TRL Analysis of IFMIF-DONES and Overview of required validation activities

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The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Outline

- **Introduction**
  - **IFMIF-DONES facility**
  - **TRL Analysis**
- **Methodology employed for the Study of TRL& required validation activities**
- **Results of the Study**
- **Summary**

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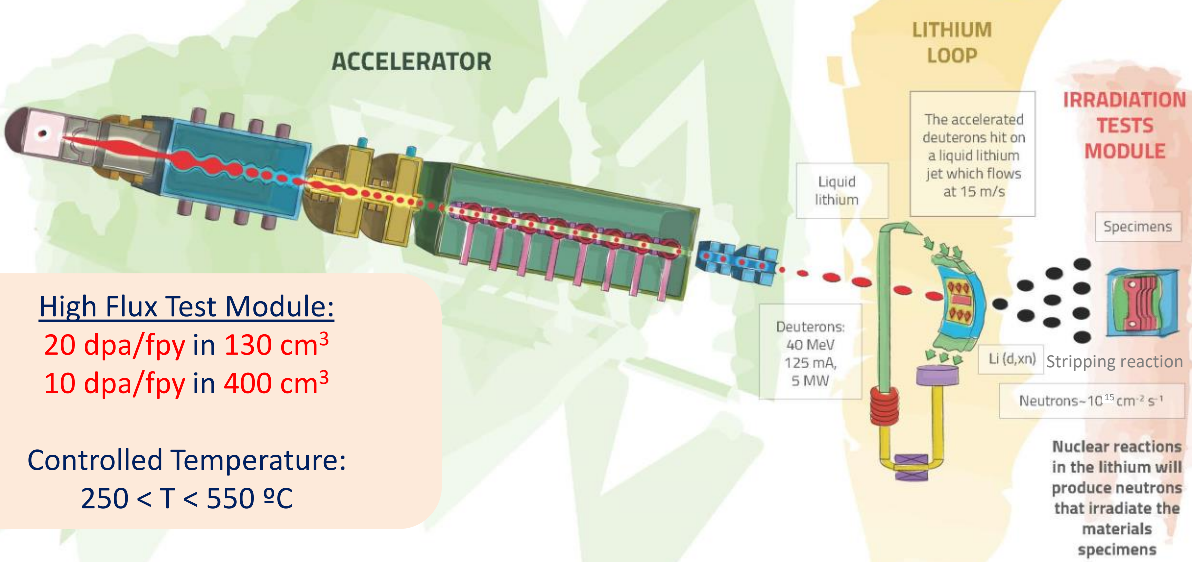
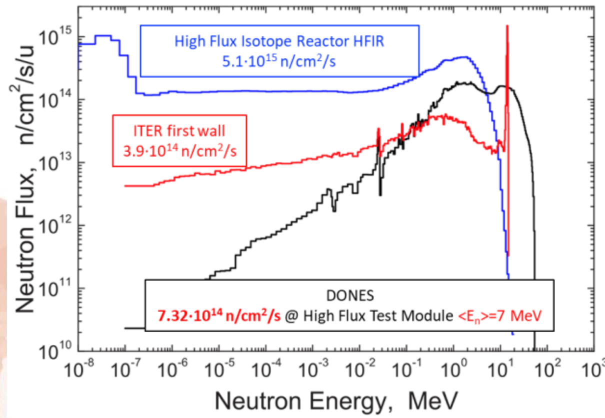
IFMIF-DONES facility

IFMIF-DONES is an accelerator based fusion-like neutron source to be used for the qualification of the materials of the DEMO Reactor

A. Ibarra PL10





<u>High Flux Test Module:</u>
20 dpa/fpy in 130 cm^3
10 dpa/fpy in 400 cm^3

Controlled Temperature:
250 < T < 550 ºC

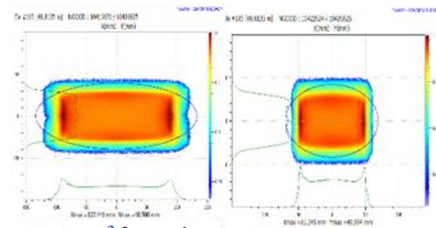
A neutron flux of ~ 10^{14} $n/cm^2/s$ is generated with a neutron spectrum up to 55 MeV energy

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

Accelerator systems

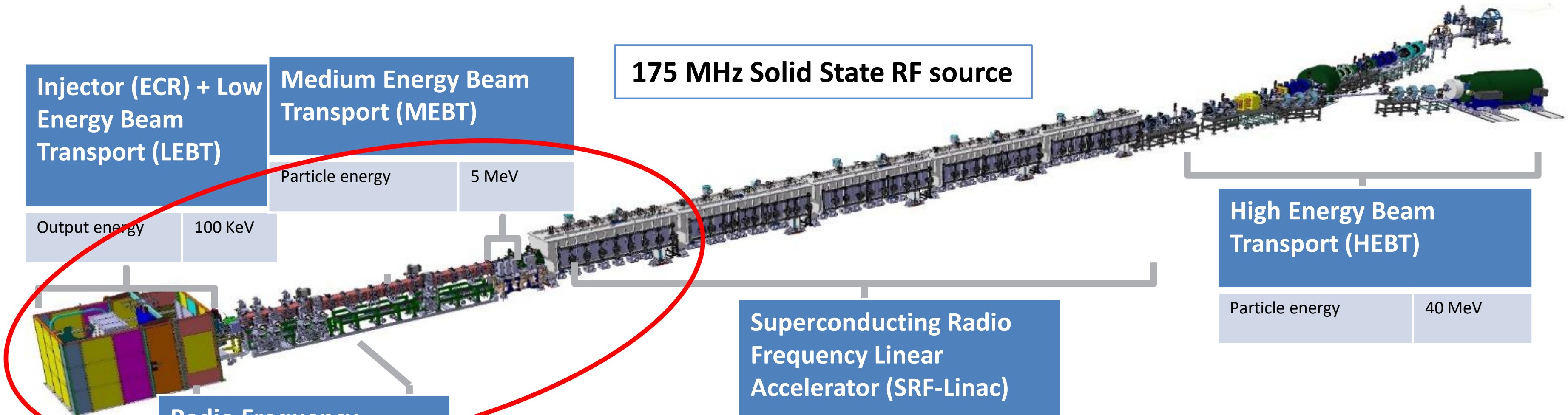
175 MHz, 5MW, 125 mA, CW, high availability: One of the more powerful accelerators in the world
Availability target 87% Hands-on maintenance in most of the accelerator

Beam footprint @ target



20x5 cm^2 footprint (reference)

10x5 cm^2 footprint (optional)



175 MHz Solid State RF source

Injector (ECR) + Low Energy Beam Transport (LEBT)

Output energy	100 KeV

Medium Energy Beam Transport (MEBT)

Particle energy	5 MeV

Radio Frequency Quadrupole (RFQ)

Output energy	5 MeV

Superconducting Radio Frequency Linear Accelerator (SRF-Linac)

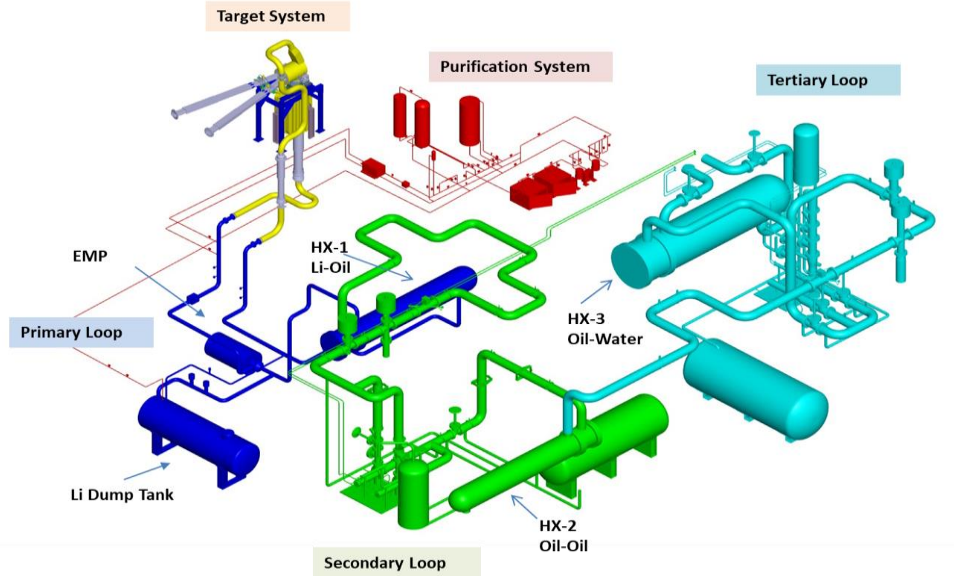
Output energy	40 MeV

High Energy Beam Transport (HEBT)

Particle energy	40 MeV

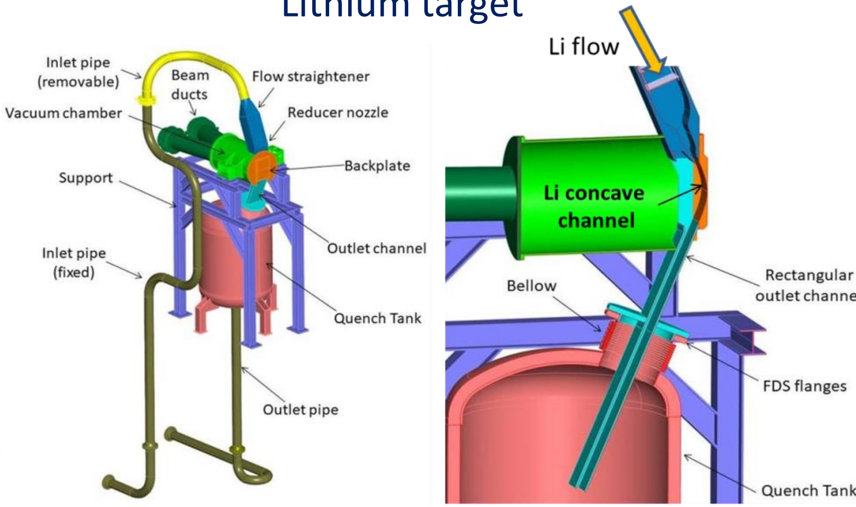
Lithium Systems

5 MW power handling, 15 m/s Li velocity, remote handling
Main requirements: Li flow stability and Li impurities control



Li volume ~14 m^3
Li flow rate ~100 l/s
Li temperature (cold side) ~300 °C

Lithium target

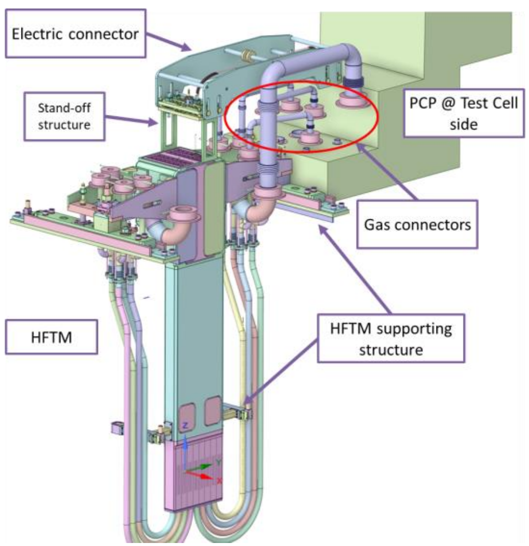


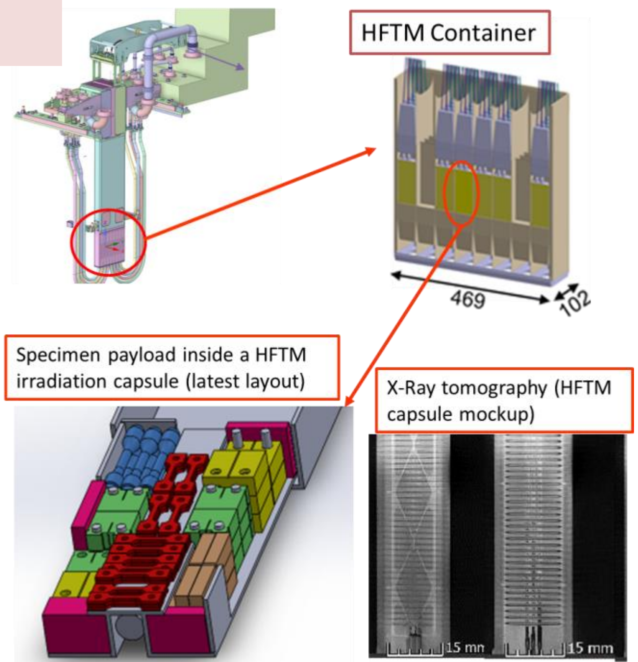
Jet thickness: 25±1 mm | Li flow velocity: 15 m/s
Chamber pressure: 10^{-3} Pa | Heat flux: 500 MW/m^2

Test Systems

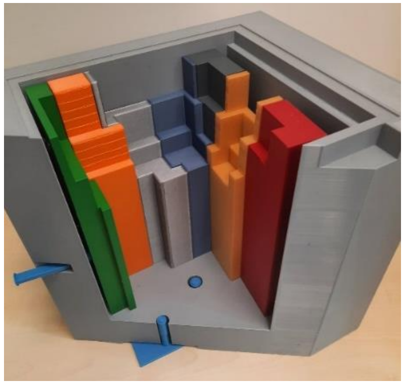
Main characteristics driven by the presence of neutrons and Li
- **Internal components cooled by He**
- **Remote Maintenance required**

HFTM upper part



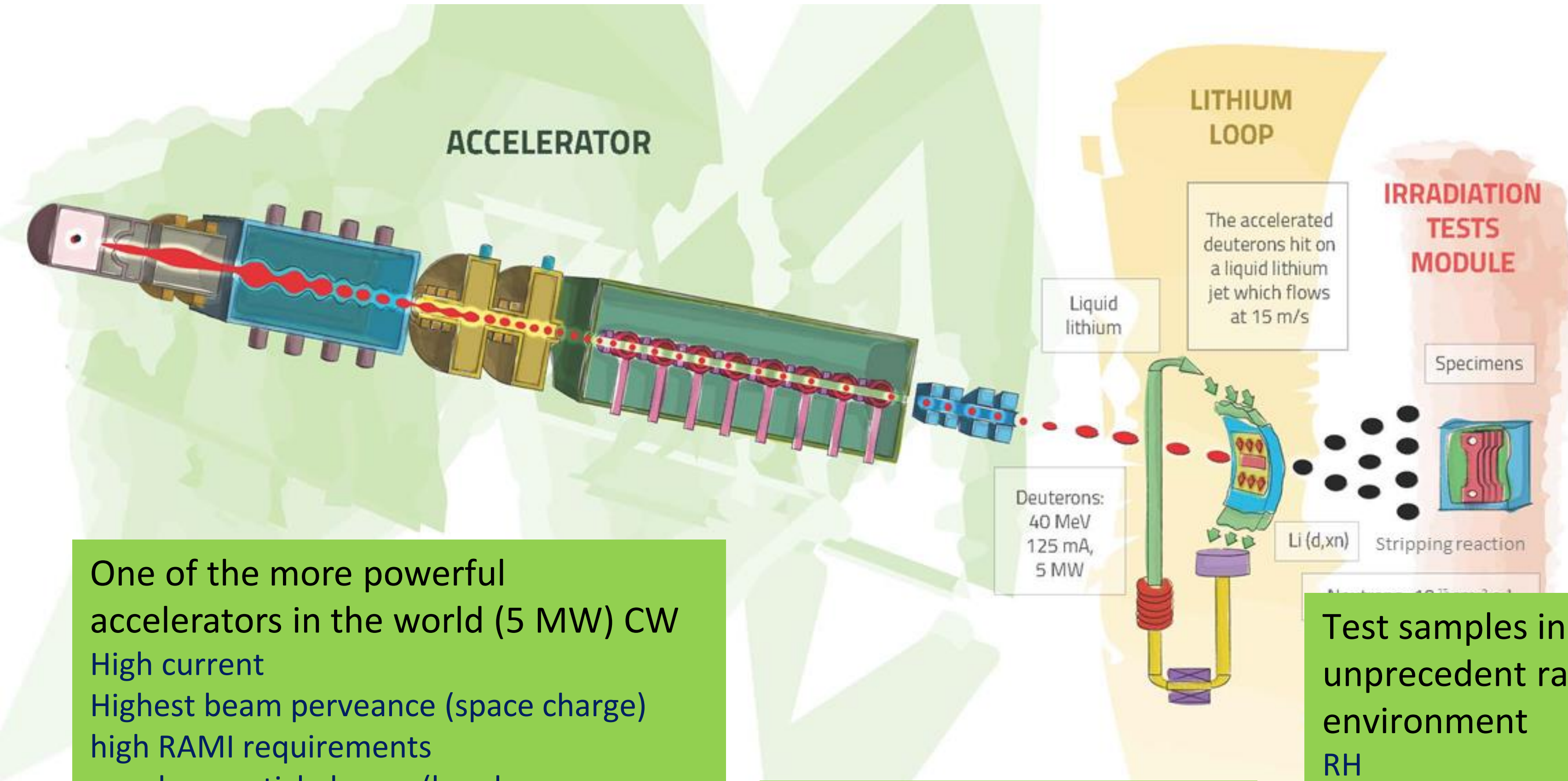


More than 850 specimens can be hold in the HFTM !!



Test Cell Removable Shielding Blocks (Maintainability and minimizing neutron streaming)

IFMIF-DONES facility challenges



One of the more powerful accelerators in the world (5 MW) CW

- High current
- Highest beam perveance (space charge)
- high RAMI requirements
- very low particle losses (hands-on maintenance)
- longest RFQ,...

Biggest Li loop in the world

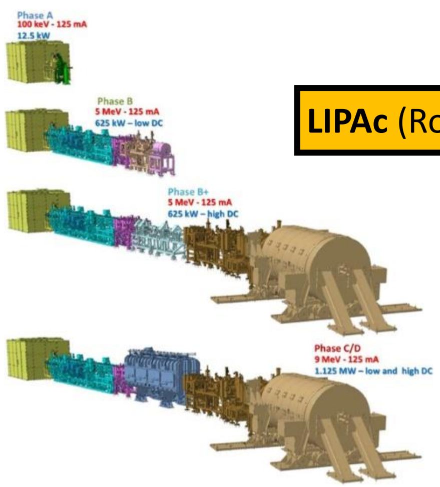
- power management
- impurities management – corrosion risks-
- reliability, lifetime,...

Test samples in unprecedent radiation environment

- RH
- Reliability
- Long term T control
- Miniaturized designs,...

IFMIF-DONES facility

- **Prototyping and validation activities have been performed since 2007**
  - BA (IFMIF/EVEDA) 2007-
  - ENS WP of EUROfusion 2015-
  - Other additional national projects



LIPAc (Rokkasho)

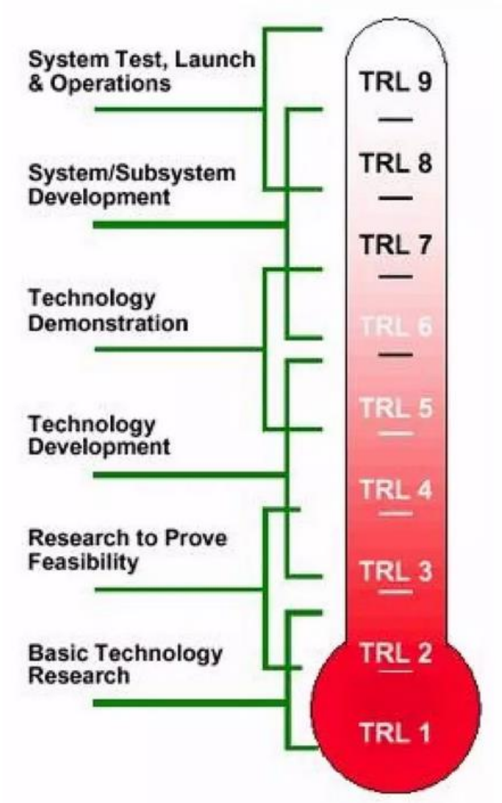
SOME PRESENT ONGOING VALIDATION ACTIVITIES

- ❑ **Start-Up Monitoring Module prototype**. Irradiation module to used during the commissioning phase in order to fully characterize the radiation map
- ❑ **Quick Disconnecting System** (QDS) for RH joints in Target Assembky and Accelerator HEBT line.
- ❑ **Multipurpose VaCuum accidental scenarios** (MuVaCas). To analyze different posible accidental scenarios
- ❑ **Electromagnetic Pump prototype**.
- ❑ **Li purification prototipe loop** (**LITEC**) to test impurity control technology (traps and monitors)
- ❑ **LIFIRE** facility to study Lithium fire risks
- ❑ **High Beta cavity & RF coupler**
- ❑ **Meander-type beam extraction** system
- ❑ **Solid State RF Power Amplifier** @175 MHz 200 kW CW
- ❑ **Shielding** benchmarking using a 35 MeV (p, Be) neutron source

- **A TRL Analysis has been performed to detect pending R&D activities to bring the designs to the right matureness level before their procurement**

TRL Analysis

TRL levels



- The development of high-tech systems depends on the succesful **synchronized evolution** of the individual technologies needed.
- **The Technology Readiness Assesment (TRA)** analyzes the maturity of a Project, allowing the consistent comparison of maturity between different types of technologies, thus contributing to risk reduction in budget and schedule.
- The elements of the Project to be analyzed are the so-called **Critical Technology Elements (CTEs)**: at-risk technologies essential to the succesful operation of the facility, which are new or are being applied in new or novel ways or environment
- After the analysis each CTE is assigned a **Technology Readiness Level (TRL),** according to a given **TRL scale**

TRL Analysis

- TRL originally developed in USA by the **NASA** in the 1980's (as a tool for communication of technology maturity and for planning)
- **DOE** and other government agencies employ it to manage the technical risk in R&D. *Technology Readiness Assesment Guide, US DOE, Washington 2011*
- In Europe, **ESA** adopts the TRL methodology in 2008 *Technology Readiness Levels Handbook for Space Applications (6 ed.). ESA. September 2008. TEC-SHS/5551/MG/ap.*
- **European Commission** is also employing technology readiness levels for funding R&D projects (from H2020) and for innovation and market penetration studies. *https://ec.europa.eu/research/participants/data/ref/h2020/other/wp/2016-2017/annexes/h2020-wp1617-annex-ga_en.pdf*

TRL scale differs slightly depending on the context of the projects being assessed

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TRL scale for DONES

- TRL scales used by DOE and EU Horizon2020 are identical up to TRL6.
- TRL7 definition used in EU Horizon2020 has been found more appropriate for the IFMIF DONES asessment.

EU Horizon 2020 technology readiness levels

Level	Description
TRL 1	Basic principles observed, the start of scientific research
TRL 2	Technology concept formulated, no to very little experimental proof of concept
TRL 3	Experimental proof of concept conducted
TRL 4	Technology validated in the laboratory
TRL 5	Technology validated in a relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6	Technology demonstrated as a fully functional prototype in a relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 7	System prototype demonstration in operational environment
TRL 8	System complete and qualified
TRL 9	Actual system proven in an operational environment (competitive manufacturing in the case of key enabling technologies or in space)

Horizon 2020 Work Programme 2016–2017
https://ec.europa.eu/research/participants/data/ref/h2020/other/wp/2016-2017/annexes/h2020-wp1617-annex-ga_en.pdf

DONES project has some special characteristics that affect its TRL Assesment:

1. Components and systems closest to the DONES target, operate under a **unprecedent radiation environment**
2. Central phenomena like the deposition of **the beam energy on the lithium** target will not be tested before the facility construction.
3. Global **operational availability requirement of 70%** imposes very strict RAMI requirements on systems and components, which will not be fully demonstrated at the start-up.

TRL scale for DONES

- TRL scales used by DOE and EU Horizon2020 are identical up to TRL6.

- TRL7 definition used in EU Horizon2020 has been found more appropriate for the IFMIF DONES assesment.

Considering the particularities of IFMIF-DONES, some adaptations are performed

- As the **radiation environment** of the systems and components closest to the DONES target cannot be re-created in any testbench, relevant / operational radiation levels will not be reached in the prototype tests. For these cases, the TRL value is estimated without considering the radiation environment. An * is added to the level to reflect this fact.
- **TRL6** (Engineering scale prototype validated with tests in a relevant environment) **has been splitted in two levels** according to the performance level attained in the tests:
  - TRL6a:. **Full performance not reached**.
  - TRL6b:. **Design conditions reached**.
- Issues that can not be proven before the facility is installed and commissioned (beam-target interaction, some RAMI data) have not been considered in the TRA

TRL scale for DONES

TRL scale	Description
TRL 1	Basic principles observed.
TRL 2	Technology concept formulated.
TRL 3	Feasibility demonstrated through calculations and experimental proof.
TRL 4	Technology validated in laboratory.
TRL 5	Technology validated in laboratory in relevant environment. [1]
TRL 6a	Engineering scale prototype tested in relevant environment. Full performance not reached. [1]
TRL 6b	Engineering scale prototype validated with tests in a relevant environment. Design conditions reached. [1]
TRL 7	Full-scale prototype demonstrates full performance in the operational environment. [1]
TRL 8	Actual system qualified.
TRL 9	Actual system qualified in full range of operating conditions.

[1]When the radiation environment conditions during tests are far from the operational ones, readiness level is denoted as TRLX*

TRL testing requirements

TRL Level	Scale of Testing	Fidelity	Environment
7 & 7*	Full	Similar	Operational
6b & 6b*	Engineering / Pilot	Similar	Relevant
6a &6a*	Engineering / Pilot	Similar	Relevant
5 & 5*	Lab/Bench	Similar	Relevant
4	Lab	Pieces	Simulated
3	Lab	Pieces	Simulated
2		Paper	
1		Paper	

Engineering Scale Typical (1/10 < system < Full Scale)

Levels with *: radiation environment is not reproduced in the tests

TRL assessment methodology

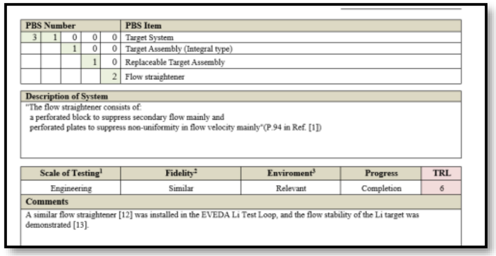
1. Identification of the CTE

- DONES Plant Breakdown Structure (PBS) up to 4th level (inclusive).
- Based on the Design reports (PEDR), and with the help of the design coordinators of the different areas, the CTEs have been identified
- Those systems and components for which tested commercial solutions exist are not CTEs

2. Assessing the Technology Readiness Level (TRL)

- A first TRL evaluation for Lithium and Test Systems was done in 2015 (S. Nitti, EFDA_D_2MN4PY)
- In 2021, a compilation of the status of all validation activities developed since 2015 was performed. The main lessons learned, the implications in the DONES systems design and remaining open points were listed for each activity by the experts in charge.
- The analysis of the maturity of the whole facility (up to 4th level in the PBS) has been performed (EFDA_D_2MUVWU) based on
  - The previous evaluation
  - The updated information about the design
  - The information compiled from the experts in charge of the past and ongoing validation experiments
  - Discussions with the coordinators of the different groups of systems (accelerator, target, test, RH)

Template sheet 2015



PBS Number					PBS Item
3	1	0	0	0	Target System
		1	0	0	Target Assembly (Integral type)
			1	0	Replaceable Target Assembly
				2	Flow straightener

Description of System

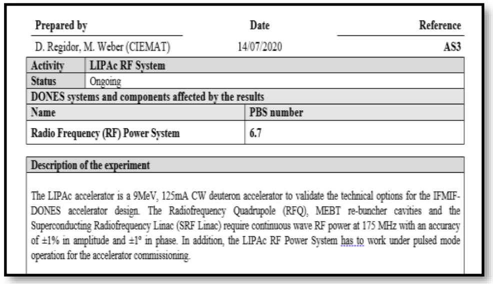
"The flow straightener consists of:
a perforated block to suppress secondary flow mainly and
perforated plates to suppress non-uniformity in flow velocity mainly"(P.94 in Ref. [1])

Scale of Testing[1]	Fidelity[2]	Enviroment[3]	Progress	TRL
Engineering	Similar	Relevant	Completion	6

Comments

A similar flow straightener [12] was installed in the EVEDA Li Test Loop, and the flow stability of the Li target was demonstrated [13].

Template sheet 2021



Prepared by	Date	Reference
D. Regidor, M. Weber (CIEMAT)	14/07/2020	AS3

Activity	**LIPAc RF System**
Status	Ongoing
DONES systems and components affected by the results	
Name	**PBS number**
Radio Frequency (RF) Power System	**6.7**

Description of the experiment

The LIPAc accelerator is a 9MeV, 125mA CW deuteron accelerator to validate the technical options for the IFMIF-DONES accelerator design. The Radiofrequency Quadrupole (RFQ), MEBT re-buncher cavities and the Superconducting Radiofrequency Linac (SRF Linac) require continuous wave RF power at 175 MHz with an accuracy of ±1% in amplitude and ±1° in phase. In addition, the LIPAc RF Power System has to work under pulsed mode operation for the accelerator commissioning.

NOTE: in some cases, the design of the components does not have enough definition for assessing their TRL (or for evaluating whether they involve CTE or not). These cases have been identified. A follow-up should be done as the design evolves.

TRL Assesment Methodology

Eng. validation& Eng. Design activities (EVEDA) → Analysis of DDD and Technical documents → Information from Recent/ongoing R&D → Discussions with Area Coordinators

Example of TRA on Lithium diagnostics

Documents

IFMIF-DONES Target System Design Description Document (DDD)

	Deliverable	X	Technical Report
	Management Report		Technical Note
	Other	Specify:	

Li flow diagnostics Systems: Requirements and State of the Art in the Contact Probe, Laser Probe, Different Alternatives

Li flow diagnostics Systems: Requirements and State of the Art in the Contact Probe, Laser Probe, Different Alternatives

	Deliverable		Technical Report
	Management Report	x	Technical Note
	Other	Specify:	

Templates

Activity	**Li jet diagnostics. Laser probe studies (3D model surface and water target)**
Status	Finished / ongoing/ under design
DONES systems and components affected by the results	
Name	**PBS number**
Li jet diagnostics	**5.2.4.1.**

Description of the experiment

Test measurements with a measurement system similar to the Optical comb absolute distance meter on different

Main results. Lessons learned

- The measurements with the 3D model surface show that the spatial resolution of the optical measurement system is sufficient
- The sensor is able to measure the surface of the tested specular metal surfaces up to an angle of approximately 15°

Open points

Those first test measurements with the ATS600 do show that measurements on a liquid metal surface with oxides are

References (articles, reports)

Further details in the IDM Report: EFDA_D_2NEAJK

Determination of required validation activities

- **Target TRL values to be achieved** before procurement were assigned to each S&C

> ❖ **New technologies developed for DONES shall in general reach TRL7 before manufacturing**. However, target TRL values have been assigned case by case considering the tests and prototypes that can be realistically performed

> ❖ For those components which will can not be **tested in relevant radiation environment** – not reaching the integrated dose expected in their lifetime–, the level to be achieved **has been set as TRL7***

> ❖ **There are some issues that cannot be fully validated before commissioning of IFMIF-DONES**. The operational experience acquired during this phase will be used to validate some technologies and to trigger improvements

- Those systems & components whose asessed TRL values are lower than the assigned target TRL require **further validation**.
- The remaining R&D activities have been worked out from the previously compiled design+validation information and taking into account the judgement of the area coordinators
- Some additional validation activities, usually affecting several components, are motivated by open issues related to Project transversal activities (safety, neutronics, control, RAMI,…)

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Results

PBS Number 1	2	3	4	PBS Item	TRL	Target TRL at handover
4				**TEST SYSTEMS**		
	2			**Test Cell**		
		4		Test Cell Liner	3	5
		8		LICS Test Cell		
			1	Neutron detectors		
				Activation Foils	4	7
				Neutron Activation Systems	2	7
				Micro Fission Chambers, SPND	4	7
	3			**High Flux Test Module (HFTM)**		
		1		HFTM Container 8x4	5	7*
		2		HFTM Attachment Adapter Assembly	3	7*
		4		HFTM Container Piping Assembly		
			10	HFTM Bellow Arrangement	4	7
		6		HFTM Capsule Set	5*	7*
		7		HFTM Local Instrumentation and Control	4	7*
		8		HFTM PCP Bridges		
			1	HFTM PCP Cable Bridge Group	2	7
	4			**Start-Up Monitoring Module (STUMM)**		
		1		STUMM Container Assembly	5	7
		2		STUMM Attachment Adapter Assembly	2	7*
		4		STUMM Cooling System Assembly		
			2	Pipes to Container	4	7*
		5		Rigs Set	5*	7*
		7		LICS of STUMM	4	7*
		8		STUMM PCP Bridges		
			1	STUMM PCP Cable Bridge Group	3	7
		9		Measuring System for Rabbit System	2	7

PBS Number 1	2	3	4	PBS Item	TRL	Target TRL at handover
5				**LITHIUM SYSTEMS**		
	2			**Target System**		
		1		Target Assembly		
			4	Backplate (BP)	4	6a*
		2		Target Assembly Support		
			2	TAA centering and positioning system	2	6a*
		3		Quench Tank		
			3	Flow Incoming Unit	4	6a*
		4		LICS of Target System		
			1	Li Jet Diagnostic	3	6a*
			2	Other diagnostics (TBD)	2	6a*
	3			Heat Removal System		
		1		Primary Loop (Li loop)		
			1	Electromagnetic Pump	6a	6b
			3	Dump Tank	4	6a
	4			**Impurity Control System (ICS)**		
		2		Traps		
			1	Cold Trap	5*	6a*
			2	Hydrogen Hot Trap	3	6a*
		3		Impurity Monitoring		
			2	Resistivity Meter	5*	6a*
			3	Hydrogen sensor	5*	6a*
			4	Off-line Sampler	3	6a*

PBS Number 1	2	3	4	PBS Item	TRL	Target TRL at handover
6				**ACCELERATOR SYSTEMS**		
	2			**Injector System**		
		1		Source and Extraction Subsystem	7	7
		2		LEBT		
			4	Beam Chopper	5	7
		3		LICS of Injector System		
			1	Current transformers	5	7
			2	Transverse Profile Monitor	5	7
			3	Emittance Meter Unit	5	7
			5	Local Control of Injector System	6	7
	3			**Radio Frequency Quadrupole (RFQ) System**		
		1		RFQ cavity	5	7
		2		RFQ Couplers	5	7
		3		LICS of RFQ System	5	7
	4			**Medium Energy Beam Transport (MEBT) System**		
		1		Re-buncher cavities	5--7	7
		2		Beam line	5--7	7
		3		Scrapers	5	7
	5			**Superconducting RF Linac (SRF) System**		
		1-2		Cryomodule 1 &2	4-5	7
		3-5		Cryomodule 3,4&5	3	6b
		6		LICS of SRF System	5	7
		7		Warm sections	5	7
	6			**High Energy Beam Transport Line and Beam Dump System**		
		1		Beam line		
			1	Beam pipes	6	7/7*
			2	Shutters	5*	7/7*
		2		Beam stoppers		
			1	HEBT Main line Scraper	5*	6b*
			2	BD secondary line Scraper	5	6a
			3	HEBT Main line Collimator	4	6b*
		5		Beam Dump	5	6a
		7		LICS of HEBT and BD	5*	7*
	7			**Radio Frequency (RF) Power System**		
		1		RFQ Block. Stations RFQ-1 to RFQ-8	3	
		3-7		Cryo-1 -5 Blocks	3	7
		8		LICS of RF Power System	5	7

Results

PBS Number				PBS Item	TRL	Target TRL at handover
1	2	3	4			
4				TEST SYSTEMS		
	2			Test Cell		
		4		Test Cell Liner	3	5

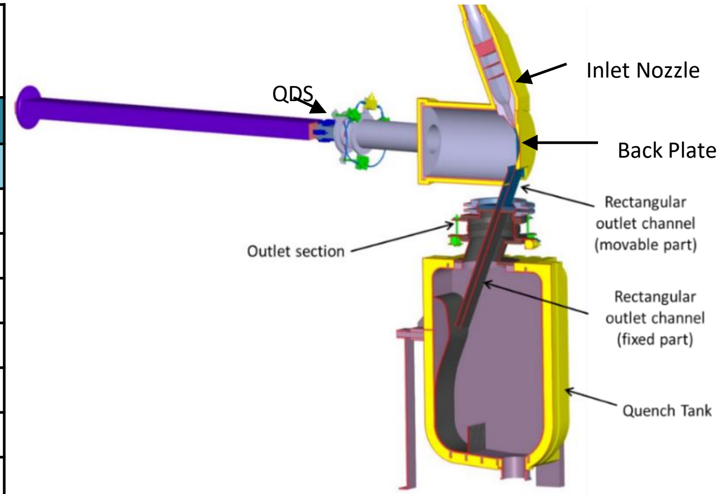
PBS Number				PBS Item	TRL	Target TRL at handover
1	2	3	4			
5				LITHIUM SYSTEMS		
	2			Target System		

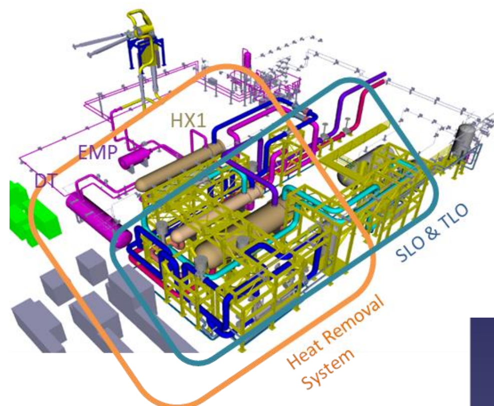
PBS Number				PBS Item	TRL	Target TRL at handover
1	2	3	4			
6				ACCELERATOR SYSTEMS		
	2			Injector System		
		1		Source and Extraction Subsystem	7	7
		2		LEBT		
			4	Beam Chopper	5	7
		3		LICS of Injector System		
			1	Current transformers	5	7
			2	Transverse Profile Monitor	5	7
			3	Emittance Meter Unit	5	7
			5	Local Control of Injector System	6	7
	3			Radio Frequency Quadrupole (RFQ) System		
		1		RFQ cavity	5	7
		2		RFQ Couplers	5	7
		3		LICS of RFQ System	5	7
	4			Medium Energy Beam Transport (MEBT) System		
		1		Re-buncher cavities	5--7	7
		2		Beam line	5--7	7
		3		Scrapers	5	7
	5			Superconducting RF Linac (SRF) System		
		1-2		Cryomodule 1 &2	4-5	7
		3-5		Cryomodule 3,4&5	3	6b
		6		LICS of SRF System	5	7
		7		Warm sections	5	7
	6			High Energy Beam Transport Line and Beam Dump System		
		1		Beam line		
			1	Beam pipes	6	7/7*
			2	Shutters	5*	7/7*
		2		Beam stoppers		
			1	HEBT Main line Scraper	5*	6b*
			2	BD secondary line Scraper	5	6a
			3	HEBT Main line Collimator	4	6b*
		5		Beam Dump	5	6a
		7		LICS of HEBT and BD	5*	7*
	7			Radio Frequency (RF) Power System		
		1		RFQ Block. Stations RFQ-1 to RFQ-8	3	
		3-7		Cryo-1 -5 Blocks	3	7
		8		LICS of RF Power System	5	7

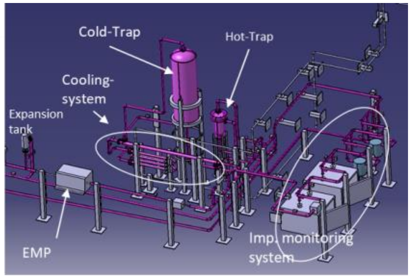
Table 8-1: Summary of validation activities

PBS number	Code	Validation Activity	Financed by	Status
3.5	{VRH 1}	Validation of the TLIC RH operations and manipulators	TBD	Under discussion
3.5	{VRH 2}	Validation of PKM operability in relevant conditions	TBD	Not foreseen
3.5	{VRH 3}	Further validation tests of the lithium cleaning machine in relevant conditions	TBD	Under discussion
3.5	{VRH 4}	Test bench to test the positioning of shielding blocks of the Test Cell	Outside	On-going
3.5	{VRH 5}	Validation of the HFTM dismantling procedure	TBD	Not foreseen
3.7	VPS1	Prototype and test of Electro-Magnetic Compatibility (EMC)	Outside	On-going
4.2	{VTS 1 }	Tests of liner penetration weldings	TBD	Under discussion
4.2	{VTS 2}	Thermal conductance tests of concrete + pipes + metal plates (for RBSBs and TC floor)	WPENS	Foreseen
4.3	{VTS 3 }	Tests HFTM including tests in HELOKA	WPENS	Foreseen
4.3	{VTS 4}	RH of cables and connector for HFTM and STUMM, including PCP bridges	WPENS	On-going
4.3	{VTS 5 }	Endurance tests of rigs/capsules	TBD	Not foreseen
4.3	{VTS 6 }	Heater, thermocouples and electrical connections irradiations	WPENS	On-going
4.3	{VTS 7 }	Capsule Sodium extraction procedure	WPENS	Under discussion
4.3	{VTS 8 }	Microfission chambers validation	WPENS	Foreseen
4.3	{VTS 9 }	NAD validation	WPENS	Foreseen
4.3	{VTS 10 }	SPNDs validation	WPENS	On-going
4.3	{VTS 11 }	Dummy proto of HFTM for RH studies	TBD	Under discussion
4.4	{VTS 12 }	Tests of STUMM leaktight joints	TBD	Not foreseen

PBS Number				PBS Item	TRL	Target TRL at handover
1	2	3	4			
5				**LITHIUM SYSTEMS**		
	2			**Target System**		
		1		Target Assembly		
			4	Backplate (BP)	4	6a*
		2		Target Assembly Support		
			2	TAA centering and positioning system	2	6a*
		3		Quench Tank		
			3	Flow Incoming Unit	4	6a*
		4		LICS of Target System		
			1	Li Jet Diagnostic	3	6a*
			2	Other diagnostics (TBD)	2	6a*
	3			**Heat Removal System**		
		1		Primary Loop (Li loop)		
			1	Electromagnetic Pump	6a	6b
			3	Dump Tank	4	6a
	4			**Impurity Control System (ICS)**		
		2		Traps		
			1	Cold Trap	5*	6a*
			2	Hydrogen Hot Trap	3	6a*
		3		Impurity Monitoring		
			2	Resistivity Meter	5*	6a*
			3	Hydrogen sensor	5*	6a*
			4	Off-line Sampler	3	6a*







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Results Lithium systems

PBS Number				PBS Item	TRL	Target TRL at handover
1	2	3	4			
5				LITHIUM SYSTEMS		
	2			Target System		
		1		Target Assembly		
			4	Backplate (BP)	4	6a*
		2		Target Assembly Support		
			2	TAA centering and positioning system	2	6a*
		3		Quench Tank		
			3	Flow Incoming Unit	4	6a*
		4		LICS of Target System		
			1	Li Jet Diagnostic	3	6a*
			2	Other diagnostics (TBD)	2	6a*
	3			Heat Removal System		
		1		Primary Loop (Li loop)		
			1	Electromagnetic Pump	6a	6b
			3	Dump Tank	4	6a
	4			Impurity Control System (ICS)		
		2		Traps		
			1	Cold Trap	5*	6a*
			2	Hydrogen Hot Trap	3	6a*
		3		Impurity Monitoring		
			2	Resistivity Meter	5*	6a*
			3	Hydrogen sensor	5*	6a*
			4	Off-line Sampler	3	6a*

➢ Performed validation: ELTL loop, Lifus6, DRP, Japanese universities, others

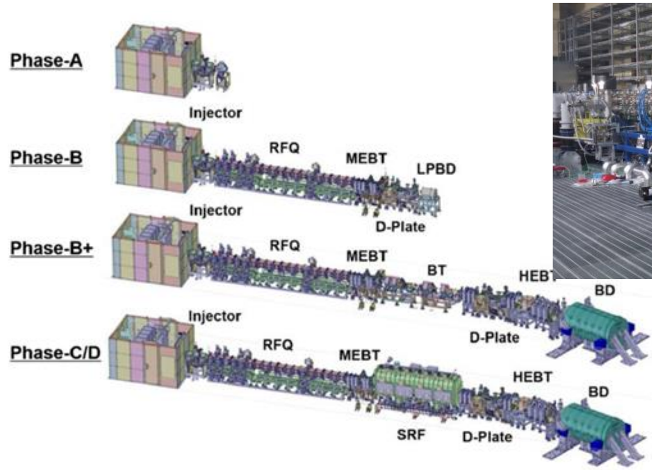
stability of Li jet & manufacturing of target assembly, cold trap (preliminary)

➢ Main remaining validation:
- Li jet diagnostic
- EM pump
- Impurity Control System: H trap, cold trap, N getter, monitors

Results Accelerator systems

PBS Number				PBS Item	TRL	Target TRL at handover
1	2	3	4			
6				**ACCELERATOR SYSTEMS**		
	2			**Injector System**		
		1		Source and Extraction Subsystem	7	7
		2		LEBT		
			4	Beam Chopper	5	7
		3		LICS of Injector System		
			1	Current transformers	5	7
			2	Transverse Profile Monitor	5	7
			3	Emittance Meter Unit	5	7
			5	Local Control of Injector System	6	7
	3			**Radio Frequency Quadrupole (RFQ) System**		
		1		RFQ cavity	5	7
		2		RFQ Couplers	5	7
		3		LICS of RFQ System	5	7
	4			**Medium Energy Beam Transport (MEBT) System**		
		1		Re-buncher cavities	5--7	7
		2		Beam line	5--7	7
		3		Scrapers	5	7
	5			**Superconducting RF Linac (SRF) System**		
		1-2		Cryomodule 1 &2	4-5	7
		3-5		Cryomodule 3,4&5	3	6b
		6		LICS of SRF System	5	7
		7		Warm sections	5	7
	6			**High Energy Beam Transport Line and Beam Dump System**		
		1		Beam line		
			1	Beam pipes	6	7/7*
			2	Shutters	5*	7/7*
		2		Beam stoppers		
			1	HEBT Main line Scraper	5*	6b*
			2	BD secondary line Scraper	5	6a
			3	HEBT Main line Collimator	4	6b*
		5		Beam Dump	5	6a
		7		LICS of HEBT and BD	5*	7*
	7			**Radio Frequency (RF) Power System**		
		1		RFQ Block. Stations RFQ-1 to RFQ-8	3	
		3-7		Cryo-1 -5 Blocks	3	7
		8		LICS of RF Power System	5	7

- **The main validation activity is the test of the** prototype accelerator **LIPAc**.



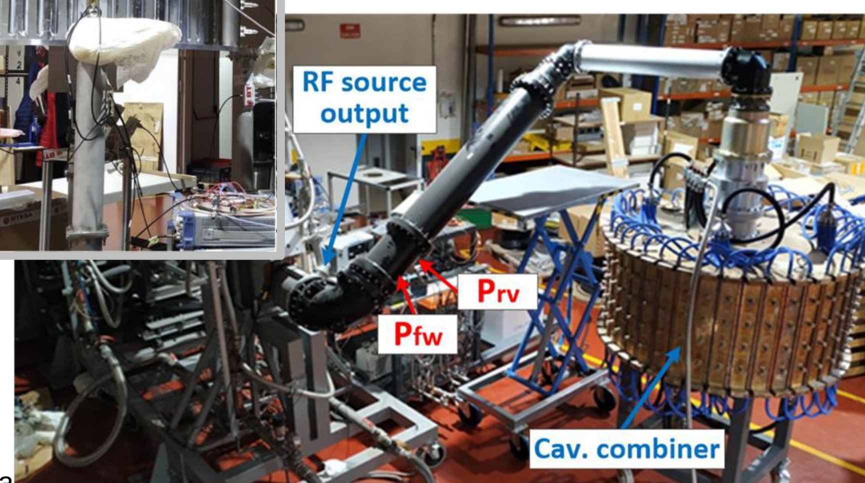
Yann Carin
This session P5B2

- As it is being commissioned in sequential phases involving beam experiments with the injector, RFQ and cryomodule and progressively increasing current and duty cycle, the accelerator elements are at different stages of the validation.
- Presently the full accelerator except the SRF linac has been installed and it has operated **with pulsed deuteron beams up to 125 mA current accelerated up to 5 MeV.**

Results Accelerator systems

PBS Number 1	2	3	4	PBS Item	TRL	Target TRL at handover
6				ACCELERATOR SYSTEMS		
	2			Injector System		
		1		Source and Extraction Subsystem	7	7
		2		LEBT		
			4	Beam Chopper	5	7
		3		LICS of Injector System		
			1	Current transformers	5	7
			2	Transverse Profile Monitor	5	7
			3	Emittance Meter Unit	5	7
			5	Local Control of Injector System	6	7
	3			Radio Frequency Quadrupole (RFQ) System		
		1		RFQ cavity	5	7
		2		RFQ Couplers	5	7
		3		LICS of RFQ System	5	7
	4			Medium Energy Beam Transport (MEBT) System		
		1		Re-buncher cavities	5--7	7
		2		Beam line	5--7	7
		3		Scrapers	5	7
	5			Superconducting RF Linac (SRF) System		
		1-2		Cryomodule 1 &2	4-5	7
		3-5		Cryomodule 3,4&5	3	6b
		6		LICS of SRF System	5	7
		7		Warm sections	5	7
	6			High Energy Beam Transport Line and Beam Dump System		
		1		Beam line		
			1	Beam pipes	6	7/7*
			2	Shutters	5*	7/7*
		2		Beam stoppers		
			1	HEBT Main line Scraper	5*	6b*
			2	BD secondary line Scraper	5	6a
			3	HEBT Main line Collimator	4	6b*
		5		Beam Dump	5	6a
		7		LICS of HEBT and BD	5*	7*
	7			Radio Frequency (RF) Power System		
		1		RFQ Block. Stations RFQ-1 to RFQ-8	3	
		3-7		Cryo-1 -5 Blocks	3	7

- **Additional** **R&D activities** are needed regarding DONES elements not included in the accelerator prototype, such as:
  - **RF power sources** based on solid state technology
  - The three last cryomodules of the **SRF linac** (high β cavities)
  - The DONES **HEBT line** (more complex, with stricter RAMI and RH requirements, and in high radiation environment close to the target)
- Most of the required R&D activities are already ongoing



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Results Accelerator systems

PENDING VALIDATION ACTIVITIES

PBS number	Code	Validation Activity	Financed by	Status
6.2-6.6	{VAS 1}	Experimental campaigns in LIPAc: including injector, RF, RFQ, SRF linac, MEBT, HEBT, Beam Dump, Cryoplant and diagnostics	WPENS	Ongoing
6.2	{VAS 2 }	Development and tests of chopper for pulsed operation (commissioning with interceptive beam diagnostics)	TBD	
6.2	{VAS 3}	Upgraded emittance meter	WPENS	On-going
6.2	{VAS 4 }	Development and tests of Safety Shutdown System		Not foreseen
6.2	{VAS 5 }	Search and tests of an alternative to the boron nitride discs, to extend their lifetime before replacement	WPENS	Foreseen
6.3	{VAS 6}	Prototyping and testing of high power RF couplers for RF without viton sealing (brazed window)	TBD	
6.3	{VAS 7}	Manufacturing and tests of a high beta cavity for the SRF LINAC	WPENS	On-going
6.3	{VAS 8}	Prototyping and testing of high power RF couplers for superconducting cavities (up to 200 kW)	WPENS	Foreseen
6.5	{VAS 9 }	Tests of Microloss monitors for the SRF	WPENS + BAII	On-going
6.6	{VAS 10 }	The use of Fluorescence Profile Monitors adapted to DONES facility. Validation of technology and procedure	WPENS	On-going
6.6	{VAS 11 }	RGBLM for longitudinal monitoring and other diagnostics systems	Outside	On-going
6.6	{VAS 12}	Beam Instrumentation for beam footprint at Li target	WPENS	Foreseen
6.3-6.6	{VAS 13}	R&D related to nBLOM for their use in DONES	WPENS	On-going
6.8	{VAS 14}	Multi-purpose vacuum experiments to validate last section of the accelerator line (HEBT) in case of accidental scenarios, this including the fast valve and argon injection system of the TAA.	Outside	On-going
6.6	{VAS 15 }	Prototype of kicker for the extraction of the beam	TBD	Foreseen
6.6	{VAS 16}	Tests of Quick disconnection systems for the acceleration chambers		Not foreseen
6.3	{VAS 17 }	Validation of RF power station at full power	WPENS	On-going
6.7	{VAS 18}	Development and tests of coaxial line with flexible supports for RF lines connection to SRF linac couplers	TBD	Not foreseen

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Validation activities

Identification of available facilities for DONES activities

Summary of facilities for testing & validation

Name	Owner	Status	Scope
Valeria Lab	UGR	New	Virtual reality of DONES for different purposes such as validating RH and Maintenance operations, and for formative/training purposes.
Lab control systems for LIPAC/DONES	UGR	New	R&Ds on control system for DONES and remote control of LIPAC facility
MuVacAs	UGR	New	Multipurpose vacuum experiments, simulating the accelerator vacuum line. Aiming at validating safety related equipment (fast valves) and analyzing different phenomenon in case of accidental scenario (shock waves, etc.)
Lyder	CIEMAT	new	Experimental facility for investigation on H-isotopes getters under quasi dynamic conditions
Li fire test facility (LiFire)	CIEMAT	New	Facility for researching on lithium safety issues in case of lithium fire
LITEC	CIEMAT	New	Development of systems related to monitoring, control and capture of impurities in flowing liquid lithium in similar conditions to DONES
CIEMAT Materials Laboratory (Spain)	CIEMAT	commissioned	Validation of SSTT techniques
High Power RF laboratory (Spain)	CIEMAT	commissioned	Validation and test of Radio Frequency systems
ANGEL	ENEA	New	Investigation on getters for Nitrogen capture in liquid Lithium
Lifus-6	ENEA	commissioned	Experimental facility for corrosion tests under Lithium environment
Lithium experimental facility (Be-7 deposition)	ISSP-UL	New	Lithium experimental facility for Be-7 deposition experiments under different working conditions.
Divertor Test Platform (DRP)	ENEA	Upgrade	Validation of Remote-Handling operations
SUPRATech (France)	CNRS/CEA	commissioned	Manufacturing and tests of a high beta cavities
MARIA reactor (Poland)	NCBJ	commissioned	Irradiation campaign of several components under representative neutron and gamma source.
HELOKA-LP Helium Loop (Germany)	KIT	commissioned	Helium Loop facility to test components of ITER, DEMO and DONES
FLEX Helium loop (Germany)	KIT	commissioned	Multi-purpose small scale gas loop for research on fluid-dynamic and/or thermodynamic applications
GALINKA gallium-indium-tin loop (Germany)	KIT	commissioned	Investigation on Lithium Free surface detection
Liquid Metal laboratory	KIT	commissioned	Handling of Na and SSTT specimens in capsules of HFTM

- Given the particularities of DONES, specific facilities are required in order to recreate the proper conditions for prototyping testing

Results

PENDING MANUFACTURING TESTS

Plant Breakdown	Code	Manufacturing Activity	Status
4.3	MTS1	Manufacturing of the container (including HIP process)	Eurofusion 2023 TS
4.3	MTS2	Manufacturing of a capsule of the HFTM	TBC
5.2	MLS1	Manufacturing techniques of TAA	On-going
6.6	MAS1	Lead shutter tests	TBC
6.6	MAS2	Tests to validate the choice for remotely aligned TIR module supports	TBC

These tests could be included as part of the manufacturing contracts, being performed by the component manufacturers. If performed before handover, these activities will be useful to detail better the procurement technical specifications as well as to obtain a better estimation of the cost, contributing probably to time and money savings in the final procurement.

Conclusions

A systematic **TRL analysis** of DONES has been carried out as a project management tool
Elements requiring further validation have been identified
Pending experimental activities have been compiled

- **Plant Systems related technologies are mostly commercial, and they do not require dedicated validation activities**, except the Remote Handing subsystem.
- Regarding the **Test Systems, there is the need of further developments of neutron detectors** adequate for DONES spectrum among other R&D activities.
- **Most of the validation activities of Lithium Systems are focused on the purification technologies**. This technologies are foreseen to be tested in LITEC under relevant DONES conditions.
- **The DONES accelerator will be validated mostly with the operation of its prototype LIPAc**. Specific R&D activities are needed regarding DONES elements not included in the accelerator prototype, such as the three last cryomodules and the HEBT line.

✓ Most of the validation activities recommended have been already considered under Eurofusion WPENS or covered by research units collaborating with the IFMIF- DONES Project
✓ **Additional future R&D activities should be guided by these findings**
✓ This analysis is intended to be periodically updated, as design and validation activities evolve.

Thanks for your attention

Validation activities

Several activities have been identified to bring the current TRLs to the level required (TRL objective)

Summary of activities for Test Systems

PBS number	Code	Validation Activity	Status
4.2	{VTS 1 }	Tests of liner penetration weldings	Under discussion
4.2	{VTS 2}	Thermal conductance tests of concrete + pipes + metal plates (for RBSBs and TC floor)	Foreseen
4.3	{VTS 3 }	Tests HFTM including tests in HELOKA	Foreseen
4.3	{VTS 4}	RH of cables and connector for HFTM and STUMM, including PCP bridges	On-going
4.3	{VTS 5 }	Endurance tests of rigs/capsules	Foreseen for 2023 TS
4.3	{VTS 6 }	Heater, thermocouples and electrical connections irradiations	On-going
4.3	{VTS 7 }	Capsule Sodium extraction procedure	Under discussion
4.3	{VTS 8 }	Microfission chambers validation	Foreseen
4.3	{VTS 9 }	NAD validation	Foreseen
4.3	{VTS 10 }	SPNDs validation	On-going
4.3	{VTS 11 }	Dummy proto of HFTM for RH studies	Under discussion
4.4	{VTS 12 }	Tests of STUMM leaktight joints	Not foreseen
4.4	{VTS 13 }	Tests of detectors working at low distances (for STUMM)	On-going
4.4	{VTS 14 }	Rabbit System. Test of transport of balls	Not foreseen still

Some examples of proposed and ongoing validation activities :

Test Cell

- Full prototype of the TC liner is not practical due to its size, but partial prototypes could be produced to clarify specific issues. **Procedure of welding/unwelding and technologies shall be tested** to minimize thermo-mechanical induced deformations to reach the required functional tolerances. **{VTS 1}**

- **The production and testing of some concrete shield blocks prototypes** with embedded pipes and/or cooling plates could be convenient to evaluate the heat transmission inside the block and deduce the value of the conductance between concrete and steel, thus validating the design and numerical analysis both of the RBSBs and of the TC floor **{VTS 2}**

HFTM

- Problems with the heaters insulation were observed during the irradiations performed in BR2 in the EVEDA phase of the IFMIF project. **Tests under neutron radiation of heater, thermocouples and electrical connectors**, to learn both about lifetime and radiation effects should be done. These tests must be performed at the foreseen operation temperatures (300 / 400 / 550 ºC). Irradiation of heaters is presently ongoing at MARIA reactor. **{VTS 6}**