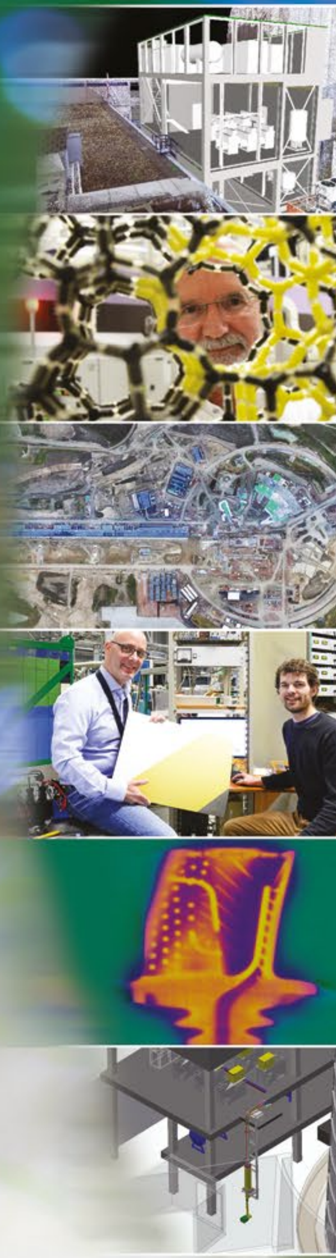
2016

OYSTER

Annual Report

Final preparations for construction



TU Delft Delft University of Technology

REACTOR INSTITUTE DELFT

2016 OYSTER Annual Report

Final preparations for construction

Foreword

I'm pleased to present you with the 2016 annual report of the OYSTER programme.

OYSTER *(Optimized Yield - for Science, Technology and Education - of Radiation)* has been devised to improve and expand the nuclear research infrastructure of TU Delft. It will enable educational, scientific and societal challenges in the fields of health and energy to be better addressed.

The programme is at an important crossroads in time: 2016 saw the final preparatory work before the first construction activities, which will start after summer this year. The OYSTER team concluded the contract definition and completed the negotiations between TU Delft and the (sub) contractors involved.

Also in 2016, the new Flexible Radiation Facility (FlexBefa) was designed and built to develop new production routes of radionuclides for medical use. And, of course, progress has been made in the development of new and the upgrade of existing instruments.

We also worked hard to formalize the Dutch commitment to the European Spallation Source (ESS), currently under construction in Lund, Sweden, which is to be the world's most powerful pulsed neutron source. As a first step, the ESS was included in the Dutch Roadmap for Large-Scale Scientific Infrastructure.

This annual report describes the past developments and looks forward to the exciting new phase the OYSTER programme will be entering in 2017.

Prof. dr. Bert Wolterbeek
Director of the Reactor Institute Delft
Head of the Department on Radiation, Science & Technology

Colophon

Text

Reactor Institute Delft, TU Delft

Graphic design

Atelier Pan

Cover design

Kennis in Beeld

Text editing

DBAR text editor

TU Delft

Reactor Institute Delft

Mekelweg 15, 2629 JB, Delft

+31 015 27 86744

www.rid.tudelft.nl

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OYSTER in short

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.

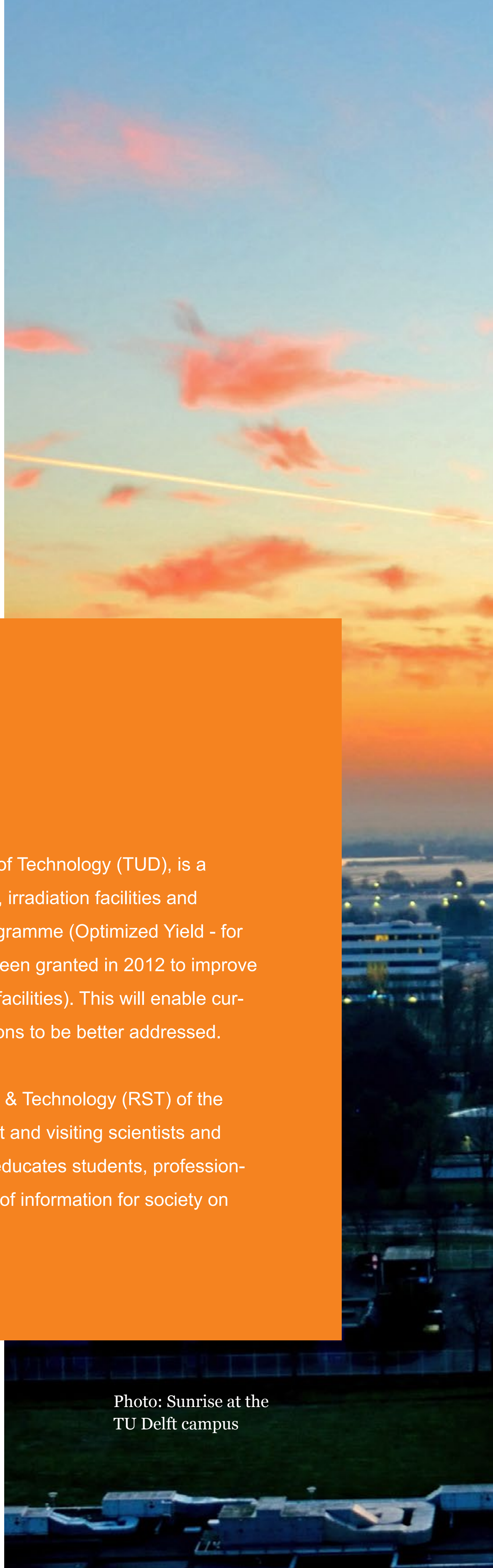


Photo: Sunrise at the TU Delft campus

Main goals of OYSTER

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.

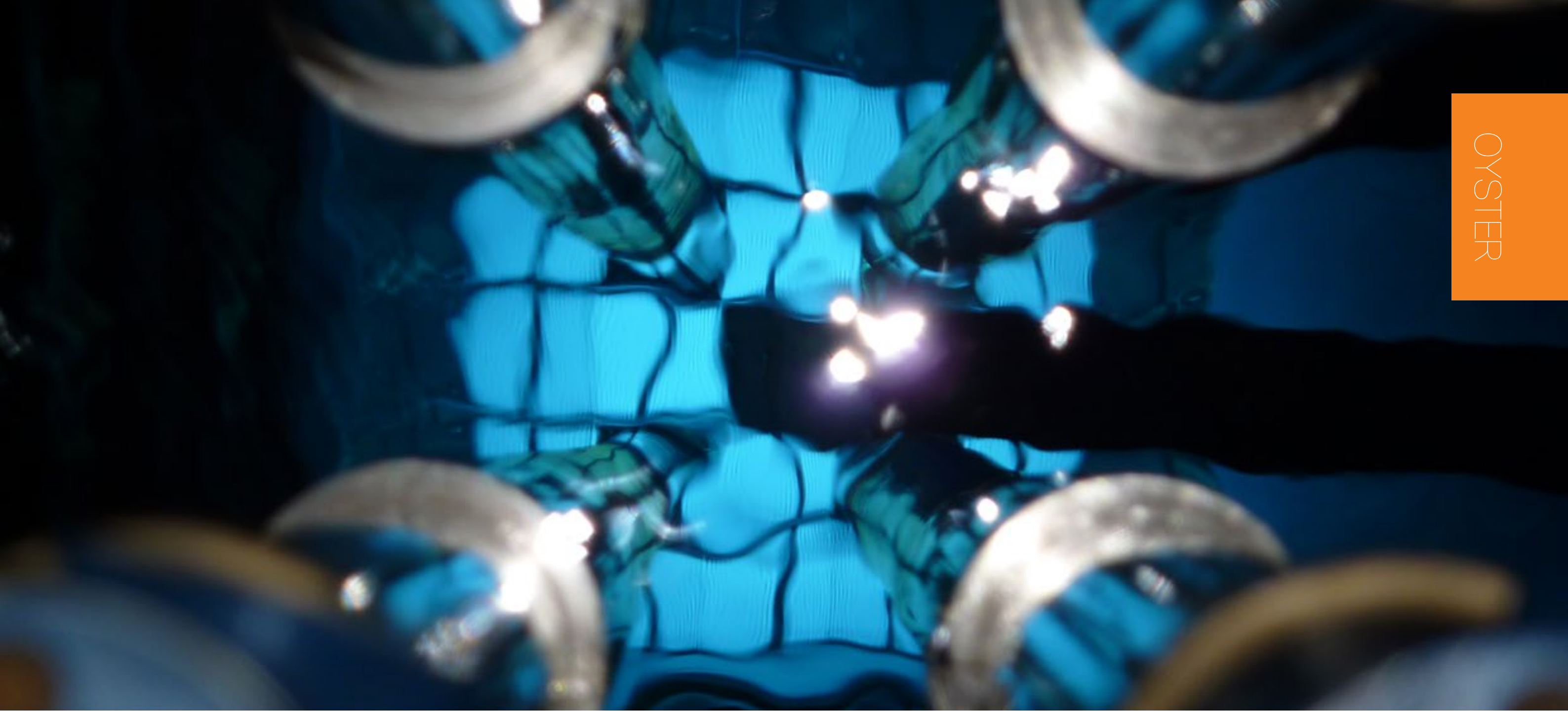
4 To create a home base for neutron scattering in the Netherlands and secure Dutch collaboration with major international neutron sources, specifically the European Spallation Source (ESS) in Lund, Sweden.

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.

Technological objectives of OYSTER

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. The new and upgraded existing instruments will exploit the (newly available cold) neutrons and positrons.
- 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, www.EuropeanSpallationSource.se, 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 of Holland Particle Therapy Centre (Holland PTC, www.HollandPTC.nl) dedicated to innovative radiation treatment of cancer, using proton beams. RID also takes part in a collaborative R&D program at TU Delft, the Leiden University Medical Centre (LUMC) and the Erasmus University Medical Centre Rotterdam (Erasmus MC). Holland PTC is under construction on the RID premises.

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

The OYSTER-initiated new irradiation facilities also enhances RID's position in DIVA (Dutch Isotope Valley). 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 for both diagnosis and therapy.

Finally, OYSTER underlines the role of TU Delft's RID as an IAEA Collaborating Centre by demonstrating the many innovative scientific opportunities in the utilization of a medium sized university research reactor.

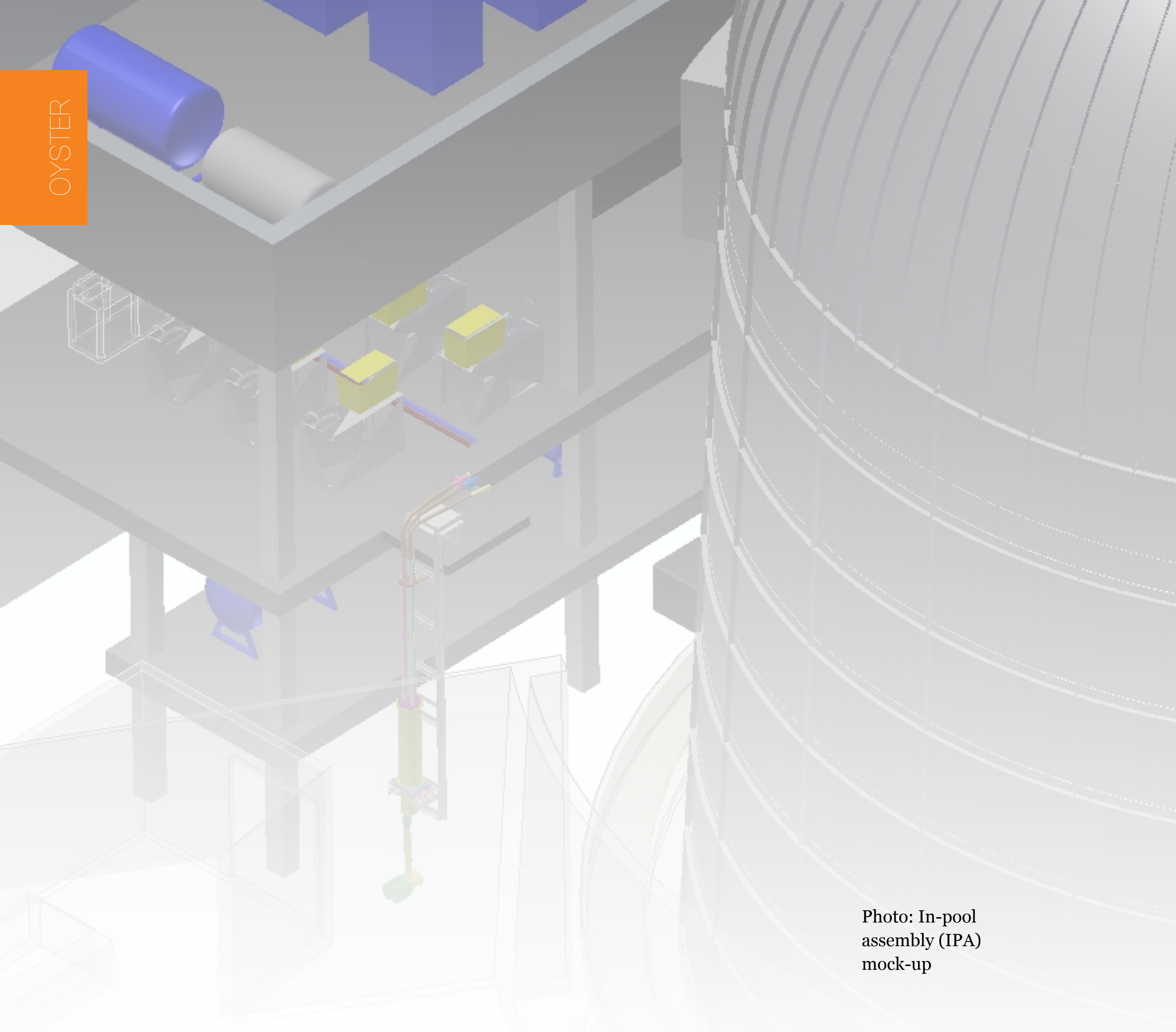


Photo: In-pool assembly (IPA) mock-up

Reactor & Utilities

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. In order 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 complete new building structure (called CNS utility building) will be realised next to the reactor hall. All CNS utility systems will be installed inside this building. On the next page we provide an overview of the status of this main part of the OYSTER project.

Delineation between scope of works

The scope of works for the CNS utility building outside the reactor hall and the IPA inside the reactor hall is delineated as follows:

- Work package 1 - The manufacturing and installation of the IPA, including the modifications of the beam-tube, will be undertaken by an international contractor with relevant construction experience with CNS equipment, as selected by the KHC consortium.
- Work package 2 - The CNS building, including the cryogenic equipment, will be realised by local Dutch suppliers. The cooling capacity offered by the CNS utility will be according to the specifications described in the consortium KHC process design and guaranteed by the local contractor.

Phased planning of licensing and preparatory testing

The split of works for the CNS in-pool assembly (work package 1) and the CNS utility building (work package 2) allows us to save time. As work package 1 can be considered as 'nuclear' while work package 2 is 'non-nuclear', the licensing process for the latter is much faster than for the former. For this reason, the CNS utility building can be realised in an early stage while the licensing for the nuclear part is still ongoing, which opens the possibility to perform an advance mock-up test for optimising the CNS support equipment after realisation of the CNS utility building but before the IPA works are executed. The test will involve a mock-up IPA, fed with liquid hydrogen from the thermosiphon. For the simulation of the thermosiphon loop, a computer programme is being developed to calculate the behaviour of the complete hydrogen and helium loop of all equipment and to predict the required cooling power and times. The test information can also be used for the optimisation of the final IPA. As another advantage of the mock-up test, it will open the possibility to train/educate the reactor operators and to get them familiar with the operation of the CNS cryogenic installation.

Optimizing the IPA and CNS equipment

The optimisation and fine-tuning of the IPA, the part that will be installed in the reactor pool, is an ongoing task shared by KHC and RID. The goal is to guarantee that the cold neutron flux to be delivered by the CNS is as high as possible. Regular contact with OYSTER's External Expert team assures the soundness of the creative proposals in this context.

The CNS parts are exposed to cryogenic temperatures; therefore, mechanical strength and thermal expansion are critical design parameters. The design of the IPA has recently been improved by moving the heat exchanger further towards the moderator cell. The advantage of this decrease in pipe length is that the mechanical strength has improved.

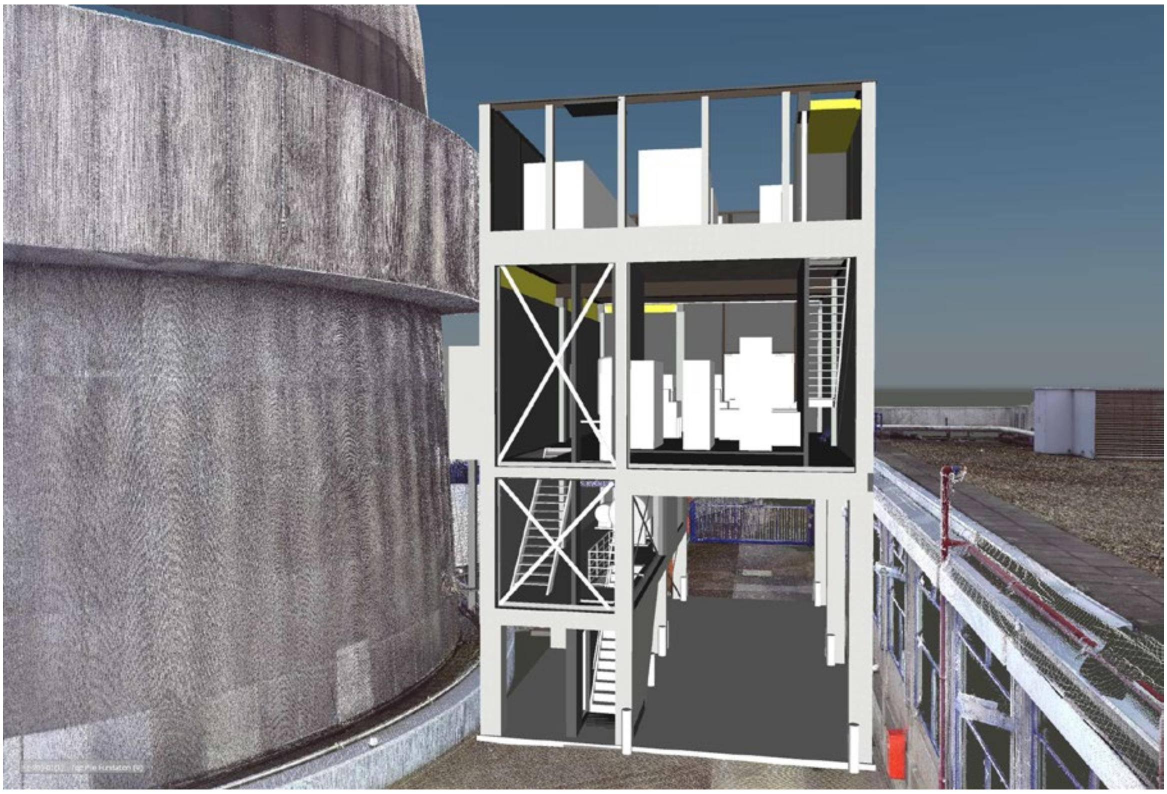
Realisation of the CNS utility building

Local Dutch suppliers will be responsible for the realisation of the civil works needed for the

>>

>> CNS utility building. The basic design is currently being optimised to better define the locations of the equipment and to improve how pipes and cables pass through the containment, in compliance with the new Dutch Safety Requirements (DSR) rules. Detailed design has also started for the instruments and control technology.

DH Industries has been selected to install the cryogenic Stirling-type cooling system. Kreber will install the specialised vessels. Strukton has been assigned to do the civil works and the overall supervision during the building of the non-nuclear part. Demaco will provide the cryogenic piping.



Review

Photo: An impression of the CNS utility building which will be built next to the reactor hall.

In 2016, focus of the OYSTER activities was mainly on the contract definition and schedule negotiation processes between RID, KHC and subcontractors. As a result, the involvement of the external expert team members was temporarily limited, except for the optimization of the cold source. Detailed engineering for the CNS facility will start once the negotiation process has been finalised. The role of the expert team will therefore become more important again in 2017.

The external expert team

As part of the OYSTER project, many technical discussions are taking place between RID, supplier and contractors. In order to have sufficient knowledge available to judge their proposals an "External Expert Team" has been established. The team became operational in 2014 and is comprised of external specialists who assist RID in handling the various technical issues.

In 2016, the External Expert Team (EET) 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

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

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

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

Robert F. Mudde

- Affiliation: Professor of Multiphase Flow, Department Chemical Engineering, Delft University of Technology.
- Expertise area: Multiphase flows
- Focus within EET: Heat and mass transfer, hydrodynamics

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 OYSTER, this permit will need to be renewed. Therefore, an important aspect of the OYSTER project concerns the licensing of the new instruments and reactor modifications. Since 2013, RID has been working on the licensing procedures and associated review schedules with the relevant regulatory body, the Dutch Authority for Nuclear Safety and Radiation Protection (ANVS). Key parts of the formal license application will be a Safety Report, a Safety Analysis Report and an Environmental Impact Assessment (MER, *milieueffectrapportage*).

Apart from this license, the regulatory body reviews the license request for the CNS utilities building with its non-nuclear equipment.

Safety Report and Safety Analysis Report

A Safety Report will be part of the license application in order to demonstrate that the reactor including the OYSTER modifications can be operated safely. The supporting documentation for this report, e.g. detailed drawings, analysis reports etc., will be part of a separate document: the Safety Analysis Report. The discussions and drafting of these documents started in 2014, and part of the chapters have been sent to ANVS in 2015 and 2016 for review. The reports will be finalised in 2018 and will be part of the license application for the new operating permit.

Environmental Impact Assessment (MER)

The preparation of the Environmental Impact Assessment (in Dutch: *milieueffectrapportage*, MER) started in 2013, when the external centre of expertise NRG was selected to prepare the assessment on the basis of the MER guidelines

for the OYSTER project (*Notitie Reikwijdte en Detailniveau*). The first chapters of the MER were drafted and discussed with the ANVS in 2015. Other chapters are waiting for additional information from the OYSTER project. The MER will be finalised in 2018 and will be part of the license application for the new operating permit.

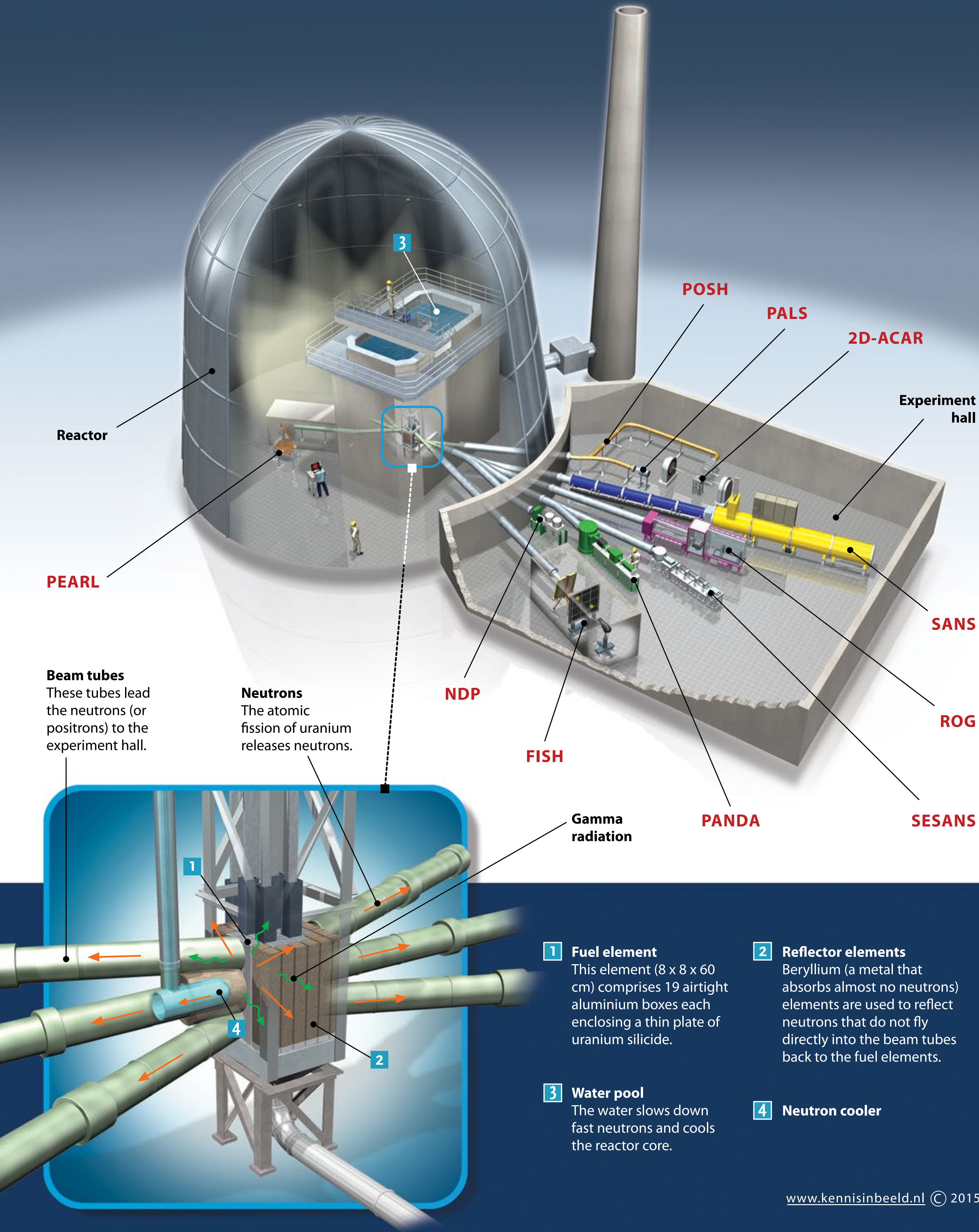
Dutch Safety Requirements (DSR)

New and more stringent Dutch Safety Requirements (DSR) for new nuclear reactors were presented in June 2013, and the Dutch nuclear community was invited to participate in the discussion with the Dutch regulator by providing advice and comments in terms of the further development of these new requirements. Finally, the formal publication of the DSR was in October 2015. This development has impact on the OYSTER planning. Because the DSR legislation formed an important aspect in the contract conditions between the consortium KHC and TU Delft, the project schedule for OYSTER was delayed. The DSR is part of the legal basis for the contract agreement between the KHC consortium and TU Delft. The DSR is also being implemented in the Safety Analysis Report, which will be finished in 2018.

OYSTER EXPANSION

Measurement instruments

around the research reactor



1 Fuel element
This element (8 x 8 x 60 cm) comprises 19 airtight aluminium boxes each enclosing a thin plate of uranium silicide.

2 Reflector elements
Beryllium (a metal that absorbs almost no neutrons) elements are used to reflect neutrons that do not fly directly into the beam tubes back to the fuel elements.

3 Water pool
The water slows down fast neutrons and cools the reactor core.

4 Neutron cooler

Instruments

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

- PEARL – a new neutron powder diffractometer (new)
- POSH-PALS – new positron annihilation lifetime spectroscopy, using positrons by POSH (new)
- POSH-ACAR – Positron Angular Correlation of Annihilation Radiation - (upgrade)
- ROG – upgrade and relocation of the time-of-flight neutron reflecto-meter to a cold beam line (upgrade)
- SANS – a new small-angle neutron diffractometer with a dedicated cold beam line (new)
- NDP – neutron depth profiling spectrometer (upgrade)
- FISH – a new multi-purpose neutron imaging facility (new 'baby'-FISH)
- SESANS – upgrade of spin-echo labelled SANS, a unique Delft instrument (upgrade)
- Mössbauer Spectroscopy – upgrade of the existing spectrometer (upgrade)

On the next page we explain what each of the instruments does (or will do), progress achieved in 2016 and prospects for 2017.

Neutron powder diffractometry – PEARL

(new instrument since 2015)

PEARL is a newly built neutron powder diffractometer, used mainly to very accurately determine the crystal structures of materials of relevance to the area of sustainable energy production, such as new generations of batteries. While X-ray diffraction is a widely used technique, neutron diffraction is complementary as neutrons are particularly sensitive to light elements and can distinguish light elements in crystal structures that contain both light and heavy atoms. Furthermore, magnetic structures and magnetic moments in the crystal can be accurately determined.

Progress 2016:

- Over the course of 2016, in-house research on PEARL focussed on solid-state electrolytes (garnets, argyrodites) and cathode materials for Li batteries, to correlate the atomic structure, site occupancies and mobility with conductivity and storage capacity properties of the materials. As well, first experiments were performed on battery cells while operational (in-operandi diffractometry).
- Crystal structure, occupancies and magnetic moments were measured in Fe2P-based magneto-calorics, varying stoichiometry and doping to tune the magneto-elastic transition. Magneto-calorics hold much promise as a new way to achieve refrigeration. In contrast to current compressor-based refrigeration, magnetic refrigeration does not involve harmful gasses, can be more energy-efficient and generates much less noise.
- The first experiments were performed on spintronics (Mn3Ga) and Heusler alloys, which are materials of interest to new generations of electronics.
- Different phases of nuclear materials (Cesium molybdenates) were investigated in the framework of fast reactors where the solid-state chemistry depends on the occupancy and linkage of oxygen.
- Based on in-house research, new international collaborations were initiated and established with several universities in: China (Tsinghua, Chinese Academy of Science), the US (Cornell, Columbia), France (Sorbonne), Canada (Quebec) and Sweden (Uppsala). Within the Netherlands

PEARL is used in collaborations on thermo-electrics (Groningen), batteries (Utrecht and Twente) and catalysis (Utrecht/Albemarle) and the first commercial experiments were performed. Read the interview with professor Eelco Vogt on how PEARL makes the crucial difference!

- In September 2016, a very successful Debye-Rietveld Symposium took place in Amsterdam, together with the Dutch Crystallographic Society (NVK) and Shell, to celebrate the Dutch contributions of Peter Debye (1884-1966) and Hugo Rietveld (1932-2016) to progress in the area of powder diffraction, 100 and 50 years ago, respectively.
- PEARL was presented at several colloquia in the Netherlands, the European EPDIC conference and at several companies. As a follow-up, the Dutch Crystallographic Society held its annual meeting at the RID in December 2016.

Prospects 2017:

For 2017 we expect to further broaden the research in batteries, magneto-calorics and nuclear materials, partially based on the experience and results from current experiments, but also due to expanded and improved sample environment capabilities. New collaborations with external partners are being pursued and we will organise and host the first national hands-on workshop for neutron and X-ray powder diffraction for PhDs, postdocs and industry. Based on the experiments of 2016 we expect a significant increase of the scientific output of PEARL in 2017. The licence is expected in 2019.

Photo: Debye-Rietveld Symposium Amsterdam, September 2016

Positron Annihilation Lifetime Spectroscopy - POSH-PALS

(new instrument)

Positron Annihilation Lifetime Spectroscopy (PALS) is a unique method to reveal the presence and properties of ultra-small open-volume defects, with dimensions ranging from atomic-scale vacancies up to nanometre-sized vacancy-clusters and voids. These 'holes' inside materials may have a large impact on the materials functionality, for example when used in the area of sustainable energy production and storage. As an example, recent research into novel photovoltaic materials has shown that such defects play a significant role in the long-term efficiency and stability of thin-film amorphous-Si and perovskite-based solar cells. In general, the size of these defects is too small and their concentrations too low to be detected by more common X-ray diffraction and (transmission) electron microscopy techniques. Since the positron annihilation rate is highly sensitive to the presence of defects, the PALS technique is eminently suited for the characterisation and evolution of these defects.

Progress 2016

At the end of 2015, computer simulations defining the electrostatic positron-beam transport system and the high-resolution positron and secondary electron timing system were completed. Early 2016, the coupling of the PALS spectrometer to the reactor-based high-intensity positron beam (POSH) was realised and first studies on the efficiency and stability of selected moderator foils and positron-beam focusing and transport elements were carried out successfully.

Prospects 2017:

For 2017, the implementation, testing and optimisation of the timing system with an expected resolution of 250 picoseconds and overall commissioning of the POSH-PALS set-up for state-of-the-art thin-film positron lifetime studies is foreseen. In parallel, innovative high-efficiency detectors with high-resolution timing properties (~100 picoseconds) are being developed that will enable future beyond-state-of-the-art positron lifetime and Doppler studies.

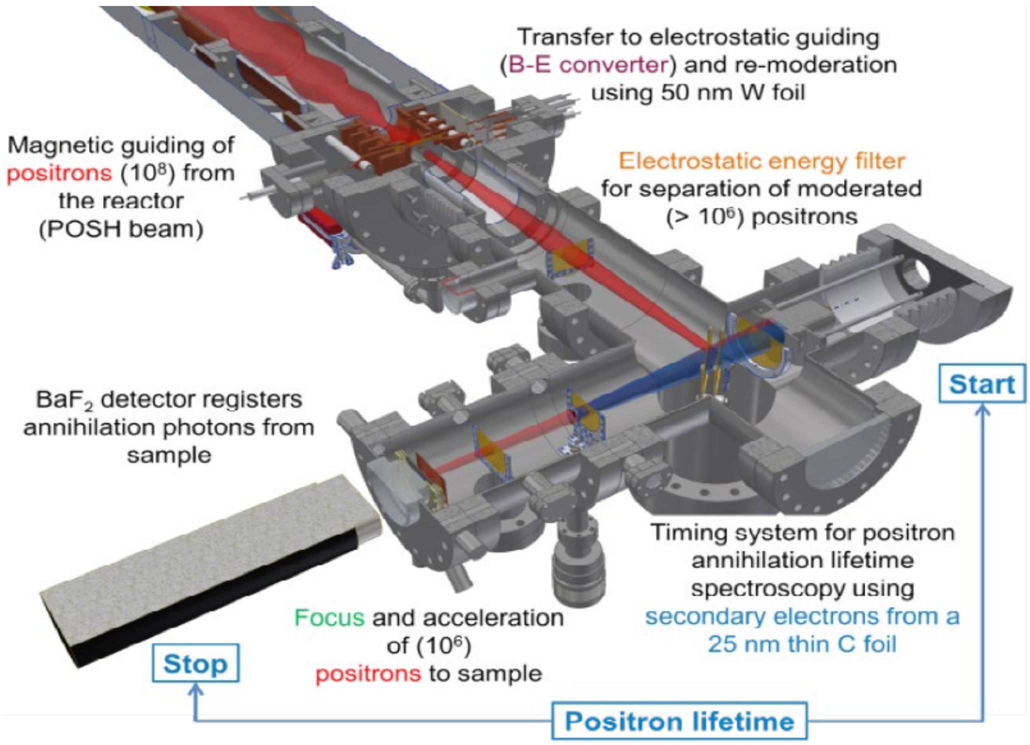
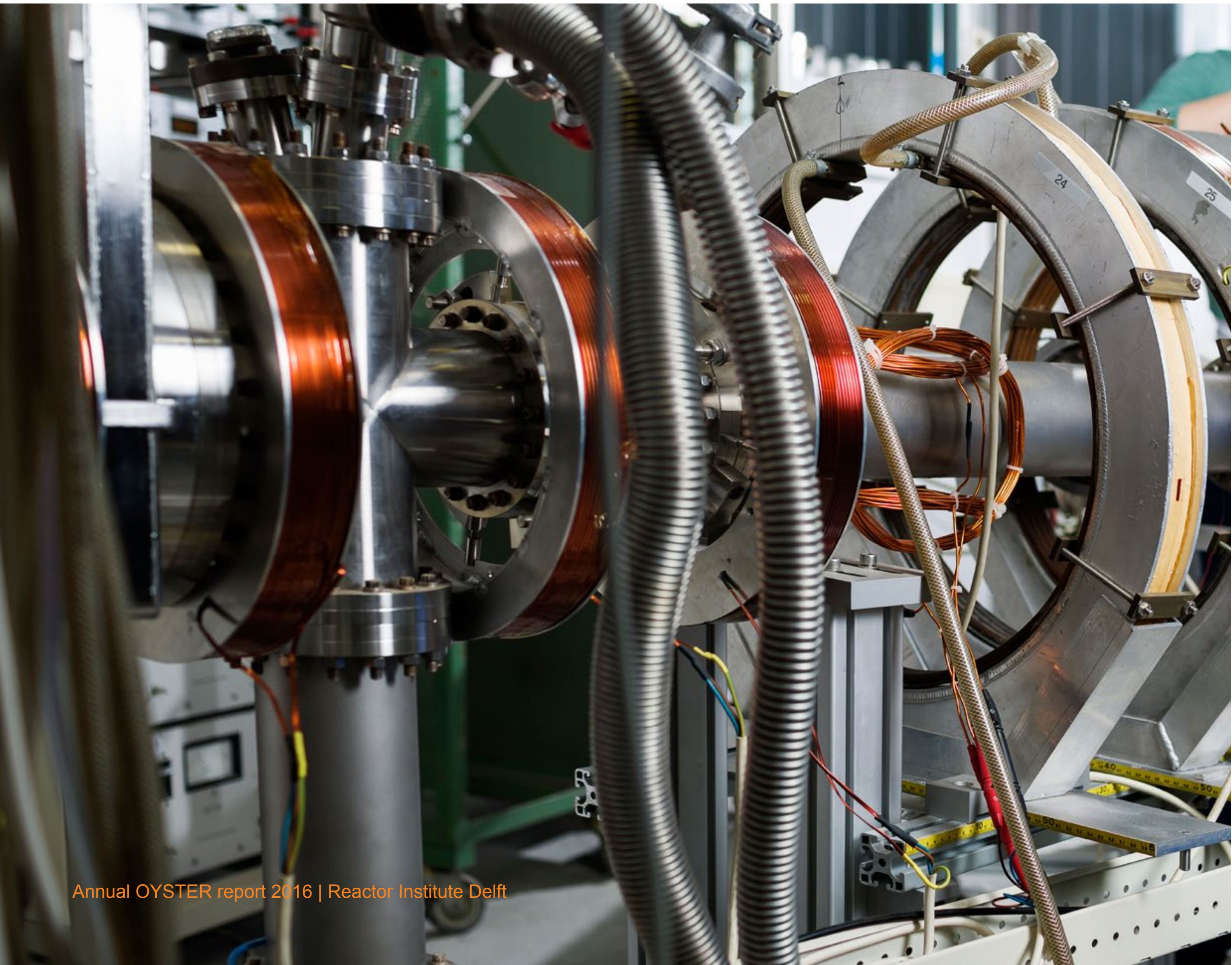


Figure:
The electrostatic guiding and timing system of the POSH - PALS set-up

Positron Angular Correlation of Annihilation Radiation - POSH-ACAR

(upgrading instrument)

Photo: The reactor-based high-intensity
POSH positron beam



Positron Angular Correlation of Annihilation Radiation (ACAR) is a technique to investigate the electronic structure of materials such as metals. At RID, a setup for two-dimensional (2D) ACAR is connected to the POSH positron source, offering unique research capabilities for studies of semiconductor quantum dots (QDs), which are highly promising building blocks for future generations of solar cells. QDs combine the advantage of low fabrication cost (owing to cheap and easily scalable chemical synthesis methods) with the prospect of reaching very high solar-cell efficiencies. A goal within OYSTER is to improve detection of POSH-ACAR setup using new detectors, increasing the count rate by a factor of 100.

During the last five years, an absolute increase in solar-cell efficiencies of more than 1% per year was witnessed, and solar-cell devices based on PbS QDs reached efficiencies higher than 10% in 2016. In order to ensure continued growth in efficiencies, proper passivation of the surfaces of the QDs with suitable ligand molecules is vital. Furthermore, long-term oxidation forms a major challenge to maintain high efficiencies during the required solar-cell lifetimes of more than 30 years.

Here, the 2D-ACAR facility POSH-ACAR at RID offers unique capabilities to determine in a non-destructive manner the attachment of ligand molecules to the semiconductor quantum dots, owing to the extremely high surface sensitivity of positron annihilation spectroscopy. Furthermore, the accessible depth range of 5 - 1000 nanometres makes POSH-ACAR very suitable for depth-resolved studies of these thin-film QD solar cells.

Progress 2016:

In 2016, studies by scientists at RID in close collaboration with colleagues of the Department of Chemical Engineering at TU Delft revealed that the attachment of oleic acid ligands to PbSe QDs occurs via oxygen binding to Pb surface atoms. Further, long-term surface oxidation was sensitively monitored with a very high surface sensitivity. It was found that the harmful oxidation can be reduced significantly by chemical passivation of the surfaces of the PbSe QDs by introduction of chlorine during the synthesis, as it acts as a strong binding agent to the Se surface atoms.

Prospects 2017:

The sensitive monitoring of these promising new thin film solar-cell devices using POSH-ACAR in combination with guided optimisation of chemical synthesis methods is expected to lead to a complete elimination of surface oxidation. The ongoing research programme includes a wide range of promising thin-film solar cells such as CIGS solar cells and the emerging class of perovskite solar cells, as well as transparent conductive oxide electrodes for solar-cell applications.

Neutron reflectometer – ROG

(upgrading instrument)

Neutron reflectometry is a technique that provides key information about the composition and concentration profiles at material interfaces. Neutron reflectometry yields information about nano-scale structures of surfaces, interfaces, and thin films that cannot be obtained by other techniques. It will contribute to many scientific challenges, such as improving the biocompatibility of joint replacements, drug-delivery systems, hydrogen sensing storage systems, and magnetic films for information storage and read out. While RID already has a neutron reflectometer instrument, OYSTER will allow it to be used in conjunction with cold neutrons, thereby greatly expanding the possibilities.

Progress 2016:

In 2016, funds have been made available to start the ROG project within OYSTER.

Prospects 2017 and beyond:

To realise ROG, it will be necessary to modify the existing instrument and move it from a beam position in the reactor hall to a cold-neutron-beam position in the experimental hall. The project will start in 2017. It is projected that, in 2019, it will deliver a modified ROG with an overall increase of performance of two orders of magnitude. The main contribution to this increase is a higher neutron flux and spectrum shift to larger wavelength, as a result of the cold neutron source, and the replacements of all neutron-optical elements, including a long focussing neutron guide.

Photo: The ROG instrument in the reactor hall.

Small-angle neutron scattering instrument - SANS

(new instrument)

The small-angle neutron scattering (SANS) technique allows users to investigate structures with particles of sizes from 1 up to a 100 nanometres. The neutron scattering is a direct result from local variations in chemical composition or magnetisation. For larger particles, the neutrons scatter under smaller angles. This allows for a direct characterisation of the particle-size distribution within the material. Using this technique, typically proteins, micelles, polymers, porous media and precipitates are investigated, which are of interest for the development of new products in the field of polymer science, colloids, emulsions, food science and metal alloys.

Progress 2016:

Awaiting the modification of the reactor and the installation of the CNS, the instrumentation of the SANS instrument reached further completion. In 2016, the velocity selector was tested.

Prospects 2017:

In 2017, the calibration of the instrument will be performed using the thermal neutrons of the current reactor source. In the period before installation of the CNS, the instrument gives us the opportunity to study strongly scattering samples and enable preliminary neutron imaging studies.

Photo: The SANS instrument

Neutron depth profiling - NDP

Li ions are becoming increasingly important in our daily lives as they are at the heart of the technology that powers our portable electronics and electrical cars. In the search of new materials and design solutions to improve battery performance, neutrons from the reactor play an important role as they can be used to monitor Li ions inside working batteries. Specifically with the technique of Neutron Depth Profiling (NDP), scientists are able to see where the Li ions are as a function of time, and how their motion is related to the battery performance.

Progress 2016:

In 2016, our researchers collaborated with colleagues at Northwestern University combining Focused Ion Beam - Scanning Electron Microscopy (FIB-SEM) with NDP to relate the microstructure of Li-ion battery electrodes with NDP observations. This allowed detailed understanding of what parameters are important to improve the charge rate of Li-ion battery electrodes. Improving the electrode morphology by templating, thus creating microscopic pathways for Li-ion transport, improves the amount of Li ions that the electrode can deliver. The fact that, in the case of the templated electrode, the distribution of Li ions throughout the battery is more flat provides insight into why these templated electrodes function better, giving direction to future electrode design. Parallel to this, the researchers in Delft are working on models to predict the Li-ion transport in batteries, which will be validated by comparing their outcomes with the NDP results.

Prospects 2017:

In the coming year, the researchers aim to investigate the first working solid-state batteries using NDP. Furthermore, in collaboration with Prof. H. van der Graaf (Nikhef and RST), novel detector designs are now being considered that can extend the possibilities of NDP, making it more suitable for measuring working batteries.

Photo: Battery testing facilities in the Battery Lab

First Imaging Station Holland - FISH and "Baby FISH"

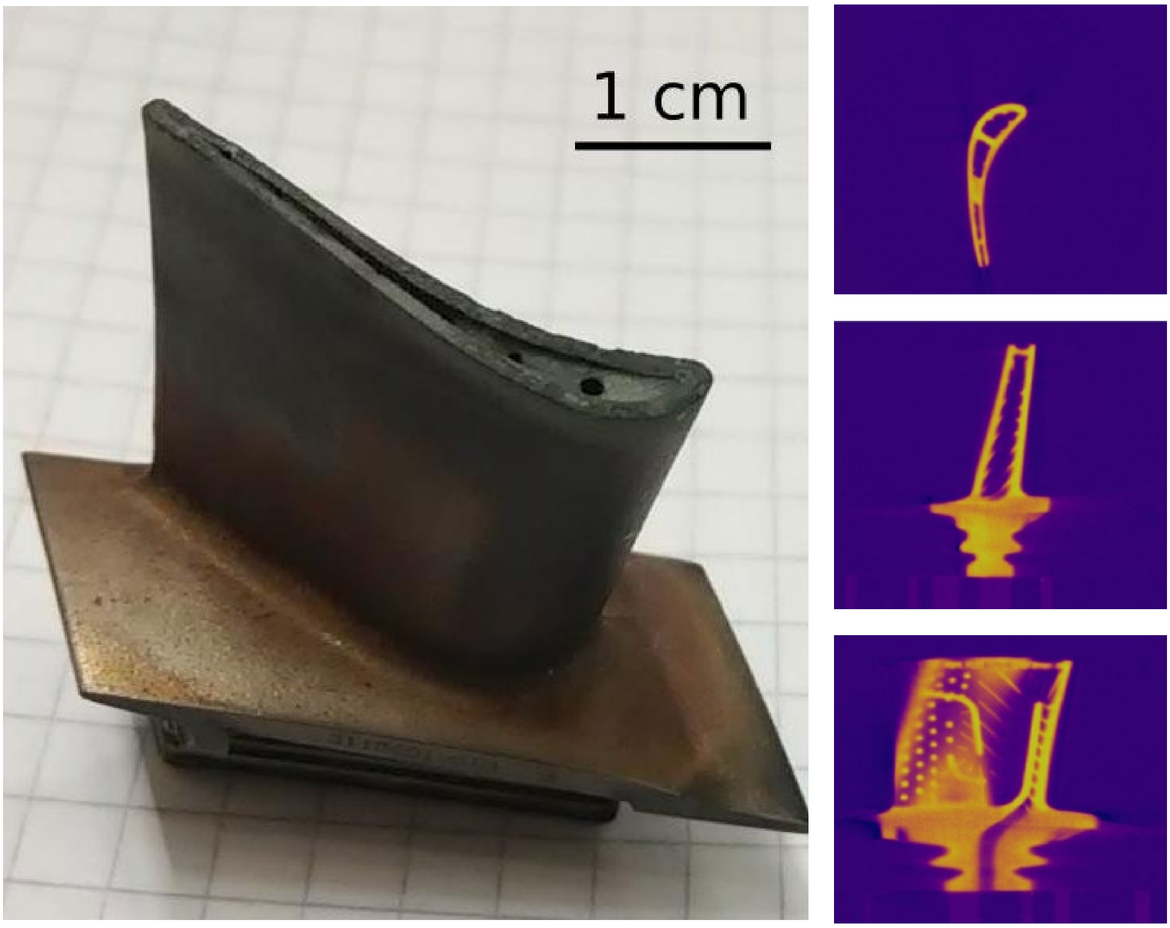
(new instrument)

First Imaging Station Holland (FISH) will be an imaging station where neutron radiography and tomography can be performed. This combination of techniques is very comparable with X-ray imaging/tomography; however, using a neutron beam from the reactor as a source gives a unique contrast, revealing elements and materials that are hard to detect with other imaging techniques. Especially light elements like hydrogen and lithium give a good contrast, even within a metal housing. This opens up possibilities in a large field of applications like solar cells, batteries, agricultural research, cultural heritage, fuel cells and material bonding (glue/composites, welding, and metal 3D printing). FISH will serve science and engineering in academia as well as industry.

Progress 2016:

In early 2016, we have upgraded a general test beamline to a permanent imaging station called "Baby FISH" which is a start-up version as we are working to acquire funding for FISH. Thanks to a small budget we are able to continue our work and now enjoy full capability to perform neutron tomography with modest resolution. We have been working on a self-developed low-budget detector, which led to a steep learning curve. Significant time was invested in data treatment (skills), as an essential component of imaging, and this made 2016 the year where we became confident to welcome external users for the FISH setup. This milestone was successfully confirmed towards the end of 2016 by our first commercial user, working in the field of solar cells.

Photos: Turbine blade of jet engine. Potential blocking of cooling channels can be investigated for instance.



Prospects 2017:

- We have started a collaboration with our Swiss colleagues who have a very strong neutron imaging group at the Paul Scherrer Institute (PSI) (https://www.psi.ch/niag/what-is-neutron-imaging). This opens up the possibility to collaborate in joint projects and to build up a showcase for FISH within the Netherlands.
- Further we expect to continue with existing collaborations and anticipate a shift in beam time use from testing/learning to dedicated scientific and commercial users.
- We also envision that 2017 will be a deciding year with respect to the continuation of the FISH project. Prominent topics will include technical design decisions, required budget and possible funding.

Spin-echo small-angle neutron scattering - SESANS

(upgrading instrument)

Photo:
The SESANS instrument

Spin-echo small-angle neutron scattering (SESANS) 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. 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 2016:

- In 2016 we have characterised the effect of processing of proteins on its microstructure to create new food materials that mimic meat, but are animal friendly and more sustainable.
- We determined the effect of mechanical processing of cellulose to improve the conversion into biofuel.
- With Shell we investigated the process of enhance oil recovery.
- We quantified the effect of salinity on micro-emulsions of crude oil and brine with industrial surfactant mixtures.

Prospects 2017:

In 2017, we will investigate more food materials, such as lipids. We will 3D-print rotating sample cells to be able to study creaming or sedimenting dispersions. We will also build new pole shoes on the electromagnets from softer iron, in order to have better and faster control of the magnetic fields, which will yield a higher polarisation and thus a higher information content of the measurements.

Mössbauer spectroscopy

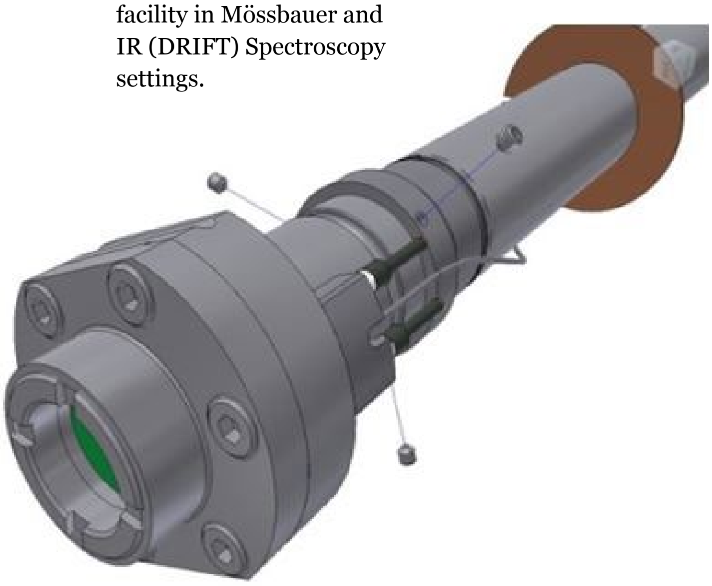
(upgrading instrument)

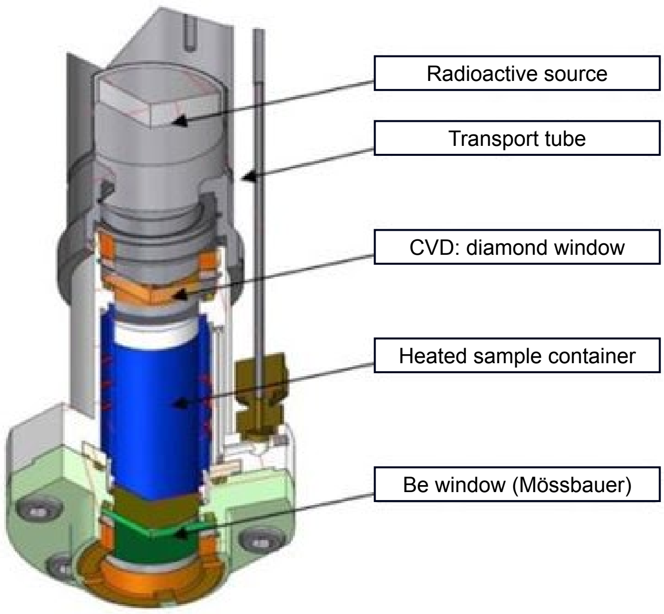
The in-beam Mössbauer instrument will expand the amount of elements which we can probe using Mössbauer spectroscopy and will be a unique facility in the Netherlands. The instrument has the possibility to open up new capabilities with applications in catalysis allowing studies into previously inaccessible elements such as potassium.

Progress 2016:

The position in and impact of Mössbauer spectroscopy on the catalysis community in the Netherlands has significantly strengthened during the past year. Making use of the unique, state-of-the-art facility for combined Mössbauer/infrared spectroscopy, collaborative partnerships have been initiated and continued with strong catalysis groups from TU Eindhoven, Utrecht University and TU Delft. The collaboration projects include also major industrial partners like: Shell Global Solutions, Johnson Matthey and Dow Chemical. The obtained Mössbauer results were included in several scientific publications during the last year. >>

Photo: The combined materials characterization facility in Mössbauer and IR (DRIFT) Spectroscopy settings.





>> Furthermore, in 2016, the collaboration project with Johnson Matthey on the study and development of new (chromium-free) water-gas shift (WGS) catalysts was continued. The WGS reaction is an important industrial reaction that is used in the manufacture of ammonia, hydrocarbons, methanol, and hydrogen. It also has potential to increase the efficiency of hydrogen fuel cells, which is of particular interest to the field of sustainable energy production. During this project, we will also manufacture additional Mössbauer/IR cells, using high-resistance nickel-base alloy, to increase their working pressure from 20 to 40 bar.

Prospects 2017:

In 2017, we will start working on the development of the neutron in-beam Mössbauer spectroscopy facility, using it specifically to study promoted catalysts for the Fischer-Tropsch reaction. This particular reaction is currently being studied as a way to produce high-quality sulphur-free synthetic diesel fuels from natural gas. The search for alternatives to non-renewable energy such as crude oil, and for sulphur-free fuels is an emerging field of study to scientists and researchers all over the world.

Upcoming technique development involves the optimisation of the usable neutron flux and gamma background by careful neutron beam port selection. We will proceed with the design of a setup to explore various concepts such as gamma background and focusing neutron guides. We will also exploit the wealth of in-house expertise in detectors to investigate energy discrimination to increase the sensitivity of the technique and improve the efficiency. In parallel with this we will investigate the feasibility of different classes of experiments with industrial partners.

Photo: Instrument scientist Iulian Dugulan

Faster and cleaner molybdenum-99 (^{99}Mo) production routes

Isotopes are used for a wide range of medical applications. Worldwide, each year, about 30-40 million clinical radiodiagnostic scans are made using technetium-99m (^{99m}Tc). ^{99m}Tc can be derived from its parent isotope molybdenum-99 (^{99}Mo). The challenge therefore is to produce sufficient 99Mo in an efficient and reliable way. Most 99Mo is currently produced by fission of uranium-235 (^{235}U). To do so, solid targets containing ^{235}U are irradiated in a nuclear reactor. 6.1% of the fission reactions lead to ^{99}Mo.

Researchers at the RID now investigate the feasibility of producing ^{99}Mo by irradiating a uranyl nitrate solution in a U-shaped loop located near the core of the reactor. Recent research has shown that the uranyl nitrate solution inside such a U-shaped loop could run continuously for more than 20 years without the need for refilling. In contrast with irradiating solid targets, this innovative approach supports online

Irradiation facilities

Flexible radiation facility - FlexBefa (new facility)

A key capability of the RID is to irradiate samples, exposing them inside the reactor to neutron radiation, for example to investigate how radiation induces material damage or to produce novel production routes for medical use.

A new and flexible radiation facility (FlexBefa) has been developed, which is expected to have great impact, both directly and indirectly.

For example, the first direct impact is the use of this facility to reduce the damage to polymeric microspheres containing radioactive Holmium-166 (^{166}Ho) used for intra-arterial liver cancer treatment. In this type of treatment, Holmium is encased in microspheres and irradiated with neutrons such that it becomes radioactive. The microspheres are essential in allowing the Holmium to travel through the arteries towards the tumour, where the radioactivity helps destroying cancer cells. The new radiation facility is designed to reduce gamma damage for different research purposes. In the case of Holmium the facility allows achieving

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extraction and therefore significantly reduces the post-processing time. Future research will concentrate on optimising microfluidic solvent extraction to selectively and continuously extract 99Mo from the irradiated uranyl nitrate solution.

To maximise production, the concentration of uranyl nitrate should be as high as possible. Due to the high concentration, however, the produced heat (a consequence of fission heat and the interaction of gamma radiation with construction material) in the facility will result in the temperature of the solution exceeding the boiling point. Therefore, another focus of further research is enhancing the heat-transfer process and cooling the U-shaped loop more effectively, so that higher uranyl nitrate concentrations can be used.

After the research and demonstration phases, the new production process of ^{99}Mo is aimed to be implemented in large-scale facilities such as the High Flux Reactor in Petten or PALLAS.

>> larger activities of it while preventing damage to the enclosing polymeric microspheres. This enables improved treatment of patients and the possibility to maintain sufficient radioactivity for a longer time, which, in turn, offers the possibility to ship the microspheres further away, reaching patients outside the Netherlands.

The facility will have indirect impact by opening up exciting new research options for the future. An example of such research is the production of carrier-free Molybdenum-99 (^{99}Mo) using the so-called Szilard-Chalmers method and paving the way to new routes for 99Mo production, which can help to reduce future shortage of 99Mo and of its daughter Technetium-99m (99mTc), the most used radionuclide in clinical diagnostic imaging.

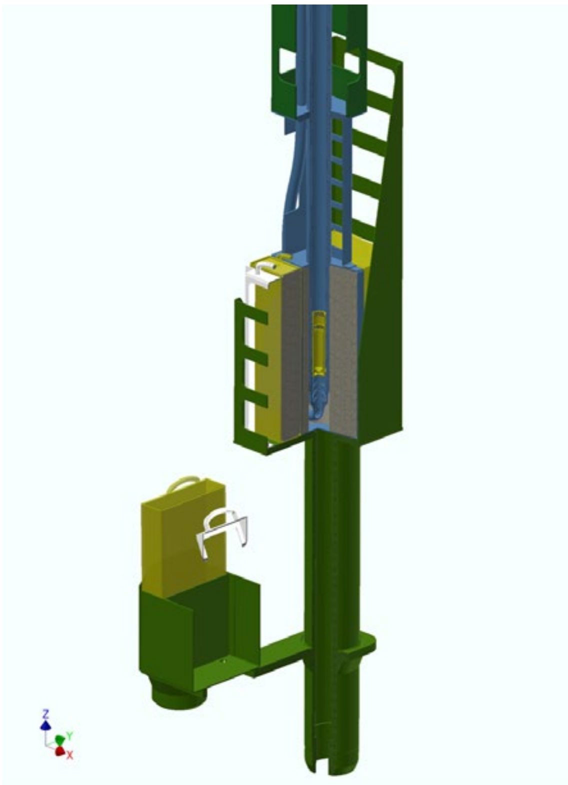


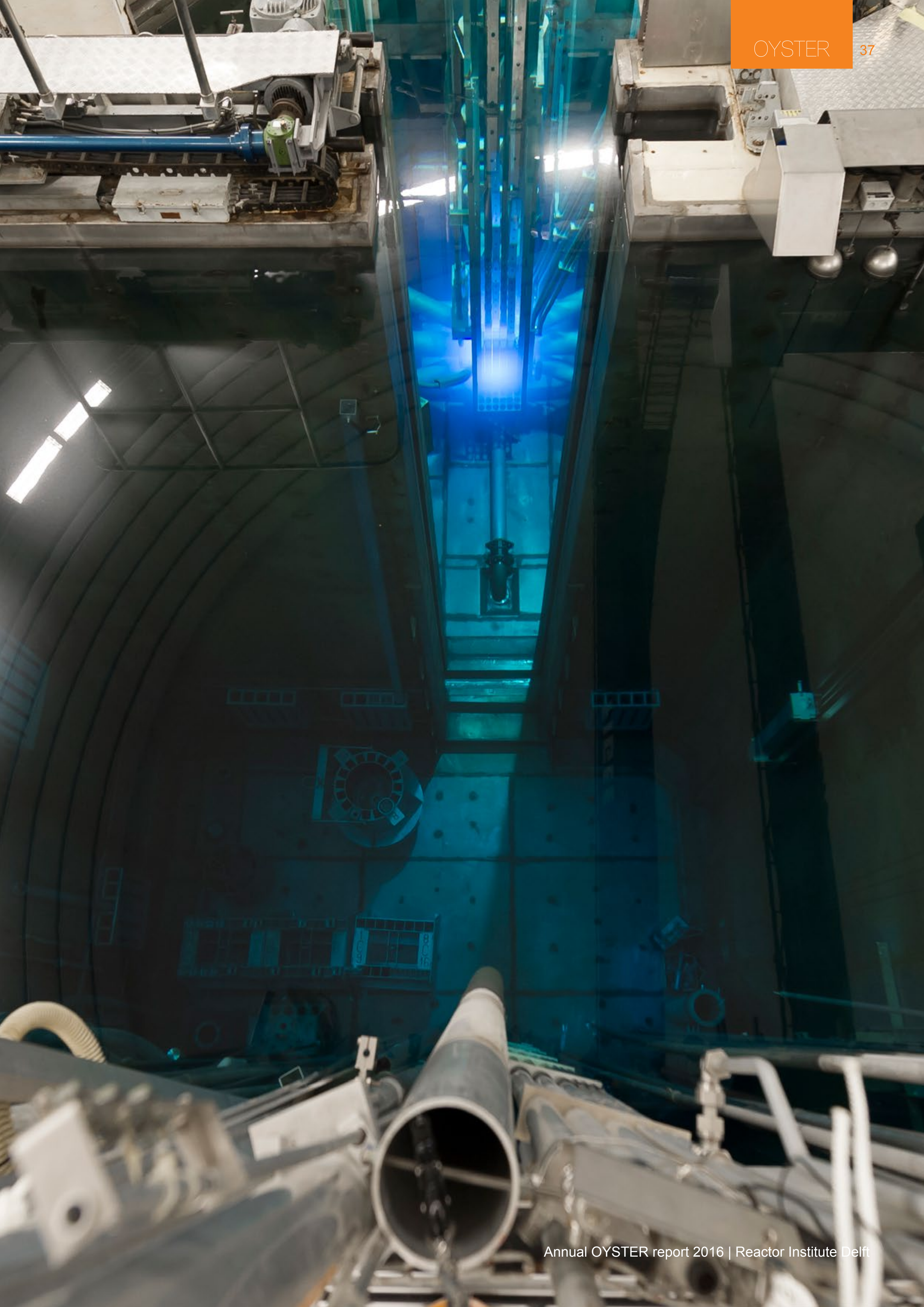
Photo: Full assembly flexible faciity (FlexBefa)

Progress 2016:

In 2016, the design of the FlexBefa was completed, after which the facility was constructed.

Prospects 2017:

The facility is expected to be moved into place in the beginning of 2017 (February) and to be used as of the end of March 2017. The first samples that will be irradiated are the Ho-165 microspheres. We plan to vary the irradiation time and determine the radiation damage to the spheres. In addition, we plan to add a cooling system to the flexible facility and perform simulation studies to determine the fluxes or relevant radiation fields when using different materials, e.g., nickel shielding instead of the lead as used in the first configuration of the facility.



NDP takes a close look at chromate-free coating technology

Peter Visser
AkzoNobel

Tomas Verhallen
PhD researcher RID

How does lithium move in (and out) of airplane coating in various aging methods? This is the question Peter Visser and Tomas Verhallen are trying to answer with Neutron Depth Profiling (NDP). The objective: estimating the lifespan of airplane coatings on the basis of lithium inhibitor technology.

The questions asked are pressing, as the aviation industry is thoroughly searching for chromate-free coating technology with a lifespan of at least 30 years. Visser: "Corrosion protection is vital in the aviation industry. Corrosion inhibitors used in coatings are adopted for this. These inhibitors are essential because of their anticorrosive properties."

How can you prove that a material you develop in five years can easily last for 30 to 40 years?

Peter Visser is Group Leader Undercoats Aerospace at AkzoNobel while also working on his doctorate at faculty 3mE at the Department of Materials Engineering. In this manner, Visser focuses on the development of coating systems for the aviation industry, specialising in corrosion protection. Tomas Verhallen works as a PhD researcher at the RID on Li-ion batteries. The work described here is thus a good demonstration of the strength of interfaculty TU Delft and industrial-based research.

In this regard, AkzoNobel carries out a lot of research and has already launched several chromate-free coating systems. These are, however, only certified for use on the outside of airplanes. Alternative coating is required to protect the structural parts of the inside of airplanes. What makes it extra complex: this coating must remain intact throughout the lifespan of an airplane; the outside is easy to inspect regularly, the inside isn't.

Photo: Peter Visser (l) and Tomas Verhallen (r).

In his PhD research Visser focuses on coatings for the protection of aluminium alloys on the basis of lithium inhibitor technology. This technology is already patented by AkzoNobel and looks promising in the required industrial tests. Now, however, it must be proved that the new technology performs as good as current coatings throughout the lifespan of an airplane, with a proven record of service. In short: how can you prove that a material you develop in five years can easily last for 30 to 40 years?

In order to fundamentally fathom the new technology, AkzoNobel and TU Delft use Neutron Depth Profiling (NDP). Verhallen: “With NDP we look at the absorption of neutrons, instead of diffraction, like most techniques. We therefore look at particles that arise as soon as a neutron is absorbed by a lithium atom and lithium 6 in particular. If this atom is hit by a neutron, it breaks up into two new particles. The energy we measure with these particles says something about where the lithium 6 was initially.”

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>> "In this case, we can see with NDP how much lithium is in the coating, where it is and how deep the coating is affected in various aging techniques", continues Verhallen. "Furthermore, we can follow the same sample through time, which is essential. The strength of the absorption technique is also that it is specifically susceptible to lithium – an element that cannot be seen with conventional techniques in materials science, like X-rays."

Coating has two functions: it acts as a barrier between the aluminium and the aggressive environment, also known as passive inhibition.

If there is a tear or scratch, another mechanism should occur, namely active inhibition: the corrosion inhibitor in the coating then has to move towards the defect. Visser: "In our research together with TU Delft we already managed to demonstrate this active inhibition of the lithium

Prof. Eelco Vogt

"The PEARL makes the crucial difference"

Prof. Eelco Vogt is research consultant at Albemarle Catalysts and professor by special appointment at Utrecht University.

Traditional research methods see no difference between elements like silicon, aluminum and phosphorus. "The PEARL neutron powder diffractometer can make that distinction, and this is exactly what we need," says Prof. Eelco Vogt, a research consultant at Albemarle Catalysts and professor by special appointment of Catalysis of Refinery Processes at Utrecht University.

Vogt conducts basic research on catalysts that can be applied to sustainable refining processes. "At Albemarle, we carry out large-scaled research on catalysts. Part of this research is aimed at improving analytical techniques. We usually examine our catalysts by means of x-ray diffraction, electron microscopy and infrared spectroscopy. These conventional techniques, however, are sometimes insufficient. When Lambert van Eijck inhibitor. In case of damage, our inhibitor dissolves in water and a protective layer of aluminium hydroxide is created, which passivates the defect."

To get from concept to practical use, knowledge is a decisive factor. Visser: "If you want to launch a new material then fundamental knowledge is necessary, and understanding of the protection mechanism. Only then will a customer become convinced that the material can be used industrially. Thanks to NDP and the unique collaboration between the academic world and the industry we can soon provide this. We can even already see a spinoff: other industries using aluminium also follow our research and want to apply lithium inhibitor technology to their applications."

at the Reactor Institute Delft asked us if we would be interested in conducting research into neutron diffraction, we were quick to respond. Soon thereafter, Lambert's small demonstration project expanded to become today's research project."

Zeolite

Vogt and his colleagues focus their research on zeolites: a class of materials made of silica and alumina that have a special pore system at the molecular level. Combining a zeolite with phosphorus improves this material's stability. Vogt: "We want to know exactly where the three elements are in relation to each other. But we also want to know where the pores are located since they are so important for catalysts. You can't get to the bottom of this with standard techniques like x-ray diffraction; they see the three elements as a single atom type, because they are located next to each other in the periodic table. With neutron diffraction, however, this distinction is made clear, and this is crucial for our research."

The catalyst that Vogt is examining is necessary for the fluid catalytic cracking process that is used to crack oil molecules in refineries. "Some refineries want to produce gasoline from heavy oil fractions. Other refineries use these heavy oil fractions to make raw materials for polymers such as propylene. The difference between producing gasoline or propylene depends on the addition of this special catalyst. Every year, tens of thousands of tons of this catalyst are used to produce tens of millions of tons of product. This means that the basic material research we are conducting using the PEARL measuring instrument has a huge commercial application. Everything we learn can be applied directly to obtain even better catalysts - and this is precisely the subject of my endowed professorship: to consolidate the basic research being conducted on the most widely used materials."

Pioneering work

The application of the PEARL to measure the materials used by Vogt was also new to Lambert van Eijck, so >>

“The basic material research that we are conducting using the PEARL in Delft is directly applicable to important commercial operations.”

Prof. Eelco Vogt

>> this required some pioneering work. “As usually happens in the beginning, the practical aspects are proving more complex than we had thought. For one thing, we need to find out exactly how to adjust the diffractometer to obtain the best possible signal. With our experiments, we’re trying to discover the limitations of what the PEARL can achieve and also how the settings influence the pattern. That takes a bit of time and special software that we are developing with an American university. In a collaborative effort involving three universities, we hope to be able to demonstrate the full potential of the use of neutrons in the analysis of this material all in one go. And although it’s still early days: the initial data looks promising.”

Vogt is very excited about the PEARL: “It’s really awesome and everyone involved is really enthusiastic. It’s precisely because we’re trying to discover how far the PEARL can take us that we’re having such interesting fired-up discussions that all of us are learning from – including the Delft University of Technology. The fact that we can do research locally is perfect. Thirty years of experience has taught me that if you’re going to try out a new technique as a researcher, you either have to be involved in it right there or do it yourself. It’s great when the technology is just an hour’s drive away.”

As far as Vogt is concerned, there’ll definitely be a sequel. “The problem of elements appearing to be indistinguishable from each other is a common one. In any case, I see a number of possible applications, both at Albemarle and Utrecht University. I can therefore say that we’ll almost certainly be coming back to Delft. Especially now that our first project is proving to be such a fantastic collaborative project and everyone’s so extremely excited about it. It’s the ideal starting point for even more research!”


P>open

Photo: The ESS construction site in Lund, Sweden.

International developments: the European Spallation Source (ESS)

OYSTER will also support the international role of the RID and its reactor. A key example is in facilitating a Dutch role in the **European Spallation Source** (ESS, www.EuropeanSpallationSource.se).

The 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, and should be fully operational in 2026. With at least 17 European countries acting as partners in the construction and operation of ESS, and an estimated 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 Founding 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 is an important step towards a Dutch full membership in ESS and represents a joint success of a consortium of 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.

The consortium has already made the initial preparations for the second essential step which is to finalise the accession process aiming at full membership in ESS in order to maintain and strengthen the position and innovative competitiveness of the Netherlands among the knowledge-driven economies.

Review by NWO

Every year, the "NWO OYSTER Advisory Committee", consisting of external experts, reviews the progress and implementation of the OYSTER project. In May 2016, the team visited RID, for the fourth time since the start of OYSTER. It consists of the following people:

Dr. Dimitri N. Argyriou
Director for Science at the European Spallation Source, Lund, Sweden.

Prof. K.N. Clausen
Head of the Neutron and Muon Research Department and Vice Director of the Paul Scherrer Institute, Villigen, Switzerland.

Prof.dr. J.F. Verzijlbergen
Head of the Department of Nuclear Medicine at the Erasmus MC, Rotterdam, the Netherlands.

Dr. Nico Kos
Senior Manager (International) Programme Innovation at the Chemical & Physical Sciences Division of the Netherlands Organisation for Scientific Research (NWO)

The NWO Advisory committee: Dr. D. N. Argyriou, Prof. K.N. Clausen, Prof.dr. J.F. Verzijlbergen and Dr. N. Kos

The committee: 'This 4th meeting has by far been the most positive meeting. First examples of the potential of the upgraded facilities were very convincing.'

Comments/Recommendations of the NWO OYSTER Advisory Committee	Implementation/Solutions by the OYSTER team
A strategy plan is needed that provides a model for operation of RID as a major research infrastructure.	The RID strategy is under development involving the RST-RID community. This includes also a reorganization of RST/RID structure and processes.
A good strategy is needed to ensure that the Dutch Safety Requirements (DSR) process can be finished according to a reasonable time scale – safety versus cost of delay or unnecessary complicated procedures.	Intensive communication about this issue with the Dutch Authority for Nuclear Safety and Radiation Protection (ANVS) resulting in speeding up the licence permit process. A separate licence application for the non-nuclear CNS building will enable the start of construction of this part by 2017.
Delay due to licensing procedures has been used well to optimise key components, define the project and proceed towards a more realistic prize and arrive at productive working relations across very different cultures.	The TU Delft Executive Board has approved the optimised project budget.
During 2019, two large European neutron facilities (the Hahn-Meitner-Institut in Germany and the Laboratoire Léon Brillouin in France) will close down, leading to a large (15 to 20%) reduction of available access to European neutrons. We therefore strongly recommend that the upgrade of the research reactor in Delft will be ready as early as possible in 2019.	The final project schedule will become available in 2017 as soon as the technical review process with the related subcontractors will be finalised. The closing out of the OYSTER project is expected at the end of 2019.

Financial overview

Budget summary

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 2016

After the final revision of the Dutch Safety Requirements (DSR) became available in October 2015 and the selection of subcontracting parties in 2016, the KHC consortium was able to prepare a cost estimate for the implementation of the DSR-related works. The additional (preliminary) costs for implementing the DSR have now been added to the original OYSTER budget. Along with the fixed price for the original scope of work as described in the agreement of 2014, a final total price estimate for the total costs for the reactor modification works was made and presented to TU Delft. The Executive Board of TU Delft decided to continue the reactor modification. Until 2016, a total of €6.4 million was spent on the licensing process, basic engineering, positioning of the OYSTER facility, and the DSR. TU Delft contributed €8.6 million in kind to the OYSTER project in 2016.

Plans are being formulated for the further realisation of the instruments (such as FISH and Mössbauer) and irradiation facilities in order to attract external funding. The funding for SANS, PEARL, 'Baby'-FISH is being continued. The funding for ROG was added in 2016.

Communication

Update 2016

In the area of communication, the overall aim is to inform all stakeholders about the facilities, instruments, opportunities, knowledge and services available at the Reactor Institute Delft.
In 2016, the communication strategy towards sharing and instilling OYSTER's key message to the relevant groups and research communities has been further expanded and broadened. This resulted in, amongst others:

- **Representation of OYSTER at a number of international exhibitions.** For example, at the IPAC (Particle Accelerator Conference) in Korea, in the Dutch pavilion of the Hannover Messe in Germany and at Physics@Veldhoven in the Netherlands. In European exhibitions the SINE2020 Call for Proposals for Industry was also promoted, offering funding to companies to use European neutron sources for test measurements or feasibility studies.
- **An internal communication strategy** for the reorganisation of the RST/RID structure and internal processes.
- **Tours of the reactor hall and experiment hall** for many interested parties. Special tours were organised for visitors of the Applied Sciences Family Festival and for RST/RID alumni. The alumni received an update about the OYSTER programme.
- **New contacts and fruitful discussions** with potential neutron-beam users from industry.
- **OYSTER update meetings** at the RID for a number of stakeholders groups: RST/RID employees and the main stakeholders from government and industry.

Prospects for 2017

In 2017 we will keep on sharing the OYSTER message. With the start of construction of the CNS utility building, which is foreseen after the summer, focus will also be on internal and external communication about the licensing and building activities. In June 2017, new, modern, visually attractive, interactive and responsive websites will be launched for RST and RID/OYSTER.

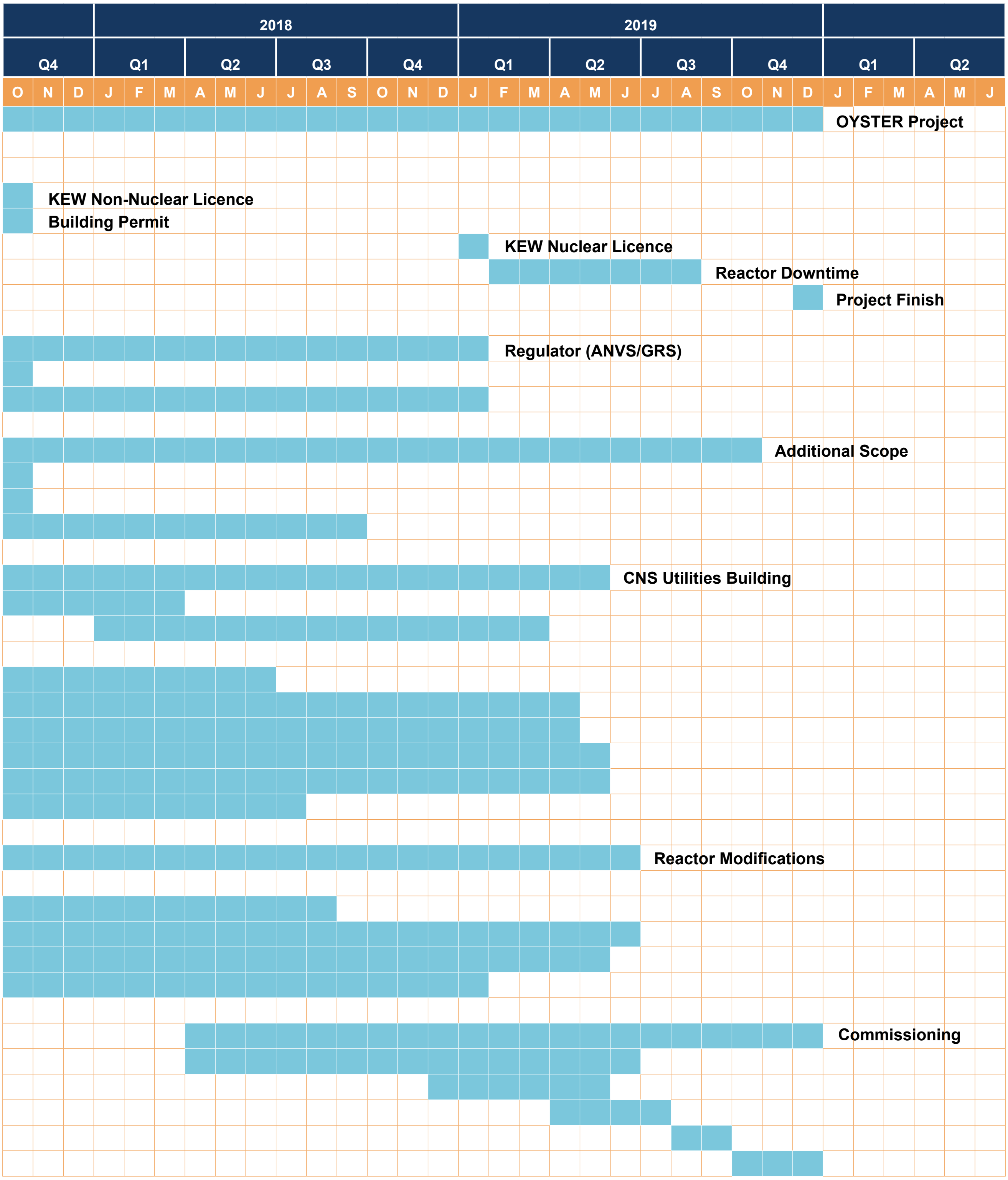
* BrightnESS is a European Union-funded project within Horizon 2020 in support of the European Spallation Source (ESS). SINE2020 is a consortium of 18 partner institutions, aiming to prepare Europe for the opportunities of the ESS in 2020 and to develop the innovation potential of large neutron facilities.

Planning

2016 saw a modification of the overall OYSTER planning. During the technical review meetings between KHC consortium and the various subcontracting parties, the delivery schedules for equipment and services required for the realisation of the modification works were discussed and finalised. Also, the definitive Safety Analysis Report (SAR)- and Safety Analysis production schemes of NRG were fixed in consultation with RID and the Authority for Nuclear Safety and Radiation Protection (ANVS), so now a solid basis for defining the construction schedule is available.

In the current planning, the start of works at the CNS Utility building is anticipated for the second half of 2017. The closing out of the OYSTER project is expected at the end of 2019, which is later than anticipated in 2015.

Task name	2017								
	Q1			Q2			Q3		
	J	F	M	A	M	J	J	A	S
OYSTER Project	■	■	■	■	■	■	■	■	■
Milestones									
Contract Amendment RID-KHC-Contractors		■							
KEW Non-Nuclear Licence									
Building Permit									
KEW Nuclear Licence									
Reactor Downtime									
Project Finish									
Regulator (ANVS/GRS)	■	■	■	■	■	■	■	■	■
KEW Non-Nuclear Licence				■	■	■	■	■	■
KEW Nuclear Licence	■	■	■	■	■	■	■	■	■
Additional Scope			■	■	■	■	■	■	■
Construction Site Layout (Logistics)					■	■	■	■	■
Entrance Experiment Hall					■	■	■	■	■
Primary and Secondary Cooling System			■	■	■	■	■	■	■
CNS Utilities Building	■	■	■	■	■	■	■	■	■
Civil & Infrastructure				■	■	■	■	■	■
Reactor Containment Building Penetration									
System Descriptions	■	■	■	■	■	■			
Helium Refrigeration System			■	■	■	■	■	■	■
Helium Transfer Lines			■	■	■	■	■	■	■
Vessels & Tanks			■	■	■	■	■	■	■
Gas Blanket Systems			■	■	■	■	■	■	■
Instrumentation & Controls			■	■	■	■	■	■	■
Electrical Systems			■	■	■	■	■	■	■
Reactor Modifications	■	■	■	■	■	■	■	■	■
Basic Design	■	■	■	■					
Test In-Pool Assembly					■	■	■	■	■
Main In-Pool Assembly					■	■	■	■	■
Beam Tube Modification	■	■	■	■	■	■	■	■	■
Reactor Protection System	■	■	■	■	■	■	■	■	■
Commissioning									
Procedures and Protocols									
Site Acceptance Test									
System Performance Test (SPT)									
Integrated System Test (IST)									
Reactor Integrated Test (RIT)									


2018
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O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J
OYSTER Project
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Additional Scope
CNS Utilities Building
Reactor Modifications
Commissioning