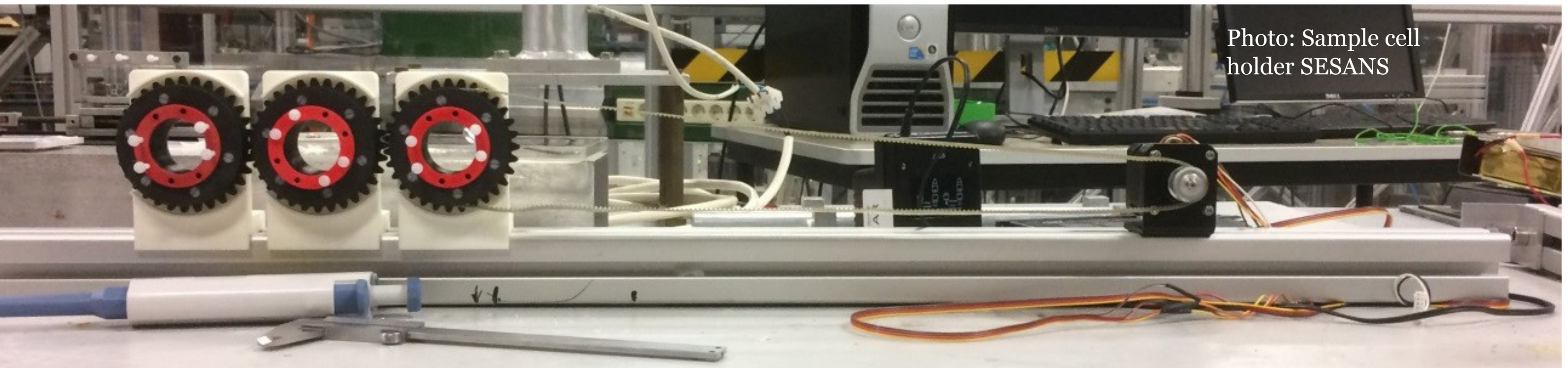


Photo: Sample cell holder SESANS

Catalysis and magnetocalorics

Mössbauer spectroscopy

Mössbauer spectroscopy utilises gamma photons emitted from materials which undergo radioactive decay. Such spectroscopy can be a powerful tool for the study of materials such as catalysts. It can provide information on both the atomic and magnetic structure of materials. However, the number of elements upon which such spectroscopy can be undertaken is limited to elements with long radioactive half-lives and dominated by studies of iron.

The Delft Mössbauer facility has been upgraded as part of the OYSTER programme, with new in-situ capabilities geared towards applications in catalysis. In 2018, we submitted a proposal to implement the technique directly on a neutron beam. This in-beam project strives to expand the range of elements that can be investigated, by activating such materials in a neutron beam. We already have interest from colleagues at TU Delft to investigate rare-earth based magneto-caloric materials for magnetic cooling. This type of cooling has tremendous applications in energy for both the cooling and liquefaction of natural gas and hydrogen and hence allows for highly efficient energy transport at high densities.

If funded, the project would develop this emergent technique at the Delft research reactor, allowing detailed studies to study low temperature magnetocaloric materials. Mössbauer spectroscopy has been shown to provide unique insights into both magnetic structures and the determination of the moment strength.

Currently, the Mössbauer laboratory is involved in three PhD research projects in collaboration with Shell Global Solutions, Johnson Matthey and Wetsus, in the areas of catalysis and water treatment applications.

Progress 2018

- Construction of a prototype detector with Nikhef (Dutch National Institute for Subatomic Physics)
- Testing of new low-vibration cryogenic equipment
- Identification of key components and beamline outline design
- Development of the science case for rare earth-based magnet cooling materials

Prospects 2019

In 2019, we will develop a new detector.

Medical isotopes

Irradiation facilities

Irradiation facilities are primarily used to produce radioisotopes that find applications in various fields among which medicine.

Progress 2018

In 2018, the flexible facility installed in 2017 was further used for research purposes as well as for irradiation of Holmium microspheres for patient use. Patients with liver cancer are treated with special radioactive microspheres that are packed with the radioisotope Holmium-166. The effect of gamma dose on the stability of the holmium microspheres was investigated by changing the configuration of the lead blocks, varying in this way the lead thickness. Three configurations were studied having 3, 6 or 9 cm of lead. The best results in terms of duration of irradiation and produced radioactivity appear to be achieved with the 6-cm lead thickness. Using this configuration, irradiations up to 15 hours appear to be possible without damaging of the microspheres.

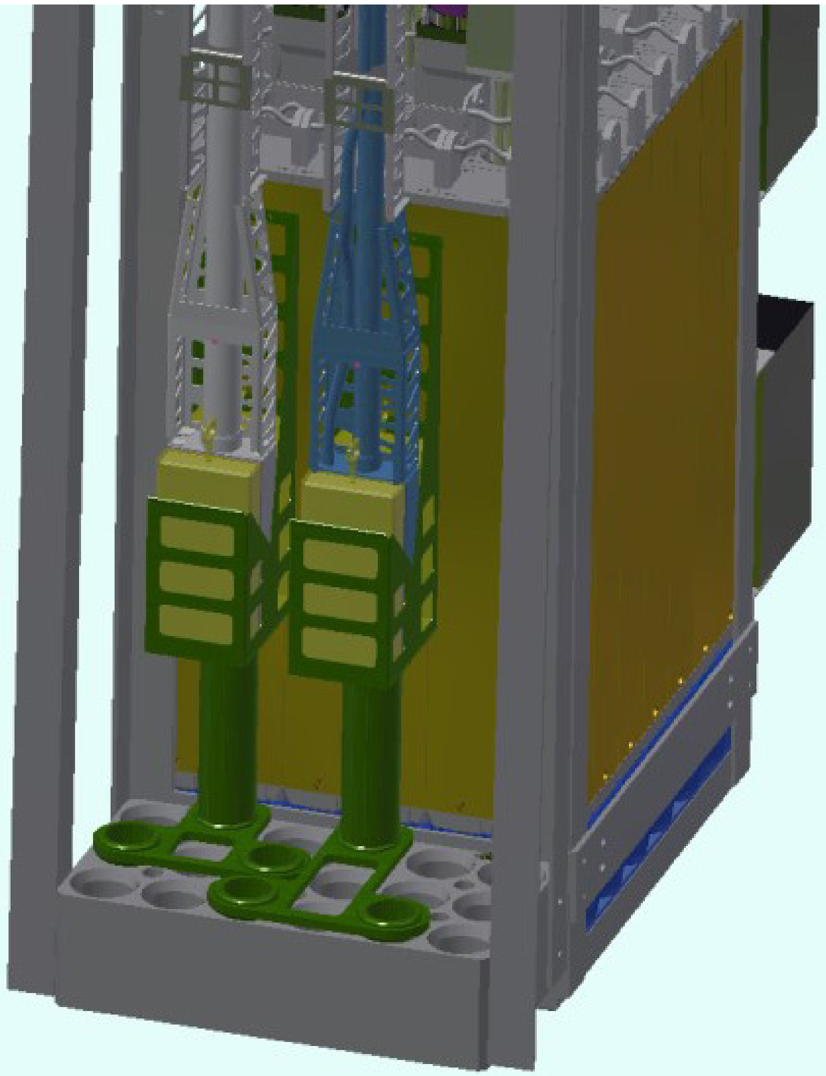


Image: Design of two new flexible pneumatic facilities

Due to the success of this facility, it was decided to build two pneumatic irradiation facilities in the future. These facilities will be placed on the experimental grid in the research reactor and the irradiated samples will be transported to the labs by the pneumatic tubes. The influence of the neutron and gamma flux due to the placement of the second facility was also studied showing only small changes in comparison to the current situation.

In 2018, we also investigated whether we can optimize other irradiation facilities such as ‘Small BeBe’ and the ‘Big BeBe’. The idea is to convert one of these facilities into a pneumatic facility, allowing for transport of samples directly to the lab, thereby avoiding unnecessary radiation exposure of the reactor operators. In addition, the possibility of constructing a removable cadmium (Cd) shielding was explored, supported by simulation studies to find the most optimal design. Such a shielding will allow for production of radioisotopes through n,p reactions where fast neutrons are of importance and thermal neutrons should be supressed to avoid unnecessary by-products. An example of such radioisotopes is 64Cu, which is used in Positron Emission Tomography (PET) but may also be applied in therapy, making it a theranostic radionuclide.

We will continue realising our plans in the research reactor after the CNS works have finished and the reactor is in use again at the beginning of 2020.

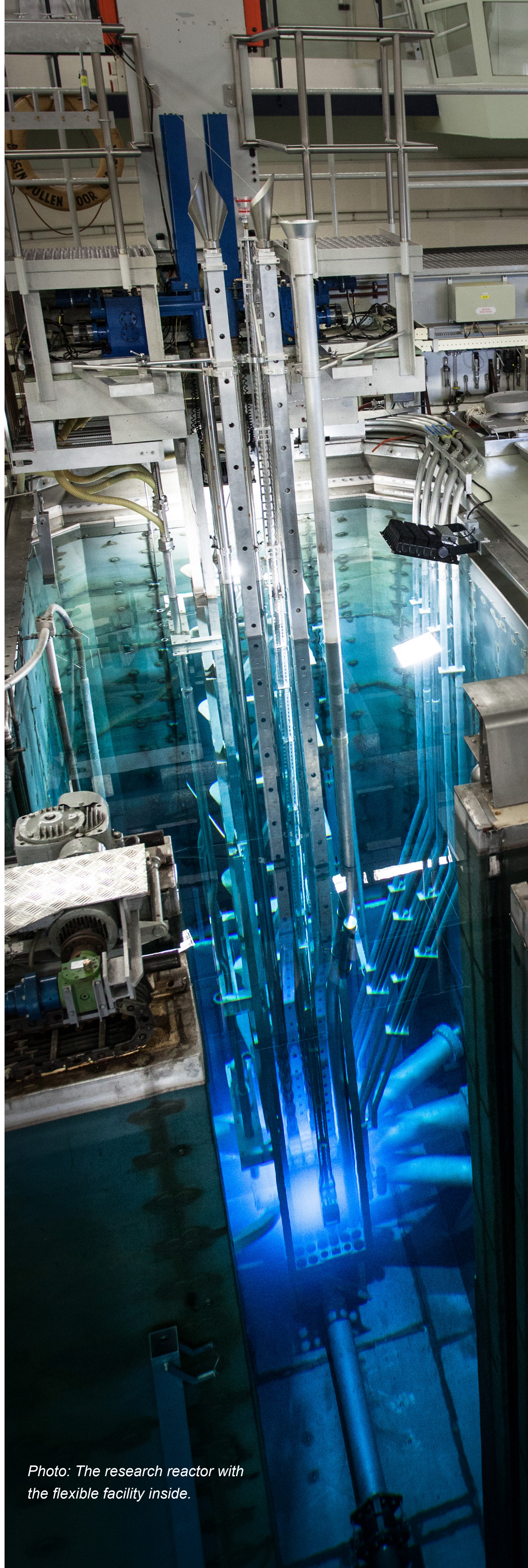


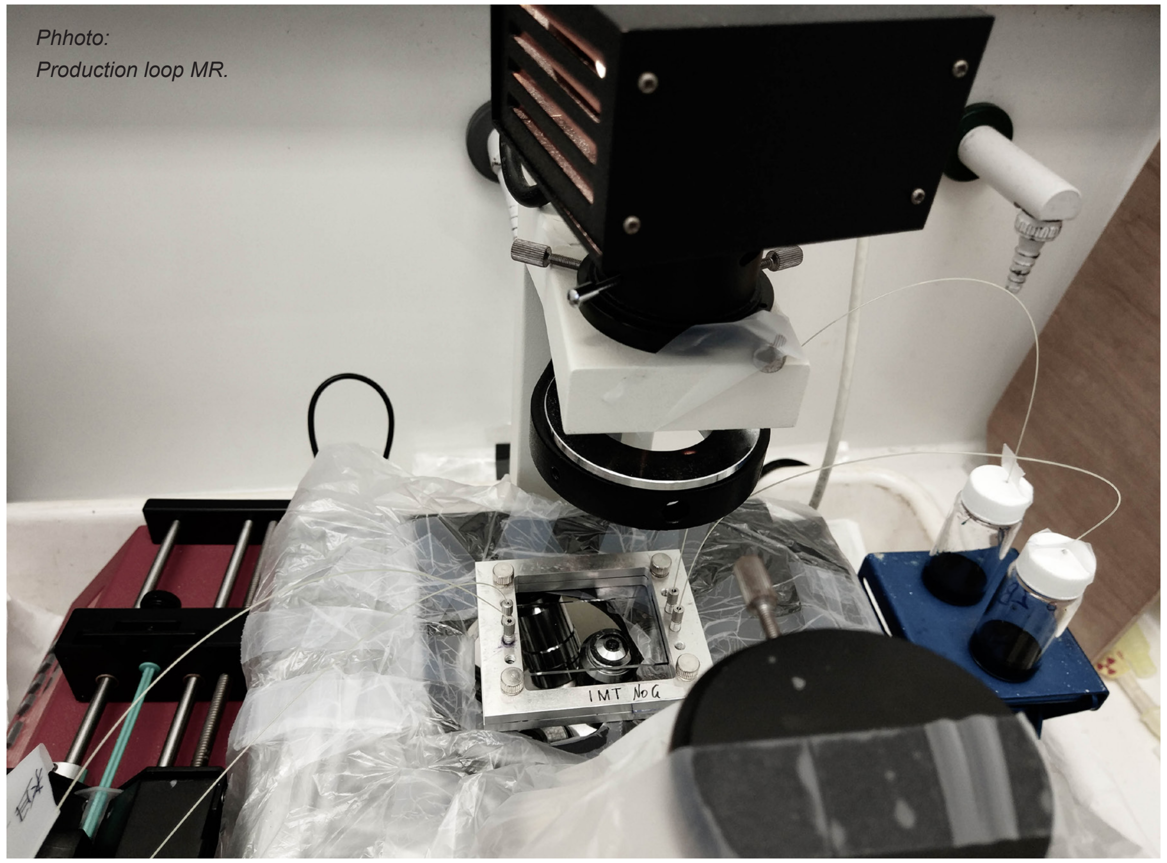
Photo: The research reactor with the flexible facility inside.

Faster molybdenum-99 production routes for medical diagnostics

Radioactive isotopes are widely used in medical diagnostics. Each year, about 30- 40 million clinical radio-diagnostic scans use technetium-99m worldwide. Technetium-99m is derived from its parent isotope molybdenum-99.

The Department of Radiation Science & Technology investigates the feasibility of producing molybdenum-99 by irradiating a uranyl nitrate solution in a continuous loop system. Compared to the conventional way of irradiating the solid targets, the innovative approach supports the online extraction and purification of molybdenum-99, which is believed to reduce the post-processing time. Research has shown that the uranyl nitrate solution inside the U-shaped loop could produce molybdenum-99 continuously for more than 20 years without refilling.

For the purpose of online extraction and purification, innovative microfluidic devices are being explored to selectively extract the newly produced molybdenum-99 from the loop. Current research is focusing on optimization of the microfluidic system to achieve the maximum extraction and purification efficiency. In 2019, a new project entitled “Fast and Efficient Purification of Medical Isotopes by Microfluidic Extraction” will start where these microfluidic devices will be studied under irradiation by neutrons from the research reactor.



Phhoto:
Production loop MR.

OYSTER

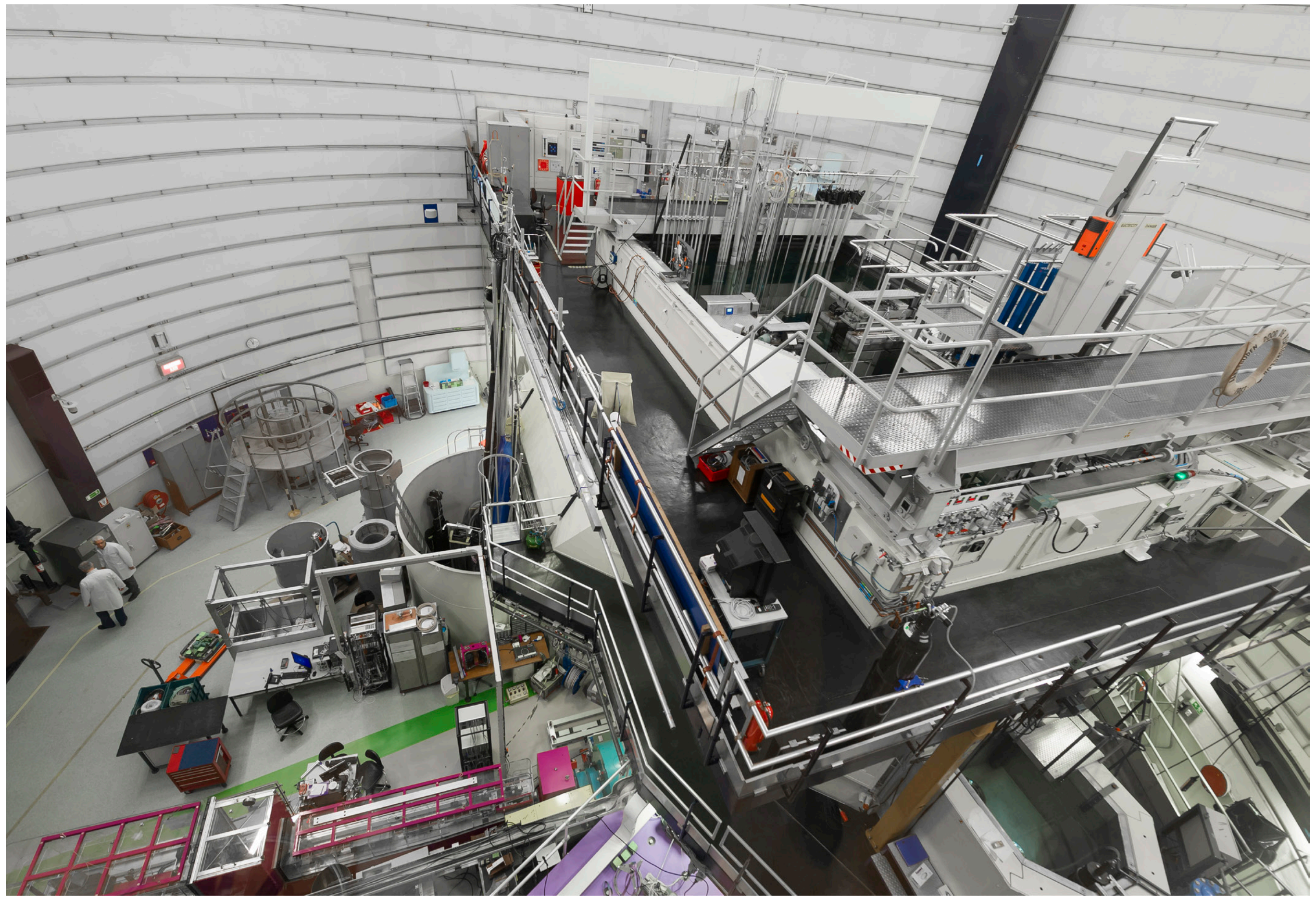
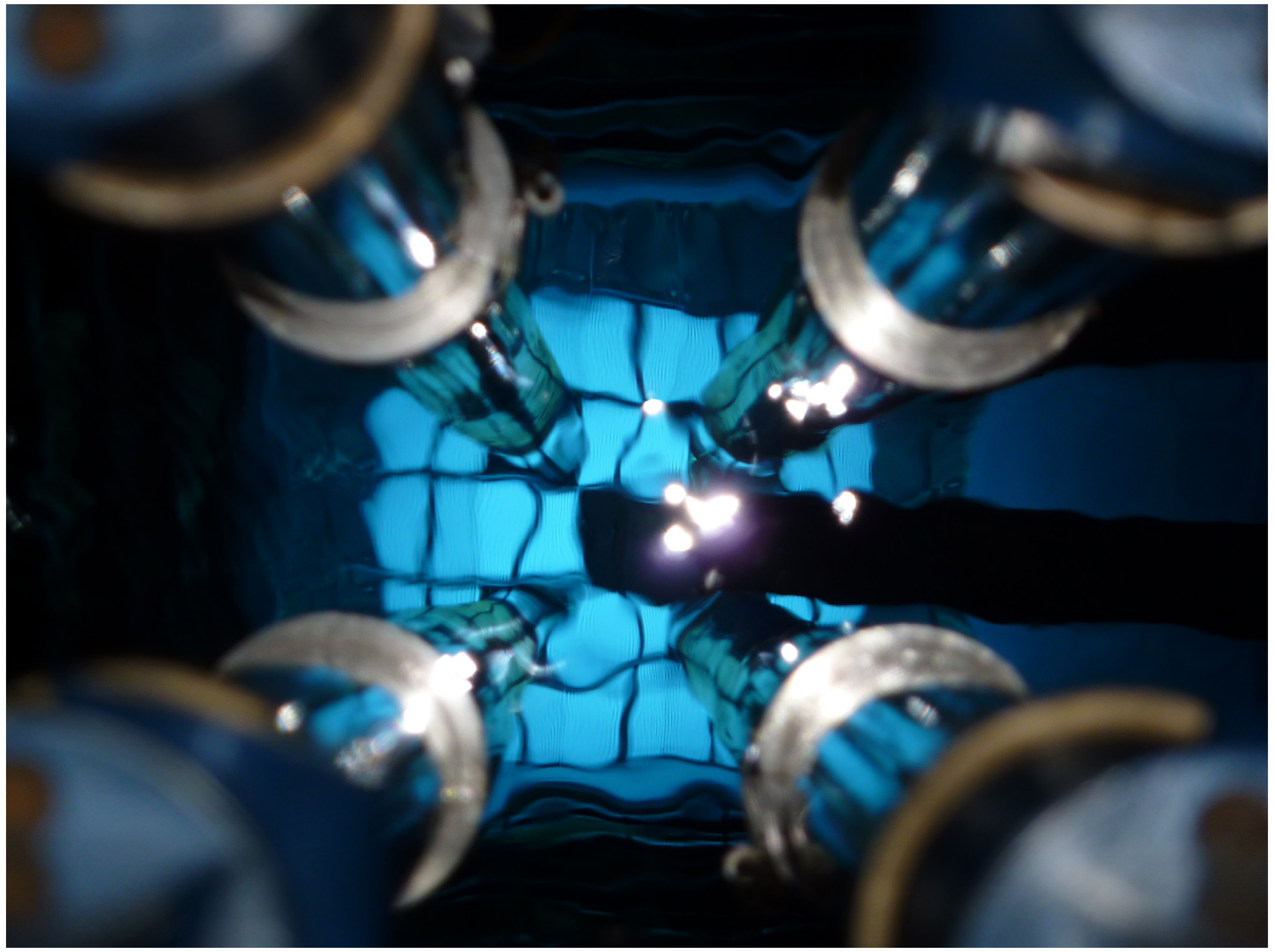


Photo: inside the reactor hall.

Photo: the ‘heart’ of the research reactor: the reactor core.



International developments: the European Spallation Source

OYSTER

The European Spallation Source (ESS) is a multi-disciplinary research facility based on what will be the world's most powerful neutron source. It is currently under construction in Lund, Sweden. With at least 17 European countries acting as partners in the construction and operation of ESS, and an estimated cost of construction of almost 2 billion euro's, it is one of today's largest science and technology infrastructure projects. The unique capabilities of this new facility will both greatly exceed and complement those of today's leading neutron sources, enabling new opportunities for researchers across the spectrum of scientific discovery, including life sciences, energy, environmental technology, cultural heritage and fundamental physics. Many countries within Europe have already partnered up with the host countries Sweden and Denmark. The Netherlands, one of the early supporters of ESS, has not made a formal financial commitment yet and holds its official status of Observer pending the completion of the required national procedures.

The first step in these procedures has been successfully completed and resulted in the inclusion of the ESS in the 'Roadmap for Large Scale Scientific Infrastructure' as presented by NWO on December 13, 2016. The Dutch Permanent Committee for Large-Scale Scientific Infrastructures recognises ESS as a research facility that bears vital importance to the development of Dutch and international science. In the Roadmap, it is stated that "The strength of the neutron radiation produced by ESS will surpass all existing sources. As a result, researchers can study materials and systems at an even smaller scale and in real-world settings. That is not only important for science but also for the business sector and for finding answers to major social challenges."

The inclusion of ESS in the National Roadmap was an important step towards a Dutch full membership in ESS and represents a joint success of a consortium of the Delft University of Technology, Eindhoven University of Technology, University of Groningen and the Wageningen University & Research Centre. The process was led by the RID, which has already a well-established cooperation with ESS through the OYSTER programme.

Photo: The ESS-construction site in Lund, Sweden.

Review by NWO

The sixth visit of the “NWO OYSTER Advisory Committee” took place in June 2018.

The Committee focussed on what has been achieved on the reactor- and instrument status, strategy and outlook for future exploitation, training, education and networking/ collaboration. Looking back at the meeting, the OYSTER organization highly appreciated the positive cooperation between NWO and RID/RST.

The outcome of the review meeting by the Committee was positive and there is a confidence in successful realisation of the OYSTER project in the coming period. For this reason the decision was made that this was the final close-out event between RID/ RST and NWO and no future review meetings were planned.
The following Committee members attended this meeting:

- **KURT CLAUSEN (CHAIRMAN)** Technical University Denmark (DTU)/Paul Scherrer Institute, Switzerland
- **SHANE KENNEDY** European Spallation Source (ESS), Sweden
- **FRED VERZIJLBERGEN** Erasmus University Medical Centre Rotterdam (Erasmus MC), Netherlands
- **ERIC VAN AERT** Netherlands Organisation for Scientific Research (NWO), Netherlands

Comments/recommendations of the NWO OYSTER Advisory Committee	Implementation/answers by the OYSTER team
Refine the new organisational structure to ensure a correct balance of responsibility and benefit between RID and RST divisions.	We established an instrument group within RID as a visible and firm entity; all technical staff of RID/ RST was grouped and shared, and an RID/RST shared strategy team was set up to provide advice on longer-term goals and measures.
RID/RST is recommended to articulate a long-term strategy (10-year plan) to establish a permanent team of instrument scientists, who are capable of acquiring research grants for their own research and instrument activities.	The RID/RST shared strategy team advices on long term goals. All instrument scientists are employed by TU Delft, under shared RST/RID governance, to ensure access to a wide range of university career paths and to ensure that instrument scientists follow the university lines and policies in research grants and funding.
Define success. When is OYSTER considered a success? Consider how you want to follow up and measure impact.	RID/RST are discussing measures of success, in terms of used capacity, acquired grants, joint research inside/outside the TU Delft and recognized positioning.
Staffing continues to be an issue that needs attention. In particular, when starting up and running user programmes beyond Delft University.	RID/RST are in the process of filling instrument scientist permanent positions; currently ROG and SANS positions are being filled, being the instruments that most strongly benefit from OYSTER’s neutron cold source.

The Integral Management System (IMS)

The Integrated Management System (IMS) for RID, which is currently under construction, forms a coherent system of processes, procedures, work instructions and performance indicators indicating the contributions of each component of the RID organisation. The IMS ensures that the safety, legal, license and customer requirements are met. For RID in general and for OYSTER specifically, these are important matters.

The IMS is based on the 'plan-do-check-act' (PDCA) cycle. This means that a cycle of establishing goals, making plans, doing the work, measuring, analysing, improving and anchoring is performed. Insight is obtained as to whether the goals are achieved, the needs for means are met and the structure and processes of the organization are suited for the purpose. If not, changes can be made, as part of continuous improvement.

Progress 2018

The IMS was further expanded in 2018. The structure of the central document management system was implemented in a joint effort with the quality coordinators. Depending on their function, all RID colleagues have access to a website with the managed documents. This website was designed together with a group of users.

For each business unit of the RID, the contribution to the business objective has been made transparent on the basis of a CANVAS business model. Based on these models, a start was made with setting up processes, using a uniform format. The entire process of "irradiations with the HOR" with the associated sub-processes was drawn up. The processes relating to access and radiation safety were also included in the document management system.

One of the most important parts of an IMS and the PDCA cycle is the internal audit. Four internal auditors were trained for this purpose in 2018. Digital forms for the reporting of findings and non-conformances have been developed and are now in use.

Prospects 2019

In 2019, the description of processes following a uniform format will be continued. Specific procedures for OYSTER will be drawn up, in particular the process "working with third parties". To ensure that the process descriptions remain in line with current practice, internal audits will be conducted. An inventory will also be made of which performance indicators are suitable as monitoring instruments for each process.

Financial overview

The available OYSTER project budget amounts to €117 million, covering the initial investments as well as the basic reactor-associated operational costs for a period of 10 years. In 2012, the Dutch government awarded €38 million for OYSTER. TU Delft will contribute a total of €74 million in kind.

Furthermore, TU Delft stands surety for an additional €5 million. This is part of the co-funding (industrial, scientific etc.) needed to fund the development, commissioning and exploitation of instruments and facilities over the total 10-year OYSTER programme period and beyond.

Update 2018

Works on the CNS Utilities (WP2) continued in 2018. The improvements according the DSR, which started in 2016, continued in 2018 as well. In total, €21,6 million was spent on engineering (including DSR), licensing process and positioning of OYSTER. Furthermore, TU Delft contributed €9,4 million in kind to OYSTER in 2018.

In the CNS IPA work package (WP1), a budget shift to the CNS Utilities work package (WP2) for RPS was realised in 2018. The new contract value of WP1 was set to €8,7 million of which 71% has been paid.

Of the CNS Utilities work package (WP2), all contracts with suppliers have been signed. In 2018, Demaco and Process Flow Systems signed their contracts. Of the contracts signed in 2017, supplier DH Industries went bankrupt in 2018. The remaining work will be executed by supplier Stirling Cryogenics (for which a new contract has been set up and signed in 2019). The building which is part of WP2 is finalised in 2018 and a start has been made with the installation of equipment.
The expected costs for services are higher due to delays in the project. For the overall project it is to be expected the costs will be within budget.

Improvements on instruments is ongoing. For the neutron diffractometer PEARL a budget is secured to expand the current sample environment. The ROG instrument is undergoing a major upgrade and the instrument was moved to its new position in the experiment hall. Instrument FISH was upgraded with professional optics and is done within budget. For irradiation facilities a budget is secured from the OYSTER project itself for which plans are being formulated to realise a pneumatic facility.

Planning

OYSTER

The schedule for executing the OYSTER project remains as communicated in the previous annual report of 2017. The actual construction works will finish at the end of 2019, after which there will be a commissioning period until the end of Q1 2020. The KEW Nuclear Licence Permit is expected to become available in the first half of 2019 after which the reactor modification (in-pool assembly) works will start in Q2 2019.