16TH NUCLEAR DATA
FOR SCIENCE AND TECHNOLOGY CONFERENCE
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IFMIF-DONES ESPAÑA

The IFMIF DONES facility: where fusion meets nuclear data

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DONES

ND 2025

Outline

- **Introduction**
- **What IFMIF-DONES needs from ND?**
- **What IFMIF-DONES can provide to ND?**
- **Where we are?**
- **Summary**

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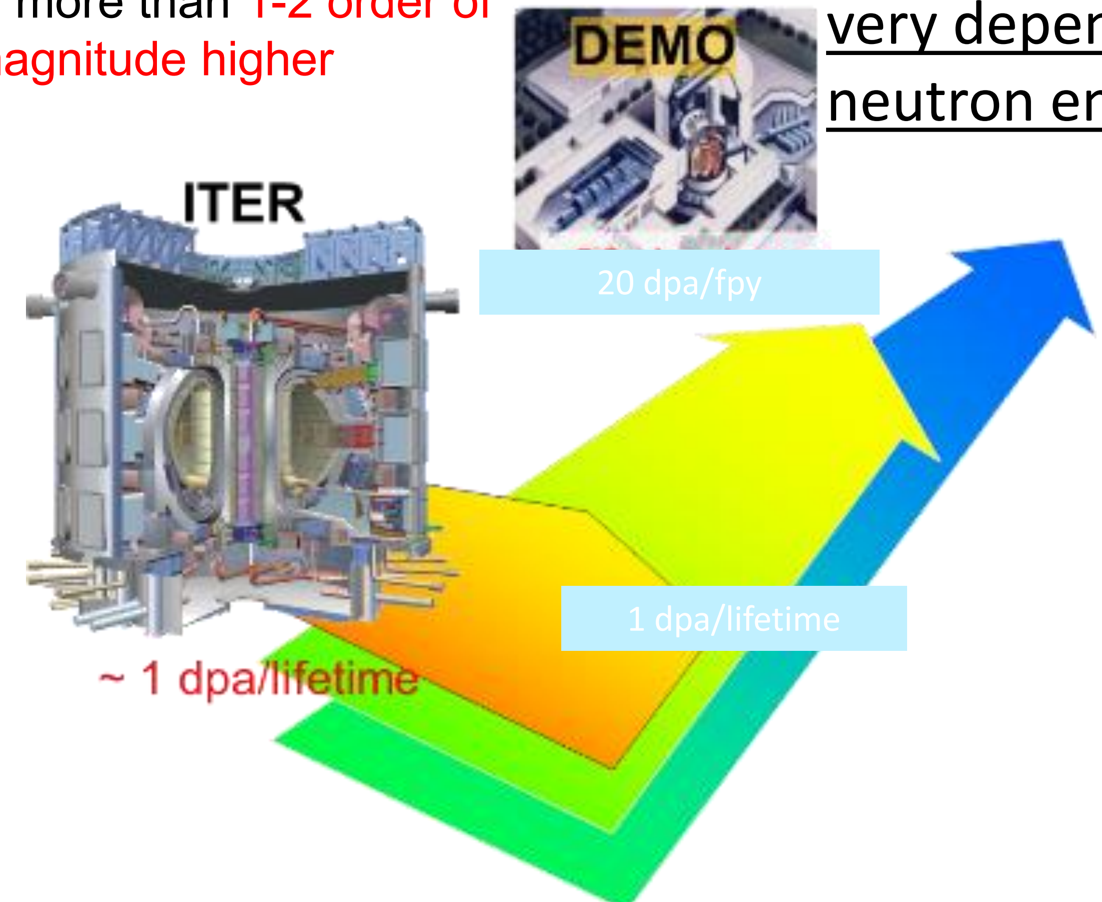
Why IFMIF-DONES?

One of the main differences between **ITER** and **DEMO** (or any fusion power plant) is the radiation dose: at DEMO more than 1-2 order of magnitude higher

Radiation damage processes and effects are very dependent on the neutron energy spectrum

Fusion neutrons spectrum differ significantly from the ones of Fission Reactors

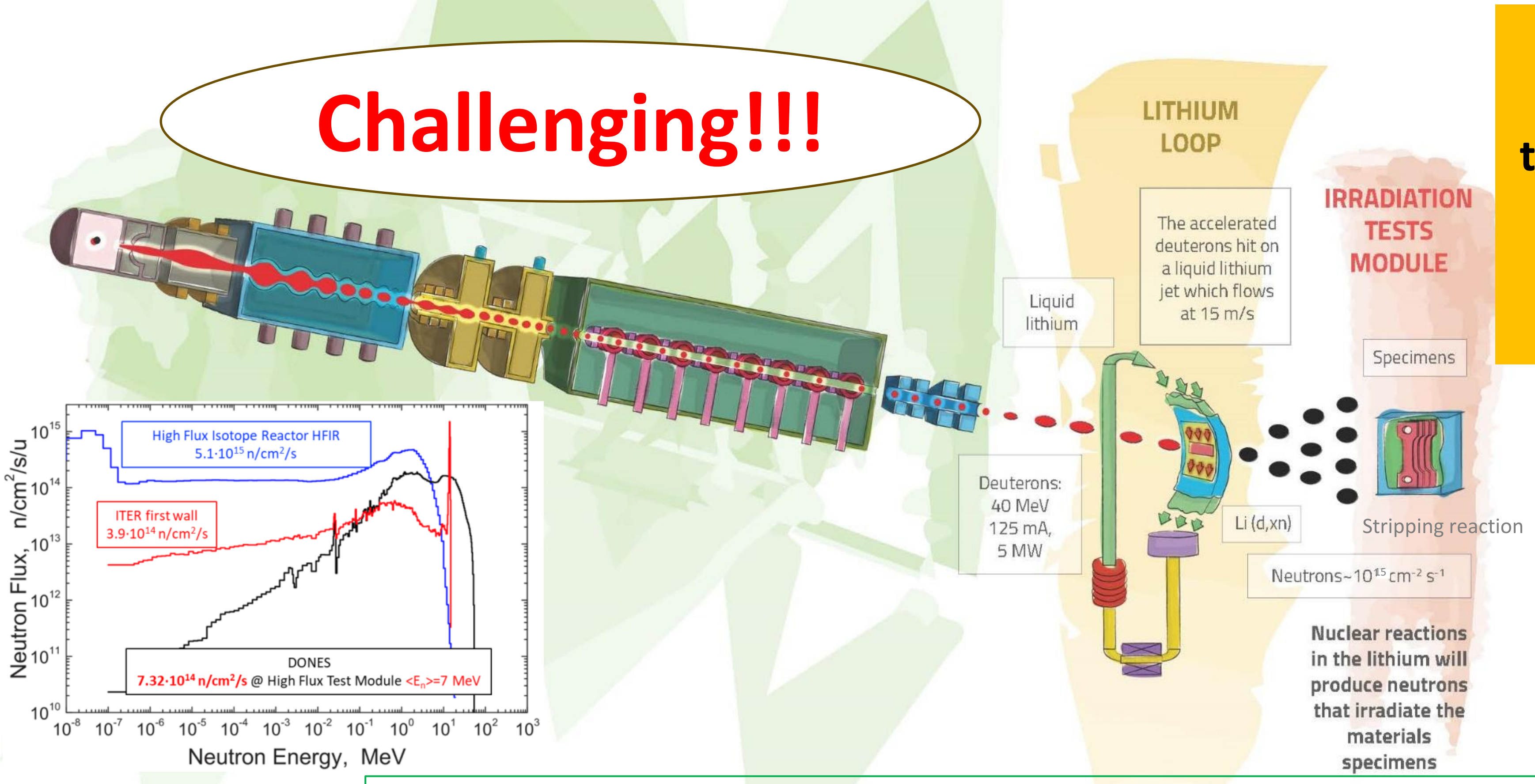


An intense fusion-like neutron source is needed to validate fusion materials and components!!!

DONES

What is IFMIF-DONES?

An accelerator based fusion-like neutron source required for the qualification of fusion materials and other fusion-related technologies to be used in fusion reactors



A neutron flux of ~ 10^{15} n/cm²/s is generated with a neutron spectrum up to 55 MeV energy

High Flux Test Module:
20 dpa/fpy in 130 cm³
10 dpa/fpy in 400 cm³

Identified as high priority in the EU Fusion Roadmap
Included in the ESFRI Roadmap as a EU strategic facility

What is IFMIF-DONES?

An accelerator based fusion-like neutron source required for the qualification of fusion materials and othe[illegible]-related [illegible]ed in fusion

Challenging!!!

It will be the only facility able to reach EoL of DEMO-like reactor components in the near (20 years?) future

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20 dpa/fpy in 130 cm^3
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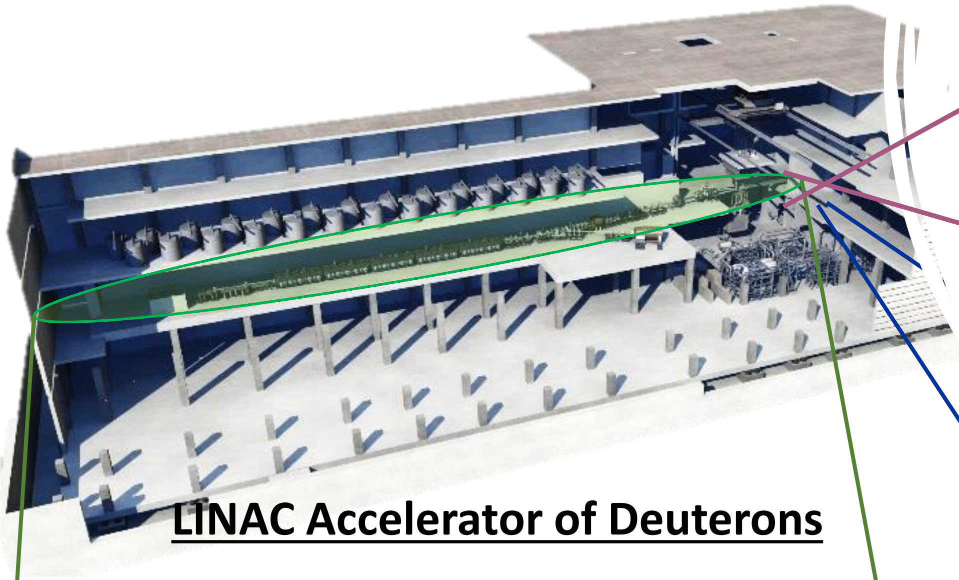
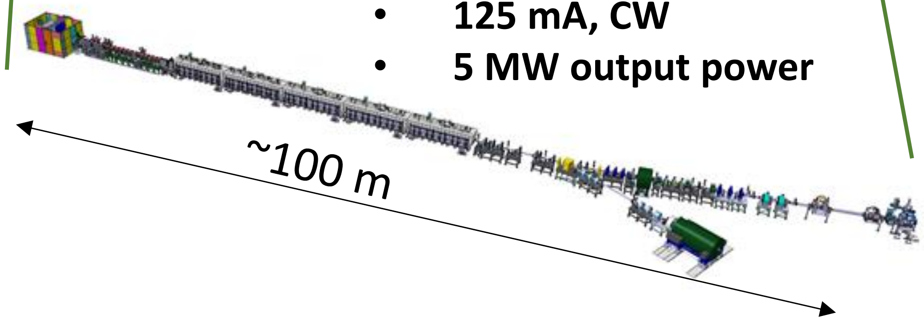
The IFMI[illegible] acility

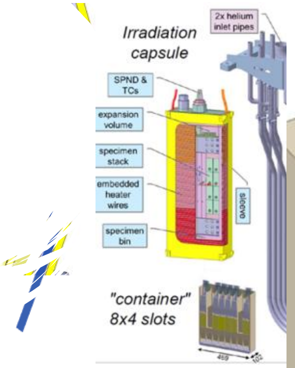


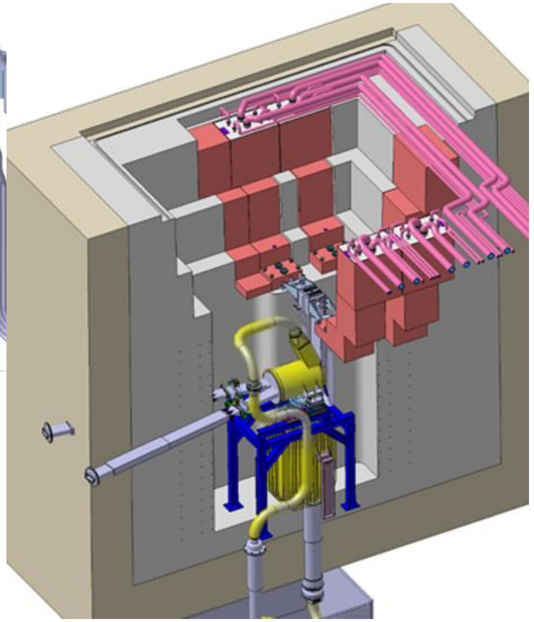
LINAC Accelerator of Deuterons

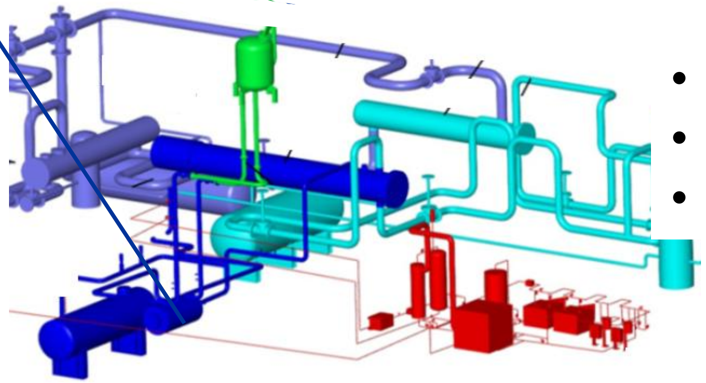
- 40 MeV
- 125 mA, CW
- 5 MW output power



Li Target, Irradiation Modules and Test Cell







- 100 l/s Li
- Strict Li Purity Control
- ~15 m3 of Li

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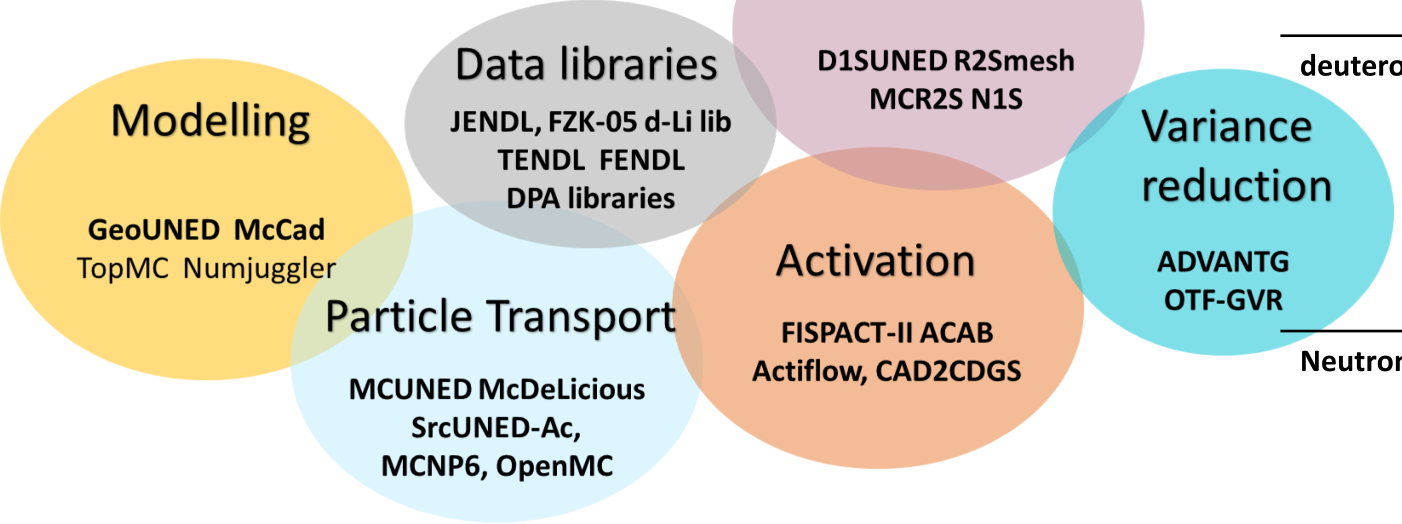
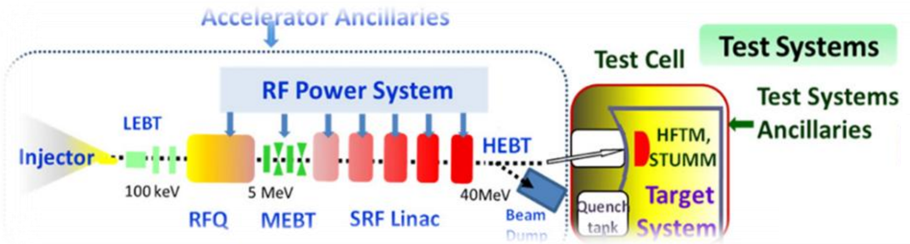
Neutronics and nuclear data in DONES

- Neutronics tools used for DONES: from available fusion neutronic tools.
- Validated and extended for charged particles, neutrons beyond fusion (> 14 MeV), and specific applications.
- Nuclear data are the key fundament for these simulation codes.



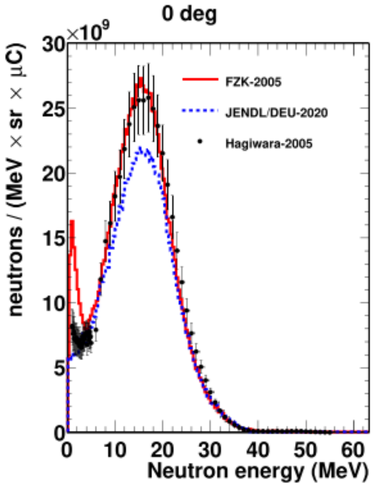


	Accelerator systems	Target and Test Cell
deuteron	**Cooper**: beam dump, RFQ, MEBT **CuCrZr**: HEBT scraper **Niobium, Titanium**: SRF **Stainless steel**: beam pipe **Aluminium**: beam pipe **Graphite**: diagnostic slit	**Lithium**: target **EUROFER**: target assembly, erosion/corrosion products **Stainless** Steel: erosion/corrosion products
Neutron	**Ordinary concrete**: shielding **SS316L**: structures, support platform, piping **Lead**, **polyethylene**, **Iron**: shielding **Water**: cooling **Air**, **Argon**: Atmosphere	**EUROFER**: target assembly, material samples **Stainless Steel**: HFTM structure, target structure, liner, piping, shielding **Ordinary and heavy concrete**: shielding **Water**: cooling **Air**: residual air in gaps

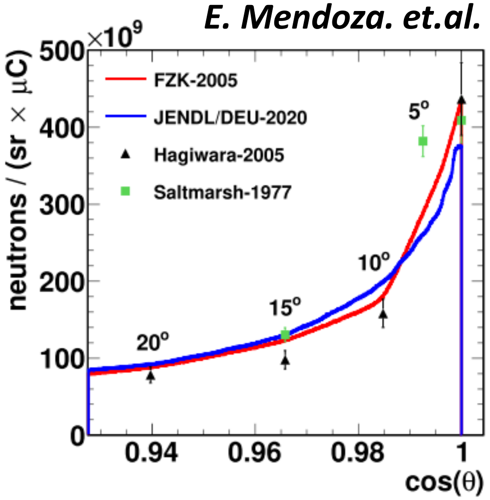
Deuteron libraries on d-Li evaluations

- d-Li Neutron productions
  - **FZK-2005**: **reference** d-Li evaluations benchmarked with thick target yield (TTY) measurement
  - **JENDL-5**:New evaluations produced with DEURACS and benchmarked with TTY.
  - Deviations ~10% at HFTM centre irradiation capsules
- d-Li activations
  - **Be-7** ($T_{1/2}$ =53.3d, E_γ =477 keV): ~150 mg at 1FPY, mostly from Li(d,x) , **Tritium** ($T_{1/2}$=12.3y): 3.78 g/fpy, ~80% from Li(d,x)
  - **Be-7 production**: 20% deviation between FZK-2005 and TENDL. Lack of measurement at E_d> 10 MeV.
  - **Tritium** production: high deviation and uncertainties at E_d> 10 MeV.

E. Mendoza. et.al.

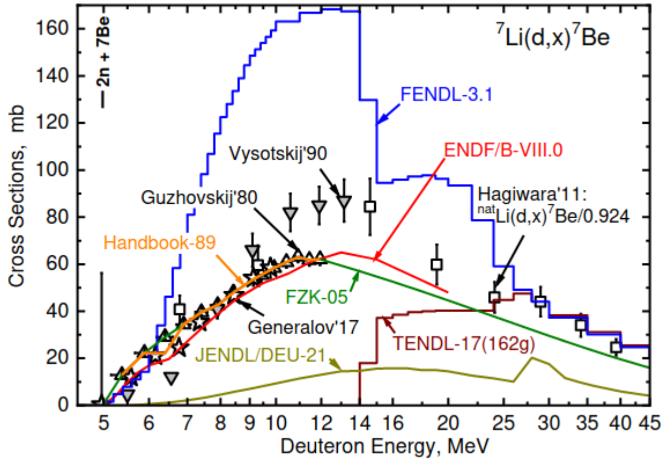


Neutron yield at the 0° forward angle

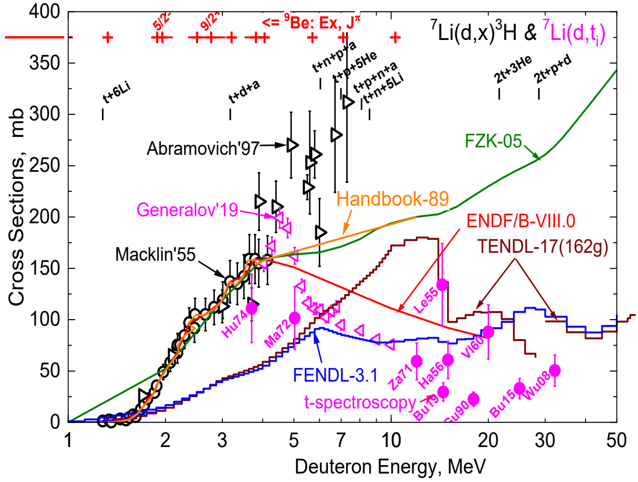


Neutron yields as a function of the emission angles

S. Simakov, et.al.



^{7}**Li** (d,x) ^{7}**Be**

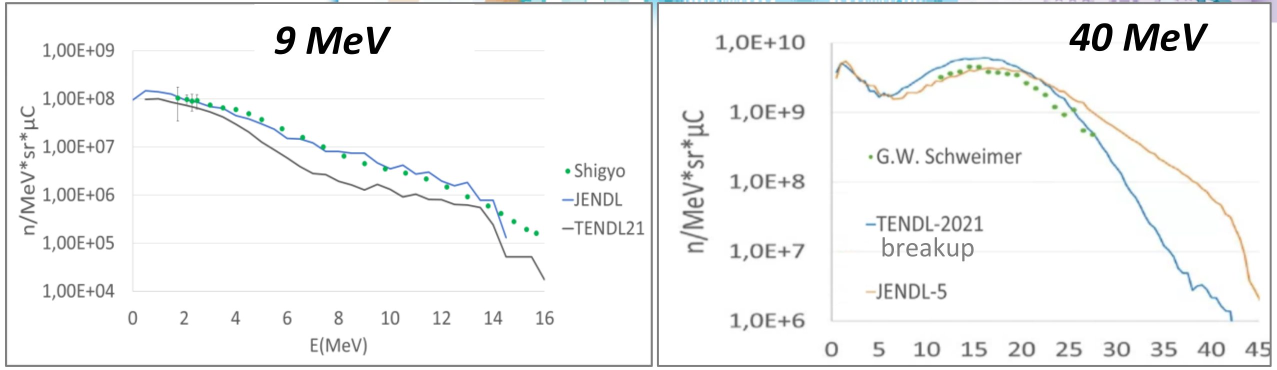


^{7}**Li** (d,x) ^{3}**H**

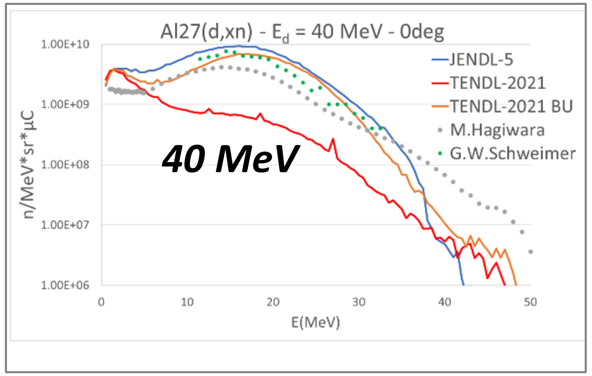
Deuteron libraries for neutron production and activation

- Data libraries
  - Important elements for DONES: **Cu, Al, Fe, W, Nb, Mn, Zr, Cr, Ti**

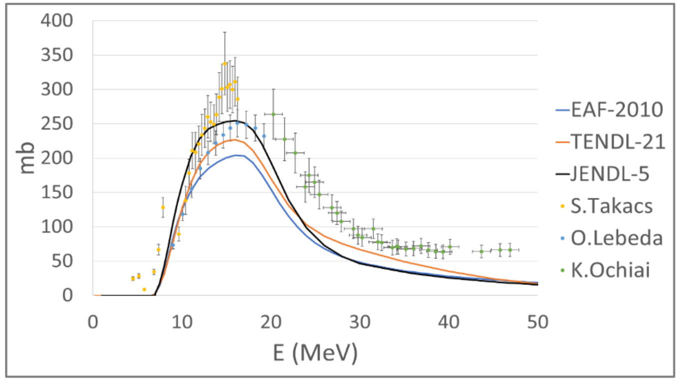
	TENDL-2021 +	JENDL-5
Isotopes	++ Comprehensive list (2850)	- 9 isotopes Li-6,7, Be-9, C-12,13, Al-27, Cu-63,65, and Nb-93
Neutron yield	-- Overall underestimated.	+ follow the measurement data
Activation	+ complete set of activation data - Many are off from experimental data	-- Lack of activation data



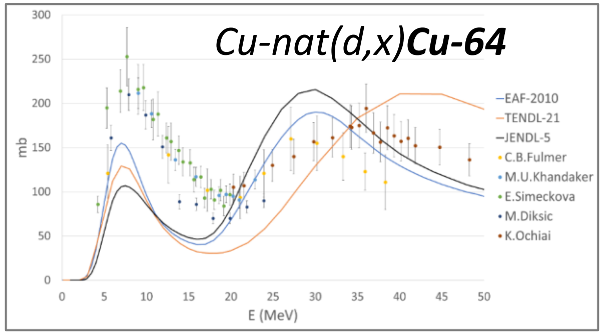
*d-^{nat}**Cu** neutron yield at 0-deg*

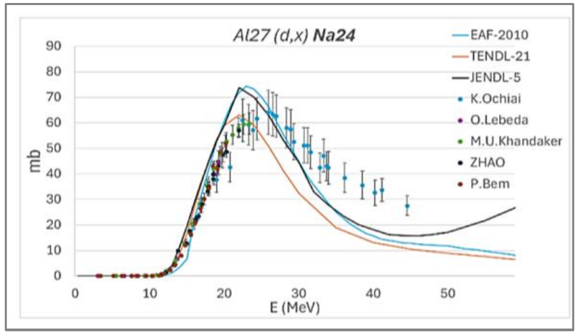


*d-^{27}**Al** neutron yield at 0-deg*



*Cu-nat(d,x)**Zn-63***



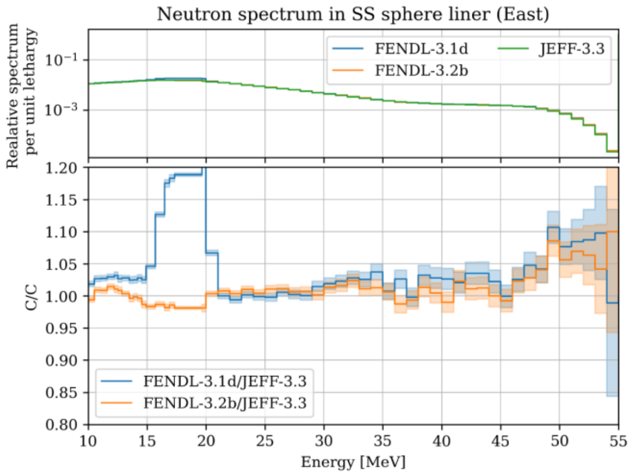


V. Lopez. et.al.

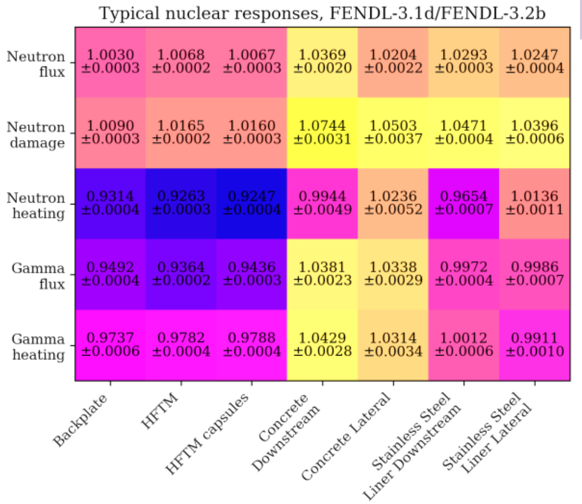
Neutron libraries for transport and activation

- Neutron Transport library
  - FENDL is recommended: energy up to 150 MeV. **FENDL-3.2b** has been released replacing **FENDL-3.1d**.
  - Isotopic comparison using **JADE code** and leakage sphere benchmark with DONES neutron spectra.
  - **FENDL-3.1d overestimates neutron flux** at 15-20 MeV range: target and test module 5%, shielding: up to 40%.
  - **FENDL3.2b predict higher neutron heating** for 7%
- Neutron activation library
  - **TENDL-2017** and newer is recommended: successfully benchmarked with CCFE's V&V suite, although benchmarks missing for DONES relevant energy (<55 MeV).
- Displacement and gas productions
  - NRT and arc-dpa model data prepared by KIT for **Eurofer and SS-316 steels**, Elements Li to U. Available through IAEA/NDS
  - Uncertainty study shows ~20% for EUROFER DPA-NRT.
  - Lack of uncertainty data for gas production. Deviation of ~15% for DONES test module

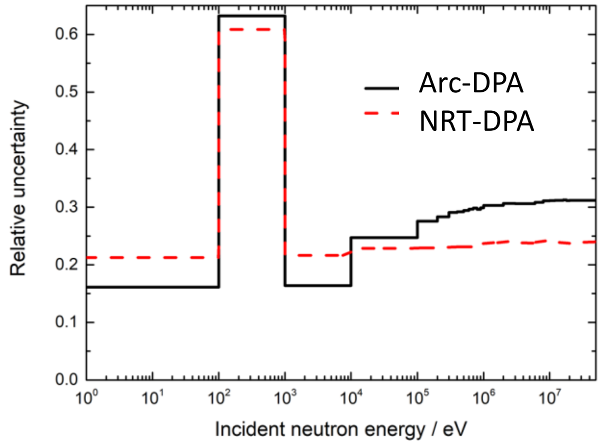
B. Kos. et.al.



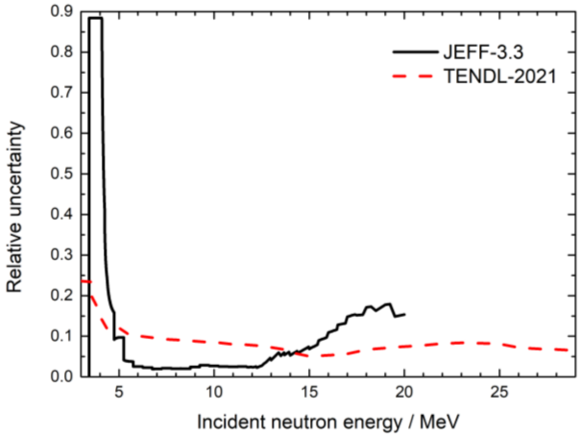
Neutron flux in downstream steel liner



Nuclear responses at different location of DONES test cell, FENDL-3.1d/FENDL-3.2b



EUROFER DPA uncertainty



Fe-56 He production uncertainty

G. Žerovnik . et.al.

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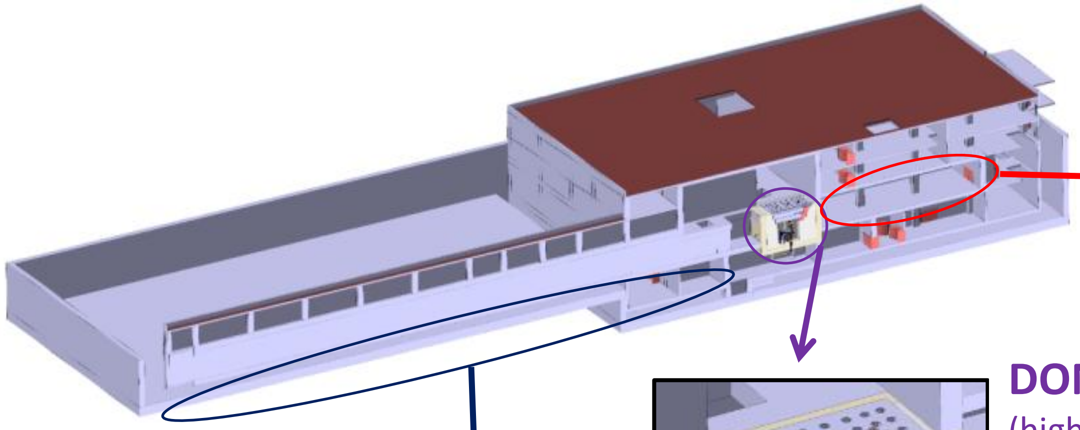
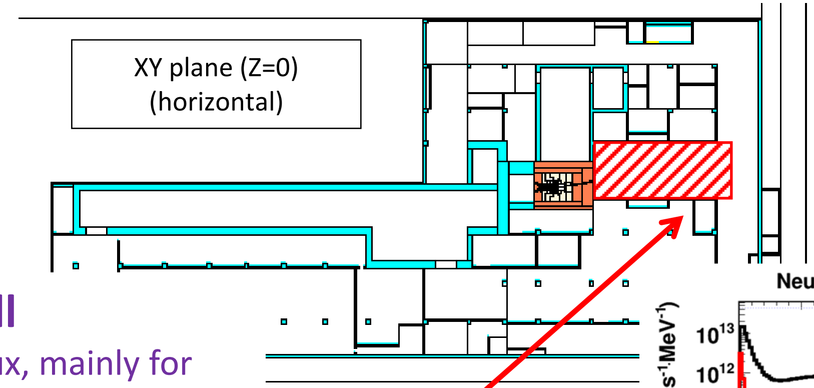
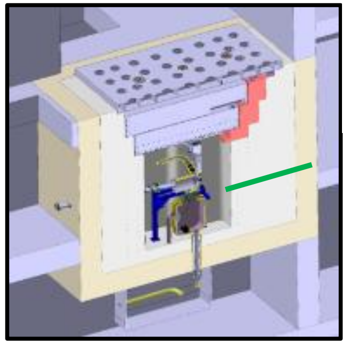
Collimated neutron beam facility – behind the Test Cell

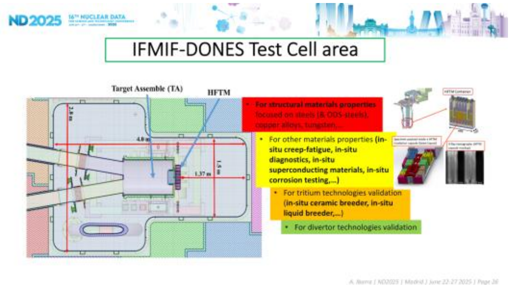




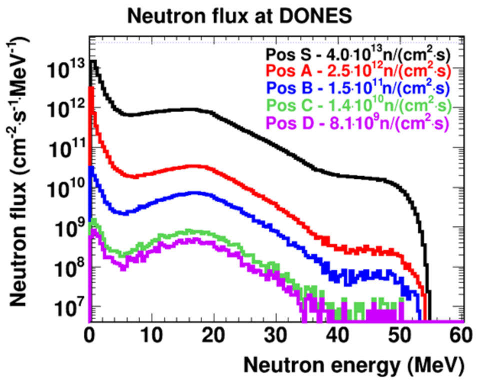
DONES Test Cell

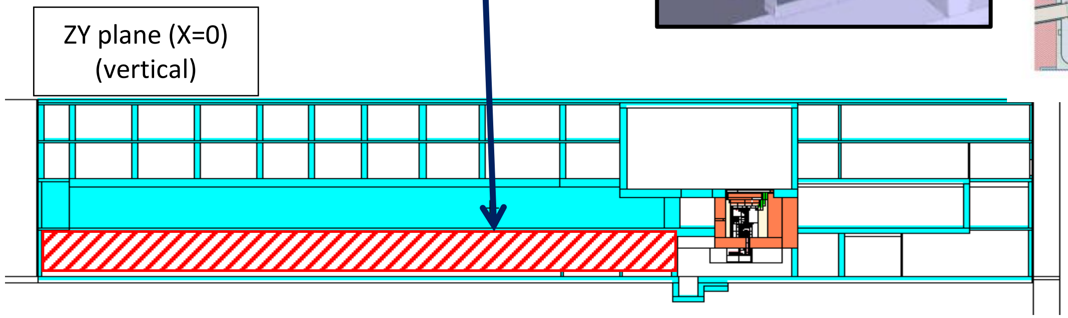
(highest neutron flux, mainly for fusion-related experiments)





Experiments with continuous neutron beam



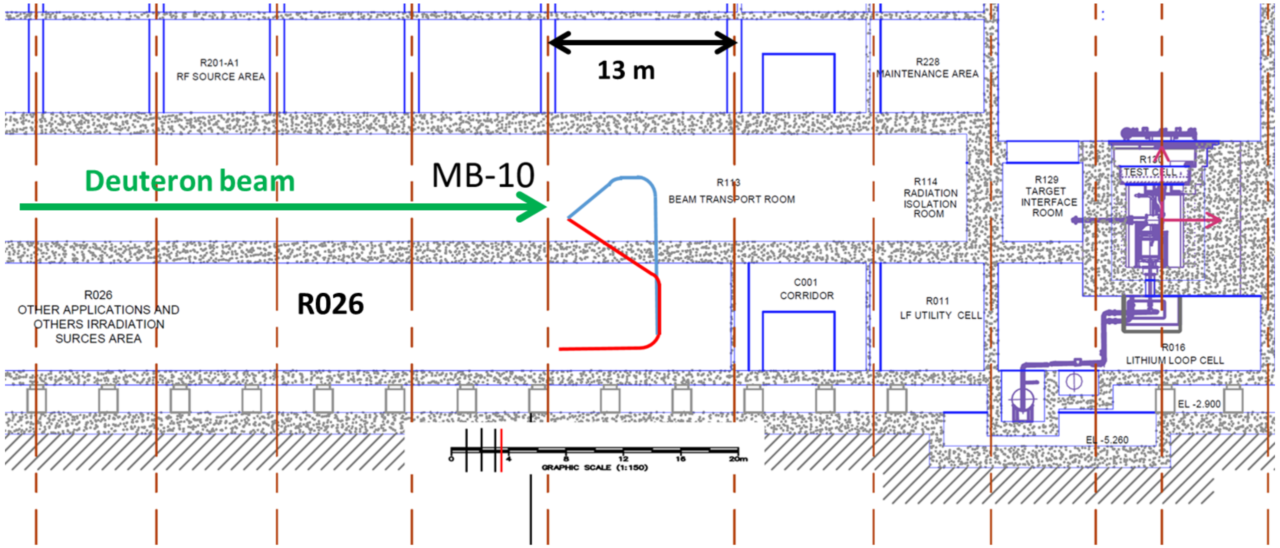


Experiments with pulsed deuteron & neutron beams
(one level below the accelerator vault)

IFMIF-DONES experimental capabilities

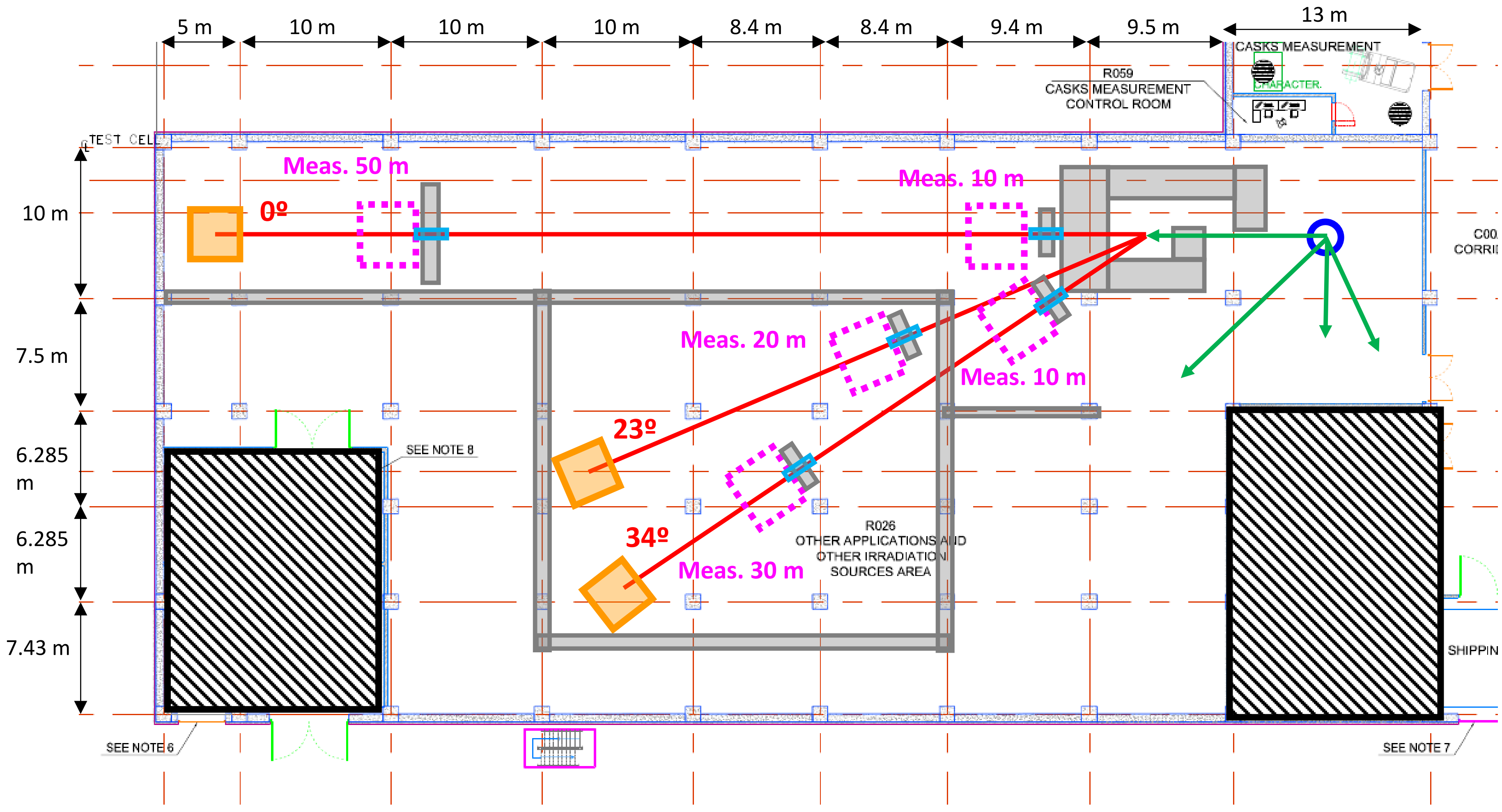
TOF-DONES Facility

- To be located at an available room below the accelerator tunnel, with very large dimensions ~ 60 x 36 x 8 m^3
- Taking 0.1% of the deuteron beam: without impact in the main fusion-related irradiation program
- Deuteron pulse width ~5.6 ns
- Frequency <= 175/n kHz
- From the technical point of view, the extraction of the deuteron beam is probably the most challenging task for TOF-DONES: design and prototypes under development

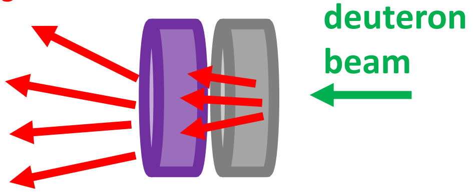


Vertical view

Design of the TOF-DONES facility



Horizontal view



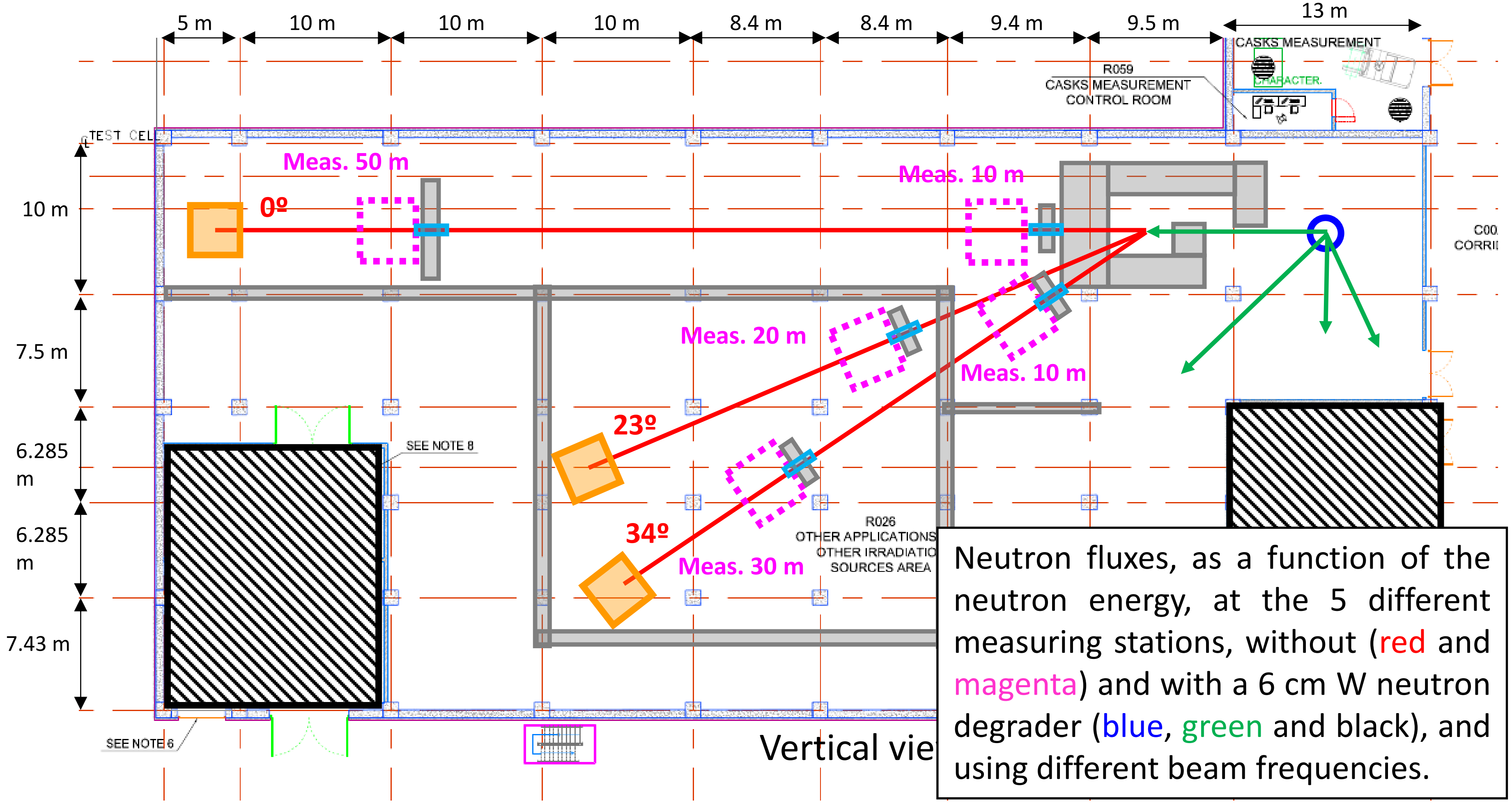
In green, the deuteron beam lines

In red, the neutron beam lines

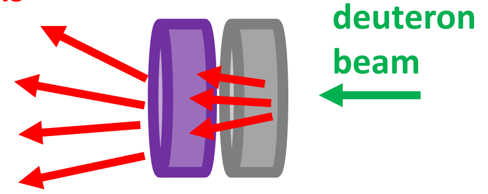
In magenta, five different measuring stations, at different TOF distances and angles with respect to the deuteron beam

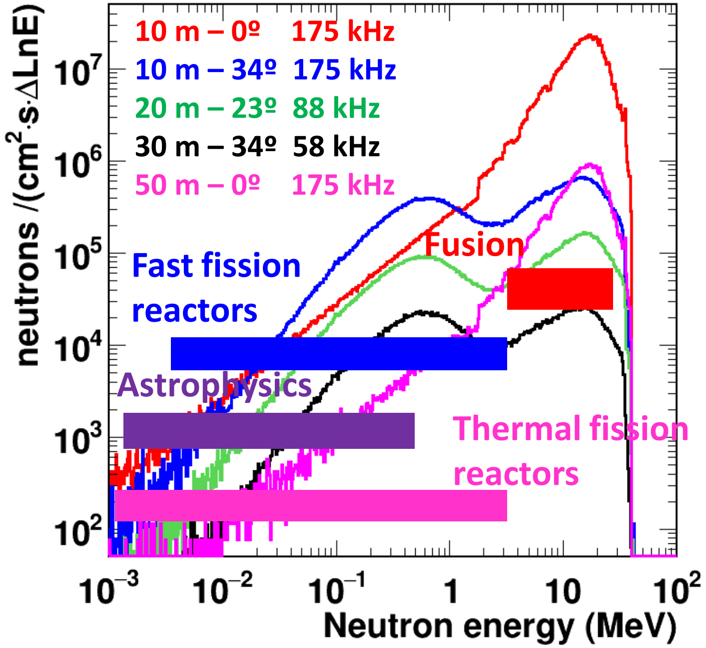
In orange, the beam dumps.

Design of the TOF-DONES facility



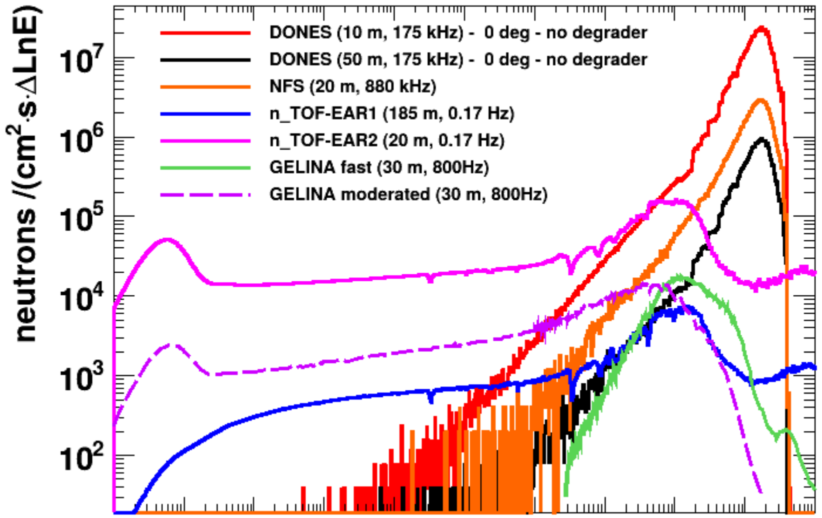
Horizontal view

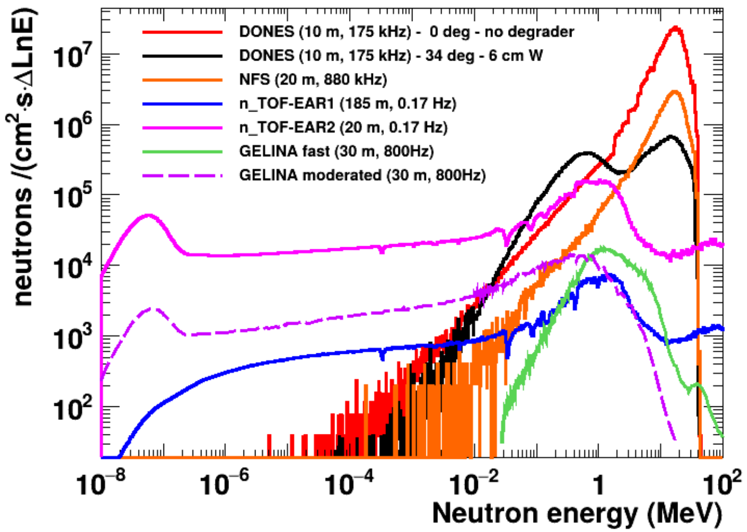


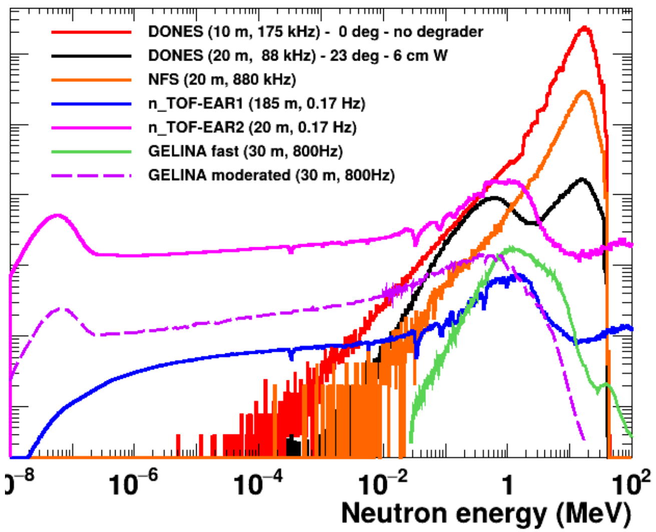


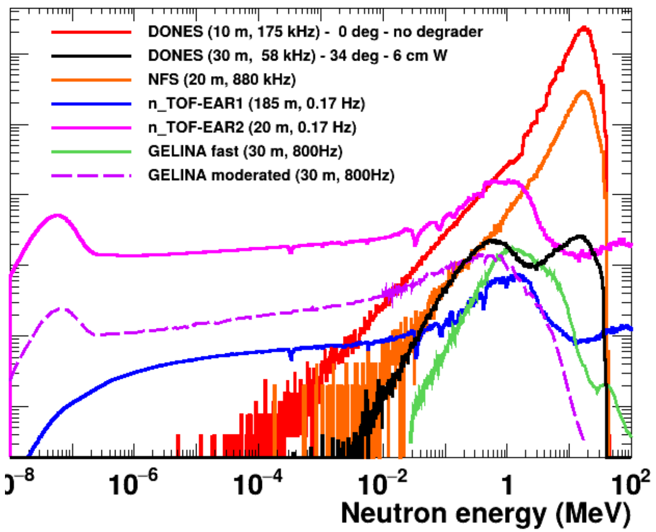
Neutron fluxes, as a function of the neutron energy, at the 5 different measuring stations, without (red and magenta) and with a 6 cm W neutron degrader (blue, green and black), and using different beam frequencies.

Comparison with other facilities









TOF-DONES experimental program

Target	Reaction	Quantity	Energy range	Sec.E/Angle	Accuracy	Cov	Field
1-H-1	(n,el)	SIG,DA	10 MeV-20 MeV	4 pi	1-2	Y	Standard
1-H-2	(n,el)	DA/DE	0.1 MeV-1 MeV	0-180 Deg	5	Y	Fission
3-LI-0	(d,x)Be-7	SIG	10 MeV-40 MeV		10	Y	Fusion
3-LI-0	(d,x)H-3	SIG,TTY	5 MeV-40 MeV		10	Y	Fusion
8-O-16	(n,a),(n,abs)	SIG	2 MeV-20 MeV		See details	Y	Fission
9-F-19	(n,2n)	SIG/SPA	239Pu(n,f)		3	Y	Fission
11-NA-23	(n,2n)	SIG/SPA	252Cf(sf)-235U(n,f)		2-5	Y	Dosimetry
13-AL-27	(n,2n)	SIG/SPA	252Cf(sf)-235U(n,f)		2-5	Y	Dosimetry
15-P-31	(n,p)	SIG/SPA	252Cf(sf)-235U(n,f)		2-5	Y	Dosimetry
17-CL-35	(n,p)	SIG	100 keV-5 MeV		5-8	Y	Fission
19-K-39	(n,p),(n,np)	SIG	10 MeV-20 MeV		10	Y	Fusion
22-TI-0	(n,x)Sc-46	SIG	15 MeV-100 MeV		5-10	Y	Dosimetry
22-TI-0	(n,x)Sc-48	SIG	15 MeV-100 MeV		5-10	Y	Dosimetry
22-TI-0	(n,x)Sc-47	SIG	15 MeV-100 MeV		5-10	Y	Dosimetry
22-TI-46	(n,2n)	SIG/SPA	252Cf(sf)-235U(n,f)		2-5	Y	Dosimetry
22-TI-47	(n,np)	SIG/SPA	252Cf(sf)-235U(n,f)		5-10	Y	Dosimetry
22-TI-48	(n,np)	SIG/SPA	252Cf(sf)-235U(n,f)		5-10	Y	Dosimetry
22-TI-49	(n,np)	SIG/SPA	252Cf(sf)-235U(n,f)		5-10	Y	Dosimetry
24-CR-50	(n,g)	SIG	1 keV-100 keV		8-10	Y	Fission
[illegible]	[illegible]	SIG/SPA	252Cf(sf)-235U(n,f)		2-5	Y	Dosimetry
[illegible]	[illegible]	SIG	1 keV-100 keV		8-10	Y	Fission
[illegible]	[illegible]	SIG/SPA	235U(n,f)		2-5	Y	Dosimetry
[illegible]	[illegible]	SIG/SPA	235U(n,f)		2-5	Y	Dosimetry
[illegible]	[illegible]	SIG/SPA	239Pu(n,f)		3	Y	Fission
26-FE-0	(n,x)Mn-54	SIG	15 MeV-100 MeV		5-10	Y	Dosimetry
26-FE-54	(n,2n)	SIG/SPA	252Cf(sf)-235U(n,f)		5-10	Y	Dosimetry
26-FE-54	(n,a)	SIG/SPA	252Cf(sf)		2-5	Y	Dosimetry
26-FE-54	(n,2n)	SIG	15 MeV-100 MeV		5-10	Y	Dosimetry
26-FE-56	(n,inl)	SIG	0.5 MeV-20 MeV	Emis spec.	See details	Y	Fission

Nuclear data needs for **nuclear technologies** (fission, fusion, dosimetry, waste management with accelerator driven systems...) → NEA/OCDE High Priority Request List → https://www.oecd-nea.org/dbdata/hprl/

^{63}Ni(n,γ), ^{79}Se(n,γ), ^{81,85}Kr(n,γ), ^{95}Zr(n,γ), ^{134,135}Cs(n,γ), ^{147}Nd(n,γ), ^{147,148}Pm(n,γ), ^{151}Sm(n,γ), ^{154,155}Eu(n,γ), ^{153}Gd(n,γ), ^{160}Tb(n,γ), ^{163}Ho(n,γ), ^{170,171}Tm(n,γ), ^{179}Ta(n,γ), ^{185}W(n,γ).

Nuclear data needs for **nuclear astrophysics**:

- F. Käppeler et al., Rev. Mod. Phys 83 (2011)
- N. Nishimura et al., MNRAS 489, 1379–1396 (2016)
- G. Cescutti et al., MNRAS 478 4101 – 4127 (2018)

^{60}Zn(n,p) , ^{64}Ge(n,p), ^{68}Se(n,p), ^{59}Zn(n,p), ^{63}Ge(n,p), ^{72}Kr(n,p), ^{77}Sr(n,p), ^{75}Sr(n,p), ^{76}Sr(n,p), ^{100}Pd(n,γ), ^{97}Rh(n,γ), ^{113}In(n,γ) , ^{117}In(n,γ), ^{57}Ni(n,p), ^{85}Mo(n,p), ^{80}Sr(n,γ), ^{93}Tc(n,γ) , ^{80}Zr(n,p), ^{86}Mo(n,p).

^{72}Ge(n,γ), ^{74}Ge(n,γ), ^{75}As(n,γ), ^{78}Se(n,γ), ^{84}Kr(n,γ), ^{85}Kr(n,γ)

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- G. Cescutti et al., MNRAS 478 4101 – 4127 (2018)

Nuclear data needs for nuclear **fusion**:

- U. Fischer et al., EPJ Web of Conferences 146, 09003 (2017)
- Mark R Gilbert, J. Phys. Energy 5 034002 (2023)
- Dedicated session to fusion during the last USA workshop on nuclear data (WANDA 2024 https://conferences.lbl.gov/event/1403/)

- Structural materials and coolants: ^{16}O, ^{54,56,57,58}Fe, and ^{90,91,92,94,96}Zr neutron reaction data.
- Shielding and tritium breeding: ^{1}H, ^{6}Li, ^{7}Li, ^{9}Be, ^{16}O, ^{28,29,30}Si, ^{54,56}Fe, ^{52}Cr, ^{58}Ni and ^{182,183,184,186}W
- ...

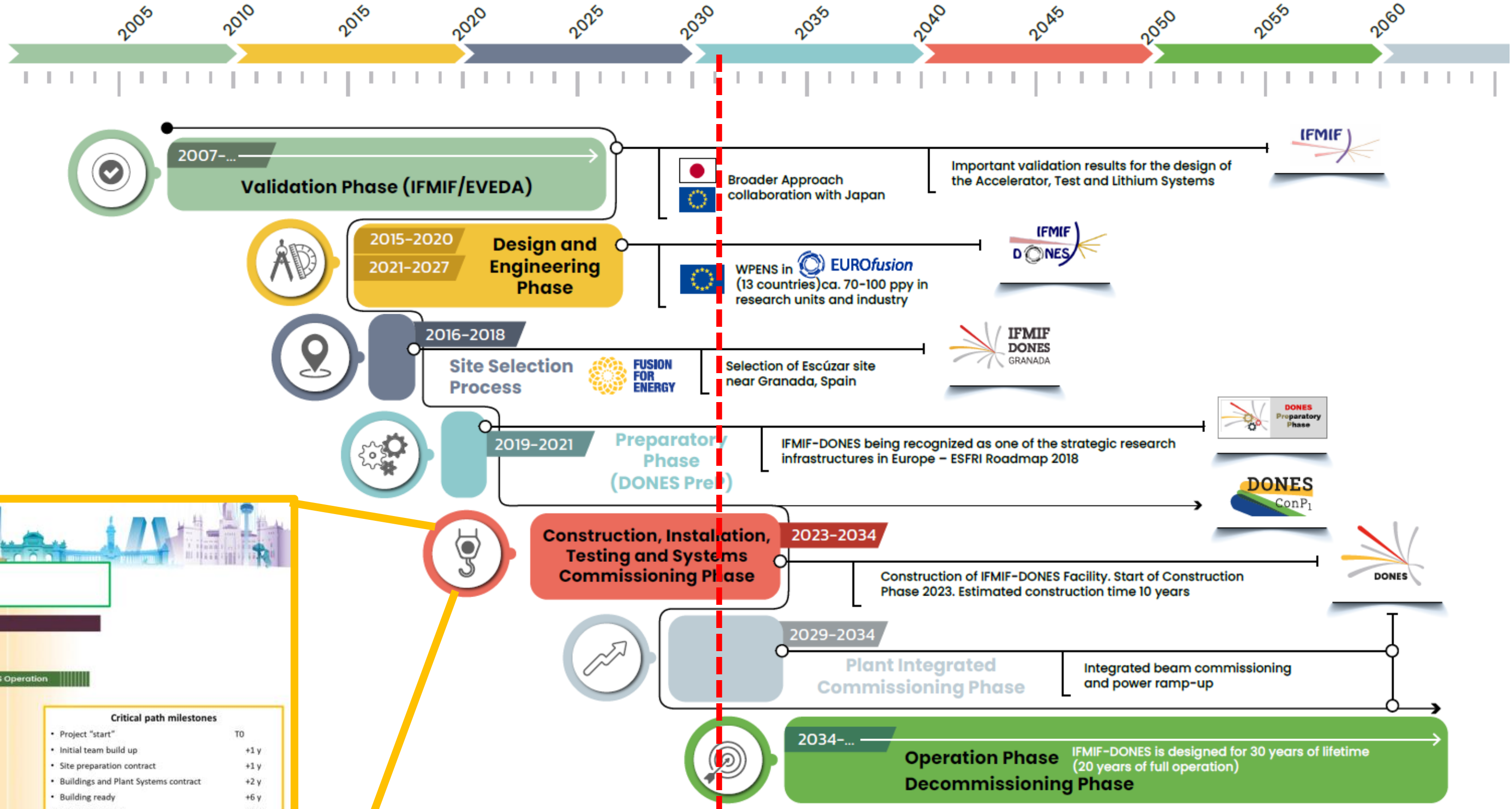
There is a program that requires decades of beam time
(and there is also the need for many other facilities)

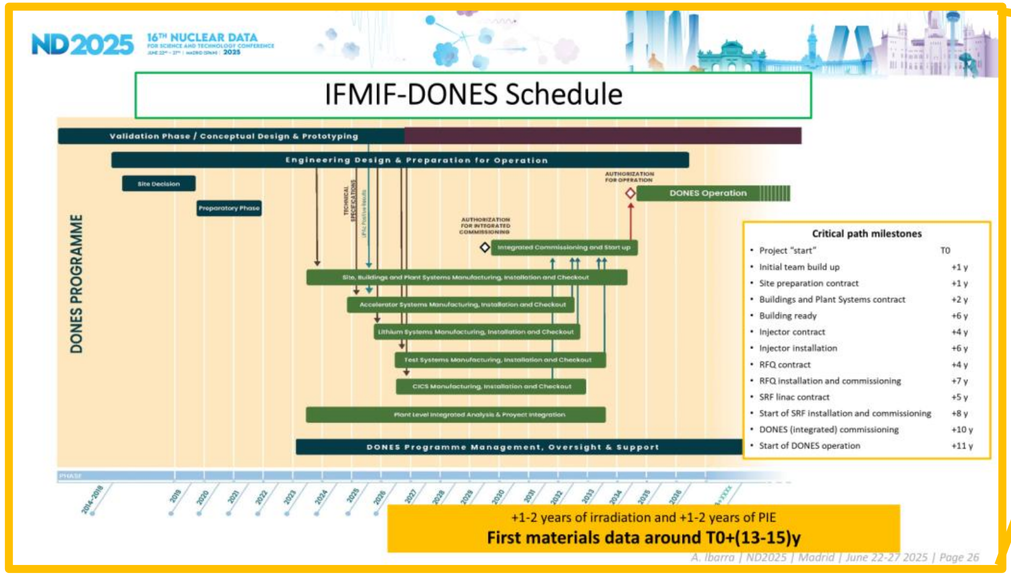
Outline

- **Introduction**
- **What IFMIF-DONES needs from ND?**
- **What IFMIF-DONES can provide to ND?**
- **Where we are?**
- **Summary**

DONES Programme Phases

The objective of the DONES Programme is not only for building the IFMIF Facility… but also to operate and to exploit it!!





Site Status

DONES

On-site experimental prototypes & tests

MuVACAS

STUMM-PROTO

LITEC for developing lithium impurities trapping technologies

Quick Disconnecting System (QDS): To validate RH connection system at the target

Outline

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Summary

- IFMIF-DONES is a deuteron accelerator-based fusion-like intense neutron source facility under construction in Granada (Spain)

- Nuclear data are a strong basis for the design, qualification, safety and licensing of the facility. Generally speaking systematic validation and verifications are necessary, as well as additional development on missing data

- IFMIF-DONES includes the proposal for a international **TOF-DONES** facility relevant to perform a large variety of nuclear physics experiments

- The TOF-DONES facility could provide ***accurate*** **nuclear data necessary for many applications**: nuclear reactors, nuclear fusion, nuclear waste management strategies, nuclear inspection techniques, dosimetry, nuclear astrophysics, nuclear structure, production of radioisotopes for medical and technological applications

DONES Users

The establishment of the **IFMIF-DONES Users Community** …

- … started as a bottom-up initiative of the potential future users of DONES discussing experimental opportunities and interacting with the designers of the facility
- The community sees its main role to establish a link of communication between the DONES engineering activities and the future users

You are invited to join the IFMIF-DONES Users Community!!!
(https://ifmif-dones.es/dones-users-2/contact-for-dones-users/)

DONES Users meetings

IFMIF-DONES ESPAÑA

2022:

IFMIF-DONES Users Workshop (on-line)
26–27 Sept 2022
Europe/Madrid timezone
109 participants, 25 presentations

2023:

Second DONES Users Workshop
19–20 Oct 2023
Parque de las Ciencias, Granada
Europe/Madrid timezone
100 participants (70 in-person)
45 presentations

2024:

1-2 October 2024 | Zagreb, Croatia | 80+ participants
38


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