Croatian Contribution to the Development of Fusion Materials Technology

Tonči Tadić, Toni Dunatov, Stjepko Fazinić, Iva Bogdanović-Radović, Donny Domagoj Cosic, Andreo Crnjac, Andreja Gajović, Milan Kostelac, Matija Hoić, Srećko Švaić, Zvonimir Tomičević, Ana Vrgoč, Nikša Krstulović, Mario Rakić, Dragan Poljak, Anna Šušnjara

CROATIAN FUSION RESEARCH UNIT

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Contents

- Historical overview
- Croatian contribution to EUROfusion, with emphasis on fusion materials' techonoly development
- Croatian contribution to IFMIF-DONES
- Future plans

Historical overview

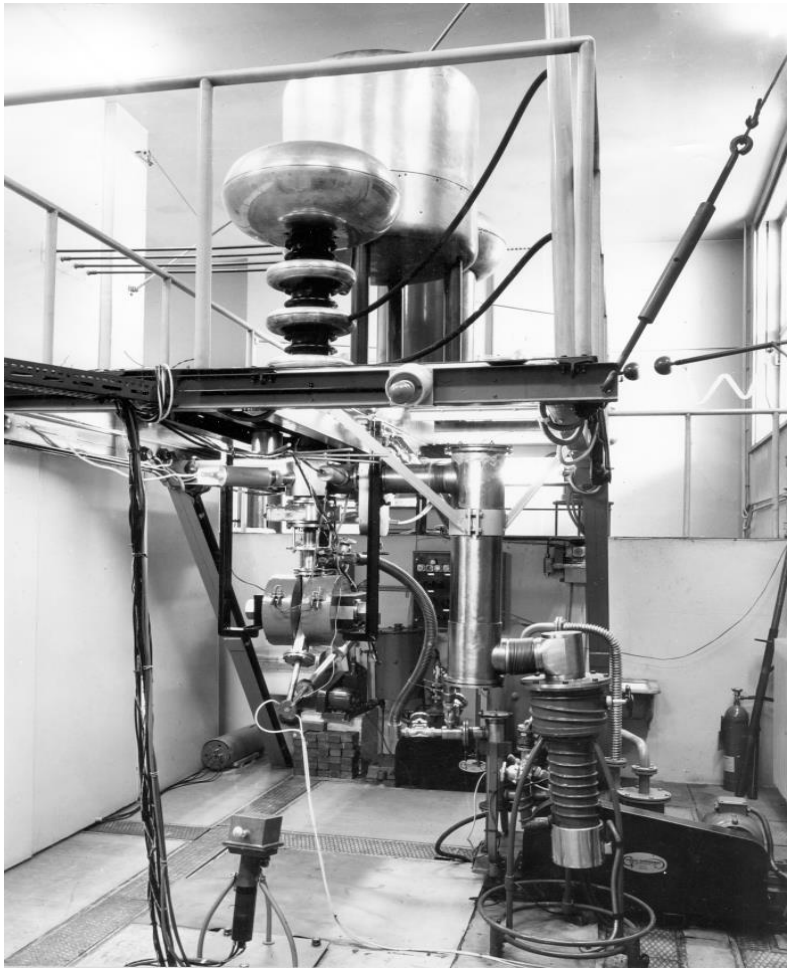
- Since 1951 – Intensive nuclear technology R&D at newly established RBI and its departments
  - Experimental Physics, Nucl. Chemistry, Nucl. Techn. & Protection
- Since 1973 – construction of NPP Krško as HR-SI joint venture; NPP Krško started in 1983
  - Privlaka NPP (in HR) was not constructed – stopped in 1986
- Since 1970s – New departments and intensive nuclear technology R&D at University of Zagreb
  - Dept. on Nuclear Materials @ Faculty of Mech. Engin. & Naval Architecture
  - Dept. on Nucl. Energy @ Faculty of Elect. Engineering & Computing
- Creation of HR business sector oriented to nuclear technology

Historical overview

- Since 1951 – Intensive nuclear technology R&D … y established RBI and its departments
  - Experimental Physics, Nucl. Ch… …
- Since 1973 – construct… …ure; NPP Krško st…
  - R… … in 1986
- Si… … intensive nuclear technology R&…
  - D… …Materials @ Faculty of Mech. Engin. & Naval Architecture
  - De… …Nucl. Energy @ Faculty of Elect. Engineering & Computing
- Creation of HR business sector oriented to nuclear technology

Minimising of R&D and/or closing of departments due to Чорнобиль disaster in 1986

RBI's fusion neutron generator (1956), made by Croatian companies



Croatia in EUROfusion

- **2013 – Croatian accession to EU & Euratom**
  - **Establishment of Croatian fusion Research Unit (CRU)**

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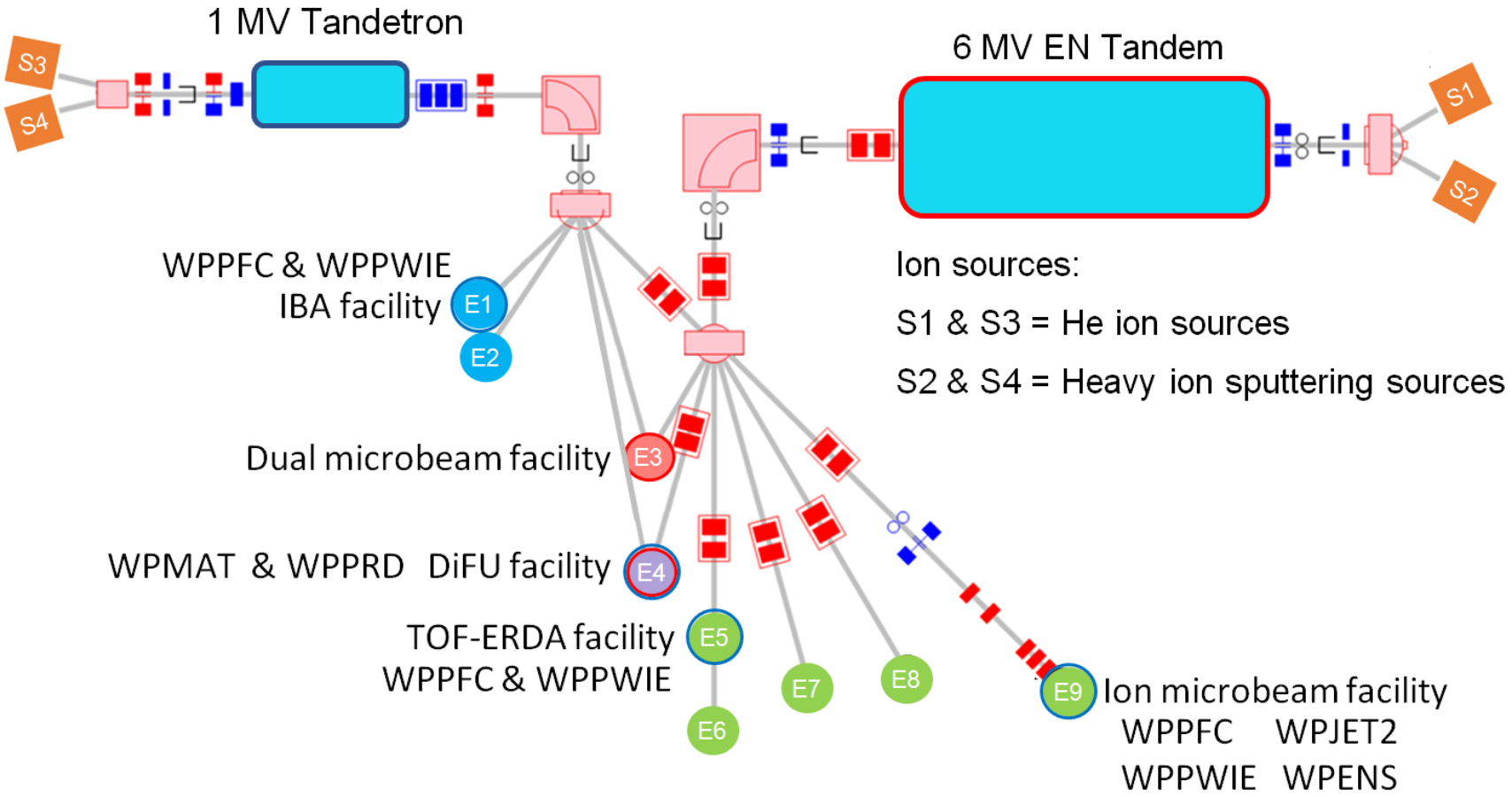
Industrial Partners:

- **Strategic orientation of CRU toward:**
  - **Fusion Materials**
  - **Plasma Facing Components**
  - **Radiation-Hard Sensors**
  - **IFMIF-DONES Preparation**
  - **Mathematical Modelling of Fusion Processes**

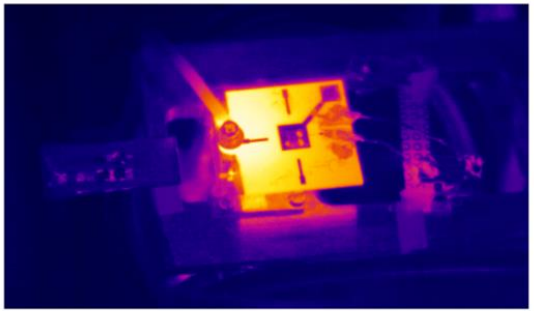
EUROfusion-related Facilites @ RBI Accelerator Centre

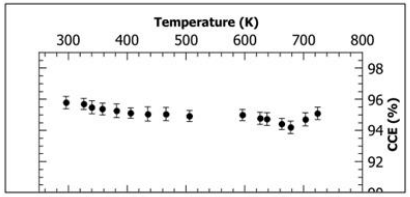


Croatian EUROfusion research highlights

Development of high-temperature radiation detectors for ITER & DEMO

WPEDU



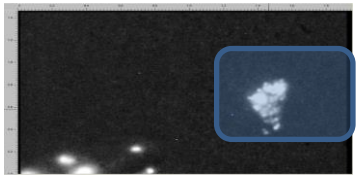


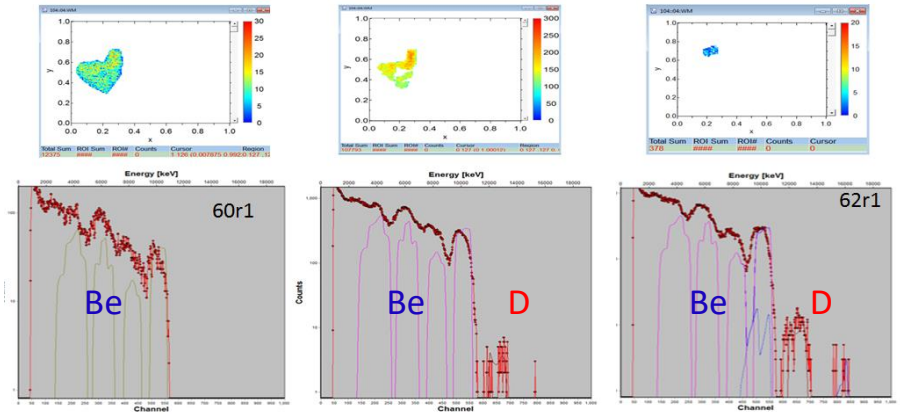
HIGHEST REPORTED TEMPERATURE FOR DIAMOND BASED SOLID-STATE RADIATION DETECTOR

725 K
450 °C

He3 ion microbeam analyses of JET dust from ILW 2011/12 & 2013/14

WPJET2



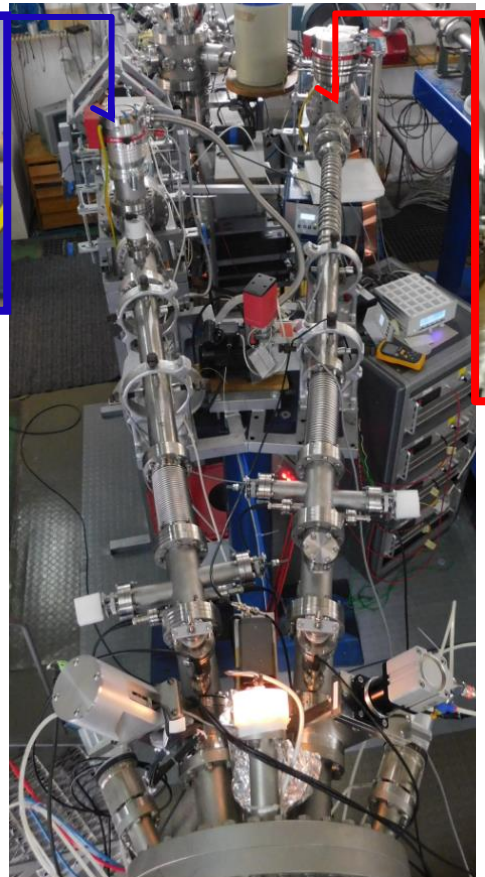


Tungsten X-ray M Lines were used for definition ion microbeam scanning area with resulting NRA spectra of Be and D

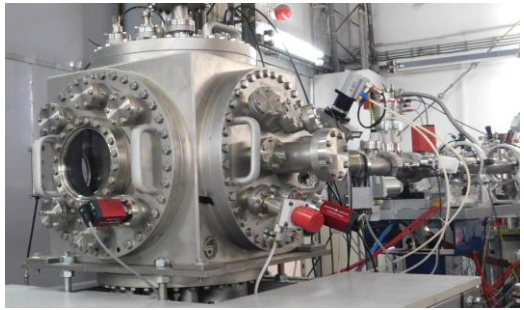
Croatian research highlights - EUROfusion WPMAT-IREMEV

DiFU – Dual-beam facility for Ion irradiation of Fusion materials

1 MV Tandetron

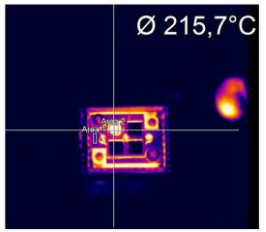


6 MV Tandem VDG



Large and versatile DiFU chamber (48 x 48 x 48 cm3) with free ports for installation of users' equipment

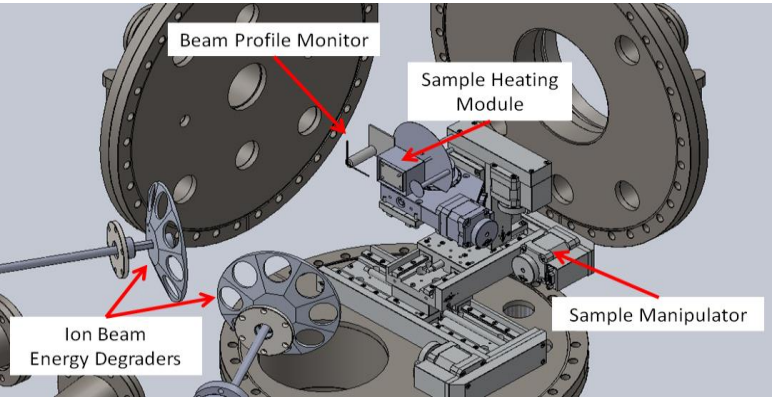
3D sample manipulator, with Small Samples' Adapter

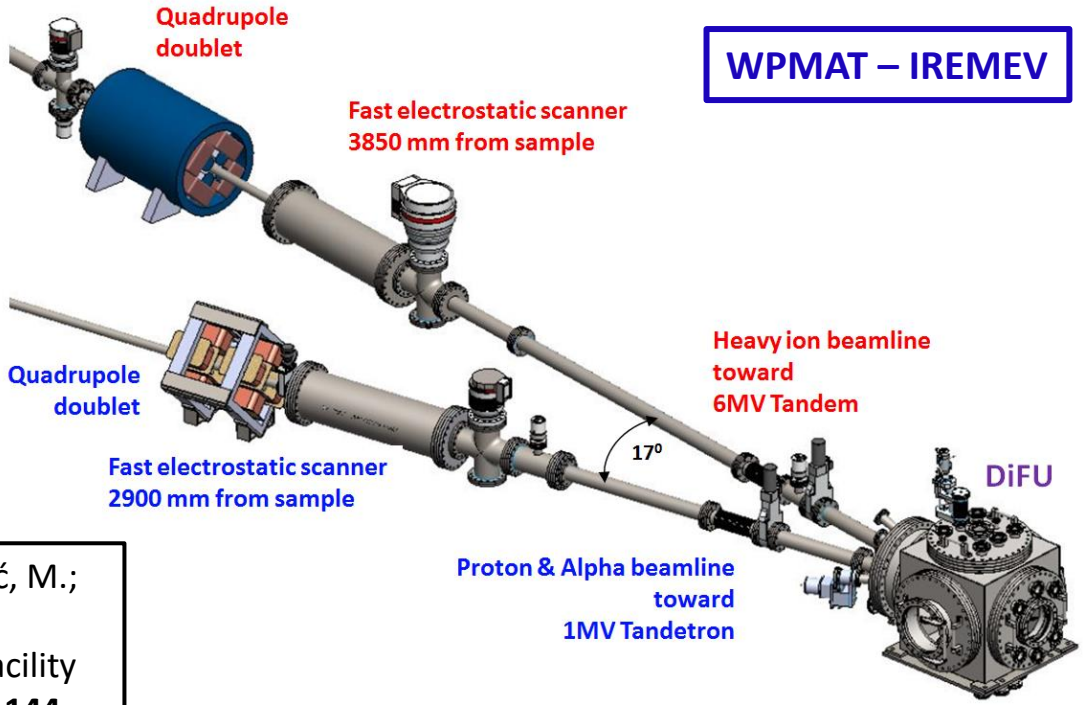


High sensitive IR camera ΔT = 1 K
Position resolution Δx = 0.4 mm

DiFU Facility was commissioned in 2019, with improvements introduced every year since
by joint support of EUROfusion WPMAT & IAEA & Croatian Ministry of Science & Education

DiFU is designed according to the ASTM E521 – 16: "Standard Practice for Investigating the Effects of Neutron Radiation Damage Using Charged-Particle Irradiation"



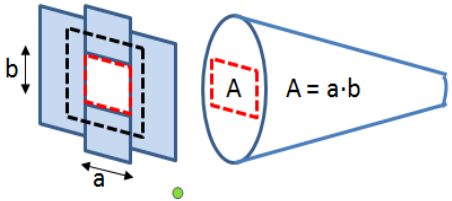


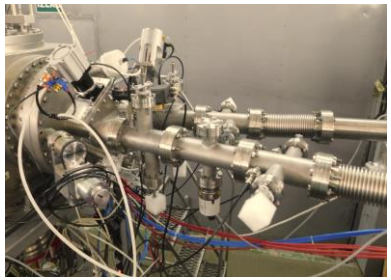
Tadić, T.; Dunatov, T.; Fazinić, S.; Cosic, D.D.; Jakšić, M.; Siketić, Z.; Vićentijević, M.; Kada, W.; Hardie, C.D. Development of the Dual-Beam Ion Irradiation Facility for Fusion Materials (DiFU). Materials **2023, 16, 1144.** https://doi.org/ 10.3390/ma16031144

Irradiation area from 5x5 to 30x30 mm^2,
by one or by two ion beams simultaneously

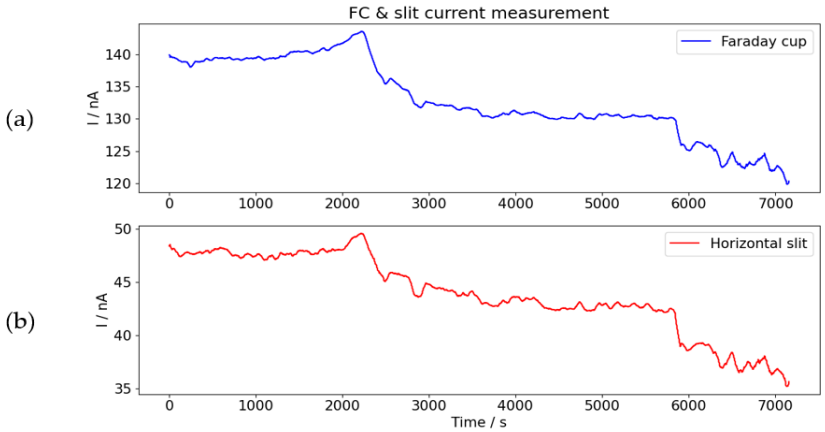
Estimation of ion flux & ion flux monitoring

For each beamline two pair of slits in front of large Faraday cup define irradiation area A, enabling precise estimation of ion flux



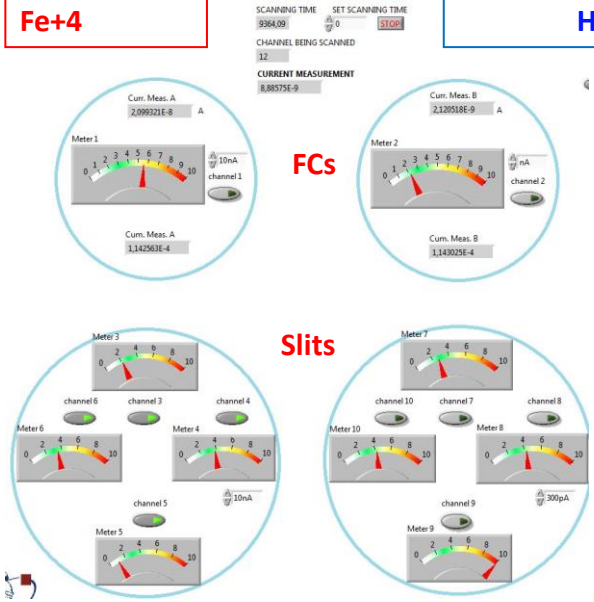


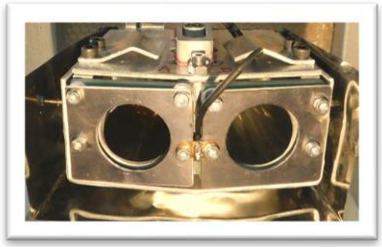
Adjustable slits at both beamlines (Max ±15 mm vertical & horizontal) enables constant monitoring of ion flux (by multiplexer and pA-meter)



10 MeV Fe+4

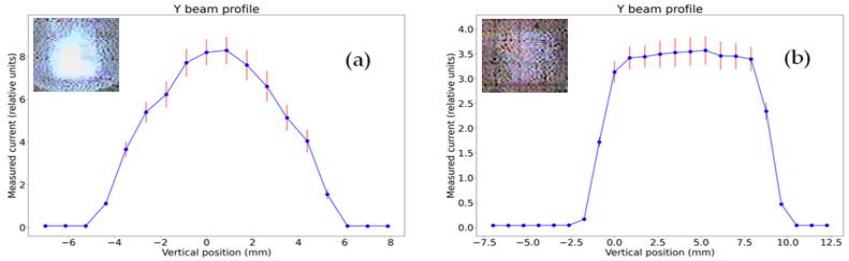
1.2 MeV He+2



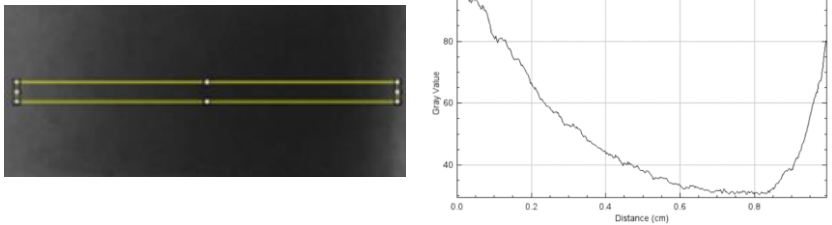


Each FC is 35 mm in diameter, w. Electron Suppressor & Thermal Shield

“Ion Beam Wobbling” is applied for ion irradiation of fusion materials, i.e. Ion beam prior to 10 kHz scanning is spreaded to cover 70% of irradiated area, and scanning is applied for homogenization of irradiation dose

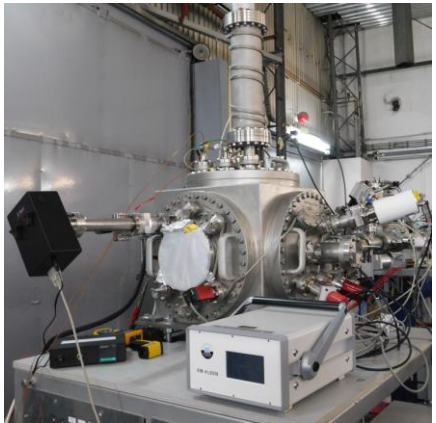


Dose-gradient irradiation is under Development; preliminary tests have been performed by darkening of Kapton foils by 10 MeV Cu ions



Mitigation of Carbon contamination of sample during ion irradiation:

- Vacuum in chamber: $3 \cdot 10^{-8}$ mbar
- Plasma Cleaning of sample & chamber by Oxygen plasma
- LN2 Cold traps in chamber and at both beamlines
- Residual Gass Analysis to check presence of CO2, CO, CH4,...



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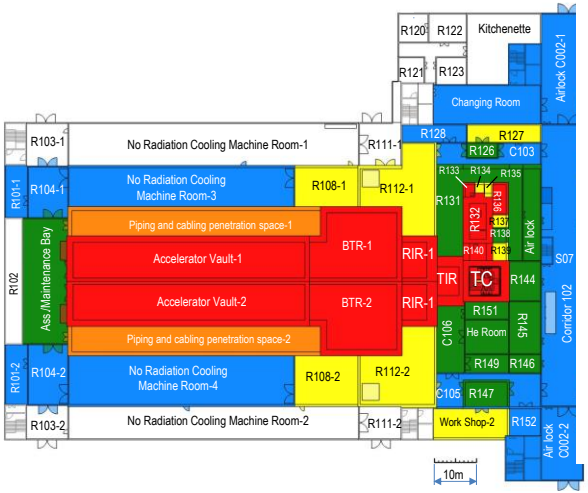
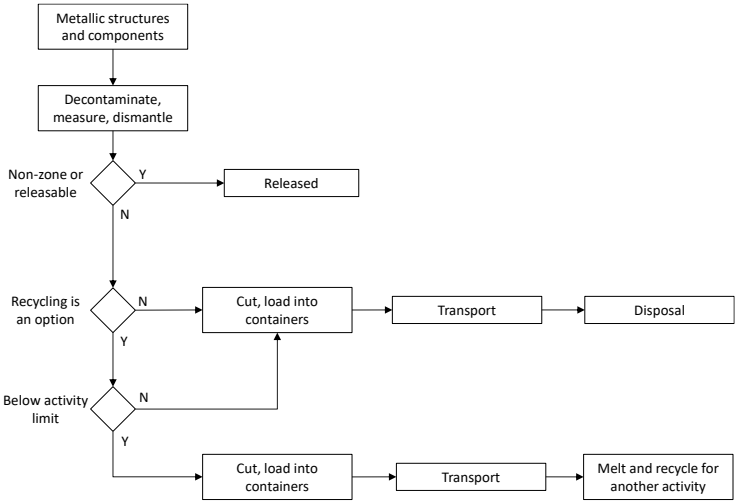
Radiation monitoring and personnel dosimetry at IFMIF-DONES



IFMIF-DONES decommissioning strategy



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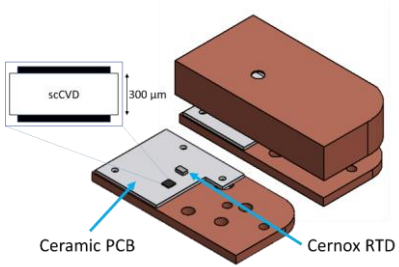
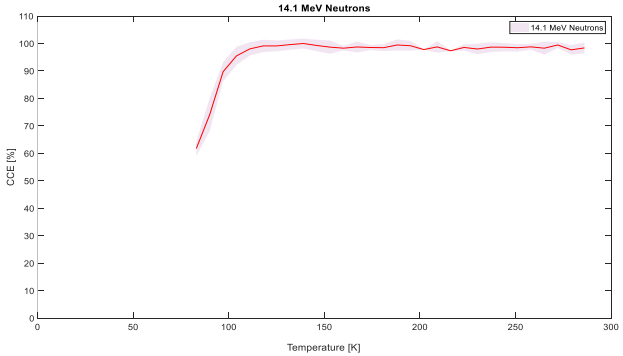
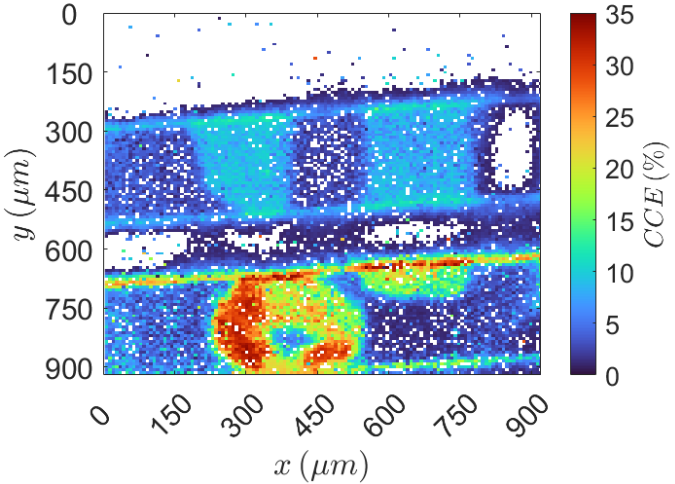
Development of Micro-Loss Monitors – neutron detectors for DONES accelerator





Assessment of neutron induced damage in electronics at DONES



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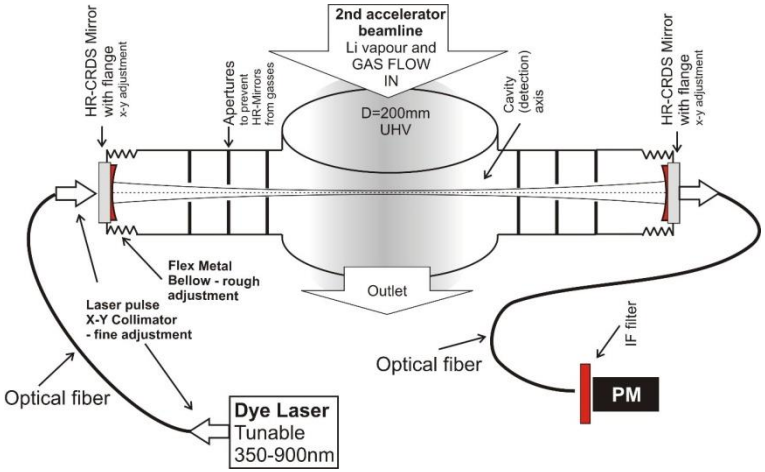
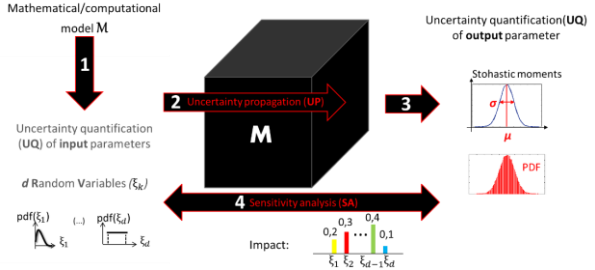
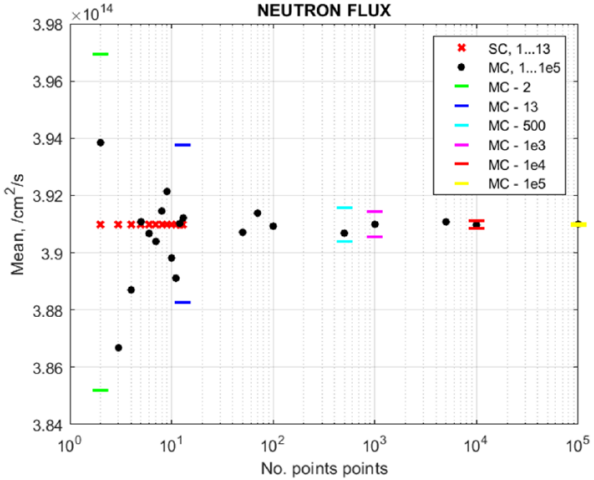
Cavity Ring-Down Spectroscopy laser systems for lithium evaporation monitoring by IF



Assessment of error propagation in tuning of DONES accelerator by FESB





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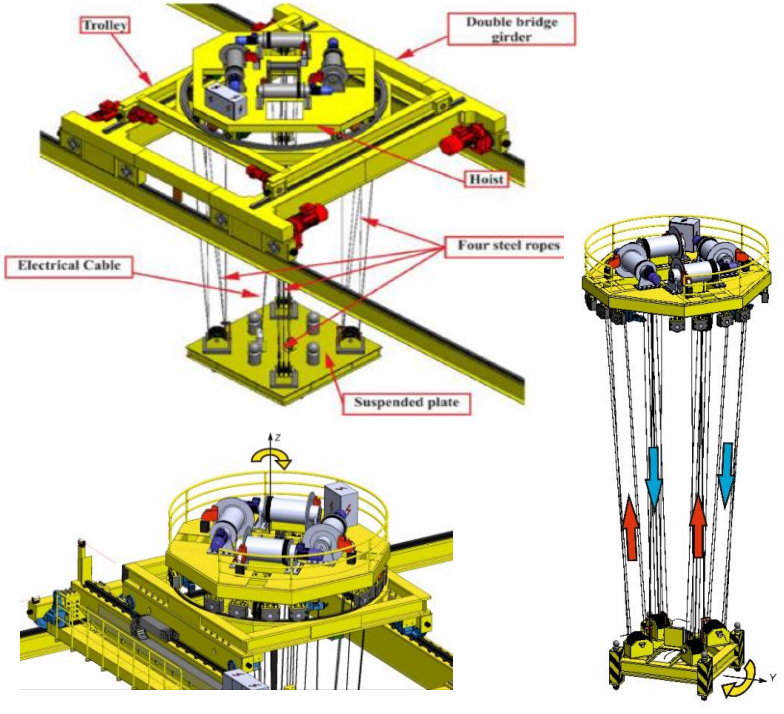
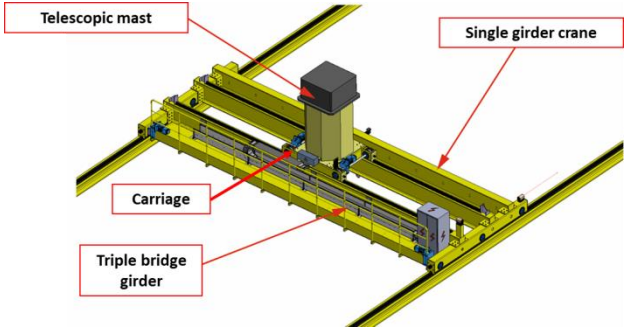
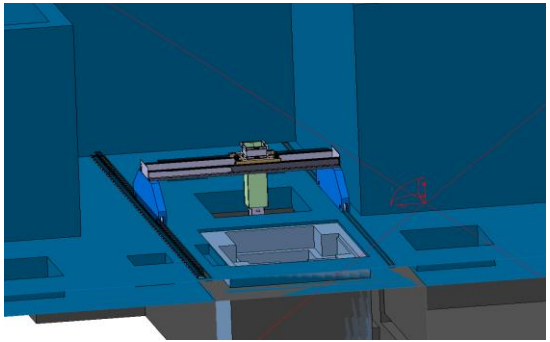
Design of Heavy Rope Crane – HROC – for removal of concrete lids at Test Cell at IFMIF-DONES



Design of Access Cell Mast Crane – ACMC – for maintenance of Test Cell and TIR at IFMIF-DONES





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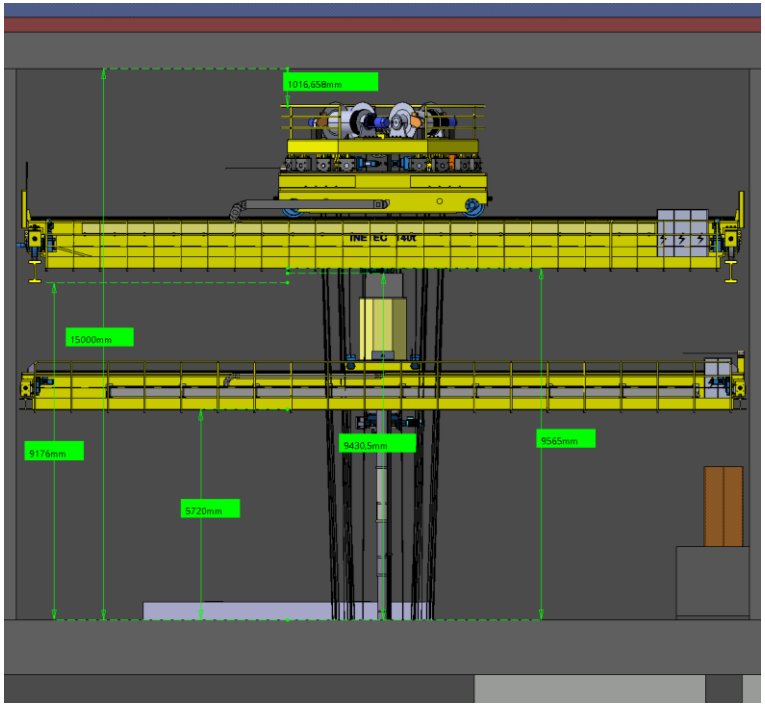
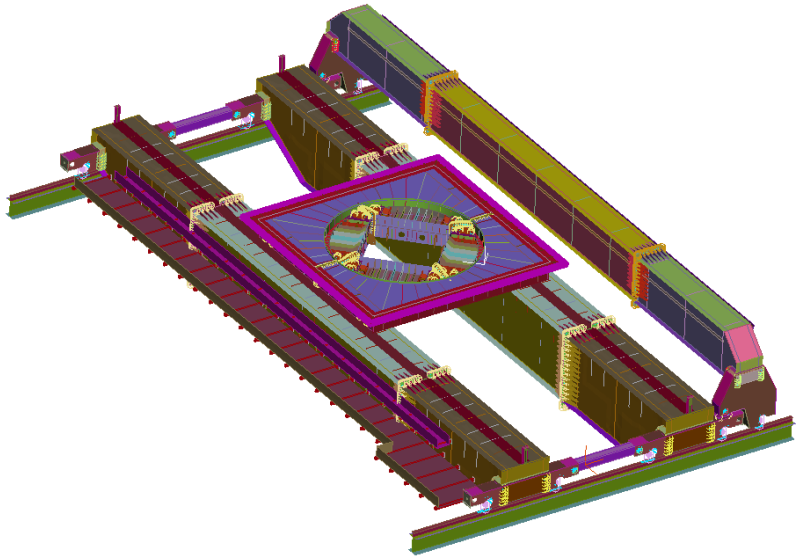
Remote Handling integration
RBI & FSB in partnership with INETEC



Seismic assessment for cranes
By FSB



IFMIF-DONES Facility

HR-ES MoU on DONES (2018)
-- From competitors for hosting of IFMIF-DONES to partners in its development

Spanish - Croatian site at Escúzar, 18 km southwest from Granada, selected by EU

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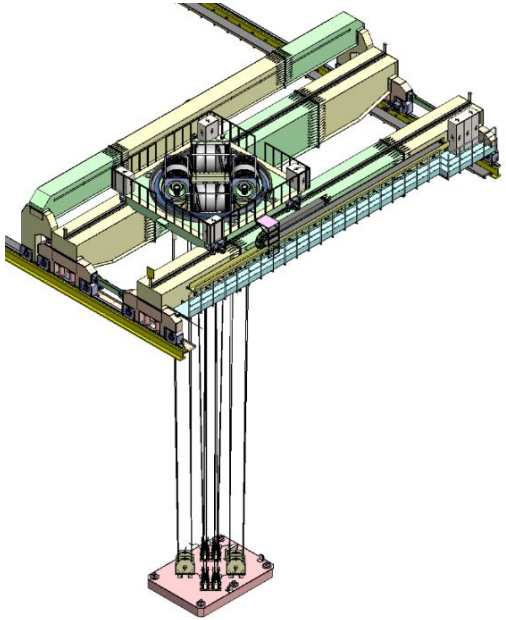
Croatian Consortium for IFMIF-DONES, est. in 2022

DONES

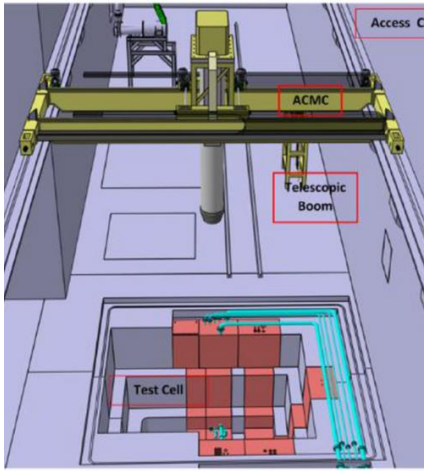
Signing of HR-ES MoU on starting of DONES in Zagreb, Nov. 2022, in presence of two heads of states

Establishing of DONES Steering Committee, Granada, 16 March 2023
Chair of DONES SC is Staša Skenžić (HR)

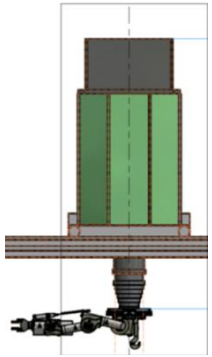
Key Cranes – HROC & ACMC, with Aux. Equipment



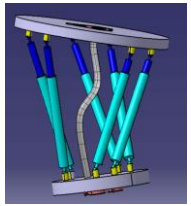
Heavy Rope Crane (HROC) for precise positioning of 100+ tons concrete lids at Test Cell of DONES



Access Cell Mast Crane (ACMC) for maintenance of Test Cell and TIR room



Robotic Arm



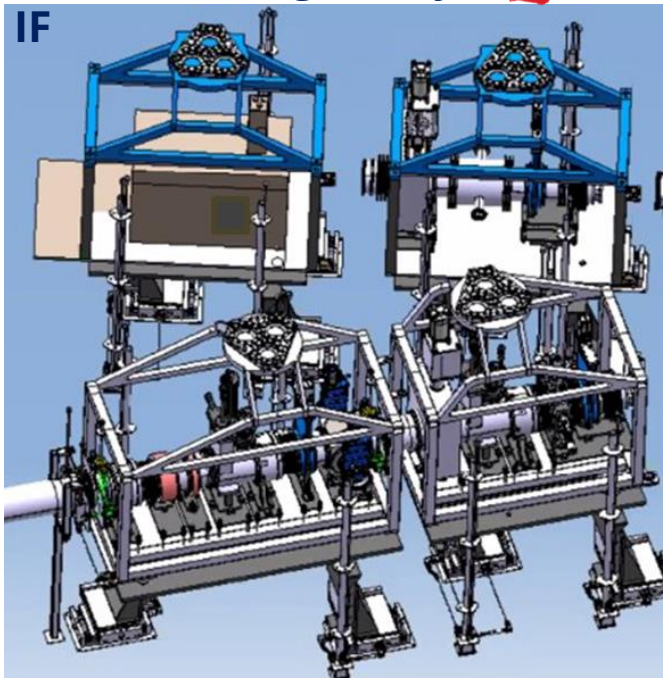
Parallel Kinetic manipulator

Croatian Contribution

Target Interface Room

The key TIR section of the IFMIF-DONES accelerator consists of four modules, with all sorts of sensor systems to diagnose the incredibly powerful ion beam of 5 MW and laser systems for characterization of “waterfall” of molten lithium.

CRDS Laser system for lithium evaporation monitoring Designed by IF



Croatian Contribution

Heat Exchangers HEX-2 and HEX-3 for Lithium Loop

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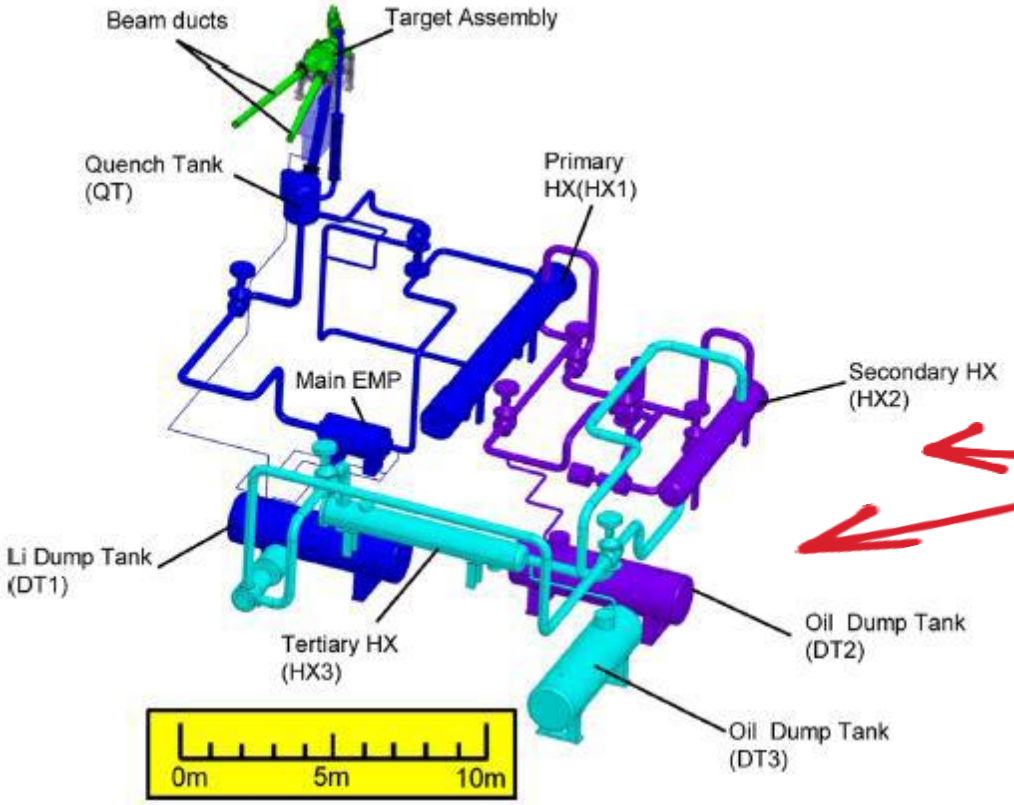
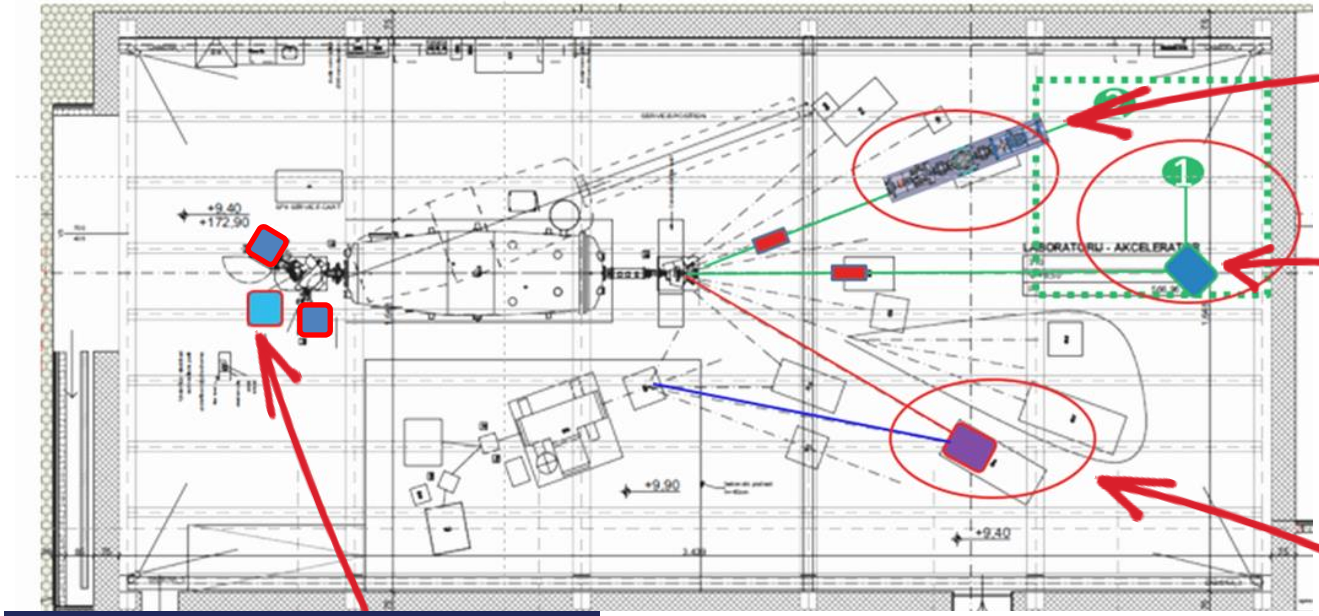


Oil-Oil and Oil-Water 10 MW Heat Exchangers with related diagnostic & control equipment

Croatian Contribution



New High-power ion sources
& High Current Accelerators

Setup for DONES
Accelerator System
Ion Beam Diagnostics
Testing

Setup for DONES
Accelerator System
Radiation Detectors
Testing

DiFU dual-beam facility
for ion beam irradiation
and pre-selection of
fusion materials

Croatian Contribution

New RBI accelerator center: DONES Support Facilities – in use for DONES Program beyond 2030

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IFMIF-DONES ENABLES FUSION POWER
For the first fusion power plant to work, a series of complex research and testing of technologies and materials will be conducted.
Here, a collaboration between academia and industry will be crucial.
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