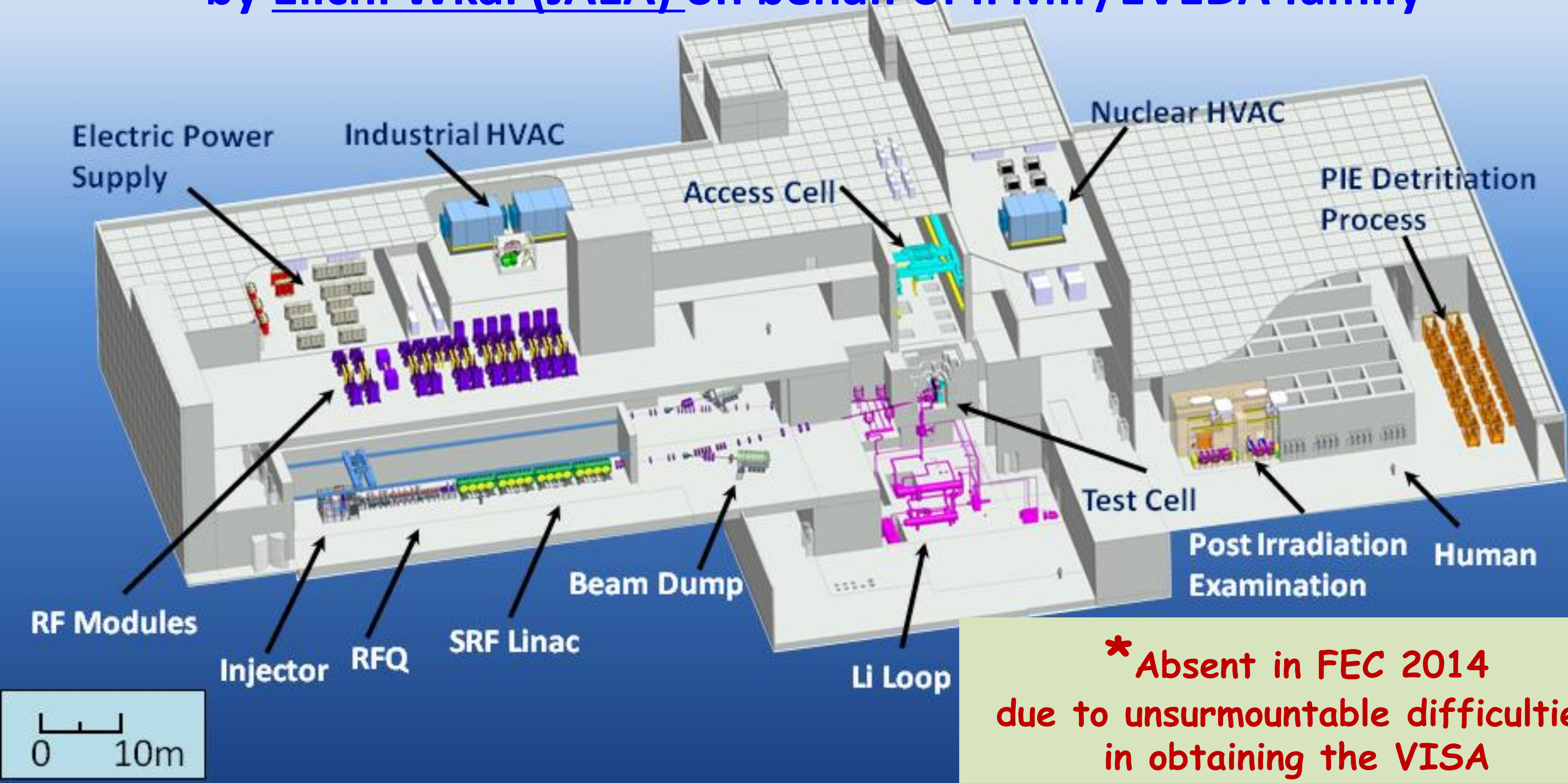
FNS/1-2Ra & MPT/1-Rb

(1) The accomplishment of the engineering design activities of IFMIF/EVEDA: The European-Japanese project towards a Li(d,xn) fusion relevant neutron source

by Juan Knaster* on behalf of IFMIF/EVEDA family

(2) Evaluation of Li Target Facility of IFMIF in the IFMIF/EVEDA Project

by Eiichi Wkai (JAEA) on behalf of IFMIF/EVEDA family



*Absent in FEC 2014 due to unsurmountable difficulties in obtaining the VISA

IFMIF/EVEDA

IFMIF:

International Fusion Materials Irradiation Facility

EVEDA:

Engineering Validation & Engineering Design Activities

Article 1.1 of Annex A of the BA Agreement

mandates IFMIF/EVEDA

…to produce an integrated engineering design of IFMIF and the data necessary for future decisions on the construction, operation, exploitation and decommissioning of IFMIF, and to validate continuous and stable operation of each IFMIF subsystem

(Signed in February 2007, Entered into force on June 2007)

IFMIF through all technical steps

IFMIF evaluation has successfully passed through all needed key steps as below:

- ✓ Conceptual Design Activity (CDA) phase in 1996

  As a joint effort of the EU, Japan, RF and US

- ✓ Conceptual Design Evaluation (CDE) report in 1998

  Towards a design simplification and cost reduction

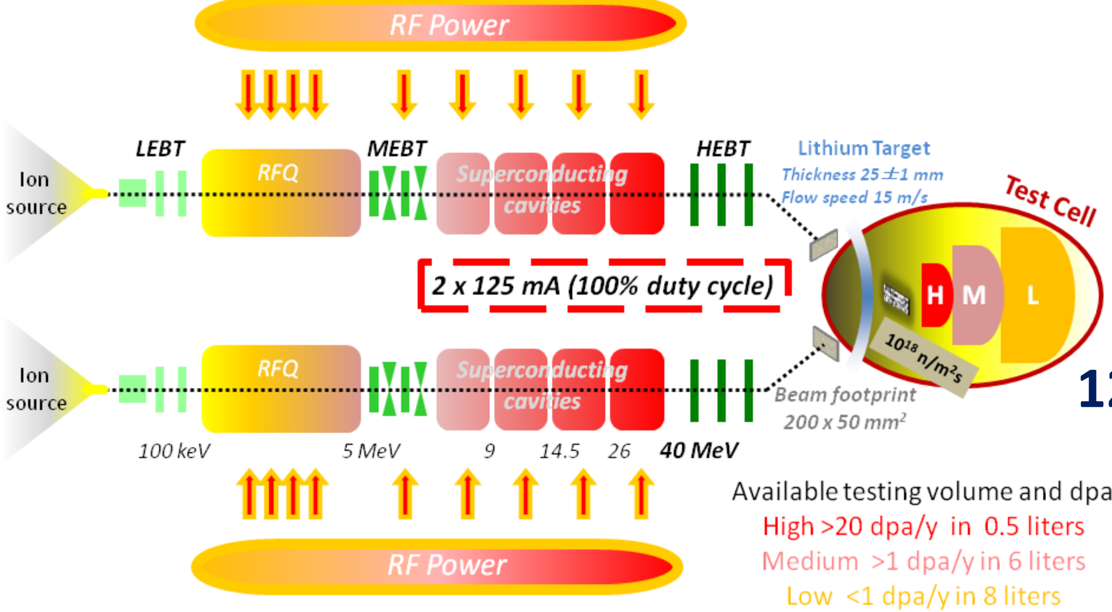
- ✓ The Conceptual Design Report (CDR) in 2004

  Co-written by a committee of EU, Japan, RF, US

- ✓ The final Phase of EVEDA within BA activities from 2007

  As an efficient risk mitigation exercise to face the construction on cost and schedule timely with the world needs for a fusion relevant neutron source

IFMIF Concept

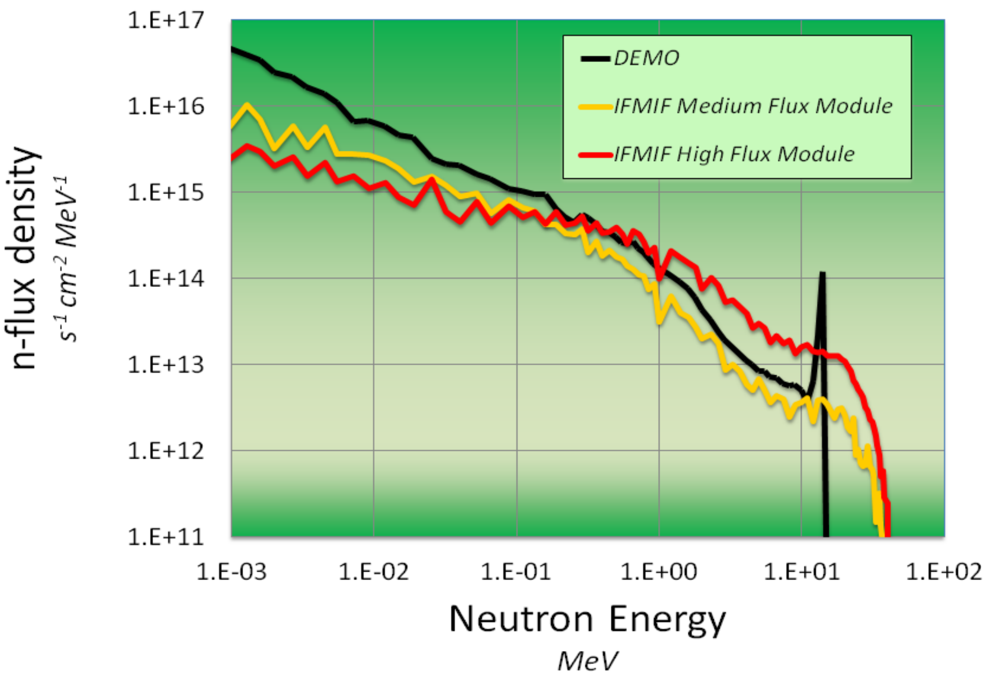


125 mA CW deuterons at 40 MeV collide on a liquid Li screen flowing at 15 m/s

A flux of neutrons of ~10^{18} $m^{-2}s^{-1}$ is generated in the forward direction with a broad peak at 14 MeV and irradiate three regions

>20 dpa/y in 0.5 liters
>1 dpa/y in 6 liters
<1 dpa/y in 8 liters

Materials will be tested in the PIE



Availability of facility >70%

A Fruitful International Collaboration

IFMIF/EVEDA

A fruitful Japanese- European

International collaboration under the BA Agreement

with 7 countries involved

with the respective main research labs in Europe

and main universities in Japan

Two Work Packages

EVEDA Phase

presents two parallel work packages

EDA Phase

Engineering Design Activities

EVA Phase

Engineering Validation Activities

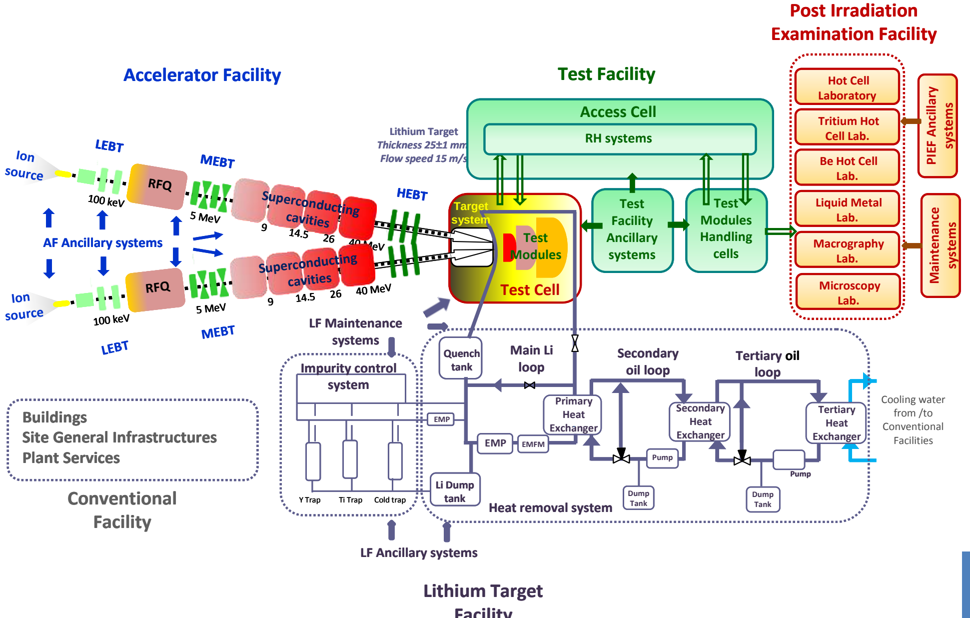
The Design of IFMIF is broken down to 5 facilities

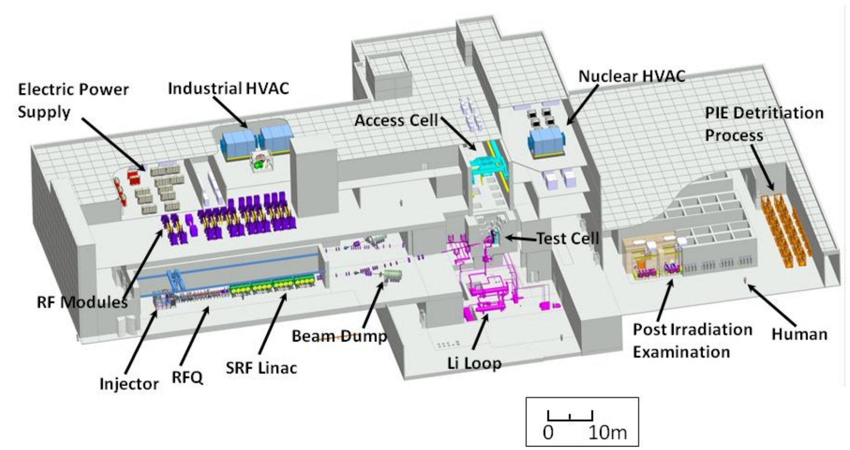
Objective of Validation activities

- Accelerator Facility
- Lithium Target Facility
- Test Facility

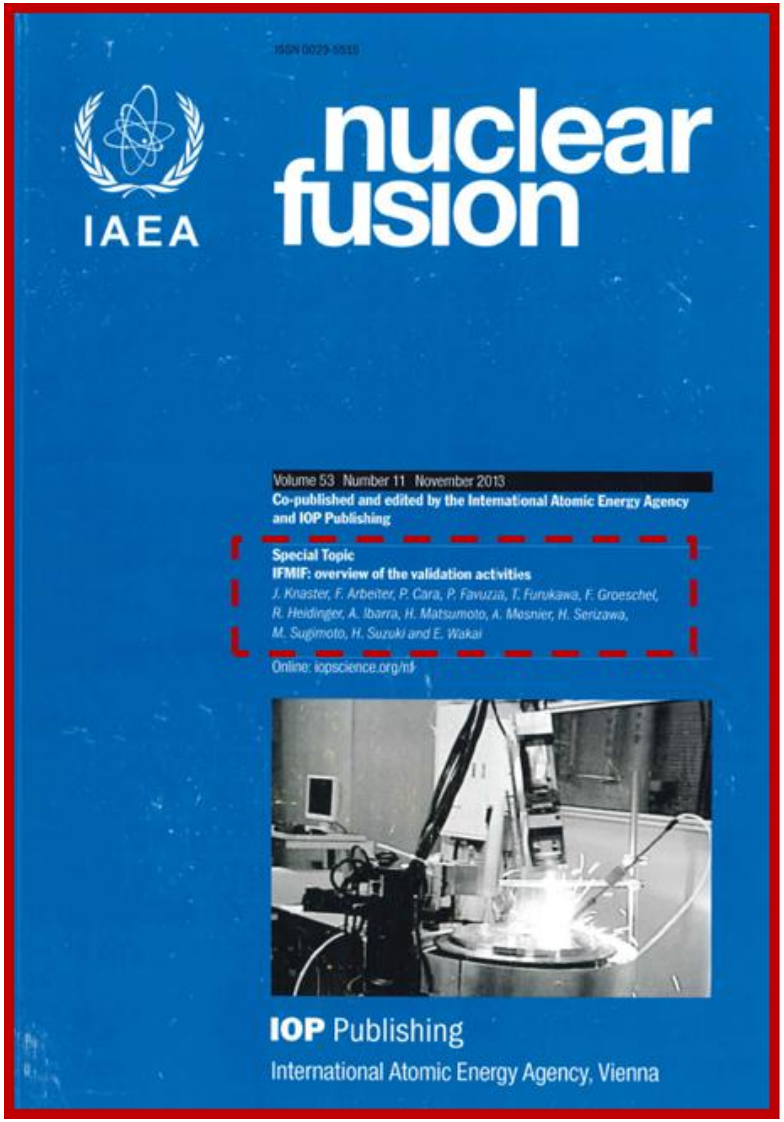
Post-irradiation and Examination Facility

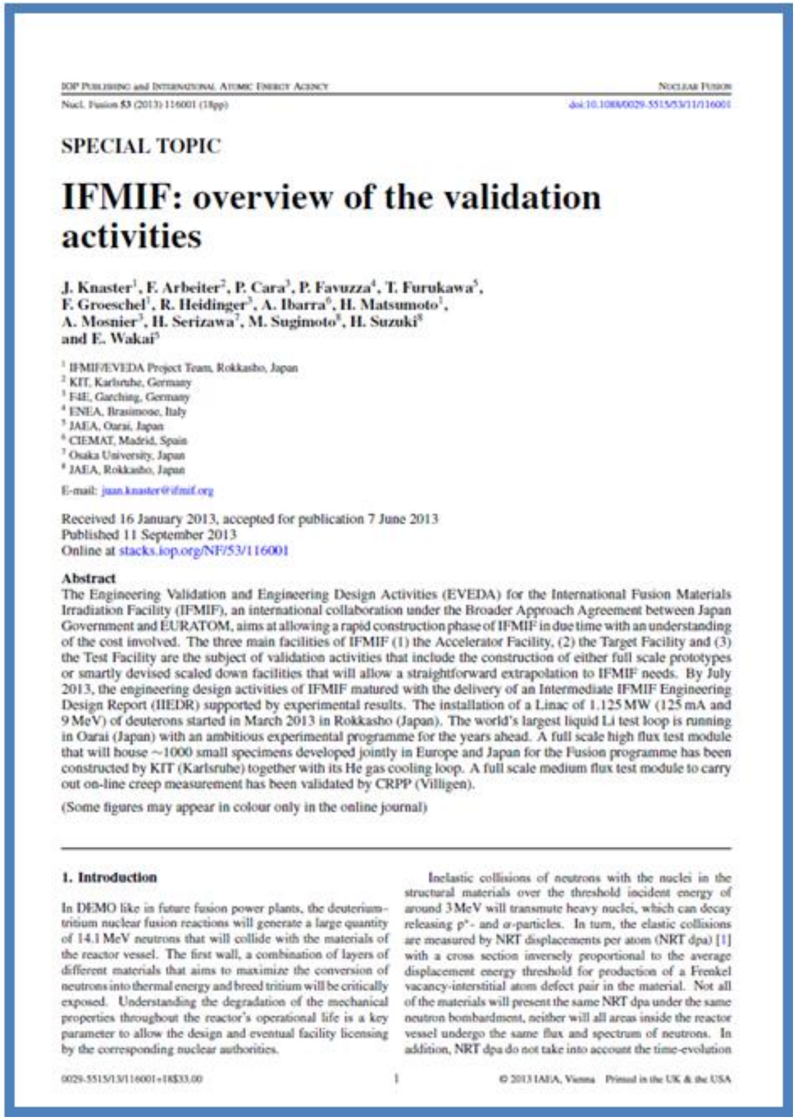
Conventional Facilities





EVA Phase Advancing Successfully





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SPECIAL TOPIC

IFMIF: overview of the validation activities

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Abstract
The Engineering Validation and Engineering Design Activities (EVEDA) for the International Fusion Materials Irradiation Facility (IFMIF), an international collaboration under the Broader Approach Agreement between Japan Government and EURATOM, aims at allowing a rapid construction phase of IFMIF in due time with an understanding of the cost involved. The three main facilities of IFMIF (1) the Accelerator Facility, (2) the Target Facility and (3) the Test Facility are the subject of validation activities that include the construction of either full scale prototypes or smartly devised scaled down facilities that will allow a straightforward extrapolation to IFMIF needs. By July 2013, the engineering design activities of IFMIF matured with the delivery of an Intermediate IFMIF Engineering Design Report (IIEDR) supported by experimental results. The installation of a Linac of 1.125 MW (125 mA and 9 MeV) of deuterons started in March 2013 in Rokkasho (Japan). The world's largest liquid Li test loop is running in Oarai (Japan) with an ambitious experimental programme for the years ahead. A full scale high flux test module that will house ~1000 small specimens developed jointly in Europe and Japan for the Fusion programme has been constructed by KIT (Karlsruhe) together with its He gas cooling loop. A full scale medium flux test module to carry out on-line creep measurement has been validated by CRPP (Villigen).

(Some figures may appear in colour only in the online journal)

1. Introduction

In DEMO like in future fusion power plants, the deuterium–tritium nuclear fusion reactions will generate a large quantity of 14.1 MeV neutrons that will collide with the materials of the reactor vessel. The first wall, a combination of layers of different materials that aims to maximize the conversion of neutrons into thermal energy and breed tritium will be critically exposed. Understanding the degradation of the mechanical properties throughout the reactor's operational life is a key parameter to allow the design and eventual facility licensing by the corresponding nuclear authorities.

Inelastic collisions of neutrons with the nuclei in the structural materials over the threshold incident energy of around 3 MeV will transmute heavy nuclei, which can decay releasing p^+- and α-particles. In turn, the elastic collisions are measured by NRT displacements per atom (NRT dpa) [1] with a cross section inversely proportional to the average displacement energy threshold for production of a Frenkel vacancy-interstitial atom defect pair in the material. Not all of the materials will present the same NRT dpa under the same neutron bombardment, neither will all areas inside the reactor vessel undergo the same flux and spectrum of neutrons. In addition, NRT dpa do not take into account the time-evolution

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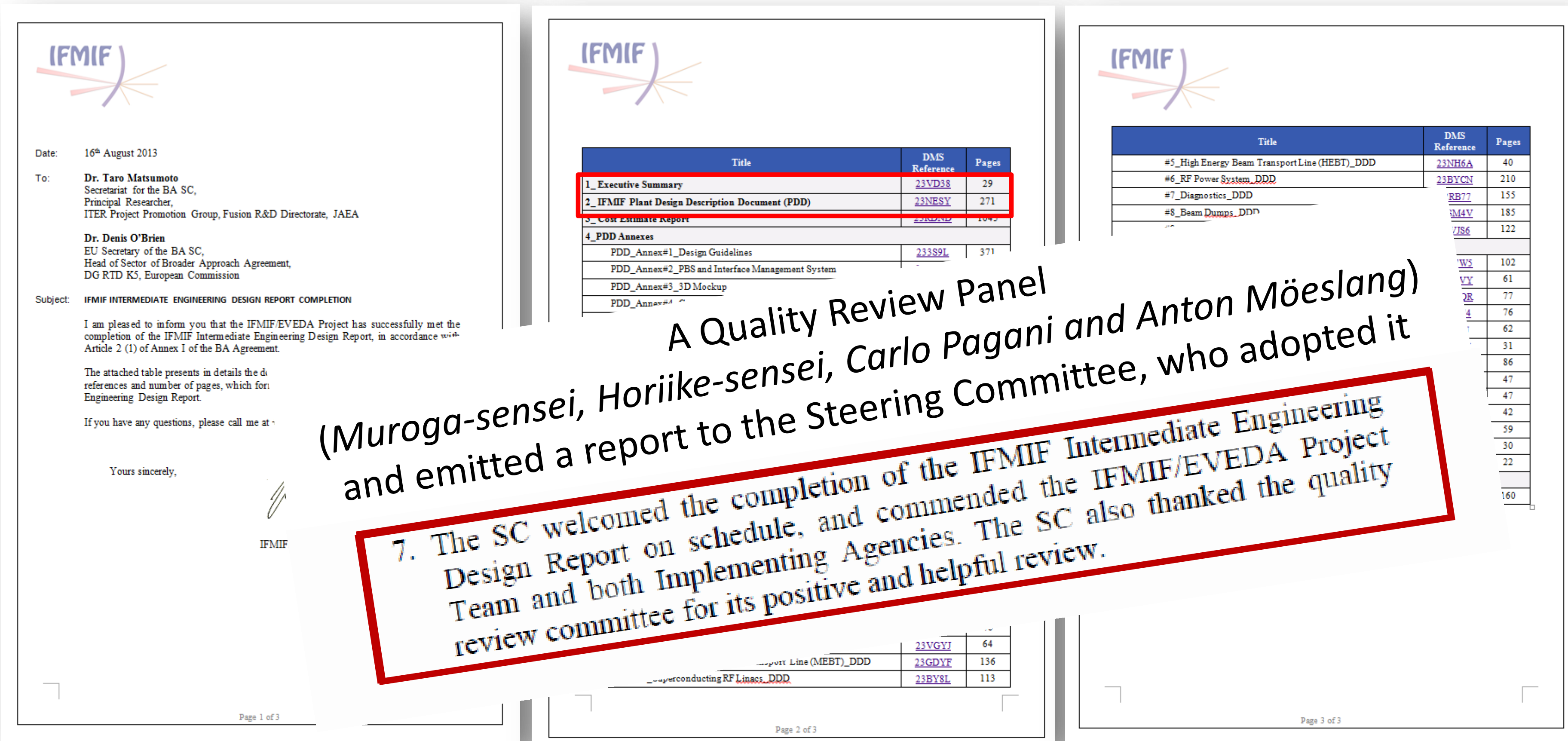
J. Knaster et al., *IFMIF: overview of the validation activities,* Nuclear Fusion 53 (2013) 116001 (18 pp)

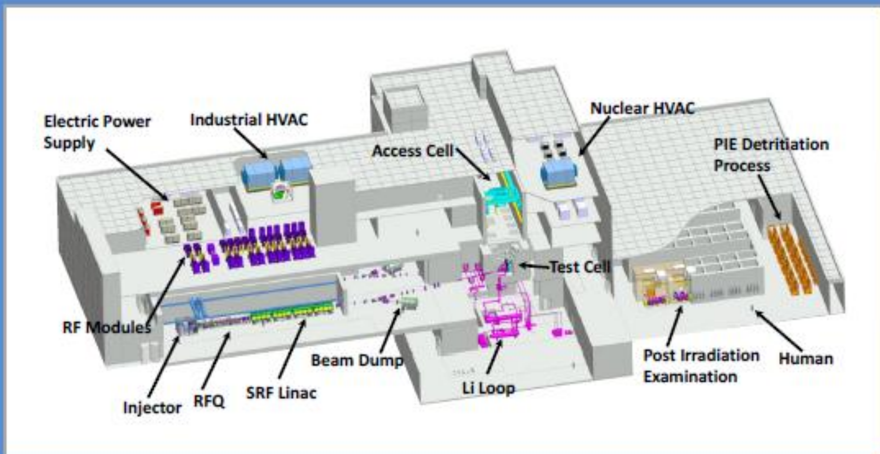
EDA Phase Accomplished on Schedule



Complete WBS, detailed 3D models of plant, RAMI of individual facilities, remote handling studies, DDDs of all sub-systems (x35), licensing scenarios, safety reports, cost and schedule…

IFMIF Plant Description document

IFMIF



THE INTERNATIONAL FUSION MATERIAL IRRADIATION FACILITY

INTERMEDIATE ENGINEERING DESIGN REPORT

The IFMIF/EVEDA Integrated Project Team

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Report available upon request at ifmif-eveda@ifmif.org

Main Design **Improvements** from CDR

(CDR: Comprehensive Design Report)

- ✓ Alvarez-type Drift Tube Linac replaced by a Superconducting RF Linac
  Reduction in beam losses and operation costs

- ✓ Configuration of the Test Cell changed
irradiation modules have no more a shielding function
  Improved irradiation flexibility and the reliability of the remote handling equipment

- ✓ Quench Tank of the Lithium loop re-located outside the Test Cell
  Reduction of tritium production rate and simplification of maintenance processes

- ✓ Maintenance strategy modified
  Allowing a shorter yearly stop of the irradiation operations
and a better management of the irradiated samples.

Mario Pérez and the IFMIF/EVEDA Integrated Project Team
The Engineering Design Evolution of IFMIF: from CDR to EDA Phase
SOFT 2014

Risk Analysis

IFMIF RISK ANALYSIS
BA_D_242P5R v1.0

IFMIF RISK ANALYSIS

Abstract

The present document briefly describes the methodology used for the IFMIF risk analysis and reports the results obtained.

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Reviewer(s)	Roland Heidinger Shigeru O'Hira	F4E JAEA
Approver	Juan Knaster	IFMIF/EVEDA PL

Project Risk Register

Probability and Impact Matrix

	1. Trivial impact	2	3	4	5. Critical impact
1. Very unlikely	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5. Quite likely	5	10	15	20	25

Exposure

0-3 = Trivial
4-9 = Minor
10-16 = Substantial
17-25 = Intolerable

Risk Reference Number (ID)	Description	Likelihood Rating 1 to 5	Impact Rating: Technical	Schedule	Cost	Exposure	Risk Management Strategy	Description of Action Required
1	Technological feasibility of running low energy hadrons over 100 mA in CW	2	4	4	4	8	Mitigate	Feasibility is to be proven in IFMIF/EVEDA Phase
2	Higher than expected losses jeopardizing hands-on maintenance	3	2	3	4	12	Mitigate	Technology upgrade to be developeed for beam formation and guidance elements
3	Injector will not provide the full current (140 mA) with less than 0.3 mmmrad emittance value	2	3	3	2	6	Accept	Run at reduced current to maintain emittance value
4	RFQ missing to reach 90% transmission factor	2	3	2	3	6	Accept	Run at reduced current to reduce total beam losses and dose rates
5	MEBT's bunchers not capable to match the beam twiss parameters with the SRF Linac	3	3	2	3	9	Accept	Run at reduced current to reduce total beam losses and dose rates in RFQ
6	Excesive losses in the Scrapers	1	2	3	2	3	Mitigate	Enarge scraper filter window to reduce loss at the cost of beam profile at target
7	Low-β cavities not able to manage high beam currents	2	4	4	4	8	Mitigate	Feasibility is to be proven in IFMIF/EVEDA Phase
8	Quenching on the cavities before nominal accelerating field is reached	1	4	5	5	5	Mitigate	Feasibility is to be proven in IFMIF/EVEDA Phase
9	Tuning of the accelerator based on micro-halo monitors is not effective	2	3	3	3	6	Transfer	Use alternative beam diagnostics
10	Operation of 8 cavities cryomodule is not reliable enough	3	4	3	3	12	Mitigate	Reliability is to be proven in IFMIF/EVEDA Phase
11	High-β cavities not able to manage high beam currents	1	4	4	4	4	Accept	Run at reduced beam currents
12	HEBT fails to properly shape the beam at the target	2	3	2	2	6	Accept	Run with a degraded beam profile at the target
13	Non-efficient beam profile monitoring	2	3	2	2	6	Accept	Run with a degraded beam profile at the target
14	Unforeseen phenomena in the D+ beam - Li free surface interaction	2	5	5	3	10	Prevent	Plan an expermental test with protons at the very early stage of commissioning
15	Excessive corrosion rate in the nozzle of the target	3	4	4	4	12	Mitigate	Reduce the operation time while improving the mechnical pefection of the nozzle
16	Height of Li waves over specified values	3	3	3	3	9	Mitigate	Reduce slighty beam energy if critical margin of Bragg peak is exceeded
17	Impurity levels (H, N and others) over specified values in the flowing lithium	4	3	4	4	16	Prevent	Plan an expermental verification of the purification system at the very early stage of commissioning
18	Lack of diagnostic systems for Li flow characterization	3	3	3	3	9	Mitigate	Reduce slighty beam energy if critical margin of Bragg peak is exceeded
19	Uncertainty on the backplate lifetime due to unknown radiation effects on material properties	4	4	3	3	16	Mitigate	Foresee several spare backplate/target assembly components for early replacement
20	Maintenance procedure of the Target Assembly longer than expected	3	2	4	4	12	Mitigate	Procedure is to be proven in IFMIF/EVEDA Phase
21	Neutron flow pattern missing to meet specifications	2	3	3	2	6	Accept	Run with degraded neutron flux pattern
22	Non-efficient neutron profile monitoring	3	3	2	2	9	Accept	Use information from neutronic analysis
23	Loss of HFTM temperature control (heaters and/or Cooling system) during one irradiation campaign	2	4	5	4	10	Prevent	Plan an expermental verification of the heating system at the very early stage of commissioning
24	Uncertainty on the PCPs lifetime	2	4	3	3	8	Mitigate	Foresee several spare PCP assembly components for early replacement
25	Maintenance procedure in the Test Cell longer than expected	4	4	5	3	20	Mitigate	Reduce number of second-order Test Module limits, extend operation time beyond specifications
26	Crane failure in the Access Cell during maintenance activities	2	3	3	3	6	Prevent	Plan an expermental verification of the crane system at the very early stage of commissioning
27	Small specimen testing techniques do not satisfy testing standards	2	3	3	3	6	Mitigate	Promote Standardisation process to cover techniques applied
28	Availability of the IFMIF plant does not reach the values predicted by RAMI analysis	3	3	5	4	15	Mitigate	Reduce operation parameters for accelerator to enhance the reliability of the accelerator
29	Major difference between calculated and experienced radioactivation	2	4	5	4	10	Mitigate	Level of radioactivation is to be proven in IFMIF/EVEDA Phase

Likelihood Rating:

1 = Very Unlikely = 0 - 20%
2 = Unlikely = 20% - 40%
3 = Likely = 40% - 60%
4 = Very Likely = 60% - 80%
5 = Near Certain = 80% - 100%

Impact Rating

Technical
1 = Minimal or no degradation on performances
2 = Acceptable, marginal reduction on performances
3 = Significant threat to facility mission
4 = Serious threat to facility mission
5 = Catastrophic threat to facility mission

Cost
1 = Negligible impact (<1% estimated cost)
2 = Potential impact of 1-10% on estimated cost
3 = Potential impact of 10% <estimated cost <20%
4 = Potential impact of 20% < estimated cost < 40%
5 = Potential impact >40% on estimated cost

Schedule
1 = Minimal or no impact
2 = Marginal impact of a key milestone (3-6 weeks delay)
3 = Significant impact on a key milestone (1-3 months delay)
4 = Serious impact on a key milestone (3-6 months delay)
5 = Unacceptable impact on a key milestone (> 6 months delay)

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IFMIF, a fusion relevant neutron source for material irradiation current status

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ABSTRACT

The d-Li based International Fusion Materials Irradiation Facility (IFMIF) will provide a high neutron intensity neutron source with a suitable neutron spectrum to fulfil the requirements for testing and qualifying fusion materials under fusion reactor relevant irradiation conditions. The IFMIF project, presently in its Engineering Validation and Engineering Design Activities (EVEDA) phase under the Broader Approach (BA) Agreement between Japan Government and EURATOM, aims at the construction and testing of the most challenging facility sub-systems, such as the first accelerator stage, the Li target and loop, and irradiation test modules, as well as the design of the entire facility, thus to be ready for the IFMIF construction with a clear understanding of schedule and cost at the termination of the BA mid-2017. The paper reviews the IFMIF facility and its principles, and reports on the status of the EVEDA activities and achievements.

1. Introduction

A fusion relevant neutron source is a more than three decades old pending step for the successful development of fusion energy. Safe design, construction and licensing of a nuclear fusion facility by the corresponding Nuclear Regulatory agency will demand the understanding of the materials degradation under the neutrons irradiation during the life-time of the fusion reactor. The deuterium–tritium nuclear fusion reactions will generate neutron fluxes in the order of 10^{18} m^{-2} s^{-1} with an energy of 14.1 MeV. The first wall of the reactor vessel, a complex combination of layers of different materials will be most exposed undergoing potentially >15 dpa_{NRT} per year of operation [1,2]. It is indispensable that the plasma facing components can withstand the operational conditions without degradation of their mechanical and physical properties beyond defined thresholds driven, not only by nuclear safety reasons, but also by investment protection aspects. The main path for increasing the efficiency of power plants consists of raising the temperatures of transformation processes and energy transmission a period long enough to make a power plant economically interesting. Qualifying suitable materials at equivalent irradiation conditions as in a fusion reactor is a first step that concurrently with the understanding of the materials behaviour will lead, in hand with computations techniques, to the development of new materials capable of making the operation of a nuclear fusion power plant viable.

2. Why a fusion relevant neutron source?

Degradation of materials under neutron irradiation is a phenomenon anticipated in 1942 by Wigner [3]. Nuclei are transmuted through nuclear interactions with the incident neutrons to stable or radioactive nuclei via (n,α), (n,p), (n,γ) or other reaction channels. Through elastic and inelastic collisions neutrons initiate primary recoil knock-on atoms (PKA) [4] with a cascade of Frenkel vacancy-interstitial pairs with threshold energies as low as 40 eV for Fe and Cr [5]. The damage in the microstructure of the metal contributes to material degradation through the internal pressure of accumulated gas molecules resulting from the nuclear reactions.

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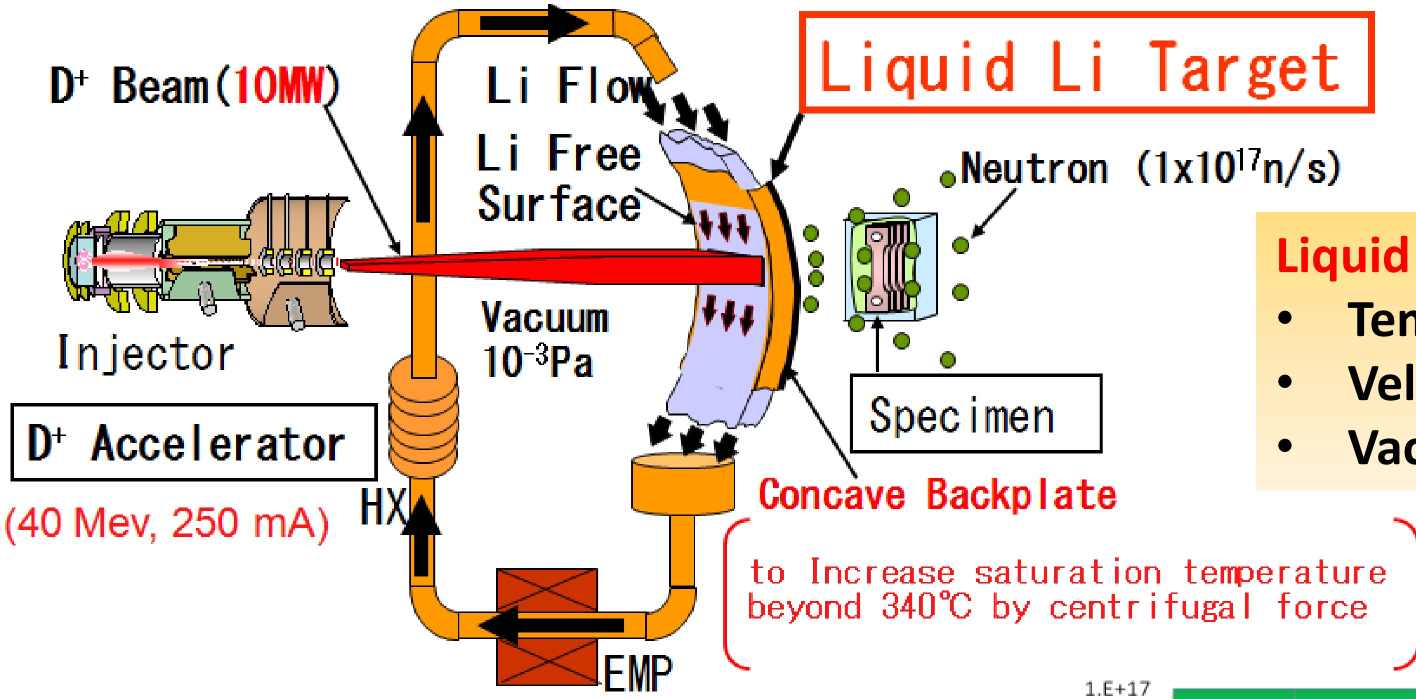
Part II:

Evaluation of Li Target Facility of IFMIF in the IFMIF/EVEDA Project

by Eiichi Wkai (JAEA) on behalf of IFMIF/EVEDA family

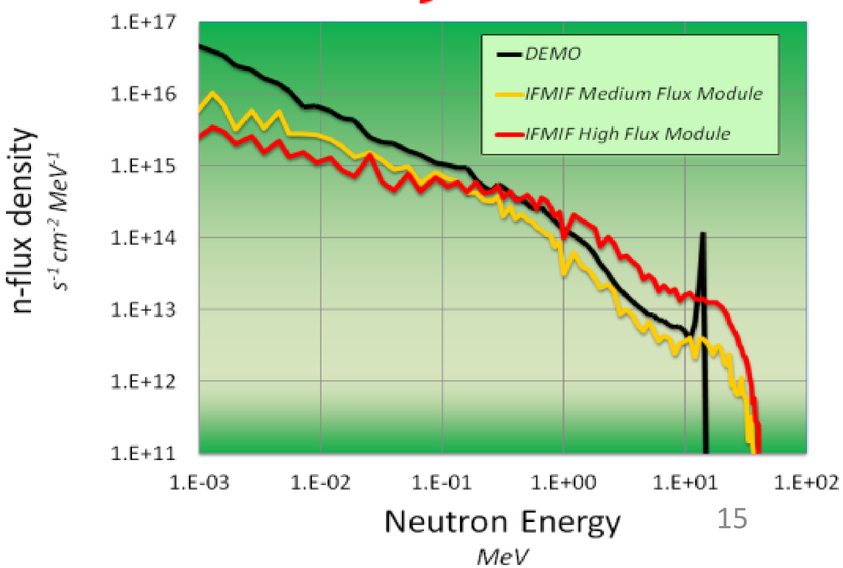
IFMIF Liquid Lithium Target Concept



Liquid Li Condition:

- Temp.: 250°C,
- Velocity: 15 m/s
- Vacuum: 10^{-2}-10^{-3} Pa

- D+-Li stripping reaction generates high intense neutrons to simulate fusion irradiation conditions.
- High-speed liquid Li flow along concave back plate is selected as IFMIF target to handle a high heat load of 10MW D+ beams.



Main Missions of EVEDA Li Test Loop (ELTL)

Major Requirements for Li Target in IFMIF

- Averaged heat flux : 1 GW/m^2
- **Jet velocity : 15 m/s (range 10-20 m/s)**
- **Jet thickness/Width : 0.025 m/0.26 m**
- **Surface wave amplitude : < +/- 1 mm**
- **Initial (inlet) Li temperature: 250 °C**
- **Vacuum pressure : 10^{-3} - 10^{-2} Pa near Li free surface**

Main Missions of EVEDA Li Test Loop (ELTL)

- Validation of **stable long-time operation of a high-speed free-surface liquid Li** simulating IFMIF target.

- Validations of **diagnostics on the Li flow** and impurity control systems for a Li loop.

Lithium Facility Subjects in IFMIF/EVEDA Projects

Engineering Validation Research

Construction, operation and tests of EVEDA Li test loop (installed at Oarai)

(1) Functional tests of each equipment
(2) Tests of high-speed fluid with a free surface under vacuum
(3) Long-duration tests

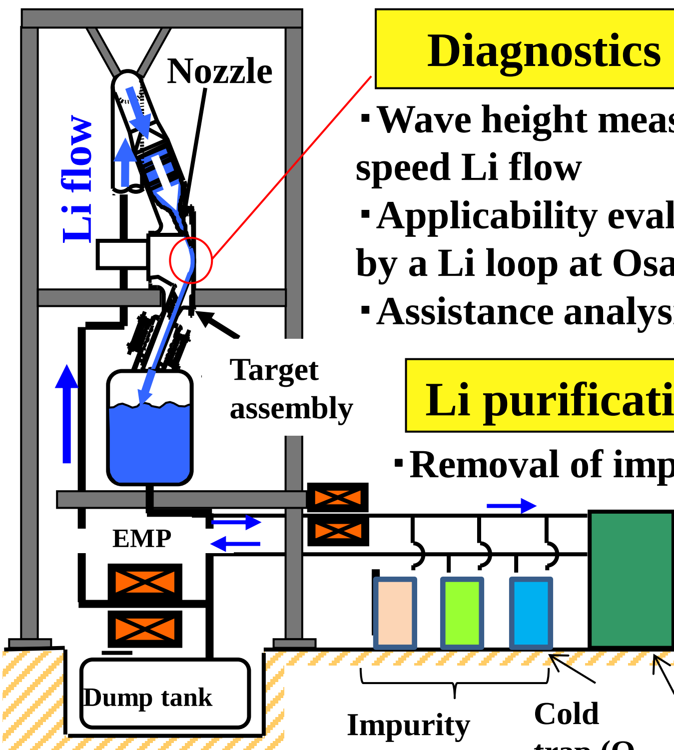
(the EU: Cavitation test, etc..)

Remote handling

- Replacement of the integrated target assembly (Japan).
- Replacement of only the backplate (the EU).

Erosion/Corrosion

- The tests for 1000 to 8000 hours in a small Li loop of the EU (F82H, Eurofer 97)



Diagnostics

- Wave height measurement of high-speed Li flow
- Applicability evaluation of diagnostics by a Li loop at Osaka Univ.
- Assistance analysis by a water test loop

Li Safety handling

- Li handling technology, fire extinguishing testing

Li purification system

- Removal of impurities in Li, impurity monitors

Engineering Design

Construction, operation and tests of EVEDA Li Test Loop (ELTL) – Schedule -

2007	2008	2009	2010	2011	2012	2013	2014

Basic Design

Engineering Design

Construction

Commissioning

Damaged by Earthquake

Repair

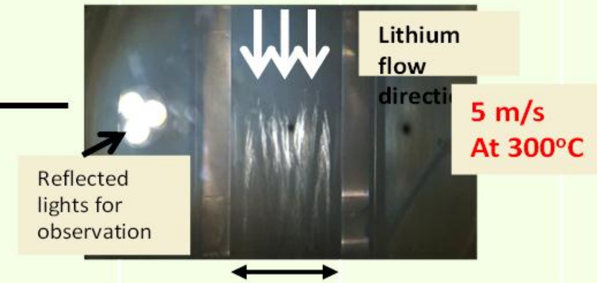
Re-Commissioning

Operation

Nov. 2009

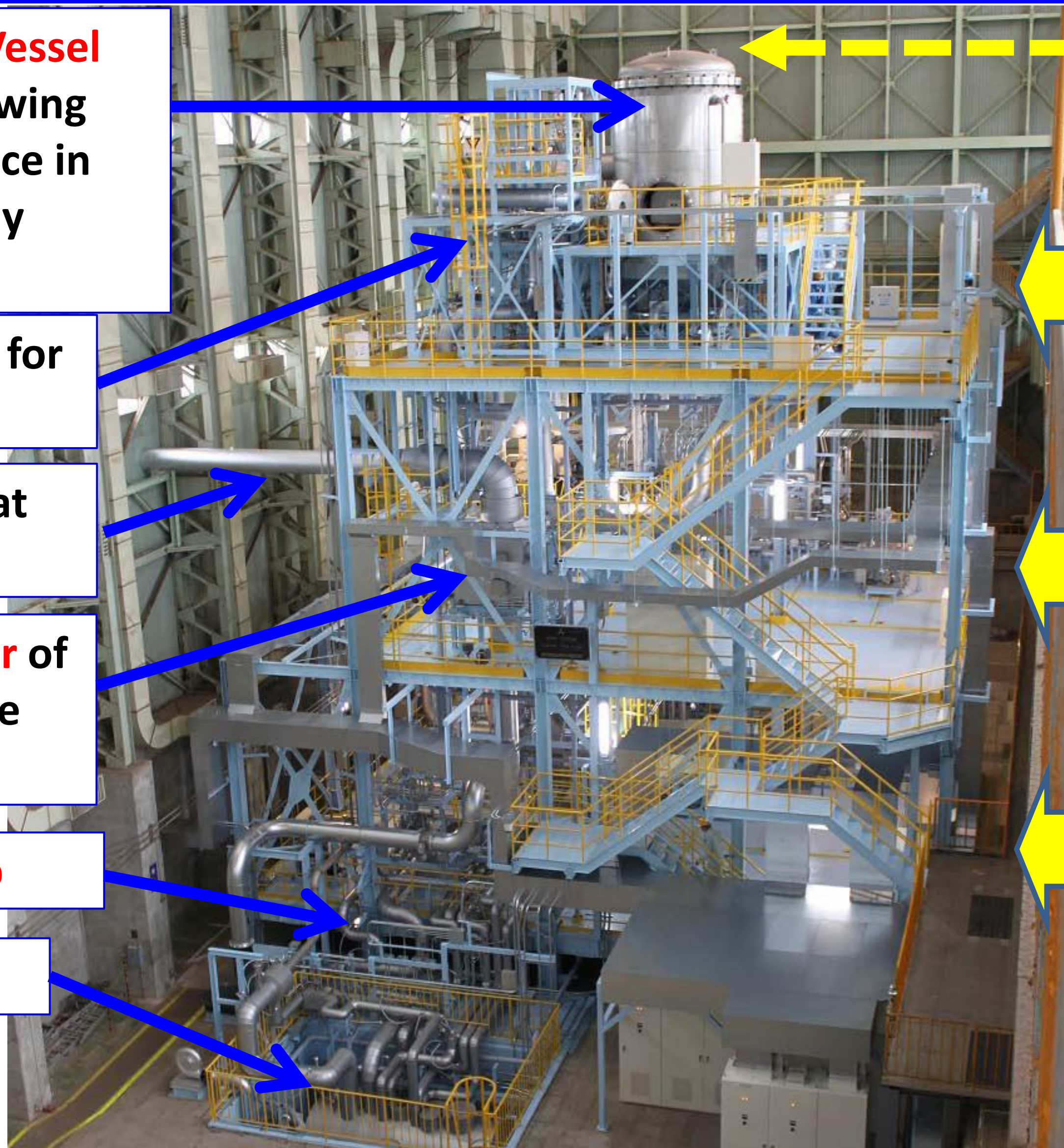
Feb. 2010

Nov. 2010



Feb. 2011

World largest liquid Li test loop constructed by JAEA in Oarai-site (Nov. 2010)



Confinement Vessel for Lithium flowing with free surface in target assembly

Vacuum pump for Target

Air Duct of Heat Exchanger

Heat Exchanger of Air cooling type

Vacuum pump

Li Dump Tank

20 m in Height

Third floor:
Target vessel,
A part of Quench Tank, etc.

Second floor:
Li sampler, Heat Exchanger, Cavitation sensor Cabinet

First floor:
EMP, Cold trap,
Cavitation Sensor, etc.

Under ground level:
Li dump tank. (2.5 ton Li (5000 L)

■ This height was needed to prevent the occurrence of cavitation in Electro-Magnetic Pump.

MAIN MEASUREMENT APPARATUS (DIAGNOSTICS)

Table:. Model and major specifications of the instruments

	Instrument	Model, Mfr	Major spec.
Flow rate	**EMF(Electro-magnetic flow meter)**	Sukegawa electric Co., Ltd.	Range: 0 ~ 3000 L/min (operational range) Accuracy (2σ): +/-55.8 [L/min] or 1.86 % FS*
Pressure	**Pressure gauge**	PTU-S, Swagelok	Range: - 0.1 to 0.3 MPaG Accuracy: +/- 0.5 % FS
	Cold- cathode Pirani gauge	M-360CP-SP/N25, Cannon Anelva Corp.	Range: 5×10^{-7} to 1×10^{5} (Pa) Accuracy: +/- 30 % RD**
Target Flow Obser.& Meas.	**Video camera**	HVR-Z7J, Sony	Record format: HDV1080/60i
	Digital still camera	D800 (Lens: AS Nikkor 28-300 mm), Nikkon	Number of pixels: 36.3 M
	Laser Distance meter	Optical Comb Absolute Distance Meter ML-5201D1-HJ, Optical Comb, Inc.	See: Next page

* FS: Full Scale, **RD: Reading

The flow rate and pressure were recorded in a control PC in the central control room every one second. On the other hand, the appearance of the Li target was monitored and recorded by a video camera and a digital camera.

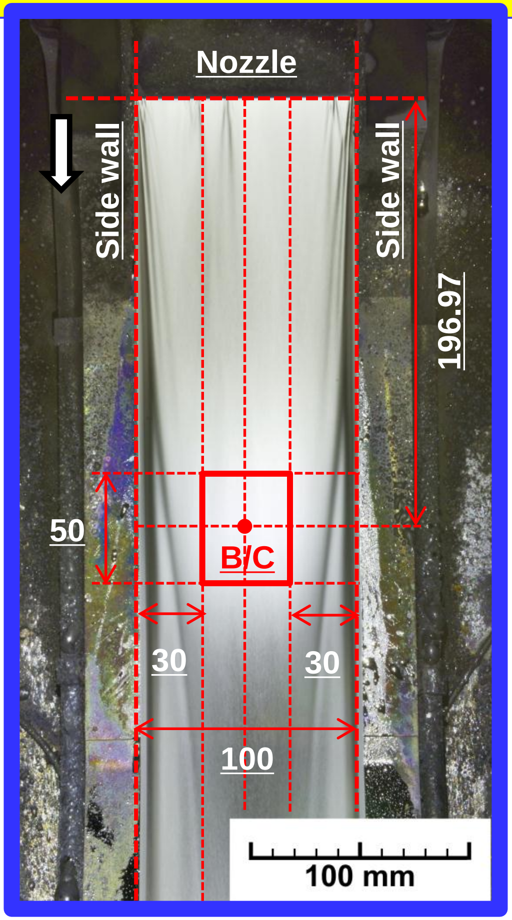
Specification of Laser Distance Meter

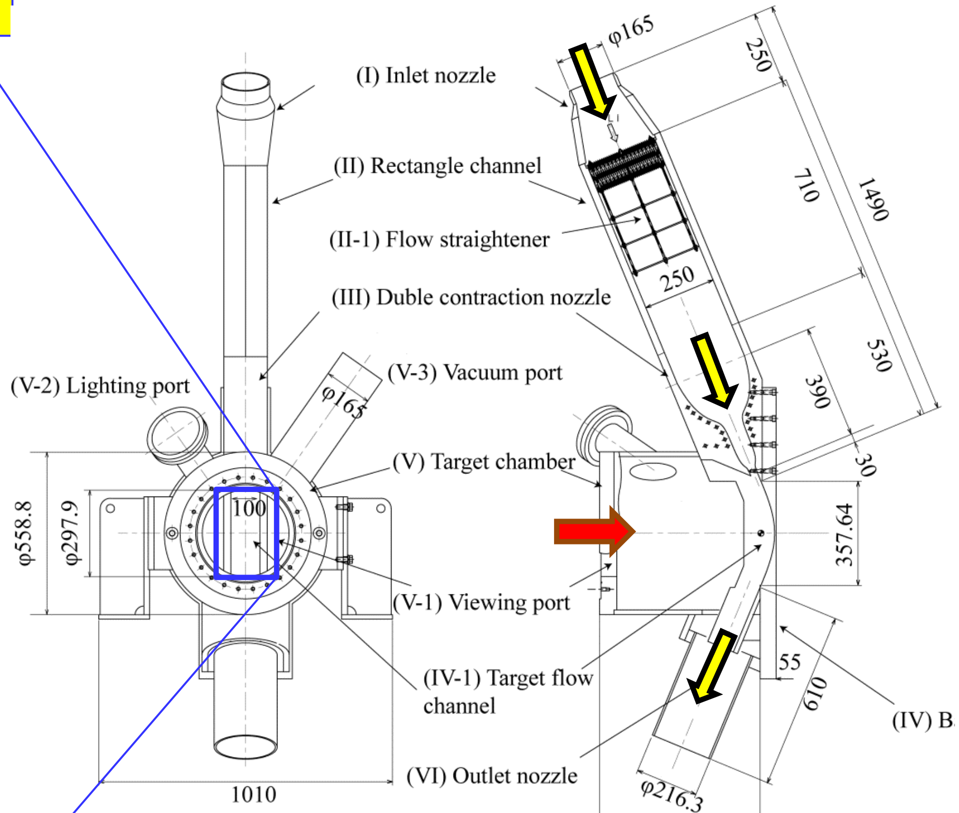
Item	Value (IFMIF condition)	
Mean Li jet speed U_m [m/s]	10, 15, 20 (10 ~ 16)	
Inlet Li temperature [°C]	250 (or 300)	
Vacuum pressure P_v [Pa]	1.6 ~ 4.0 x 10^{-3} (10^{-3} ~ 10^{-2})	1.6 ~ 2.1
Measurement positions [mm]*	At Y = 0 mm: -50 <= X <= 50 At X = 0 mm: -50<= Y <= 50 (-25 <= X <= 25 and -20 <= Y <= 20)	Whole measurement range: -50 <= X <= 50 and -50 <= Y <= 50 (-25 <= X <= 25 and -20 <= Y <= 20)
Sampling frequency [kHz]	500	
Data recording time [sec]	60 (one-turnover circulation time of approximately 60 s at 15 m/s)	
Laser wavelength [nm]	1550	
Laser spot diameter [mm]	**0.13** (determined based on the preliminary result)	
Measurement error [mm] (Evaluated experimentally)	**0.04 (for target thickness)** **0.02 (for wave height)**	

*The intervals of measurement positions are 10 or 15 mm for the X direction and 5 mm for the Y direction.

Flow appearance of Li target

V = 15.1 m/s, P = 1.3 x 10^{-3} Pa
T = 250 °C



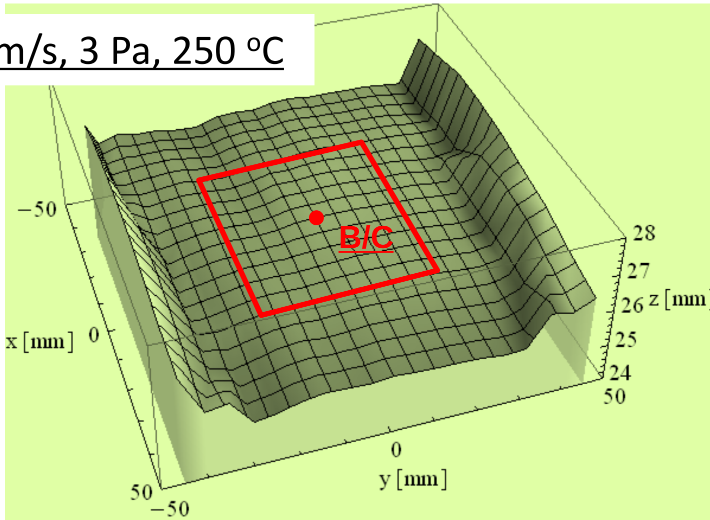


(a) Flow straightener
(b) Double contraction nozzle
(c) Target flow channel (back plate)
(d) Viewing port

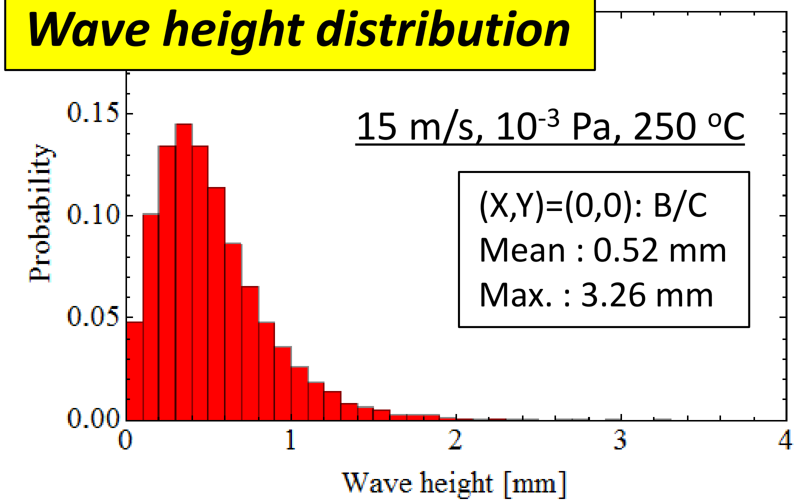
Li target measurement

Time-averaged thickness of Li flow
-3D image -

15 m/s, 3 Pa, 250 °C



Wave height distribution



Laser-probe method

- **Laser-distance meter (Optical Comb Inc.)**

Time-of-flight (TOF) measurement

- **Analysis method:**

Zero-up crossing method
for average thickness and statistical properties of wave height

Average thickness :
- 26.08 +/- 0.08 mm (1σ) at B/C
- Nonuniformity (max.-min.) is 0.16 mm

Wave amplitude (= height/2) :
- Mean : 0.26 +/- 0.02 mm (1σ) at B/C
- 99.7 % are less than 1 mm (requirement)
- Weilbull Distribution

T. Kanemura, H. Kondo et al., "Measurement of Li-target thickness in the EVEDA Li Test Loop", To be published in Fus. Eng. Des.

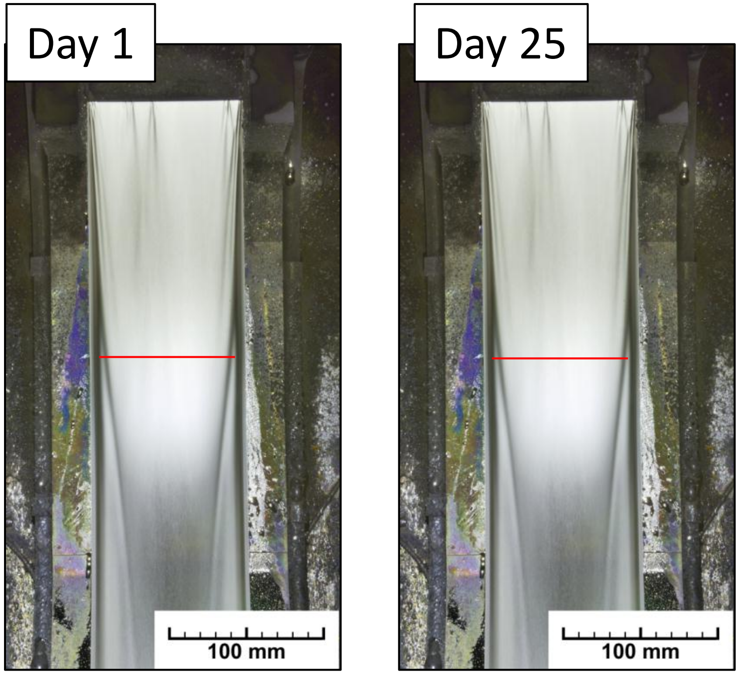
Long-time continuous operation

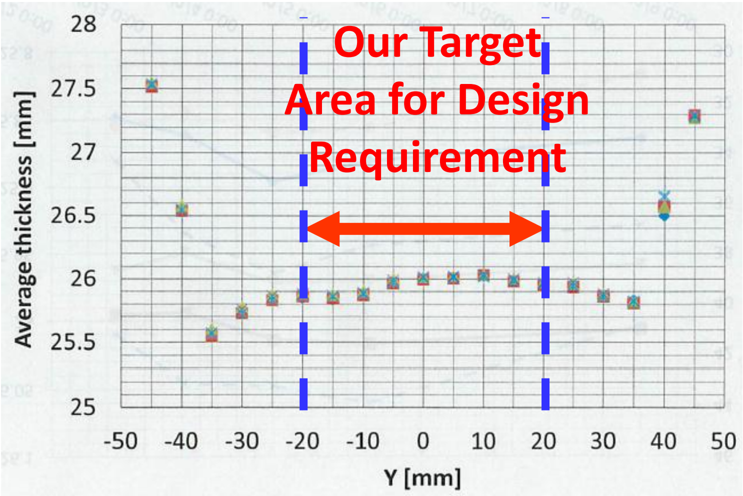
- Period: 1 month (2 – 26 Sep. 2014)
- Condition: Li target (15 m/s, 300 – 250 ^{o}C, 120 kPa) in parallel with the purification system (cold trap at 200 ^{o}C)

✓ Stable Li target throughout the continuous operation

✓ Accumulated time of Li target operation > 1000 hours

(At present it is continuing the Li flowing up to end of Oct. 2014)





Long-time stability of the Li target was successfully demonstrated.

Li Target Validation Tests - Summary -

✓ **Validation of the Li target was the highest priority subjects for the Li target system of the IFMIF/EVEDA project. To achieve this goal, we designed and constructed the ELTL, and produced a stable Li target that complies with IFMIF requirements.**

1. **The Li target in the IFMIF conditions (250 ºC, 15 m/s, 10^{-3} Pa) and its stability were successfully demonstrated.**

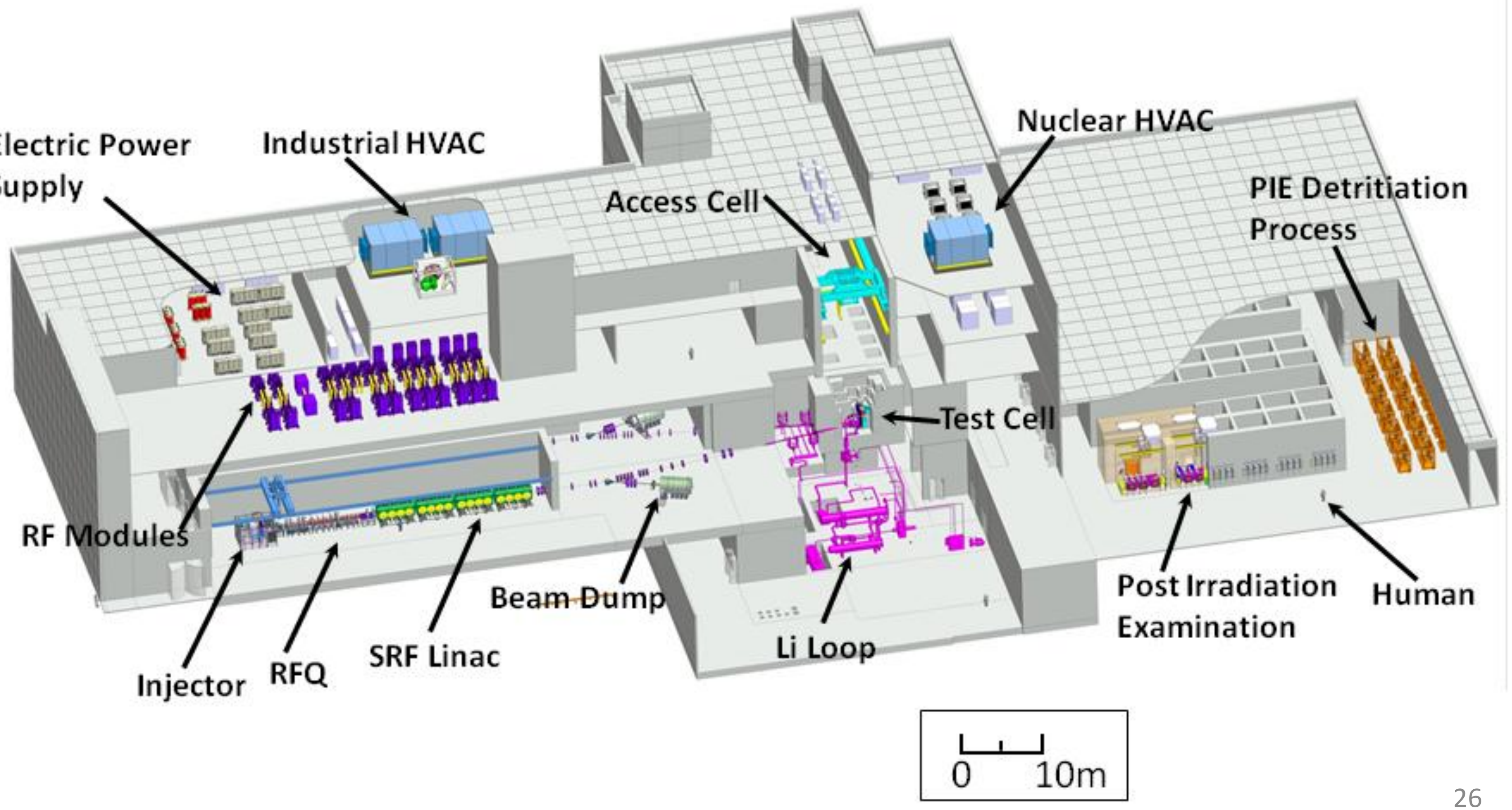
- **Average thickness: 26.08 ± 0.08 mm (1σ)**
- **Mean wave amplitude: 0.26 ± 0.02 mm (1σ)**
- **Maximum wave amplitude: 1.45 ± 0.14 mm (1σ)**

The maximum wave amplitude is very few over the design requirement of 1 mm, and 99.7 % of the total wave components are within the requirement. Therefore, we confirmed that *the Li target of the current design was quite stable and satisfies the design requirement. We finally validated the Li target stability.*

2. **Continuous long-term operation of the Li target was conducted (continuous operation: 1 month, accumulated time: >1000 h).**

(The validation operation of the Li test loop is continuing up to the end of Oct. 2014.)

Thank you for your attention



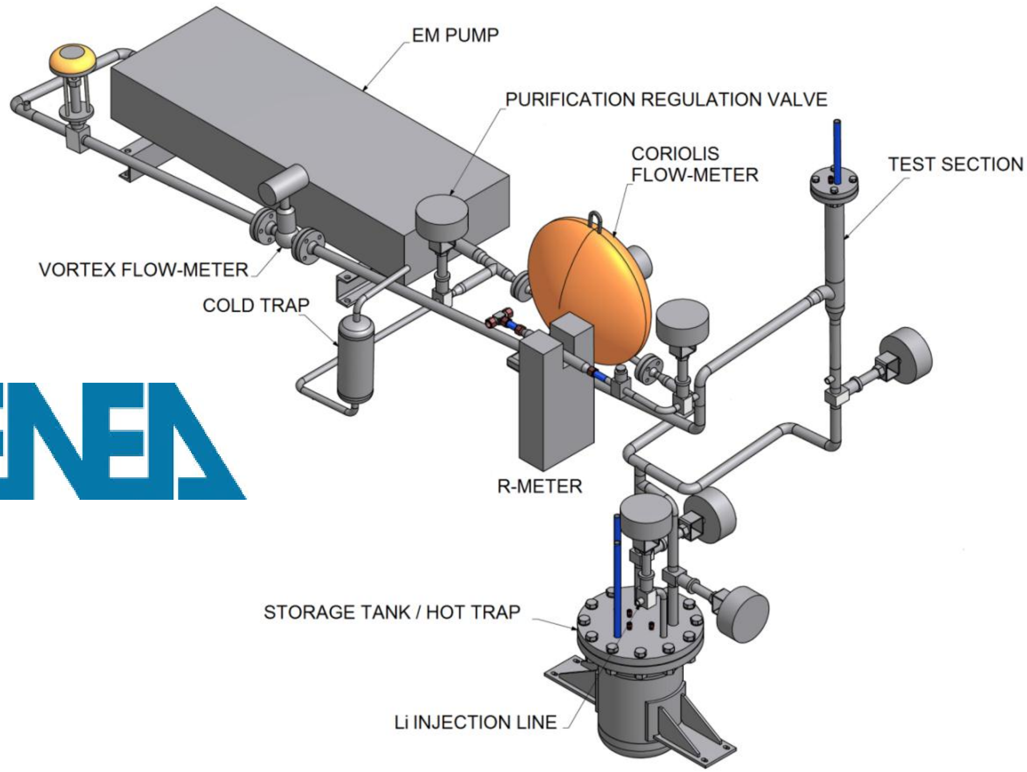
Specification of ELTL and IFMIF LF

Items	ELTL	IFMIF Lithium Facility
Nozzle design	Double-contraction	Double-contraction
Back wall	Concave (316L)	Concave (RAFM)
Jet thickness [mm]	25 mm	25 mm
Jet width [mm]	100 mm	260 mm
Max. jet velocity / surface pressure [m/s]	20/10^{-3} Pa to atmospheric pressure	15 (max.16)/ <10^{-2} Pa
Max. flow rate [L/s]	50 L/sec	133 L/sec
Temperature [°C]	250-350℃	250-300℃
Li inventory [m^3]	5.0 m^3	9 m^3
Status	In Operation	Design stage

Erosion/corrosion

including Purification

- To perform corrosion/erosion tests at constant temperature (reference 350° C) and velocity (reference 16 m/s in test section) under the purification control for Li with less than 30 wppm N
- To test lithium purification and impurities monitoring systems

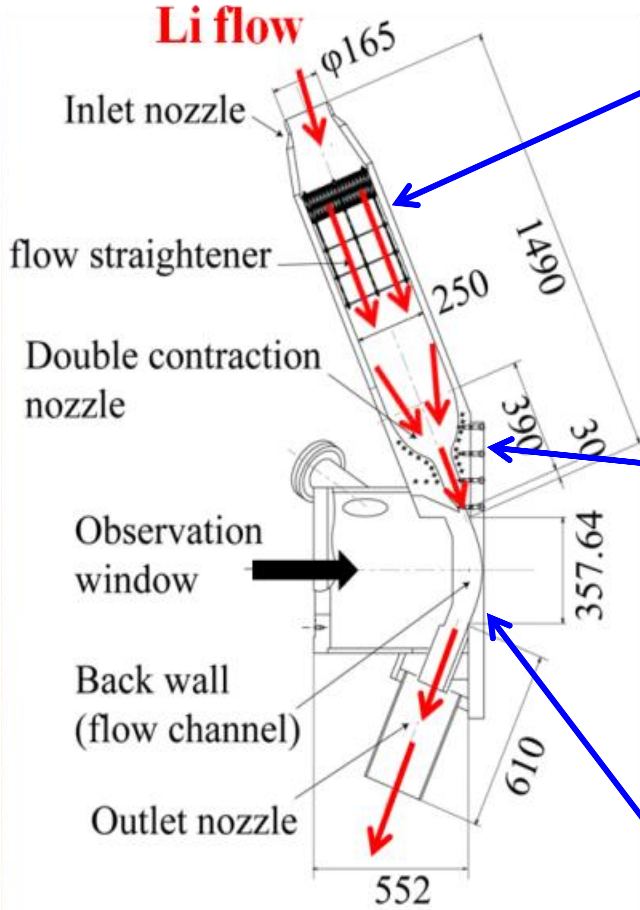


Material	Exposure [h]
F82H/ Eurofer	~ 1000 ~ 2500 ~ 3500

ENEA Brasimone Lithium Loop: Lifus 6

Design Specification of Proto Type of EVEDA Lithium test loop (ELTL)

Li inventory	2.5 tons (5000 l)
Li flow rate	3000 L/min (max.)
EM flow meter range	± 3000 L/min
Li flow velocity in Target	≤ 20 m/s
Material	S.S. 304 for pipe, 316L for back-plate
Li temp.	250-350 °C
Design temp.	400 °C
Design pressure	10^{-3} Pa to 0.75 MPa G



(a)Flow Straightener

- A honeycomb for removing large scale turbulence.
- Three perforated plates for flattening velocity distribution.

(b) Contraction Nozzle

- Two-step contraction, contraction ratio is 10. (250 mm to 25 mm in thickness)

To obtain flow velocity up to 20 m/s.

(c) Target Flow Section (back plate)

i) *Flow Width and Thickness : 100 and 25 mm*

ii) *Viewing Ports: Two Ports*

Measurement for Li free surface in ELTL (Non-Contact Method – Developed Laser distance meter)

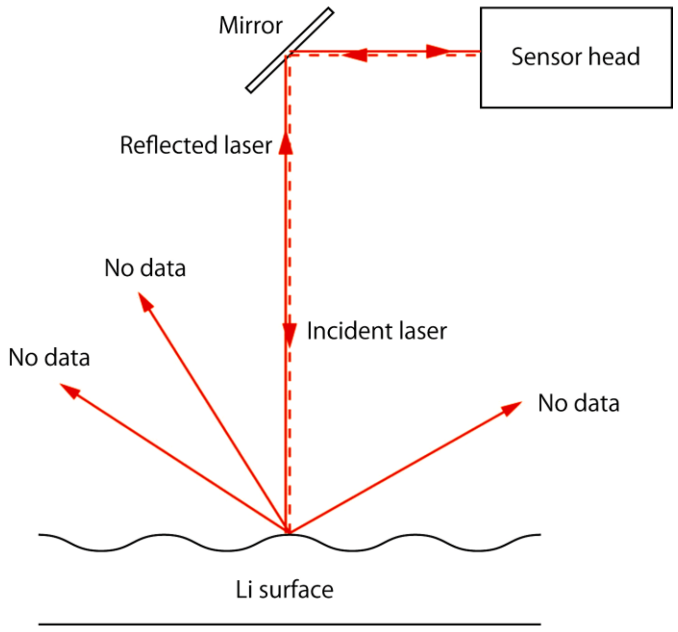


Fig. Interference condition of laser

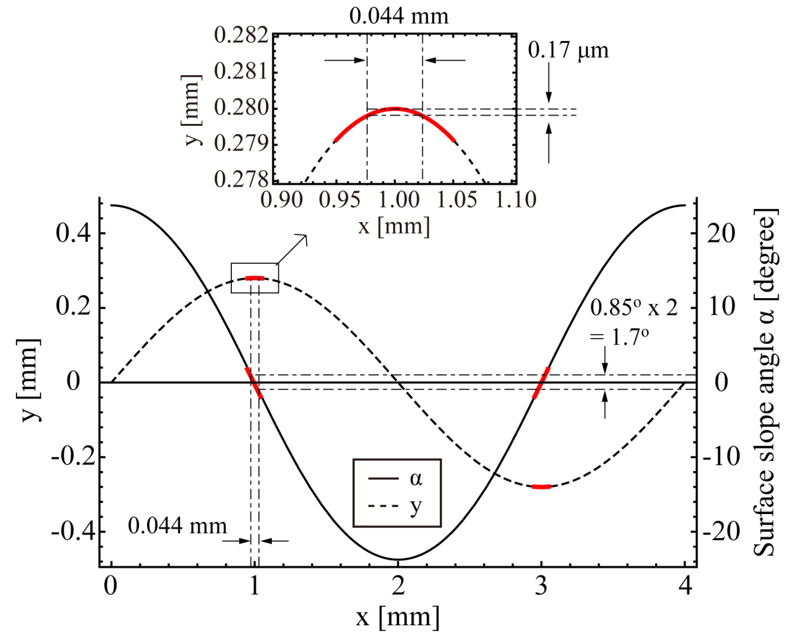


Fig. Slope angle α (solid line) with sine curve y (dashed line)

$$y = A\sin(2\pi x / \lambda)$$

$$\alpha = \tan^{-1}(dy / dx)$$

A: 0.28 mm

λ: 4 mm [3]

The present laser condition:

- Spot diameter: 0.1 mm (MFD)
- Laser incident angle: 0.85°

The incident laser is returned to the laser head from the region of 0.044 mm. This means **62 % of the total energy is returned** (the laser energy is distributed to normal distribution), which is considered to be large enough for a significant signal.

Laser Distance Meter

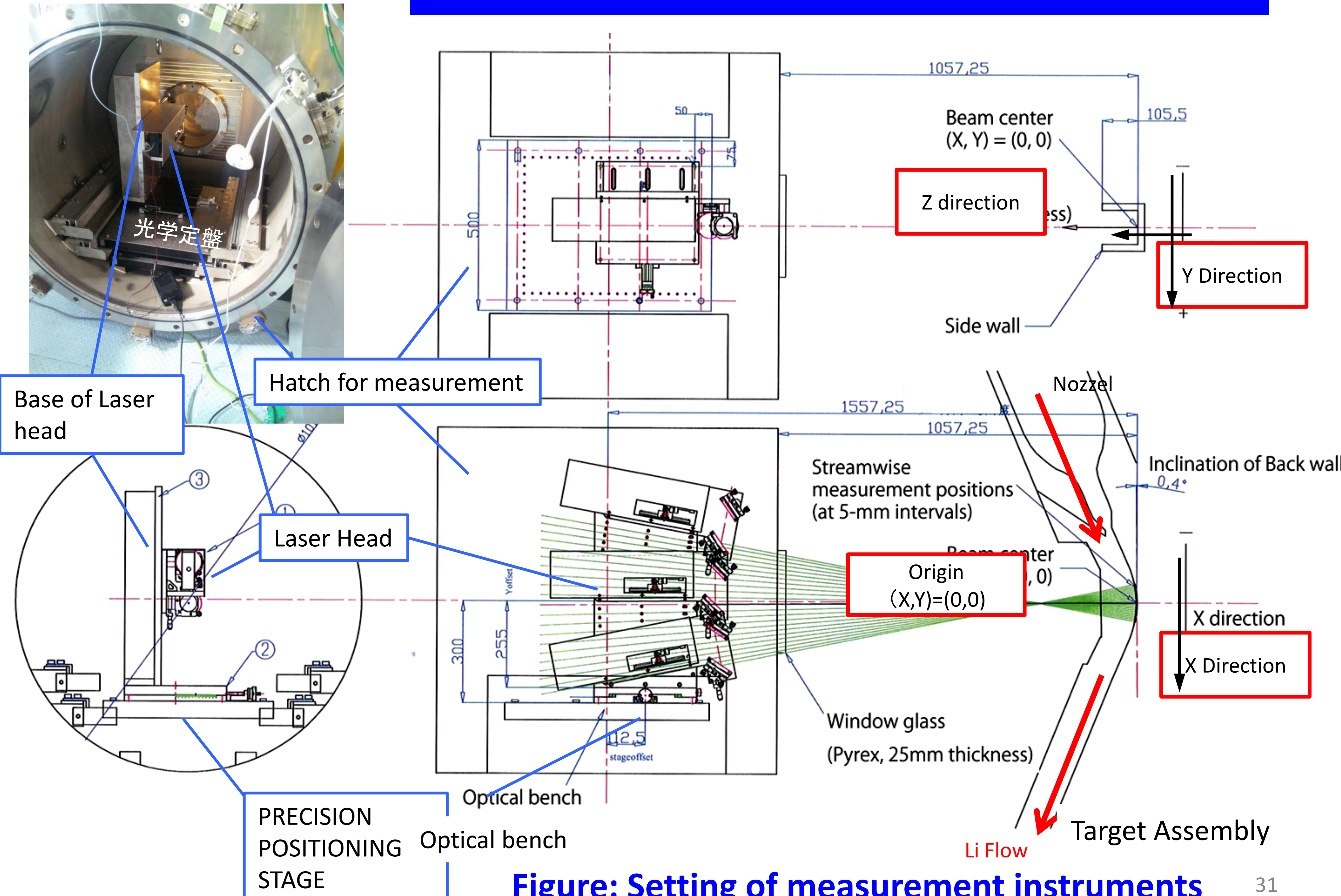


Figure: Setting of measurement instruments

Temporal fluctuation

- The target stability limit: 2 mm in wave height H
- Mean wave height $\overline{H} \approx 0.5$ mm for all data
- Thus, nodimensional stability limit: $H/\overline{H} \approx 4$

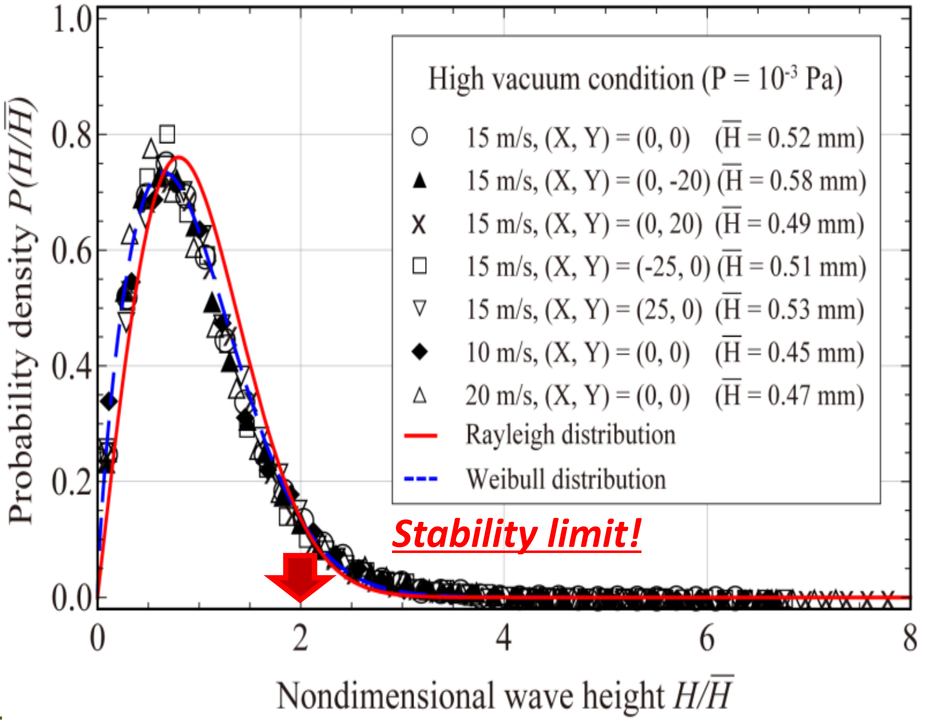
99.7 % of the total wave components is within the limit!

The solid red line denotes the Rayleigh distribution,

$$P(H) = \frac{\pi}{2}\frac{H}{\overline{H}} exp\left[-\frac{\pi}{4}\left(\frac{H}{\overline{H}}\right)^2\right] \qquad (1)$$

The dashed blue line denote the **Weibull distribution**, the "parent" distribution of the Rayleigh distribution,

$$P(X) = \frac{k}{\lambda}\left(\frac{X}{\lambda}\right)^{k-1} exp\left[-\left(\frac{X}{\lambda}\right)^k\right] \qquad (2)$$



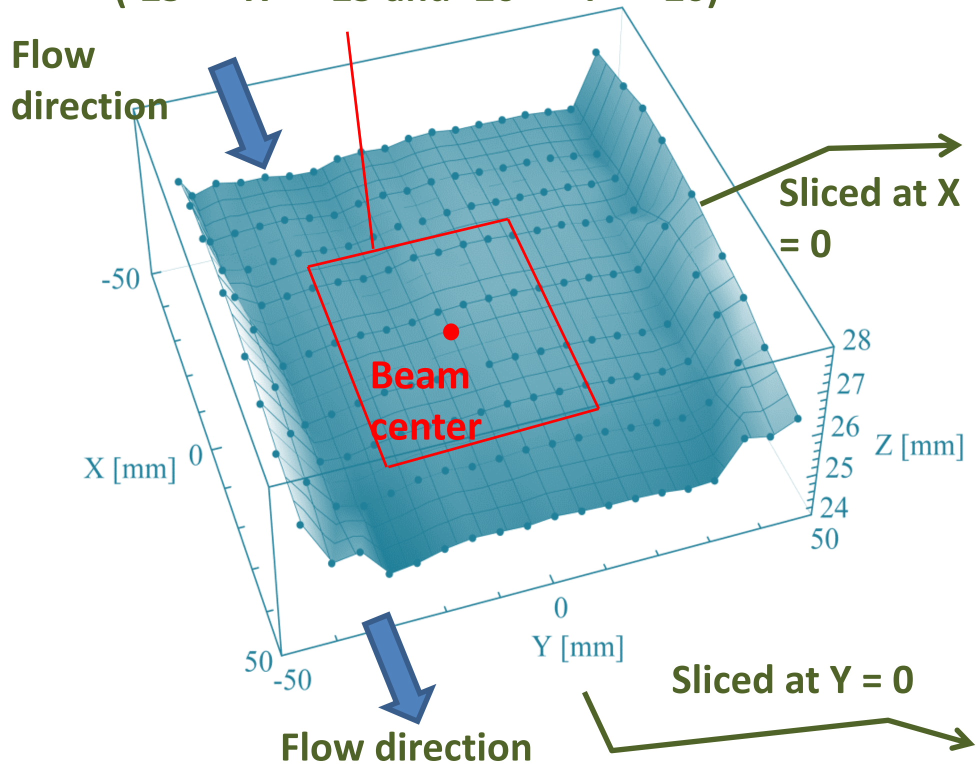
Nondimensional wave height distribution at $P_v = 1$

where k > 0 is the shape parameter and λ > 0 is the scale parameter of the distribution. When k = 2 and λ = $\sqrt{4/\pi}$, Eq. (2) is reduced to Eq. (1). The parameter of the fitting curve is k = 1.73 ± 0.03, λ = 1.07 ± 0.02.

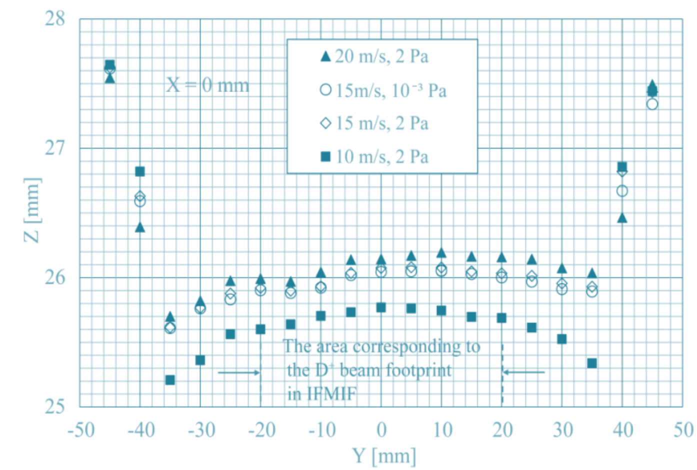
Average thickness of Li Target

Presented by T. Kanemura in SOFT2014

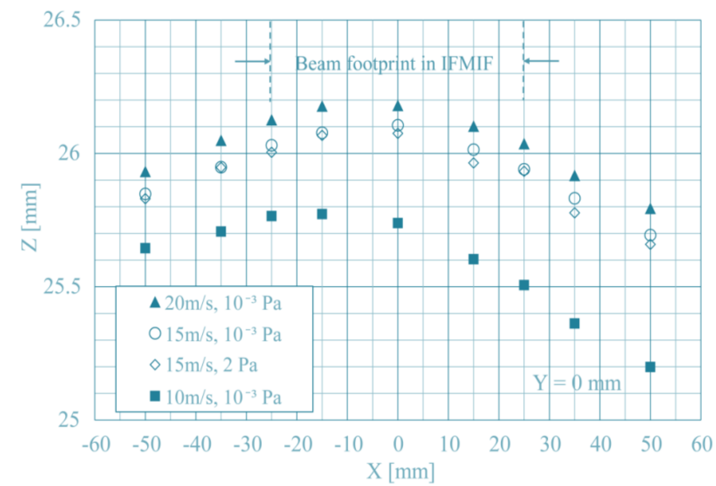
The area corresponding to the IFMIF beam footprint
(-25 <= X <= 25 and -20 <= Y <= 20)



Three-dimensional plot of the average thickness of the Li target at U_m = 15 m/s at P_v = 1.8 Pa.
(Black symbols denote measurement data)



Average thickness distribution along the Y (spanwise) direction at X = 0.



Average thickness distribution along the X (streamwise) direction at Y = 0.

Un-uniformity inside the beam footprint was

- **0.16 mm along the Y (spanwise) direction,**
- **0.10 mm along the X (streamwise) direction.**

The Li target is adequately smooth on average.

Statistics of measurement results

Presented by T. Kanemura in SOFT2014

Statistics of measurement results obtained at the beam center (X, Y) = (0, 0) under the IFMIF condition.

U_m [m/s]	10	15	20	Design requirement
N*	5	6	2	-
A_{mean} [mm]**	0.23 ± 0.02 (1σ) ***	**0.26 ± 0.02 (1σ) *** **	0.24 ± 0.01 (1σ) ***	1 mm
A_{max} [mm]**	1.50 ± 0.11 (1σ) ***	**1.45 ± 0.14 (1σ) *** **	1.66 ± 0.10 (1σ) ***	
η_{mean} [mm]	25.73 ± 0.07 (1σ) ***	**26.08 ± 0.08 (1σ) *** **	26.15 ± 0.08 (1σ) ***	25 mm

N: the number of the data samples, A_{mean}: Mean wave amplitude, A_{max}: Maximum wave amplitude, η_{mean} : Average thickness

*The data were obtained on different days to check reproducibility.

**Amplitude A is half wave height ($A = H/2$).

***Measurement uncertainty includes variation of measured data itself and measurement error.

The Li target of the current design is quite stable and satisfies the design requirement.

Purification of Lithium

Total content of H isotope in Li	(≤ 10 wppm)
T content in Li	(≤ 1 wppm)
N content in Li	(≤ 10 wppm)
O content in Li	(≤ 10 wppm)

Purposes of impurity reduction

- suppression of corrosion (C, N, O)
- suppression of erosion (H(?), C, O)
- reducing of radio-activity of Li (T(H,D))
- preventing Y from degradation (N, O)

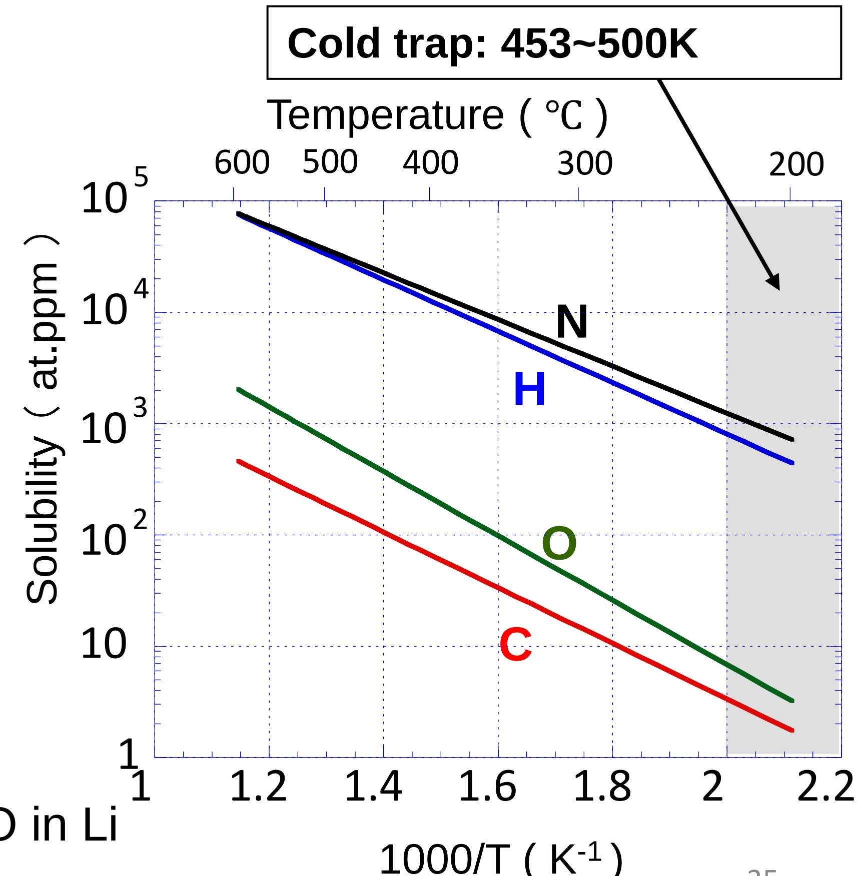
C, O : solubility is small enough to use cold trap.

N : Formation of Li-Cr-N is one of the most serious corrosion for S.S. (>60~70wppmN)

YN is very stable, which degrades hydrogen gettering efficiency .

⇒Titanium react with N even N in Li is less than 1wppm

H : Hydrogen distribution ratio between Y/Li is very large.
However, Yttrium easily react with N and O in Li



Solubility of H, C, N, O in Li