Delft University of Technology

OYSTER 2012

Annual Report

TU Delft Delft University of Technology

REACTOR INSTITUTE DELFT

Colofon

Coördination & text

TU Delft | Reactor Instituut Delft

Design cover

Verdult - Kennis in Beeld, www.kennisinbeeld.nl

Figures 1 - 2 Verdult - Kennis in Beeld, www.kennisinbeeld.nl

Figures 3 - 12 TU Delft | Reactor Instituut Delft

Text editing

DBAR www.DBAR.nl

Graphic lay out

LIN! Grafisch Ontwerp

Production date

February 2013

Funding

On January 20, 2012, the Dutch Council of Ministers decided to provide a financial contribution to the Reactor Institute Delft to implement the OYSTER program. This funding is provided via the Netherlands Organisation for Scientific Research (NWO project number: 195.069.000). Besides funding from the government, Delft University of Technology has also received co-funding from COVRA N.V.. At printing date of this annual report co-funding by other parties is at an advanced stage.

TU Delft

Reactor Instituut Delft

P.O. Box 5042 - 2600 GA Delft

Mekelweg 15 - 2629 JB Delft

T +31 015 27 86744

F +31 015 27 86422

I www.rid.tudelft.nl

The First Year of OYSTER

Foreword

The research reactor of the Delft University of Technology (TU Delft) has been in operation since 1963. It is a powerful research tool around which the TU Delft developed and strengthened research and educational programs. The Reactor Institute Delft (RID) was formed as a knowledge center on nuclear issues, operating the reactor, irradiation facilities, and neutron- and positron instruments. In conjunction with the scientific Department of Radiation Science and Technology (RST) of the Faculty of Applied Sciences, RID accommodates resident and visiting scientists from a variety of scientific disciplines, educates students, professionals and scientists, and serves as an independent source of information for society on radiation- and nuclear-related issues.
Over the years, the scientists around the reactor have gained a strong reputation in developing and using new and often unique instruments, irradiation facilities and methods. As a result, RID is one of the few IAEA Collaborating Centers worldwide.
Obviously we are thrilled by the opportunity to further develop and expand the potential of the research reactor by the OYSTER program, of which the first ideas were born in 2005. OYSTER stands for "Optimized Yield -for Science, Technology and Education- of Radiation", and is co-funded by the Dutch government, the TU Delft and a number of commercial parties, all of whom are gratefully acknowledged. OYSTER aims to improve and expand the infrastructure around the reactor to better address current and future educational, scientific and societal questions. OYSTER was granted in January 2012 and spans a ten-year period for new research and education on reactor-based radioisotope production, neutron activation analysis, positron annihilation spectroscopy, neutron scattering and imaging. The innovative facilities and instruments that will be built as part of OYSTER will be accessible to Dutch scientists from academia and industry and will thus become useful tools in developing materials and technologies that are better and/or more sustainable than current ones.
This report is a retrospective of the first year of OYSTER: of the activities, the choices and the progress we made in our ambition to take on the scientific and societal challenges of the future.

Prof. dr. Bert Wolterbeek
Director of the RID, Head of the Department of RST
February 2013.

Contents

Foreword		1
INTRODUCTION		3
"OYSTER: a Swiss-knife tool for the challenges of the future"		4
About this report		3
AIMS AND IMPACT		3
Towards a national center of knowledge, research, education and experimental facilities		3
• A knowledge center		3
• A research center		3
• An educational center		4
• A national center for large-scale experimental facilities		4
OYSTER in short		5
Role in (inter)national collaborations		5
ANTICIPATING OYSTER		6
DEVELOPMENT OF THE OYSTER PLANS		6
Cold-eye review (February 2012)		6
Update and external reviews (June 2012)		7
Update and external review (December 2012)		8
Update and external reviews (Mid 2013)		8
TECHNICAL ASPECTS		9
Towards more cold neutrons		9
OYSTER utilities		9
OYSTER neutron and positron instruments		9
OYSTER irradiation facilities		9
LICENCING ASPECTS		9
OYSTER ORGANISATION		10
10OYSTER Team		10
Platform neutron-users		10
Management Team of the Department of RST		10
OYSTER project team		11
OYSTER PLANNING AND CURRENT STATUS		12
Current status		12
Issues currently being addressed		12
NEW MANPOWER		12
FINANCIAL OVERVIEW		12
COMMUNICATION		13
Appendix A	Neutron and positron instruments and irradiation facilities	14
Appendix B	Referees of the June 2012 Review	23
Appendix C	Planning	24/25

Introduction

In 1963, a nuclear reactor fully dedicated to academic research and education became operational at the campus of Delft University of Technology (TU Delft), called the "Hoger Onderwijs Reactor" or HOR. An open pool-type reactor using low-enriched Uranium-235 as fuel, the HOR has been generating neutron radiation for research in the area of nuclear energy, materials science and for the production of radioisotopes for medical purposes ever since.

Since the sixties, (nuclear) science has progressed immensely, and so should the HOR. OYSTER ("Optimized Yield -for Science, Technology and Education- of Radiation") has been conceived as a major package for the HOR and its experimental facilities to make sure the reactor is optimally geared towards contributing to state-of-art research and education in as many scientific disciplines as possible.

On January 20, 2012, the Delft University of Technology (TU Delft) was awarded 38 million euro by the Dutch government for the OYSTER project after a period of productive discussions and (external) reviews. OYSTER will expand the capabilities of the research reactor, including neutron-, and positron instruments and irradiation facilities, for the sake of the broader Dutch and international research communities. It will thus provide new scientific and innovative output and collaborations that in turn will secure the long-term future of the reactor.

Since the first concepts of the OYSTER program were proposed in 2005, many technological and scientific innovations have been achieved in the field of neutron and positron sources and their corresponding scientific instrumentation. The European Spallation Source (ESS) and PALLAS reactor in Petten are examples of such progress since 2005. The scientific and technological innovations have been closely followed by TU Delft, and when the OYSTER program was awarded in January 2012, an augmented and updated program was quickly sent for assessment to an international panel of scientists.

In parallel, the main OYSTER project kicked off in February 2012, spanning a 10-year period and comprising the following items:

- OYSTER - Instruments and Facilities: design, development, construction and installation of facilities and instruments. The suite of instruments and facilities will be incrementally realized over the time span 2012-2018;
- OYSTER - Reshaping the Reactor: reshaping of the reactor core, increasing the power, and implementing a cold neutron source. The new core and the cold source will be operational in 2016;
- OYSTER - Exploiting the New Possibilities: Scientific programs and output, PhDs, collaboration with industry and academia.

"OYSTER: a Swiss-knife tool for the challenges of the future"

About this report

The OYSTER organization will report on its progress on a yearly basis. This first annual report on OYSTER addresses all relevant developments that took place in the time span 2005-2012, i.e. including the period before the program was formally granted.

Aims and impact

Towards a national center of knowledge, research, education and experimental facilities.

The OYSTER program will catalyze the research activities around the HOR and establish a national center by combining activities in the areas of research, education, use of the large-scale facility. Two organizations currently surround the reactor: the Radiation Science and Technology Department (RST, dedicated to research and education) of the Faculty of Applied Science of TU Delft and the Reactor Institute Delft (RID, dedicated to operating the reactor and the facilities). Both organizations will evolve along with OYSTER to be able to address key challenges of the future.

Through OYSTER, a national center of knowledge, research, education and large-scale experimental facilities will emerge:

A knowledge center

The experts at both the RID and RST generate knowledge (through research programs), transfer knowledge (through educational programs), and work towards explaining the relevance of that knowledge to our everyday life. Over the years, the knowledge center at TU Delft has become a contact point for the general public for information about nuclear- and radiation related issues. As an independent base of Dutch nuclear knowledge and research infrastructure, it is unique in the Netherlands.

A research center

The combined efforts of the RID and RST have led to an impressive number of research partnerships and collaborations, involving some 85 universities worldwide. The current research program focuses on sustainable energy and health, and has four main themes:

1. (New routes for the) production of (new) radioisotopes and the development of the necessary irradiation facilities.
2. Development and application of nuclear (neutron, positron, gamma-ray) probe instruments for materials science and nuclear medicine.
3. Design of nuclear reactor concepts for production of energy and isotopes
4. Study, synthesis and application of materials for energy storage and conversion.

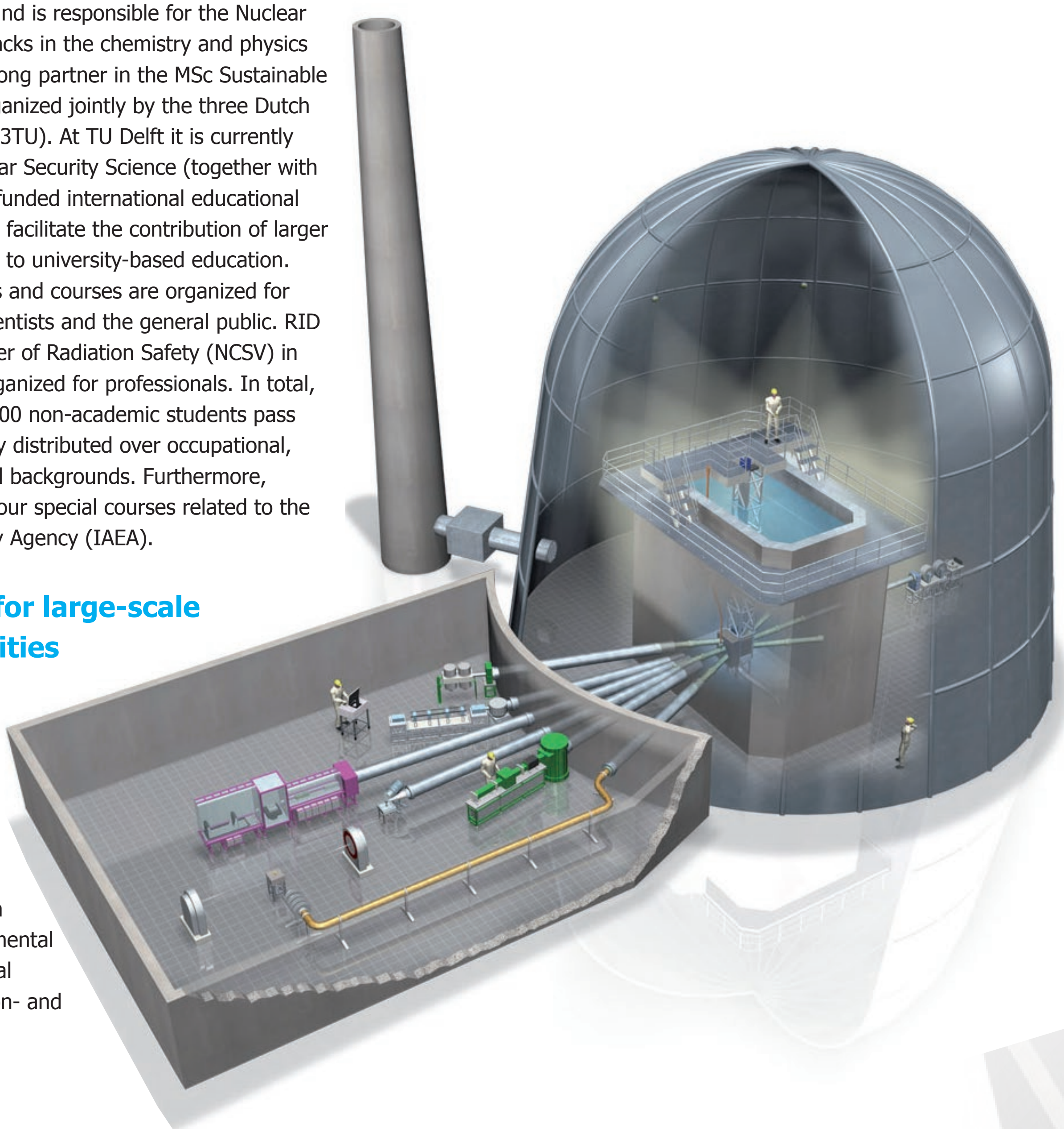
An educational center

The experimental facilities around the reactor play a vital role in training young researchers and students. In particular the scientific department RST contributes to the BSc and MSc programs of TU Delft and is responsible for the Nuclear Science and Engineering tracks in the chemistry and physics education. RST is also a strong partner in the MSc Sustainable Energy and Technology, organized jointly by the three Dutch Universities of Technology (3TU). At TU Delft it is currently setting up an MSc on Nuclear Security Science (together with Delft TopTech), and an EU-funded international educational program GENTLE, meant to facilitate the contribution of larger nuclear (industrial) facilities to university-based education.
In addition, various lectures and courses are organized for students, professionals, scientists and the general public. RID also runs the National Center of Radiation Safety (NCSV) in which many courses are organized for professionals. In total, some 300 academic and 1000 non-academic students pass our doors every year, evenly distributed over occupational, industrial and governmental backgrounds. Furthermore, about 130 students attend our special courses related to the International Atomic Energy Agency (IAEA).

A national center for large-scale experimental facilities

The HOR reactor hosts a comprehensive assembly of advanced facilities where the radiation (both neutrons and positrons) generated by the reactor can be used for scientific experimentation. Through a wealth of additional experimental facilities, such as radiological laboratories, X-ray diffraction- and Mössbauer instrumentation, solid-state NMR, a Van der Graaff accelerator, lithium battery labs, solid-state chemistry labs and equipment, and various characterization facilities, a center of large-scale experimental facilities is formed that is unique to the Netherlands. These facilities do not only address the area of nuclear energy, but a large variety of disciplines, including chemistry, physics, biology, medicine, art, archaeology, and materials science.
By facilitating high-quality multidisciplinary research, the center will plant seeds for new science and technology by enabling new insight into materials for sustainable energy, catalysis, magnetic data storage, superconductivity, biophysics, medicine, quantum physical phenomena, construction materials and various other scientific domains, such as biotechnology, nutrition technology, nanotechnology etc.

Figure 1. Schematic overview of the reactor building and experimental hall



OYSTER in short

OYSTER aims:

- to further develop RID/RST as a coordinating center for the application of neutron, positron and radioisotope science and techniques, radiation detection and reactor technology, thereby supporting and uniting the Dutch scientific community;
- to create a home base for neutron scattering applications and mobilize the scientific community to secure Dutch close collaboration with major international neutron sources;
- to establish RID/RST as a knowledge center and training institute in Europe, and thus a coordinating partner in European research networks;
- to stimulate ground-breaking innovations in the field of neutron, positron and radiochemistry science;
- to sustain RID/RST leading role in the use and knowledge of world-class instruments such as continuous positron beams, the development of new routes for radioisotope production and the ISO 17025 accredited laboratory for Instrumental Neutron Activation Analysis;

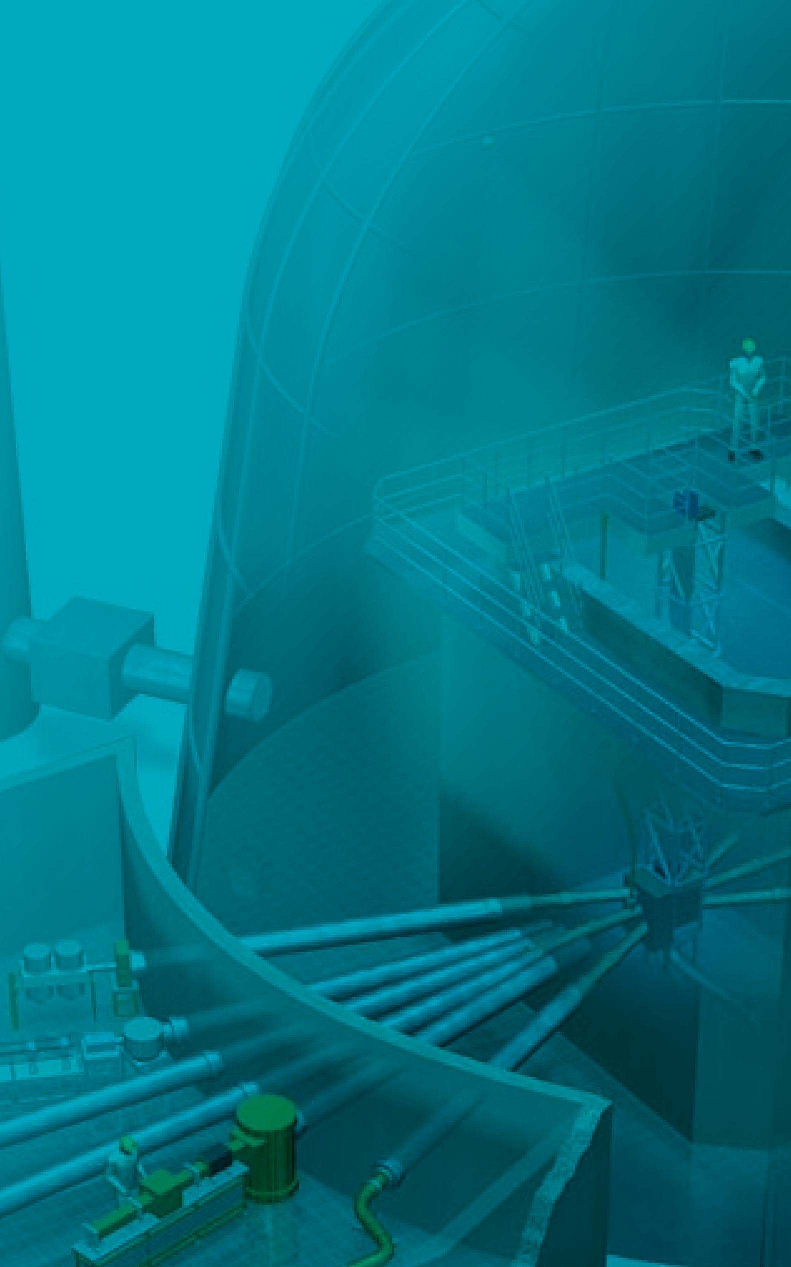
OYSTER technically comprises:

- the reshaping of the reactor core, thereby using the highest currently approved and proved density of uranium fuel, maximizing the neutron- and gamma-ray flux (since gamma-ray flux determines positron source brightness);
- an increase of the reactor power to 3 MW , thereby increasing the neutron- and gamma-ray flux;
- the installation of a Cold Neutron Source (CNS), which will cool neutrons from room temperature to -250 ^{0}C and will thus increase the flux of low-energy neutrons by more than an order of magnitude. This will improve the sensitivity of already existing top-class instruments, such as SESANS or the neutron reflectometer ROG;
- the design and construction of new experimental facilities such as, PEARL, FISH and PALS;
- the (re)design and construction of (new) irradiation facilities which permit the (development of) production of radioisotopes with unprecedented purity.

Role in (inter)national collaborations

Through OYSTER, TU Delft is better equipped to participate in large national and international collaborations:

- The development of the European Spallation Source (ESS, www.EuropeanSpallationSource.se) in Lund, Sweden, which is a collaborative facility for materials research using neutron scattering techniques. The Dutch contribution to the pre-construction phase of the ESS is financed through OYSTER. For this purpose two postdocs are being appointed, who will work on the development of novel instrumental concepts for the ESS and in close collaboration with the ESS. The progress of this project can be monitored at the weblog http://hollandess.weblog.tudelft.nl/.
- Holland Particle Therapy Center (HollandPTC, www.HollandPTC.nl). This planned center for an innovative radiation treatment of cancer, using protons instead of X-rays, is a collaboration of TU Delft, the Leiden University Medical Centre (LUMC) and the Erasmus University Medical Centre Rotterdam (Erasmus MC). It is anticipated to be located next to the RID/RST buildings.
- It also strengthens the role of the TU Delft in supplying innovative ideas towards the envisioned PALLAS reactor, one of the world's leading production sites for medical isotopes.



Anticipating OYSTER

OYSTER has been designed to meet the needs and wishes by scientists from a variety of scientific fields, from academia and industry. These were translated into a first proposal of a suite of instruments and a line-up of irradiation facilities, which, for optimal operation, both required a reshaping of the reactor and its components. From 2005 to 2012, the plans continuously evolved, fuelled by frequent interactions with Scientific Research Councils (e.g. FOM, NWO, STW), the Ministries of OCW, EZ and VWS, and various national and international partners.

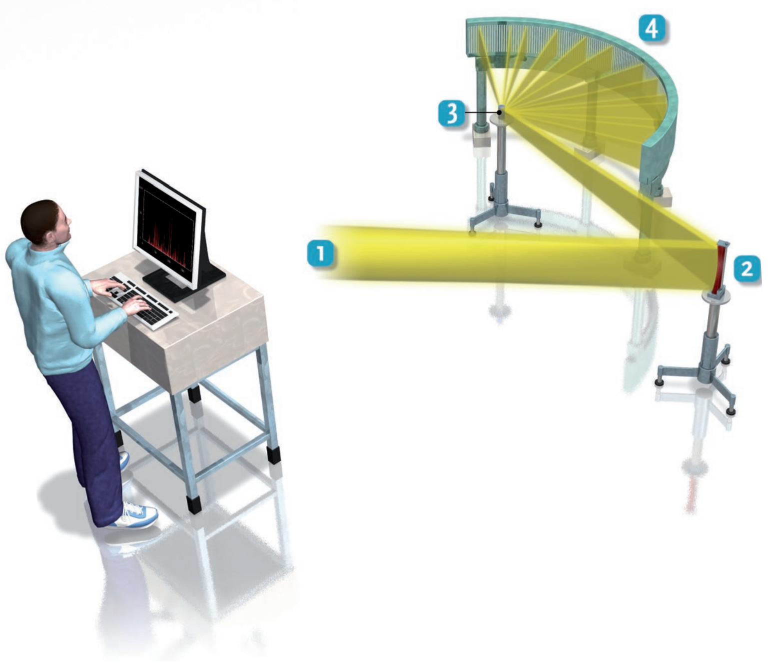


Figure 2.

Impression of the diffractometer PEARL. 1. Beamtube, 2. Monochromator, 3. Sample environment, 4. detector

Even before a positive decision on the OYSTER plans, TU Delft already acquired key equipment to extend the experimental facilities of the HOR:

- A cryogenic installation for a **cold neutron source (CNS)** was purchased from the Helmholtz Zentrum Geesthacht (HZG), Germany, in 2010. The neutrons generated by the reactor are cooled down using liquid hydrogen (-250 degrees Celsius). These cold neutrons are more sensitive to nanoscale objects or interfaces. This CNS had previously been used at a 5 MW research reactor,, and the possibility to buy proven technology at that particular moment was regarded as a one-time only opportunity.
- A **Small-Angle Neutron Scattering instrument (SANS)** was also acquired from HZG even though it was not included in the original OYSTER proposal. However, SANS is one of the most widely used neutron scattering techniques, relevant to a broad scientific community in the Netherlands.
  It is anticipated that when the instrument will be fully operational with cold neutrons in 2016 (the instrument will be ready – with thermal neutrons – in spring 2013), it will become a highlight of OYSTER and an everyday research tool for Dutch scientists.
- In parallel, the Department of RST launched a project to design and develop the **neutron diffractometer "PEARL"**, which was included in the early OYSTER proposal. A new and compact design has been adopted, which will lead to a high-brilliance instrument that is to be installed in 2013. First measurements are expected in 2014.
- In 2005, TU Delft offered the Dutch government to implement a backup facility for the production of the medical radioisotope Mo-99. This facility is sufficient to accommodate the equivalent of the Dutch demand for medical diagnostics. It was commissioned in January 2012 and is meant to be operated only when asked for: larger scaled commercial production units such as PALLAS should be the primary sites for Dutch routine industrial production, with the TU Delft facility as a research facility and backup

Development of the OYSTER plans

Cold-eye review (February 2012)

The OYSTER plans have evolved from 2005 onwards. In order to formally assess and document the status quo early 2012, a "cold-eye review" (CER) was organized to make a snap-shot analysis of the program. It was performed by Ron Goetjaer from the Nuclear Research and Consultancy Group (NRG) in Petten, an independent specialist, experienced with the execution of projects of similar or larger size and complexity. He performed the analysis based on OYSTER documents and additional input from the scientific and technical staff of RST and RID. The CER was performed from 13 through 16 February 2012. The recommendations, as presented on 7 March 2012, included:

- Determine the Scope of Work at the earliest.
- Define the Scope of Work within the boundary condition of a maximum available budget. This means that, as not all new requests for new instruments, reactor modifications etc. may be granted, priorities must be defined and choices must be made.
- Select additional manpower. Establish an OYSTER project organization based on an integrated team approach. This implies that the project team will be defined as a combination of part-time involvement of own personnel and external hired-in specialists.
- Involve external stakeholders in the development of the OYSTER project plan right from the start. This also refers to local and national authorities such as KFD, ministry of EZ and OC&W.

- Assume a 35 % inaccuracy of estimated OYSTER budgets.
- Start licensing procedures immediately.
- Involve external expertise for the preparation of the Environmental Impact Study ("Milieu effect Rapportage", MER) and the Request for Quotation documents with respect to the European tendering procedure.

The conclusions and recommendations were used as basis for the further development of the OYSTER project. Based on the feedback from the CER, on 1 April 2012, a new OYSTER project organization was established and the project entered a new phase.

Update and external reviews (June 2012)

Following the decision of January 2012, the plans for a suite of scientific instruments and facilities were updated and renewed. In addition the associated performance criteria to be met by the reactor and the cold neutron source were re-determined. Addressing all societal, scientific, and financial aspects, the updated plans were not limited to allocated OYSTER funds. Instead, they provide a blueprint for the future, even if they might require additional funding sources. OYSTER will act as a flywheel for such future funding. As detailed in Appendix A, the resulting list of instruments and (irradiation) facilities includes:

A. **Update of the original proposals:** the Positron Annihilation Lifetime Spectrometer (PALS) remained as proposed, the design of the Neutron Diffractometry Facility (NDF) evolved into the very competitive diffractometer PEARL, the Cold Neutron Irradiation Facility (CNIF) evolved into a full suite of various dedicated irradiation facilities with adjustable neutron and gamma-ray spectrum characteristics.
   The Scanning Neutron Microscope (SNM) and neutron polarization analysis set-up (PANDA) merged into a general purpose neutron imaging/microscope station: the First Imaging Station Holland (FISH).
B. **New proposals** were drafted such as a high-resolution single photon emission computed tomography facility (HR-SPECT), a hot cell for handling highly active radioisotope production samples, and an in-beam Mössbauer spectrometer.
C. **Update of existing instruments and facilities** with the positron 2D-ACAR system, the SANS instrument that is being commissioned, the reflectometer ROG, the SESANS, the neutron depth profiling (NDP) the Instrumental Neutron Activation Analysis as well as the Mo-99 back-up production facility.

In June 2012, these updated proposals were sent out for review to several independent experts. The referees, listed in Appendix B, were asked to give their opinion on the proposals and their relevance to OYSTER, as well as their advice on the planning and sequence of the program to be executed. The following list summarizes their responses:

- Differing recommendations on the reactor power increase: one reviewer advocated an increase to 5 MW, another recommended NOT to focus on increasing the power. The positive advice was founded on the broad positive effect on all instruments and irradiation facilities, the negative related to a strong focus on the benefits of the neutron cold source.
- Give high priority to the installation of the cold neutron source, which will have beneficial impact to both neutron scattering instruments and some specific irradiation facilities.
- Design the cold neutron source design to target gains higher than 15 times at λ=5 Å and higher than 25 times at λ = 10 Å, defined relative to a thermal neutron source at the same position.
- Make sure that the thermal neutron flux at the entrance of selected beam tubes targets 10^{14} $cm^{-2}s^{-1}$ and is no less than $6x10^{13}$ $cm^{-2}s^{-1}$.
- Define a program planning and a top-three instrument suite with FISH, PEARL, SANS as first instruments. Already make a schedule for the second wave of instrumentation. An alternative approach assumed a broad first wave throughout the whole palette of instruments and facilities by first focusing on FISH, HR-SPECT and the assembly of instruments and irradiation facilities to be employed in nuclear analytical methods.
- Give high priority to the installation of new irradiation facilities, of variable designs.
- Include necessary sample environments in facility integration (e.g. temperature, pressure, magnetic field control).
- Set up a mechanism and budget for scientific and support staff for beam facilities.
- Set up support for PR and communication.

Another important issue addressed by the referees concerned the possibilities for further fund raising by identifying the subprojects that could be funded from outside OYSTER. The general opinion was that the Mo-99 back-up facility was a good candidate even though the referees did not know that external funding for this facility had already been secured. This facility was included in the OYSTER plans to ensure that the re-designed reactor core configuration would remain compatible with the Mo-99 back-up operation. With respect to funding issues, we note the following:

- The technical requirements for the neutron and positron instruments as well as for the irradiation facilities determine the requirements for the reactor modifications, and the costs for the reactor modifications determine the available OYSTER funding for instruments/facilities.
- The financial breakdown of the original OYSTER plans was based on the early line-up of instruments and reflected estimations going back several years. The revised suite of

instruments and facilities of June 2012 extends well beyond the original OYSTER program, both in terms of capabilities and costs. Clearly, the OYSTER program should be used as a flywheel for obtaining further funding.

Update and external review (December 2012)

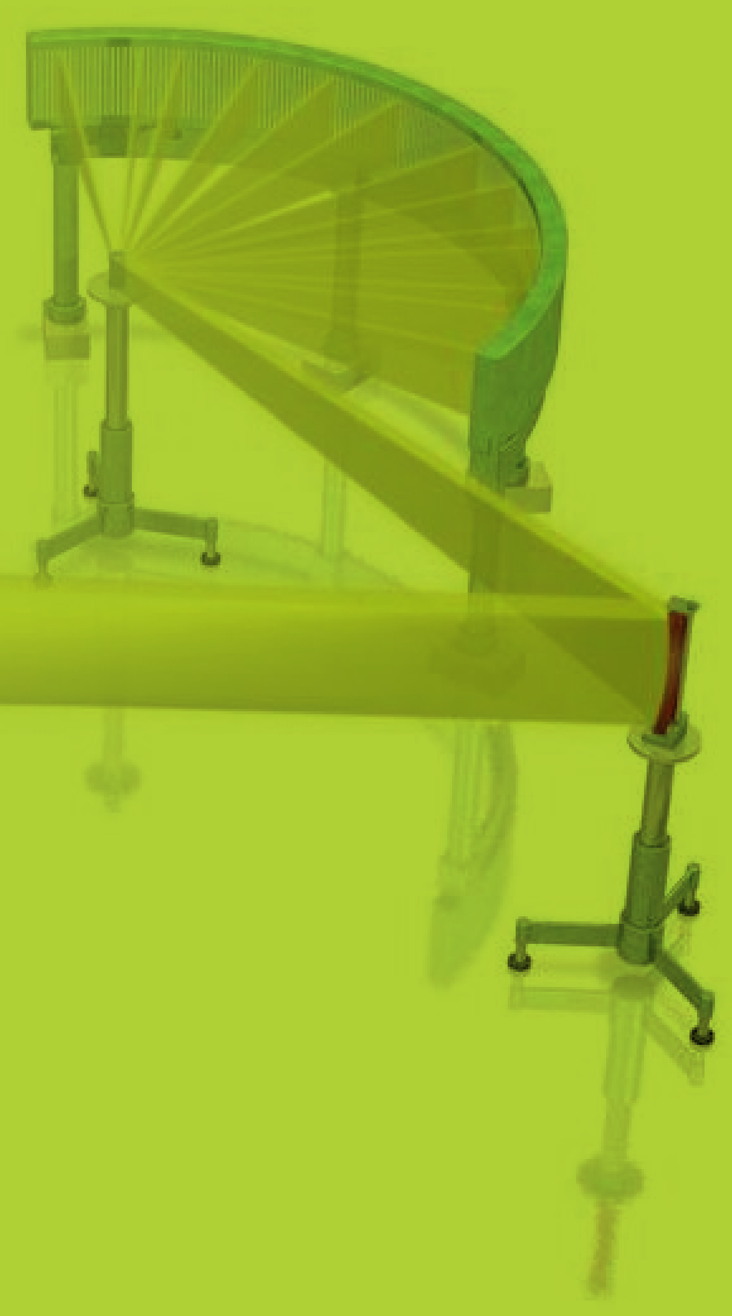
In December 2012, one of the referees who reviewed the June 2012 update (Dr. Shane Kennedy from ANSTO Australia, an IAEA Collaborative Center for Neutron Scattering Applications) was asked to review not only the instrument suite but also the whole of OYSTER, including the design of the reactor and of the cold source. In this more comprehensive evaluation of the project, Dr. Kennedy was given additional information e.g. on technicalities and finances. Based on his experience in managing the new Research Reactor project OPAL in Australia, he acknowledged the relevance of the flywheel notion and recommended to reserve a 20% contingency (added to agreed-upon costs) for any approved project within OYSTER. Additional recommendations were:

- Set up a governance structure on OYSTER and on RID/RST.
- Set up an additional review process for a second wave of instruments.
- Set up an additional review process for the medium-flux and high-flux irradiation facilities.
- Secure ongoing operational funds beyond the ten-year period of OYSTER funding.
- Maintain community consultation for a continuous and dynamic scope definition.

Various points raised by Dr. Kennedy have already been taken into operational account, while others are currently under discussion.

Update and external reviews (Mid 2013)

A third round of external peer reviews, to be organized by the Dutch Science Foundation (NWO), will focus on scientific instruments, irradiation facilities and project organization. It is to be scheduled for the first half of 2013.



Towards more cold neutrons

The early ideas put forward in the original OYSTER proposal implied a major increase (more than one order of magnitude) in the cold neutron flux available to a suite of neutron instruments (i.e. SESANS, ROG, PANDA, NDP and SNM). Cold neutrons hold major potential for (materials) research. The increased availability of cold neutrons was to be achieved by increasing the reactor power from 2 to 3 MW, compacting the reactor core and installing a cold neutron source (CNS).

However, in 2012, Dr. Stuart Ansell, a specialist in neutron production, moderation and transport from ISIS, England, performed computer optimizations of the CNS geometry and efficiency. These revealed that by adequate design the efficiency of the CNS could be increased by an additional factor of three, as compared to the original OYSTER proposal. This was regarded as a more important gain in neutron flux than the one expected from core compaction. At the same time, it became clear that core compaction could have a negative effect on the homogeneous distribution of the neutron flux in the core and thus on the performance of other instruments that don't receive the neutrons of the cold source, such as the neutron diffractometer PEARL. In addition, the core compaction would reduce the availability of positions for the irradiation facilities in and near the core. Furthermore, core compaction would be relatively expensive, with initial investments estimated at 5 M€ and high operational costs due to reduced nuclear fuel efficiency. These considerations, together with advice from several referees, led to the decision to abandon plans to compact the reactor core. A CNS with an optimized geometry, a reactor power increase to 3 MW and state-of-the-art neutron optics and instrumentation will lead to substantial gains in cold neutron flux, possibly higher than anticipated in the original OYSTER proposal, while the irradiation facilities remain secured.

OYSTER utilities

The CNS comes with a cryogenic system that requires e.g. 250 kW electrical power and its own control room. This equipment will be situated outside the reactor hall and are designated as "utilities".

OYSTER neutron and positron instruments

These instruments comprise the equipment needed to use the positrons or the neutrons that are generated by the reactor for various scientific experiments. They are listed in Appendix A. New instruments are being built and installed, such as SANS, PEARL, others are being conceived, such as FISH. The bulk of the construction work will be performed in-house.

OYSTER irradiation facilities

By irradiating materials with the neutrons produced by the reactor, radioisotopes for medical use can be produced. This is done in dedicated irradiation facilities. A variety of such facilities will be built in-house, to be used for radioisotope production and the development of innovative radio-isotope production methods, as well as for neutron activation analysis. The irradiation facilities are described in Appendix A.

Licensing Aspects

The part of the OYSTER project concerned with reshaping the reactor necessitates a modification of the existing license for the HOR reactor or even a completely new one.

- In September 2012, a draft proposal for a construction schedule (Revision 3) was presented to the Dutch authority in this area, the Ministry of Economic Affairs (EZ), detailing the basic approach of the OYSTER project with respect to licensing issues. This draft was based on extensive discussions with EZ. Close-out of the project was foreseen in the 1st quarter of 2015.
- On 20 November 2012 EZ provided a preliminary licensing schedule where a timeframe was set to come to a permit to start construction works for OYSTER. The starting point for construction was later than foreseen and RID modified the construction schedule accordingly. In this new draft (Revision 4) the close-out date of the project was adjusted to January 1, 2016, which means an extension in time of 7 months.
- During the meeting of 14 january 2013 a further updated schedule was presented bij EZ. The consequence is that the close-out of the OYSTER project is extended to July 1, 2016. This brings the total extension to 14 months.

OYSTER Organisation

With OYSTER, the number of potential users of the reactor facilities in Delft will increase strongly. Therefore, the management of the OYSTER facilities must take into account the needs and wishes of a large users base. In order to determine the optimal form of organization, TU Delft established an internal team to investigate how to implement OYSTER within the RST-RID organization (10OYSTER, see below), and started initial discussions on setting up a platform of neutron users (see below) as a think-tank on how to best exploit the beam instruments by a broad scientific community.

The OYSTER program impacts the entire RST-RID organization: the irradiation facilities and the positron- and neutron instruments are to be fully exploited for the research goals of RST and operated as part of the RID infrastructure serving the national scientific community. The 10OYSTER team is responsible to liaison OYSTER with the RST and RID organizations. It consists of:

Bert Wolterbeek, chairman
Director of RID and head of the Department of RST, in charge of the 10-year strategic plan of RST-RID and responsible for the external positioning of both RID and RST.
Rik Linssen,
General manager of RID, responsible for the RID exploitation and valorization.
Ron Goetjaer,
Project manager seconded from NRG, responsible for the OYSTER project (reactor modifications and utilities).
André Groenhof,
Department manager of RST, executive secretary and responsible for communication issues
Corinne de Vries-Posthoorn,
Controller of the Finance Department of TU Delft, responsible for financial monitoring and reporting.

Apart from the reactor, which will be operated fully by the RID, one of the issues raised was the manpower to be assigned to each and every neutron and positron instrument in its operational phase. The “Research and Education Committee” (IOOC) of the Department of RST was asked to organize an RST-RID-wide discussion on how the necessary manpower and responsibilities should be arranged. Based on the outcomes of that discussion, it has been decided that each instrument is to be assigned to an RST scientist who is responsible for it. Together with his/her postdocs and PhD students, this scientist fully explores and exploits the instrument, and generates and accommodates the outside scientific community experiments, assisted by RID staff for technical support and basic instrument maintenance. A decision regarding the irradiation facilities is still to be reached.

Platform neutron-users

To optimize contacts with outside scientists who wish to use the neutron instruments, a “platform-neutron-users” has been initiated, with Prof. Thom Palstra (RUG), dr. Ilja Voets (TUE) and Prof. Kees de Kruijf (NIZO). At the present early stage, the aims and ambitions of the platform are formulated and additional members will be invited. The platform shall operate as a “think tank” for the further development and use of neutron instruments from a user’s points of view. This platform may serve to gather (inter)national best practices, generate appreciation of OYSTER and exploit the neutron instruments’ analytical power by researchers from a large variety of scientific fields. This role in welcoming a broad research community is closely related to the commitments by TU Delft towards NWO in relation to the European Spallation Source (ESS), which is to be constructed in Lund, Sweden.

Management Team of the Department of RST

With the OYSTER facilities closely related to the Department of RST, the Department’s Management Team sets priorities and specifications for the irradiation facilities and the neutron and positron instruments. It also identifies those projects, which should seek additional funding (such as the Mo-99 backup facility and in-beam Mössbauer).

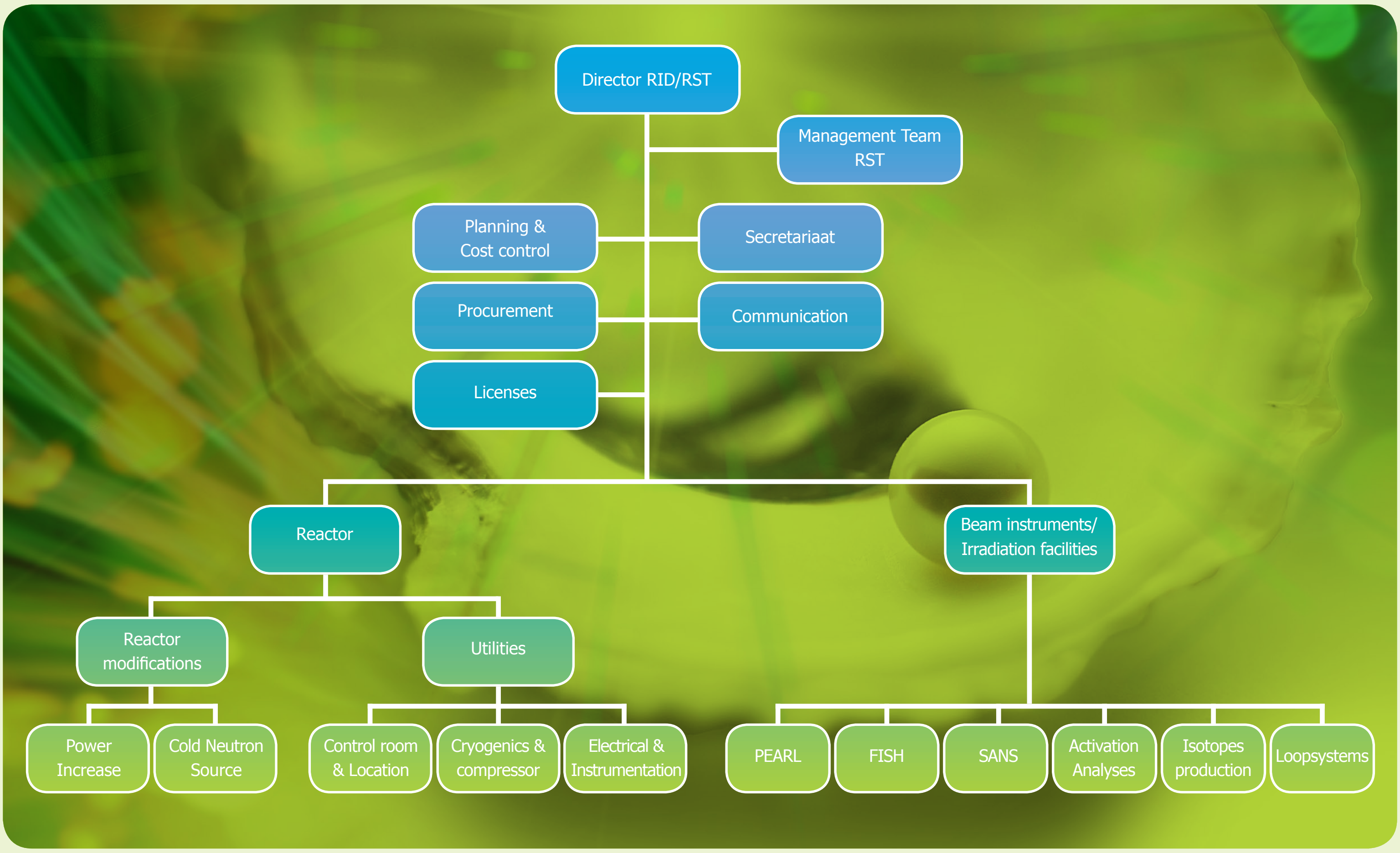
OYSTER project team

After the cold-eye review, Ron Goetjaer was appointed project manager for the technical part of the OYSTER project as of April 1, 2012. His first tasks were to establish a project organization and to complete the definition phase of the project, in which the scope of work is finalized. He is also responsible for scheduling the later phases of the project, starting January 1, 2013.

With the OYSTER project given the highest priority within RID and RST, a project team was constituted with representatives of all relevant parts of the RID and RST organizations. The organogram is shown in Figure 3. The team meets on a weekly basis to determine what the decisions of the RST Management Team imply with respect to the reactor modifications and the tendering process.
Major efforts have been made in defining the scope of work, and it was decided that the execution of the project will be split in three work packages:

- The **"Reactor Modifications"** work package consists of a modification of the core in order to increase power from 2 to 3 MW, and the installation of the near-core part of the cold neutron source. Core compaction is no longer envisioned, as explained earlier. A preliminary optimization study for the cold neutron source has been performed. Optimization of the core design in order to realize the best conditions for the irradiation facilities is also part of this work package.
- The **"Utilities"** work package consists of the installation of all support systems outside the reactor building.
- The **" Instruments and Irradiation Facilities"** work package consists of all neutron and positron instruments and irradiation facilities that will be installed or upgraded.

A timeline is being set up for the instrument design and construction, the bulk of which will be realized inhouse, thus making a request for quotations (RFQ) unnecessary. Two new instruments, the Small Angle Neutron Scattering (SANS) and the PEARL diffractometer will be completed in the near future, long before the construction phase of the reactor modification package will commence.
The three work packages are preferably executed in parallel, in order to get as many as possible of the new scientific instruments and facilities operational at the close-out of the project



OYSTER planning and current status

For each of the three work packages, standard project phases have been defined: definition phase, basic engineering phase, detailed engineering phase and construction phase. The commissioning date for the reshaped reactor was originally planned for January 1, 2015 and later postponed to September 2016, due to licensing issues.

The basic engineering, detailed engineering and construction phases of the first two work packages will be carried out by external suppliers. These will be selected by a tendering process in accordance with European regulations, where RID will be assisted by an external company that is specialized in such tendering procedures. Three potential contractors for the Reactor Modifications work package will be asked to perform the basic engineering phase. Based on the outcomes hereof, one of these parties will be selected to execute the detailed engineering and construction phases.
More details about the planning can be found in Appendix C.

Current status

The definition phase of the Reactor Modifications and Utilities work packages is almost complete. On March 1, 2013, the user requirements for these work packages will serve as basis for a preliminary "request for quotation" (RFQ) document. Potential companies for execution of the project have been visited in order to be able to better tailor our RFQ to the input needs of these companies. For the Reactor Modifications work package, the first invitations for tendering, i.e. the pre-qualification round, have been sent out on December 20, 2012. The selection of the three bidders will take place in February 2013.

Issues currently being addressed

The following list is an overview of on-going project steps:

- Completion of the user requirements for Reactor Modifications work package. Besides necessary changes to the existing equipment, reactor-ageing issues are being investigated. A major update of the original reactor drawings is being executed.
- Completion of user requirements for the Utilities work package. The CNS utilities as imported from Germany are being scrutinized to decide which parts will be reused and which have to be replaced. The preferred location for installation of the utilities, outside of the reactor containment, has been determined.
- Completion of the user requirements for the Instruments and Irradiation Facilities work package.
- Sourcing external support for the licensing procedure. For the MER study, NRG will offer support.
- Completion of the project schedule (engineering + detailed/ construction phase)
- Completion of the total investment cost overview as well as of the cash-out curve.

New Manpower

As mentioned above, Ron Goetjaer was appointed project leader for 2.5 days per week, on secondment from NRG. Niels van Wijk was appointed technical project employee as of December 13, 2012. Additional, mostly temporary staff is being appointed in order to complete the project in good time. NRG has been contracted to contribute specialized assistance with the environmental impact study (MER). Manpower is increased according to the OYSTER schedule: as of January 2013 a temporary technician position has been added to the HOR-development group and a scientist position has been opened within RST. Also, as mentioned above, two postdocs are being appointed for the design of instruments for the ESS.

Financial Overview

OYSTER amounts to M€ 116.9, covering the initial investments as well as the operational costs over a period of 10 years. TU Delft contributes M€ 74 in kind, industrial partners M€ 5, for which the TU Delft stands surety.
On January 20, 2012, the government awarded M€ 38 for OYSTER. The Ministry of Education, Culture and Science (OC&W) will be in charge. OC&W formally informed the Board of Directors of TU Delft on February 14 2012 of this decision. On March 22, 2012, the Board informed OC&W that the project will commence on April 1, 2012, and proposed a cash flow. The Board also confirmed that it will stand surety for the industrial M€ 5. The Dutch government asked the Dutch Science Foundation (NWO) to monitor the project and its cash flow. Before the official start of the project, expenditure included new equipment for the reactor control room (M€ 1.3), PEARL (M€ 0.6) and start-up investments for SANS. For 2013 the total expenditure is estimated at M€ 5.9 on modifications to the core, neutron and positron instruments, irradiation facilities and

licensing costs. In addition the TU Delft will contribute to the operational costs of the institute.
All costs are recorded according to Dutch regulations and accounting standards as well as standard TU Delft procedures.

Communication

Communication with internal and external stakeholders is essential to the success of the OYSTER program.

- Internal communication aims to ensure that every employee is continuously informed about the progress. It includes monthly plenary RID/RST meetings, articles in the internal newsletter "Reactor Reactie", monthly project reports of the OYSTER project team and face-to-face meetings.
- External stakeholders will be informed about the progress of OYSTER and about the scientific questions that can be addressed after the reshaping of the reactor core and construction of new instruments and irradiation facilities. This is done through monthly project reports, annual meetings and annual progress reports. Also, publications will be produced in periodicals such as Technisch Weekblad, Kernvisie, and C2W to inform a wider audience about OYSTER.

Further development steps of the communication strategy are in progress (website, weblog, social media). It has been agreed with the Ministry of Economic Affairs that all communication with the general public about the licensing of OYSTER will be coordinated jointly.

Appendix A

Neutron and positron instruments and irradiation facilities

The Neutron and Positron instruments

These instruments are large-scale experimental setups that use the neutrons or positrons to perform sophisticated experiments, which reveal material properties at the atomic level.

The First Imaging Station Holland "FISH"

Thermal and cold neutrons can penetrate several centimeters of metals like steel and lead. At the same time they are very sensitive to some light elements such as carbon. This provides high contrasts in images of metal components containing oils, plastics, adhesives etc. as illustrated by Figure 2.
As a result, neutron tomography and radiography are increasingly used for investigations of industrial components and materials, as well as for cultural heritage studies. In the automotive and aviation industry, structures and defects at the µm (0,001 mm) scale can be observed directly, and the combustion process in engines can be monitored.

Visible light | X-rays | Neutrons

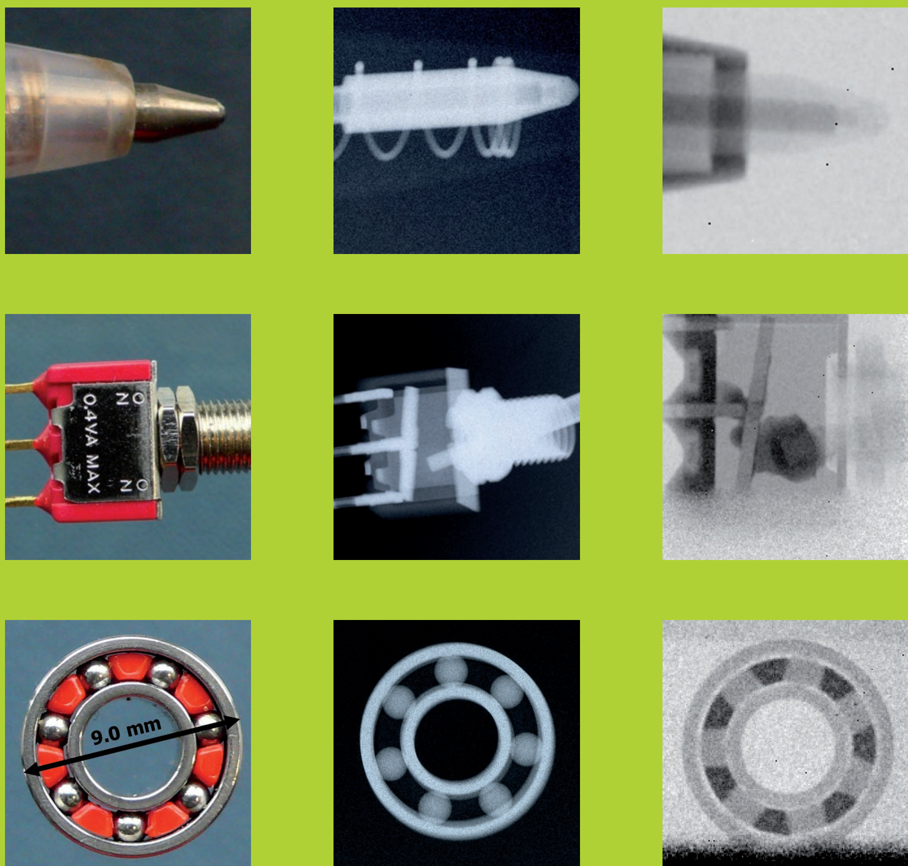


Figure 4: First neutron imaging results at the TU Delft comparing visible light, X-ray and neutron imaging of a pen, an electric switch and a ball bearing. The neutrons "see" the plastic parts and the ink in the pen, where the X-rays see the metal parts.

The original imaging (SNM) and depolarization (PANDA) instruments of OYSTER are now to be combined in a single instrument: FISH. The resulting multi-purpose instrument will make it possible to look into materials in a non-destructive way and will be used for scientific investigations of industrial or cultural heritage objects

The diffractometer “PEARL

Neutrons are best known as sub-atomic particles. However, they also behave as waves. Just like light waves and X-rays, they are reflected by crystalline structures in very specific directions. This physical principle, called neutron diffraction, can be used to determine the atomic structure of crystals. Neutron diffraction is a powerful tool for microscopic structural studies inside bulky materials. In particular when the position of very light atoms like hydrogen or lithium are of interest. For this reason the OYSTER proposal includes a state-of-the-art neutron powder diffractometer. In 2009, TU Delft gave a “go-ahead” for this project in anticipation of OYSTER. The design of the powder neutron diffractometer “PEARL”, shown in Figure 5, started in the summer of 2010 and commissioning is expected in 2014. Thanks to its innovative design, it will be a highly performing instrument, which will give Dutch science a competitive edge as a consequence.

Typical applications include hydrogen storage materials, hydrogen fuel cell materials, lithium batteries, magnetocaloric devices, solar cells and integrated electronic devices, thus materials that provide sustainable alternatives to fossil-based energy sources. The progress of the PEARL project can be followed at the weblog http://pearl.weblog.tudelft.nl/.

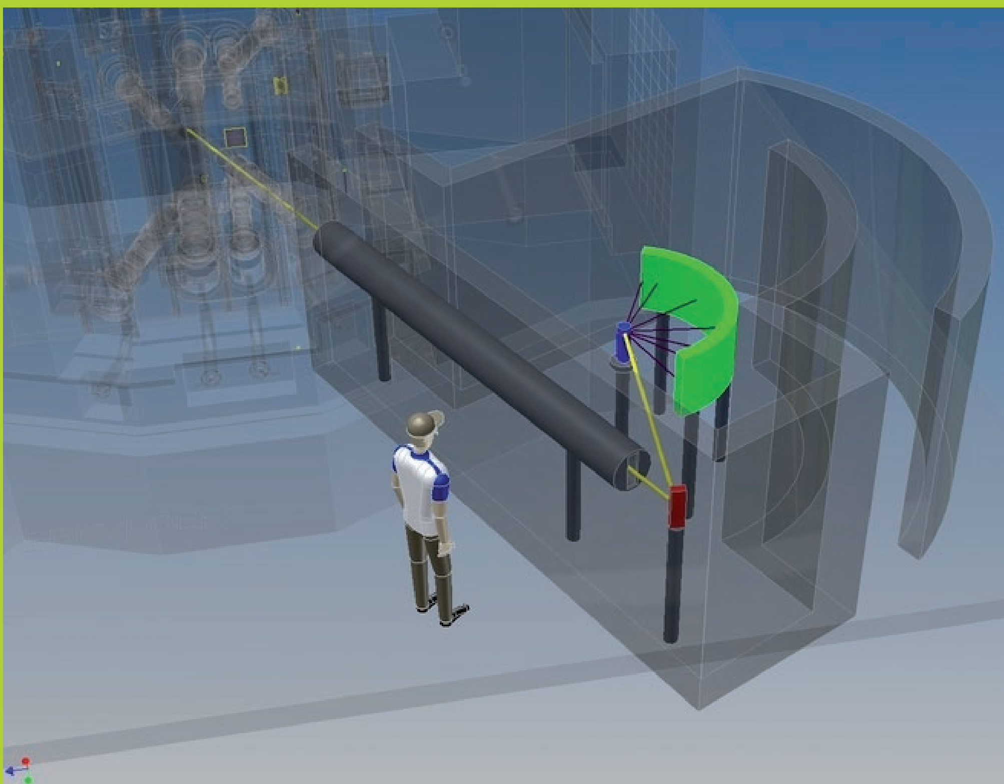


Figure 5: Schematic drawing of the neutron diffractometer PEARL.

The small-angle neutron scattering instrument “SANS”

When neutrons are scattered by very small particles with sizes from 1 up to a 100 nanometers, they scatter under small angles. This effect can be measured with the special setup of small-angle neutron scattering instruments (SANS), which gives direct information on the structures and size ranges involved. SANS is a multipurpose technique with typical applications in the fields of proteins, micelles, polymers, porous media, precipitates, detergents, foodstuff, or the development of novel high aluminum alloys.

The original OYSTER proposal did not include a SANS instrument. However, TU Delft decided to acquire one in 2010 from the Helmholtz Zentrum Geesthacht. The SANS instrument will be operational in the next months but full performance will only be reached with cold neutrons and thus after the installation of the cold neutron source. Figure 6 shows a photo of a beam collimation component and the progress of the project can be followed at the weblog http://sans.weblog.tudelft.nl/.

The small-angle neutron scattering instrument "SESANS"

Spin-echo SANS is comparable to SANS, but uses a special encoding of the neutron trajectories, through the Larmor precession of the neutron spin in an external magnetic field. It is used to investigate structural inhomogeneities with sizes extending from 50 nanometers to almost 10 micrometers. The TU Delft developed the first SESANS instrument worldwide and has also successfully created the scientific framework around it, with applications in the material studies of for example food, granular matter, fine powders, colloids, porous materials (rocks, concrete, graphite) or precipitates in metals.
As stated in the original OYSTER proposal, the existing SESANS instrument will greatly benefit from the cold neutron source. Investigations done towards the update of the OYSTER proposal revealed that additional flexibility can be achieved with moderate investments.

Figure 6:
The first, 10 meter long section of the SANS instrument under construction.

The reflectometer "ROG"

Due to their wave properties, neutrons are reflected by surfaces, similarly to light, as well as by layered structures. This property can be used to reveal the composition and thicknesses of layers ranging from 1 to 500 nanometers. Neutron reflectometry is a well-established research tool to investigate the structure of surfaces, thin-film or buried interfaces, as well as processes occurring at surfaces like corrosion, adhesion and interdiffusion. Applications vary from coatings of artificial joints in medicine, to food stability, drug delivery systems, thin film lithium-ion batteries, solar cells or hydrogen storage materials. The TU Delft has built and operates the state-of-the-art reflectometer ROG, which requires cold neutrons to maximize its potential as research tool, as acknowledged by the original OYSTER proposal. The updated OYSTER documents from June 2012 show that, just like SESANS, moderate investments can boost the performance of this multi-purpose instrument.

The neutron depth profiling spectrometer "NDP"

Some elements produce charged particles with high energies when irradiated with neutrons. These charged particles can be observed from outside the irradiated material, revealing their concentration and depth at the same time. This information can be used to determine the depth profile of the particular element. The NDP can be used for example to directly observe the motion of lithium ions inside batteries. This is very helpful in gaining better understanding of battery ageing as well as of material properties that limit the efficiency of batteries. The large-scale introduction of electric vehicles hinges on this understanding.

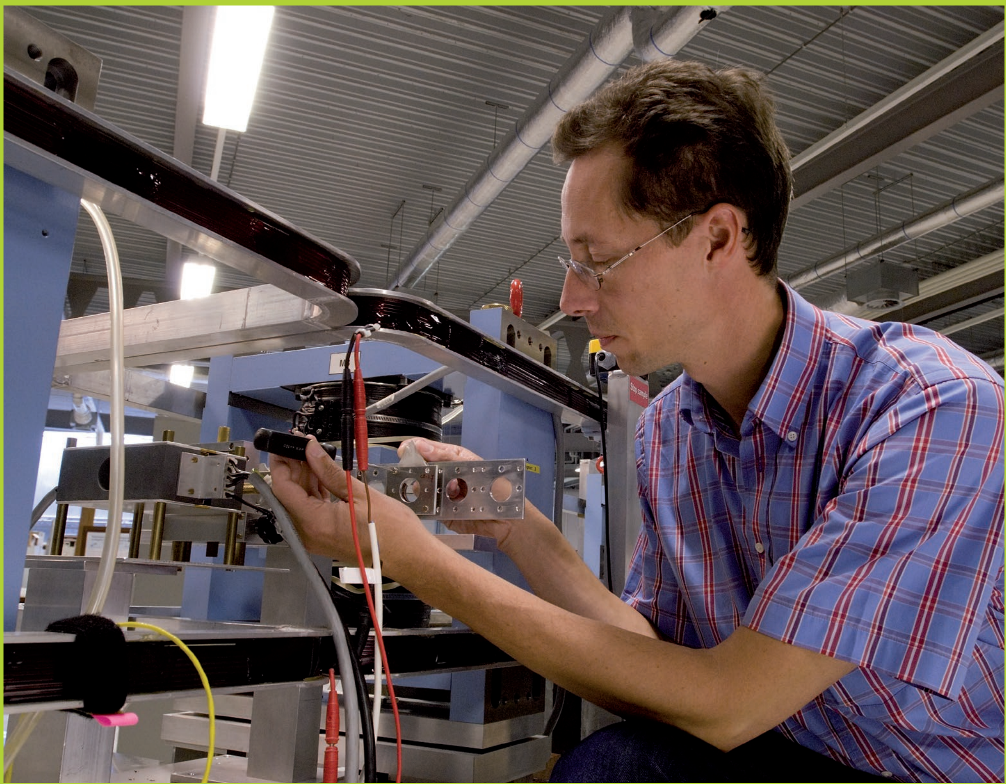


Figure 7:
The sample position of the SESANS instrument.

The in-beam Mössbauer spectroscope

Mössbauer spectroscopy allows researchers to determine the chemical condition of an atom, in a non-destructive way. It can be used for example for the development of better catalyst particles for the production of synthetic fuels and other chemical processes. Catalysts have a huge impact on the energy usage of the chemical processes. The right catalyst can make the difference between a wasteful fossil-based fuel and a sustainable, "greener" fuel.
Mössbauer spectroscopy normally can only be applied to a few selected elements. However, when the spectrometer is built so that the sample is held in a neutron beam, many more chemical elements can be observed.

The positron source "POSH"

The HOR nuclear reactor not only produces neutrons but also prompt gamma rays. These gamma rays can be used to form pairs of positrons (e+) and electrons (e-). When the positrons produced in this way are implanted in solids they are efficiently trapped by atomic-size defects such as vacancies, voids and small precipitates. Applications in which atomic-size defects play a crucial role include charge/discharge cycles of hydrogen storage materials and repeated mechanical stress, which is known to induce metal fatigue. The positron beam at the TU Delft reactor is the only one in its kind in the world and the only high-intensity positron beam facility coupled to a 2D-ACAR setup.

The positron angular correlation instrument "2D-ACAR"

While non-trapped positrons quickly annihilate, releasing two photons per positron that can be detected outside of the material, the trapped ones do so more slowly. By carefully measuring the energy of and the angle between the two annihilations photons, information about the type, depth distribution as well as the chemical environment of the defects is obtained. This analysis is called two-dimensional angular correlation of annihilation radiation (2D-ACAR) and the 2D-ACAR instrument observes the angle between the two annihilation photons emitted when the positron annihilates with an electron. By collecting a large number of annihilation events a two-dimensional (2D) projection of the 3D-electron momentum distribution is obtained.
The information thus derived is crucial in, for instance, the development of 3rd generation photovoltaic cells, where the aim is to use effectively all wavelengths of visible light, including blue. This goal is attained by precisely engineering the nanoscale structure of the crystalline material of the solar cell. 2D-ACAR can be used to elucidate the desired change in electronic structure.

The positron lifetime spectrometer "PALS"

The PALS technique is based on the measurement of the time elapsed between the injection and subsequent annihilation of a positron in a solid. As the annihilation involves an electron from the material, this lifetime is inversely proportional to the electron density at the annihilation site. PALS is a key technique for obtaining the size of the vacancy type defects.
The information obtained is extremely useful in gaining understanding of structure transformations in hydrogen storage materials, mechanical fatigue in metals and polymer systems, and of self-healing materials such as new aluminum alloys for the airplane industry. Because of its application potential, PALS was already included in the original OYSTER proposal.

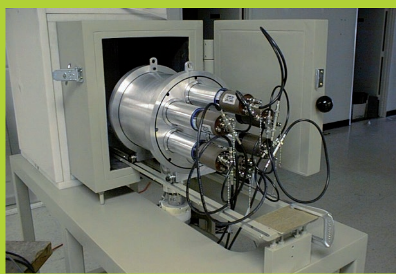
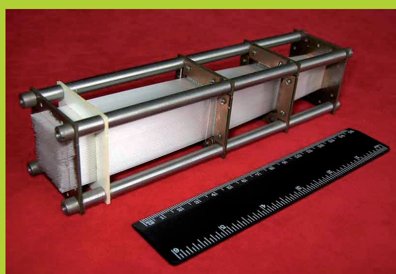


Figure 8: Prompt-gamma spectrometer set-up with BGO shield covering the Ge detector.



Poly-capillary neutron lens.

The irradiation facilities

The irradiation facilities of the reactor at TU Delft allow materials to be irradiated with neutrons or other types of radiation in a well-controlled environment. They are used for the production of radioisotopes and for analytical purposes such as Neutron Activation Analysis (NAA, see below). For each specific purpose there is a dedicated facility. The irradiation conditions (e.g. samples shielded from γ-rays, cooled, irradiated by cold, thermal or epithermal neutrons, short- or long irradiations), mostly depending on the characteristics of the isotopes of interest, can be used for both isotope production and analysis.

Radioisotope Production

Nuclear research reactors are indispensable for the production of a range of radioisotopes, which are used in medical clinical- and research institutes for (radio-)diagnosis and -therapy, as well as for industrial applications. Developments by end-users prompt radioisotope production sites to respond with new radioisotopes, higher specific activities, better (radio)chemical and –nuclide purity or for production from targets of different composition and shape. Many radioisotopes with attractive features for medical applications can become available by careful conditioning of the irradiation conditions and focusing on specific nuclear reactions. To this end, new irradiation facilities have to be designed and tested. Delft's focus is on the testing and optimization of nuclear reactions with reactor irradiation (neutrons and/or photons) for production of radioisotopes relevant for use in the applied fields; and on the development of methodologies for improving the radiochemical and radioisotope purity of these radioisotopes produced. The development and testing of targets of different sizes is an integral part of this program, as (whenever relevant) is the recycling of the target material after the irradiation and the waste processing.

Neutron Activation Analysis (NAA)

Materials irradiated with neutrons become radioactive in a way that is specific for almost all chemical elements. This makes it possible to determine the composition of any material by neutron activation analysis (NAA). The sensitivity of the method varies from element to element in a way that is completely differently from any other analytical technique. The resulting complementary nature of NAA to other analytical methods has resulted in its continuous use by industry and academia to keep up with innovations in material science (e.g. impurities of metals, composites, etc.), food and food supplement science, nanotoxicity studies, and other issues that are relevant to society (e.g. related to consumer protection, forensic issues, fine air particulate matter concern, metal-related diseases such as allergies etc.). The various irradiation facilities, described below, allow for the non-destructive analysis of samples ranging from a few milligrams to tens of kilograms, employing a neutron spectrum tailored to the elements of interest.
Isotopic NAA permits the observation of the behavior of metals (by using metals in their enriched stable isotopic forms in e.g. metal supplements in physiology or pathology, nanoparticles, metal implants), thereby distinguishing these "isotopic" metals in a matrix of natural metals of the same sort.

The Reactor Institute Delft is the first-ever university-based nuclear facility that operates with laboratory accreditation (ISO/IEC:17025) for quality management in neutron activation analysis and is one of the few IAEA Collaborating Centers worldwide as a result. In addition, it has the highest throughput capacity in the world under an ISO:17025 accredited quality assurance system.

Figure 9: Polyethylene (PE) "rabbits" in which four strings of plastic-packaged (PE) sample-capsules. Each string contains four samples with neutron flux monitors, adding up to 16 samples per PE rabbit, irradiated together in a pneumatically operated irradiation facility

Samples that are to be irradiated for NAA analysis can be transferred into the reactor either pneumatically or via manual operation. Small samples are often packaged in colored polyethylene containers, nicknamed "rabbits" (referring to a white rabbit disappearing into its hole, see Figure 9). Each irradiation facility is unique in terms of the allowed size of samples, the radiation level that can be achieved, the speed with which samples can be recovered or cooled during irradiation, etc.

Pneumatically operated small-target irradiation facilities

CAFIA-thermal and CAFIA-epithermal

Mostly, NAA is performed through irradiation in any of the irradiation facilities that RID offers, followed by a measurement in a separate spectrometer. The "CAFIA" (Carbonfiber Autonomous Facility for Irradiation and Analysis) is a dedicated system where irradiation facility and spectrometer are combined in a single instrument so that very short-lived radioactivity (i.e. half-lives down to 1 second) can be included in the analysis. It should be noted here that when the radioactivity is even shorter lived, measurement must take place simultaneously during the irradiation using an external neutron beam. Such a "prompt" system is envisioned as a component of the FISH instrument, where it will even be possible to focus the neutrons on details of the object to be investigated that are smaller than 1 mm, by using a poly-capillary lens.

OYSTER foresees the implementation of CAFIA systems under both thermal and epithermal neutron regimes to expand its analytical power.

PRT-C

The cooled pneumatic rabbit transfer (PRT-C) facility allows samples to be cooled to under 0 degrees Celsius during irradiation. It is positioned in the water reflector ex-core and can be irradiated by a thermal neutron flux of more than 10^{13} $cm^{-2}s^{-1}$. This facility permits the irradiation of heat-sensitive samples, such as organic targets, which otherwise may decompose by heating up. Examples are medical-purpose organo-metallic targets (e.g. Ho-polylactic acids, Mo-hexacarbonyls), which are used in clinical radiotherapy.

PRT-T

Three pneumatic rabbit transfer (PRT) facilities, positioned in the water reflector ex-core, irradiated by a thermal neutron flux of more than 10^{13} $cm^{-2}s^{-1}$ are available to be used for NAA in elemental analysis of samples of largely varying texture and composition.

PRT-E

Samples in this pneumatic rabbit transfer facility are shielded by 1 mm Cd during irradiation with cooling $< 400\ ^{0}$C for the suppression of (neutron, gamma) reactions during radioisotope production. Samples can be exposed to epithermal (flux of more than 10^{12} $cm^{-2}s^{-1}$) and fast reactor neutrons only. This facility is to be used for the specific production of radioisotopes, which, by the very nature of the production reaction, are eventually easily separated from the targets, thereby yielding highly pure radioactivity products for e.g. medical use.

Manually operated small-target irradiation facilities

CNIPF

The Cold Neutron Isotope Production Facility (CNIPF) is an irradiation facility positioned immediately behind the cold neutron source inside the radial beam tube. The facility must be retractable. The facility allows for irradiation with a high flux of cold neutrons (high effective cross section) and a relatively low flux of gamma rays.

ICIPF

The In-Core Isotope Production Facility (ICIPF) is used to produce radioisotopes by long irradiations at the highest neutron flux (5 – 8x10^{13} $cm^{-2}s^{-1}$). The facility has an option for under-water unloading and transfer of targets towards the underwater connection of the hot-cell/decanning facility (see below).

LIF

The Long Irradiation Facility (LIF) is an ex-core irradiation facility for radioisotope production by long irradiations at a thermal neutron flux of choice (1 – 10x10^{12} $cm^{-2}s^{-1}$) inside the reactor's water reflector.

SIPF

The Shielded Irradiation Pneumatic Facility (SIPF) is an isotope production facility with a removable gamma-ray shield of an up to 15 cm adjustable thickness between target and reactor surface. The gamma-ray shielding is essential for improving the amount of Mo-99 obtained by chemical separation from Mo-targets, irradiated in this facility. The varying thickness will allow for optimizing the neutron over gamma-ray dose. The facility must have an option for target cooling with media varying from cold water to LN2 which will further reduce the radiation damage during irradiation and enhance the quality of the final products.

Figure 10: Pneumatically operated small-target irradiation facilities. The photograph shows the PE rabbit loaded into the inlet of the pneumatically operated transport system (to and from the irradiation position).

The facility should also be equipped with retractable 1 mm thick Cd shield. Target sizes variable between 0.5 mL and 1 L; under-water unloading and transfer of targets towards the underwater connection of the hot-cell/decanning facility (see below).

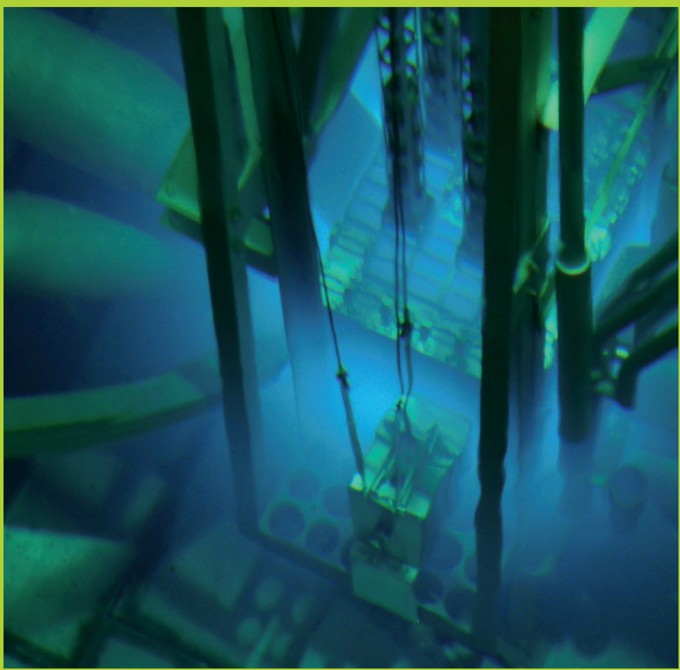


Figure 11:
SIPF early prototype of a gamma-ray-shielded irradiation facility (rectangular Pb-block in the centre of the photograph), positioned with steel cables in the irradiation position.

RIF
The Resonance Irradiation Facility (RIF) is a facility with adjustable and removable neutron filters for optimized use of resonance neutrons in isotope production. This facility for irradiation with 'resonance' neutrons of a selectable energy will be world-unique and can result in unprecedented improvements of the radioisotope purity and specific activity. Radioisotopes can then be produced by activation in a neutron energy spectrum with the highest intensity in the region of specific resonance neutron energies and (if relevant) simultaneous reduction of the thermal neutron production of interfering radioisotopes.

GIPF
The Gamma Irradiation Production Facility (GIPF) is used for producing highly energetic (Eg> 9 MeV) prompt gamma radiation for specific nuclear reactions and for the production of neutron-deficient radioisotopes. Such radioisotopes often emit positrons during their decay, and thus may be of interest for medical PET imaging. The facility will be equipped with target shielding against thermal neutrons.

Large-target irradiation facilities

BISNIS [existing, to be modified]
BISNIS (Big Samples Neutron Irradiation System) is a large-sample irradiation facility inside the reactor's thermal column. It will be modified in order to reach a thermal neutron flux exceeding 5x10^9 $cm^{-2}s^{-1}$. Suitable for targets with maximum dimensions 15 cm diameter, 100 cm length, 50 kg mass. This facility will be used for especially large-volume inhomogeneous samples, for which subsampling is hardly possible or generally in-adequate. Examples vary from complex electronic components, complete meals in epidemiological studies to objects of archaeological origin and cultural heritage.

PLSF
The Pool-side intermediate Large Sample Facility (PLSF) allows sample masses of 10 – 100 g for research on the optimal target dimensions for industrial production. It is positioned in water reflector ex-core, thermal neutron flux 1-10x10^{11} $cm^{-2}s^{-1}$.

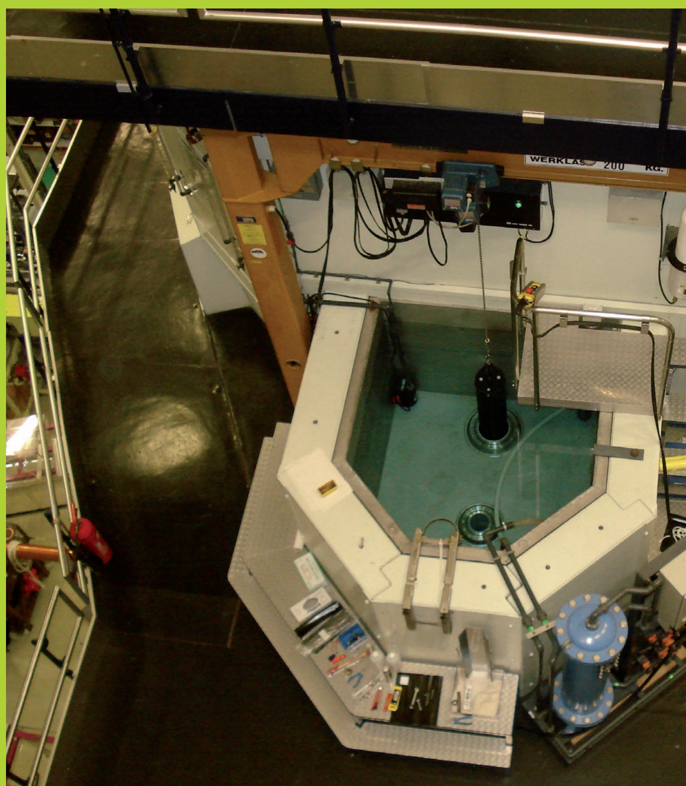


Figure 12:
Bird eyes' view on the BISNIS facility.

Loop irradiation facilities

IPL

The Isotope Production Loop (IPL) is a loop irradiation system to be positioned in radial or tangential beam tube for on-line radioisotope production in solutions containing uranium and subsequent on-line separation of the products from the solution.

MSL

The Molten Salt Loop (MSL) is a loop irradiation system for circulating aqueous fissionable elements containing solutions between reactor core and processing facility outside the reactor's biological shield for studies of the chemistry of prototype aqueous homogeneous reactors. Positioned in tangential beam tube.

Decanning Hot cell

UWC

Under Water Connection (UWC), used e.g. in the large reactor pool, supplies a connection towards a hot cell outside the reactor's biological shield for rapid decanning and handling of irradiated objects within 0.5 h after completion of the irradiation. Typical useful throughput dimensions: max. 30 cm diameter circular.

The hot cell

A hot-cell is a facility where high levels of radioactivity can be handled safely. Such a hot cell, directly connected to the reactor pool, is needed for rapid decanning (i.e., within 0.5 h after completion of the irradiation) for scale-up research towards industrial radioisotope production. Targets with induced activity levels of 1-10 Ci, have to be studied and processed for radiation damage studies. The latter will be done by analysis of sub-samples. A rapid decanning facility is also essential for expanding the research to the production of radioisotopes with short half-lives in the range of 1 to 3 h.

Molybdenum-99 production facility

Neutron irradiation of U-235 is the dominant method for producing the radioisotope Mo-99. Mo-99 is the parent radioisotope of Tc-99m, the main radioisotope in nuclear medicine SPECT diagnostics and used daily for ca. 70,000 treatments worldwide. Unscheduled shutdowns (repairs, maintenance) of the five main production facilities results in such shortages in Mo-99 that medical diagnoses and related treatments have to be postponed, which eventually can be life threatening to patients. It has been demonstrated that production in the RID reactor can easily result in an availability of Mo-99, equivalent to the need of the medical centers in Netherlands, i.e. approximately 120 Ci (6-d) per week.

The targets are to be irradiated with the highest possible neutron flux, if possible in the center of the reactor core. After the irradiation, the targets are immediately shipped elsewhere (e.g. to facilities in Petten) for further processing.

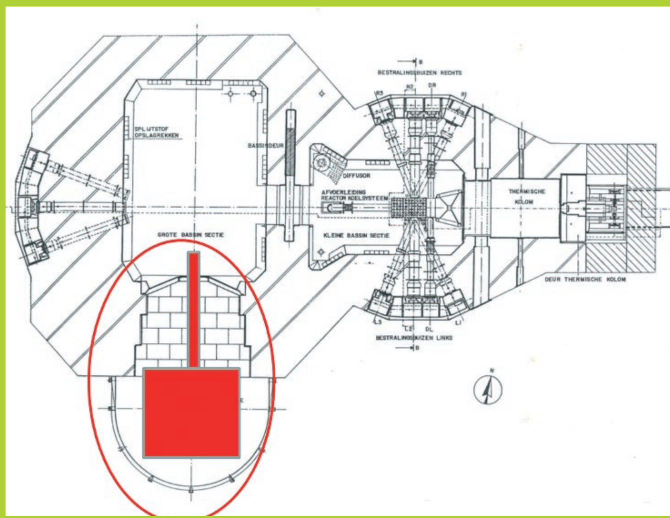


Figure 12:
Floor plan of HOR with schematic positioning of intended underwater connection and location of the hot cell.

A commercially available hot cell.

Appendix B

Referees of the June 2012 Review

Prof. H. Bijl.
Professor of Computational Fluid Dynamics, head of the Department of Aerodynamics, Wind Energy and Flight Performance and Propulsion, head of the Delft Energy Initiative and other positions, including member of the Advisory Board of the Energy research Centre of the Netherlands (ECN).

Prof. K.N. Clausen. Head of the Neutron and Muon Research Department of the Paul Scherrer Institute, in Switzerland. He is head of the technical advisory committee for the European Spallation Source project. He was previously head of neutron scattering and magnetism and superconductivity research at Risø National Laboratory in Denmark and external professor at the Niels Bohr Institute in Copenhagen. Since 1996, Clausen has been the coordinator and chair of the European roundtable for neutron scattering and muon spectroscopy.

Prof. G. Dollinger.
Head of the Institute of Applied Physics and Measurement Technology within the Faculty of Aeronautics and Astronautics at Bundeswehr University Munich. Main fields of research: Experimental Physics, Materials Science, Metrology, Radiobiology, Ion-matter interactions, Positron-matter interactions, Ion microscopy: development and application in materials science and radiobiology, Positron microscopy: development and application in materials science.

Dr. S.J. Kennedy.
Senior Principal Research Scientist at the Australian Nuclear Science and Technology Organisation and Technical Director of the Bragg Institute. He has 30 years experience in the application of neutron scattering techniques to condensed matter research in Australia and at world leading facilities (principally in Europe and Japan). Kennedy's most significant achievement has been in leading the development of Australia's new scientific neutron source, the OPAL Research Reactor, in which he led a multidisciplinary team of over 50 staff.

Prof. dr. E.P. Krenning.
Head of the Department of Nuclear Medicine at Erasmus MC, Rotterdam (1985-2012) and Professor of Nuclear Medicine (since 1990). Fellow of the Royal College of Physicians, London, U.K., since 1999. Krenning has participated in the educational responsibilities at Erasmus MC, lecturing in internal medicine, nuclear medicine, and endocrinology throughout his career. His main research interests include thyroidology and molecular medicine with radioactive-labeled peptides for imaging and therapy.

Prof. F. Mezei.
Member of the Hungarian Academy of Sciences and of Academia Europaea and inventor of the neutron spin-echo spectroscopy method, which has had far-reaching implications for the understanding of polymers, proteins, glasses and magnetic materials. Ferenc Mezei is an internationally renowned scientist, formerly the Scientific Director of ESS Hungary, the Hungarian bid to host the ESS. Mezei is currently a visiting scholar at the Los Alamos National Laboratory in USA. Previously he was the Director of the Berlin Neutron Scattering Center, which is now part of the Helmholtz Zentrum für Materialen und Energie.

Prof. B.M.W. Tsui.
Professor of Radiology at Johns Hopkins University. His research interest is in medical imaging, particularly in the area of Single-Photon Computed Emission Tomography (SPECT), Positron Emission Tomography (PET), and magnetic resonance imaging (MRI).

Prof.dr. J.F. Verzijlbergen.
President Elect at the European Association of Nuclear Medicine (EANM), Nuclear physician at the Rivierenland hospital in Tiel, The Netherlands. President of the Board of the Dutch Society for Nuclear Medicine (NVNG) in 2011, head of the Department of Nuclear Medicine, Erasmus MC Rotterdam, The Netherlands (2013 onwards).

Prof. L. J. van Vliet.
Full professor in multi-dimensional image analysis at Delft University of Technology as well as at Leiden University. Currently. He is director of the Delft Health Initiative at the TU Delft, leader of the Quantitative Imaging Group and head of the Department Imaging Science & Technology. He is on the board of the International Association for Pattern Recognition (IAPR), the Dutch graduate school on Computing and Imaging (ASCI), and Medical Delta.

Prof. S. van der Zwaag.
Full professor in the field of novel aerospace materials, which concentrates its research on the design of novel high performance metals, polymers and polymer fibres, self healing materials and functional composites. Professor Van der Zwaag is also director of the Delft Centre for Materials and chairman of the national IOP program on Self Healing Materials. He is member of the Royal Dutch Society for Sciences and fellow of the (British) Institute of Materials, Minerals and Mining. In 2012 he was granted the honorary title 'distinguished professor' by the Board of the Delft University of Technology.

Appendix C

Planning

OYSTER Project Reactor Modifications & Utilities - Engineering Phase

Activity ID	Activity name	Start	Finish	2013 jan	feb	mrt	apr	mei	jun	jul	aug	sept	okt	nov	dec	2014 jan	feb	mrt	apr	mei	jun	jul	aug	sept	okt	nov	dec
Milestones																											
M001	TIC overall begroting +/- 30% beschikbaar		30-aug -13								■																
M002	Constructie uitvoeringsplanning beschikbaar		30-aug -13								■																
M003	Bespreking/opstelling definitieve vergunning afgerond		31-dec-14																								■
M004	Engineering fase afgerond		31-dec-14																								■
M005	Start construction phase		1-jan-14																								
Activity																											
RABZ	*Algemeen*																										
	TIC overall begroting +/- 30%								■	■	■																
	Overall uitvoeringsplanning								■	■	■																
RABX	*Reactoraanpassingen*																										
	MER vooroverleg/indienen Mededeling			■	■	■																					
	MER opstellen/aanleveren								■	■	■	■	■	■	■	■	■	■	■	■	■						
	DSR vastlegging eisenpakket			■	■	■	■	■																			
	VR opstellen/aanleveren								■	■	■	■	■	■	■	■	■	■	■	■	■						
	Concept vergunning opstellen															■	■	■	■	■	■	■	■	■			
	Bespreking/opstelling definitieve vergunning																								■	■	■
	EPC contractor inventarisatie + voorselectie (max.3)			■	■																						
	Pakket van Eisen Reactoraanpassingen opstellen					■	■	■																			
	Basic Engineering PI 3 MW + CNS (incl. moderator design)								■	■	■																
	Selectiefase EPC contractor + contractverstrekking											■															
	Detailed Engineering PI 3 MW + CNS (incl. moderator design)												■	■	■	■	■	■									
	Ontwerp aanpassing koelsysteem binnen reactorgebouw															■	■	■									
	Selectie leverancier + contractverstrekking aanpassing koelsysteem																		■								
	Ontwerp aanpassing E&I binnen reactorgebouw															■	■	■	■	■	■						
	Selectie leverancier + contractverstrekking E&I binnen reactorgebouw																					■					
	Selectie leverancier + contractverstrekking bouw Mock-up testopst.											■															
	Ontwerp + bouw Mock-up testopstelling koude bron in bundelbuizen												■	■	■	■	■	■									
	Ontwikkeling + bouw special tools tbv inbouw koude bron in bundelbuis																		■	■	■	■	■	■			
	Mock-up testen installatie koude bron R2																								■	■	■
	TIC deelbegroting Reactoraanpassingen +/- 30%								■	■	■																
	Uitvoeringsplanning Reactoraanpassingen								■	■	■																
RABY	*Utilities*																										
	Pakket van Eisen Utilities opstellen					■	■	■																			
	Basic Engineering nieuwe regelkamer en locaties								■	■	■																
	Selectie leverancier + contractverstrekking nieuwe regelkamer en locaties											■															
	BasicEngineering aanpassing koelsysteem en compressor								■	■	■																
	Selectie leverancier + contractverstrekking aanpassing koels. en comp.											■															
	Basic Engineering aanpassing E&I											■	■	■													
	Selectie leverancier aanpassing E&I														■												
	TIC deelbergoting Utilities +/- 30%												■	■	■												
	Uitvoeringsplanning Utilities												■	■	■												

Date	Revision	Approved
5 september 2012	Rev. 3	
27 november 2012	Rev. 4	
23 januari 2013	Rev. 5	

OYSTER Project Reactor modifications & Utilities - Construction Phase

Activity ID	Activity name	Start	Finish
Milestones			
M001	TIC overall begroting +/- 10% beschikbaar		31-mrt -13
M002	Start fabricage CNS koude bron + PI hanger en roosterplaat		1-apr -14
M003	Reactor uit bedrijf		1-sept-15
M004	Opstart reactor (proef)bedrijf		1-apr-16
M005	Afsluiting OYSTER Project Reactoraanpassingen		30-jun-16
Activity			
RABZ	*Algemeen*		
	TIC overall begroting +/- 10%		
	Overall uitvoeringsplanning		
RABX	*Reactoraanpassingen*		
	Conceptvergunning opstellen en bespreken		
	Vergunningenprocedure		
	Detailed Engineering PI 3 MW + CNS (incl. moderator design)		
	Fabricage PI nieuwe hanger en roosterplaat		
	Fabricage CNS moderator + aanverwante apparatuur		
	Reactorstop + kern ontladen		
	Reactorbassin drainen 1st fase + ontmanteling hanger etc.		
	Kern + bassin configuratie as-built vastlegging		
	Reactorbassin drainen 2de fase; bundelbuizen droog		
	Afbreken spiegelfilter R2		
	Uitvoering aanpassing bundelbuis R2		
	Aankleden Reactorvat en Reactorbassin vullen 1st fase		
	Plaatsing hanger en roosterplaat + nieuwe regelstaven		
	0-meting + Reactorbassin vullen 2e fase		
	Detailed Engineering aanpassen koelsysteem binnen reactorgebouw		
	Aanpassen koelsysteem binnen reactorgebouw		
	Detailed Engineering aanpassing E&I binnen reactorgebouw		
	Aanpassen E&I binnen reactorgebouw		
	Start-up/commissioning		
RABY	*Utilities*		
	Detailed Engineering nieuwe regelkamer en locaties		
	Uitvoering nieuwe regelkamer en locaties		
	Detailed Engineering aanpassing koelsysteem en compressor		
	Uitvoering aanpassing koelsysteem en compressor		
	Detailed Engineering aanpassing E&I		
	Uitvoering aanpassing E&I		
	Start-up/commissioning		

Date	Revision	Approved
5 september 2012	Rev. 3	
27 november 2012	Rev. 4	
23 januari 2013	Rev. 5	

OYSTER

TU Delft Delft University of Technology

REACTOR INSTITUTE DELFT