EUROfusion

THE HENRYK NIEWODNICZAŃSKI INSTITUTE OF NUCLEAR PHYSICS POLISH ACADEMY OF SCIENCES

Seminarium Fizyki Jądra Atomowego, Uniwersytet Warszawski, 18.01.2024

IFMIF-DONES – laboratorium neutronowe dla programu syntezy termojądrowej, fizyki i badań interdyscyplinarnych

Wojciech Królas

Eurofusion ENS work package
DONES Users, IFJ PAN

International Fusion Materials Irradiation Facility – DEMO Oriented Neutron Source

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Outline

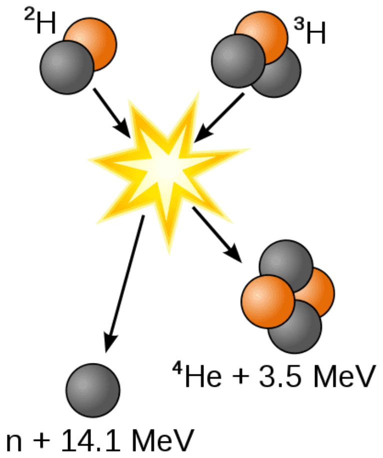
- Brief introduction to the European Roadmap to Fusion Electricity
  - → fusion as one of the solutions to the energy problem, European Roadmap
  - → why do we need a high-intensity fast neutron source?
- IFMIF-DONES neutron source requirements and design
  - → how can it be achieved?
  - → engineering design, construction status, timeline
- IFMIF-DONES as a multidisciplinary neutron facility
  - → neutron science and applications
  - → nuclear physics at DONES

International Fusion Materials Irradiation Facility – DEMO Oriented Neutron Source

Light ↔ Energy ↔ Civilization

Nuclear fusion as source of energy:
unlimited, safe, clean

Nuclear fusion, how does it work?

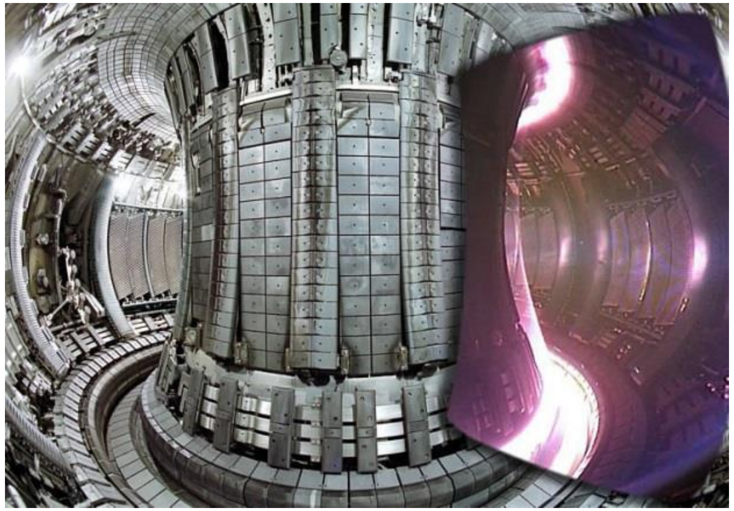


$D + D \rightarrow {}^3He + n + 3.2$ MeV; $D + D \rightarrow {}^4He + n + 4.0$ MeV

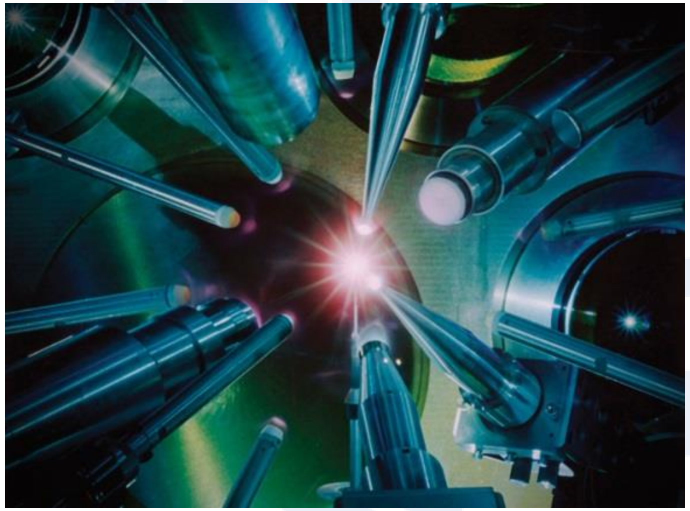
$D + T \rightarrow {}^4He + n + 17.6$ MeV; $T + T \rightarrow {}^4He + 2n + 11.3$ MeV

How do we make it work in the laboratory:

- Fusion plasma – an ionized state of matter similar to a gas, composed of charged particles (positive nuclei and negative electrons) provide the environment in which light elements can fuse and yield energy
- Magnetic confinement of plasma: ***Tokamaks, stellerators***
- Inertial confinement: ***laser compression,*** other

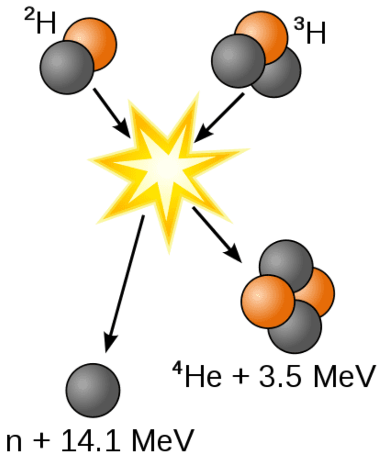


The chamber of the JET Tokamak (CCFE, UK)



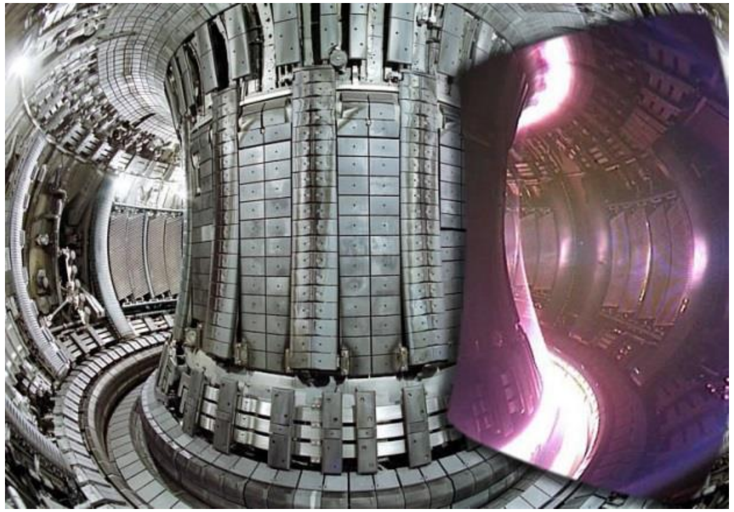
National Ignition Facility NIF (LLNL, US)

Recent achievements in controlled fusion

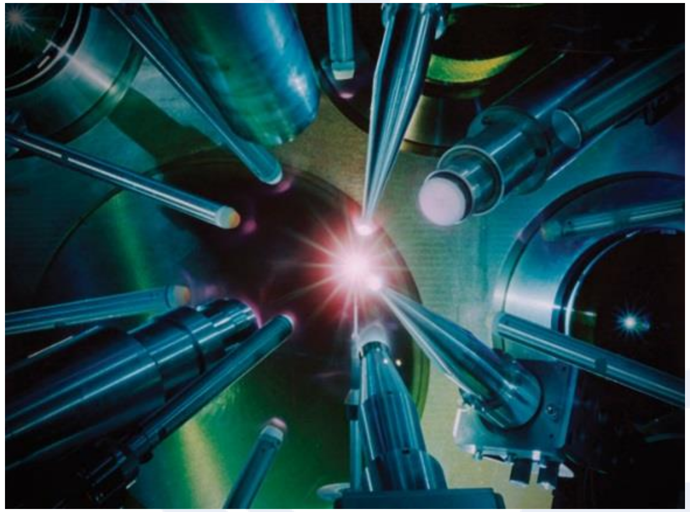


A record fusion experiment was performed in December 2021, at the Joint European Torus (JET), achieving total fusion energy of 59 MJ and maintaining 10 MW of fusion power for 5 s

An inertial confinement fusion experiment in December 2022 at the NIF achieved ignition and energy gain, delivering 2.05 MJ of energy and producing 3.15 MJ of fusion energy

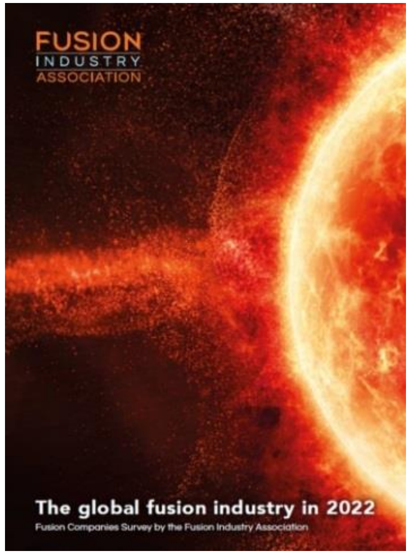


The chamber of the JET Tokamak (CCFE, UK)



National Ignition Facility NIF (LLNL, US)

New (private funding) fusion landscape



- A network of 30+ private fusion companies
- Many different approaches
  - Magnetic
  - Inertial
  - Others, some very exotic…
- Private fusion funding of approximately 5 billion USD (2022)
- 2021 -> 2022 funding increase of 140%

IAEA: World Survey of Fusion Devices 2022

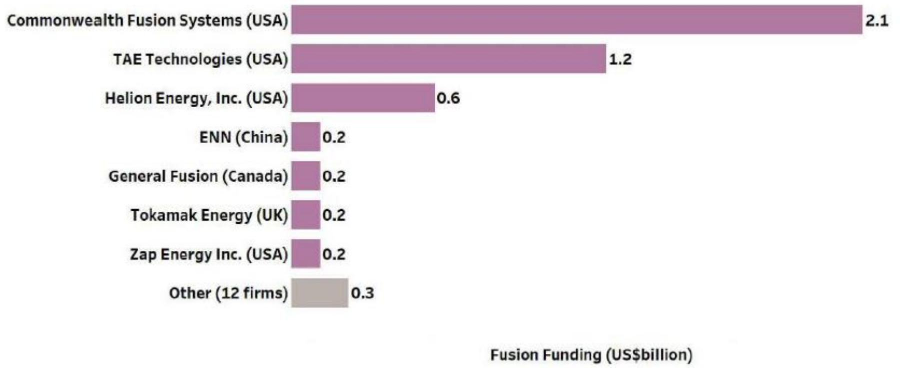
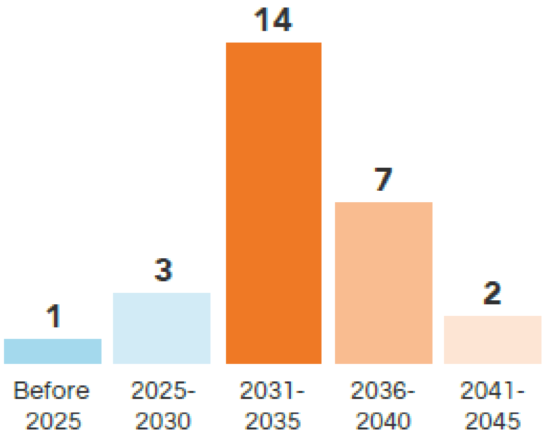


FIG.6. Private sector companies have disclosed around US$5 billion in fusion funding (more than $3 billion since June 2021). Readapted and updated from: The chase for fusion energy, Nature (2021); The global fusion industry in 2022, Fusion Industry Association (2022).

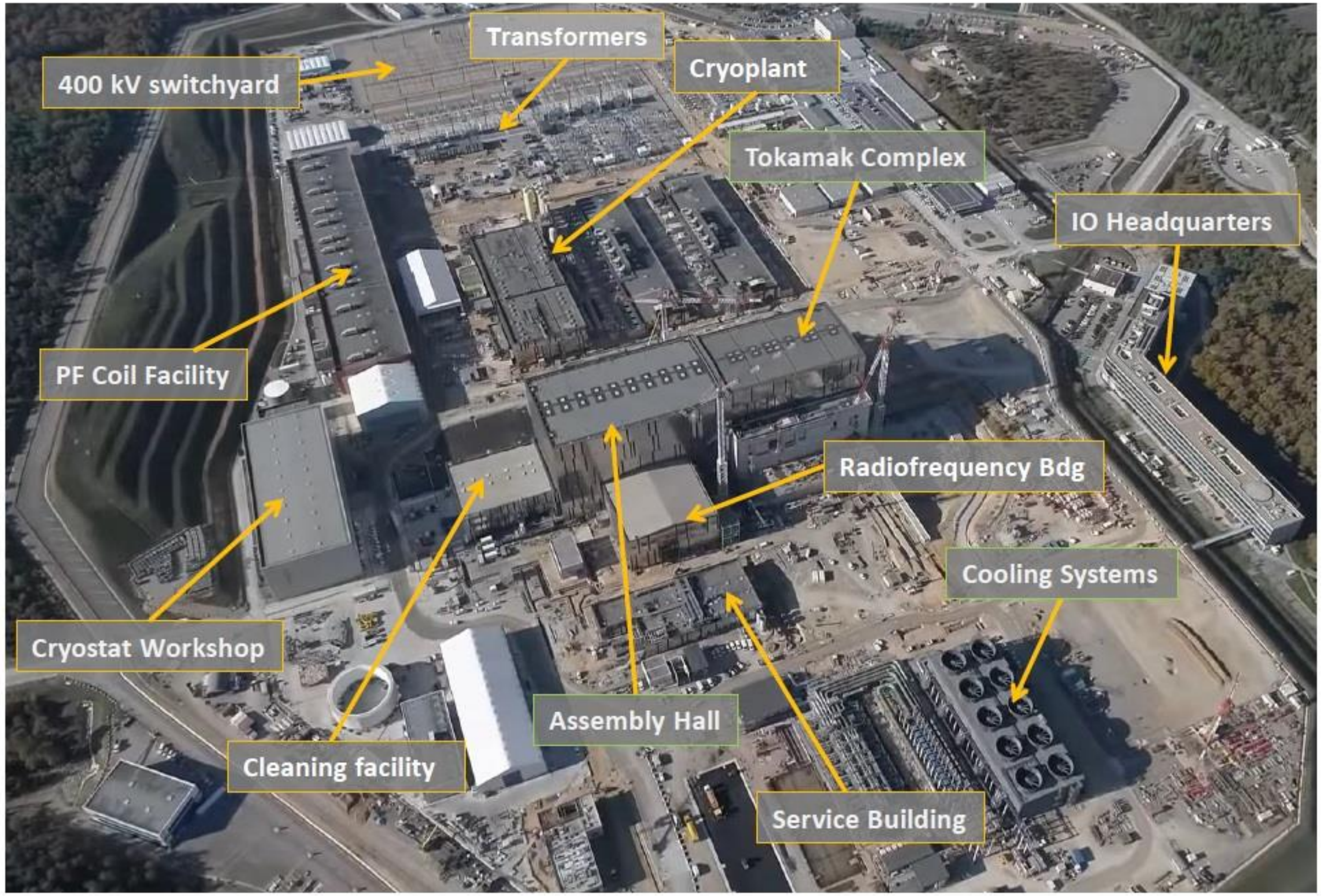
FIA predictions for fusion on the grid

When will the first fusion plant deliver electricity to the grid? (27 responses)



ITER Industry Liaison Office, July 2023

Coming next … ITER



http://ITER.org

Objectives: Efficiency (Q): up to 10
Steady state plasma up to 1000 s

Main goals:

- Achieve a deuterium-tritium plasma in which the fusion conditions are sustained mostly by internal fusion heating
- Generate 500 MW of fusion power
- Test the tritium breeding technology (fuel cycle)
- Demonstratate the integrated operation of technologies for a fusion power plant
- Demonstrate the safety characteristics of a fusion device

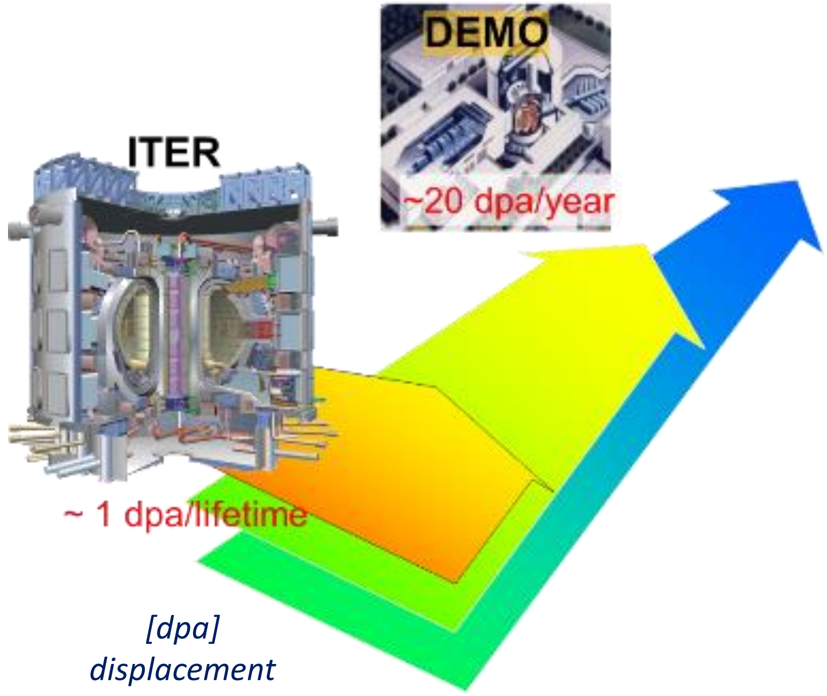
Basic parameters:

Torus radius: ……… ….. 6.2 m
Plasma volume: ……… 300 m^3
Plasma current: ……… up to 15 MA
Magnetic field: ……….. up to 5.3 T
Power produced: ……. ~ 500 MW

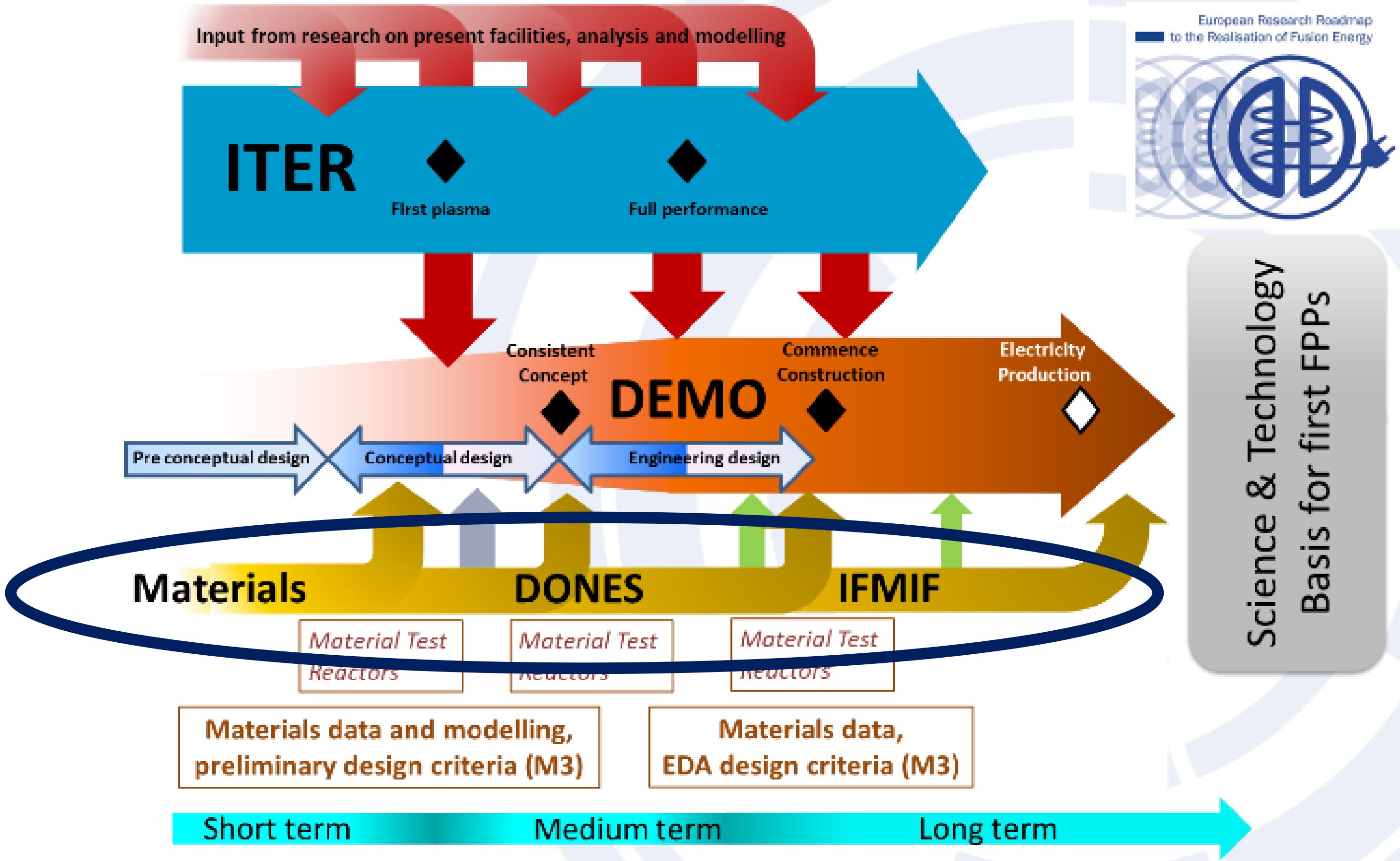
European „roadmap to fusion electricity”

ITER: international organization, 7 partners, research reactor under construction since 2010

DEMO: steady operation, fusion power converted into electricity for the grid



[dpa]
displacement
per atom in solid



https://euro-fusion.org/eurofusion/roadmap/

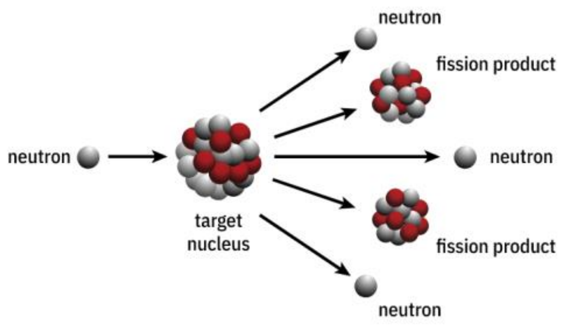
One of the main differences between ITER and DEMO is the radiation dose: at DEMO more than two orders of magnitude higher

Fusion – strategy for materials irradiation with neutrons

Fission irradiations

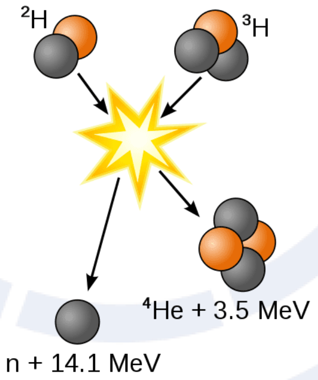
- Extensive use of **Material Test Reactors (MTR)** for fission irradiation:
  50 M€ to be spent in the next decade

  However: the number of MTRs with reasonable n-fluence is becoming limited!
- Irradiations with doped materials (Ni, B, Fe-54…) are needed to „simulate”
  He-effects on degradation of material properties



Fusion-like irradiations

- Mandatory: a dedicated facility for material qualification that reproduces **a 14 MeV neutrons spectrum** with reasonable irradiation volume, fluence, and homogenity in temperature/time with the objective to validate in-vessel and structural materials



In DONES neutrons with a relevant energy spectrum will be generated in D+Li stripping reaction

Assumption: fusion-related effects will appear only at high dose (>10-20 dpa)

[dpa] displacement per atom in solid

Neutron energy spectra in fission, fusion and spallation

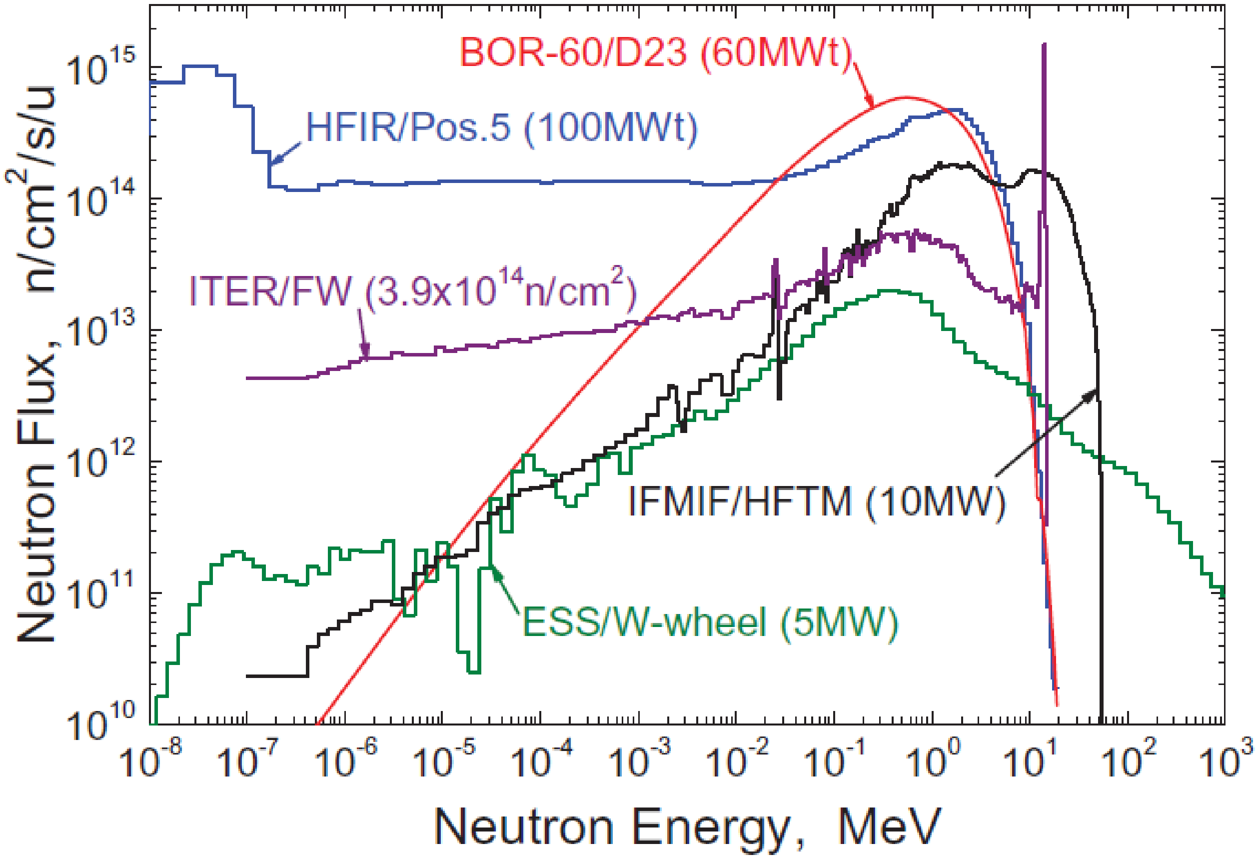
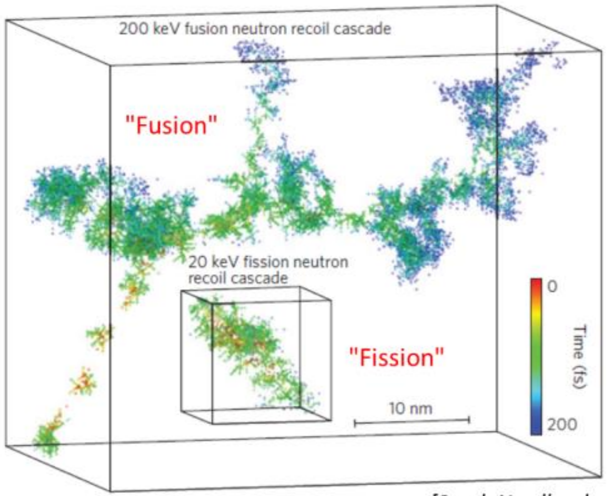


Figure 7. Neutron energy spectra in the fission, fusion and spallation nuclear facilities.

S.P. Simakov et al.,
EPJ 146 (2017) 02012

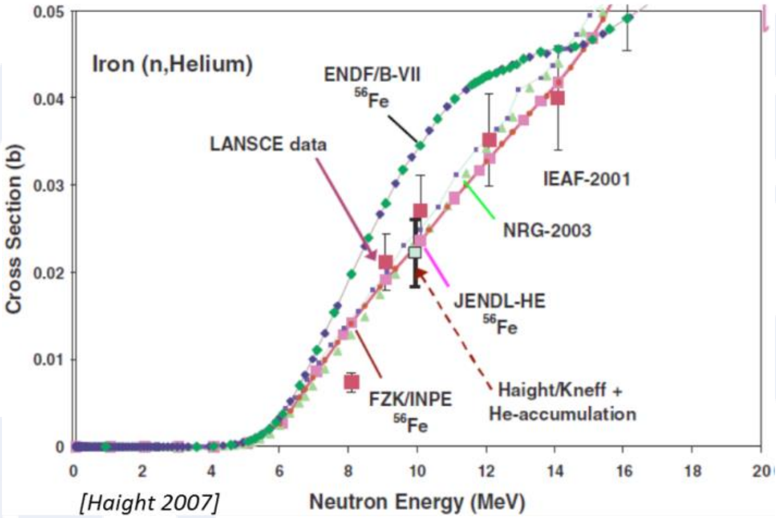
What is different with fusion neutrons?



[Sand, Nordlund in Knaster 2016]

Displacements cascades caused by fusion / fast neutrons propagate much deeper

Helium production cross sections for Fe (and Ni, Cr) have a threshold > 5 MeV (neutron energy)



[Haight 2007]

This causes severe degradation of structural properties:

- Swelling
- Embrittlement
- Radiation hardening, loss of ductility
- Change of transport properties: thermal conductivity, permeation (e.g. hydrogen)
- Irradiation enhanced creep
- …

Functional properties are also affected:

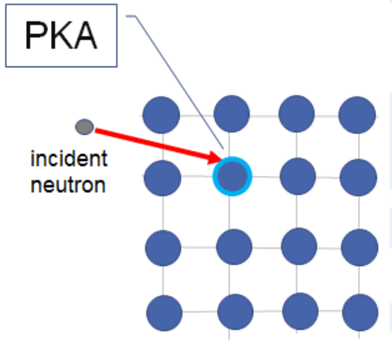
- Radiation induced electrical degradation of insulators
- Loss of electrical conductivity
- Optical transmission, reflectivity
- …

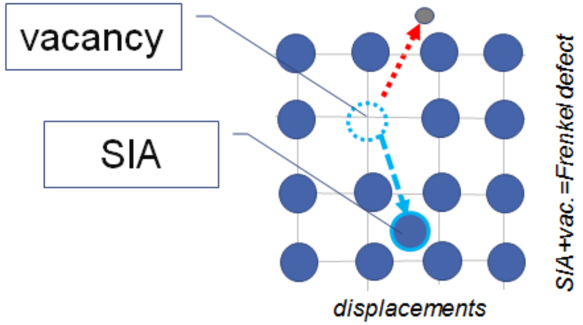
Primary irradiation damage

Displacement damage:

- ✓ incident neutron hits primary knock-on atom (PKA)
- ✓ PKA can dislocate more lattice atoms

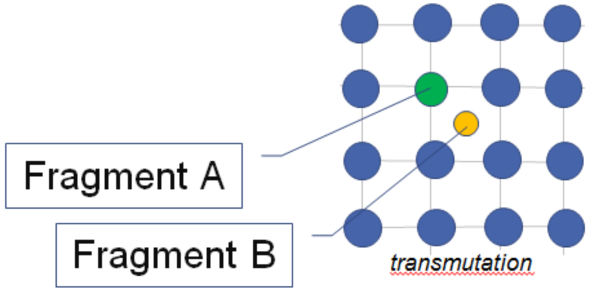
  → damage cascade
- ✓ After the energy is distributed below the displacement energy E_d (i.e. 40 eV for Fe), the lattice is left with vacancies and self interstitial atoms (SIA)
- ✓ dpa: displacements per atom ≠ surviving defects!
- ✓ Relevance of PKA energy spectrum





Transmutation:

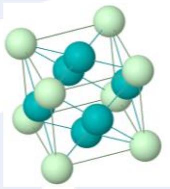
- ✓ nuclear reaction of neutron and lattice atom according to incident energy and cross section
- ✓ new alloying elements are introduced!
- ✓ Example: W → W-18Re-3Os @ 50 dpa!



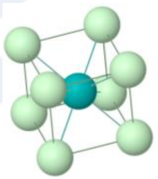
F. Arbeiter, PhDia Fusion 2021

Void swelling

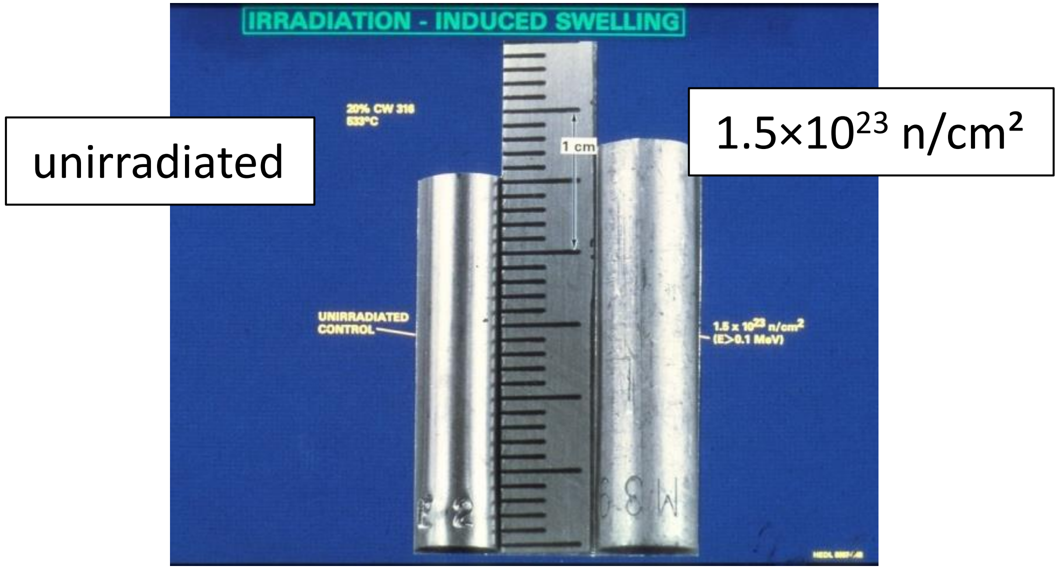
- ✓ Phenomenon: Increase of volume (at significant levels!), ΔV/V [%]
- ✓ occurs also in absence of stress
- ✓ more intensive in fcc lattice than bcc lattice
- ✓ incubation phase, followed by "linear regime"
- ✓ condensation of excess vacancies left behind in lattice into voids



face centered cubic
fcc
→ *austenitic steels*

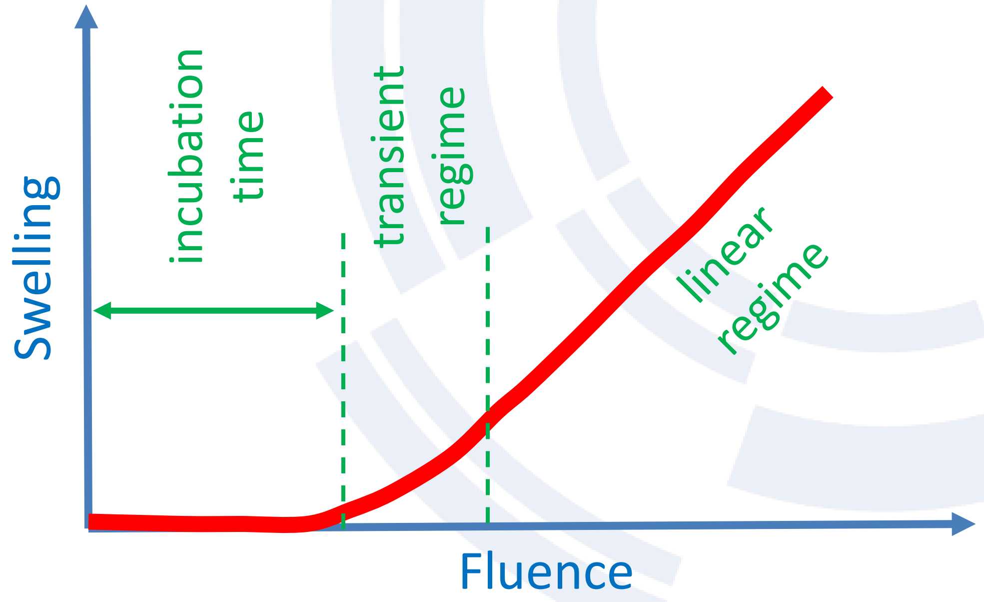


body centered cubic
bcc
→ *ferritic steels*



316L (cw) @ 533°C, [Straalsund 1982]

F. Arbeiter, PhDia Fusion 2021



Irradiation embrittlement: ductile vs. brittle behaviour

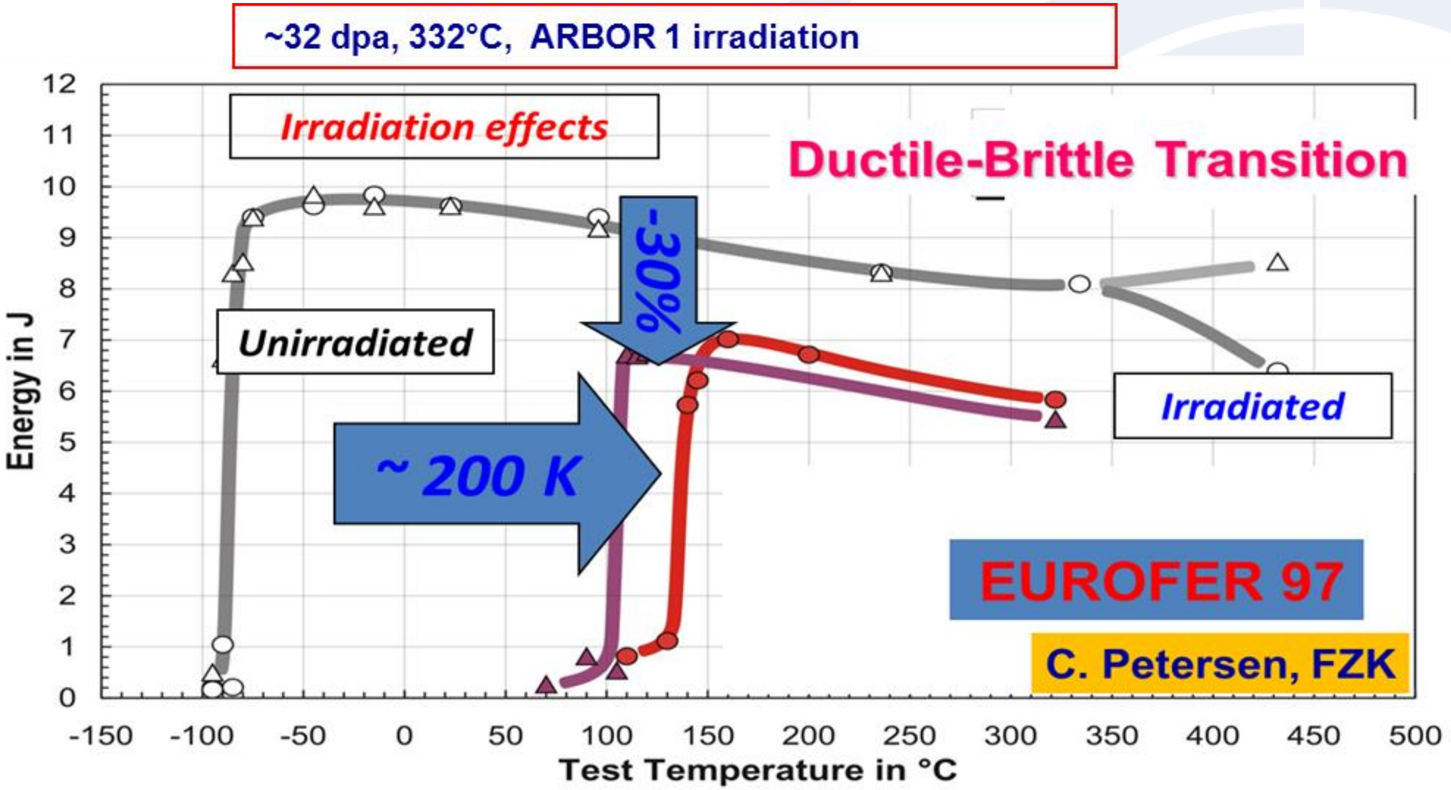
(a) Ductile Materials:
Materials deform irreversibly
→ "significant" plastic regime

Mask of Agamemnon

(b) Brittle Materials:
Materials crack instantaneously
→ "insignificant" plastic regime

Codex Hammurabi

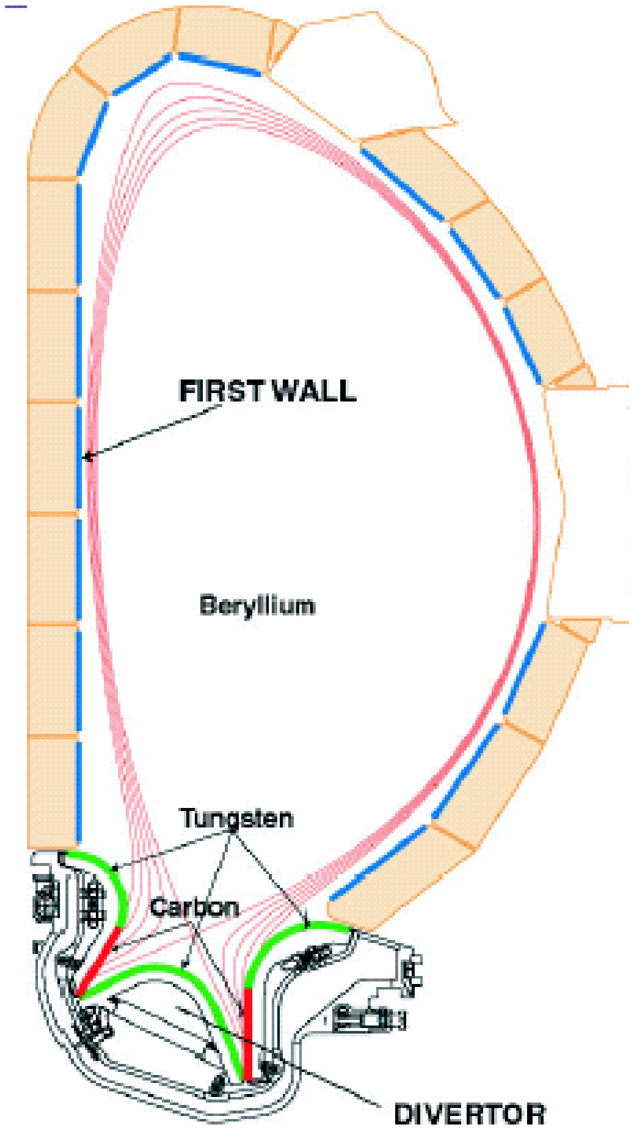
When loads (forces) exceed the limit given by the elastic regime



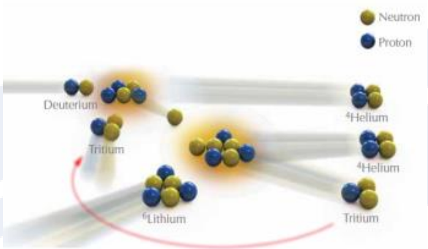
Grey unirradiated Red, Purple irradiated with a dose of 32 dpa

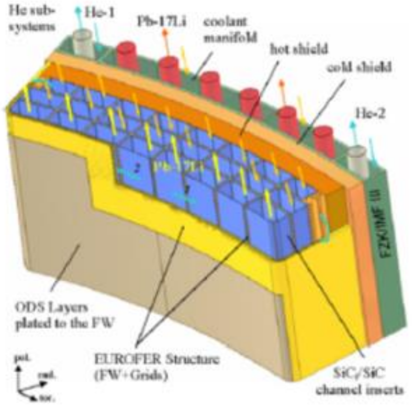
- ✓ Large shift in „ductile" to „brittle" transition temperature
- ✓ Potential effect of Helium generation, not fully studied

In summary: qualification of first wall materials for fusion reactors



Most of the neutron energy will be absorbed by the first wall material





First wall of ITER designed for

R < 2 [dpa]

DEMO reactor after 5 years of running

R ~ 30-100 [dpa]

Threshold (no systematic data exists)

R > 30 [dpa]

At about 30 dpa, particular effects due to Helium generation are predicted to set in, influencing the ductile-to-brittle transition

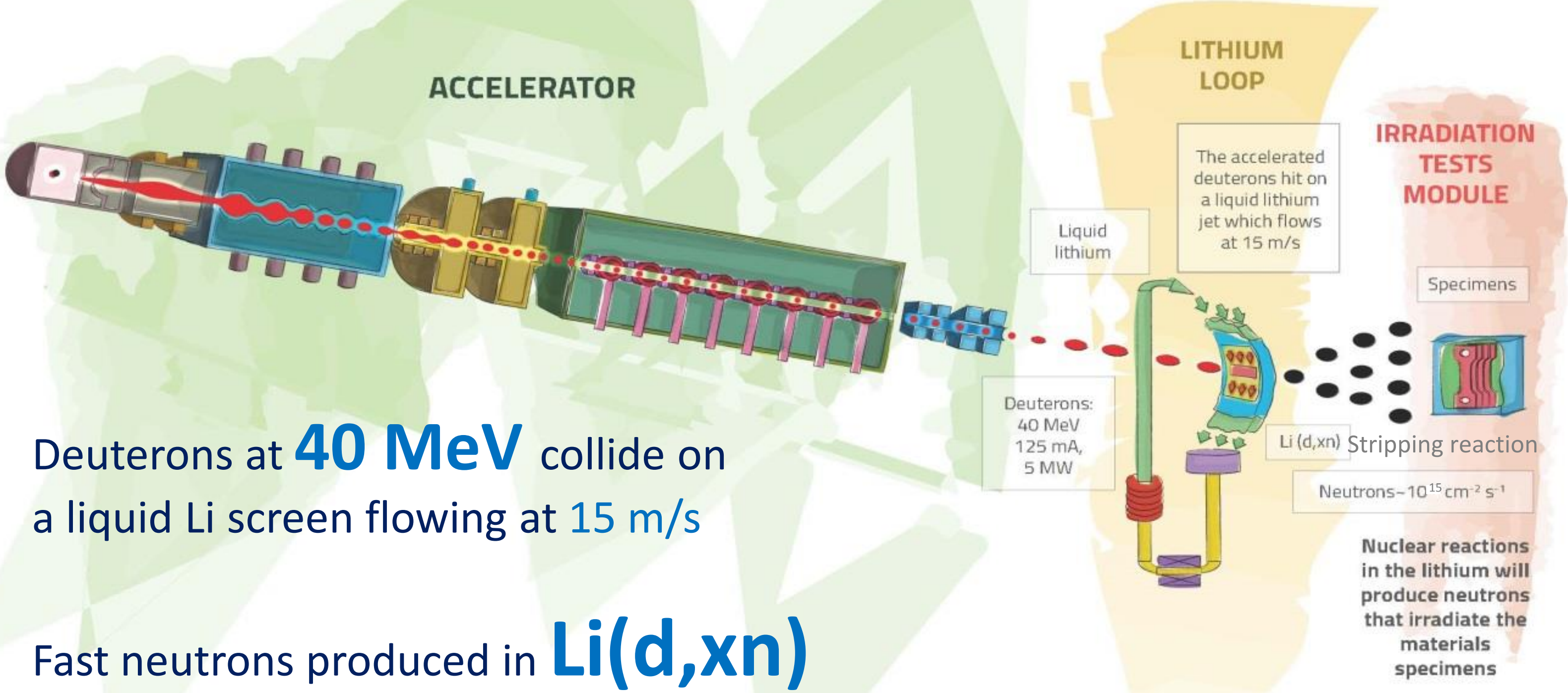
To be studied and validated: steel (EUROFER), structural material, Tungsten W, the divertor material, Cu alloys, etc.

[dpa] displacement per atom in solid

What is IFMIF-DONES?

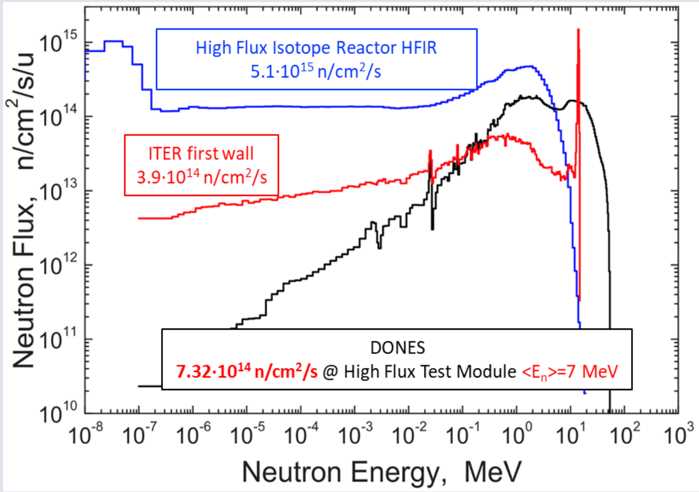
International Fusion Materials Irradiation Facility – DEMO Oriented Neutron Source

An accelerator based fusion-like neutron source to be used for the qualification of the materials to be used in the DEMO reactor and future fusion power plants



Deuterons at **40 MeV** collide on a liquid Li screen flowing at 15 m/s

Fast neutrons produced in **Li(d,xn)** stripping reactions



A neutron flux of ~10^{15} n/cm^2/s simulating D+T fusion is generated with an energy spectrum up to 55 MeV

What is IFMIF-DONES?

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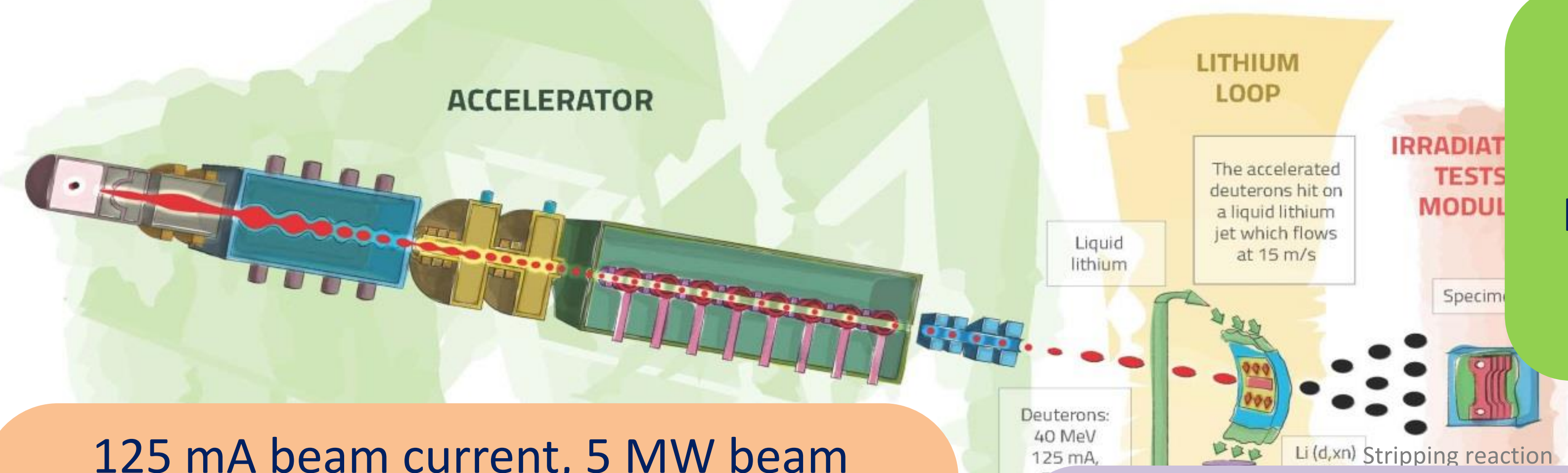
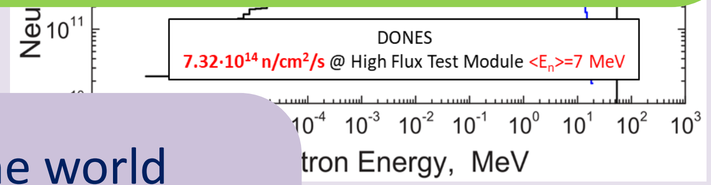




First of a kind facility

Challenges: high in-beam radiation dose, high activation inventory, need of remote maintenance, required high availability, control of the plant, …

125 mA beam current, 5 MW beam power: one of the most powerful accelerators in the world!

Challenges: high power, high space charge, continuous wave (CW) operation, high reliability, longest RFQ, …

Biggest liquid Li loop in the world

Challenges: large mass of liquid metal circulating, power management, impurities control, corrosion, reliability, lifetime, …

~10^{15} n/cm²/s
usion is generated with
um up to 55 MeV

IFMIF-DONES facility

The site is located at Escúzar
18 km from Granada, Spain

DONES Programme

DONES Construction Phase started in 2023

1st **DONES Steering Committee** held on 16 March 2023

2nd DONES Steering Committee held on 23 October 2023

DONES-SC Parties:

- *Croatia*
- *Spain*

DONES-SC Observers:

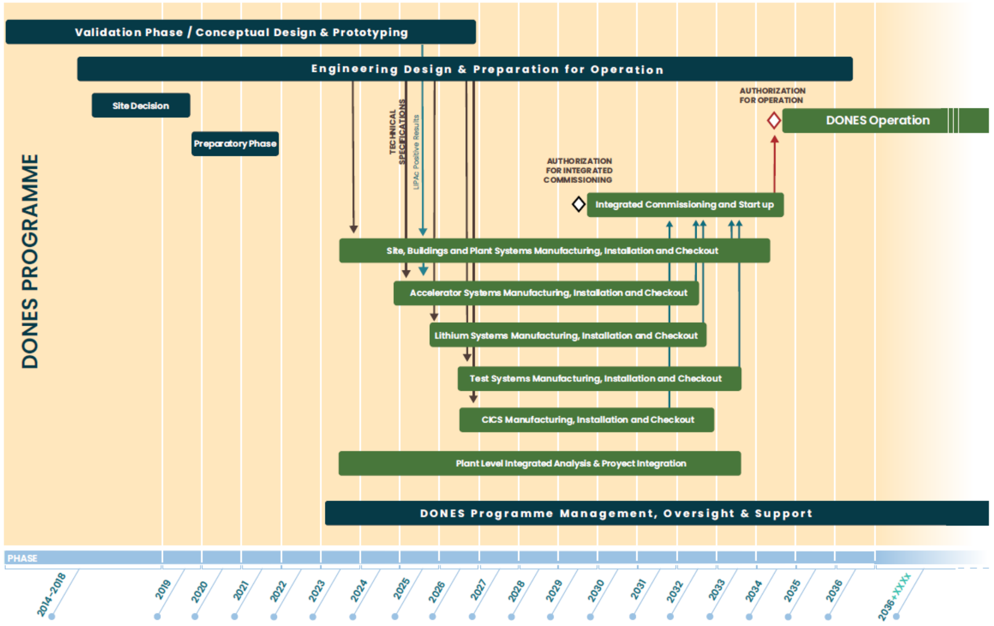
- *Austria*
- *Belgium*
- *Czech Republic*
- ***Euratom (+F4E and EUROfusion)***
- *Finland*
- *France*
- *Germany*
- *Hungary*
- *Italy*
- ***Japan***
- *Latvia*
- *Lithuania*
- *Romania*
- *Slovakia*
- *Slovenia*
- *Ukraine*

Cost sharing status

Construction planned for 2023-2032
Installation, commissioning and start-up 2029-2034
Full power operation from 2034

Total projected cost 700 M€
(plus possible extensions)

Agreed (or close to agreement) financing packages:



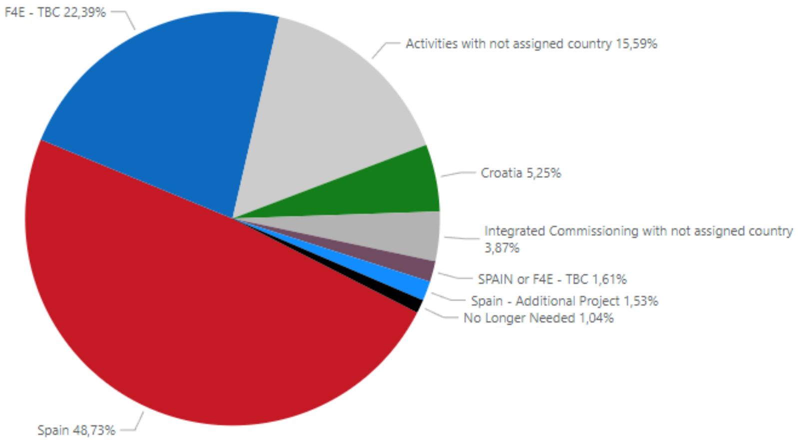
Sharing Status (November 2023)

Agreed:
- Spain 55%
- Croatia 5%

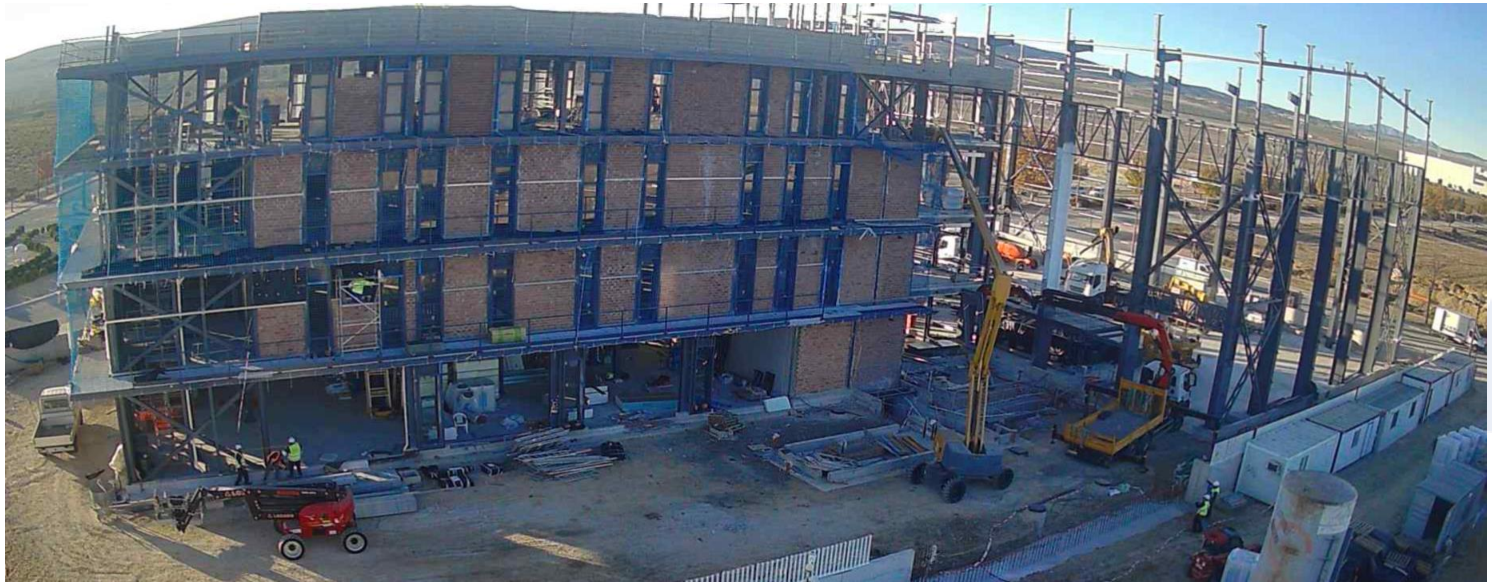
Advanced discussions: *Fusion for Energy (F4E) 20-25%*

Technical discussions:
- Japan, Italy, Germany, Slovenia

Exploratory activities:
- US, some private companies



Construction of the first auxilliary buildings



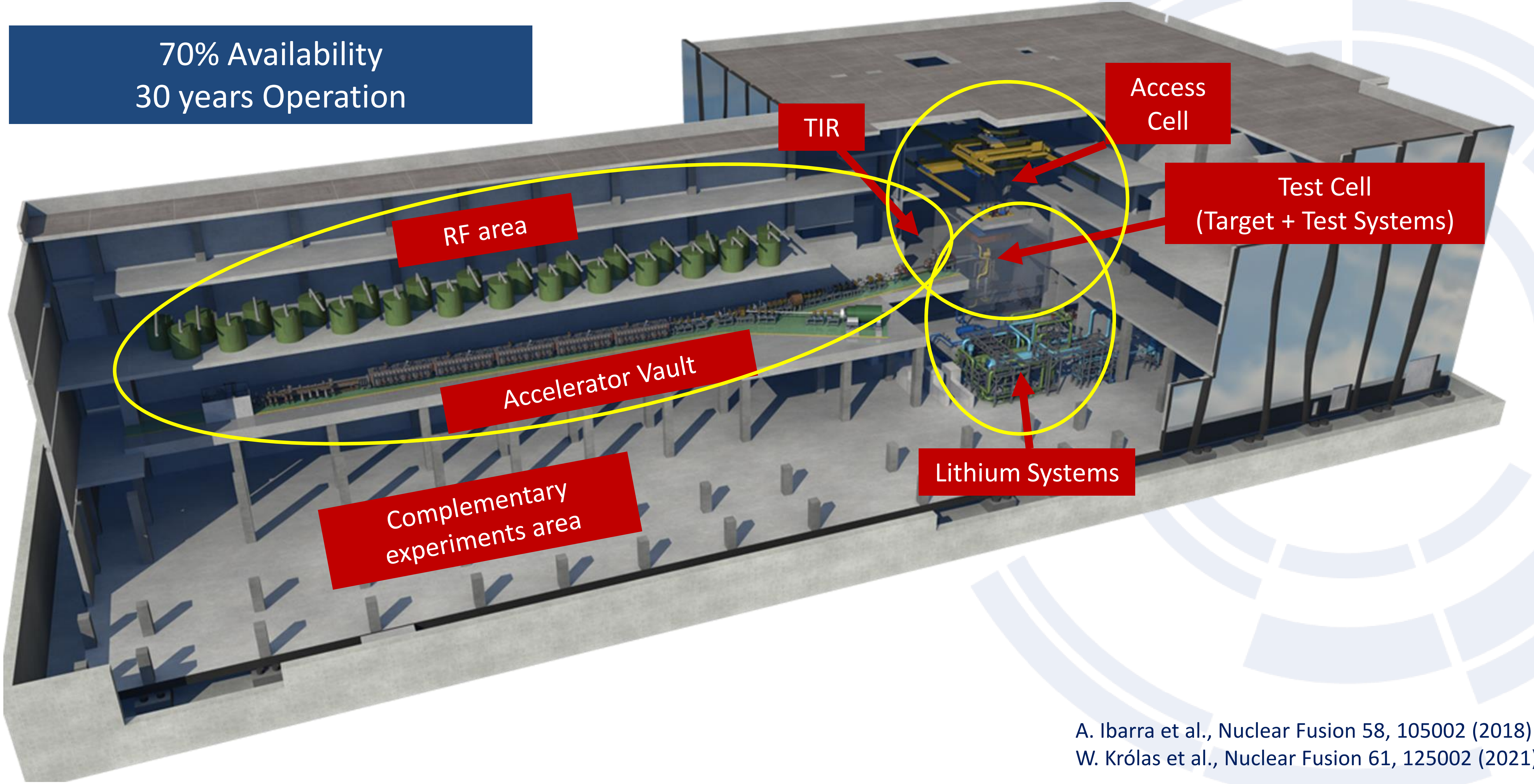
A number of relevant prototypes and facilities:

- MuVaCaS facility,
- STUMM module,
- QDS prototype,

have been ordered / have arrived / are under construction and will be used for testing and validation of the design!

IFMIF-DONES principal systems

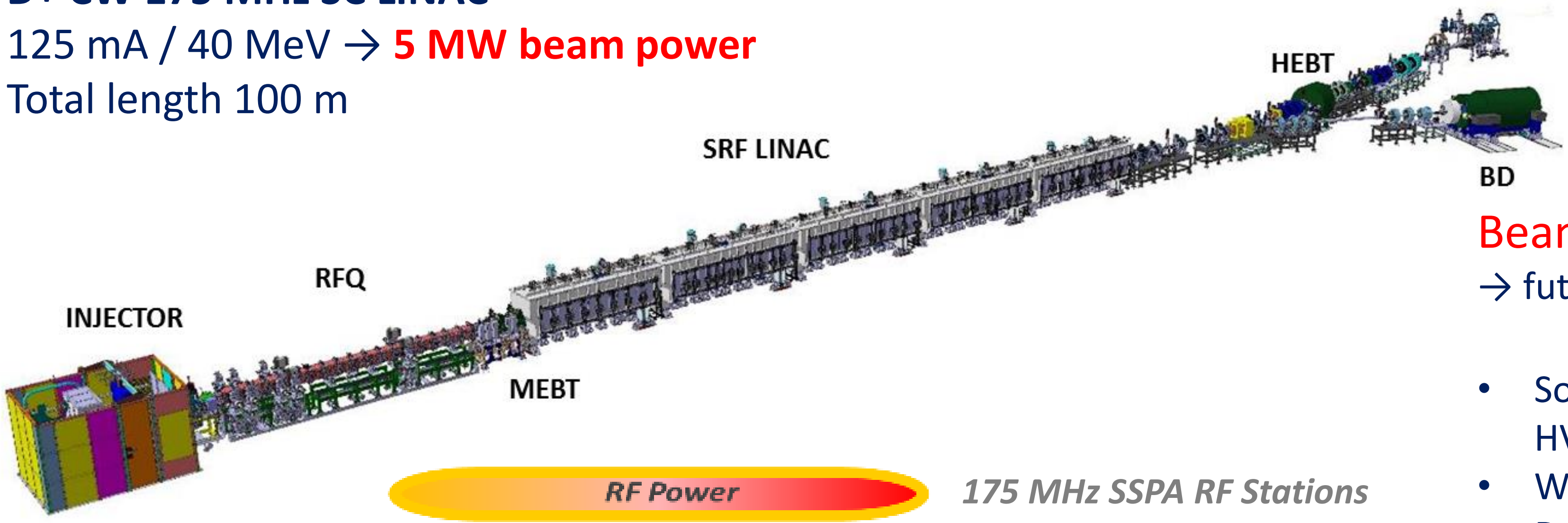
70% Availability
30 years Operation

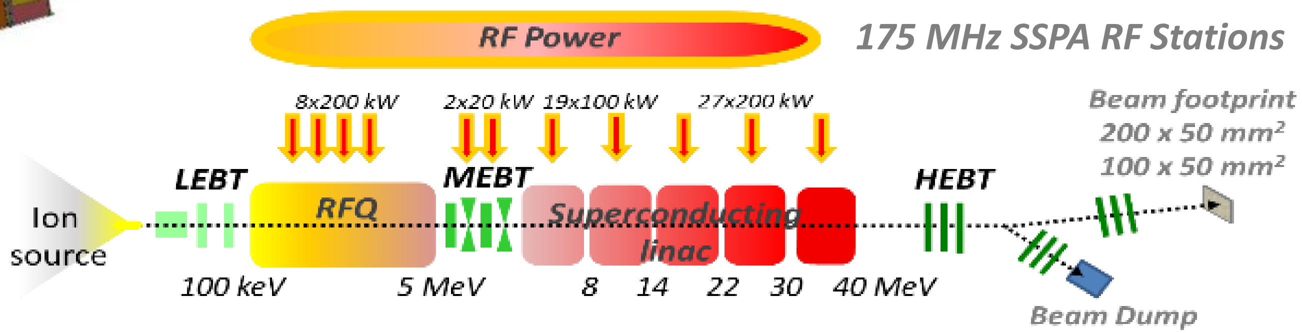


A. Ibarra et al., Nuclear Fusion 58, 105002 (2018)
W. Królas et al., Nuclear Fusion 61, 125002 (2021)

IFMIF-DONES Accelerator: Deutrons up to 40 MeV

D+ CW 175 MHz SC LINAC
125 mA / 40 MeV → **5 MW beam power**
Total length 100 m





Accelerator design based on a prototype built in Rokkasho, Japan

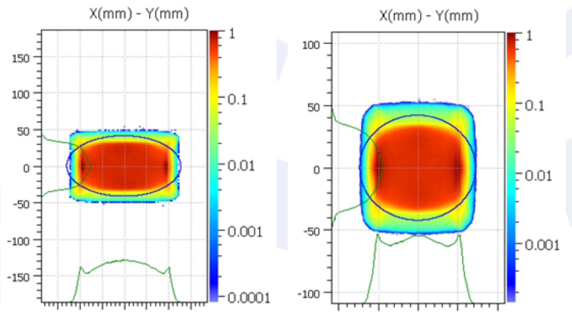
Designed for:

- 30 years operation
- 87% availability

Beam incident on target at 9°
→ future upgrade to two accelerators

- Solid State (SS) technology for the HVPS in the RF source
- Windowless liquid **Li target**
- Demonstrated feasibility of different beam sizes/shapes

Beam footprint @ target

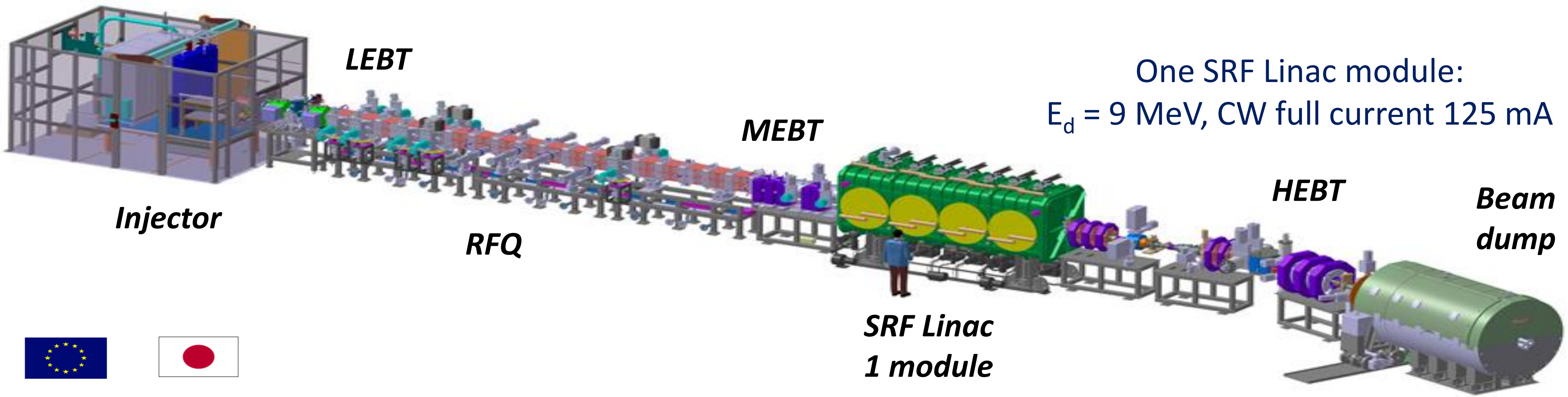


20x5 cm² footprint (reference)

10x5 cm² footprint (optional)

IFMIF/EVEDA – LIPAc accelerator

Courtesy of IFMIF/EVEDA Broader Approach activities

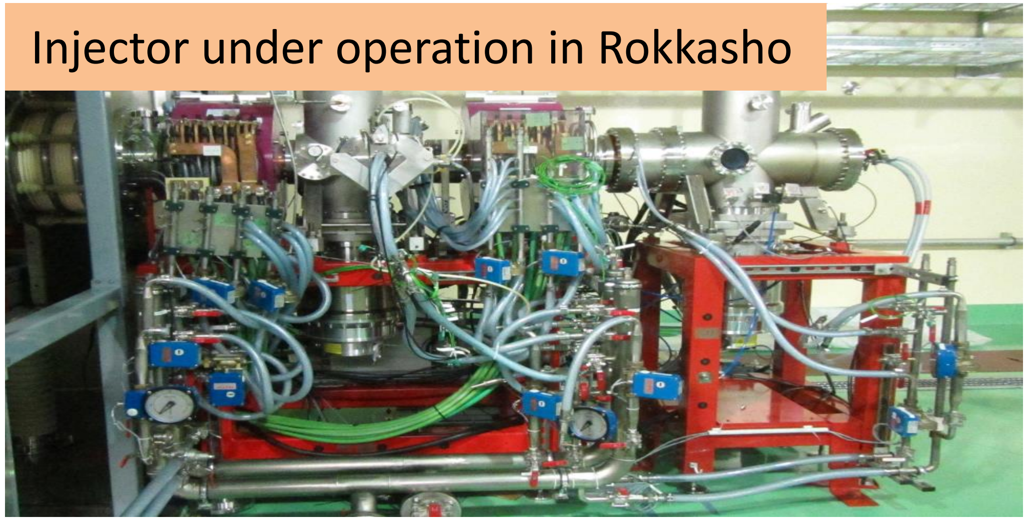


One SRF Linac module:
E_d = 9 MeV, CW full current 125 mA

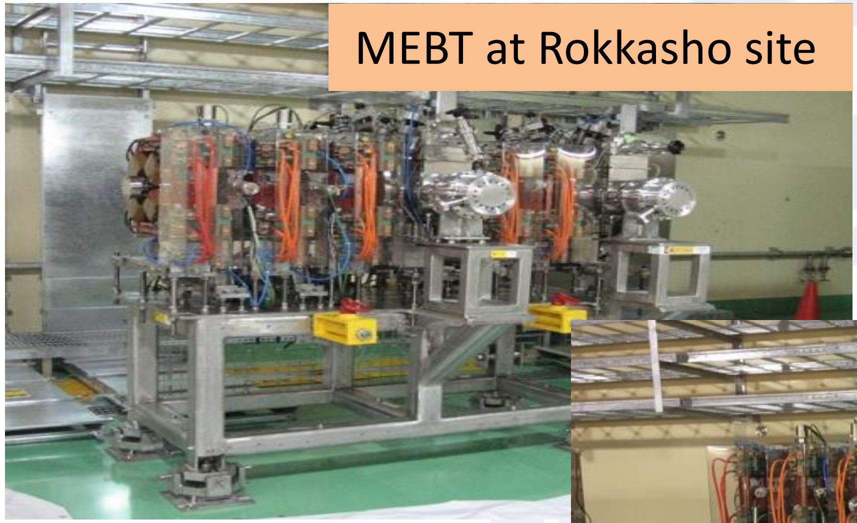
For the main part designed and manufactured in Europe, installed and commissioned in Rokkasho, Japan as part of the Broader Approach agreement between the EU and Japan

IFMIF/EVEDA – LIPAc accelerator

Courtesy of IFMIF/EVEDA
Fusion for Energy (F4E)
Broader Approach



Injector under operation in Rokkasho



MEBT at Rokkasho site

Diagnostics Plate

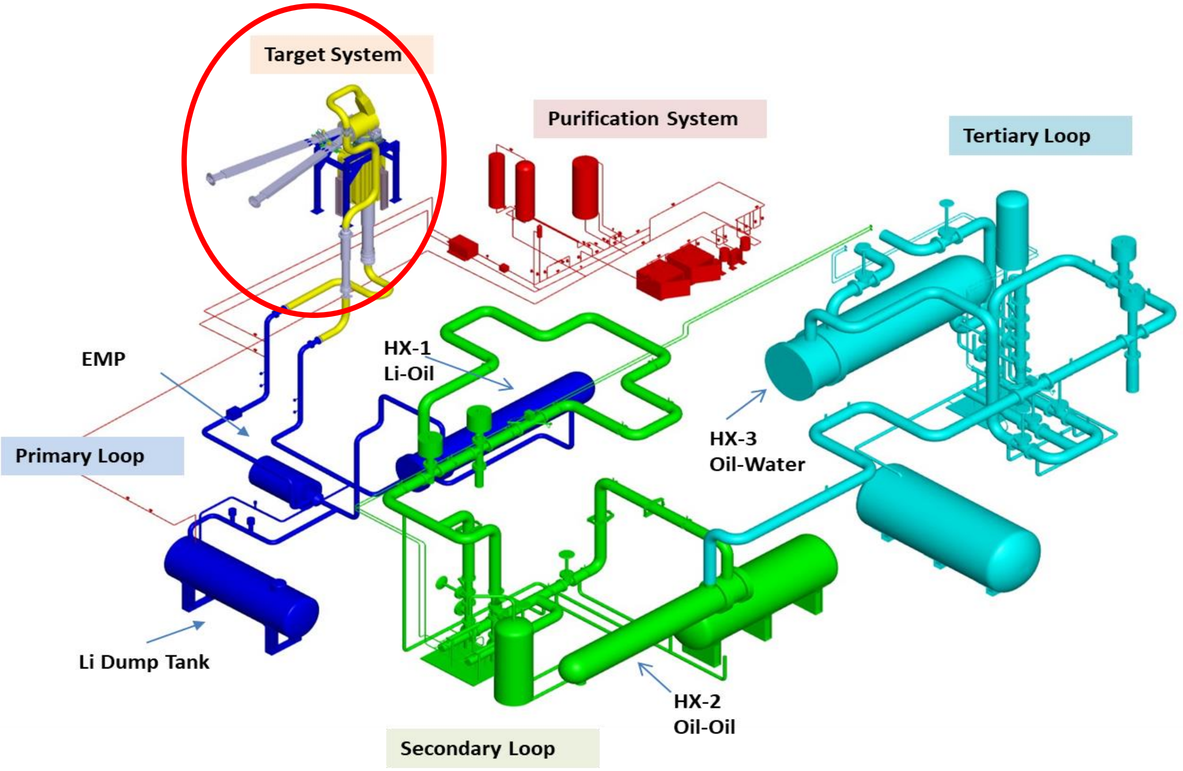
Important milestone 2023:
125 mA of D+ in pulsed mode transmitted by the RFQ with very high efficiency

RFQ under commissioning

Part of the RF system under operation at Rokkasho

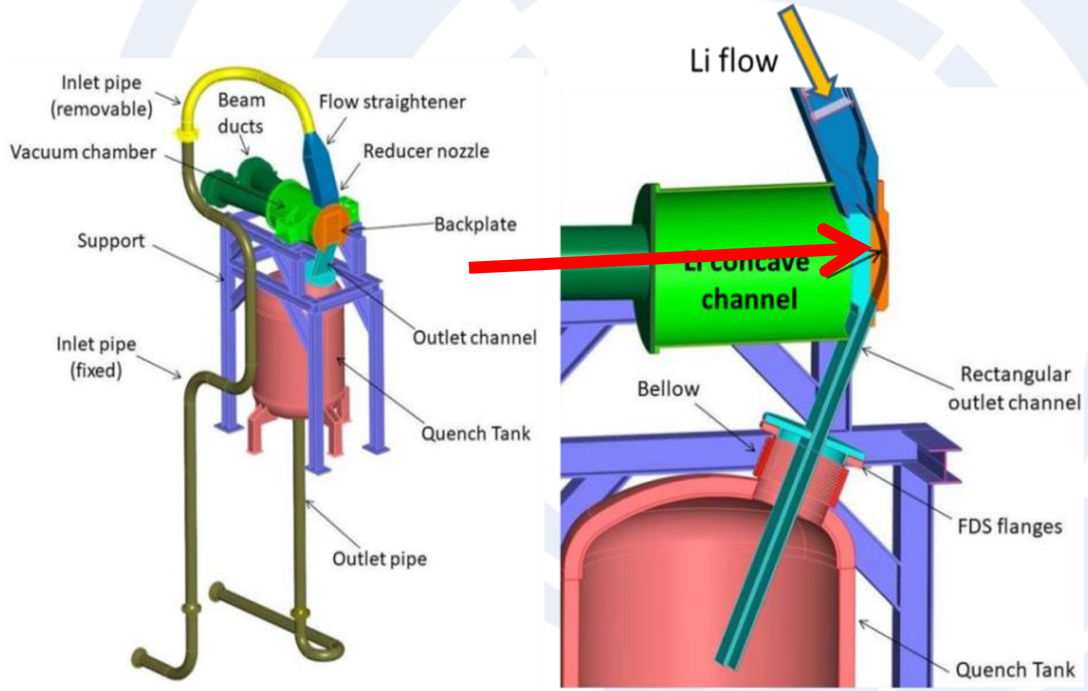
IFMIF-DONES Lithium loop and target

5 MW power handling, 15 m/s Li velocity, Remote Handling
Main requirements: stable Li flow and Li impurities control – corrosion and reaction products



Design parameters:
Li volume ~14 m^3 Mass ~ 8 tons Li flow rate ~100 l/s
Li temperature (cold side) ~300 °C

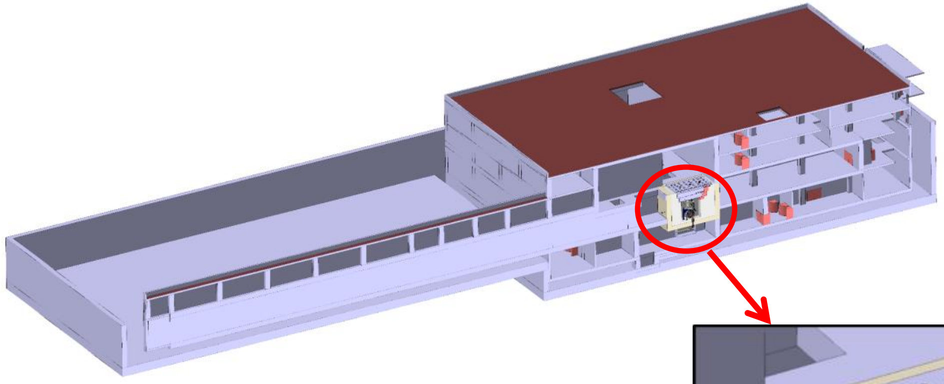
Lithium target

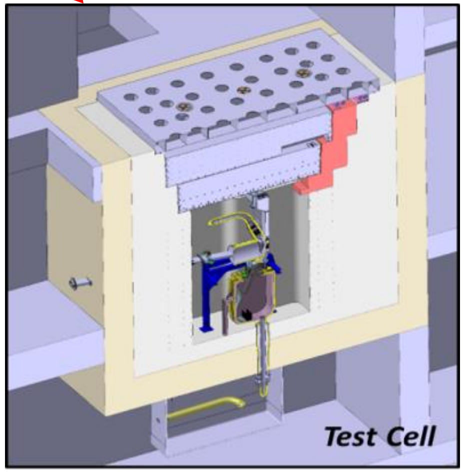


Jet thickness: 25±1 mm Li flow velocity: 15 m/s
Chamber pressure: 10^{-3} Pa Heat flux: 500 MW/m^2

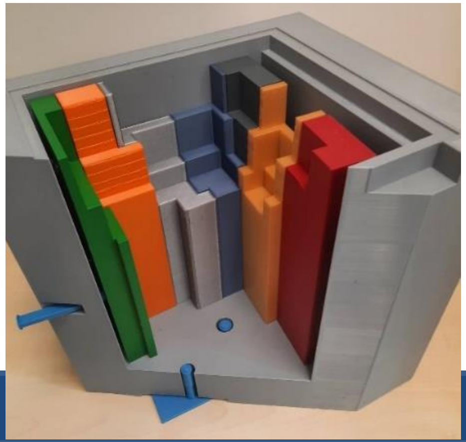
D. Bernardi et al., J. Fusion Energy 2022

IFMIF-DONES Test (irradiation) systems



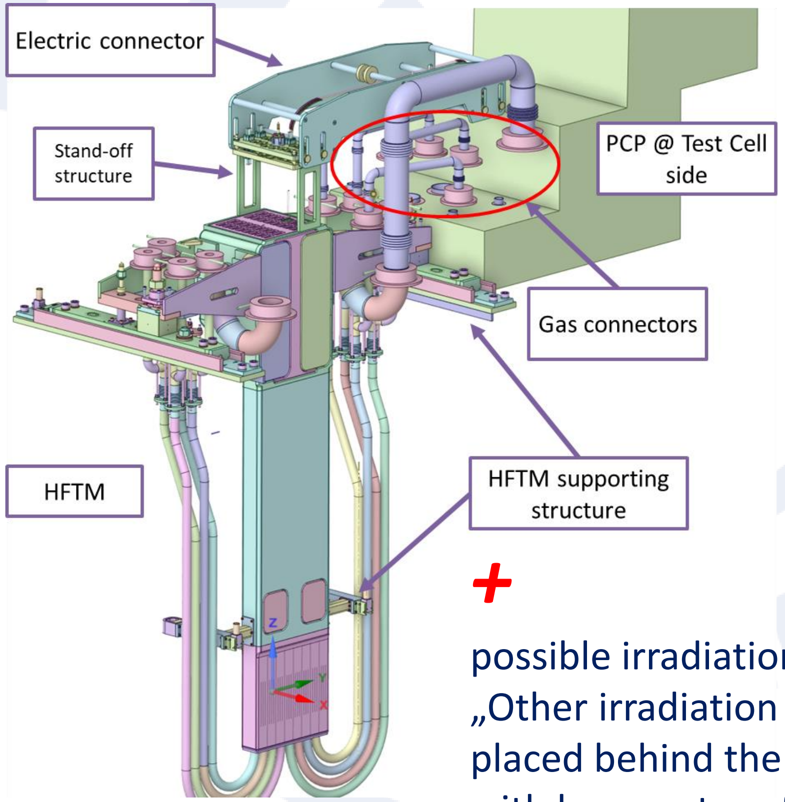


Test Cell (irradiation cell)
with shielding composed of cooled and removable concrete blocks shaped for maintainability and to minimize neutronstreaming



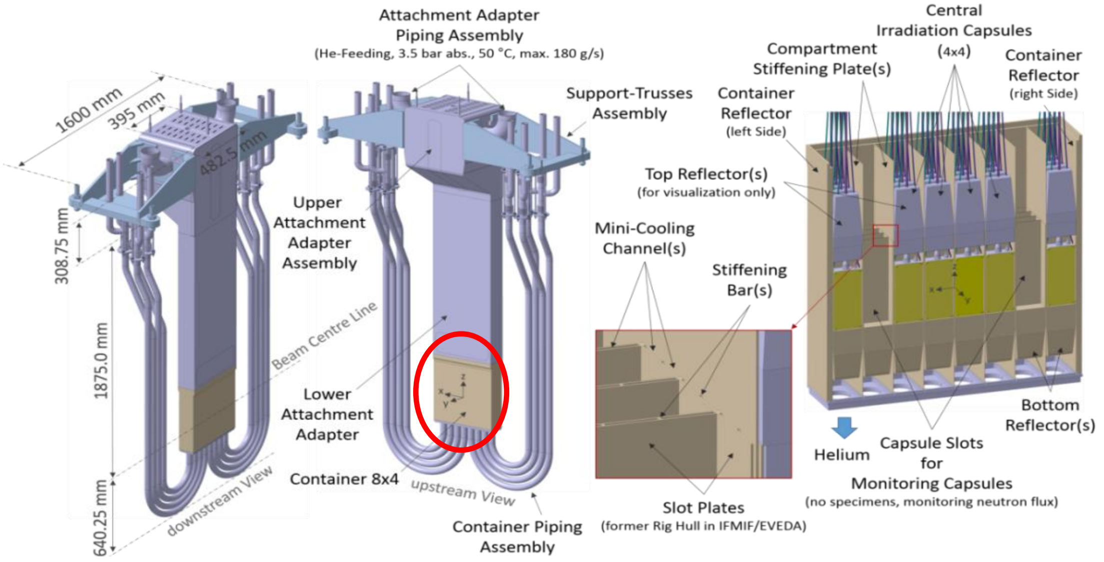
High-flux Test Module (HFTM)

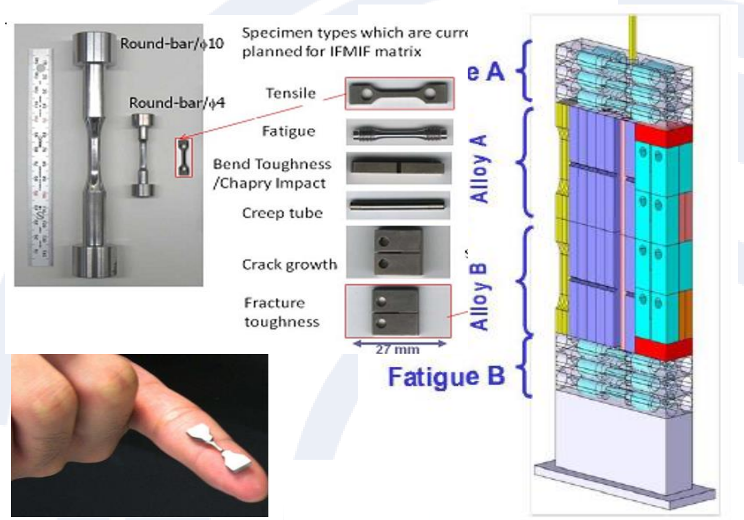
HFTM Irradiation dose:
20 dpa/fpy in 130 cm^3 or 10 dpa/fpy in 400 cm^3
Controlled Temperature: 250 < T < 550 ºC



+
possible irradiation of „Other irradiation modules", placed behind the HFTM, with less neutron flux

High-flux Test Module (HFTM)





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

- Active volume 0.5 l with damage rate higher than 10 dpa/fpy (with 200 x 50 mm^2 beam footprint)
- Heaters for temperature control of the specimens in the Irradiation Capsules (250, 350, 450, 550 °C)
- Mini cooling channels filled with circulating Helium
- Neutron reflectors around the specimens
- Monitoring of the field gradient

Housing over 850 specimens in controlled irradiation and temperature conditions!

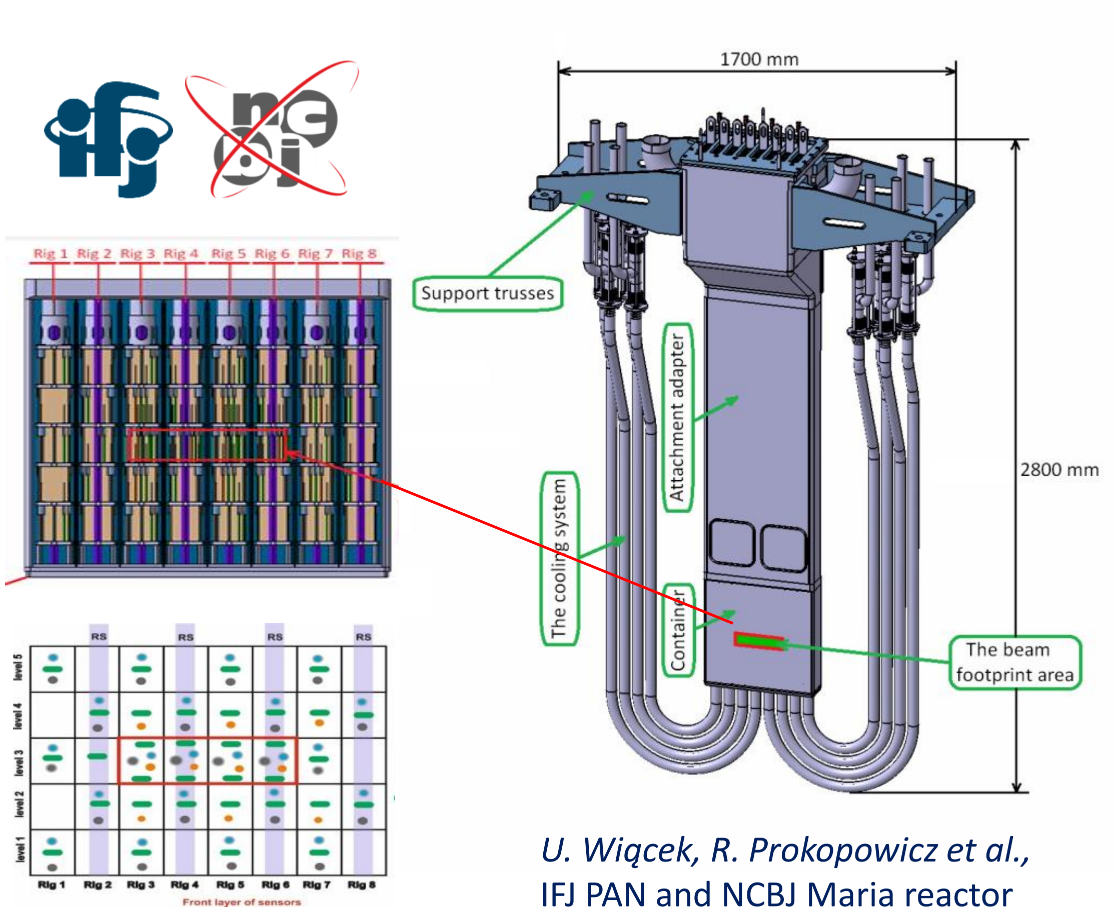
Small Sample Test Techniques

SSTT will be used for the samples irradiated in the HFTM for testing of radiation induced degradation of basic physical properties of materials

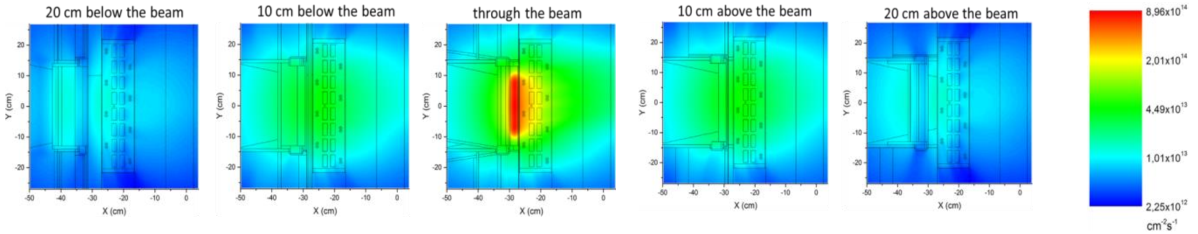
Main materials of interest (structural):

steel (EUROFER), other structural materials, Tungsten W, the divertor material, Cu alloys, etc.

Start-up and monitoring module (STUMM)



U. Wiącek, R. Prokopowicz et al.,
IFJ PAN and NCBJ Maria reactor



To be used at commissioning and before starting each irradiation campaing for the characterization of the radiation field, gradient and validation of the neutronics (radiation transport modelling)

- Rabbit system for activation (RS) x8, 1 per rig, sensitive to thermal, epithermal and fast neutrons
- Micro fission chambers MFC U238, for fast neutrons
- Micro fission chambers MFC U235 or SPND, for thermal and epithermal neutrons
- Gamma thermometers
- Thermocouples

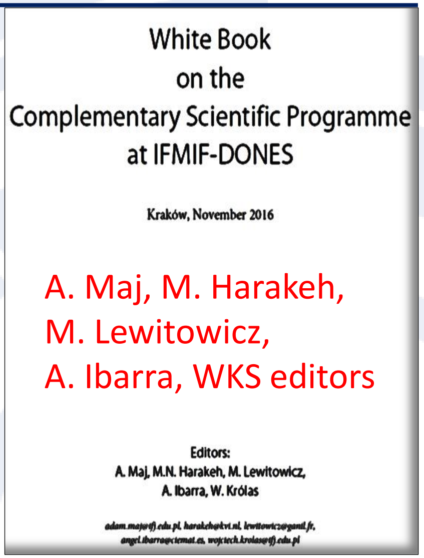
As output:
Complete characterization of the radiation field in the irradiation volume:

- neutron and gamma flux,
- neutron and gamma spectrum

STUMM prototype ordered by University of Granada, to be delivered and studied this year

Complementary experiments at DONES

- Background: the idea of using DONES for multidisciplinaty neutron science (apart from fusion material irradiation) has been proposed in 2015 when Poland was considered as a possible site of DONES
- Various scientific areas were considered: medical applications, basic physics studies, nuclear physics and industrial application of neutrons
- A White Book report on „IFMIF-DONES for isotope production, nuclear physics applications, materials science and other research topics” was prepared following two scientific workshops held in Kraków and Rzeszów
  https://www.ifj.edu.pl/badania/publikacje/raporty/2016/2094.pdf


White Book
on the
Complementary Scientific Programme
at IFMIF-DONES

Kraków, November 2016

Editors:
A. Maj, M.N. Harakeh, M. Lewitowicz,
A. Ibarra, W. Królas

A. Maj, M. Harakeh,
M. Lewitowicz,
A. Ibarra, WKS editors

DONES part of the ESFRI 2018 and 2021 roadmap

European Strategy Forum on Research Infrastructures

(…) IFMIF-DONES will play a strategic role in the Energy domain for the implementations of Nuclear fusion solutions to the massive production of energy (…)

- DONES Preparatory Phase 2 year Euratom grant 2019-2021
- DONES Consolidation Phase 2 year Euratom grant 2023-2025

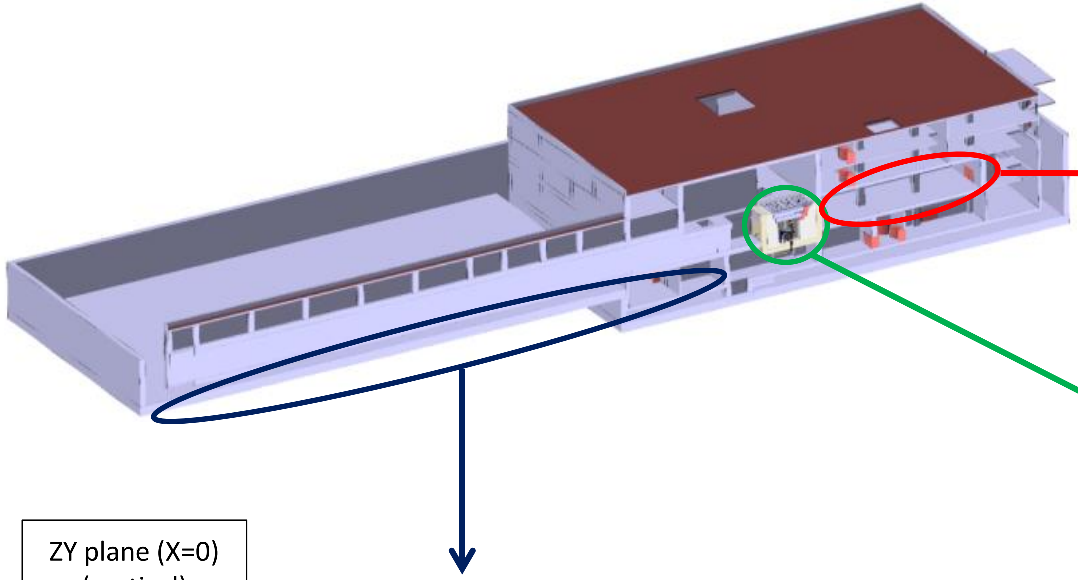
These two projects provided/ provide financing among other topics, also for the

- extensive studies and *conceptual design of complementary experiments* at DONES
- as well as the build-up of the *DONES Users Community*

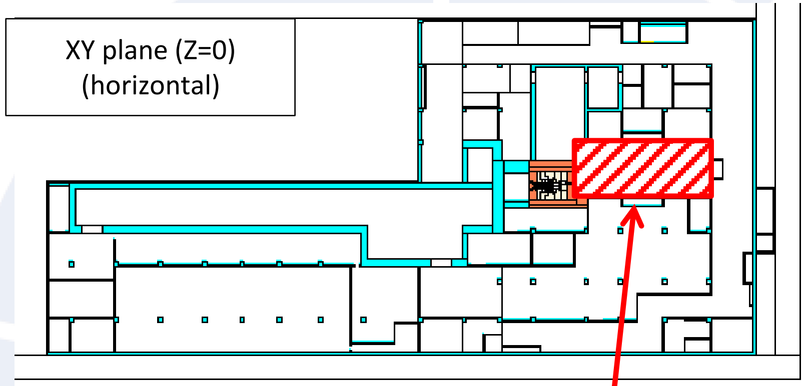
DONES ConP1

2. Outreach, development & engagement of scientific and engineering user community (IFJ PAN)
   Task 2.2 Non-Fusion Users (coord. A. Maj)
   Task 2.3 IFMIF-DONES Users Community (coord. WKS)

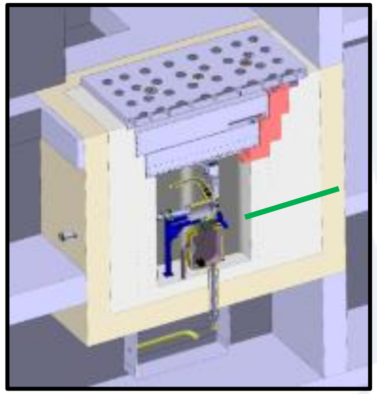
IFMIF-DONES facilities for complementary experiments



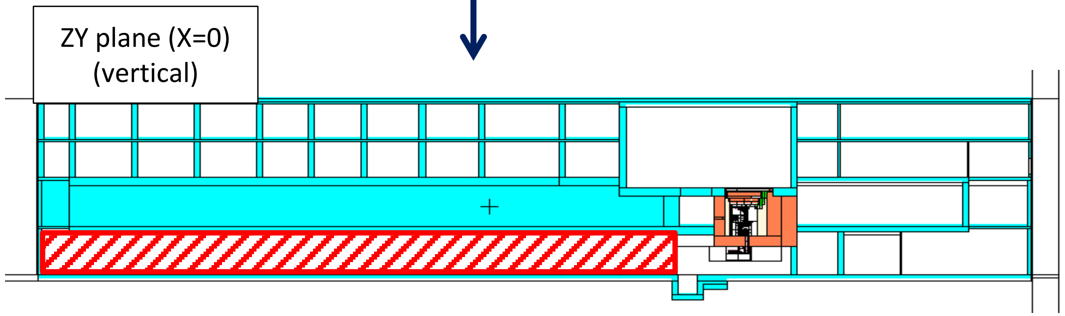
Collimated neutron beam facility – behind the Test Cell



DONES Test Cell

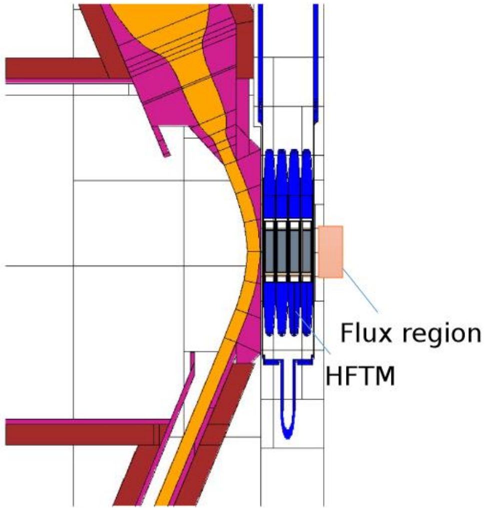


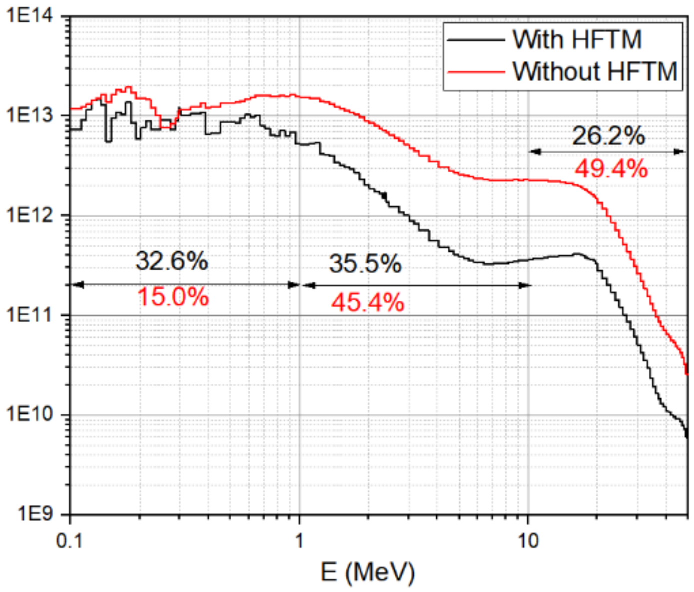
Experiments with continuous neutron beams
Compl. Exp. Hall R160



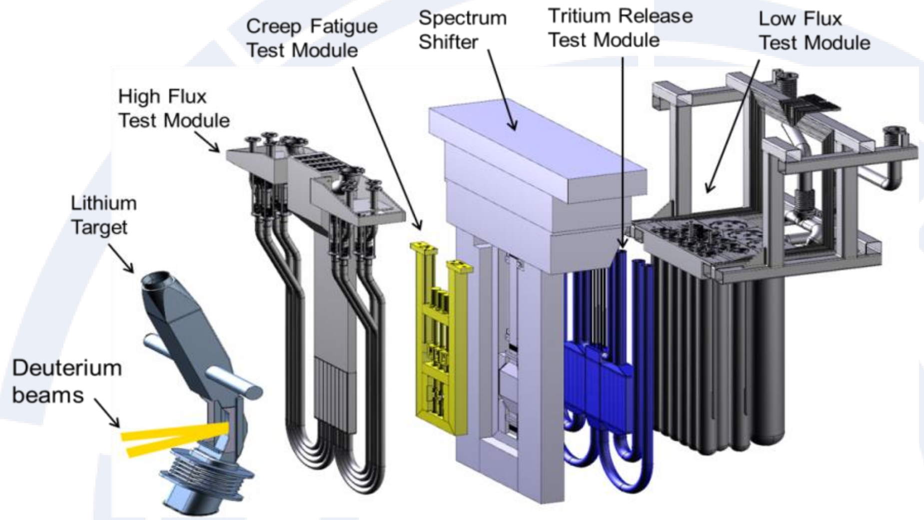
Experiments with deuteron beam and pulsed neutrons
(one level below the accelerator, R026)

Experiments with neutrons in the Test Cell





Courtesy of Y. Qiu



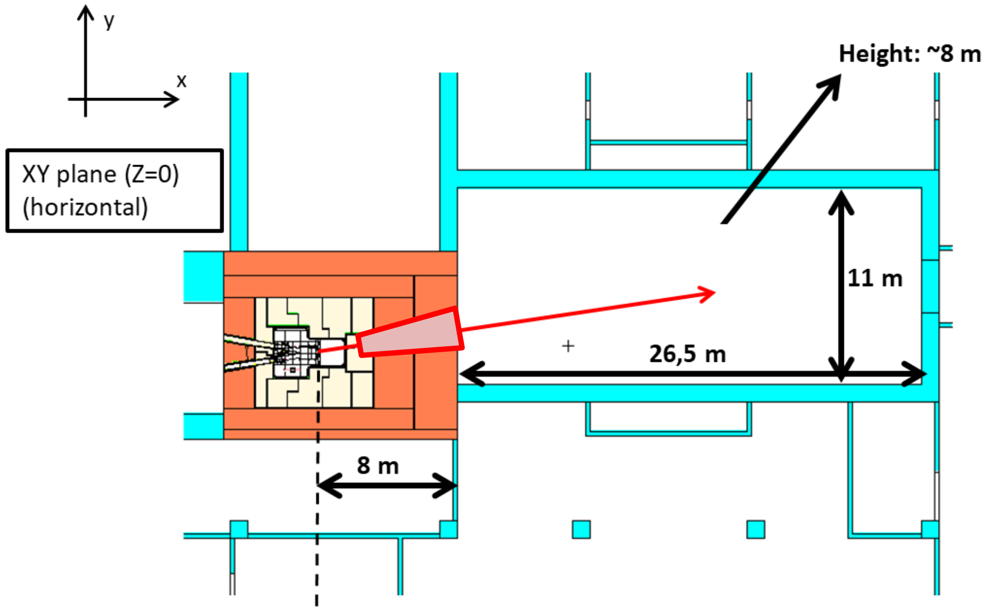
A high neutron flux in the TC behind the HFTM with somewhat moderated energy spectrum

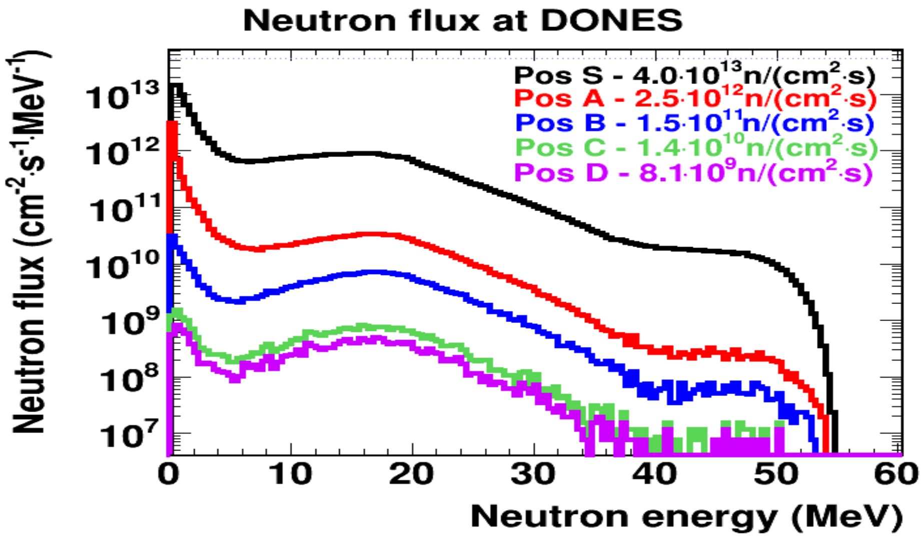
- ✓ Possible „Other irradiation modules" behind the HFTM e.g. radionuclides production, tritium release module
- ✓ Neutron beam line to the adjacent experimental area

Fusion community is engaged in the design of the Tritium Release Test Module to test segments of Tritium breeding blankets

Also, possible implementarion of a Radioactive isotope production module has been studied, using as a target liquid material circulating into and out of the Test Cell

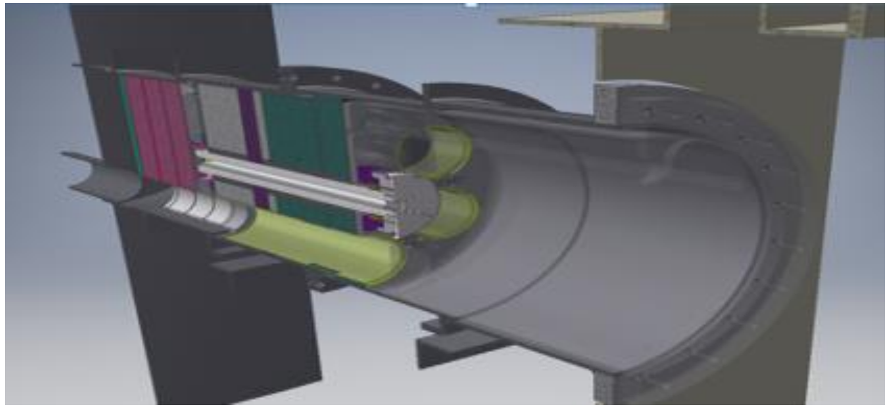
Collimated neutron beam experimental area

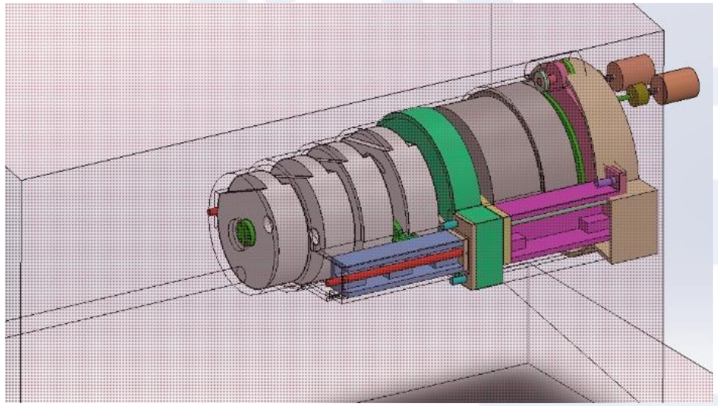




High-flux ~2. 10^{10} n $cm^{-2}s^{-1}$ covering a large energy range, collimated beam (~ 98% of the neutrons with $\theta < 1^\circ$)

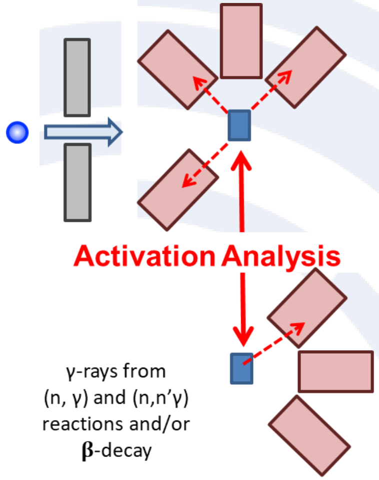
A neutron transport line with shutter are being designed to operate this experimental area independently of the Test Cell irradiation





Potential experiments with collimated neutron beams

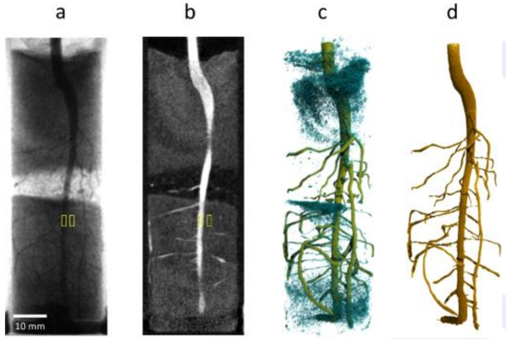
- **Nuclear physics studies with moderated and unmoderated neutrons**
  - Analysis of neutron-rich isotopes production by neutron induced fission
    → fast-neutron-induced fission: different fragment distributions!
  - Spectroscopy of very exotic and short lived nuclei
  - Maxwellian-averaged capture cross-section for some stellar nuclear reactions studied by activation techniques with neutrons

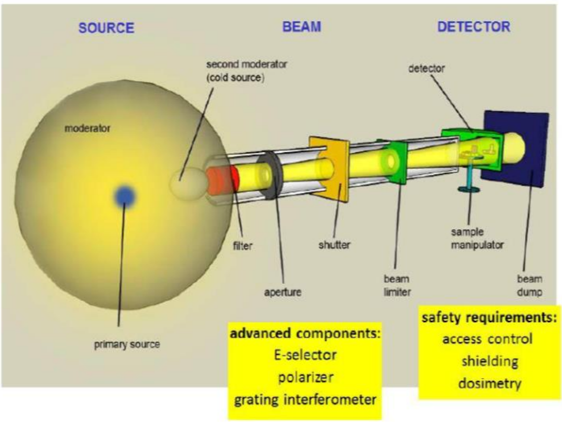


- **Others**
  - Neutron scattering with moderated neutron beams (biological matter)
  - Characterization of materials by radiation analysis (for medicine, chemistry, biology, forensics, …)
  - Imaging techniques with neutrons - neutron radiography
  - Radioisotope production for medical applications (e.g. ^{99}Mo)
  - Fast neutron irradiation of components, devices or bio-samples
  - Materials doping

- IFMIF-DONES has higher neutron flux than other facilities but no selectivity of neutron energy

- A high flux for radioisotope production by (n,x) reaction

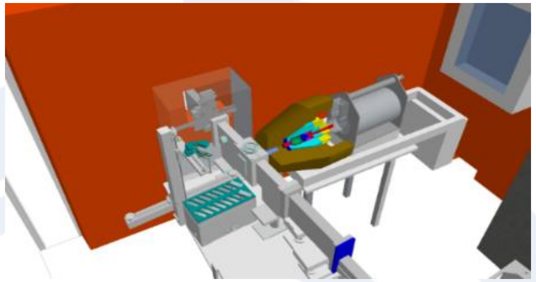




Neutron scattering and neutron activation analysis

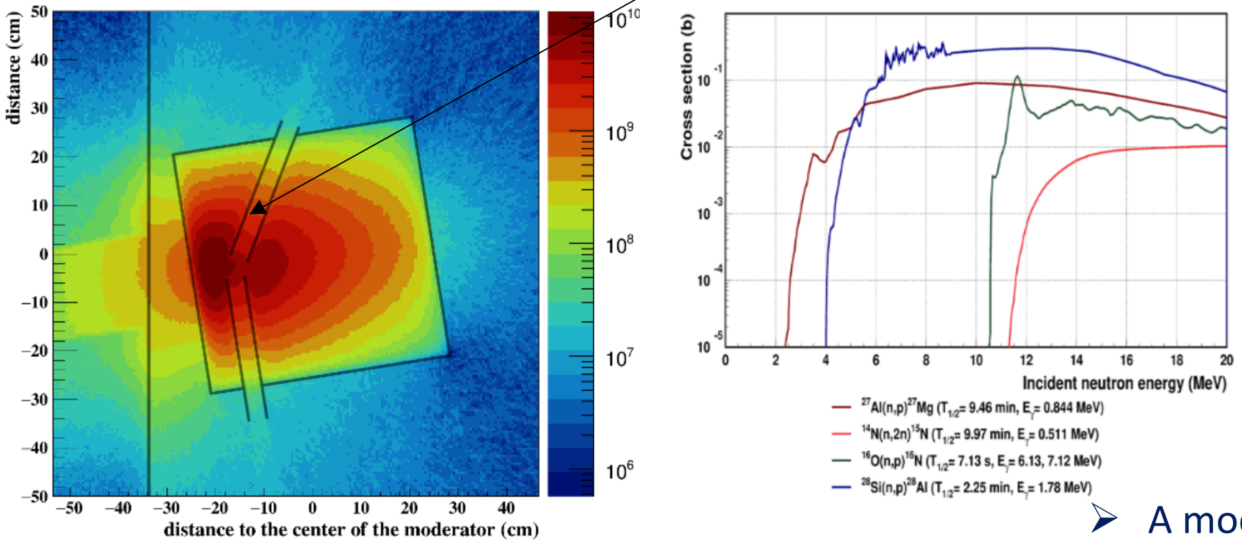
- Non-destructive method to determine the elemental composition of materials
  - with thermal Neutrons (NAA and Prompt Gamma AA)
  - with Fast Neutrons (FNAA and PGAA)

- Neutron flux is a key parameter:
  - ~10^{12-14} n/cm^2/s for NAA ; ~10^8 n/cm^2/s for PGAA,
  - ~10^8 n/cm^2/s for FNAA



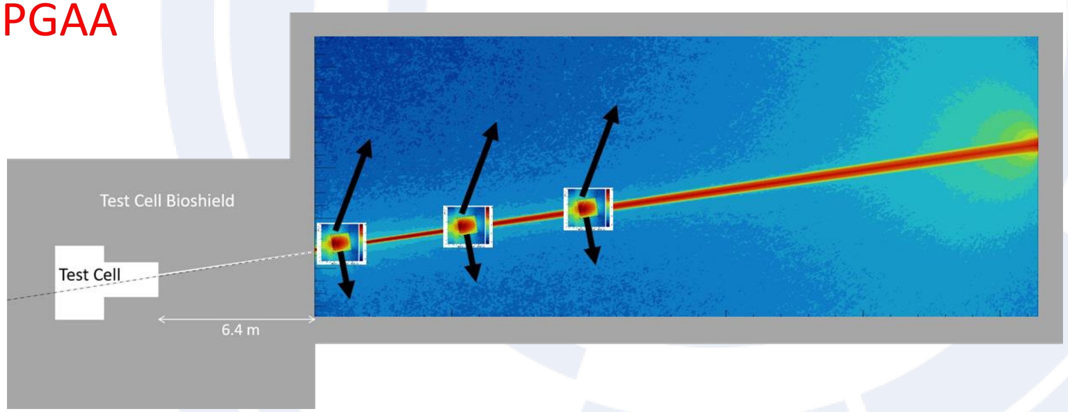
PGAA station @Budapest Neutron Center

Irradiated sample to be analyzed



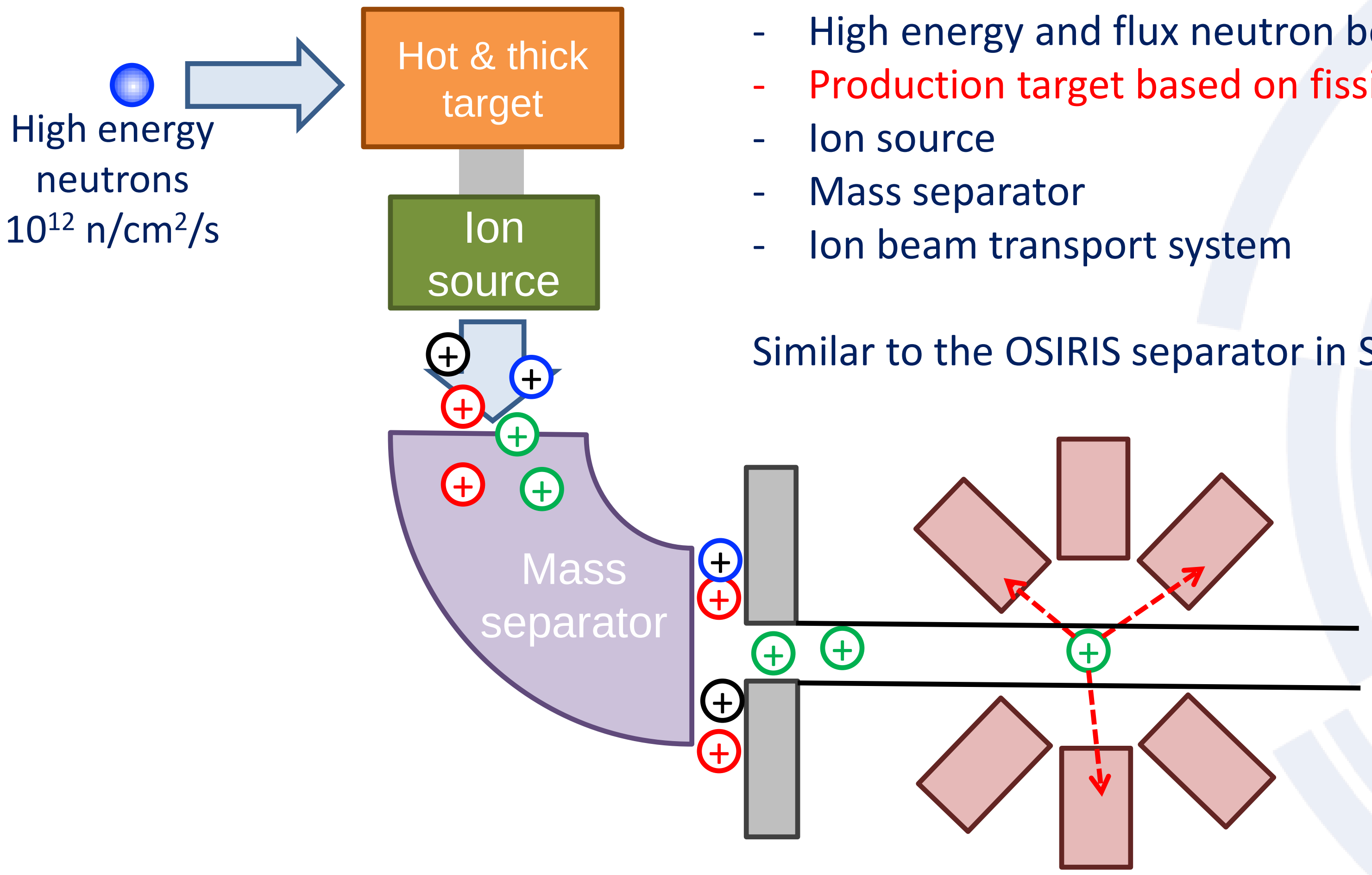
Fast Neutron Activation Analysis

IFMIF-DONES has the advantage to provide both thermal and fast neutrons and is competitive for FNAA and PGAA



- A moderator block installed at the neutron transport line from the Test Cell
- At the exit of the tubes, the thermal neutron flux is ~ 10^7 n/cm^2/s below 400 meV but with a large fast neutron contamination
- The space available offers the possibility to put moderators in cascade

DOMISOL: DONES Magnetic Isotope Separation On Line

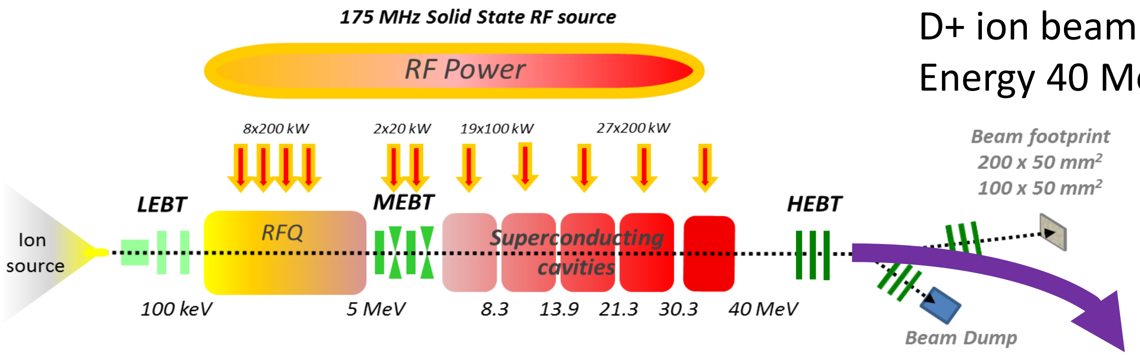


- High energy and flux neutron beam
- Production target based on fission reactions
- Ion source
- Mass separator
- Ion beam transport system

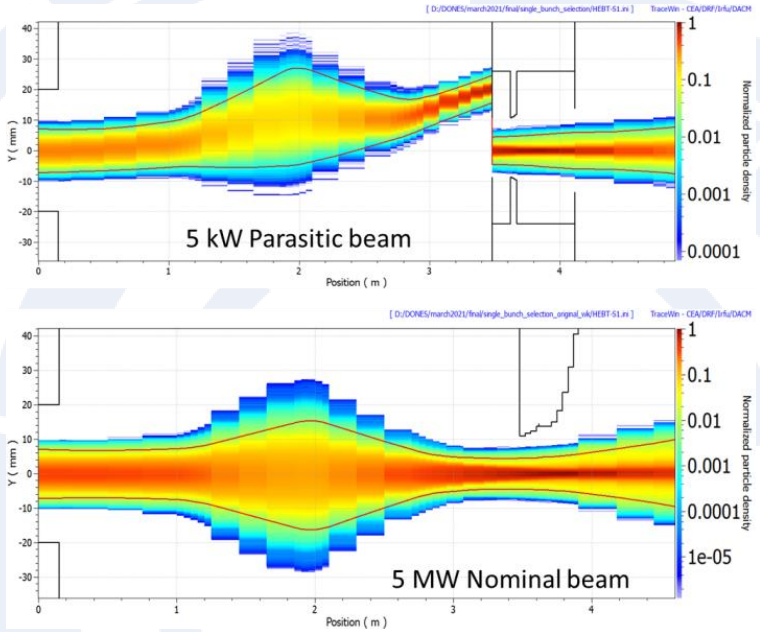
Similar to the OSIRIS separator in Studsvik

Short transport time allowing for spectroscopy of very exotic and short lived nuclei

Complementary experiments with deuterons

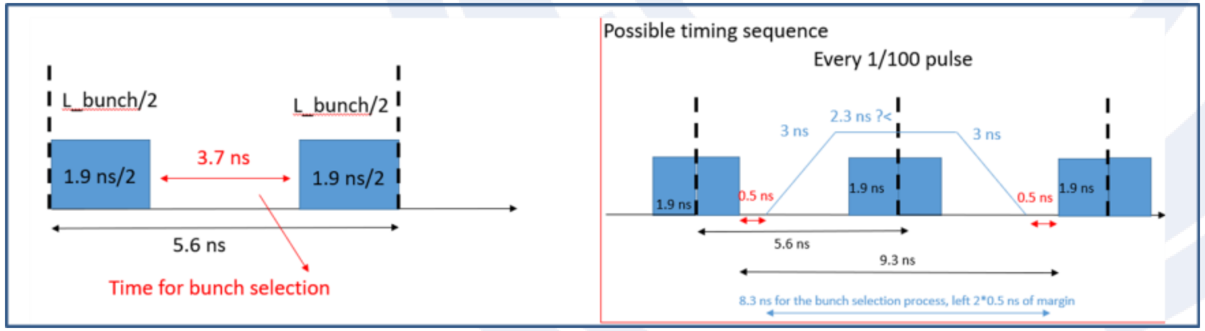


D+ ion beam 125 mA,
Energy 40 MeV



Planned extraction of a fraction (~0.1%) of the beam at 40 MeV:

- ✓ Extraction in the high-energy beam transport line
- ✓ A configuration of a meander line of 3.5 m + electrostatic septum + septum magnet is proposed
- ✓ Timing conditions:
  a beam bunch length of 1.9 ns,
  separation between bunches of 3.7 ns
- ✓ Other option: a slow extraction,
  more flexible, also being studied



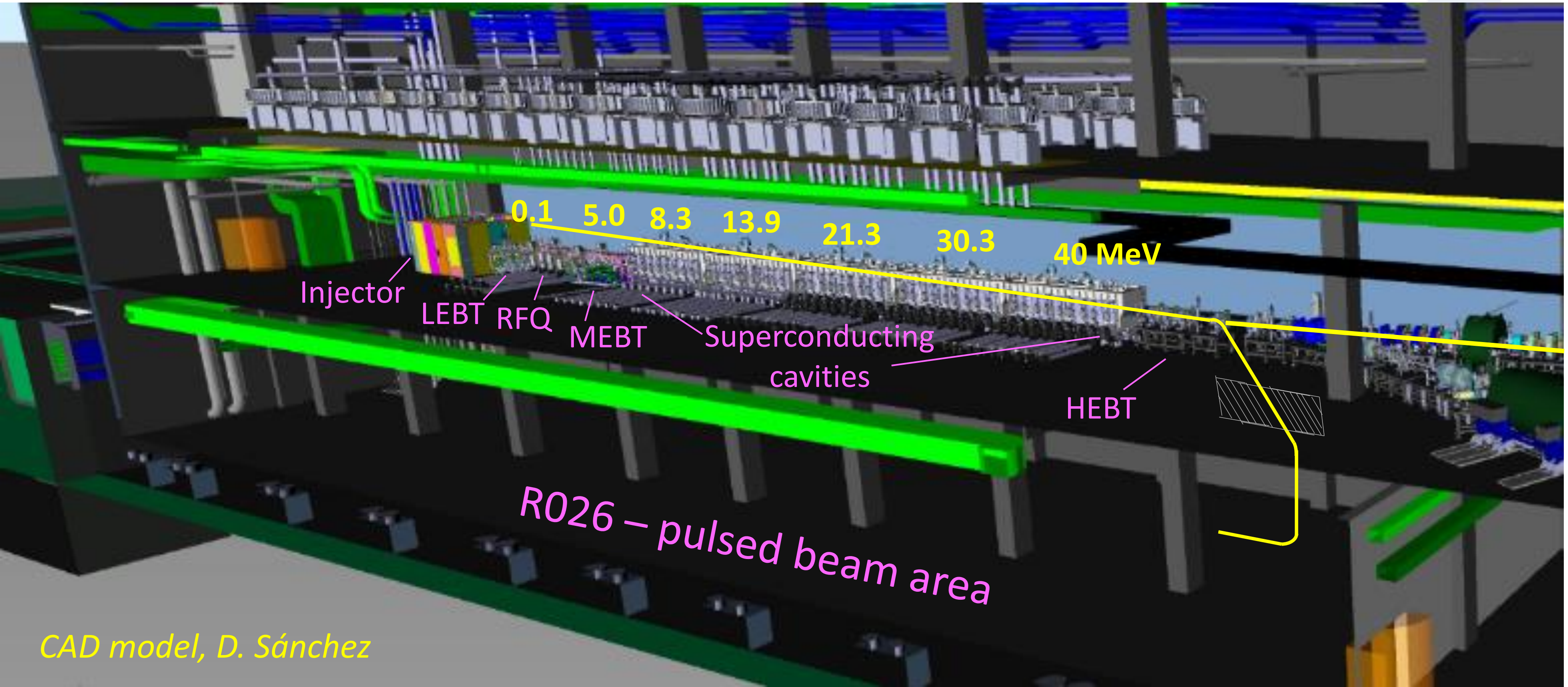
L. Bellan, M. Comunian, A. Pisent, I. Podadera

D+ Beam extraction mode – single bunch

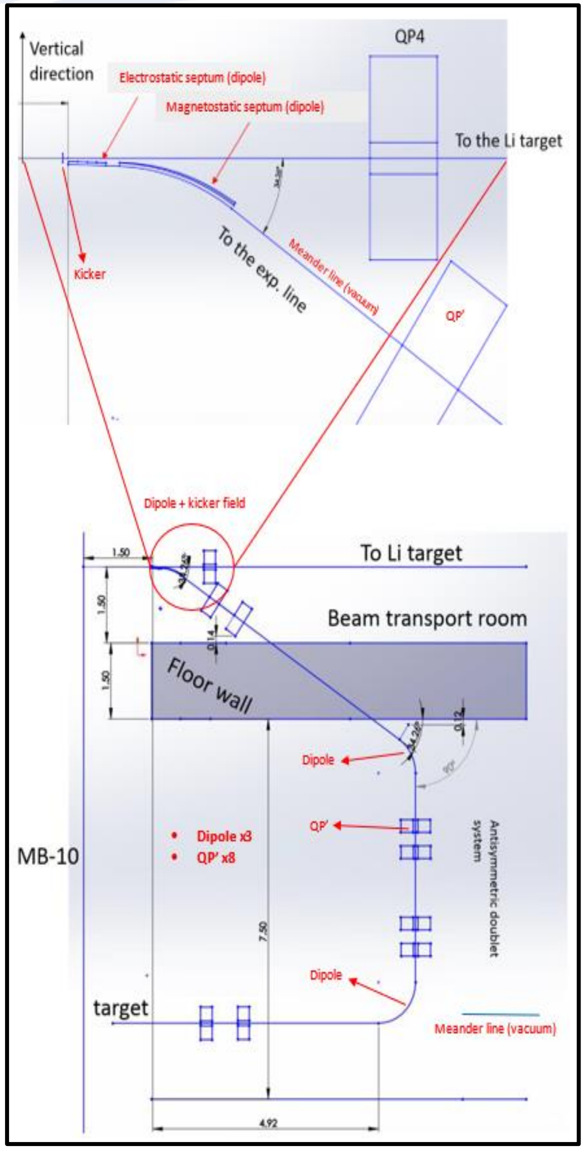
L. Bellan, M. Comunian, A. Pisent LNL INFN
M. Di Giacomo, M.H. Moscatello CEA GANIL

D+ parisitic beam extraction between QP3 and QP4 of the HEBT

- Kicker meander line and electrostatic septum for fast selection of a single bunch
- Septum magnet to extract and bend extracted beam by 34°
- 2 additional dipoles to complete the whole 180° of the beam
- 4 quadrupole (QP) doublets to keep the extracted beam focused
- Extraction simultaneous to the ongoing irradiation of the Li target



CAD model, D. Sánchez



M. Vázquez et al.

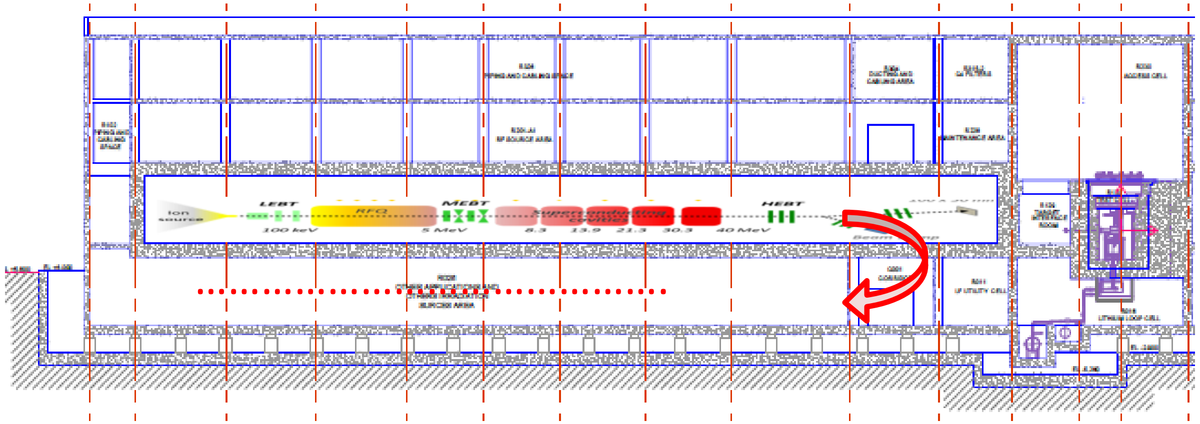
Using the 40 MeV deuteron beam: neutron TOF facility

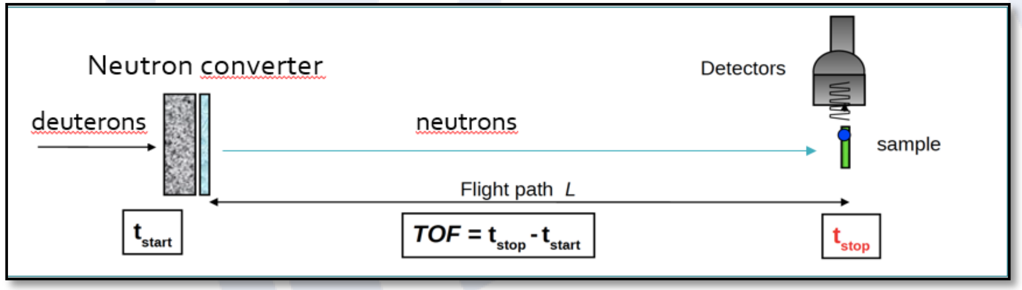
- ✓ A pulsed beam of 40 MeV deuterons could be used directly for (nuclear) physics experiments

- ✓ It could also be used on another production target (e.g. Li, Be, graphite) to produce neutrons, in that way a pulsed source of neutrons would be obtained

(similar to Neutrons For Science facility at GANIL, n_TOF at CERN)

DONES building, section view
Accelerator at level 1, nTOF at ground level



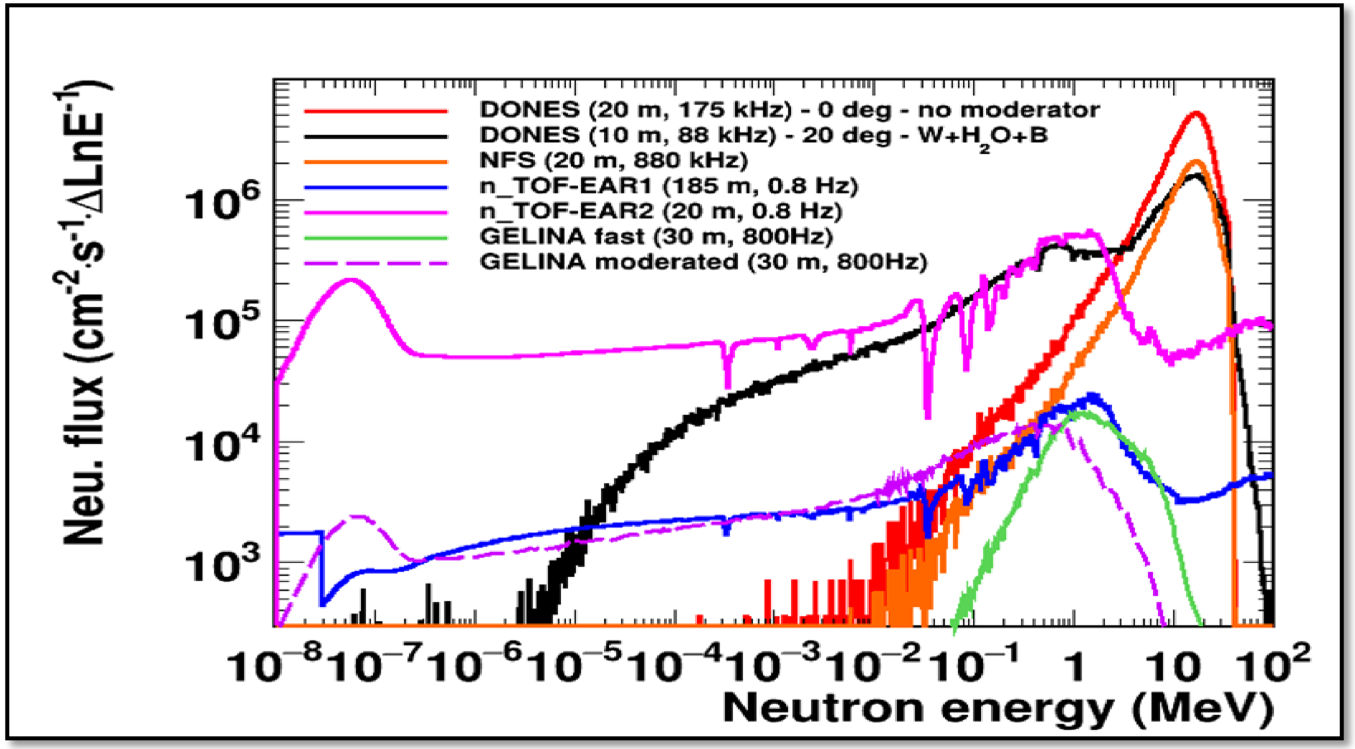


Neutron time-of-flight facility (n_TOF)

This option is being considered and studied:
- Possible characteristics of parasitic D beam
- Integration with the optics of the nominal beam
- Feasibility of n_TOF facility (or experiments with D)
- Catalogue of possible experiments

DONES nTOF

DONES nTOF would be world's highest intensity TOF neutron source



D. Cano-Ott, First DONES Users Workshop, 2022

Broad experimental program is possible on neutron induced reaction cross section measurements for nuclear technologies, astrophysics, fusion, particle physics

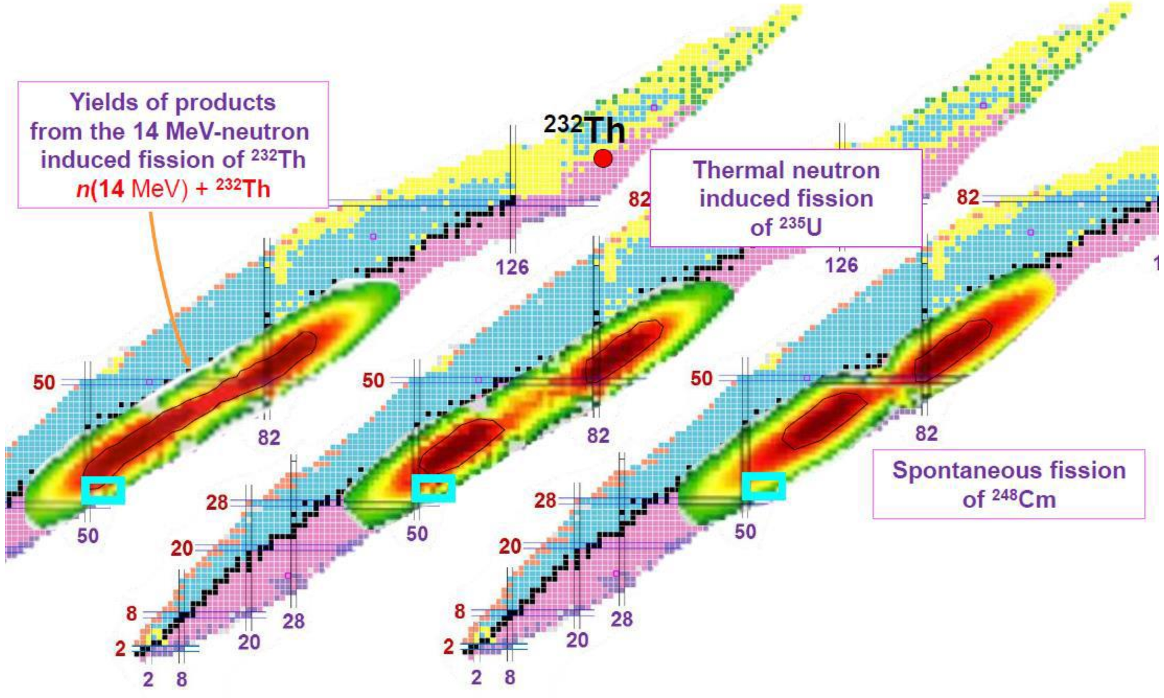
- (n,el) - elastic
- (n,γ) - capture
- (n,n'γ) -inelastic
- (n,xn) – neutron multiplication
- (n,f) - fission
- (n,p), (n,d), (n,t), (n,α)… - charged particle production

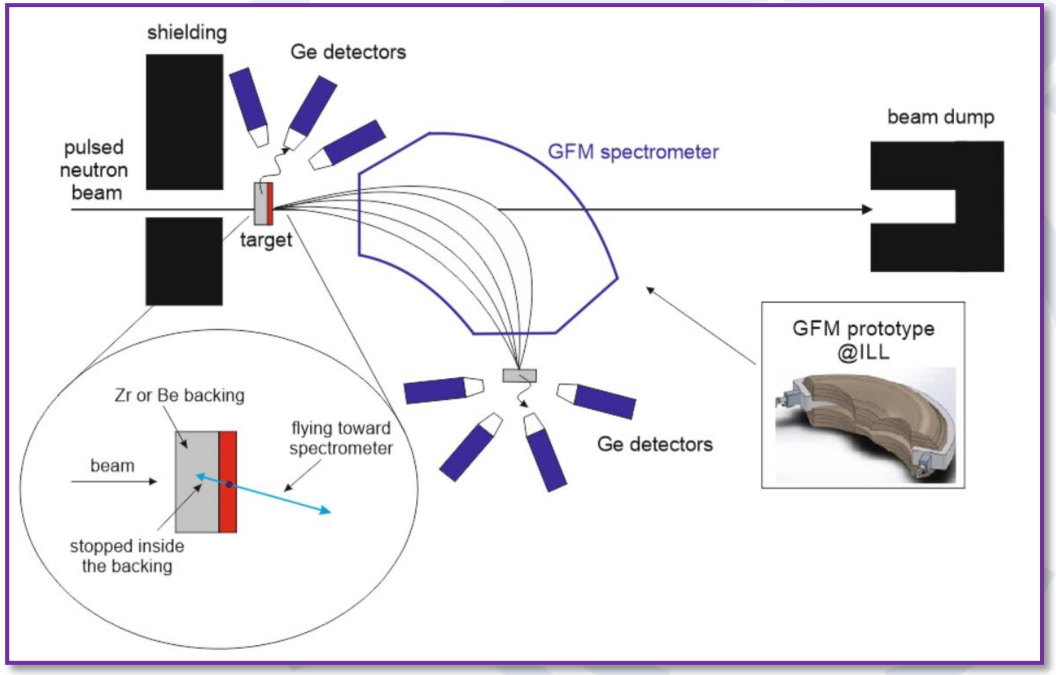
Measurements over several decades:

- 52 isotopes listed in the **High Priority Request List** for nuclear technologies
- Over **35 (n,γ) prioritary cross section measurements** for astrophysics

Gamma spectroscopy of nuclei produced in fast-neutron-induced fission

Distribution of the fission products which correspond to different target materials

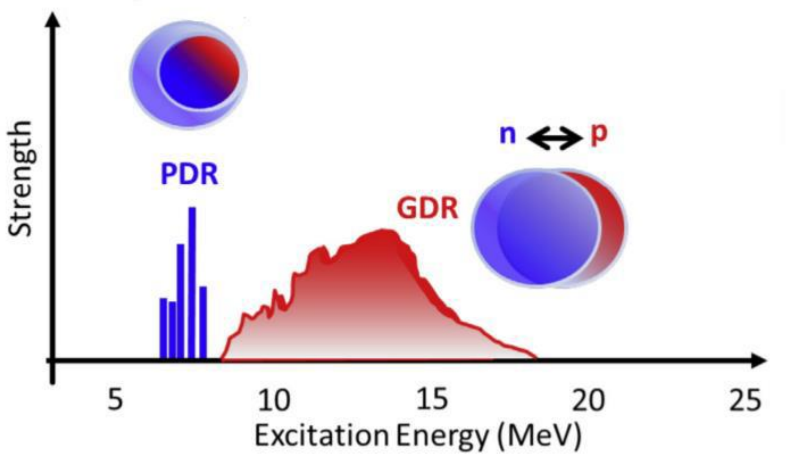




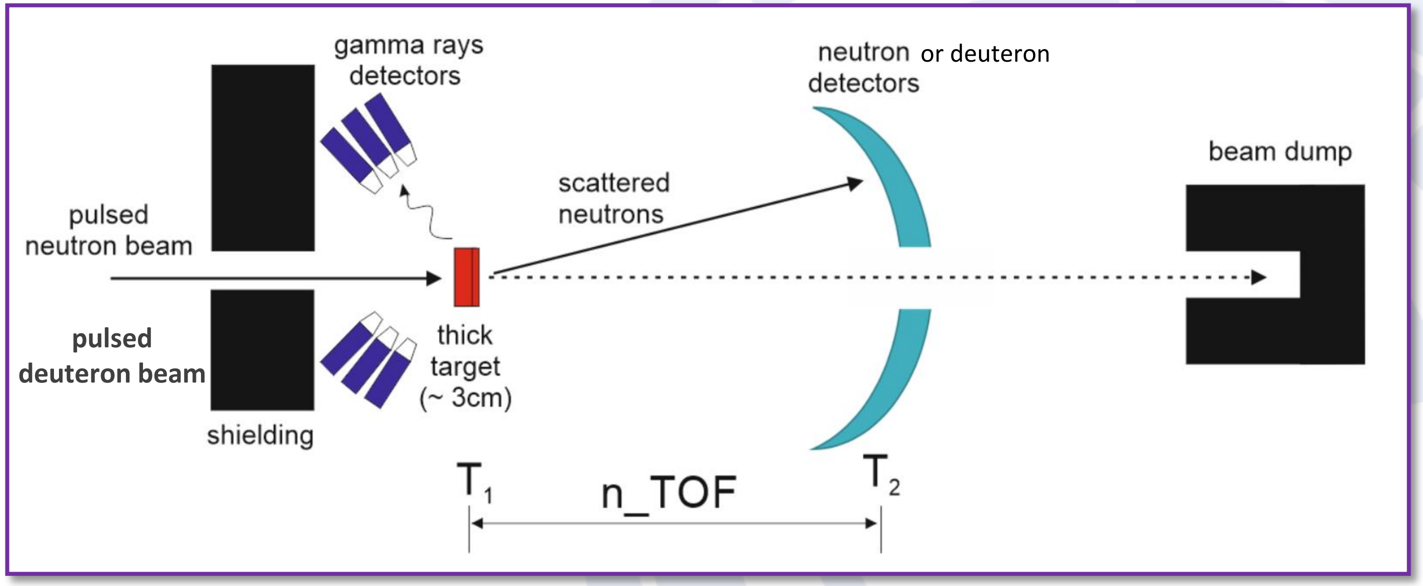
The secondary beam line at DONES offers unprecedented opportunity for gamma spectroscopy studies of neutron-rich nuclei, as it should allow accessing excited states and observing their gamma decay in nuclei which could not be reached for nuclear structure investigations so far

B. Fornal, First DONES Users Workshop, 2022

Study of the pygmy dipole resonance with (n,n'γ) or (d,d'γ) reactions



… inspired by experiments performed at NFS@GANIL/SPIRAL2



- The DONES facility is an excellent place to systematically study PDR excitations (and other resonances) in nuclei from different regions of the nuclear chart using neutrons or deuterons as a probe
- The high intensity of the neutron/deuteron beam and the possible long duration of the experiments will ensure high statistics data which is crucial for obtaining detailed information on the nature of the PDR

A. Maj, First DONES Users Workshop, 2022

IFMIF-DONES Users Community

DONES Users

Second DONES Users Workshop

- Held in Granada, 19-20 October 2023
- 100 participants, 43 presentations arranged in 7 topical sessions
- Workshop materials online at https://indico.ifmif-dones.es/e/DONES-UsersWS2

The **key objective** was to contribute and consolidate the international DONES Users Community representing all the different scientific and technological areas of interest

Discussed areas of scientific interest:

fusion

- Fusion materials qualification
- Tritium breeding technologies
- Other irradiation modules

non-fusion

- Nuclear physics including DONES neutron time-of-flight
- Radioisotopes and medical studies
- Biological and industrial applications
- Cultural heritage
- Neutron imaging and other experiments

First approach to the Irradiation Program proposal
Discussion on the role of the DONES users community

Multidisciplinary DONES Users Committee established

Third DONES Users Workshop
will be held in September 2024
in Zagreb, Croatia *(t.b.c.)*

Contact: users@ifmif-dones.es

Conclusions and outlook

„Materials qualification is one of the key pending issues in the development of fusion as an energy source”

The IFMIF-DONES facility will be built for the irradiation and qualification of fusion reactor materials

→ the construction phase has just started!

IFMIF-DONES will also host state-of-the-art experimental activities in other scientific areas

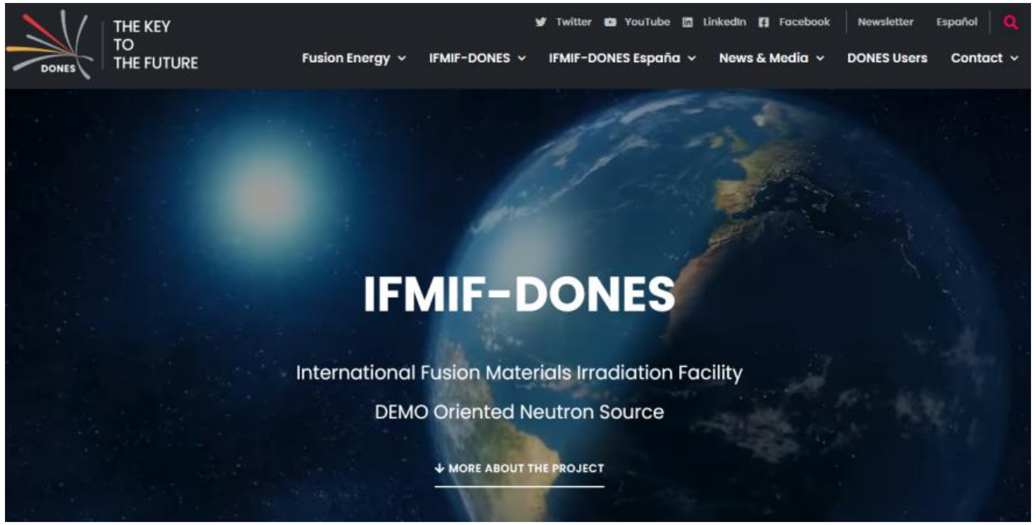
- ***A collimated neutron beam facility*** allows IFMIF-DONES to be a first class laboratory for techniques using fast neutrons and a medium flux facility for techniques using thermal neutrons
- The deuteron pulsed beam allows IFMIF-DONES to be a ***first class nTOF facility***

EUROfusion DONES ConP$_1$ IFMIF DONES GRANADA

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

IFMIF-DONES: The key to the future

Web site including DONES users registration and news



https://ifmif-dones.es/

Search on youtube „IFMIF-DONES: The key to the future"

https://www.youtube.com/watch?v=qupecxxcZTQ

Contact: users@ifmif-dones.es