The initiative to host IFMIF-DONES in Poland: status and complementary scientific program

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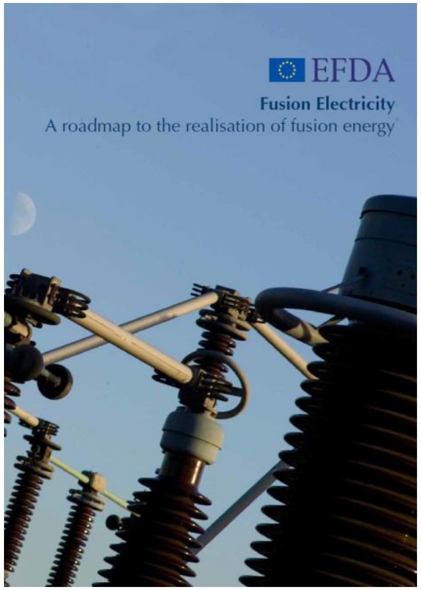
- IFMIF as part of the European roadmap to fusion energy
- Description of IFMIF / IFMIF-DONES concept and validation activities
- ELAMAT initiative to host IFMIF-DONES in Poland
- Complementary science program

The 2nd Joint Workshop of the COLL-AGAIN, COPIGAL, and POLITA (Italy-Poland) collaborations

European roadmap to fusion energy



European Fusion Development Agreement

EUROfusion Consortium (from 2014)

The target of the European roadmap to realisation of fusion energy is to produce fusion electricity by 2050

From the Executive Summary:

(1) ITER is the key facility in the roadmap

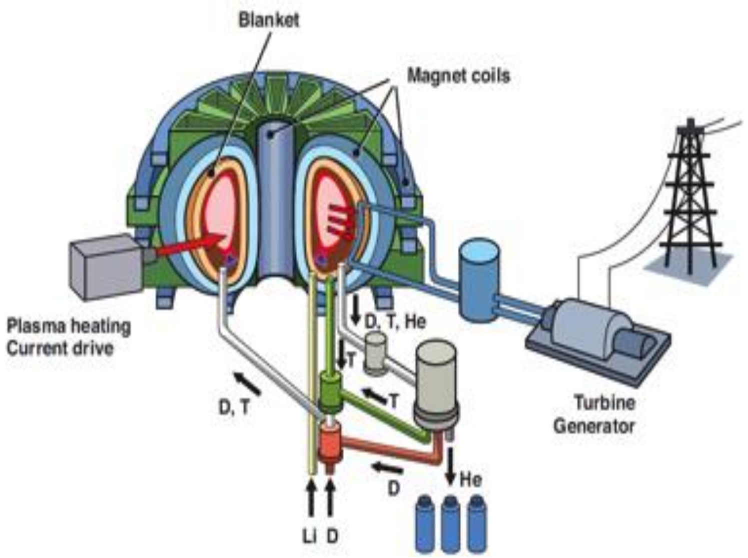
...

(3) A dedicated neutron source is needed for material development

DEMO: Demonstration Power Plant envisaged to follow ITER

European roadmap to fusion energy

The European roadmap is based on a scenario with an early (ca. 2030) construction of DEMO



- ❖ That means early selection of DEMO technologies and immediate specific needs for fusion materials database
- ❖ **A neutron source is needed for materials qualification**
- ❖ Critical materials to be irradiated for DEMO:
  Reference steels (as structural material),
  Cu alloys (as interface material between W and steel) and
  W (high dpa dose: as first-wall material and structural divertor material)

Neutron source requirements

to produce **fusion-line neutrons** @14 MeV!

- Intensity large enough to allow accelerated (as compared to DEMO) testing **> 10 dpa(Fe) / fpy**
- Damage level above the expected operational lifetime **20 dpa(Fe) in 1.5 y / 50 dpa(Fe) in 3.5 y**
- Irradiation volume large enough to allow the characterization of the macroscopic properties of materials required for the engineering design of DEMO (and the Power Plant) **300 cm3**
- Irradiation conditions (neutron flux, temperature) to be homogeneous for standarised specimens: Over a gauge volume flux gradient <10% and temperature gradient within ±3% with the long time stability must be achieved **T: 250-550ºC**

The most feasible approach based on

Li(d,xn) sources

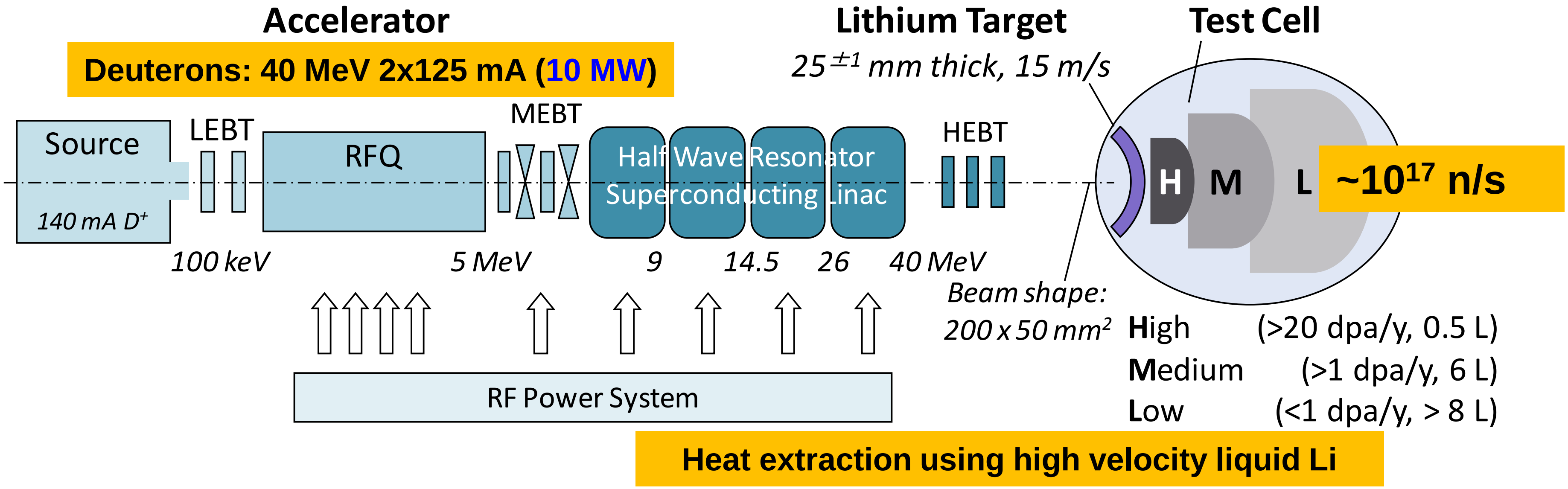
IFMIF: International Fusion Material Irradiation Facility

The IFMIF plant design consists of 3 key systems:

(1) A 40 MeV Deuteron Accelerator system with 2 identical LINACs

(2) A Lithium Target system providing intense high energy neutron beam

(3) A Test Facility with High, Medium and Low Flux Test Modules



The 2014 EU Roadmap concluded that DEMO requirements can be fulfilled with a smaller neutron source **(one accelerator)**

IFMIF-DONES
(DEMO-Oriented Neutron Source)

Work status and activities

IFMIF-EVEDA activities as part of the EU-Japan Broader Approach Agreement **:**

The Intermediate Engineering Design Report of IFMIF (full version) was issued in 2013 as part of EDA Phase

The Engineering Validation Activities are ongoing (till 2019)

- ❖ Accelerator Validation: **LIPAc**
- ❖ Target Facility Validation: **Orai Li loop**

EUROfusion

The WPENS Early Neutron Source work package (2015-2018/20) in EUROfusion prepares the **IFMIF-DONES Engineering Design Report**

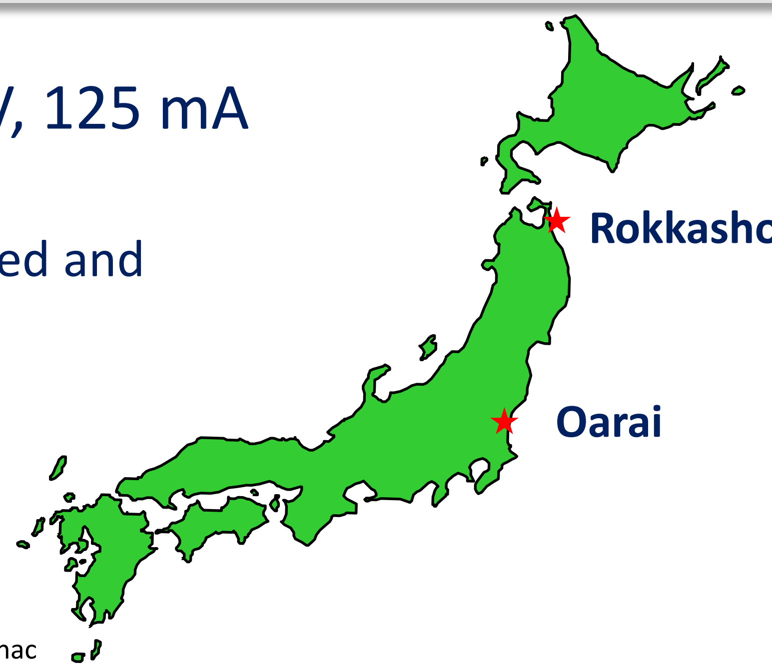
FUSION FOR ENERGY

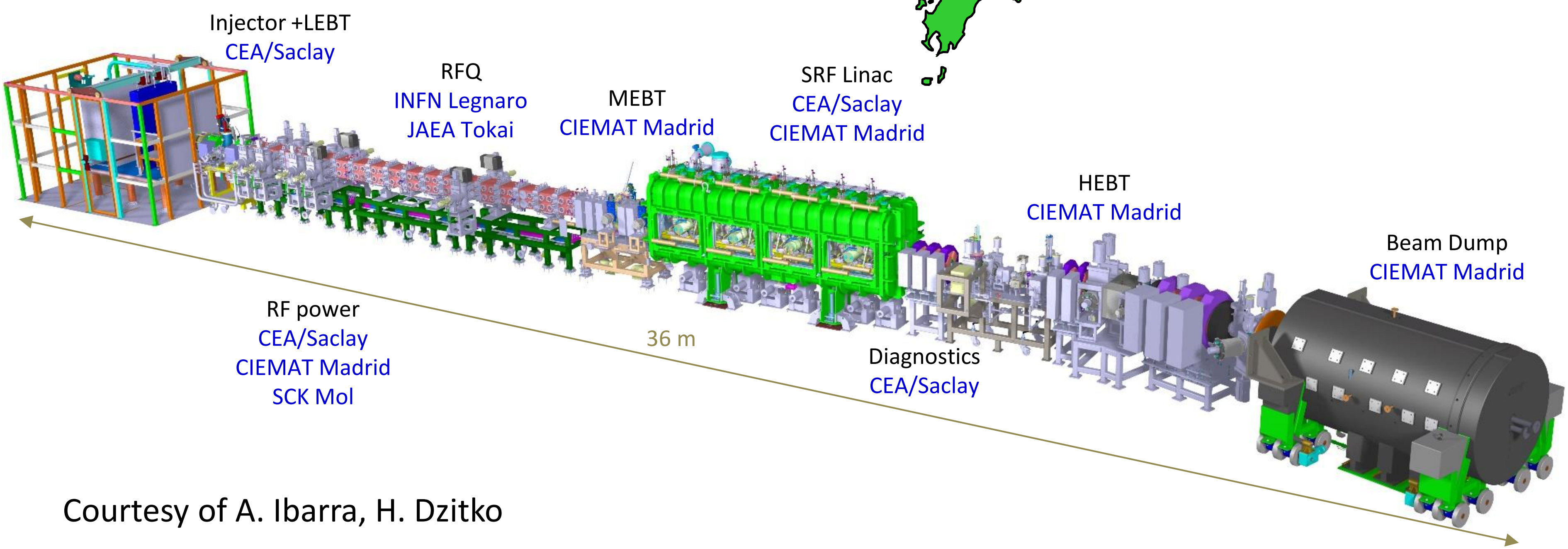
F4E asked EU countries to put forward proposals to site IFMIF-DONES – site decision expected in 2017

Accelerator Validation: LIPAc

Prototype accelerator: D, 9 MeV, 125 mA

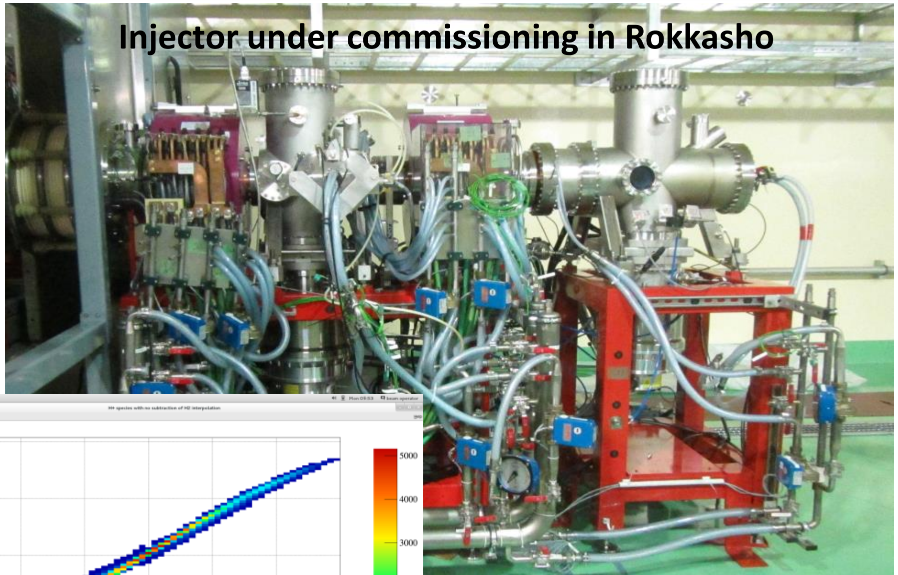
Designed and manufactured in Europe, installed and commissioned in **Rokkasho**

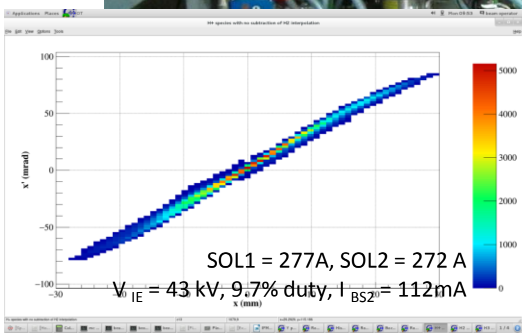




Courtesy of A. Ibarra, H. Dzitko

Construction status of LIPAc


Injector under commissioning in Rokkasho




MEBT at Rokkasho site

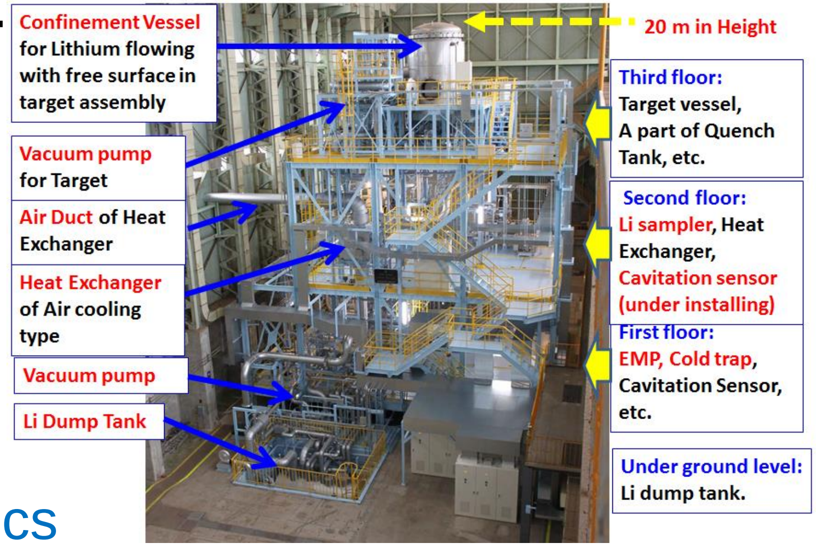
Courtesy of A. Ibarra, H. Dzitko

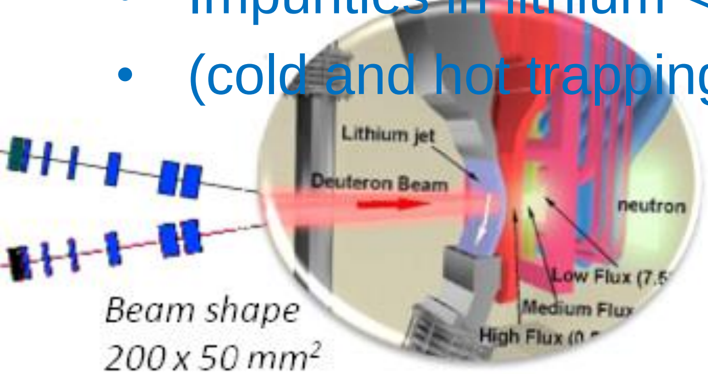

RFQ recently installed at Rokkasho


RF sytem partially installed at Rokkasho

Objective: To demonstrate the feasibility of operational conditions:

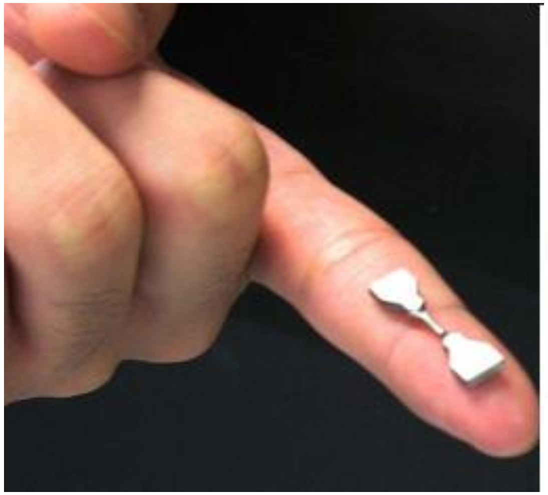
- Lithium temperature at 250 °C
- Flow speed at 15 m/s
- Stable flow with +/- 1 mm amplitude
- 10^{-3} Pa on free surface
- Long term operation stability
- Free surface interferometry diagnostics
- Impurities in lithium < 10 ppm
- (cold and hot trapping)



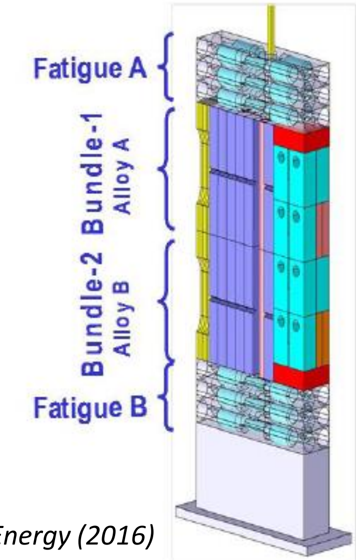


H. Kondo et al., Fusion Engineering Design (2016)

Material Testing Techniques



G.E. Lucas et al., J. of Nuclear Materials 367, 1549 (2007)



F. Arbeiter et al., Nuclear Materials and Energy (2016)

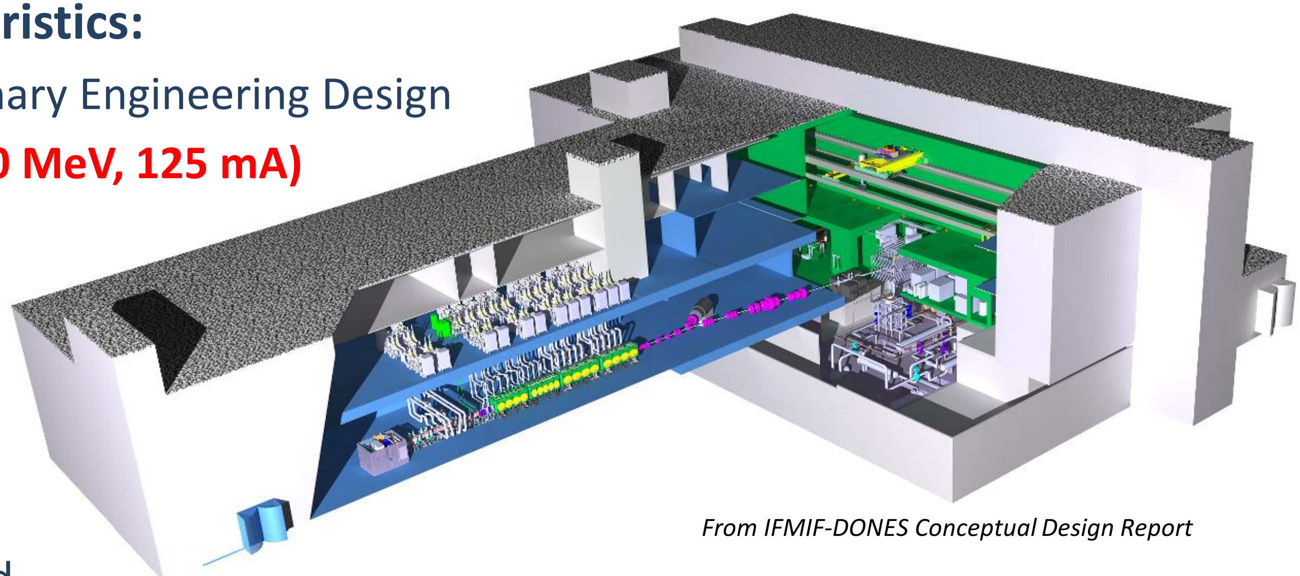
High Flux Test Module (HFTM)

- Small Specimen Testing Technology will be developed and applied
- Samples specially shaped to allow testing of critical mechanical properties
- All materials of interest stacked in special bundles and irradiation modules
- Modules will be placed in volumes with homogenous and controllable irradiation and temperature conditions

IFMIF-DONES Materials Irradiation Facility

Main technical characteristics:

- Based on IFMIF Preliminary Engineering Design
- **Only one full energy (40 MeV, 125 mA) deuteron accelerator**

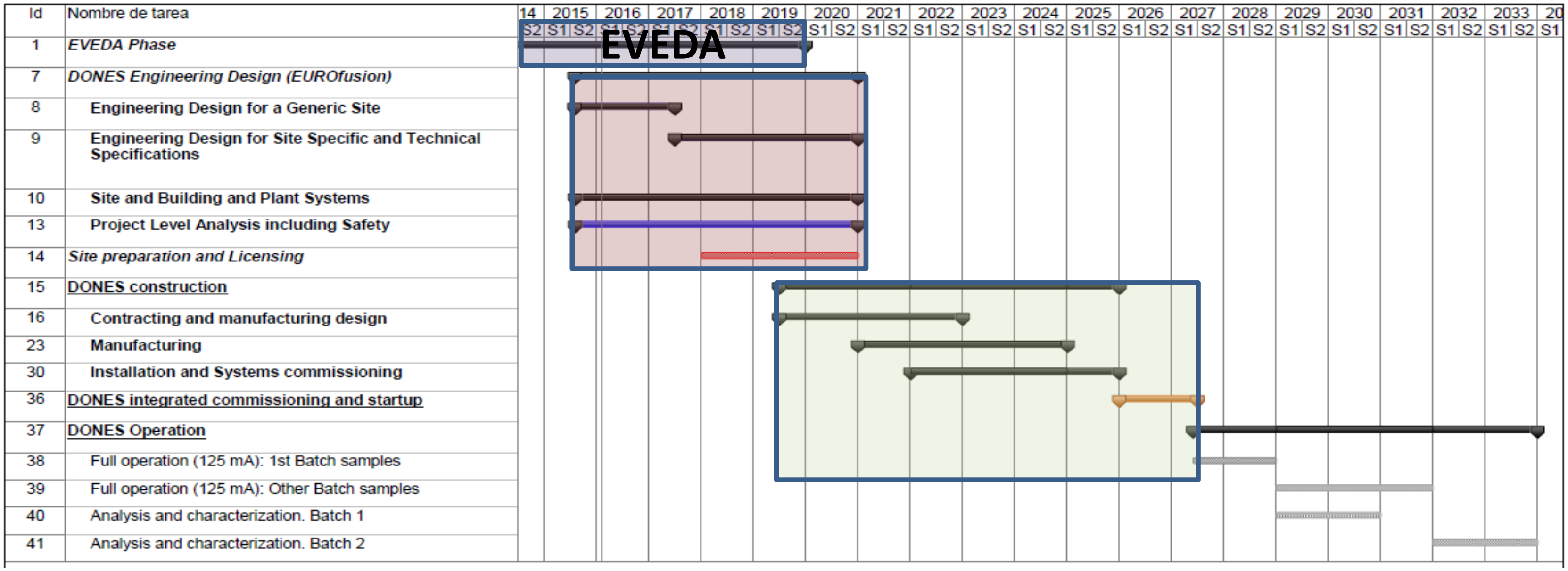


From IFMIF-DONES Conceptual Design Report

- Full size IFMIF Test Cell: only half cooling needed
- Full size IFMIF Li loop: only half cooling, half purification system needed
- Reduced number of irradiation modules : High Flux Test Module (HFTM) only
- Minimum irradiated materials (modules, target,…) manipulation in the plant: irradiated HFTM transferred in a cask to an external facility (if possible)
- Waste management reduced to the minimum: all wastes transferred to external facilities

- **Upgrade to full IFMIF feasible**

Reference Time Schedule



"feasible" time schedule based on the assumption that engineering design activities are developed continuously in the near future

AND

manufacturing activities will start right after the end of IFMIF/EVEDA project

AND

on F4E budget availability assumptions

→ **Time to be ready for operation: 10-12 years**

Site decision to be taken in 2016-17

(F4E already asked to EU countries for proposals; EU-JA scope discussions are going-on)

IFMIF-DONES Complementary Science Program

- It has been proposed to extend the objectives of IFMIF-DONES beyond its standard program of material studies for fusion reactors (A. Maj et al.)

- This initiative is supported by **WPENS project** in the EUROfusion Consortium and by the **ELAMAT Consortium** which is preparing a bid to site IFMIF-DONES in Poland. ELAMAT: a bottom up initiative of research institutions

- Various scientific areas, such as medical applications, basic physics studies, nuclear physics, and industrial application of neutrons are under consideration as complementary research topics.

- A White Book report on „IFMIF-DONES for isotope production, nuclear physics applications, materials science and other research topics" is in preparation. The conclusions of the White Book will identify the most promising science projects that could be developed at IFMIF-DONES without compromising its main role.

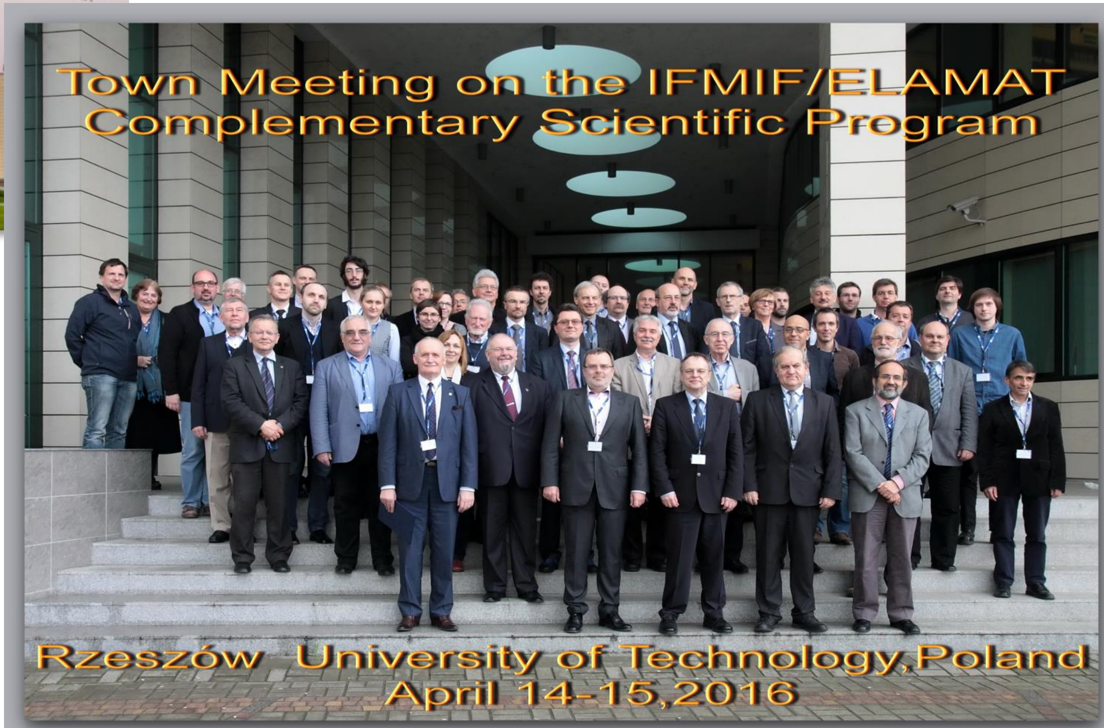
ELAMAT PODKARPACKIE

EUROfusion

"Town Meeting on the IFMIF/ELAMAT Complementary Scientific Program"

took place on April 14-15, 2016, hosted by the Rzeszów University of Technology, Poland

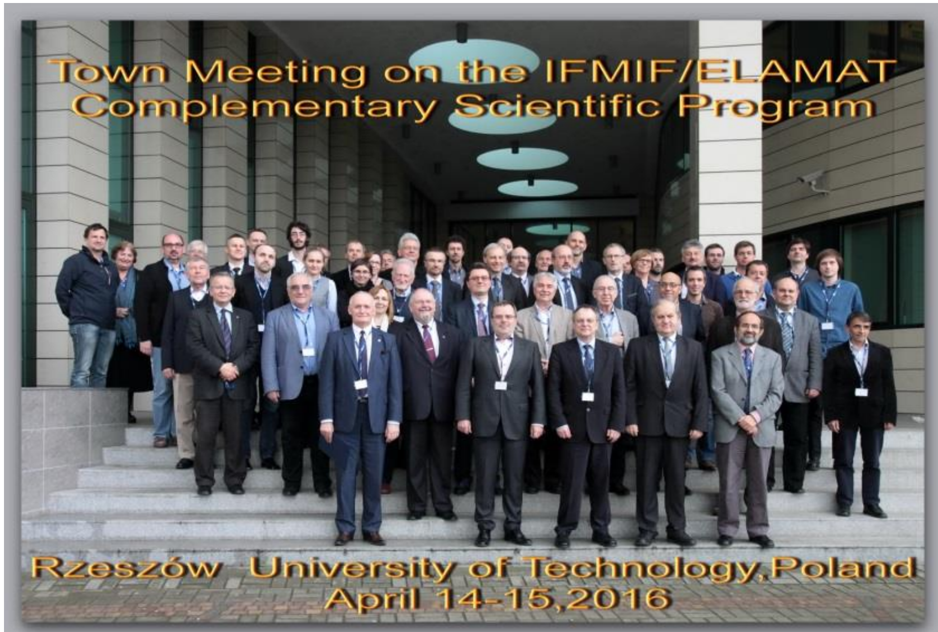
http://elamatscience.ifj.edu.pl



ELAMAT
PODKARPACKIE

IFMIF/ELAMAT Scientific Council

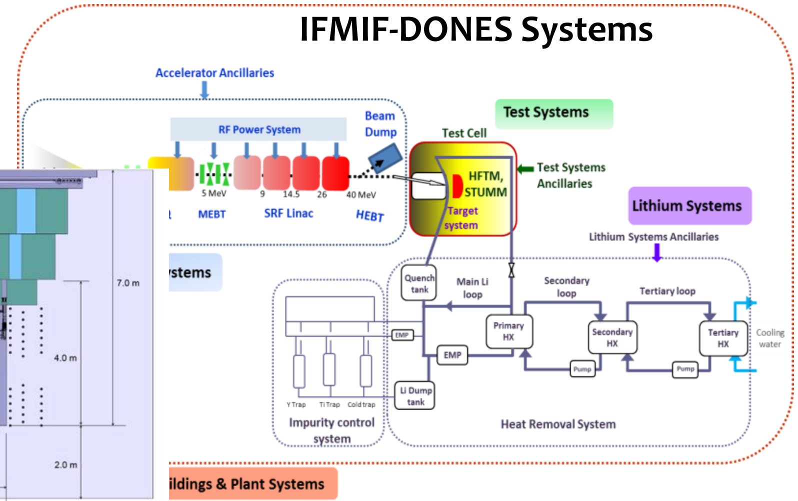
Nicolas Alamanos (IRFU CEA Saclay)
Faical Azaiez (IPN Orsay)
Alain Becoulet (IRFM CEA Saclay)
Maciej Chorowski (Wrocław UT)
Łukasz Ciupiński (Warsaw UT)
Władysław Dąbrowski (AGH University of Science and Technology)
Giovanni Fiorentini (INFN Legnaro)
Zsolt Fulop (ATOMKI Debrecen)
Sydney Gales (ELI-NP Bucharest)
Muhsin Harakeh (KVI Groningen)
Roland Heidinger (Fusion for Energy)
Angel Ibarra (CIEMAT Madrid)
Lesław Karpiński (Rzeszów UT)
Stanisław Kistryn (Jagiellonian University)
Marek Lewitowicz (GANIL)
Adam Maj (IFJ PAN Kraków) Chair of the Council
Tomasz Matulewicz (Warsaw University)
Anton Moeslang (KIT Karlsruhe)
Błażej Skoczeń (Kraków UT)
Robert Stieglitz (KIT Karlsruhe)
Wojciech Szuszkiewicz (Univ. of Rzeszów and PAN)
Grzegorz Wrochna (NCBJ Świerk)



Complementary Science: Boundary Conditions

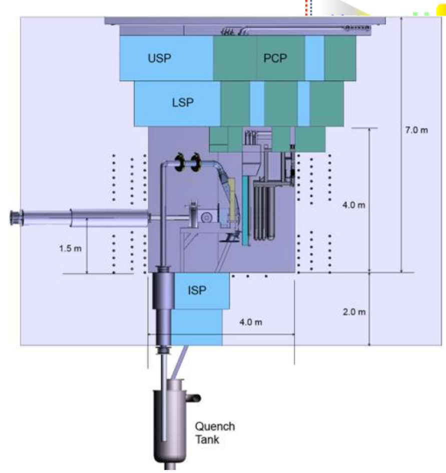
Main IFMIF-DONES mission: irradiation of fusion materials

(that requires several years of continuous irradiation)

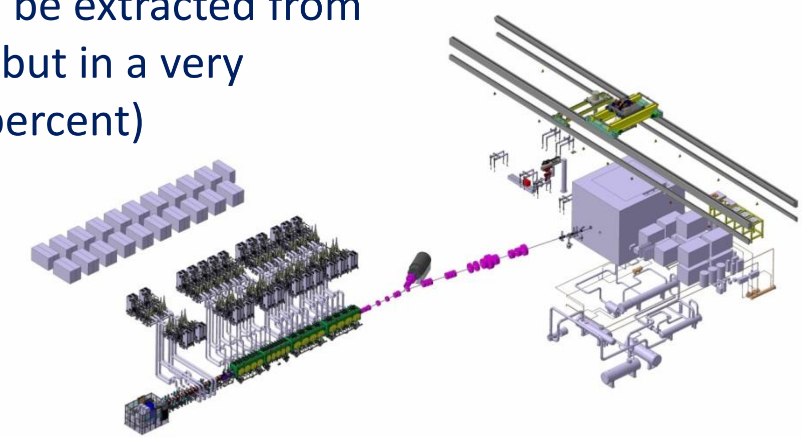


So, complementary applications can use:

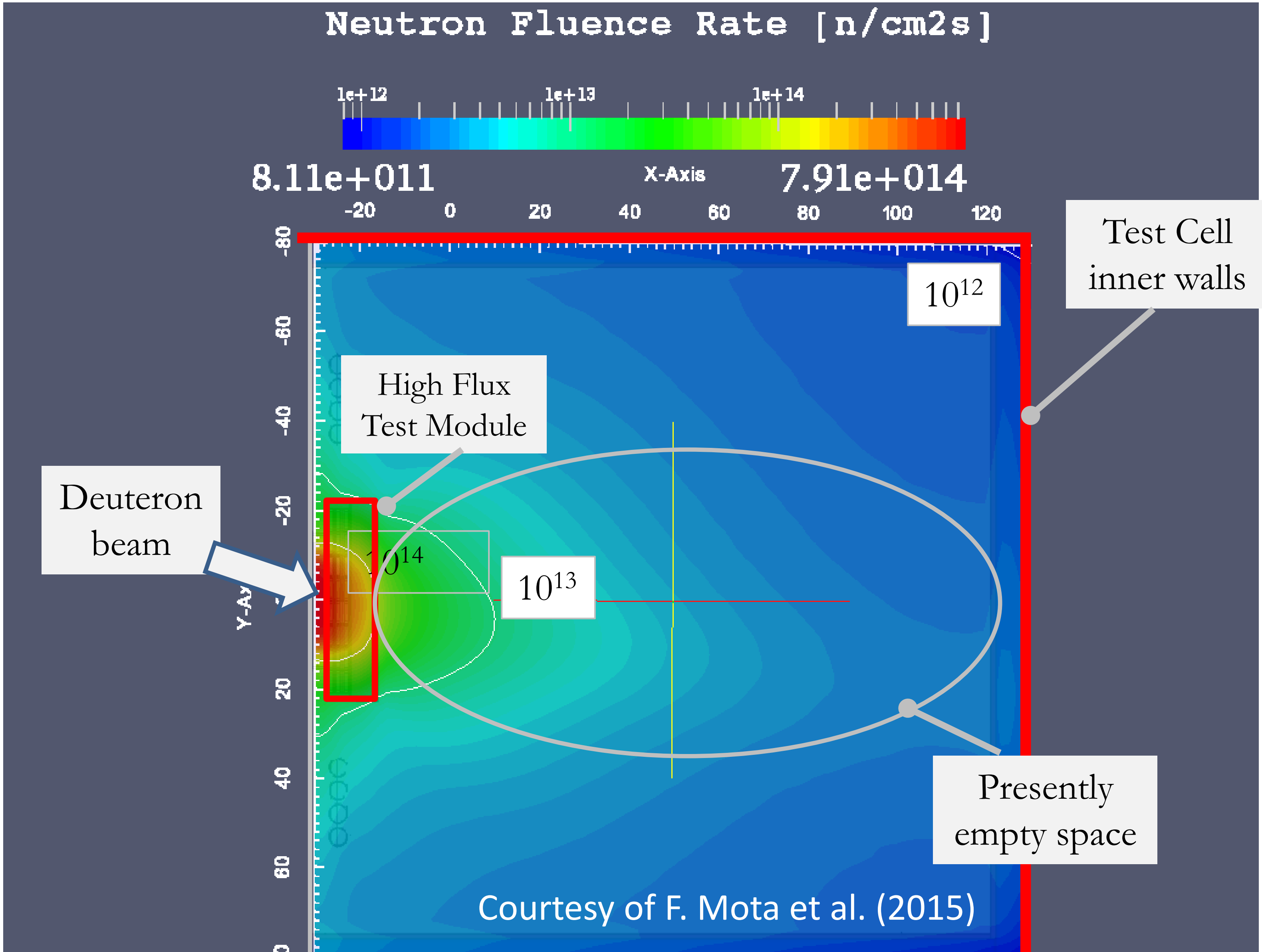
- **Neutrons** available behind Irradiation Module either inside Test Cell or in a new additional Experimental Hall



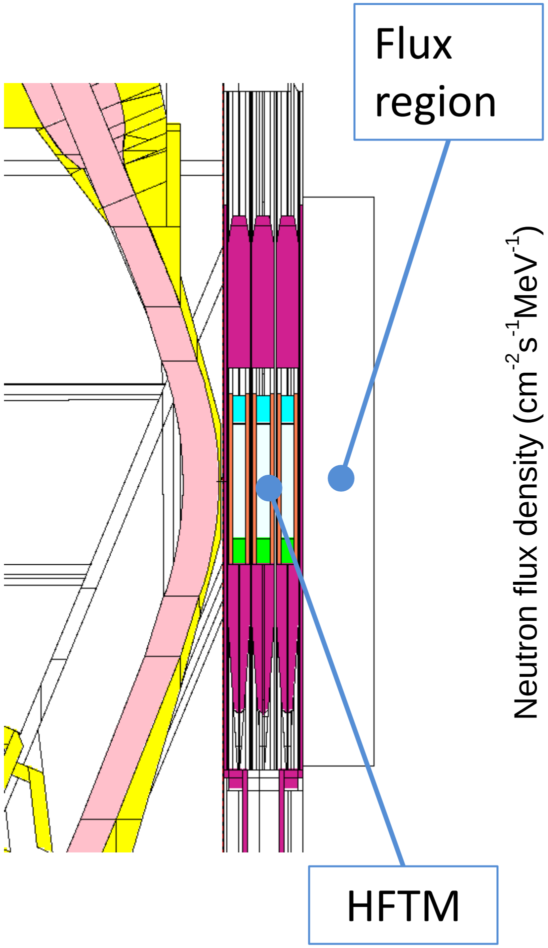
- **Deuterons** maybe can be extracted from the accelerator beam but in a very small fraction (a few percent)



DONES Test Cell – Neutron flux map



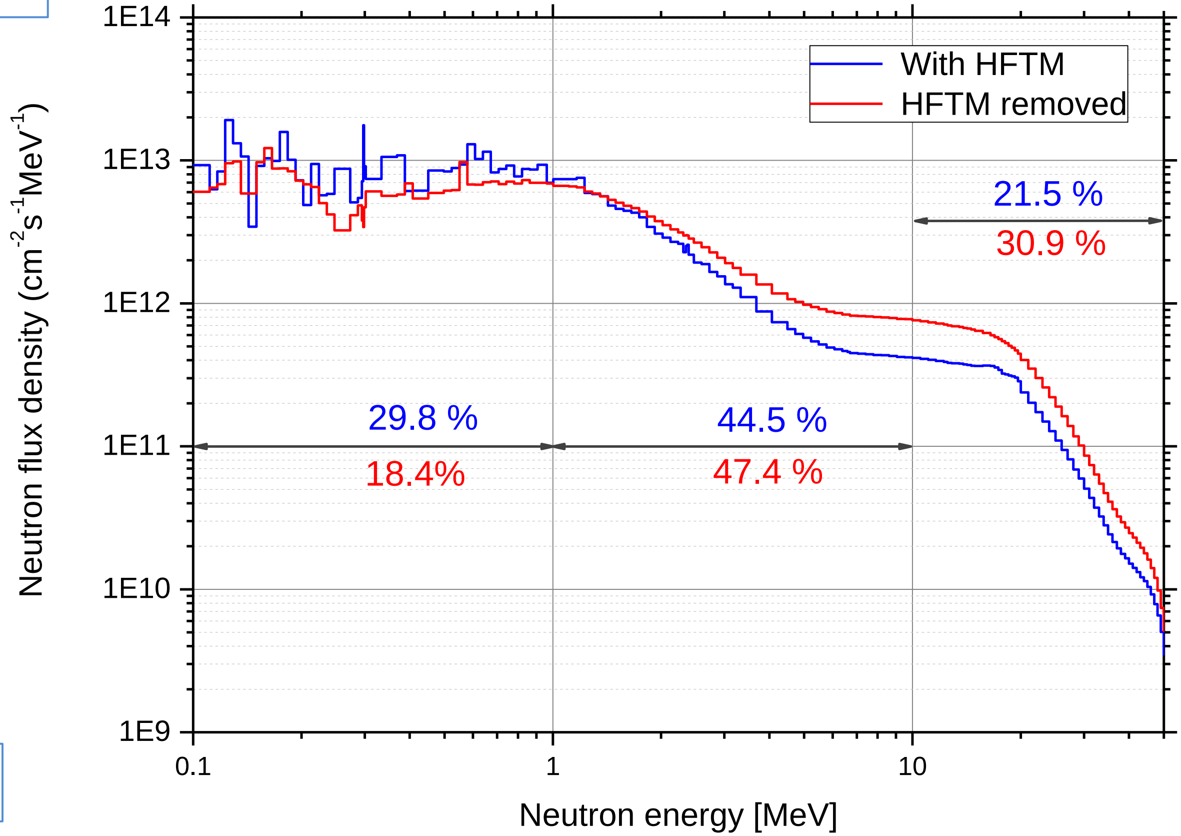
Flux region behind High Flux Test Module with HFTM in place and HFTM removed



Courtesy of U. Fischer

HFTM in place
ϕ_{tot} = 2.57 10^{13} $cm^{-2}s^{-1}$

HFTM removed
ϕ_{tot} = 3.12 10^{13} $cm^{-2}s^{-1}$



IFMIF-DONES Complementary Science Program

Four areas of interest identified during the Meeting:

Applications of medical interest

Basic physics studies

Nuclear physics and radioactive ion beam facility

Industrial application of neutrons

Applications of medical interest

Conveners: Sydney Gales, Marek Jeżabek, N. Alamanos

Their feasibility is still to be evaluated

Perspectives on the production of $^{99}Mo/^{99m}Tc$ — A. Marchix, CEA Saclay

The $^{99}Mo/^{99m}Tc$ is an important radioactive tracer isotope used for a multitude of diagnostic tests. Following the medical isotopes crisis (due to the shutdown of many reactors), international agencies (IAEA, OECD) have mandated groups of expert to find solutions for improving the reliability of $^{99}Mo/^{99m}Tc$ supply. One of alternative solutions is the use of accelerator-based neutron source using a deuteron beam so as to produce fast neutrons that induce the production of ^{99}Mo via the reaction $^{100}Mo(n, 2n)^{99}Mo$. IFMIF-DONES facility fits perfectly with the neutron source characteristics required since it leads to a most probable neutron energy of 14 MeV.

Radionuclides and radiopharmaceuticals for therapy — R. Mikołajczak, NCBJ

Potential new applications of radionuclide therapy (particularly in the field of oncology) reflect advances in **antibody engineering** (radioimmunotherapy), the identification of tumor antigen targets or the synthesis of peptide analogues (peptide receptor radionuclide therapy). These compounds are subsequently complexed with β, α or Auger emitting radionuclides which can be produced using the beams of IFMIF-DONES.

Accelerator-Based Boron Neutron Capture Therapy — P. Colautti, INFN Legnaro

BNCT is a dual therapy. First a ^{10}B carrier, with high tumour-cell specificity, is locally, or through the circulatory system, injected into the patient. When the tumour/ healthy-tissue ^{10}B-concentration ratio has reached the maximum value, **the tumour region is irradiated with intense thermal neutrons**, which induce exothermic nuclear reactions in ^{10}B nuclei. After thermalizing, neutrons from IFMIF-DONES might be of use.

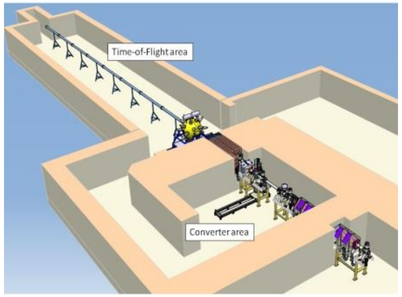
Nuclear physics and radioactive ion beam facility

Conveners: Marek Lewitowicz, Muhsin Harakeh

Their feasibility is still to be evaluated

Neutrons for Science at SPIRAL2

X. Ledoux, GANIL

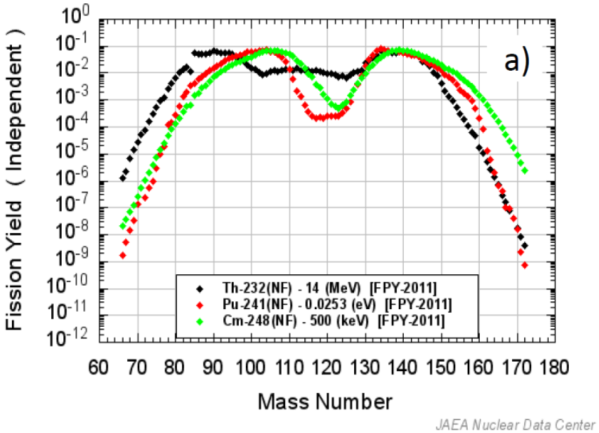


A large number of applications like transmutation of nuclear waste, design of future fission and fusion reactors, accelerator driven systems and nuclear medicine use fast neutrons. Therefore the NFS facility was built at GANIL. It will use the thin or thick target of lithium or beryllium to convert the high intensity ion beam of SPIRAL-2 linear accelerator into a high intensity pulsed neutron beam. Continuous and quasi-mono-energetic spectra will be available with energy up to 40 MeV. The facility includes a long (35 m) experimental hall for time-of-flight experiments and irradiations stations located in the vicinity of the converters. Extension of the studies which could be performed at IFMIF-DONES will be discussed.

Gamma-ray spectroscopy of nuclei at the edges of neutron-induced fission product distributions at IFMIF-DONES

B. Fornal, IFJ PAN Kraków

The discrete gamma-ray spectroscopy of nuclei produced in spontaneous or thermal-neutron induced fission of actinides has extensively been used in the past to study yrast and near-yrast structures in neutron-rich species. In spontaneous or thermal-neutron induced fission, however, the region of neutron-rich species with Z=46-48 is not populated with yield sufficient to perform gamma-gamma coincidence measurements. This can be overcome by using fission induced by 14 MeV neutrons on actinide targets.



Nuclear physics and radioactive ion beam facility

Conveners: Marek Lewitowicz, Muhsin Harakeh

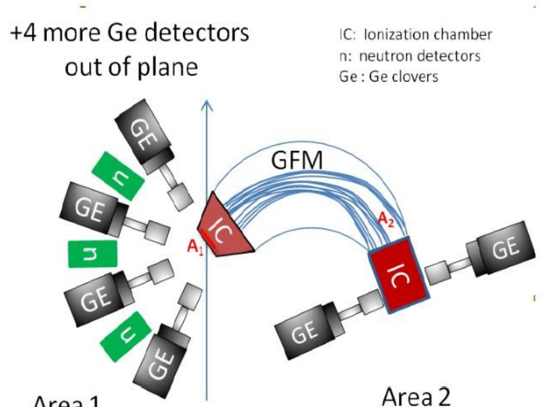
Their feasibility is still to be evaluated

Production and study of the most exotic neutron-rich nuclei via fast neutron induced fission

J. Wilson, IPN Orsay

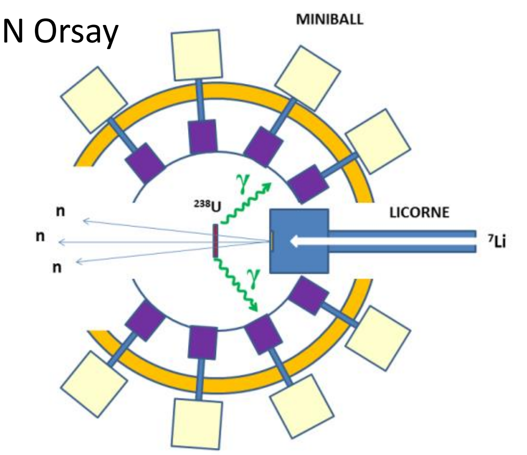
FFIPS recoil separator at Grenoble

A. Blanc, ILL Grenoble



FIPPS @ILL Grenoble

LICORNE @IPN Orsay



Estimates for fast neutron induced fission fragment distributions

P. Delahaye, GANIL

Basic physics studies

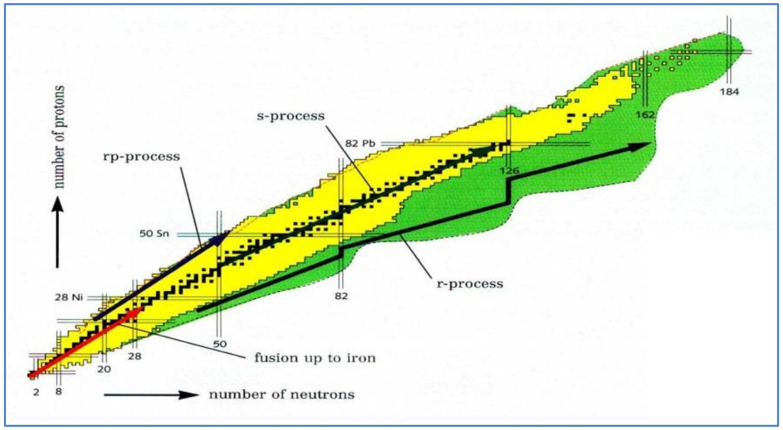
Conveners: Zsolt Fulop, Tomasz Matulewicz

Their feasibility is still to be evaluated

Neutrons in Astrophysics

R. Reifarth, Goethe University Frankfurt

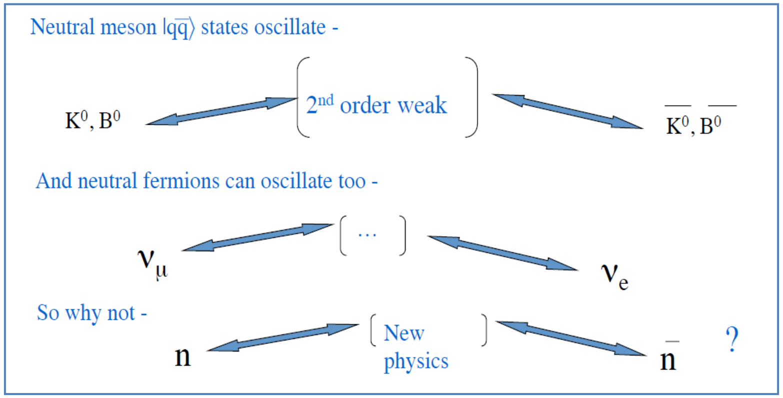
While the elements from carbon to iron were found to be produced by charged particle reactions during the evolutionary phases from stellar He to Si burning, all elements heavier than iron are essentially built up by neutron reactions in the slow (s) and rapid (r) neutron capture processes. New intense neutron sources, such as DONES, can provide neutrons for irradiating stable material to produce radioactive isotopes or neutrons to actually determine astrophysically interesting reaction rates.



Neutron and Neutrino oscillations

A. Letourneau, CEA Saclay

Why is there more matter than anti-matter in the universe? What is the character of the neutrino? These two fundamental questions can be addressed using very intense neutron sources. In particular could one expect an improvement of precision of the neutron-antineutron oscillation measurement?



Basic physics studies

Conveners: Zsolt Fulop, Tomasz Matulewicz

Their feasibility is still to be evaluated

Neutrons in solid state physics — W. Szuszkiewicz, University of Rzeszów

Ab-initio modelling of materials with defects — P. Piekarz, IFJ PAN Kraków

Future scientific possibilities at the European Spallation Source — A. Hiess, ESS Lund

The LENOS Project: a thermal to 70 MeV neutron beam facility — P.F. Mastinu, INFN Legnaro

Probing fundamental interactions by precision measurements of β-ν correlations at SARAF facility — M. Hass, Weizmann Institute

Industrial application of neutrons

Conveners: Władysław Dąbrowski, Krzysztof Kurek, Alain Becoulet, Grzegorz Wrochna

Their feasibility is still to be evaluated

The potential use of fast neutrons to perform computed tomographic imaging

J. Wilson, IPN Orsay

The technique of producing tomographic 2D and 3D images of the interior of objects using X-rays is well developed in nuclear medicine, archeology, material testing. However the limitations of using X-rays are their lack of penetration into dense objects. Another possibility is therefore to **use fast neutrons for CT imaging**, as they are complementary to gamma-rays. First results from the LICORNE neutron source in IPN Orsay will be presented and potential use of neutrons from the IFMIF-DONES facility discussed.

Damage accumulation in irradiated materials: influence on structural and functional properties

J. Jagielski, NCBJ Świerk

Complementary Scientific Program – General discussion

- Now time to select and study in-depth a few most promising science cases
- Feasibility evaluation necessary
- Complementary experiments either in Test Cell or neutron guides leading outside to another shielded experimental area
- Fast neutrons availability, thermalization considered as a remote option

Authors of proposals have been asked to provide: **by A. Maj, editor**

1. Scientific case of the program you are proposing for ELAMAT/IFMIF-DONES.
2. The beam characteristics that you will need to carry on your program most efficiently. This information will be needed at an early stage in order to implement it in the design of the facility.
3. The equipment that you will need to pursue your objectives.
4. The space that will be needed for the scientific program, i.e. for transport and placement of equipment and for other purposes (e.g. for ToF measurements, or white rabbit, etc.).
5. Any other information necessary to perform your program which may influence the design of IFMIF-DONES (consider compatibility with main production target and high radiation conditions).
6. Uniqueness or benefits of doing your research at IFMIF-DONES (compared to existing facilities).

White Book report on „IFMIF-DONES for isotope production, nuclear physics, materials science and other applicatons”

Outlook for IFMIF-DONES

- **Ongoing review of the Roadmap to the realisation of fusion electricity**

- **White Book** on ***„IFMIF-DONES for isotope production, nuclear physics applications, materials science and other"*** will be prepared by June 2016.
  The conclusions of the **White Book** will be „site-independent"

- **Site decision** due in 2017 (by Fusion for Energy)

- **The Early Neutron Source** work package of Eurofusion continues till 2018/20
  – Engineering design of systems in critical path ready for preparation of technical specifications in 2019
  – Design of remaining systems ready for 2020

- **IFMIF/DONES** construction 2021-2025

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