MYRRHA

Multi-purpose hYbrid Research Reactor for High-tech Applications

A research infrastructure **for a new era**

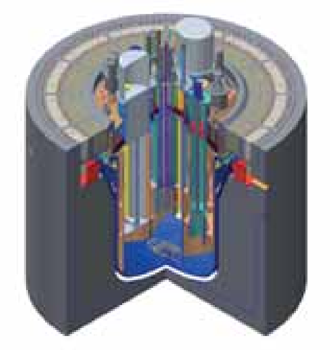
MYRRHA

A flexible fast spectrum research facility at SCK•CEN, the Belgian Nuclear Research Centre in Mol

Scope of MYRRHA

The Belgian Nuclear Research Centre (SCK•CEN) in Mol is working since several years on the design of a multi-purpose flexible irradiation facility to succeed the BR2 reactor, operated since 1962 as a multi-purpose materials testing reactor (MTR).

MYRRHA, a flexible fast spectrum research facility, is conceived as an accelerator driven system (ADS), able to operate in sub-critical and critical modes. It consists of a proton accelerator of 600 MeV, a spallation neutrons source and a nuclear core with MOX fuel, cooled by liquid lead-bismuth (Pb-Bi).



The MYRRHA reactor

MYRRHA on the European scene

SCK•CEN is positioning MYRRHA as one of the corner stones of the European Research Area of Experimental Reactors (ERAER). As stated in the Strategic Research Agenda (SRA) of the Sustainable Nuclear Energy Technology Platform (SNETP), Europe can only retain its worldwide leading position in the field of reactor technology and related future developments, if it provides for the necessary research infrastructures needed for this development such as MYRRHA.

Applications catalogue of MYRRHA

MYRRHA will:

- be a flexible fast spectrum irradiation facility for material developments for innovative fission and fusion reactors;
- demonstrate the ADS concept at adequate power level;
- allow the study of the efficient transmutation of high level nuclear waste;
- contribute to the development of lead fast reactors as a European Technology Pilot Plant;allow fundamental research by making use of the proton beam of the accelerator;
- allow production of radioisotopes for medical and industrial applications.

Implementation of MYRRHA

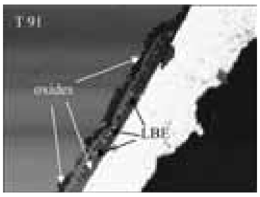
If still in 2010, when the Belgian Government took the decision to support this programme, MYRRHA was thought to be operational at full power around 2026, after full commissioning of the facility, the Fukushima accident and the economic crisis that started in 2008 and became more severe since 2011 have strongly impacted the programme development, timing and budget. The optimisation of the primary system design of the reactor, integrating with time the new R&D results made available, together with a time consuming pre-licensing process intended to better cope with the enhanced safety requirements of the regulatory authorities, have led end 2014 to reconsider at the Board level the implementation strategy of the programme.

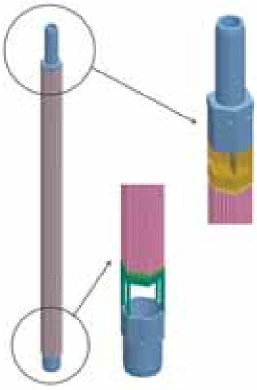
A phased implementation strategy spreading investment costs and mitigating the technical, cost and planning overrun risks was decided. A 100 MeV accelerator sub-programme has been launched in early 2016 as a first phase of the full programme allowing to have on site a research facility operational in 2024 allowing physics R&D through an ISOL-target and producing radio-isotopes. The second phase will extend the accelerator to 600 MeV beam energy based on the design and prototyping already performed until 2024. The third phase is the construction of the reactor. The realisation of phases 2 and 3 can be conducted in parallel depending on consortium build-up and financial constraints at that time.

The future implantation of the MYRRHA facility at the SCK•CEN technical site.

Design activities

SCK•CEN is conducting the design of the primary system that incorporates the reactor core design & physics, the mechanical and thermal hydraulic design of the vessel and all in-vessel components and the associated instrumentation and the conceptual design of peripheral systems such as the different heat removal systems, the LBE and cover gas conditioning systems. In this programme, also safety studies are conducted to guide the design and to prove the technical sound-fullness and feasibility of the chosen safety options and provisions. The accelerator design is coordinated by SCK•CEN in an international context and the first phase of the MYRRHA accelerator (up to 100 MeV) will be tested during this period to study and enhance the reliability.





Material qualification

Dedicated steels for the different components need to be tested in relevant conditions to validate the choice. Tests in stagnant and flowing liquid Pb-Bi are on-going to investigate the influence of the coolant on the mechanical properties of the materials (first figure left). Also dedicated irradiation tests are conducted in BR2 and BOR60 to study the behaviour of these materials under irradiation.

Fuel qualification

Before loading new types of fuel and cladding (fourth figure left) in a reactor, one needs to prove that they will be able to withstand operational conditions and anticipated transients. Due to the choice of fast reactor MOX fuel, one can largely rely on the existing database that needs to be complemented by specific data for MYRRHA conditions.

Accelerator development

For the accelerator and its components (second figure left) the main area of research is related to the increase of the reliability. The design of the accelerator will be performed in such a way that the malfunctioning of one module can be compensated by other modules in the high energy part. In the low energy part, the main challenge is the fabrication of adequately cooled normal conducting radio frequency cavities.

Liquid metal technology

In the liquid metal technology R&D programme, loops are developed and constructed in support of the material programme, component testing and chemistry R&D. Also the construction of a scaled down version of the MYRRHA pool (and filtering system) is envisaged to study thermal hydraulics in MYRRHA.

Inspection and repair strategy

Remote controlled manipulators will be deployed out-vessel to operate, maintain and inspect the facility (third figure left).

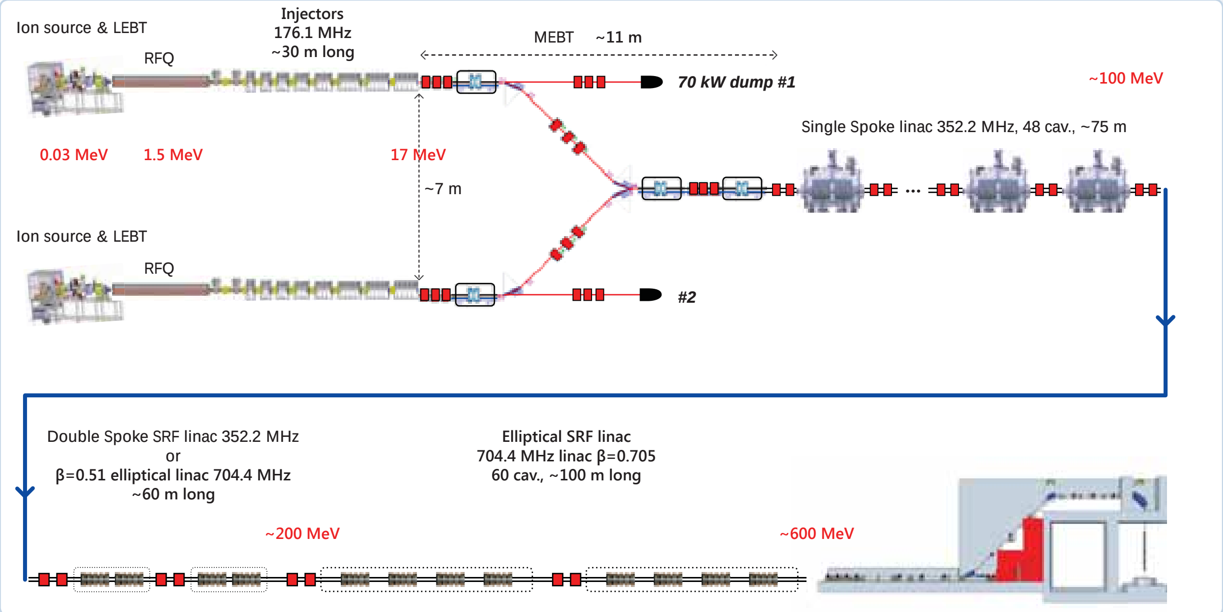
Reactor physics programme

The reactor physics R&D programme encompasses the development of adequate neutronic codes for MYRRHA (e.g. core management code) and the validation of the codes by integral measurements.
The GUINEVERE experiment (last figure left) foresees on the one hand the validation of the methodology for the control of an ADS and on the other hand validation experiments to reduce uncertainty margins hence guaranteeing a safe operation regime.

Pre-licensing programme

The objective of the pre-licensing is to obtain at the end of this programme a positive statement from the Federal Agency of Nuclear Control (FANC/AFCN) on the licensability of MYRRHA. It requires the demonstration that the safety options, security requirements and safeguards obligations implemented in the design of the facility meet regulator's requirements. The pre-licensing is based on the evaluation of so-called "focus points", identified as technological items specific to MYRRHA, through their innovative character and potential safety impact. Environmental aspects will be developed in parallel for the reference design.

The MYRRHA accelerator



An Accelerator Driven System at the VENUS installation

What was VENUS used for?

The VENUS reactor is an experimental low-powered reactor of the "zero-power critical facility" type. It was critical for the first time in 1964 with a water-moderated core. VENUS was converted in 1968 to carry out neutron studies of new reactor configurations. Large power reactor cores were reproduced on a small scale (about 50 x 50 x 50 cm). The VENUS reactor was modernised in 1991 and in 2000-2001, the internal parts of the reactor vessel were modified in order to enable to load fuel of 1 m instead of 50 cm for new application areas.

Calculations for a more efficient fuel use

VENUS has been used for the validation of reactor codes. They have proven their usefulness for the determination of the optimal nuclear fuel configuration with regard to parameters like power distribution, neutron economy and neutron irradiation of the reactor vessel. If, however, one wants to deviate from the standard configuration and enter new domains, the codes must be revalidated. The critical VENUS facility was particularly fit for this purpose: the flexibility of the installation enables the development of realistic simulations.

In June 2003, SCK•CEN carried out a unique experiment in VENUS. For the first time a fuel assembly, irradiated in a power reactor like Doel or Tihange, was loaded. Because of burning in the nuclear reactor, irradiated fuel contains less uranium than non-irradiated fuel. The difference is called the "burn-up credit". The risk of attaining a critical mass diminishes and the irradiated fuel can be placed closer together than non-irradiated fuel. This affects the storage in nuclear power plants and less irradiated fuel transports are needed. The codes have been validated in VENUS for the calculation of the burn-up credit.

The GUINEVERE project

The GUINEVERE project was a project within IP-EUROTRANS, a programme in the 6th Framework Programme (FP6) of Euratom. IP-EUROTRANS addresses main issues for Accelerator Driven System (ADS) development in the framework of partitioning and transmutation for nuclear waste volume and radiotoxicity reduction.

The GUINEVERE project was carried out in the context of domain 2 of IP-EUROTRANS, ECATS, devoted to specific experiments for the coupling of an accelerator, a target and a subcritical core. A major item to be investigated by these experiments was the validation of the subcriticality monitoring for an ADS since the guarantee of subcriticality is of fundamental importance for the safety of an ADS.

Analysing the outcome of the FP5 MUSE project with regard to this issue, two points were left open for significant improvement. To validate the methodology for reactivity monitoring, a continuous beam was needed, that was not present in MUSE. In the definition of MUSE, from the beginning also a strong request was made for a lead core in order to have representative conditions of lead-cooled ADS which were only partially answered by the MUSE programme. For this purpose, there was a need for a lead fast critical facility connected to a continuous beam accelerator.

Since such a programme or installation was not present at the European nor at the international level, SCK•CEN proposed to use a modified VENUS critical facility located at its technical site in Mol and to couple it to a modified GENEPI deuteron accelerator working in continuous mode (with and without beam trips) and in pulsed mode: the GUINEVERE project (Generator of Uninterrupted Intense NEutrons at the lead VEnus REactor). The picture left shows the accelerator inserted in the core of the VENUS reactor.

The FREYA project

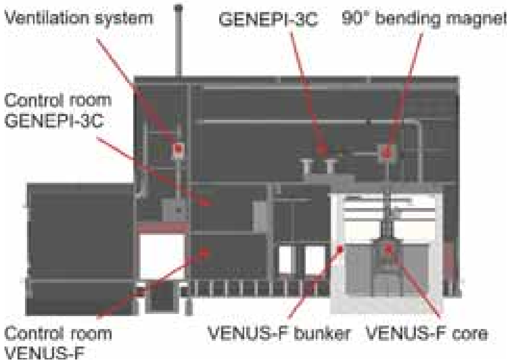
As a follow-up of the GUINEVERE project, in the 7th Framework Programme (FP7) of Euratom, the FREYA project was started. FREYA (Fast Reactor Experiments for hYbrid Applications) aims to:

- Complete the experimental programme for the validation of the methodology for on-line reactivity monitoring initiated within the GUINEVERE project.
- Conduct the necessary experiments in support of the design and licensing of the MYRRHA/FASTEF type reactor.
- Conduct the necessary experiments in support of the design and licensing of Lead Fast Reactors (LFR).

Present status

The commissioning tests for the licensing of the new installation were started in the summer of 2010 with the commissioning of the GENEPI-3C accelerator in stand-alone mode. The commissioning tests of the reactor in critical mode started in January 2011. The 4th of February, VENUS-F became critical for the first time. In November 2013 the commissioning process has been concluded and the experimental programme foreseen in the FREYA project was started.

The conversion of the VENUS reactor to an accelerator driven system consisted of two types of modifications at the SCK•CEN site. First of all, there are the modifications which are connected to the installation of the new GENEPI-3C accelerator at the VENUS critical facility and its coupling to the core. The second type of modifications is linked to the adaptation of the VENUS critical facility to host a fast lead core, further on referred to as VENUS-F.



GENEPI-3C characteristics

The construction of the accelerator GENEPI-3C was carried out by the French research centre CNRS. For the penetration of the accelerator into the core, it was decided early in the project to have a vertical penetration because it has significant scientific advantages. An additional floor was constructed on top of the existing installation. In the figure above you see the drawing of the additional floor with the ventilation system on top of the already existing bunker in the VENUS hall.

The GENEPI-3C (GEnérateur de NEutrons Pulsé Intense-3 Continu) accelerator is the third of a series designed for neutronic experiments. The GENEPI machines are 250 kV deuteron accelerators ended by copper targets with titanium-tritium (TiT) or titanium-deuterium (TiD) deposits, providing 14 MeV or 2.5 MeV neutrons.

The new GENEPI-3C machine cumulates specifications of the first GENEPI accelerator, designed for the MUSE experimental programme at MASURCA reactor (CEA Cadarache, France, 2000-2004), i.e. pulsed mode operation with very sharp and intense beam pulses (1 µs, 50 mA peak current), with new continuous mode specifications summed up in the table above. In this new continuous mode, it will also be possible to operate with beam interruptions (beam trips) with a programmable duration and a low repetition rate for the needs of the foreseen experiments.

Mean current	160 µs to 1 mA
Beam trip rate	0.1 to 100 Hz
Beam trip duration	~20 µs to 10 ms
Transition time (on/off)	1 µs
Beam spot size	20 to 40 mm in diameter
Max. neutron production	5×10^{10} n/s

Due to the vertical coupling conditions, the GENEPI-3C machine required a special design allowing the entire removal of the vertical line partly inserted in the reactor: this is necessary for target changes and for reactor or accelerator maintenance. To do so, the vertical line was embedded in a supporting structure that can be hoisted along guiding structures by means of a crane, and then lifted above the reactor bunker ceiling to be stored on a stand surrounded by working platforms. To allow the structure to move, the 90° bending magnet was made removable too and supported by a mobile cart that can be moved along two rail tracks.

VENUS-F characteristics

To obtain a fast lead core in the VENUS vessel, all internals were removed and replaced by a core made of lead and uranium fuel. The fuel was provided by CEA (Commissariat à l'Energie Atomique) in the framework of the IP-EUROTRANS project.

Based on uranium rodlets of about 1.27 cm diameter, lead plates and square lead rodlets of 1.27 cm thickness, a fuel assembly is made based on the pattern given in figure a below. The active height of the core region is about 60 cm. About 80 to 90 fuel assemblies are needed to obtain a critical configuration (figure b below).

The core region is contained within a 12 x 12 square of assemblies. The other assemblies (green squares figure b) are lead assemblies that act as the reflector. To allow a safe shutdown in all situations, 6 safety rods made of boron carbide with a fuel/lead follower are foreseen in the core (yellow squares in the core region of the figure). The control rods (yellow squares in the periphery region) are made of boron carbide.

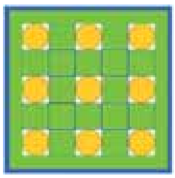


Figure a

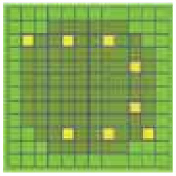


Figure b

ISOL@MYRRHA

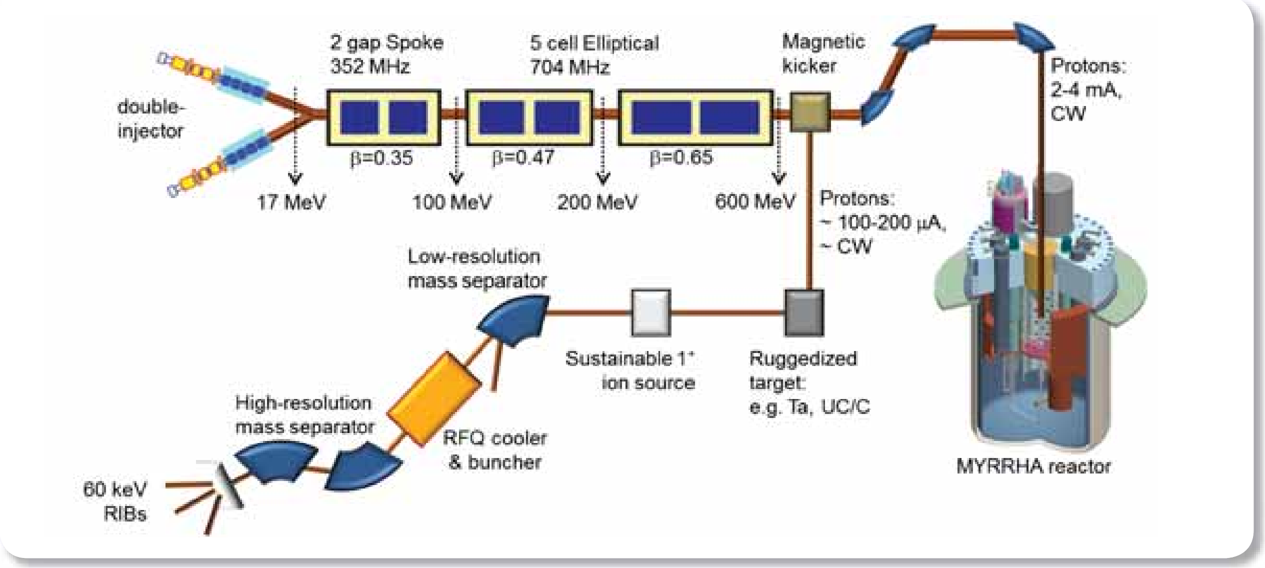
An ISOL facility at the MYRRHA accelerator

ISOL@MYRRHA

In parallel to the accelerator driven system (ADS) MYRRHA, plans are being developed at SCK•CEN for ISOL@MYRRHA: a radioactive ion beam (RIB) facility of the isotope separator on-line (ISOL) type focusing on fundamental science research. Using just a small fraction (< 5%, 100-200 μA) of the proton-beam intensity delivered by the MYRRHA accelerator, one can achieve production of high-intensity RIBs. Research fields which are typically addressed, are: nuclear, atomic and solid-state physics, fundamental-interactions studies and medical physics.

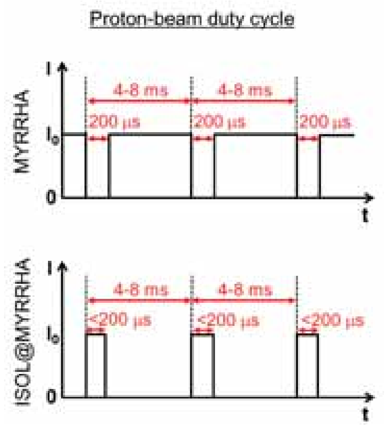
Concept

ISOL@MYRRHA will follow closely the RIB production schemes that are developed and successfully used at the ISOLDE-CERN and TRIUMF facilities. It will be equipped with ruggedized target ion-source systems that allow the use of a selection of target materials, including actinide targets, which can withstand the high proton-beam power without compromising the reliability, the longevity, the diffusion and effusion properties, and the yield of particular radioactive isotopes.



Operational approach

The scenario is to operate both MYRRHA and ISOL@MYRRHA in parallel, which requires a continuous beam splitter. A fraction of up to 5% of the main beam (corresponding to 100-200 μA average current) will be delivered to ISOL@MYRRHA.



Why ISOL@MYRRHA?

Radioactive ion beam research has been recognized as one of the top priorities in nuclear physics. Moreover, RIBs create a wide area of research opportunities in other fields. On the other hand, going more and more exotic is a driving incentive of several research programmes. Thus even vigorous efforts to improve beam intensity and purity, and detection efficiency and sensitivity will not substantially decrease the demand of beam time.

This limitation prohibits potentially very interesting programmes, involving experiments which:

- need very high statistics;
- need many time-consuming systematic measurements;
- hunt for very rare events;
- have an inherent limited detection efficiency.

These particular experimental programmes can be uniquely addressed at ISOL@MYRRHA, given the availability of extended beam times (several weeks up to months) with the high intensity and the high reliability of the MYRRHA accelerator.

Ion sources

Three types of ion sources are foreseen for selective ionization of the products: the hot-surface ion source, the resonant ionization laser ion source (RILIS), and the electron cyclotron resonance ion source (ECRIS).

Mass separators

Additional purification occurs by mass separation after extracting the ions over a potential difference of up to 60 kV forming the RIB.

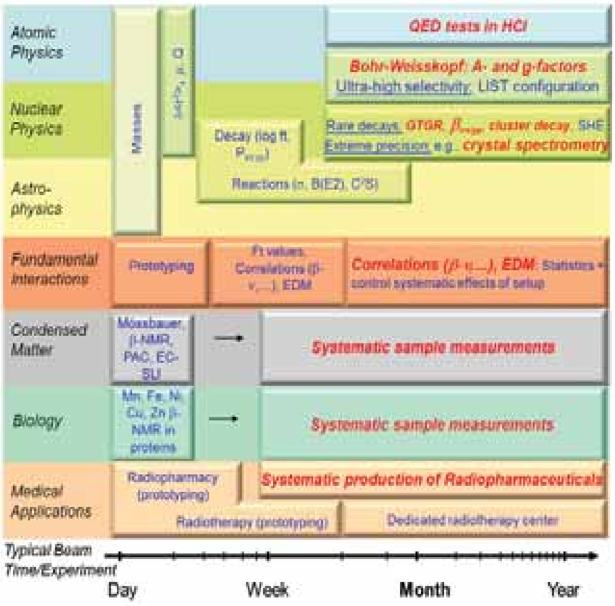
In order to make effective use of the beam time, the parallel multi-users aspect of ISOL@MYRRHA is an important issue in the design study. Since a high-resolution mass separator prevents the use of different beams at the same time, a pre-separator with low-mass resolution is considered. In this way, one could envisage a scenario in which the lower-mass isotopes (e.g. ^{8}Li for b-NMR in solid-state physics) are used in parallel with an experiment using heavier nuclei.

Beam preparation

The pre-separation avoids a too intense RIB loading of the RFQ cooler and buncher, which allows a high-quality low-emittance beam. As a result, the high-resolution magnet can be exploited to its full potential with a mass-resolving power M/ΔM in the order of 10^4.

Expected yields

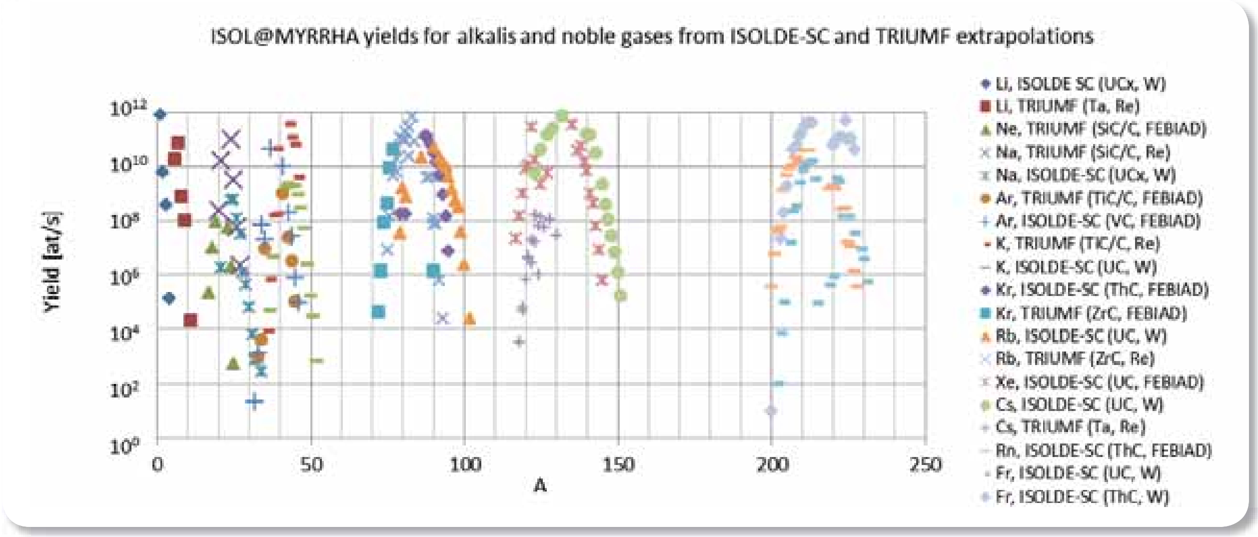
For a first indication, the expected yields at the ISOL@MYRRHA facility are estimated by linearly extrapolating the available production yields listed in the ISOLDE-SC (600 MeV proton beam on UC and ThC targets) and ISAC (500 MeV proton beam on ruggedized spallation targets like Ta, SiC/C, TiC/C, and ZrC/C targets) databases. In this approximation, it is assumed that diffusion and effusion losses, the ion-source efficiencies and the separator-transport efficiencies are the same.



Physics cases

Measurements with high-intensity beams and long/regular beam times are an important source of information for quasi all fields in science making use of RIBs.

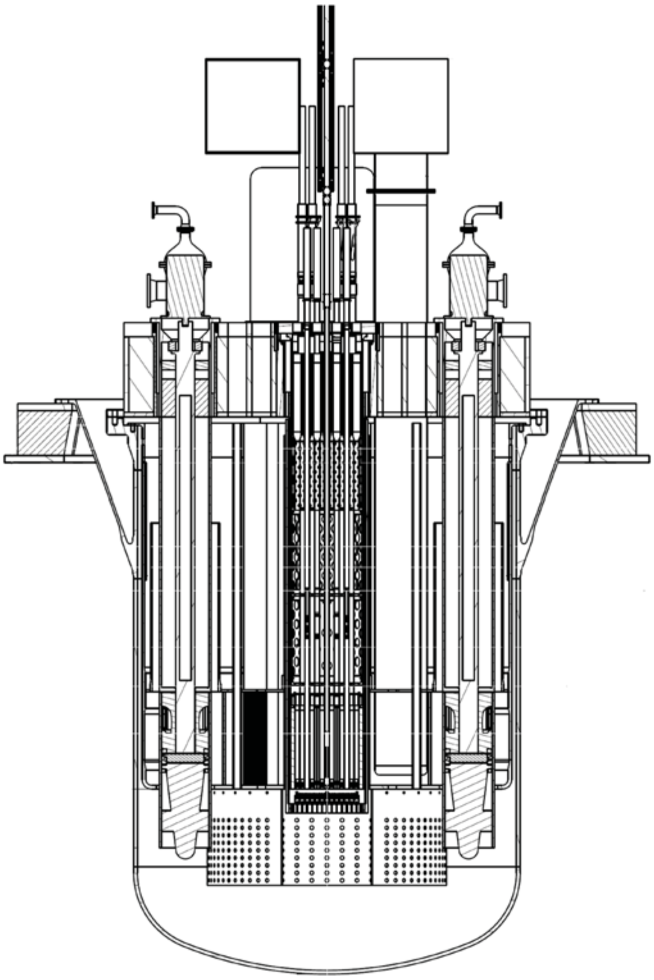
The figure below shows an overview of typical RIB research over the different fields with ISOL@MYRRHA opportunities indicated in red font.

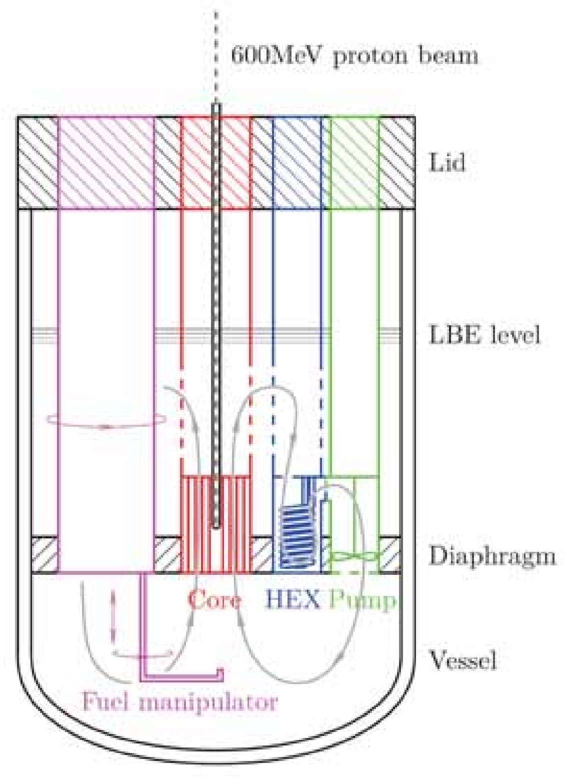


More information: isolmyrrha@sckcen.be | http://isolmyrrha.sckcen.be

MYRRHA

Multi-purpose hYbrid Research Reactor for High-tech Applications





System description

- Currently in design phase
- Cooled by liquid metal at 200 – 400°C
  45% lead / 55% bismuth
- Fast neutron spectrum
- Accelerator driven system
- Up to 100MW thermal power
- Submerged robotic fuel manipulation

Applications

- European fast spectrum irradiation facility
- Demonstration of reduction of radio toxicity of nuclear waste
- Material research for current and future reactor systems
- Medical isotope production
- Silicon doping
- Fast flux irradiation facility for the ITER fusion reactor

20140320

HELIOS3

A setup for conditioning of Lead Bismuth Eutectic (LBE)

LBE Conditioning

LBE = Lead-Bismuth Eutectic

- 44.5 wt% Lead + 55.5 wt% Bismuth
- Cooling fluid + Spallation target for MYRRHA

☹ Corrosion of structural steels
☹ Precipitation of oxides

Mitigate through control of the oxygen concentration in LBE = conditioning

Optimal oxygen concentration [O]?

- Too high → formation of PbO and other oxides
- Too low → corrosion attack of structural steels
- [O] for MYRRHA ~10^{-7} wt%
  = 1 ppb = 1 mg O per kg LBE

Conditioning methods

- Cover gas → low interaction rate
- Dissolution of PbO pebbles in LBE → only [O] ↑
- Gas bubbling: most versatile
  → [O] ↑ of ↓ by adapting the gas mixture

Gas bubbling

Initial setup: 2 mm diameter bubble pipe

☹ Large bubbles effects → violent bubble collapse
→ Low gas flow rates (6 l/h)

☹ Slow conditioning rate (20 kg of LBE takes 2 weeks of conditioning)

Optimization of the bubbling process

Maximization of liquid-gas interaction

- Increase of gas –liquid interaction area through minimization of bubble size:
  → use of gas sparger, hole size ~10 µm
- Increase in gas-liquid interaction time by maximizing the bubble residence time
  → mixing, vessel geometry

Validation in water

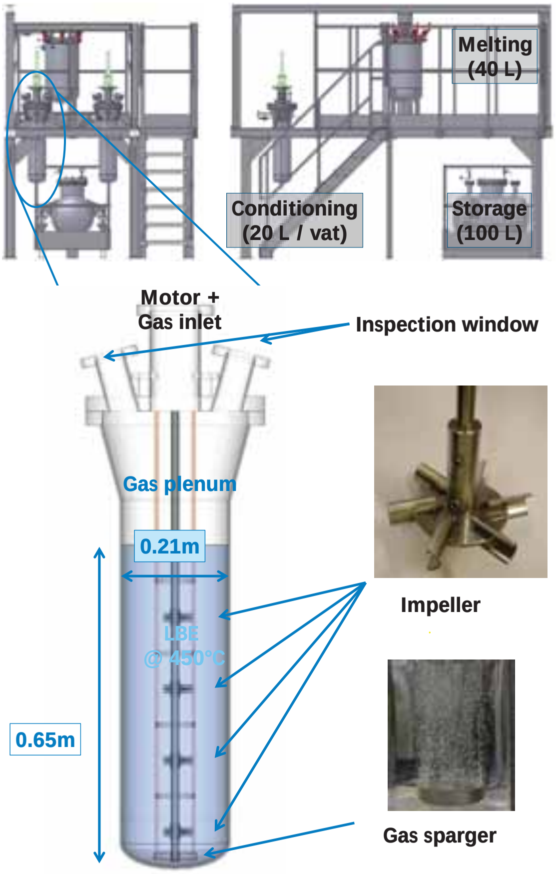
- 1:1 model
- air/ inert gas for enhancing/decreasing dissolved oxygen concentration in water

HELIOS 3

Target/Purpose

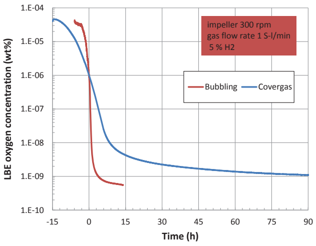
- Delivery of conditioned LBE to other experiments
- Study of conditioning methods
- Study of calamity effects (steam ingress, oxygen ingress, …)

Setup



Results

- 220 kg of LBE reduced from 10^{-5} wt% to 10^{-9} wt % in a few hours through bubbling
- Bubbling much more efficient than LBE-cover gas interaction

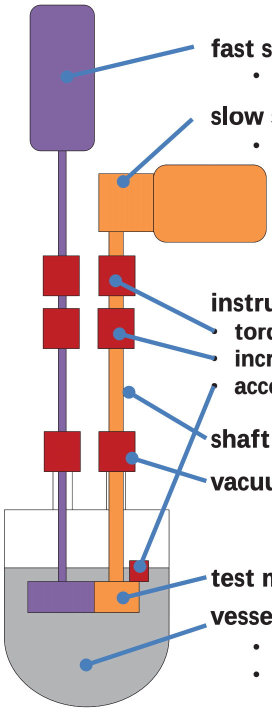


RHAPTER

Remote HAndling Parts TEst Rig

Construction

in operation since 09/2011



fast shaft
- 1000 rpm – 10 Nm

slow shaft
- 10 rpm – 1000 Nm

instrumentation:
- **torque sensor**
- **incremental encoder**
- **accelerometer**

shaft cooling

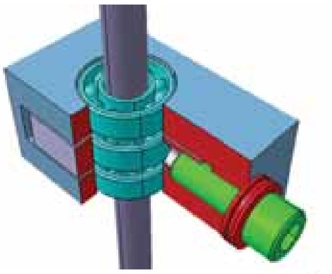
vacuum feedthrough

test module

vessel with LBE
- 150 to 450 °C
- Argon cover to control oxygen level

Test programme

ball & journal bearings

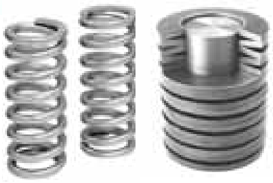


- chrome steel, stainless steel, ceramics
- low speeds (0 to 50rpm)
- reciprocating

gears

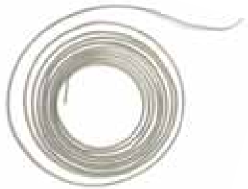
- spur & bevel gears

springs



- helicoidal & disc springs

electrical cables



- different configurations, coatings, heat treatments
- in air & LBE

leadscrews

Results

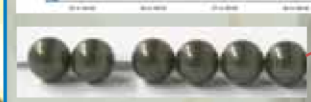
a good bearing

materials: races: AISI 52100
balls: SiN ceramic
cage: pressed sheet steel

test: speed: 10 rpm
load: 5000 N
duration: 1 week

torque graph

nice and even over complete test run



smooth balls

light discoloration, but smooth surfaces

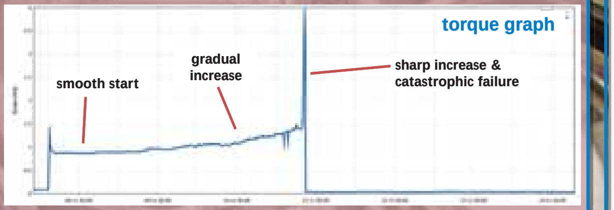
inner race

outer race

a bad bearing

materials: races: AISI 52100
balls: AISI 52100
cage: graphite

test: speed: 10 rpm
load: 5000 N
duration: 1 week

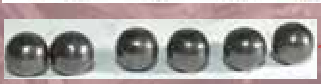


torque graph

smooth start

gradual increase

sharp increase & catastrophic failure



still smooth balls

heavy denting

complete breakdown

inner race

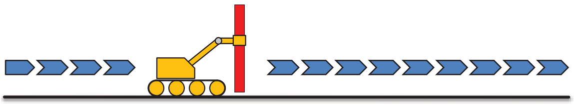
outer race

MYRRHA In-Vessel Robotics

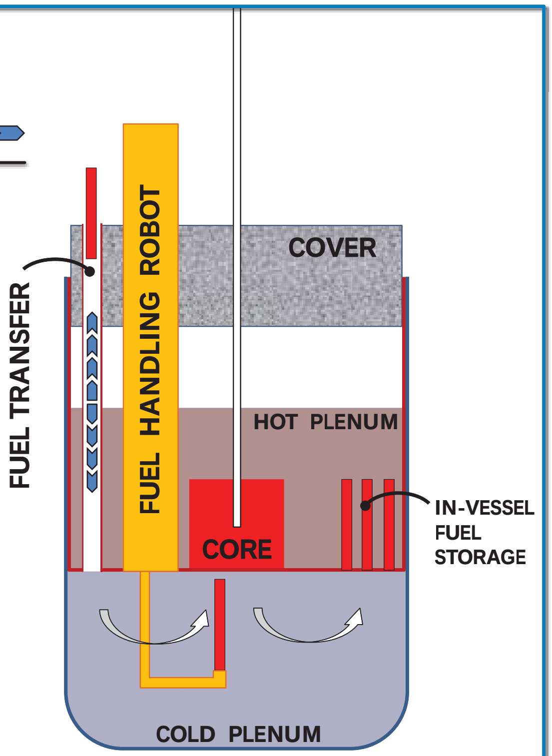
Using robots to move fuel assemblies in LBE

Fuel manipulation in MYRRHA

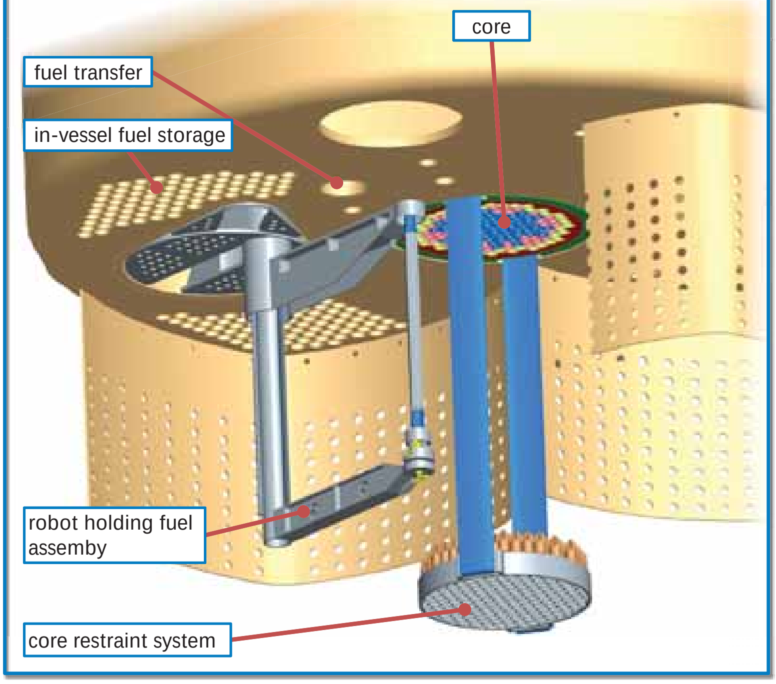
fuel assembly



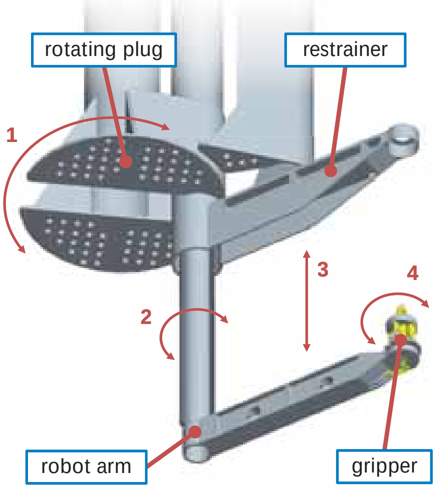
- fuel assemblies are transported from offline storage to the MYRRHA vessel
- the fuel transfer device transports the assemblies to the cold plenum
- loading and unloading of fuel assemblies in the core is done from below
- the fuel is stored in-vessel during reshuffling of the core and to cool down after use
- spent fuel is sent back to offline storage after cool-down



MYRRHA as seen from below



The robot in detail



- motors and instruments are located above the cover
- gears, bearings, cables etc. operate in LBE
- visualisation by ultrasound

201406 BCaers

COMPLOT

COMPonent LOop Testing

Goal

Characterize the hydrodynamic behaviour of reactor components

- in a flowing Lead-Bismuth Eutectic (LBE) environment
- representative of a single MYRRHA channel

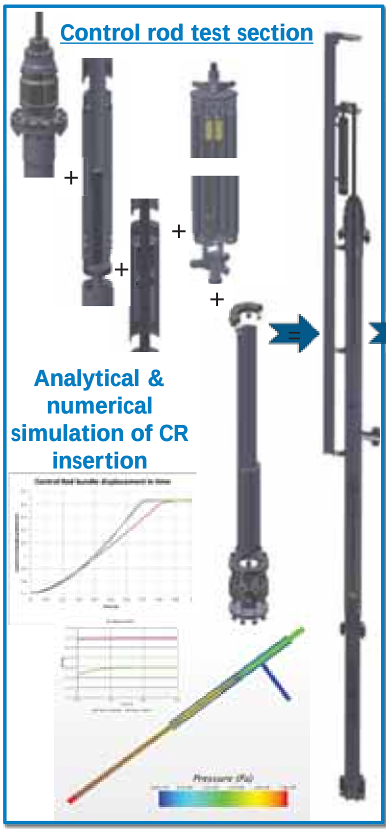
- to support the MYRRHA reactor design
- to ensure safe and reliable operation

Test programme

Component	Measurement
Fuel assembly	LBE pressure drop and flow induced vibration
Control and safety rods	Proof of operating principle and rod insertion time
Spallation target	LBE pressure drop and velocity profile at the beam window

COMPLOT design characteristics	
Loop configuration	closed
Maximum temperature (isothermal)	400 °C
Maximum flow rate	36 m^3/h
LBE Volume	750 l
Total height	12 m

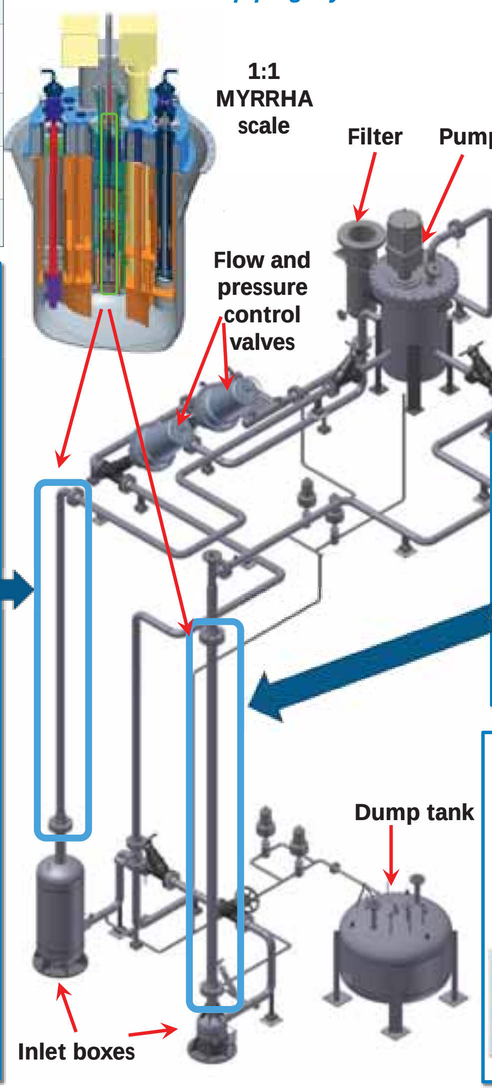
Control rod test section



Analytical & numerical simulation of CR insertion

COMPLOT

As-built 3D piping layout

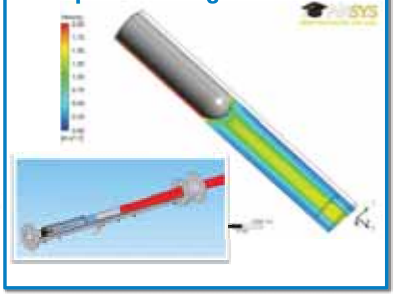


MYRRHA core

Representative single MYRRHA channels are installed into COMPLOT for testing

Fuel assembly test section

Numerical simulation of spallation target flow



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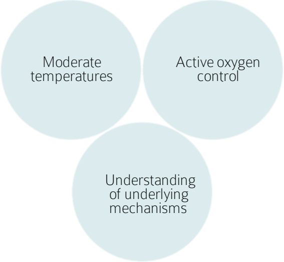
CRAFT

Corrosion Research for Advanced Fast Reactor Technology

Purpose

Development of a medium scale installation for corrosion experiments in liquid lead-bismuth eutectic under well controlled flow, temperature and chemistry conditions.

Strategy



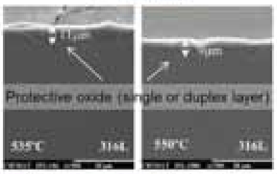
Moderate temperatures

Active oxygen control

Understanding of underlying mechanisms

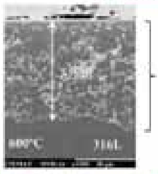
LBE corrosion / erosion

1. Oxidation



316L: 500 h, stagnant LBE, $[O] = 3\text{-}8\times10^{-6}$ wt%
(Martin et al., J Nuclear Mater, **335** (2004) 194-198)

2. Dissolution



- LBE penetration
- Loss of elements, esp. Ni and Cr

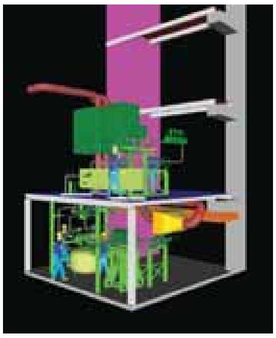
316L: 500 h, stagnant LBE, $[O] = 3\text{-}8\times10^{-6}$ wt%
(Martin et al., J Nuclear Mater, **335** (2004) 194-198)

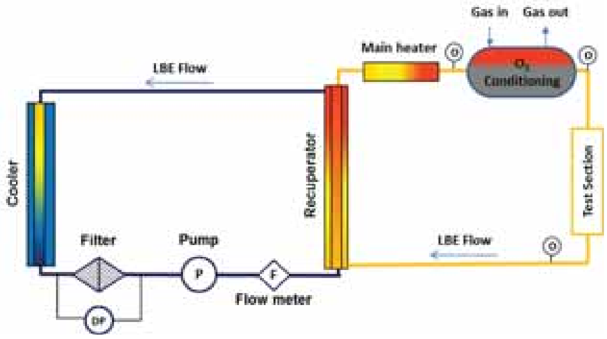
3. Erosion

- Severe material loss & compromise of structural integrity
- Observed at high LBE flow velocities, two-phase flow, and sites of flow diversion

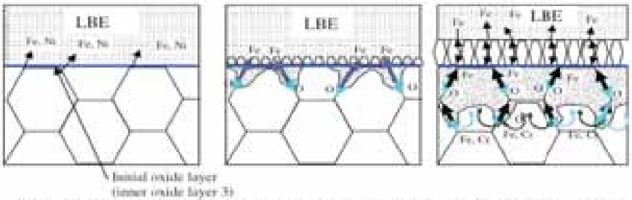
316L: 2000 h, flowing LBE - flow velocity: 2 m/s, $[O] = 1\times10^{-6}$ wt%
(Müller et al., J Nuclear Mater, **301** (2002) 40-46)

3D design and schematic P&ID of CRAFT





Corrosion mechanism



Schematic drawing presenting the oxide layer growth mechanism proposed in *Hosemann et al., J. Nucl. Mat., 2008, 375(3), 323-330*

Oxidaton mechanism proposed in *Müller et al., J Nucl. Mat., 2000,* ***278****, 85-95*

Goals:

- Explain existing data
- Identify important parameters
- Predict LMC in operating conditions

MEXICO

Lead-bismuth eutectic chemistry control loop

R&D facilities for the licensing and engineering of MYRRHA

Coolant chemistry

MEXICO

HELIOS 3

LILIPUTTER 2

Material compatibility

CRAFT

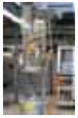
LIMETS 2

LIMETS 3

LIMETS 4

Components & TH

RHAPTER



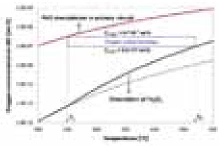
COMPLOT

Scaled MYRRHA

ESCAPE

MEXICO (Mass EXchanger In Continuous Operation)

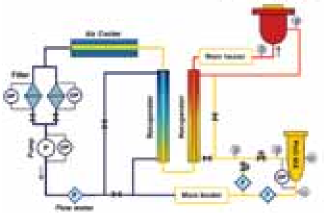
Lead Bismuth Eutectic (LBE) has been chosen as a spallation target and primary coolant of MYRRHA. It is widely recognized that the control of the dissolved oxygen activity is essential in the use of lead alloys in order to minimize the corrosion of structural steels and to avoid the oxidation of the coolant itself (PbO formation) by excessive oxygen. MEXICO was constructed recently and has been commissioned recently in order to study LBE coolant chemistry focusing on oxygen control and LBE purification technology. Experimental results will be used for the licensing of MYRRHA.



Oxygen control boundary for an LBE coolant system

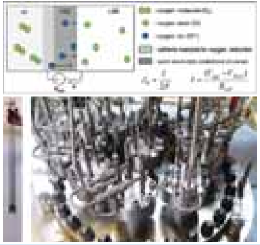
Materials and methods

P&ID of MEXICO loop

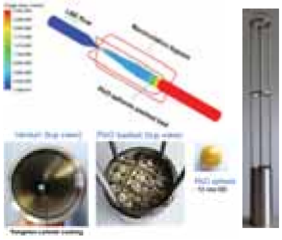


Total volume: ca. 700 liters (7,000 kg of LBE), T= 200-450 °C

Electrochemical oxygen pump



PbO mass exchanger

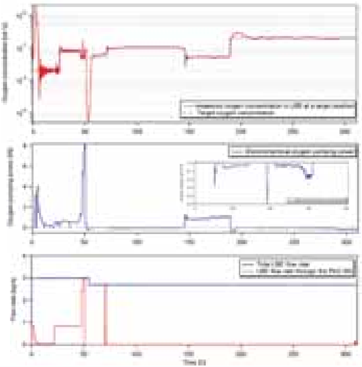


Filtration

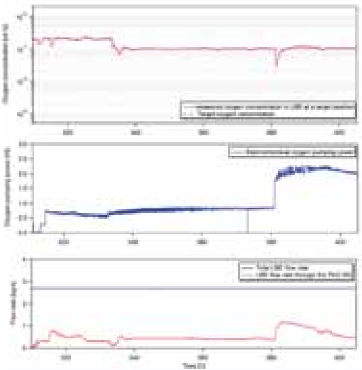
Ceramic filter (porosity =40μm)

Results

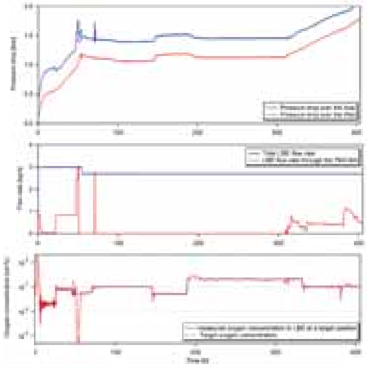
Oxygen control by oxygen pump



Oxygen control by PbO mass exchanger



Pressure drop over the filter



Conclusion

- An LBE coolant chemical process control loop, MEXICO, was constructed and has been commissioned successfully in 2014.
- Two types of oxygen control systems including an electrochemical oxygen pump and a PbO mass exchanger have been developed and implemented in MEXICO.
- Highly accurate oxygen control was achieved by both oxygen control systems during the first experimental campaign.
- The fast increase of pressure drop over the filter during the operation of the PbO MX, must be solved.
- A robust oxygen control system for MYRRHA will be developed based on the results from MEXICO.

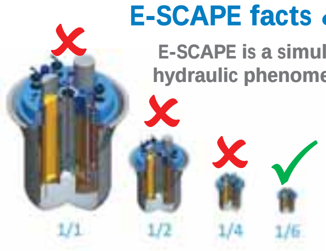
For more information (references)

- J. Lim, A. Mariën, K. Rosseel, A. Aerts and J. Van den Bosch, “Accuracy of potentiometric oxygen sensors with Bi/Bi2O3 reference electrode for use in liquid LBE”, Journal of Nuclear materials, 429 (2012), pp. 270-275
- J. Lim, G. Manfredi, A. Mariën, J. Van den Bosch, “Performance of potentiometric oxygen sensors with LSM-GDC composite electrode in liquid LBE at low temperatures”, Sensors & Actuators B: Chemical, 188 (2013), 1048-1054
- J. Lim, G. Manfredi, S. Gavrilov, K. Rosseel, A. Aerts, J. Van den Bosch, “Control of dissolved oxygen in liquid LBE by electrochemical oxygen pumping”, Sensors & Actuators B: Chemical, 204 (2014) 388–392
- A. Marino, J. Lim, S. Keijers, J. Van den Bosch, J. Deconinck, “Numerical modeling of oxygen mass transfer from PbO spheres packed bed to liquid lead bismuth eutectic: A venturi-type PbO mass exchanger”, Nuclear Engineering and Design, 265 (2013), 576–581
- A. Marino, J. Lim, S. Keijers, J. Van den Bosch, J. Deconinck, F. Rubio, K. Woloshun, M. Caro, S. A. Maloy, “Temperature dependence of dissolution rate of a lead oxide mass exchanger in lead-bismuth eutectic”, Journal of Nuclear Materials, 450, (2014) 270-277

E-SCAPE

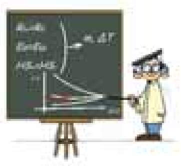
European SCAled Pool Experiment

E-SCAPE facts & figures

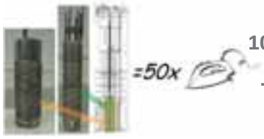


E-SCAPE is a simulator of the main thermal hydraulic phenomena occurring in MYRRHA

Geometrical scaling factor: 1/6 ⇨ 1.4 m diameter, 2 m height

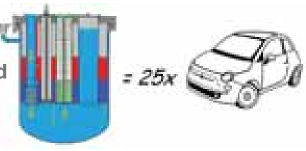


Main parameters (flow rate, temperatures, pressure drops) scaled down according to similarity



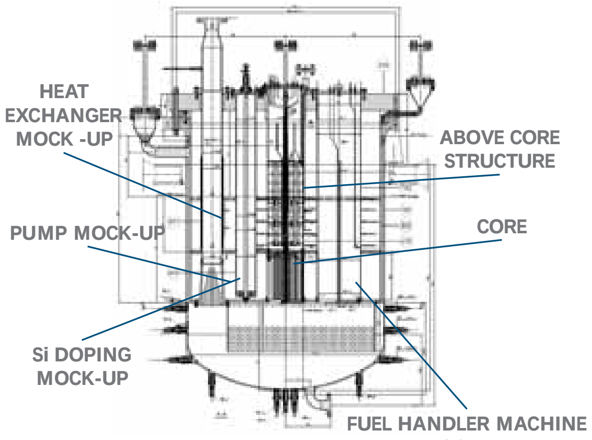
100 kW electrical core, 200 kW total power consumption
Temperatures: lower plenum 200°C, upper plenum 210°C÷310°C

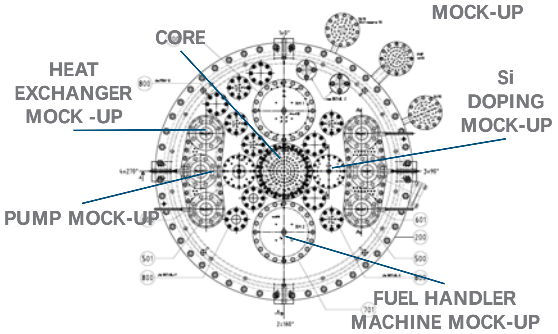
Working fluid: 25 tons Lead Bismuth Eutectic
Flow rates: 120 kg/s in forced circulation, 5 kg/s in natural circulation



Constraints: physical limitations, manufacturability, available space, ease of use, initial and operational costs

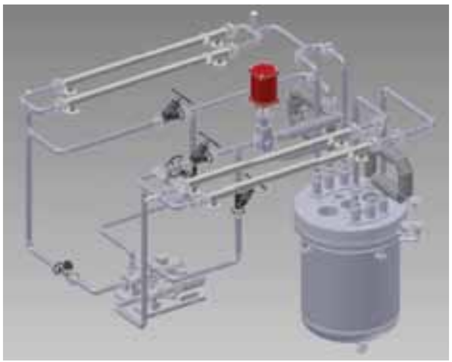
Primary vessel





Primary cooling system

Working fluid: Lead-Bismuth



Components

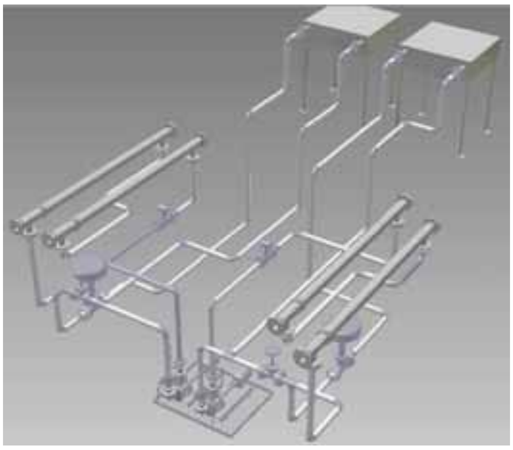
- Main pool 3000 l
- 2 separate circuits (50 m total 3” piping) for pumping and cooling
- Storage tank 3000 l
- 2 centrifugal pumps 5 kW
- 4 LBE-Oil heat exchangers
- 1 filter
- Valves for throttling and safety
- Tracing and insulation 85 kW

Instrumentation

- 2 Coriolis flow meters
- 10 Pressure gauges
- 2 radar level sensors
- 350 Thermocouples
- 45 UDV probes

Secondary cooling system

Working fluid: diathermic oil



Components

- 2 linked circuits
- 2 centrifugal pumps 2 kW
- 4 LBE-Oil heat exchangers
- 2 Oil-Air coolers power 2 kW
- Valves for throttling and safety
- Tracing and insulation 10 kW

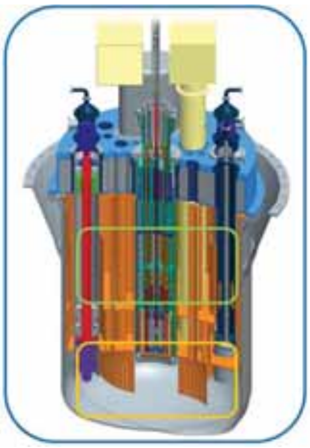
Instrumentation

- 2 vortex flow meters
- 4 pressure gauges
- 8 thermocouples

201411 MGreco

E-SCAPE

European SCAled Pool Experiment



MYRRHA thermalhydraulic assessment

Integral system behaviour
- Natural convection decay heat removal via HXs
- Residence times of fluid particles

Upper plenum
- Thermal mixing and stratification
- Flow distribution
- Free surfaces oscillations

Lower plenum
- Flow distribution
- Pump jet behaviour

Test matrix

Steady state conditions

CASE	POWER	PUMPS	HX
1 Shutdown	Long term decay	0	4
2 Reduced Power	Reduced	2	4
3 HX failure	Peak and Long term decay	2	2
4 Pump failure	Peak and Long term decay	1	4
5 Bubble transport	Reduced Long term decay	2	4
6 Particle transport	Reduced Long term decay	2	4

Transient conditions

CASE	POWER	PUMPS	HX
1 LOF	Peak and Long term decay	C	4
2 LOF+LOHS		C	0
3 Start-up	Long term decay	2	4
4 HX failure	Peak and Long term decay	2	2
5 Pump failure	Peak and Long term decay	1	4

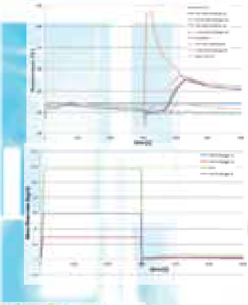
Numerical codes validation

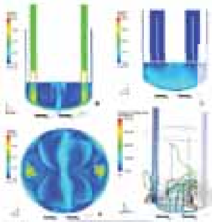
Computational Fluid Dynamics codes

Pre-test analyses
- Confirmation of theoretical scaling
- Support to E-SCAPE design

Post-test analyses
- Validation activities
- Support to MYRRHA design & safety
- Focus on hot topics: e.g. turbulent Prandtl number

Codes
- CFX
- OpenFOAM (myrrhafoam solver developed at VKI)

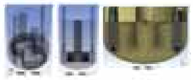


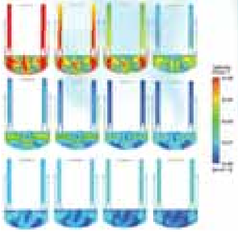


Codes coupling

Pre-test analyses
- Off-line coupled analysis of the lower plenum (CFX) and external circuits (RELAP5)

Post-test analyses
- Complete on-line coupling
- Validation activities
- Support to MYRRHA design & safety



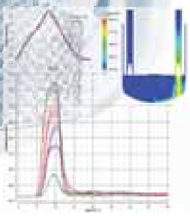


Thermalhydraulic System codes

Pre-test analyses
- Confirmation of theoretical scaling
- Support to E-SCAPE design

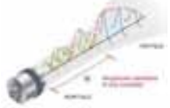
Post-test analyses
- Validation activities
- Support to MYRRHA design & safety

Codes
- RELAP5



In-Vessel measurements

- **UDV**
  - 45 Ultrasonic Doppler Velocimetry probes characterise the velocity field in the lower plenum
- **Thermocouples**
  - 400 TC for establishing temperature profiles
  - Outlining the pump jet behaviour by following the path of an injected hot plug
- **Pitot tube**
  - Velocity profile at pump tube discharge
- **Pressure sensors**
  - Pressure drops across the main components (core, Above Core Structure, barrel)
- **Radar level sensors**
  - They continuously track the levels in the two plena



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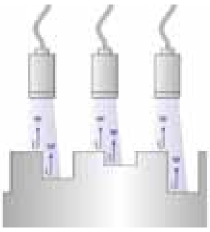
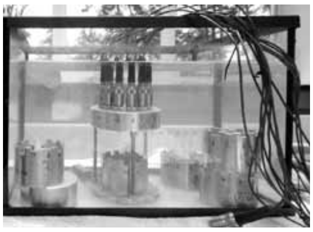
Seeing by listening, a nuclear application

Robust identification of individual fuel assemblies

A unique pattern of 12 notches at the inflow nozzle identifies a fuel assembly



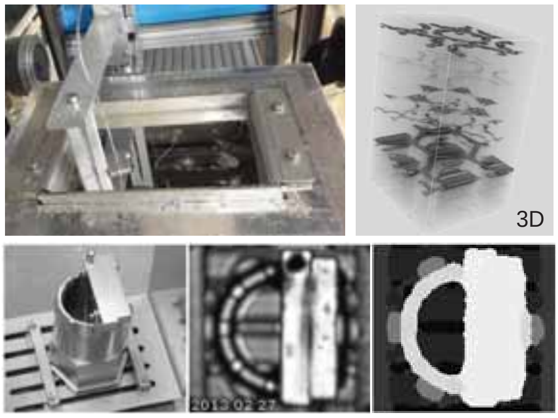
Principle of the differential ultrasonic read-out system. 12 ultrasonic sensors provide immediate identification.



Experimental validation in water. The special error correcting code makes the identification extremely reliable. 40% of the ultrasonic sensors may fail.

Detailed inspection and object localization

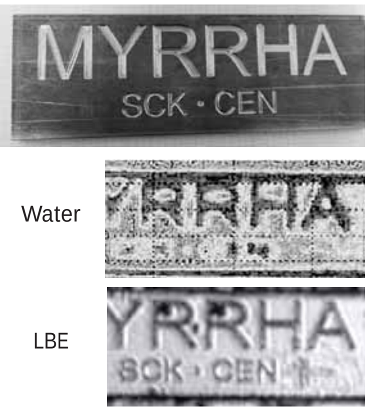
SCK-CEN ultrasonic sensors render images in LBE



Echo strength

Echo depth

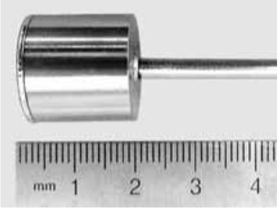
Resolution in water versus LBE



Echo strength

Ultrasonic sensors

- Dedicated design for use in heavy liquid metal
- High temperature up to 400°C
- Radiation hard
- All LBE facing parts in stainless steel



Special wetting procedure required for ultrasonic sensors in stainless steel

INNOVATING

is in our genes

MYRRHA

www.sckcen.be/MYRRHA

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